

**PEDESTRIAN LEVEL  
WIND STUDY**

1815 Montréal Road  
Ottawa, Ontario

Report: 23-116-PLW-2024



December 18, 2024

PREPARED FOR

14193679 Canada Inc.  
1606 Proulx Drive  
Ottawa, ON K4A 1T5

PREPARED BY

Sunny Kang, B.A.S., Project Coordinator  
Omar Rioseco, B.Eng., Junior Wind Scientist  
David Huitema, M.Eng., P.Eng., CFD Lead Engineer

## EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy Zoning By-Law Amendment and Site Plan Control application submission requirements for the proposed residential development located at 1815 Montréal Road in Ottawa, Ontario (hereinafter referred to as “subject site” or “proposed development”). Our mandate within this study is to investigate pedestrian wind conditions within and surrounding the subject site, and to identify areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where 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-5, and summarized as follows:

- 1) All grade-level areas within and surrounding the subject site are predicted to experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, transit stops, lay by, walkways, and in the vicinity of building access points, are considered acceptable.
- 2) During the typical use period (May to October, inclusive), conditions within the Level 4 common amenity terrace are predicted to be suitable for standing, or better, with an isolated region suitable for strolling at the northwest corner of the terrace, while conditions within the MPH Level common amenity terrace are predicted to be suitable for a mix of sitting and standing.
  - a. It is recommended to implement 1.8-m-tall wind screens along the perimeters of the amenity terraces. Canopies extending from the tower façade and that wrap around the northwest and northeast corners of the tower above the Level 4 terrace are recommended to diffuse downwashing winds incident on the Level 4 terrace. Mitigation inboard of the perimeter for the Level 4 terrace could take the form of wind screens and/or other landscaping features, such as raised planters and high-back bench seating.



- b. The extent of the mitigation measures is dependent on the programming of the noted spaces. An appropriate mitigation strategy may be developed in collaboration with the building and landscape architects as the design of the proposed development progresses.
- 3) The foregoing statements and conclusions apply to common weather systems, during which no dangerous wind conditions, as defined in Section 4.4, are expected anywhere over the subject site. During extreme weather events, (for example, thunderstorms, tornadoes, and downbursts), pedestrian safety is the main concern. However, these events are generally short-lived and infrequent and there is often sufficient warning for pedestrians to take appropriate cover.

**TABLE OF CONTENTS**

**1. INTRODUCTION ..... 1**

**2. TERMS OF REFERENCE..... 1**

**3. OBJECTIVES ..... 2**

**4. METHODOLOGY ..... 3**

**4.1 Computer-Based Context Modelling ..... 3**

**4.2 Wind Speed Measurements ..... 3**

**4.3 Historical Wind Speed and Direction Data ..... 4**

**4.4 Pedestrian Wind Comfort and Safety Criteria – City of Ottawa ..... 6**

**5. RESULTS AND DISCUSSION ..... 8**

**5.1 Wind Comfort Conditions – Grade Level..... 9**

**5.2 Wind Comfort Conditions – Common Amenity Terraces ..... 10**

**5.3 Wind Safety ..... 10**

**5.4 Applicability of Results..... 11**

**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 14193679 Canada Inc. to undertake a pedestrian level wind (PLW) study to satisfy Zoning By-Law Amendment and Site Plan Control application submission requirements for the proposed residential development located at 1815 Montréal Road in Ottawa, Ontario (hereinafter referred to as “subject site” or “proposed development”). A PLW study was completed in May 2023<sup>1</sup> for the previous design of the proposed development. Our mandate within the current study is to investigate pedestrian wind conditions within and surrounding the subject site, and to identify areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

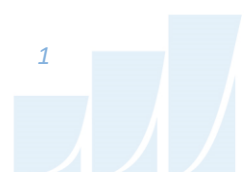
Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings prepared by Roderick Lahey Architects Inc. in November 2024, surrounding street layouts 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 1815 Montréal Road in Ottawa, situated approximately 220 metres (m) east of the intersection of Montréal Road and Beckenham Lane, on a parcel of land bounded by Montréal Road to the south, a future two-storey office building to the west, and low-rise residential dwellings to the north and east. The proposed development comprises a near-rectangular 21-storey residential building. The proposed development includes two and a half storeys of parking, with the uppermost level (P1) and the rooftop amenity space each considered a “storey” under the City of Ottawa Zoning By-Law. The rooftop includes a mechanical penthouse (MPH) and amenity spaces. Access to underground parking is provided by a ramp to the east.

---

<sup>1</sup> Gradient Wind Engineering Inc., ‘Pedestrian Level Wind Study – 1815 Montréal Road’, [May 26, 2023]



The ground floor of the proposed development includes a lobby at the southeast corner with a main entrance to the south, a co-working area, bike storage, and a loading area at the southwest corner, shared building support spaces to the west, a central elevator core, and residential units throughout the remainder of the level. Private patios are located to the northwest and along the north and east elevations.

Levels 2, 3, and 5-19 are reserved for residential use while Level 4 includes an indoor amenity to the north and residential units throughout the remainder of the level. The building steps back from the north and east elevations at Level 4, accommodating a common amenity terrace. Private terraces are provided at the southeast corner at Level 4, to the south and southwest at Level 5, to the north at Level 17, and to the east and west at Level 19. The MPH Level includes a party room to the east and mechanical spaces to the south and west and is served by a common amenity terrace within a setback from the north elevation.

The near-field surroundings, defined as an area within 200 m of the subject site, include low-rise residential dwellings in all compass directions. Notably, a development comprising a two-storey office building and a one-storey multi-purpose accessory building is under construction at 1795 Montréal Road, to the immediate west of the subject site. 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 low-rise massing in all compass directions with isolated mid- and high-rise buildings to the west-northwest and from the southeast clockwise to the south. Green space and the Pine View golf course are situated from the east clockwise to the south-southeast.

A site plan for the proposed massing scenario is illustrated in Figure 1, while Figures 2A-2D illustrate the computational models used to conduct the study.

### **3. OBJECTIVES**

The principal objectives of this study are to (i) determine pedestrian level wind 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 subject 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>2</sup>. 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 subject 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 stronger wind speeds.

### **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 16 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a radius of 480 m.

---

<sup>2</sup> City of Ottawa Terms of References: Wind Analysis  
[https://documents.ottawa.ca/sites/documents/files/wind\\_analysis\\_tor\\_en.pdf](https://documents.ottawa.ca/sites/documents/files/wind_analysis_tor_en.pdf)

Mean and peak wind speed data obtained over the subject 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 amenity terraces serving the proposed development 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.

