

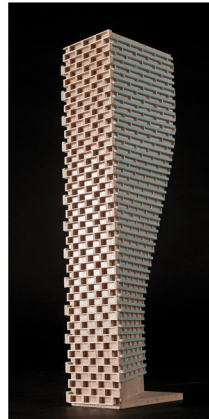
# GRADIENTWIND

ENGINEERS & SCIENTISTS

## PEDESTRIAN LEVEL WIND STUDY

1619-1655 Carling Avenue  
Ottawa, Ontario

Report: 19-192-PLW-2020



November 3, 2020

PREPARED FOR  
Surface Developments  
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## EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy the requirements of a Site Plan Control application submission for the proposed development located at 1619-1655 Carling Avenue 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 (Section 5), illustrated in Figures 3A-4D, 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, walkways, transit stops, and building access points, are considered acceptable for the intended pedestrian uses throughout the year.
- 2) To ensure conditions over the Level 6 amenity terrace are suitable for sitting or more sedentary uses during the typical use period, we recommend introducing a minimum 2.4-m tall solid wind barrier along the north perimeter and a minimum 2.0-m tall wind barrier along the south perimeter. Additional wind barriers or coniferous plantings in a dense arrangement may be required inboard of the perimeters to achieve the 80% criterion for sitting within the full area of the terrace. Mitigation strategies will be developed in collaboration with the building and landscape architects to ensure the wind comfort criteria are satisfied.
- 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.



- 4) 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.



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## **1. INTRODUCTION**

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Surface Developments to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control application submission for the proposed development located at 16919-1655 Carling Avenue in Ottawa, Ontario (“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 prepared by RLA Architecture in October 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 situated on a parcel of land bordered by Tillbury Avenue to the north, Churchill Avenue to the east, Carling Avenue to the south, and Cole Avenue South to the west. The proposed development comprises separate 18-storey and 16-storey buildings, plus mechanical penthouses, rising from a common 5-storey podium. The 18-storey building is referred to as the “West Building”, while the 16-storey building is referred to as the “East Building”.

The podium planform is rectangular with the long axis oriented along Carling Avenue. The ground floor comprises retail units fronting Carling Avenue, as well as indoor amenity space, a residential lobby, and building support facilities. A driveway extending along the west and north perimeters of the site provides access to surface parking spaces and a ramp to below-grade parking at the northeast corner of the podium. Levels 2 and above are reserved for residential occupancy, except for indoor amenity space at the Level 6 of each building. At Level 6, the floorplate sets back from the centre towards to the east and west to accommodate an outdoor amenity area situated between the buildings. Additionally, at Levels 6 and 7, the floorplate sets back at the east side of the East Building and the west side of the West Building to provide private terraces. The nearly rectangular planform buildings share the same orientation as the



podium and rise with a uniform planform. At Level 15 of the East Building, the floorplate sets back at the east side, while at Level 17 of the West Building, the floorplate sets back at the west side.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) are characterized by suburban low-rise residential developments along the north side of Carling Avenue and low-rise commercial developments on the south side. The far-field surroundings (defined as an area beyond the near-field but within a 2 kilometre (km) radius of the subject site) are characterized by a mixture of parks and low-rise suburban buildings from the southeast clockwise to the southwest, and predominantly low-rise suburban exposure in all other directions. The Queensway is situated approximately 250 m to the southeast of the subject site, oriented southwest to northeast. An open exposure created by the Central Experimental Farm lies approximately 1.5 km to the southeast of the site, while the Ottawa River is approximately 1.7 km to the northwest.

Key areas under consideration include surrounding sidewalks, walkways, bus stops, and building access points. 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<sup>1</sup>. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

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<sup>1</sup> City of Ottawa Terms of References: Wind Analysis  
[https://documents.ottawa.ca/sites/default/files/torwindanalysis\\_en.pdf](https://documents.ottawa.ca/sites/default/files/torwindanalysis_en.pdf)



## 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.

## 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 and the common 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. 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.

