

PEDESTRIAN LEVEL WIND STUDY

1815 Montréal Road
Ottawa, Ontario

Report: 23-116-PLW



May 26, 2023

PREPARED FOR

CSV Architects

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy concurrent 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 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-10, 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 stop, laneway, walkways, surface parking, and in the vicinity of building access points, are considered acceptable.
- 2) Regarding the common amenity terrace serving the proposed development at Level 2, wind conditions during the typical use period are predicted to be suitable for sitting, with an isolated region predicted to be suitable for standing along the south perimeter, as illustrated in Figure 8. The noted conditions are considered acceptable.
- 3) Regarding the common amenity terrace serving the proposed development Level 7, wind conditions during the typical use period are predicted to be suitable for sitting, with isolated regions predicted to be suitable for standing along the west and east perimeters, as illustrated in Figure 10. The noted conditions are considered acceptable.



- 4) 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.



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1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by CSV Architects to undertake a pedestrian level wind (PLW) study to satisfy concurrent 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 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 CSV Architects, in April 2023, 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 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 nine-storey residential building, topped with a mechanical penthouse.

Above two below-grade parking levels, the ground floor of the proposed development includes a main entrance to the south, central elevator core, bike storage, theater, and co-working space, and residential units throughout the remainder of the level. Private patios are located along the south and west elevations. Access to underground parking is provided by a ramp at the northeast corner via a laneway from Montréal Road. This noted laneway also provides access to surface parking located near the northeast and southeast corners of the proposed development. Levels 2-6, 8, and 9 are reserved for residential use while Level 7 includes a party room at the northwest corner and residential units throughout the remainder of the level. Private terraces are provided to the north and east at Level 2, to



the north at Levels 5 and 8, and to the north and at the northeast and northwest corners at Level 6. Amenity terraces are located near the southeast corner at Level 2 and to the north at Level 7.

The near-field surroundings, defined as an area within 200-metres (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. A large area of green space and the Pine View golf course are situated to the southeast and to the south-southeast, respectively.

Site plans for the proposed and existing massing scenarios are illustrated in Figures 1A and 1B, while Figures 2A-2H illustrate the computational models used to conduct the study. The existing massing scenario includes the existing massing and any future developments approved by the City of Ottawa.

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 criteria¹. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

¹ City of Ottawa Terms of References: Wind Analysis
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 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 12 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a radius of 480 m. The process was performed for two context massing scenarios, as noted in Section 2.

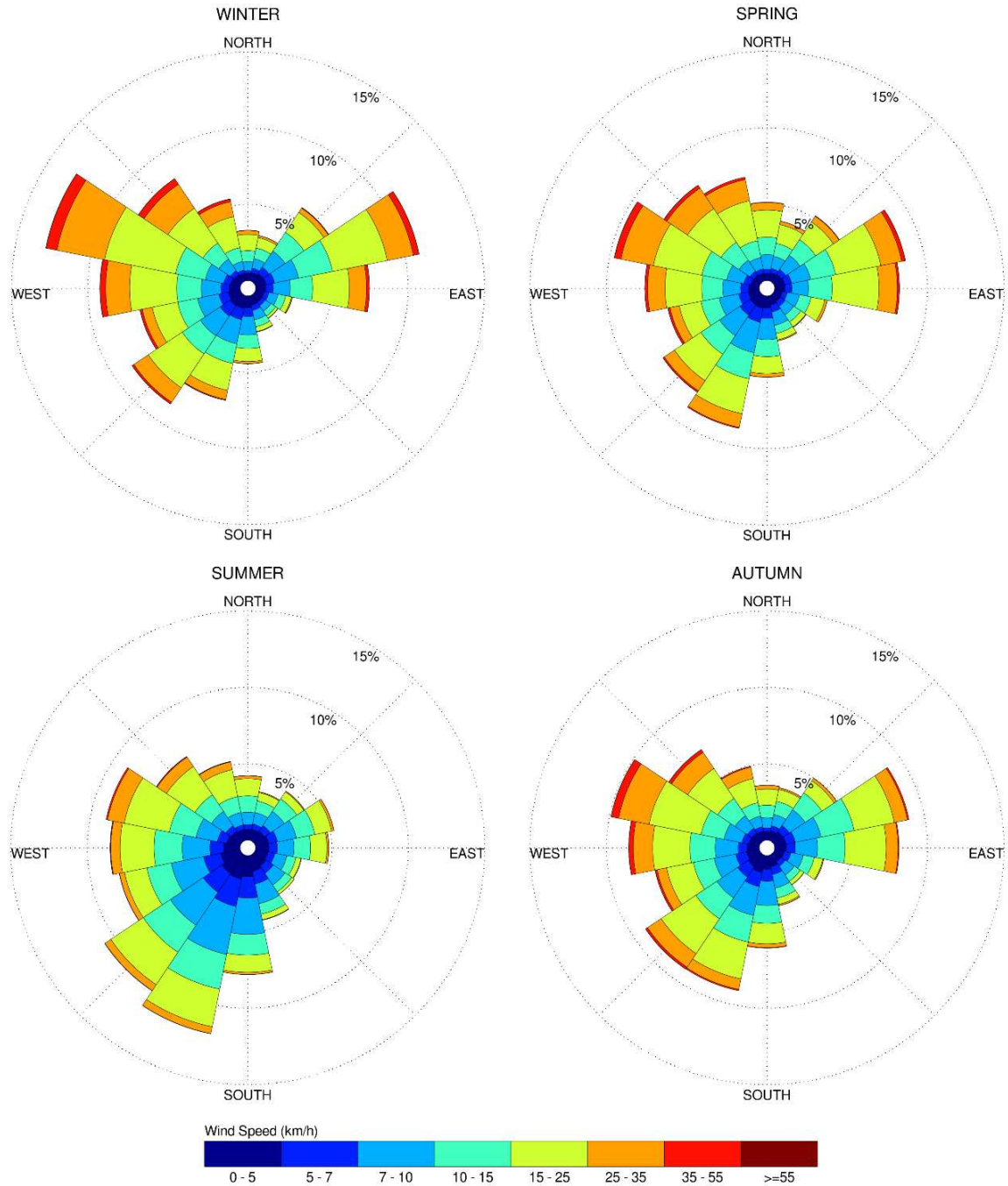
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the common amenity terraces serving the proposed development 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 for each month of the year to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns.