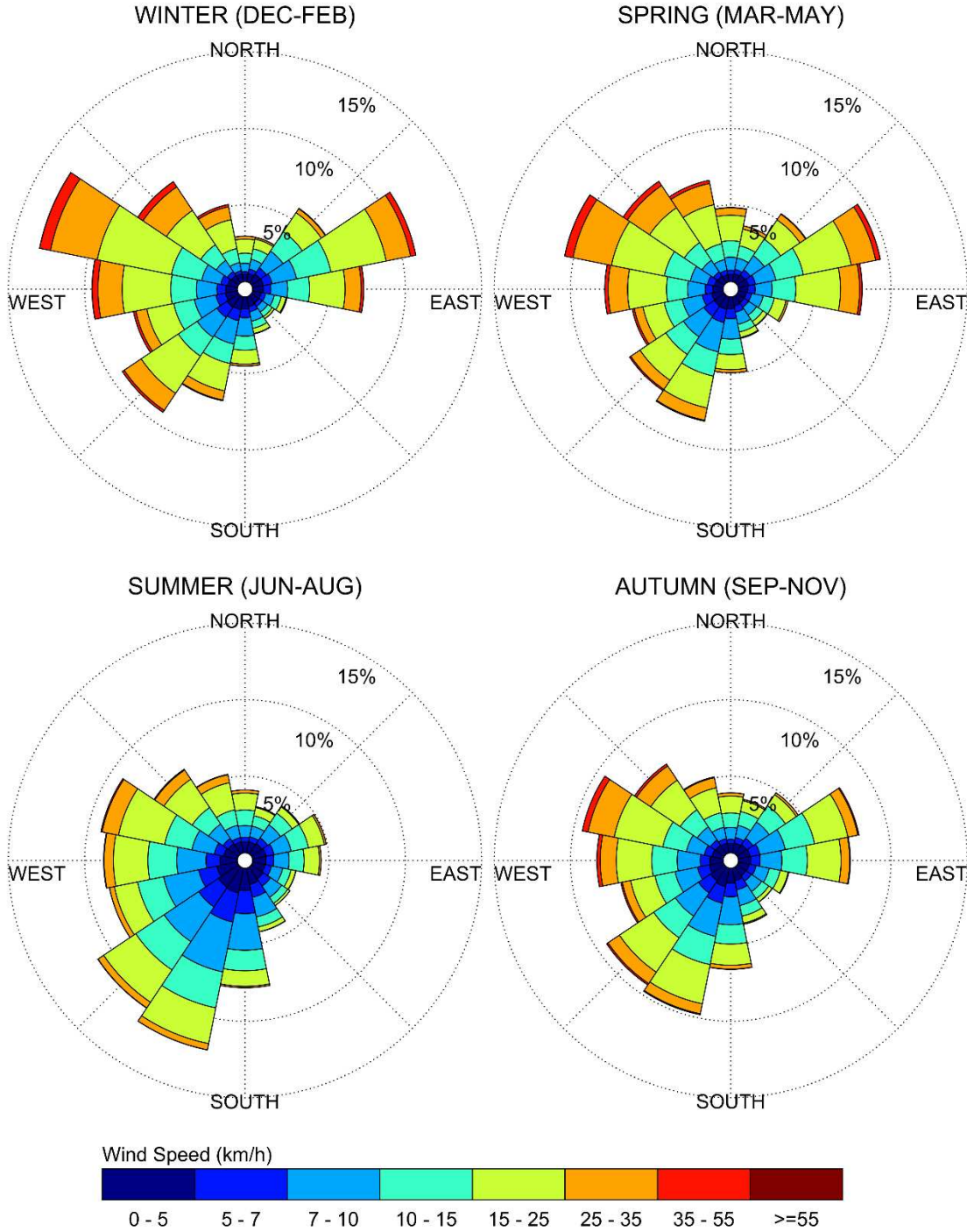
### 4.3 Historical Wind Speed and Direction Data

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 during the appropriate hours of pedestrian usage (that is, between 06:00 and 23:00) and divided into four distinct seasons, as stipulated in the wind criteria. Specifically, the spring season is defined as March through May, the summer season is defined as June through August, the autumn season is defined as September through November, and the winter season is defined as December through February, inclusive.

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 prominent 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 prominence 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 Wind Comfort and Safety Criteria – City of Ottawa

Pedestrian wind comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (that is, temperature and relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes based on 20% non-exceedance mean wind speed ranges are used to assess pedestrian comfort: (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. The gust speeds, and equivalent mean speeds, are selected based on the Beaufort scale, which describes the effects of forces produced by varying wind speed levels on objects. Wind conditions suitable for sitting are represented by the colour blue, standing by green, strolling by yellow, and walking by orange; uncomfortable conditions are represented by the colour magenta. Specifically, the comfort classes, associated wind speed ranges, and limiting criteria are summarized as follows:

##### PEDESTRIAN WIND COMFORT CLASS DEFINITIONS

Wind Comfort Class	Mean Speed (km/h)	Description
SITTING	≤ 10	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.
STANDING	≤ 14	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.
STROLLING	≤ 17	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.
WALKING	≤ 20	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.
UNCOMFORTABLE	> 20	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.

Regarding wind safety, 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. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall. Notably, 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.

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 (equivalent gust wind speed of approximately 16 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 (equivalent gust wind speed of approximately 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 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 subject 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 target comfort classes, which are dictated by the location type for each region (that is, a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their typical windiest target comfort classes are summarized on the following page. Depending on the programming of a space, the desired comfort class may differ from this table.

**TARGET PEDESTRIAN WIND COMFORT CLASSES FOR VARIOUS LOCATION TYPES**

Location Types	Target Comfort Classes
Primary Building Entrance	Standing
Secondary Building Access Point	Walking
Public Sidewalk / Bicycle Path	Walking
Outdoor Amenity Space	Sitting / Standing
Café / Patio / Bench / Garden	Sitting / Standing
Transit Stop (Without Shelter)	Standing
Transit Stop (With Shelter)	Walking
Public Park / Plaza	Sitting / Standing
Garage / Service Entrance	Walking
Parking Lot	Walking
Vehicular Drop-Off Zone	Walking

**5. RESULTS AND DISCUSSION**

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-D, which illustrate wind conditions at grade level for the proposed massing scenario, and by Figures 4A-D, illustrating wind conditions over the common amenity terraces serving the proposed development at Level 4 and at the MPH Level. Conditions are presented as continuous contours of wind comfort throughout the subject site and correspond to the comfort classes presented in Section 4.4.

Wind comfort conditions are also reported for the typical use period, which is defined as May to October, inclusive. Figure 5 illustrates wind comfort conditions within the noted common amenity terraces during this period, consistent with the comfort classes illustrated in Section 4.4.

The details of these conditions are summarized in the following pages for each area of interest. For a summary of the existing conditions over the subject site, refer to the previous PLW study from May 2023, as noted in Section 1.