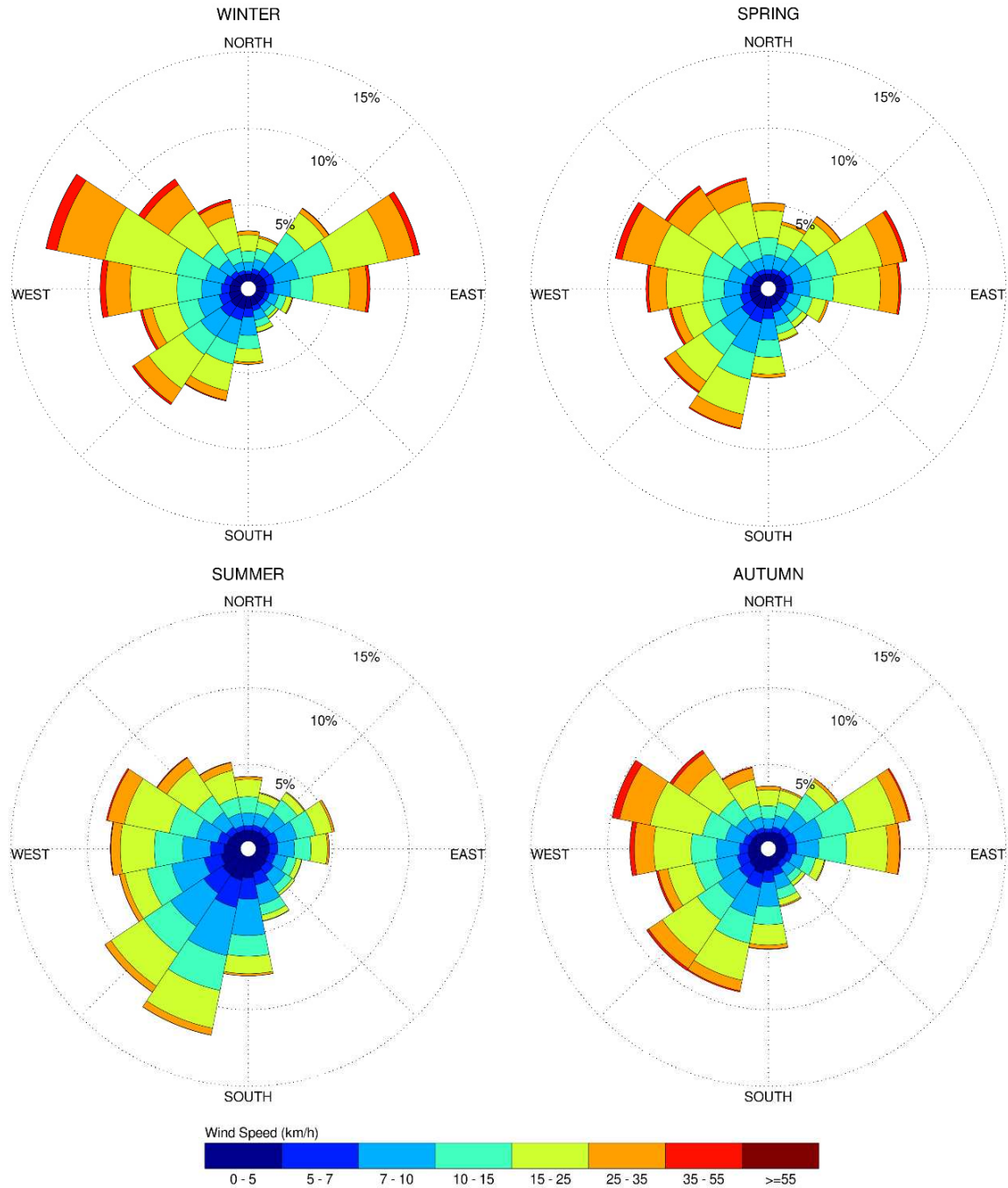
### 4.3 Meteorological Data Analysis

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	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 common elevated amenity terrace, respectively. Wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site.

The colour contours indicate various wind 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, and walking by blue. Uncomfortable conditions are represented by magenta. Pedestrian comfort is summarized below for each area of interest.

### 5.1 Wind Comfort Conditions – Grade Level

**Sidewalk and Building Entrances along Carling Avenue:** Conditions over the sidewalk along Carling Avenue are predicted to be suitable for sitting during the summer, becoming mostly suitable for a mix of sitting and standing throughout the remainder of the year. During the winter, a small region at the

southwest corner of the subject site will experience conditions suitable for strolling. Owing to the protection of the façade, conditions at building entrances are generally calmer than the adjacent sidewalk. Conditions in the vicinity of building entrances along Carling Avenue are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

**Laneway and Building Entrances along West Elevation:** Conditions over the laneway along the west side of the subject site are predicted to be suitable for a mix of sitting and standing during the spring, summer, and autumn, becoming suitable for a mix of sitting, standing, and strolling during the winter. Conditions within the driveway beneath the podium along the west elevation of the subject site are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

**Laneway and Building Entrances along North Elevation:** Conditions over the laneway along the north side of the subject site are predicted to be suitable for sitting during the summer, becoming mostly suitable for a mix of sitting and standing throughout the remainder of the year. During the winter, a small region at the northeast corner of the subject site will experience conditions suitable for strolling. Owing to the protection of the façade, conditions in the vicinity of building entrances are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

## 5.2 Wind Comfort Conditions – Common Elevated Amenity Terrace

**Level 6 Amenity Terrace:** Wind conditions over the Level 6 amenity terrace are predicted to be suitable for a mix of sitting and standing during the typical use period of late spring through early autumn. To ensure conditions are suitable for sitting or more sedentary uses during the typical use period, the implementation of tall wind barriers, typically in the form of glazed guards, will be required. Specifically, to shelter the terrace from strong horizontal wind flows, we recommend introducing a minimum 2.4-m tall solid wind barrier along the north perimeter and a minimum 2.0-m tall wind barrier along the south perimeter. Additional wind barriers or coniferous plantings in a dense arrangement may be required inboard of the perimeters to achieve the 80% criterion for sitting within the full area of the terrace. Mitigation strategies will be developed in collaboration with the building and landscape architects to ensure the wind comfort criteria are satisfied.

### 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 common elevated amenity terrace were found to experience conditions that could be considered dangerous, as defined in Section 4.4.

### 5.4 Applicability of Results

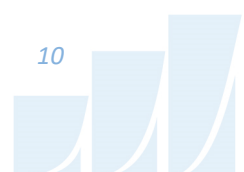
Wind conditions over surrounding sidewalks beyond the subject site, as well as at nearby primary building entrances, will be acceptable for their intended pedestrian uses during each seasonal period upon the introduction of the subject site. Pedestrian wind comfort and safety have been quantified for 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-4D. 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, walkways, transit stops, and building access points, are considered acceptable for the intended pedestrian uses throughout the year.