The statistical model of the Ottawa area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The 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 comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (that is, temperature, relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 20% non-exceedance mean wind speed ranges, which include (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

- 1) **Sitting:** Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 16 km/h.
- 2) **Standing:** Mean wind speeds no greater than 14 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 22 km/h.
- 3) **Strolling:** Mean wind speeds no greater than 17 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 27 km/h.
- 4) **Walking:** Mean wind speeds no greater than 20 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 32 km/h.
- 5) **Uncomfortable:** Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.

The pedestrian safety wind speed criterion is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of 90 km/h is classified as dangerous. The gust speeds, and equivalent mean speeds, are selected based on 'The Beaufort Scale', presented on the following page, which describes the effects of forces produced by varying wind speed levels on objects. Gust speeds are included because pedestrians tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also create problems for pedestrians.

THE BEAUFORT SCALE

Number	Description	Gust Wind Speed (km/h)	Description
2	Light Breeze	9-17	Wind felt on faces
3	Gentle Breeze	18-29	Leaves and small twigs in constant motion; wind extends light flags
4	Moderate Breeze	30-42	Wind raises dust and loose paper; small branches are moved
5	Fresh Breeze	43-57	Small trees in leaf begin to sway
6	Strong Breeze	58-74	Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty
7	Moderate Gale	75-92	Whole trees in motion; inconvenient walking against wind
8	Gale	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 (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 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 (that is, a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their typical windiest desired comfort classes are summarized on the following page. Depending on the programming of a space, the desired comfort class may differ from this table.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired 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-6B, illustrating wind conditions at grade level for the proposed and existing massing scenarios, and by Figures 7A-7D and 9A-9D, illustrating wind conditions over the common amenity terraces serving the proposed development at Levels 2 and 7, respectively. Conditions are presented as continuous contours of wind comfort throughout the subject site and correspond to the comfort classes presented in Section 4.4. 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.

Wind comfort conditions at grade and over the noted amenity terraces are also reported for the typical use period, which is defined as May to October, inclusive. Figures 8 and 10 illustrate comfort conditions over the Level 2 and 7 amenity terraces, respectively, consistent with the comfort classes in Section 4.4. Conditions at all areas studied are considered acceptable for the intended pedestrian uses. The details of these conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Sidewalks and Transit Stop along Montréal Road: Following the introduction of the proposed development, conditions over the public sidewalks along Montréal Road are predicted to be suitable mostly for sitting during the summer, becoming suitable for a mix of sitting and standing during the autumn, and suitable for standing, or better, with isolated regions predicted to be suitable for strolling during the winter and spring. Conditions in the vicinity of the nearby transit stop along Montréal Road are predicted to be suitable for sitting during the summer and autumn, becoming suitable for standing during the winter and spring. The noted conditions are considered acceptable.

Wind comfort conditions over the public sidewalks along Montréal Road with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing during the spring and autumn, and suitable for standing during the winter. Conditions in the vicinity of the nearby transit stop along Montréal Road are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing during the autumn, and suitable for standing during the winter and spring. While the introduction of the proposed development produces windier conditions over the sidewalks along Montréal Road in comparison to existing conditions, wind comfort conditions over the nearby transit stop are predicted to improve in comparison to existing conditions. The noted conditions are considered acceptable.

Laneway and Surface Parking East of Subject Site: Wind comfort conditions over the laneway situated along the east elevation of the subject site are predicted to be suitable mostly for sitting during the summer, becoming suitable for a mix of sitting and standing throughout the remainder of the year. Conditions over the surface parking near the northeast corner of the proposed development are predicted to be suitable for sitting throughout the year, with a small, isolated region suitable for standing during the spring. Conditions over the surface parking near the southeast corner of the proposed development are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for standing throughout the remainder of the year. The noted conditions are considered acceptable.

Walkways: Wind comfort conditions over the walkways along all elevations of the subject site are predicted to be suitable for sitting with an isolated region suitable for standing at the southwest corner of the subject site during the summer, becoming suitable for a mix of sitting and standing throughout the

remainder of the year, with small, isolated regions suitable for strolling near the southwest and northwest corners of the subject site during the winter. The noted conditions are considered acceptable.

Building Access: Wind comfort conditions in the vicinity of all building access points are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

5.2 Wind Comfort Conditions – Common Amenity Terraces

Level 2 Common Amenity Terrace: During the typical use period, wind comfort conditions within the common amenity terrace serving the proposed development at Level 2 are predicted to be suitable for sitting, with an isolated region predicted to be suitable for standing along the south perimeter, as illustrated in Figure 9. The noted conditions are considered acceptable.

Level 7 Common Amenity Terrace: During the typical use period, wind comfort conditions within the common amenity terrace serving the proposed development at Level 7 are predicted to be suitable for sitting, with isolated regions predicted to be suitable for standing along the west and east perimeters, as illustrated in Figure 11. The noted conditions are 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 within or surrounding the subject site are expected to experience conditions that could be considered dangerous, as defined in Section 4.4.

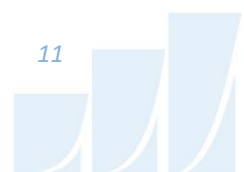
5.4 Applicability of Results

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-10. 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 stop, laneway, walkways, surface parking, and in the vicinity of building access points, are considered acceptable.
- 2) Regarding the common amenity terrace serving the proposed development at Level 2, wind conditions during the typical use period are predicted to be suitable for sitting, with an isolated region predicted to be suitable for standing along the south perimeter, as illustrated in Figure 8. The noted conditions are considered acceptable.
- 3) Regarding the common amenity terrace serving the proposed development Level 7, wind conditions during the typical use period are predicted to be suitable for sitting, with isolated regions predicted to be suitable for standing along the west and east perimeters, as illustrated in Figure 10. The noted conditions are considered acceptable.