## 5.1 Wind Comfort Conditions – Grade Level

**Sidewalks and Nearby Transit Stop along Montréal Road:** Following the introduction of the proposed development, wind comfort conditions over the nearby public sidewalks along Montréal Road are predicted to be suitable for strolling, or better, during the summer and autumn, becoming suitable for mostly standing and strolling during the spring and winter, with walking conditions to the south of the proposed development.

During the winter season, a limited and isolated region of conditions that may be considered uncomfortable for walking is located to the south of the proposed development. Where conditions may be considered uncomfortable for walking, they are predicted to be suitable for walking for approximately 79% of the time during the winter, representing an exceedance of 1% of the walking comfort criterion. These conditions are located within a limited region of the north sidewalk along Montréal Road and the noted exceedance may be considered marginal. As such, the noted conditions may be considered satisfactory.

Conditions in the vicinity of the transit stop along Montréal Road are predicted to be suitable for sitting during the summer and autumn, becoming suitable for standing during the spring and winter. The noted conditions are considered acceptable.

**Lay By Serving the Subject Site:** Conditions over the lay by serving the subject site are predicted to be suitable for a mix of standing and strolling during the summer and autumn, becoming suitable for a mix of standing, strolling, and walking during the spring and winter. The noted conditions are considered acceptable.

**Walkways Serving the Subject Site:** Conditions over the walkways serving the proposed development are predicted to be suitable for a mix of mostly sitting and standing throughout the year, with isolated regions suitable for strolling and walking. The noted conditions are considered acceptable.

**Building Access Points:** Owing to the protection of the building's façades, conditions in the vicinity of the primary and secondary access points serving the proposed development are predicted to be suitable for sitting during the summer, and standing, or better, throughout the remainder of the year, which is considered acceptable.

## 5.2 Wind Comfort Conditions – Common Amenity Terraces

**Level 4 Common Amenity Terrace:** During the typical use period, wind comfort conditions within the common amenity terrace serving the proposed development at Level 4 are predicted to be suitable for mostly standing, with sitting conditions predicted closer to the tower façade and an isolated region suitable for strolling at the northwest corner of the terrace, as illustrated in Figure 5.

Wind screens, typically glazed and preferably solid, are recommended to extend at least 1.8 m above the local walking surface along the perimeter of the Level 4 terrace. It is also recommended to implement canopies extending from the northeast and northwest corners of the tower above the terrace, wrapping around the northwest and northeast elevations to diffuse downwashing winds incident on the terrace. Targeted mitigation inboard of the perimeter could take the form of wind screens and/or other landscaping features.

The extent of the mitigation is dependent on the programming of the terrace. An appropriate mitigation strategy may be developed in collaboration with the building and landscape architects as the design of the proposed development progresses.

**MPH Level Common Amenity Terrace:** During the typical use period, wind conditions within the common amenity terrace serving the proposed development at the MPH Level are predicted to be suitable for sitting at the southeast corner and to the west and suitable for standing elsewhere throughout the terrace, as illustrated in Figure 5. The areas predicted to be suitable for standing are also predicted to be suitable for sitting at least 77% of the time during the same period, where the target is 80% to achieve the sitting comfort criterion. It is recommended to implement 1.8-m-tall wind screens along the perimeter of the MPH Level terrace to provide shielding against direct winds and extend sitting conditions over the terrace.

## 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 within or surrounding the subject site are expected to experience conditions that could be considered dangerous, as defined in Section 4.4.

## 5.4 Applicability of Results

Pedestrian wind comfort and safety have been quantified for the specific configuration of existing and foreseeable construction around the subject site. Future changes (that is, 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 subject site would alter the wind profile approaching the subject site; and (ii) development in proximity to the subject site would cause changes to local flow patterns.

## 6. CONCLUSIONS AND RECOMMENDATIONS

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

- 1) All grade-level areas within and surrounding the subject site are predicted to experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, transit stops, lay by, walkways, and in the vicinity of building access points, are considered acceptable.
- 2) During the typical use period (May to October, inclusive), conditions within the Level 4 common amenity terrace are predicted to be suitable for standing, or better, with an isolated region suitable for strolling at the northwest corner of the terrace, while conditions within the MPH Level common amenity terrace are predicted to be suitable for a mix of sitting and standing.
  - a. It is recommended to implement 1.8-m-tall wind screens along the perimeters of the amenity terraces. Canopies extending from the tower façade and that wrap around the northwest and northeast corners of the tower above the Level 4 terrace are recommended to diffuse downwashing winds incident on the Level 4 terrace. Mitigation inboard of the perimeter for the Level 4 terrace could take the form of wind screens and/or other landscaping features, such as raised planters and high-back bench seating.



- b. The extent of the mitigation measures is dependent on the programming of the noted spaces. An appropriate mitigation strategy may be developed in collaboration with the building and landscape architects as the design of the proposed development progresses.
- 3) The foregoing statements and conclusions apply to common weather systems, during which no dangerous wind conditions, as defined in Section 4.4, are expected anywhere over the subject site. During extreme weather events, (for example, thunderstorms, tornadoes, and downbursts), pedestrian safety is the main concern. However, these events are generally short-lived and infrequent and there is often sufficient warning for pedestrians to take appropriate cover.