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- 2) To ensure conditions over the Level 6 amenity terrace are suitable for sitting or more sedentary uses during the typical use period, we recommend introducing a minimum 2.4-m tall solid wind barrier along the north perimeter and a minimum 2.0-m tall wind barrier along the south perimeter. Additional wind barriers or coniferous plantings in a dense arrangement may be required inboard of the perimeters to achieve the 80% criterion for sitting within the full area of the terrace. Mitigation strategies will be developed in collaboration with the building and landscape architects to ensure the wind comfort criteria are satisfied.
- 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.
- 4) 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.

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

Sincerely,

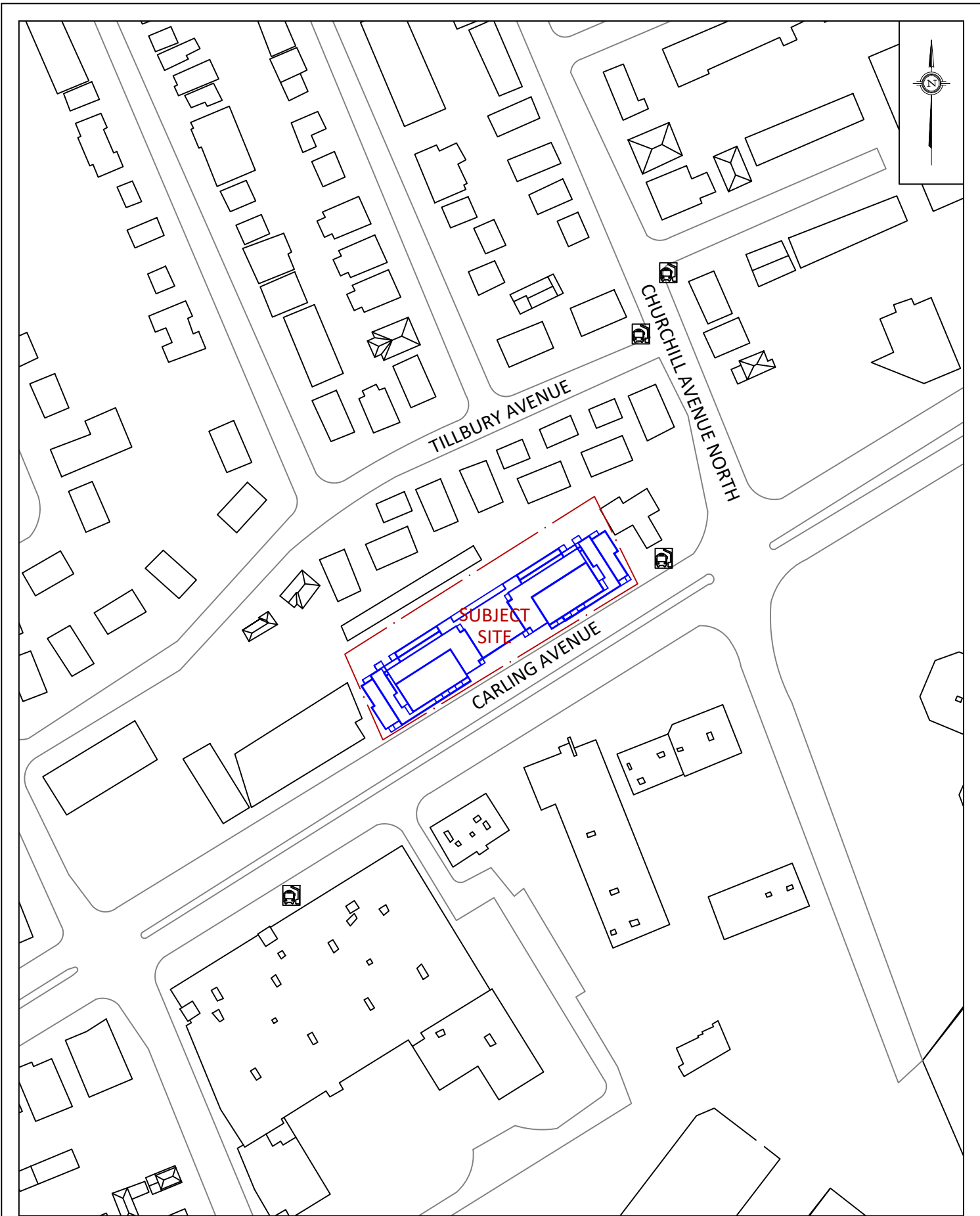
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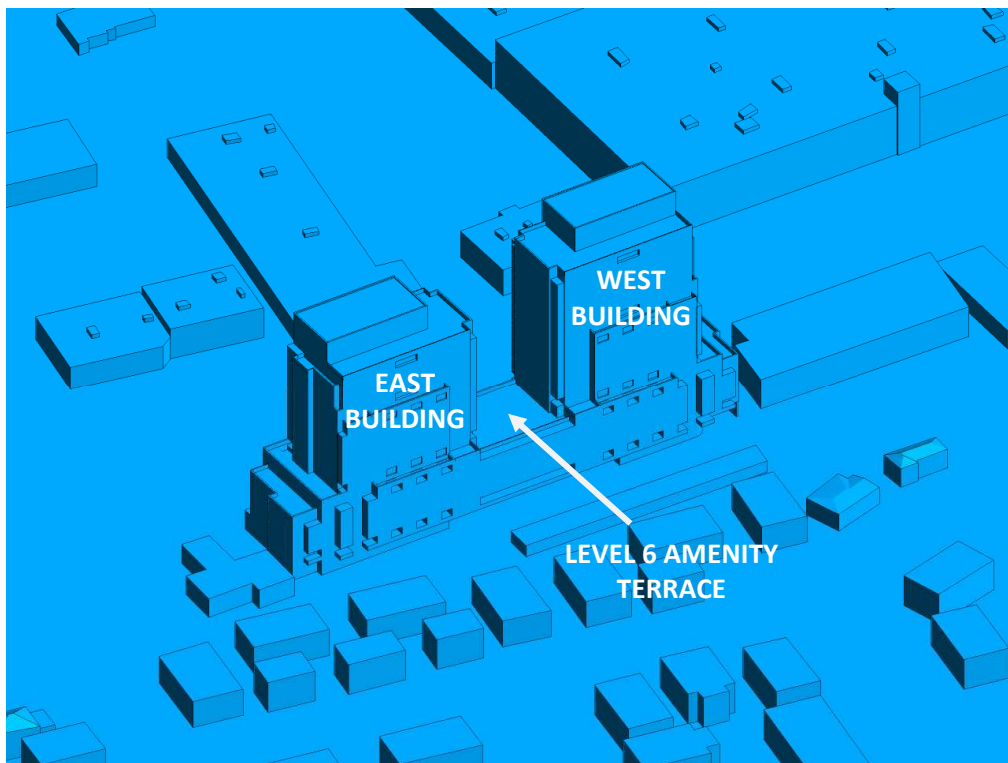
PROJECT	1619-1655 CARLING AVENUE, OTTAWA PEDESTRIAN LEVEL WIND STUDY	
SCALE	1:2000	DRAWING NO. 19-192-PLW-2020-1
DATE	NOVEMBER 3, 2020	DRAWN BY N.M.P.