- 4) 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

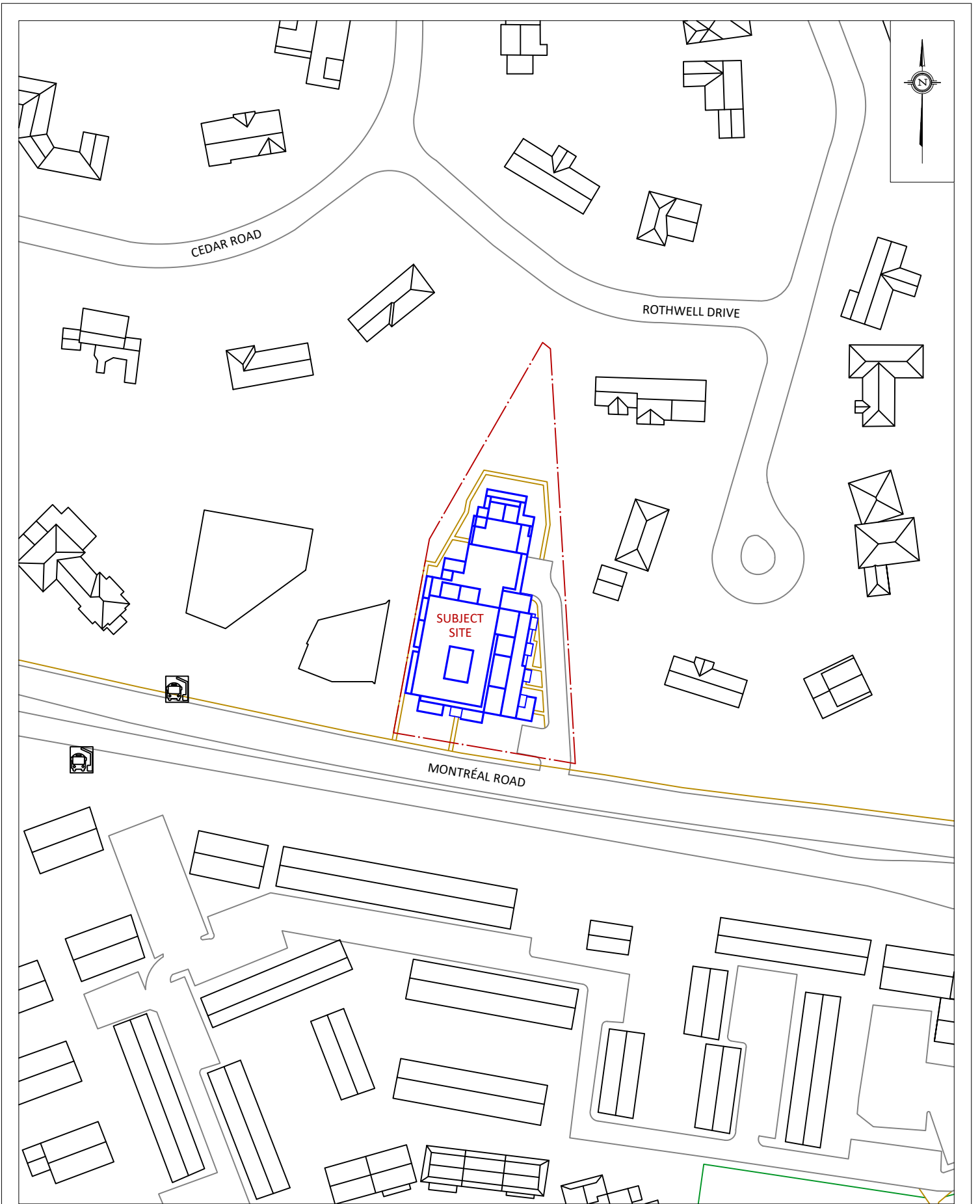


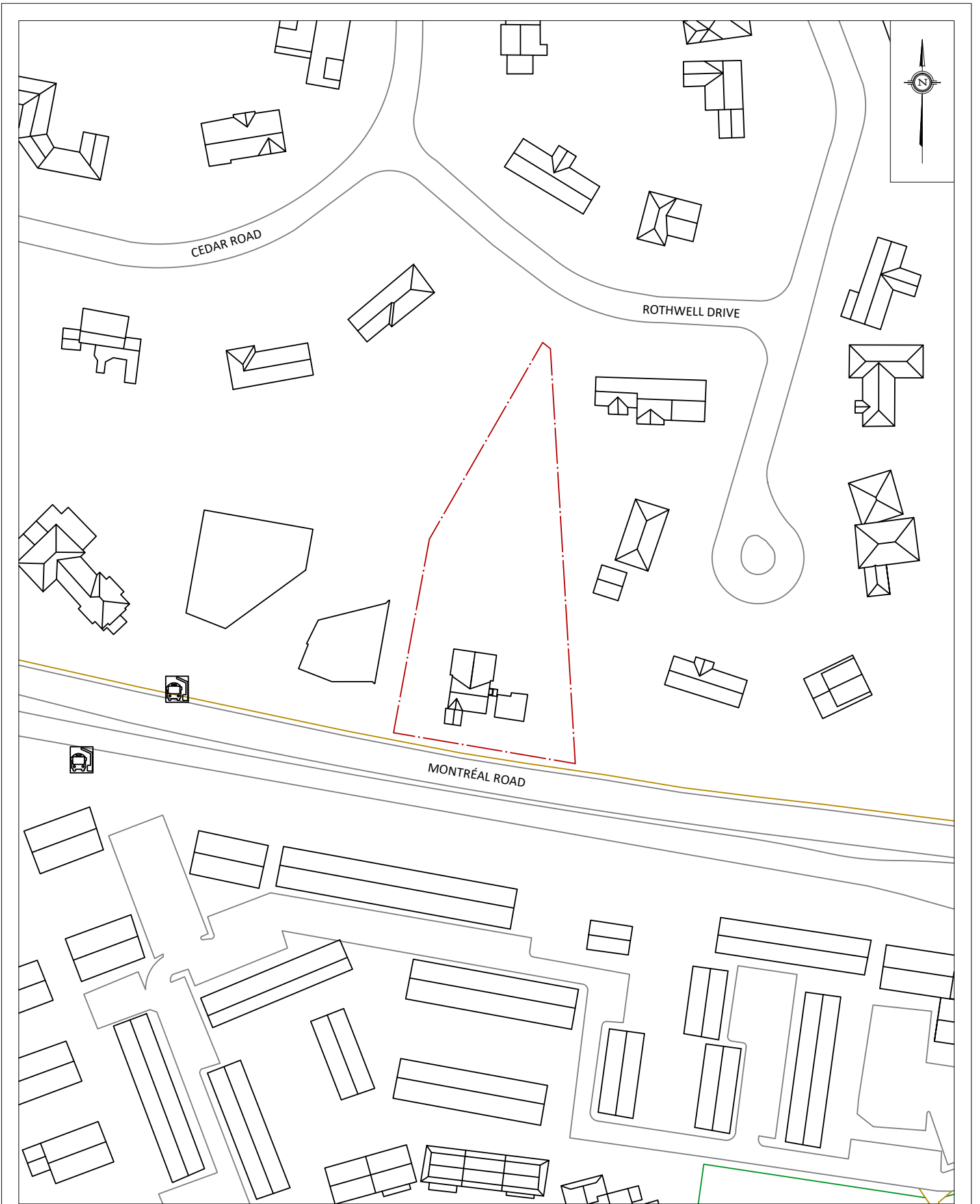
Sunny Kang, B.A.S.
Project Coordinator



Justin Ferraro, P.Eng.
Principal







GRADIENTWIND ENGINEERS & SCIENTISTS 127 WALGREEN ROAD, OTTAWA, ON 613 836 0934 • GRADIENTWIND.COM	PROJECT	1815 MONTRÉAL ROAD, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION	FIGURE 1B: EXISTING SITE PLAN AND SURROUNDING CONTEXT
	SCALE	1:1500	DRAWING NO.	23-116-PLW-1B	
	DATE	MAY 25, 2023	DRAWN BY	S.K.	