Sincerely,

**Gradient Wind Engineering Inc.**



Omar Rioseco, B.Eng.  
Junior Wind Scientist

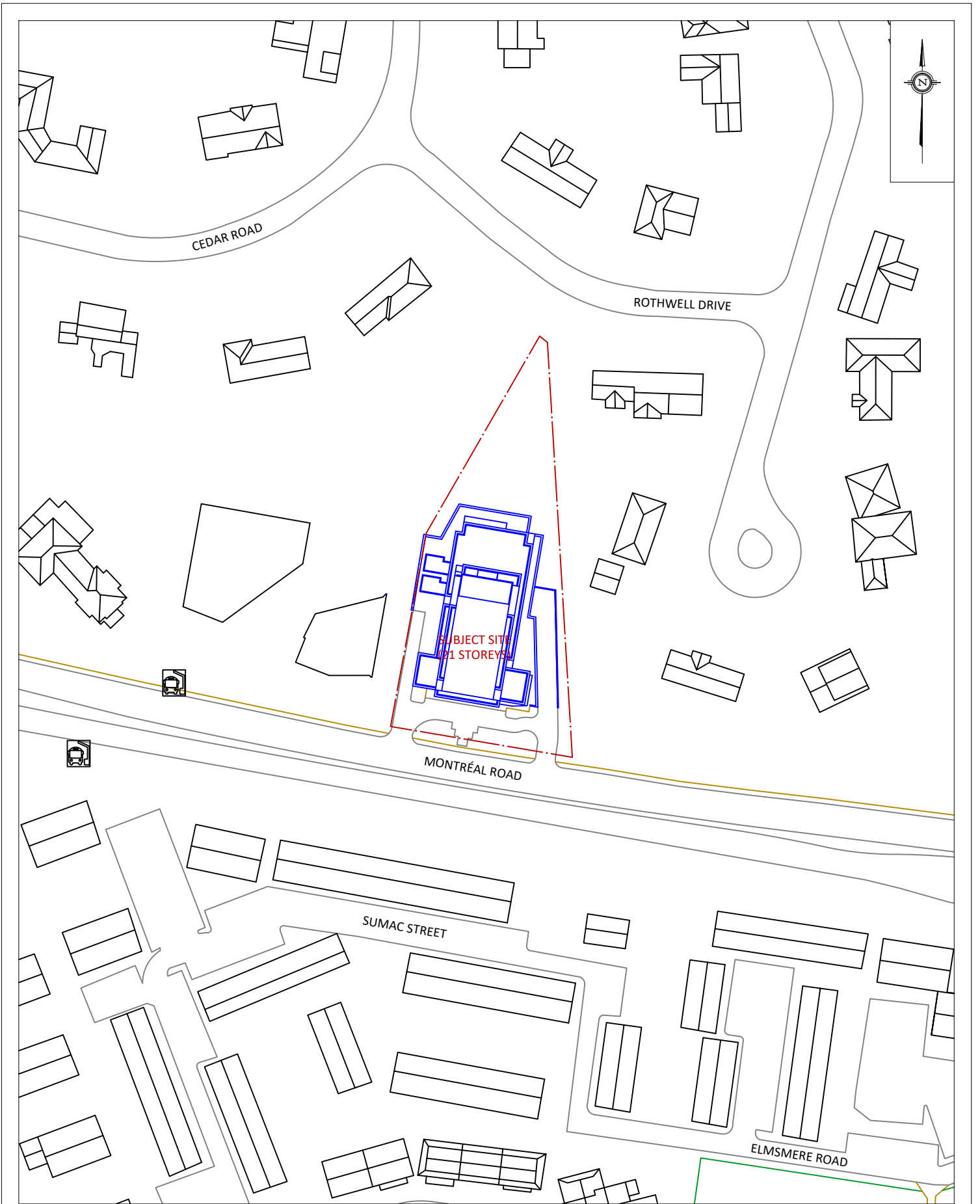


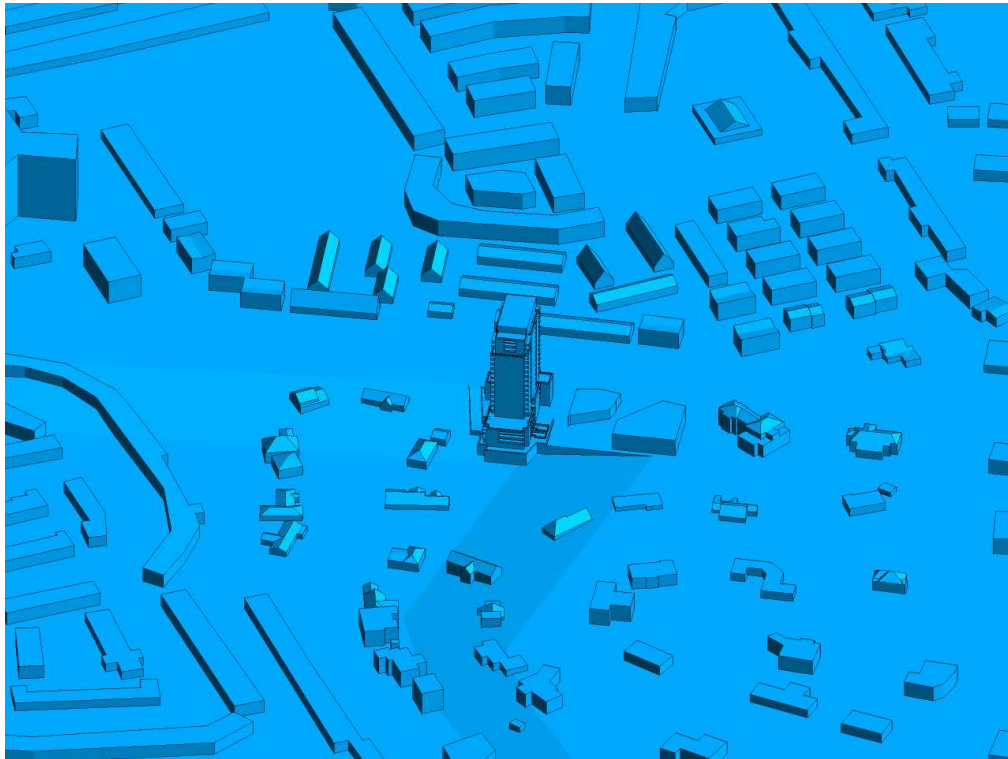
Sunny Kang, B.A.S.  
Project Coordinator



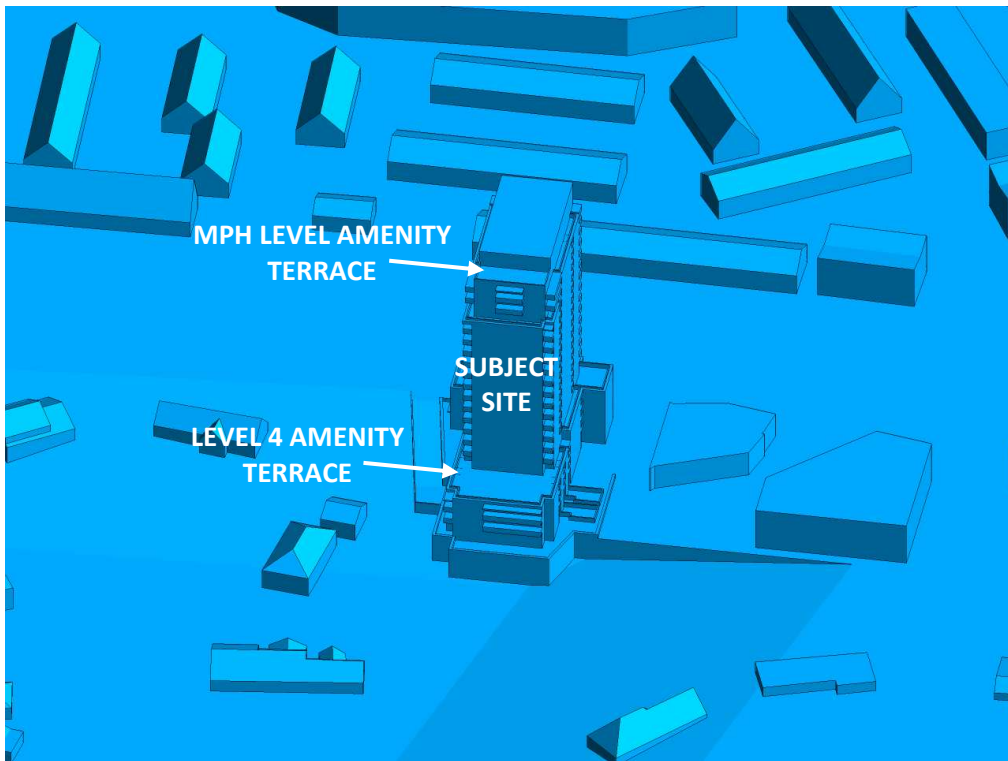
David Huitema, M.Eng., P.Eng.  
CFD Lead Engineer