DESCRIPTION	FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
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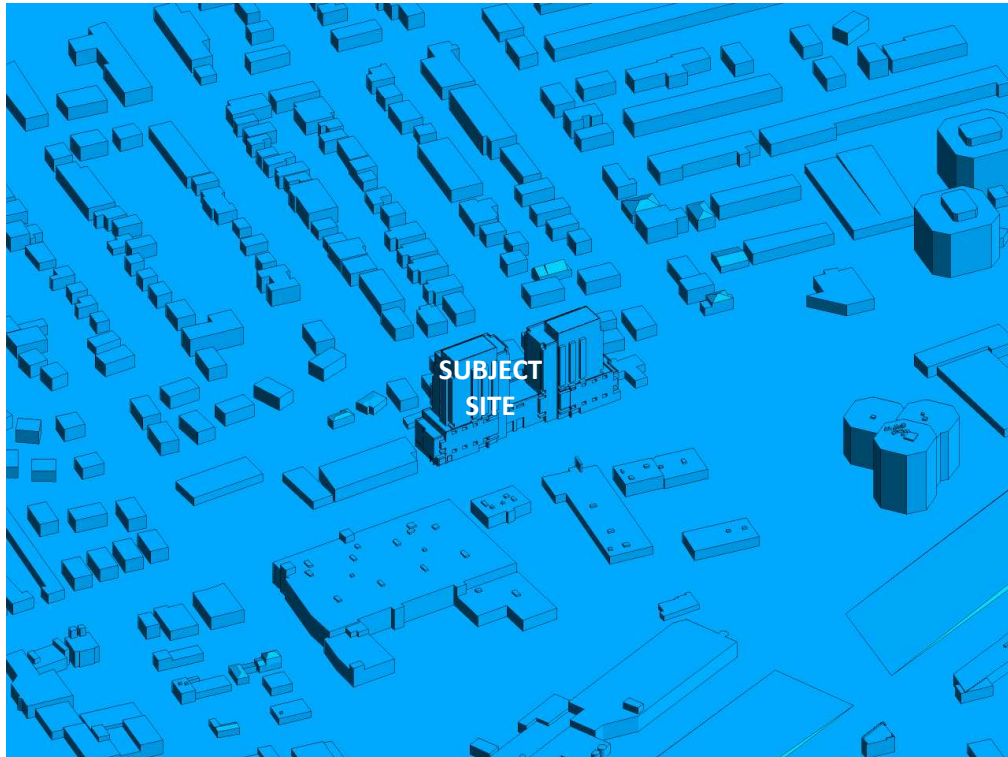


**FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE**

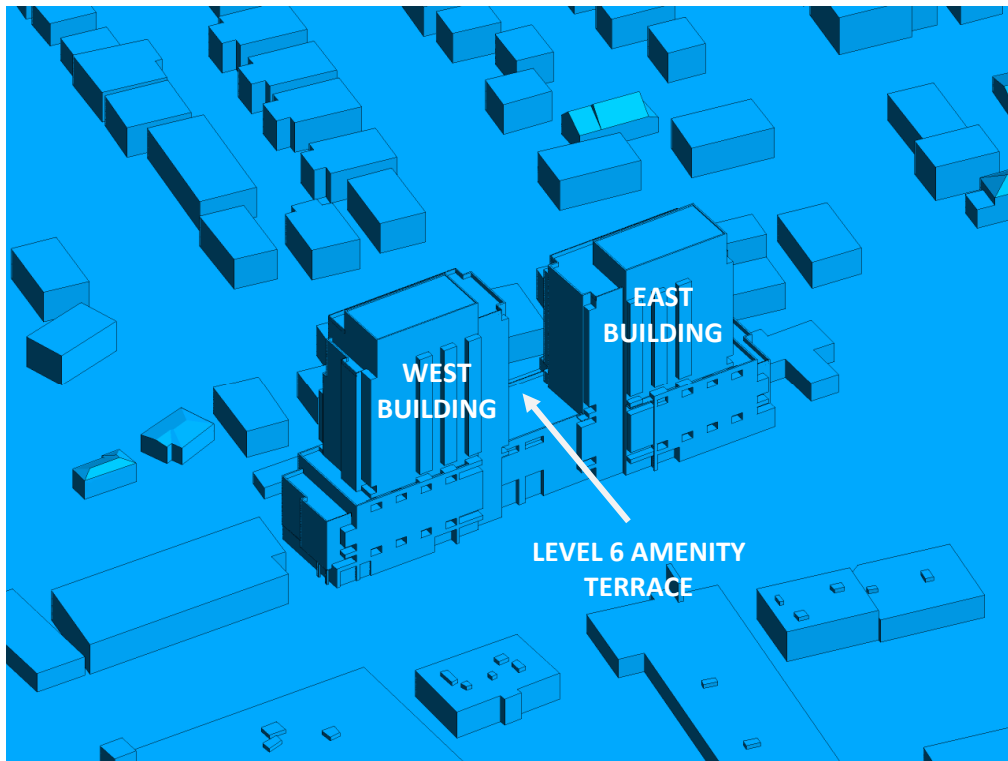


**FIGURE 2B: CLOSE UP OF FIGURE 2A**



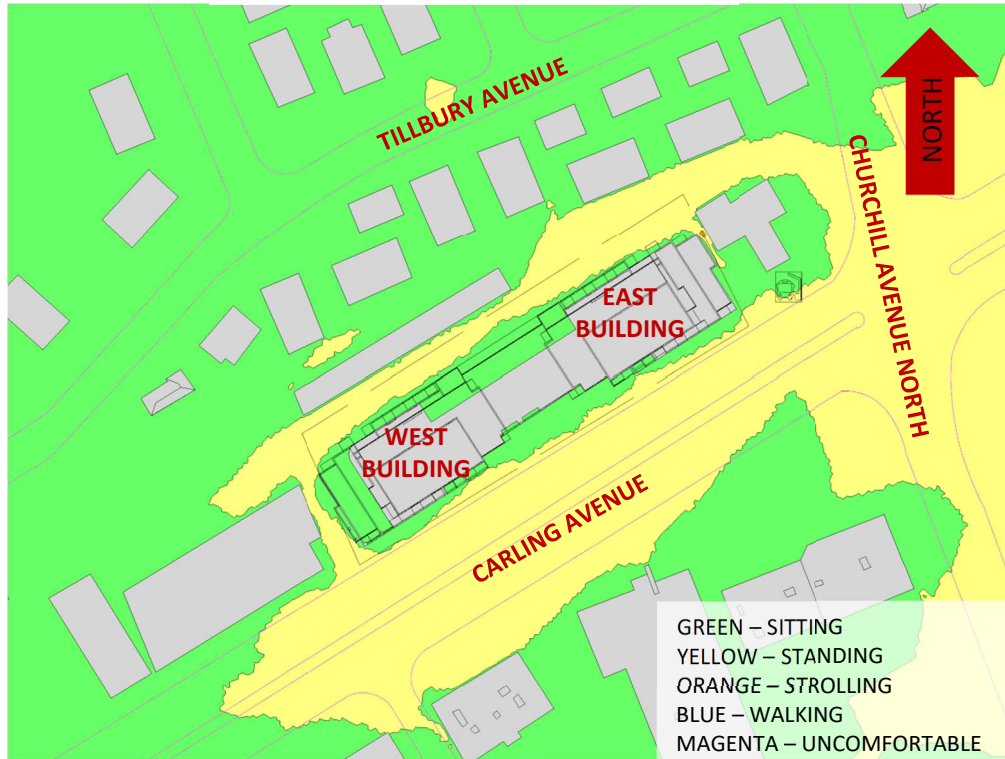


**FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE**

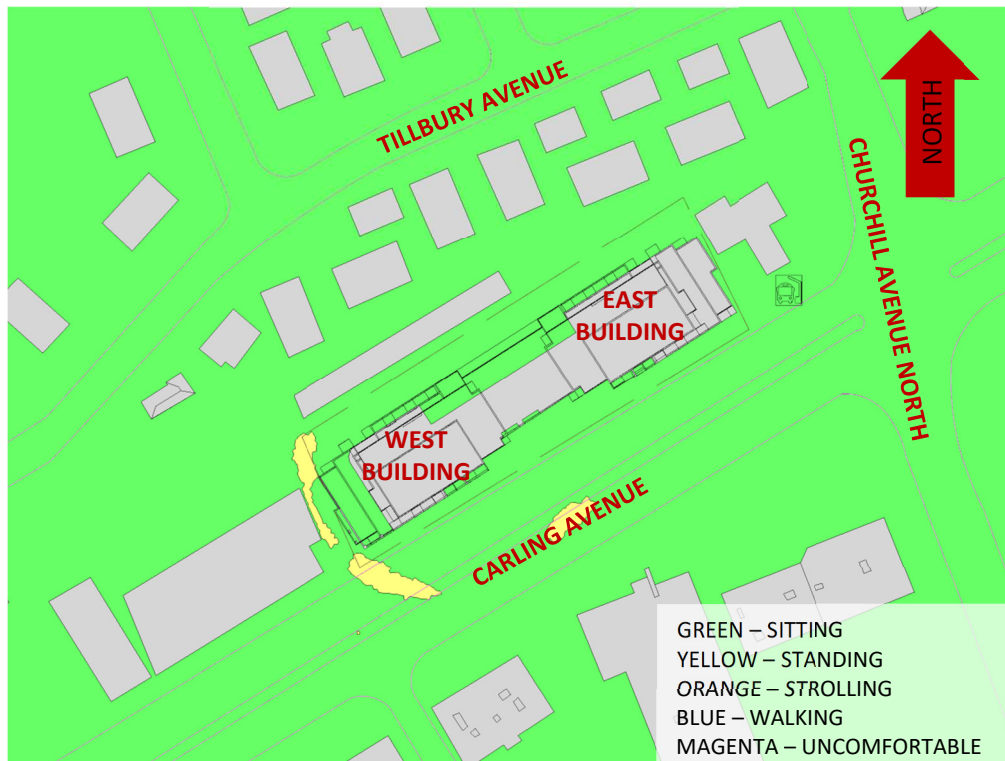


**FIGURE 2D: CLOSE UP OF FIGURE 2C**



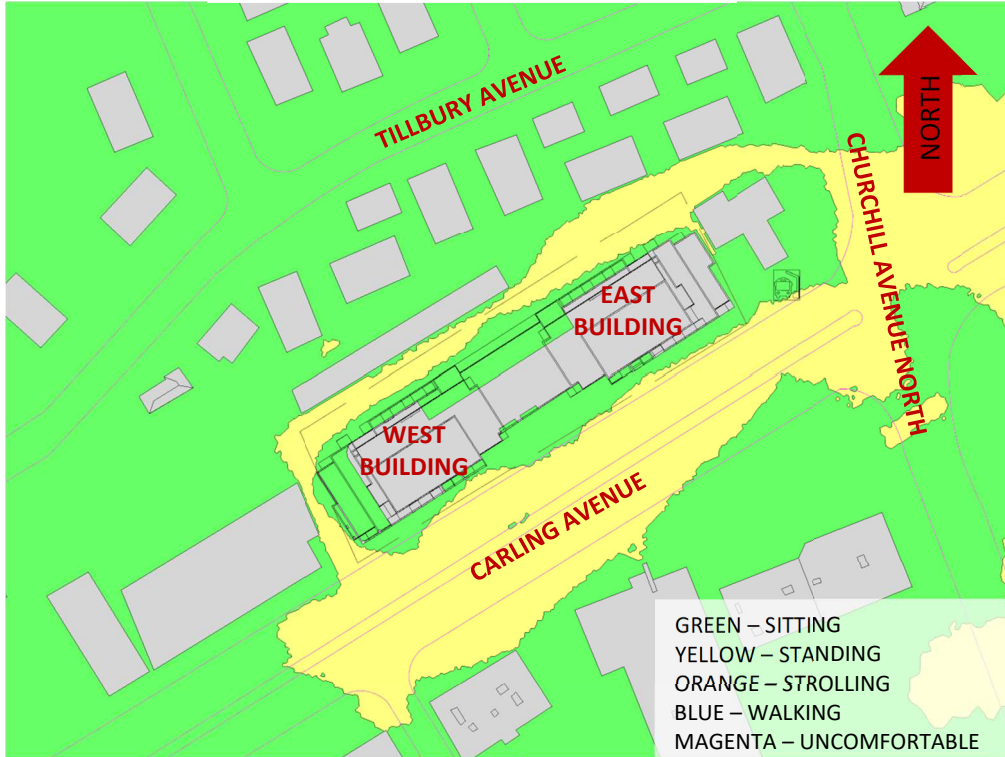


**FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL**

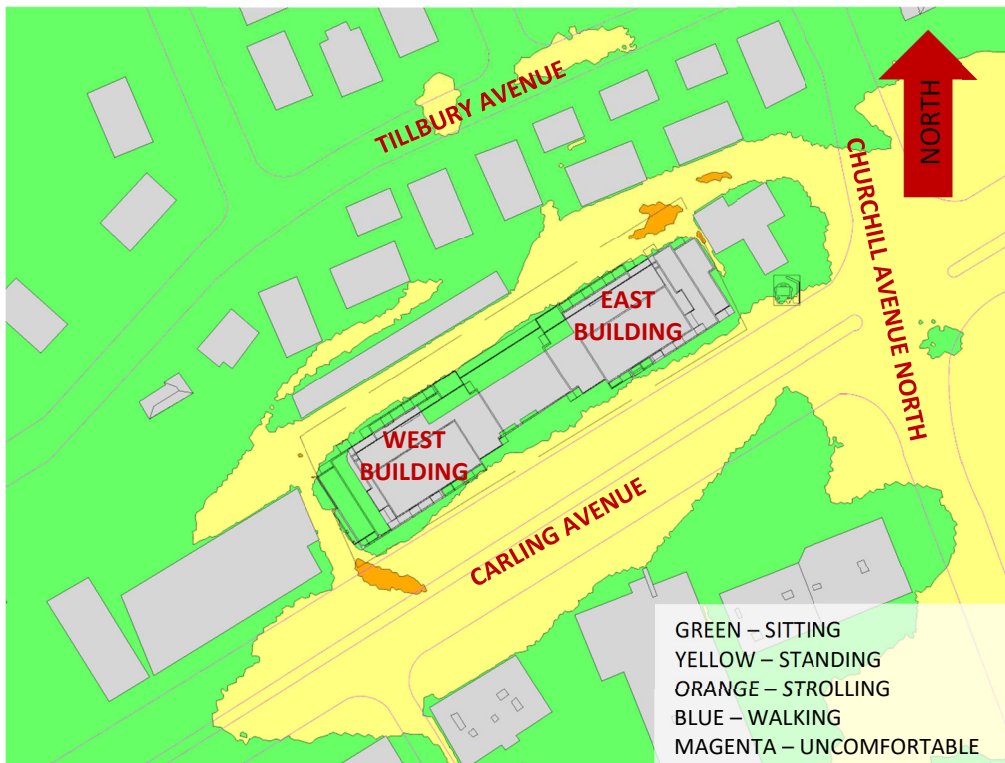


**FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL**



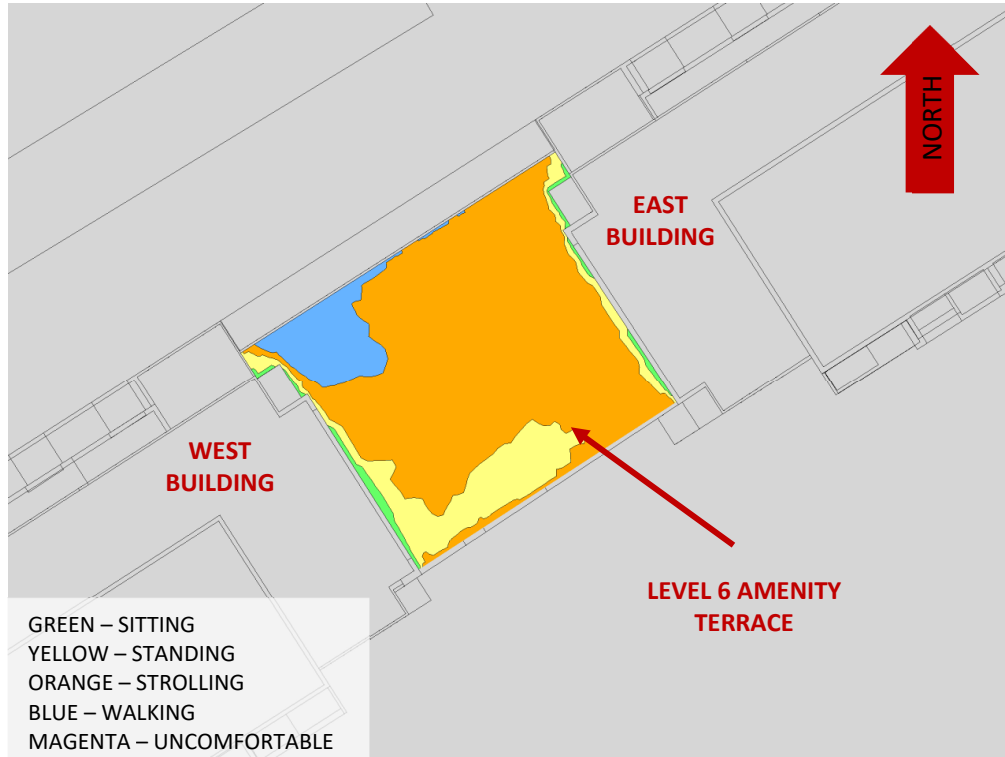


**FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL**

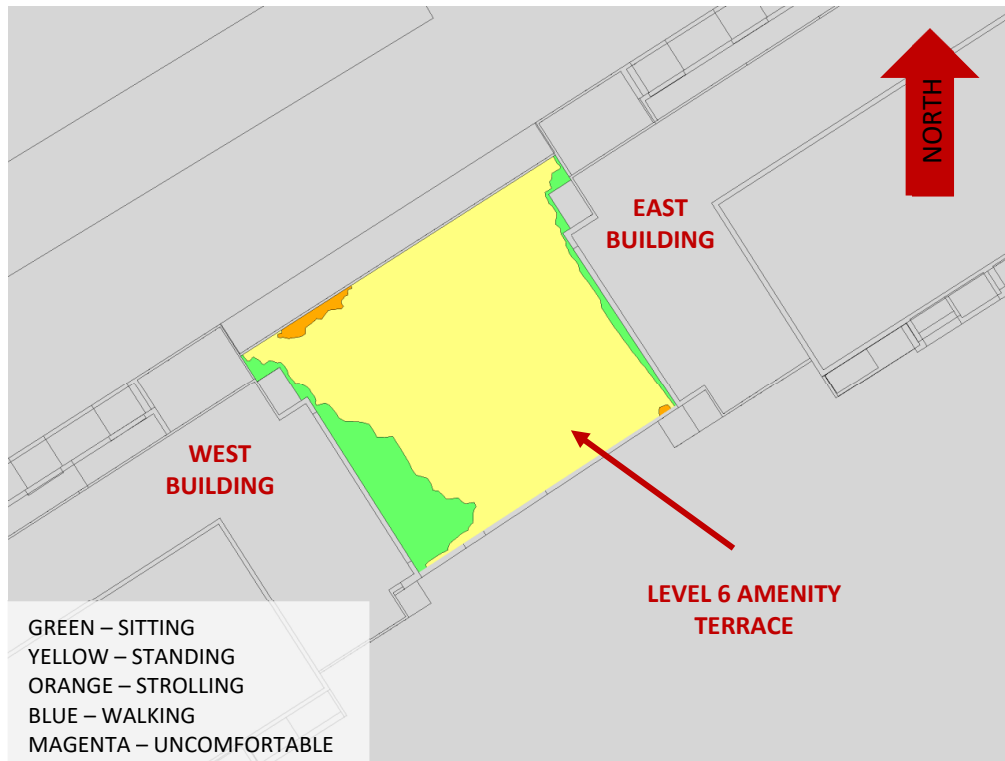


**FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL**





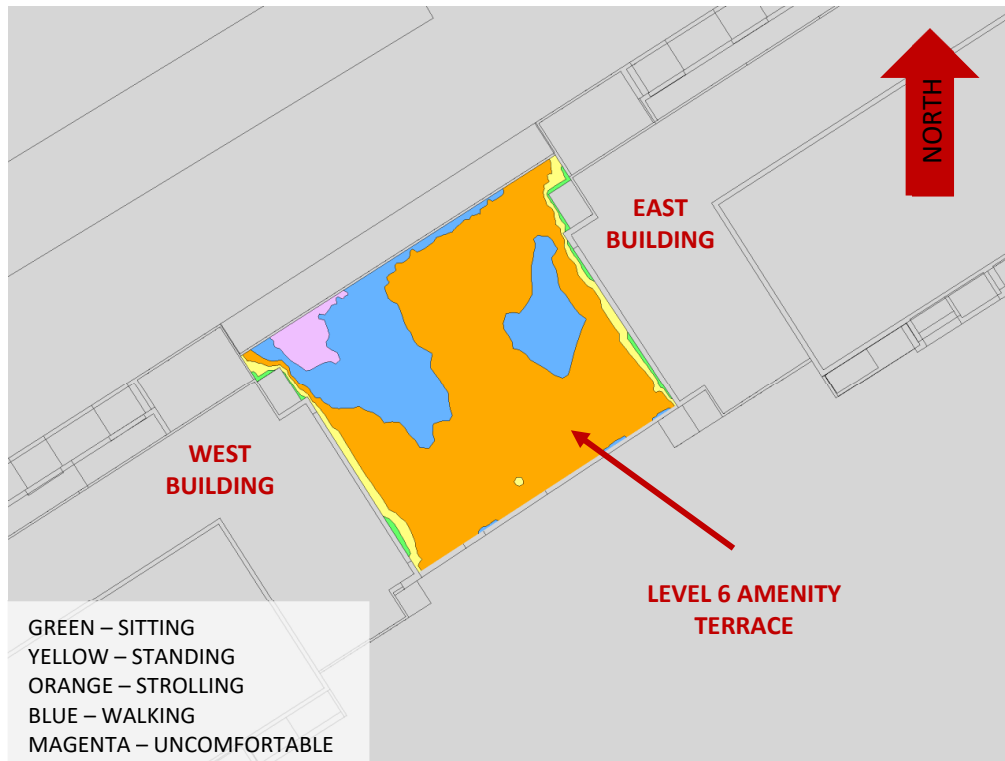
**FIGURE 4A: SPRING – WIND CONDITIONS, COMMON AMENITY TERRACE**



**FIGURE 4B: SUMMER – WIND CONDITIONS, COMMON AMENITY TERRACE**



**FIGURE 4C: AUTUMN – WIND CONDITIONS, COMMON AMENITY TERRACE**



**FIGURE 4D: WINTER – WIND CONDITIONS, COMMON AMENITY TERRACE**



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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  $\alpha$  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.

$\alpha$  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  $\alpha$  used in this study, while Table 2 presents several reference values of  $\alpha$ . When the upstream exposure of the far-field surroundings is a mixture of multiple types of terrain, the  $\alpha$  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 ( $\alpha$ ) Value
0	0.25
49	0.25
74	0.23
103	0.24
167	0.24
197	0.24
217	0.25
237	0.25
262	0.24
282	0.23
302	0.23
324	0.24

**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].

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

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

where,  $I$  = turbulence intensity,  $L_t$  = turbulence length scale,  $Z$  = height above ground, and  $\alpha$  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.

## REFERENCES

- [1] P. Arya, "Chapter 10: Near-neutral Boundary Layers," in *Introduction to Micrometeorology*, San Diego, California, Academic Press, 2001.
- [2] S. A. Hsu, E. A. Meindl and D. B. Gilhousen, "Determining the Power-Law Wind Profile Exponent under Near-neutral Stability Conditions at Sea," vol. 33, no. 6, 1994.
- [3] Y. Tamura, H. Kawai, Y. Uematsu, K. Kondo and T. Okhuma, "Revision of AIJ Recommendations for Wind Loads on Buildings," in *The International Wind Engineering Symposium, IWES 2003*, Taiwan, 2003.