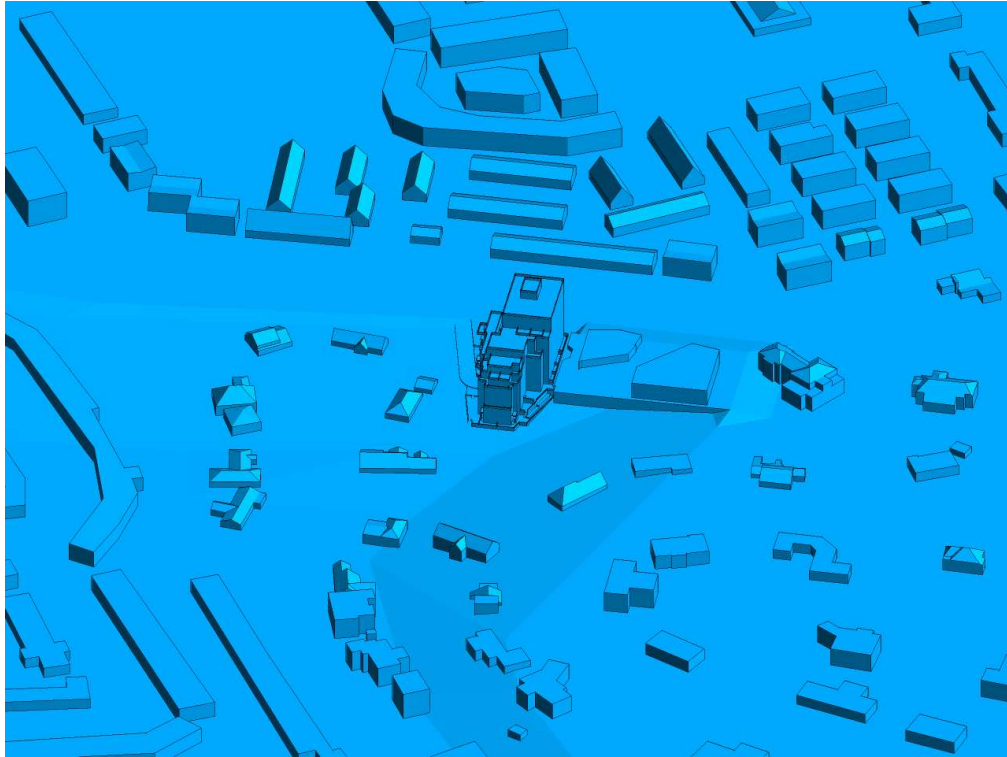


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTH PERSPECTIVE

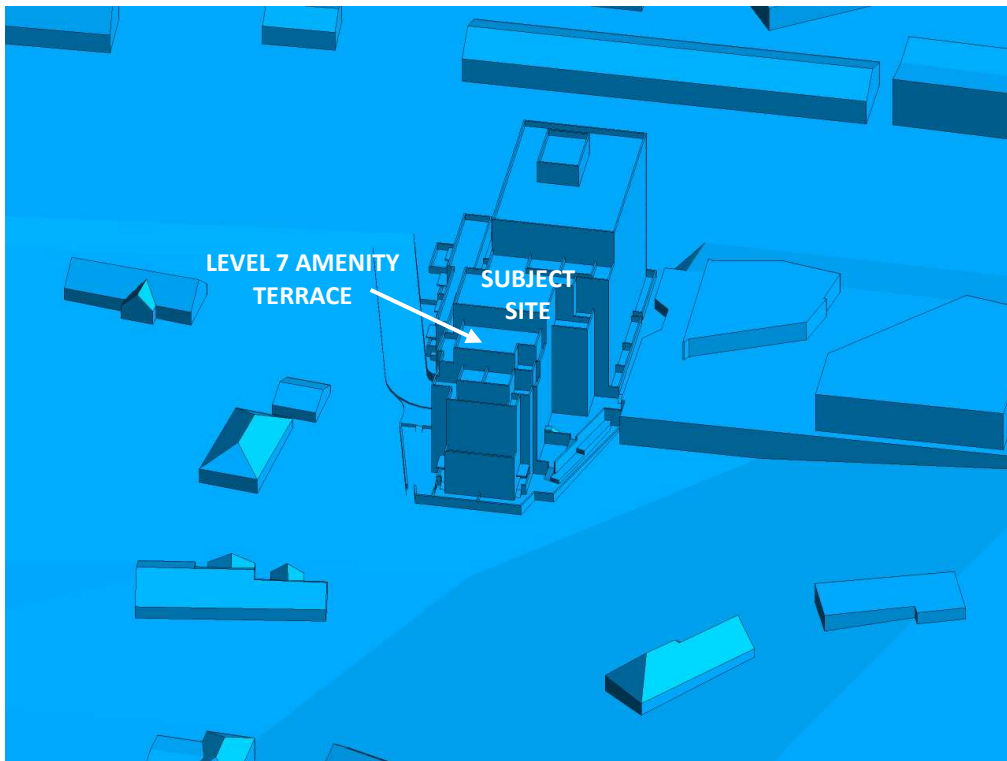


FIGURE 2B: CLOSE UP OF FIGURE 2A





FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, NORTH PERSPECTIVE