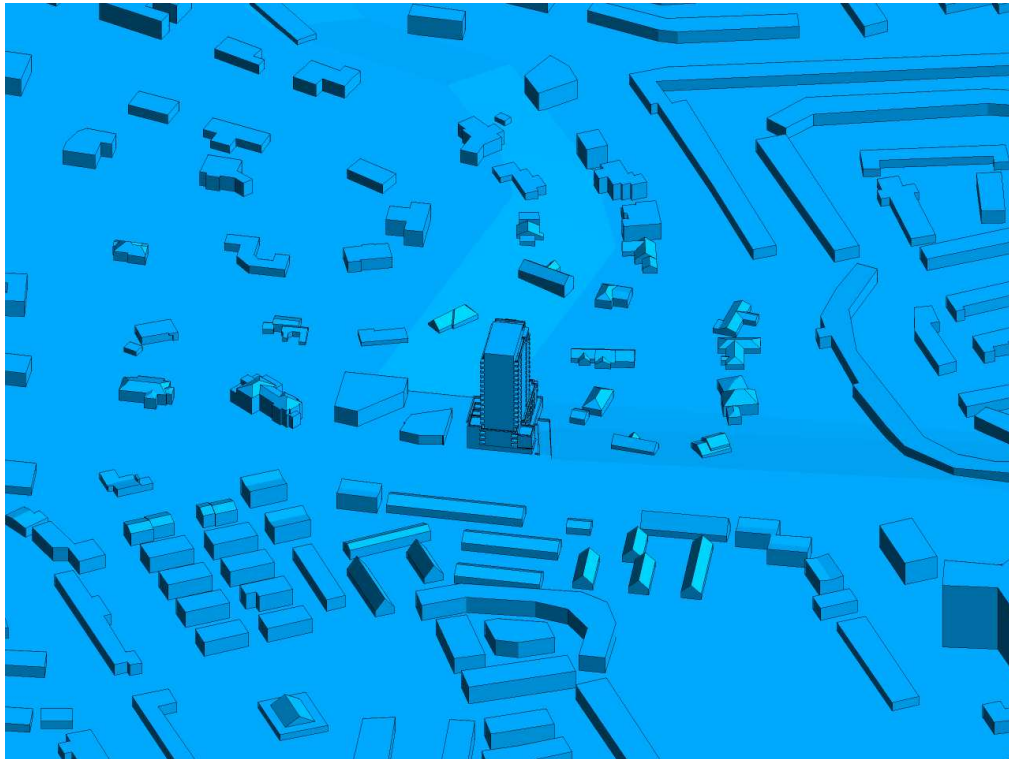


**FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTH PERSPECTIVE**

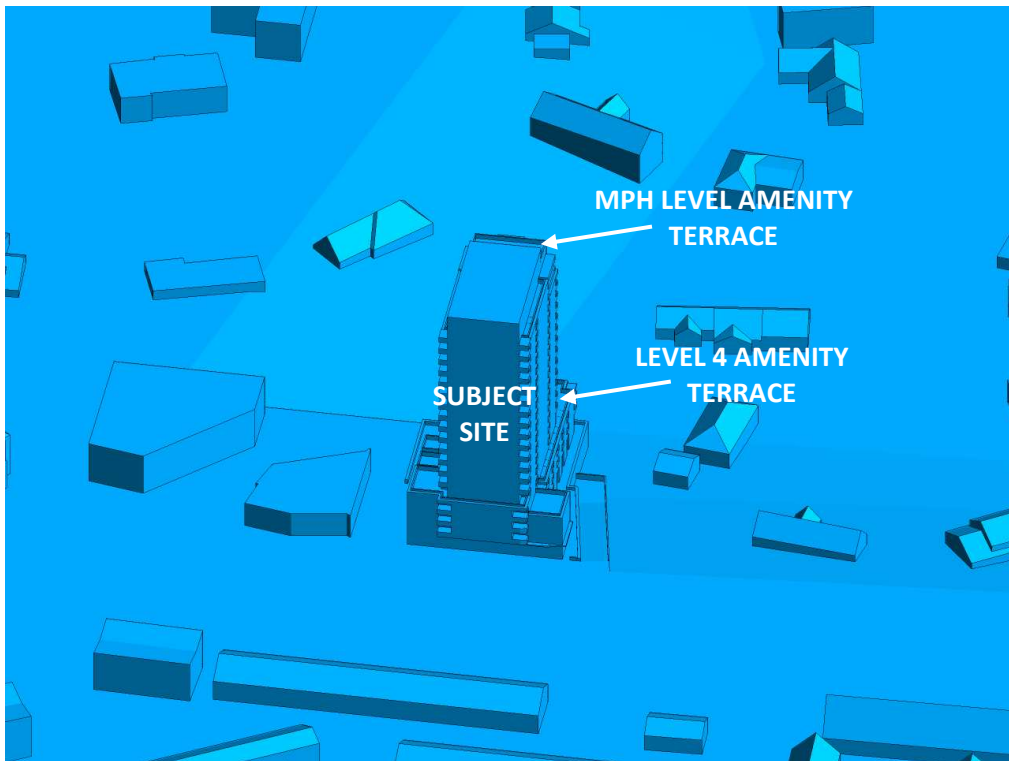


**FIGURE 2B: CLOSE UP OF FIGURE 2A**

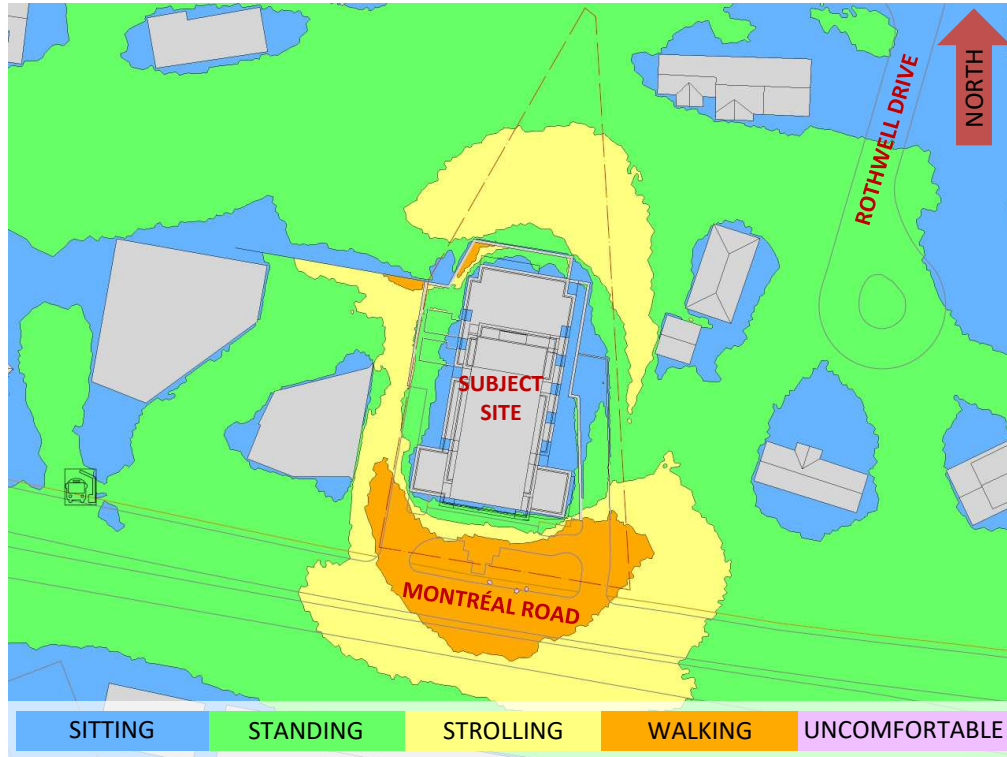




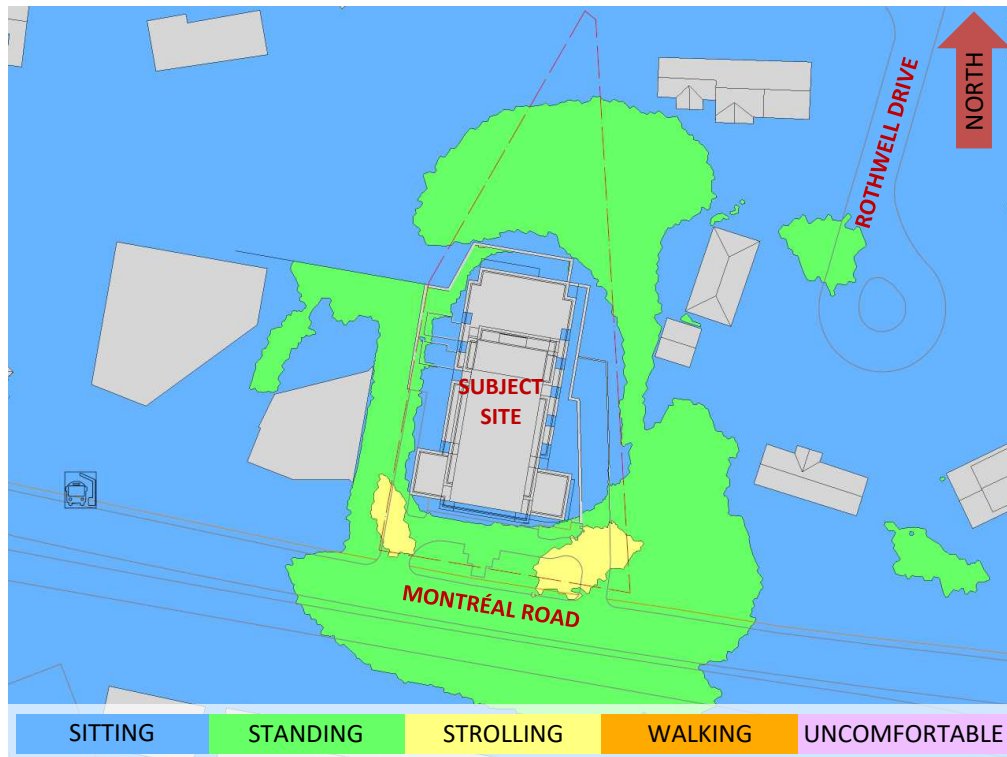
**FIGURE 2C: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTH PERSPECTIVE**