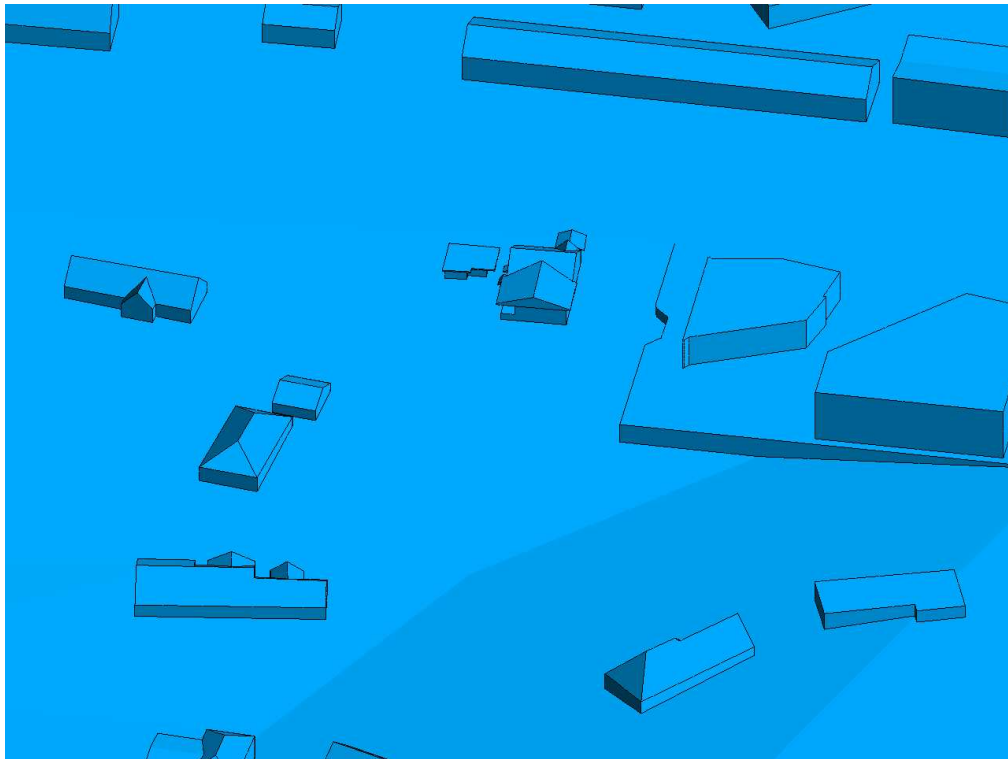


FIGURE 2D: CLOSE UP OF FIGURE 2C



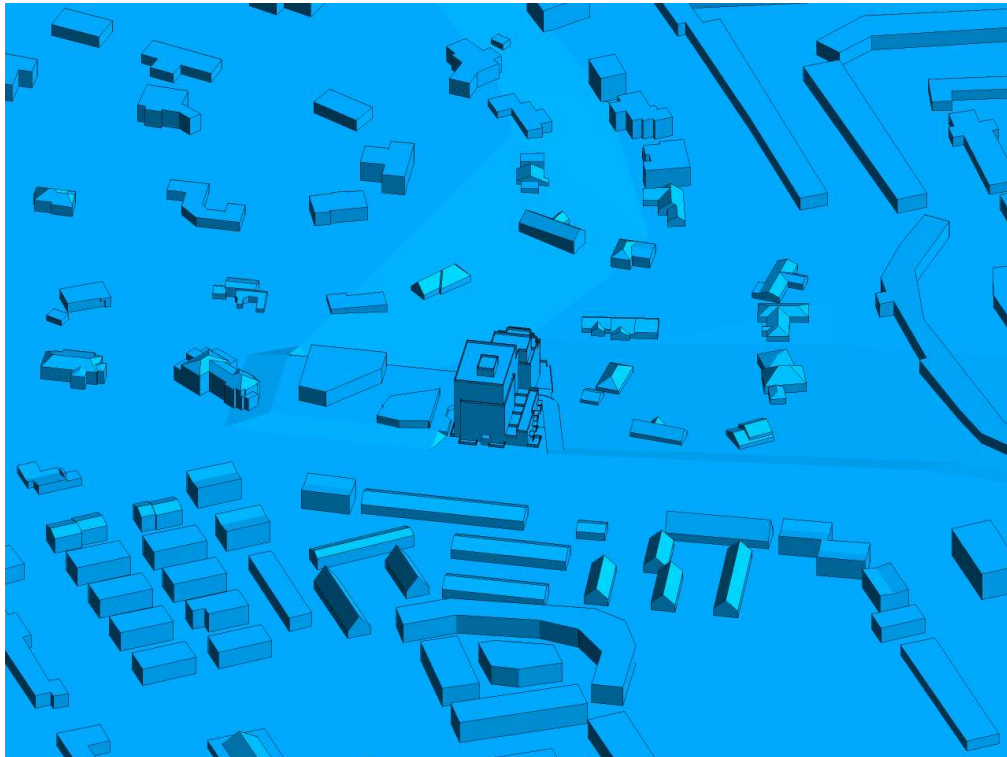


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTH PERSPECTIVE

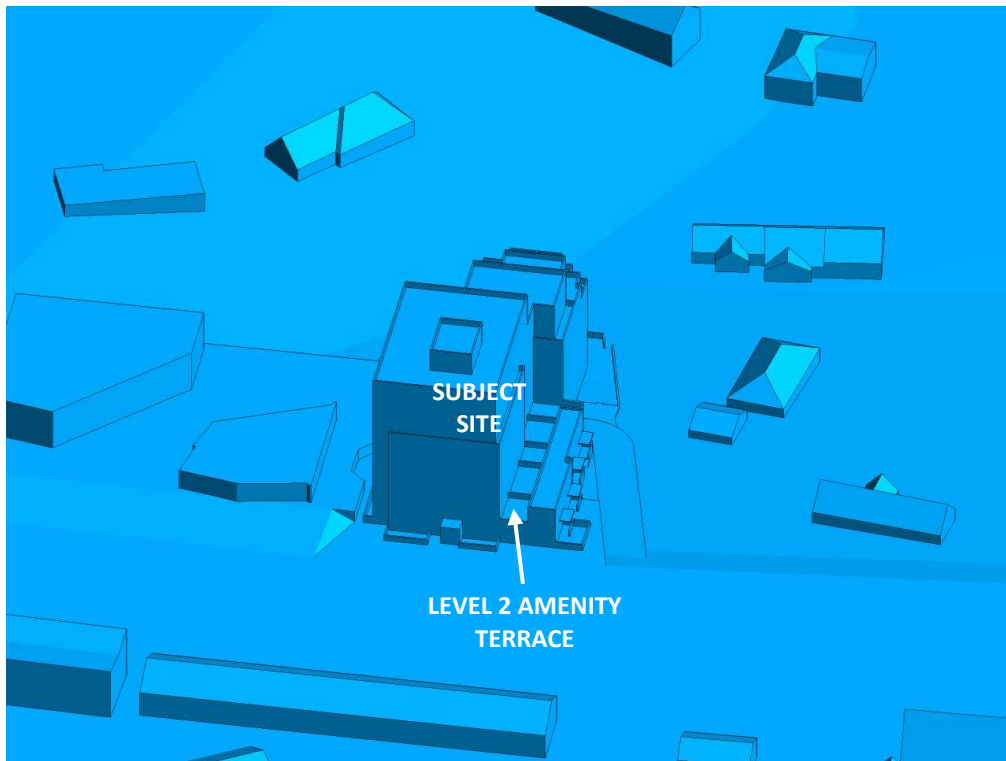