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



**FIGURE 3A: SPRING – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING**



**FIGURE 3B: SUMMER – WIND COMFORT, GRADE LEVEL– PROPOSED MASSING**



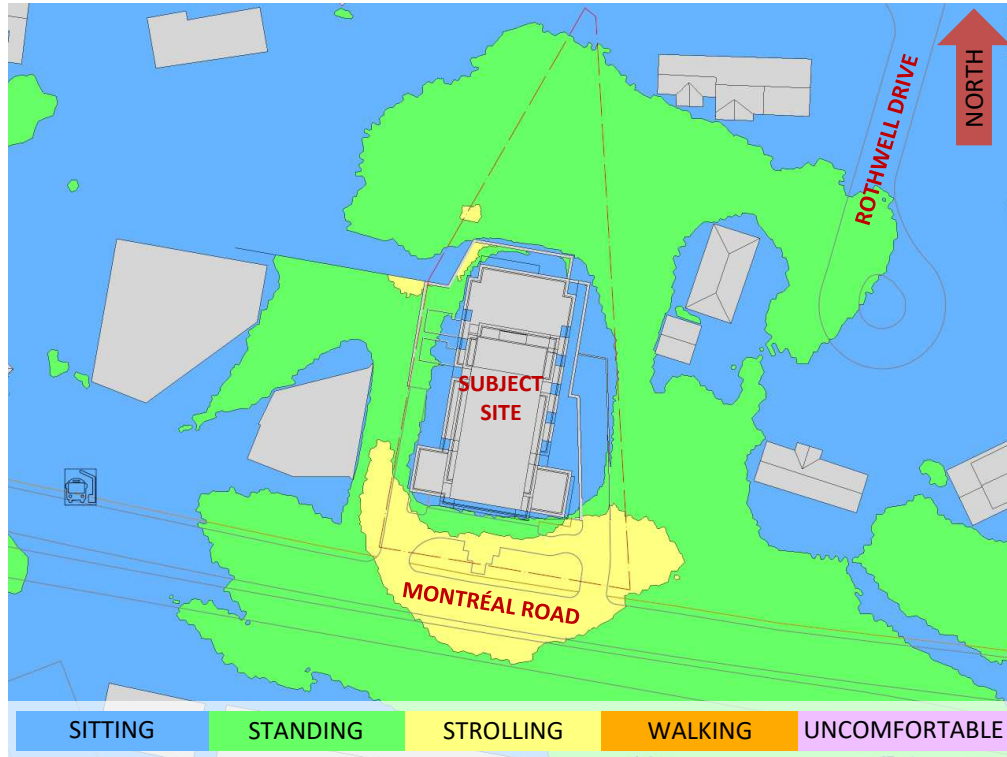


FIGURE 3C: AUTUMN – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

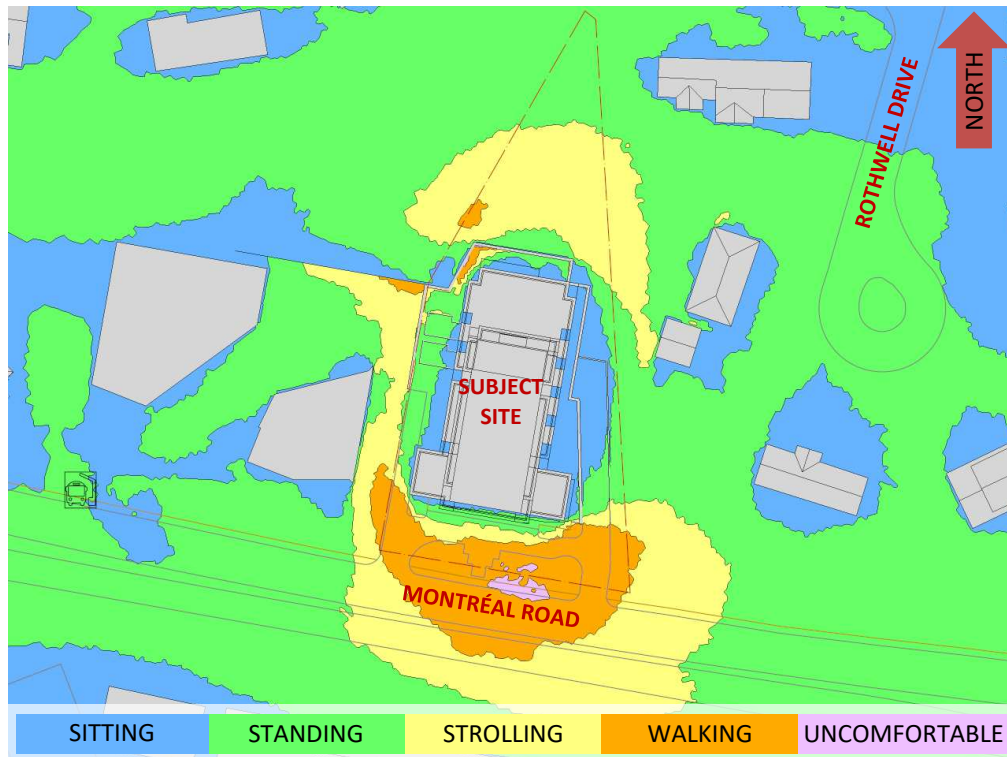
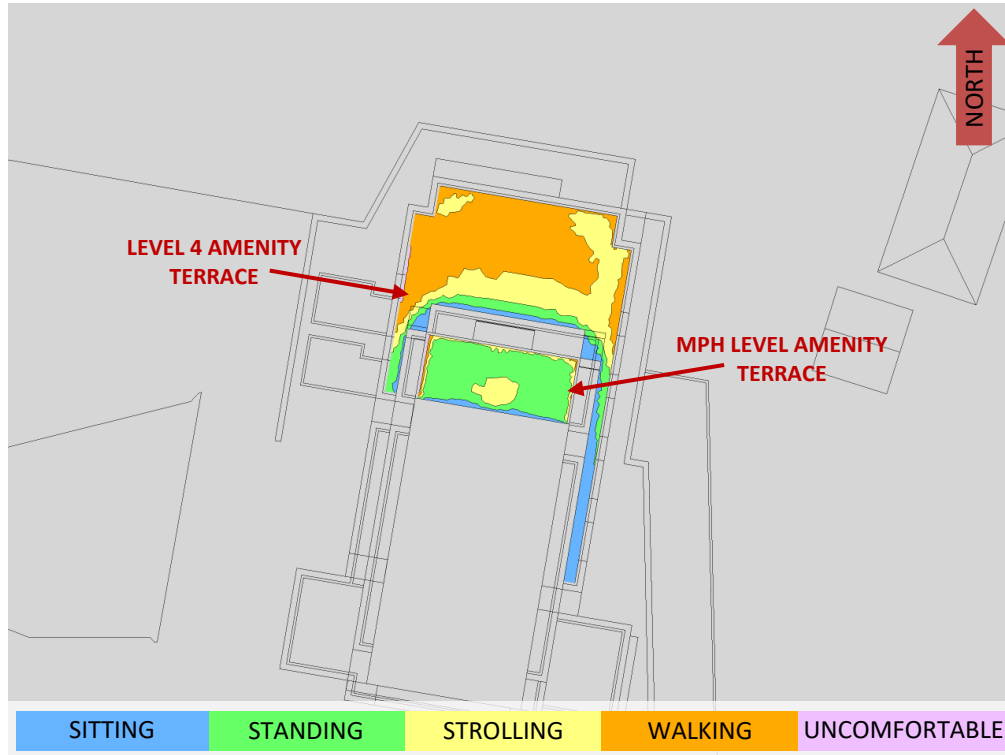


FIGURE 3D: WINTER – WIND COMFORT, GRADE LEVEL– PROPOSED MASSING



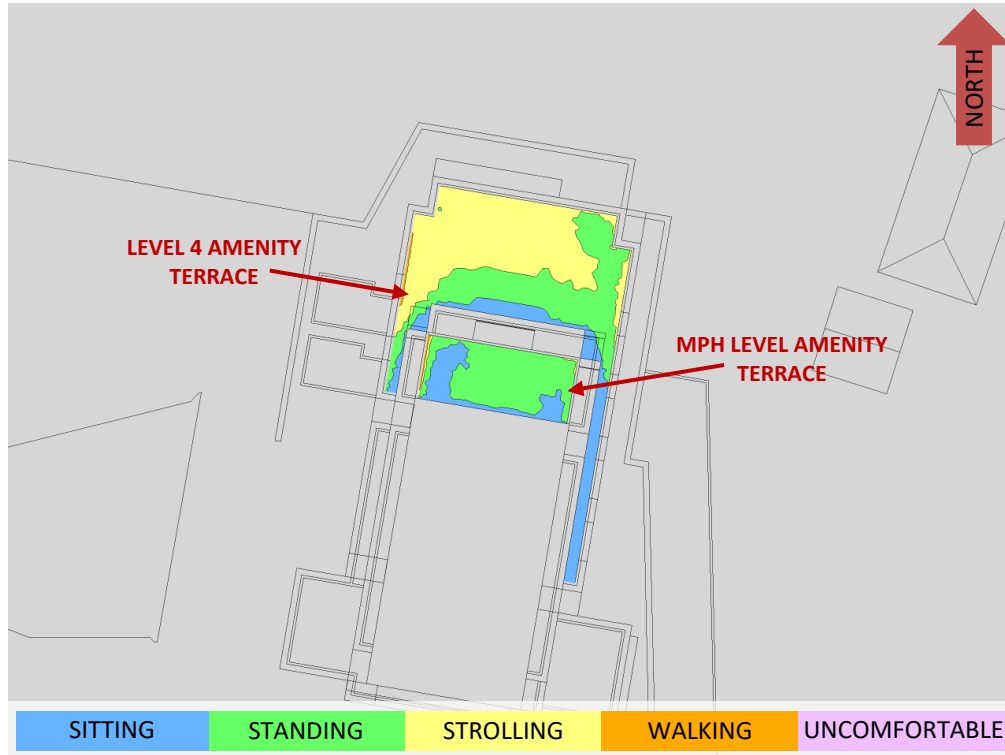


**FIGURE 4A: SPRING – WIND COMFORT, COMMON AMENITY TERRACES**

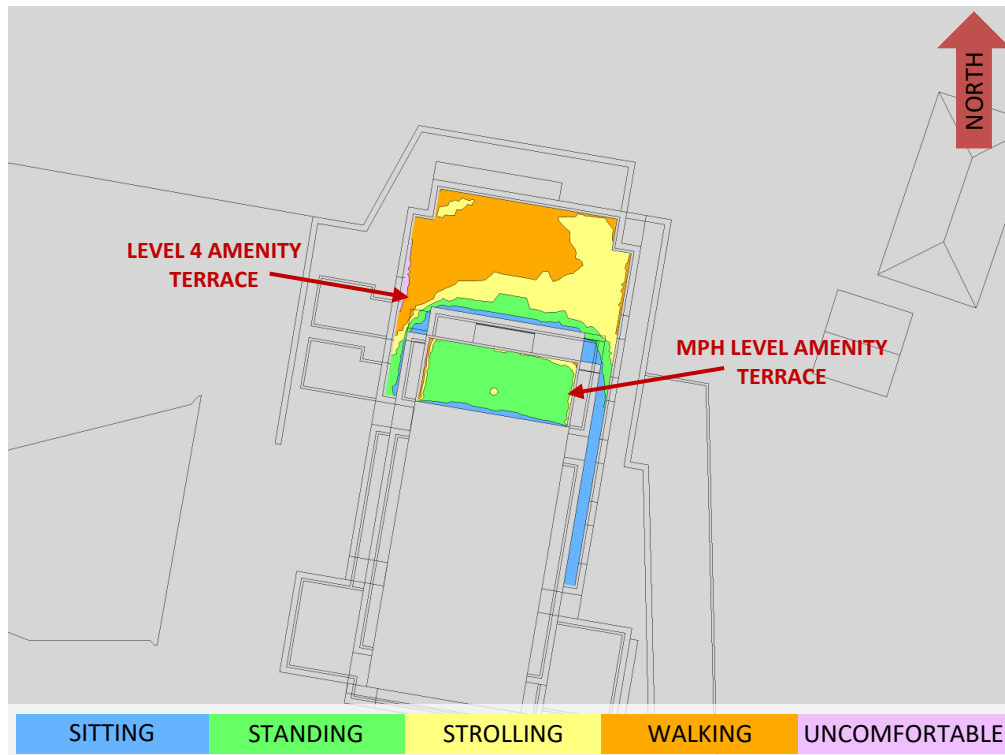


**FIGURE 4B: SUMMER – WIND COMFORT, COMMON AMENITY TERRACES**

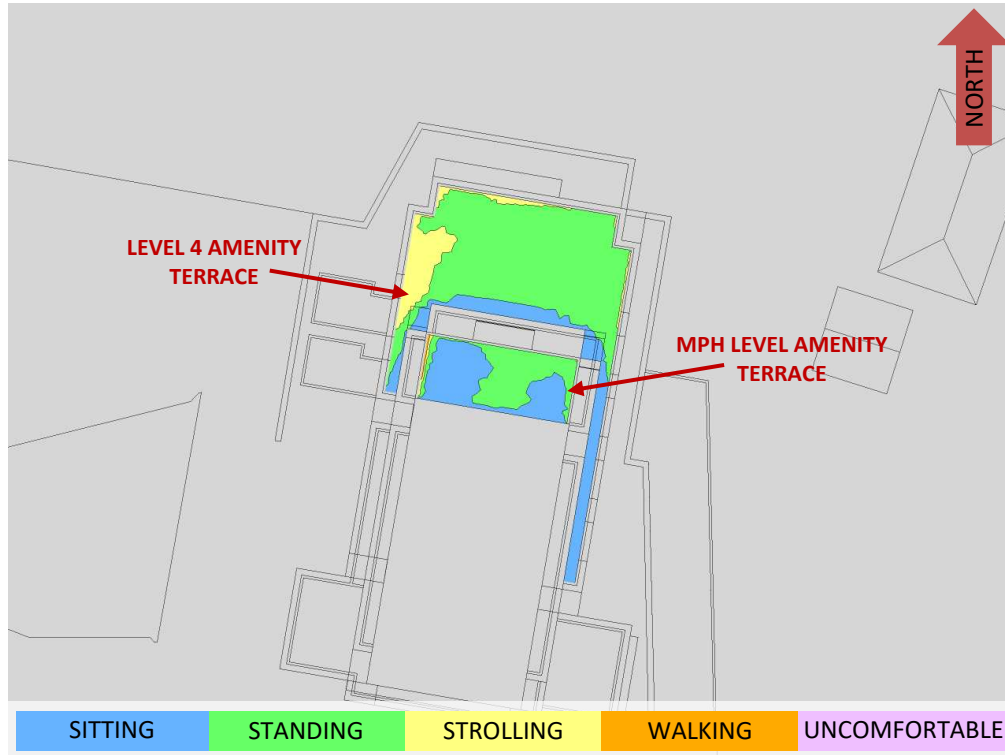




**FIGURE 4C: AUTUMN – WIND COMFORT, COMMON AMENITY TERRACES**



**FIGURE 4D: WINTER – WIND COMFORT, COMMON AMENITY TERRACES**

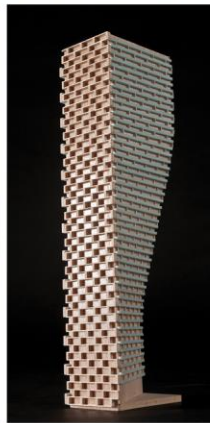


**FIGURE 5: TYPICAL USE PERIOD – WIND COMFORT, COMMON AMENITY TERRACES**



# GRADIENTWIND

ENGINEERS & SCIENTISTS



## 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 (that is, 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 (Degrees True)	Alpha Value ( $\alpha$ )
0	0.23
22.5	0.23
45	0.23
67.5	0.23
90	0.22
112.5	0.23
135	0.22
157.5	0.22
180	0.24
202.5	0.24
225	0.24
247.5	0.24
270	0.25
292.5	0.24
315	0.23
337.5	0.23

**TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)**

Upstream Exposure Type	Alpha Value ( $\alpha$ )
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.