FIGURE 2F: CLOSE UP OF FIGURE 2E



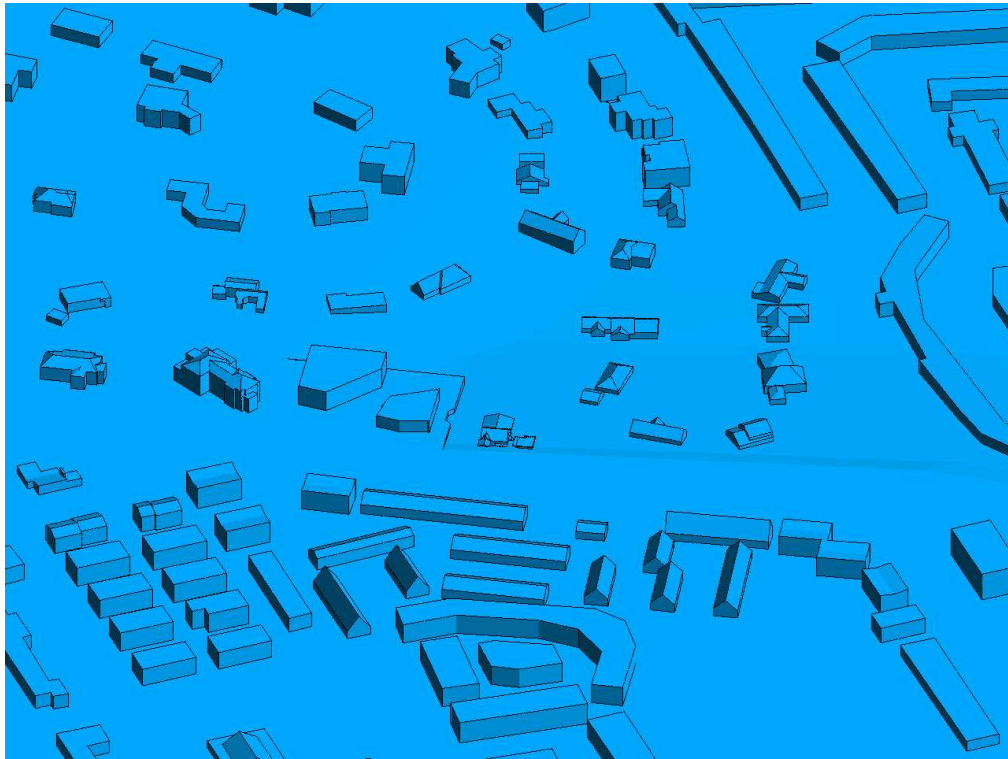


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, SOUTH PERSPECTIVE

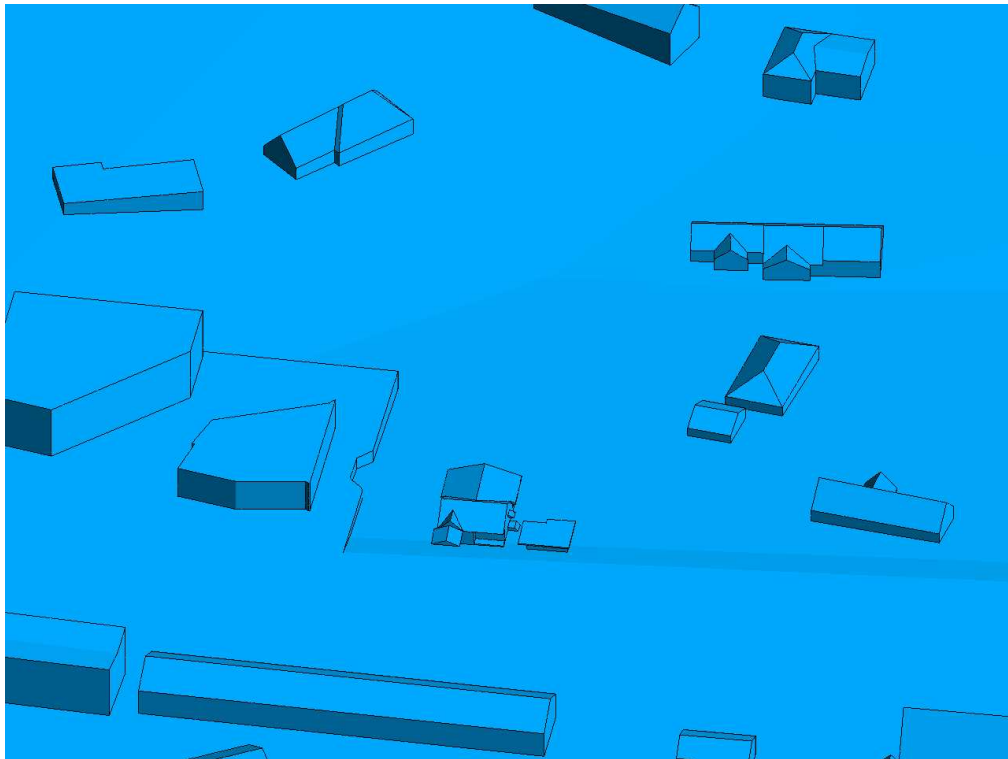


FIGURE 2H: CLOSE UP OF FIGURE 2G



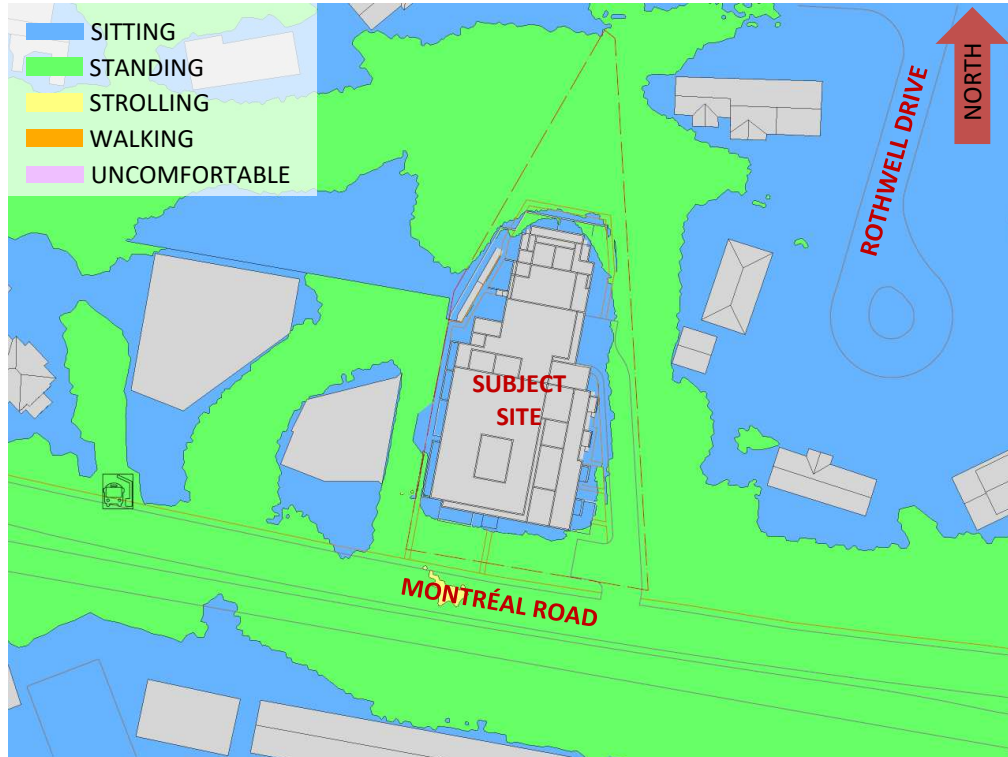


FIGURE 3A: SPRING – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

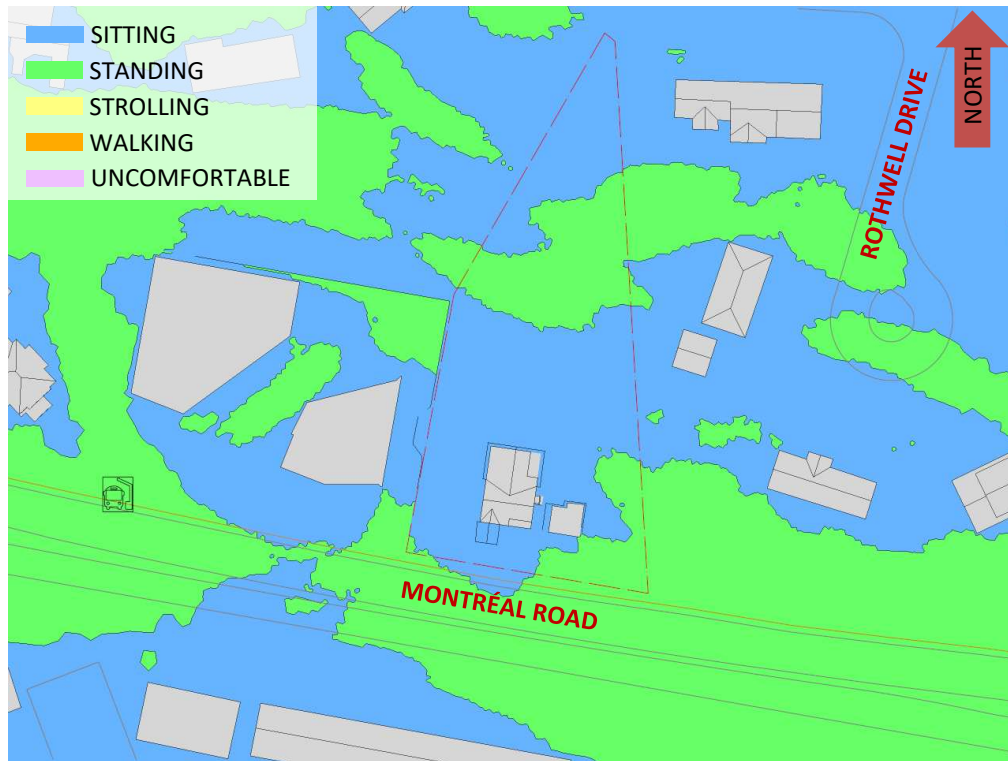


FIGURE 3B: SPRING – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



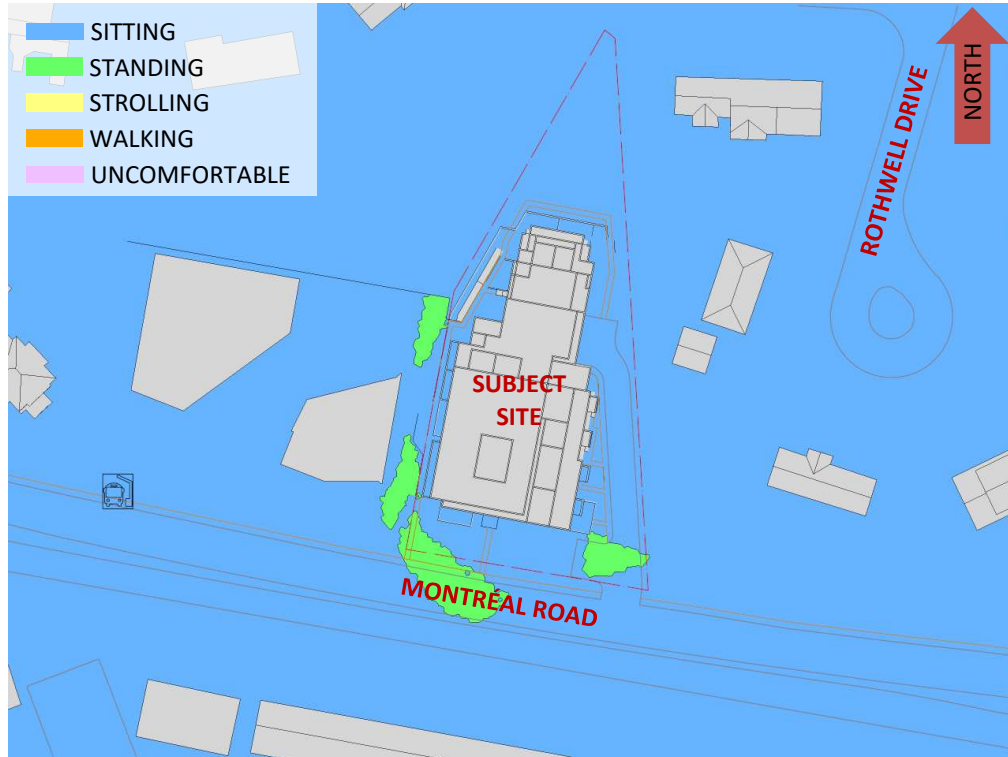


FIGURE 4A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

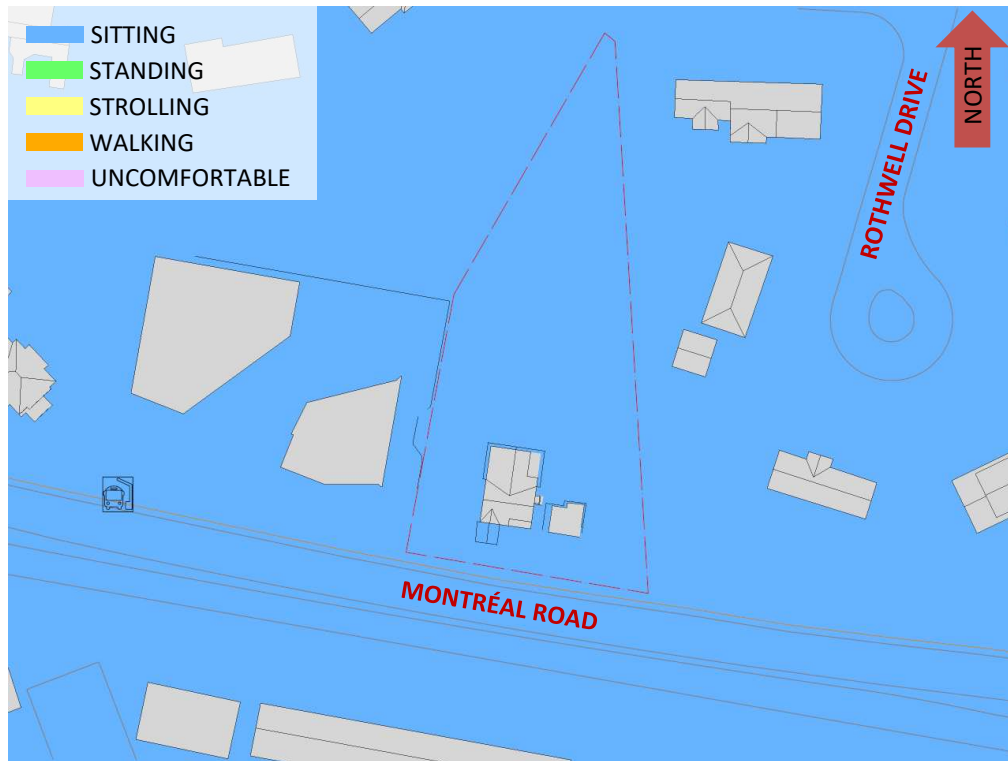


FIGURE 4B: SUMMER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



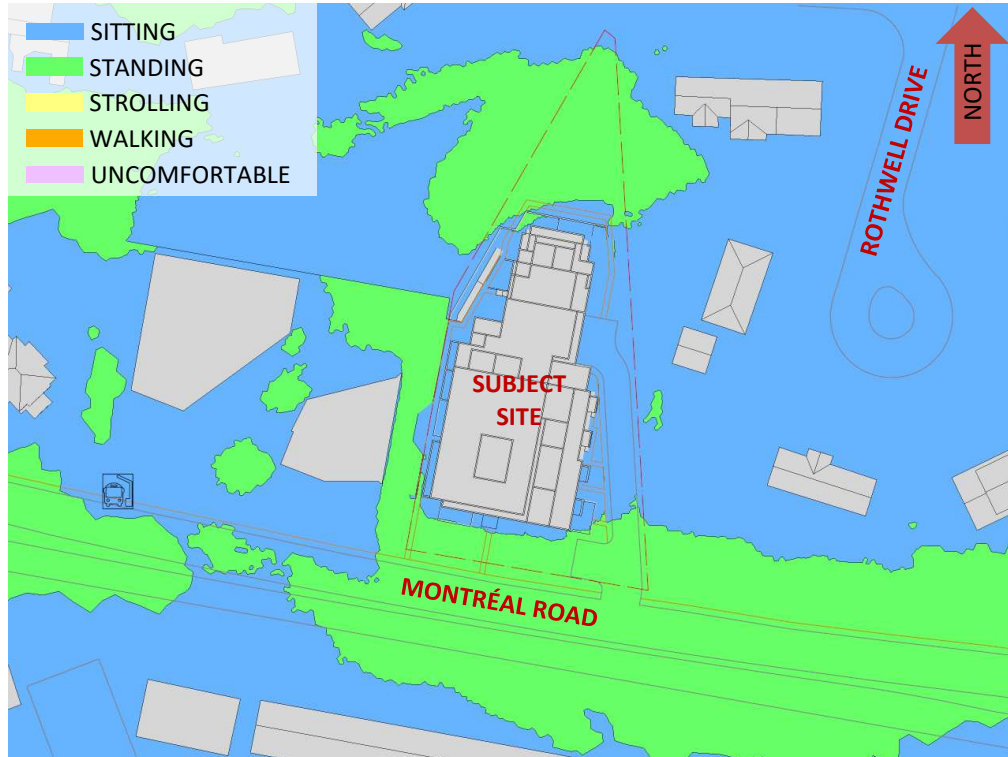


FIGURE 5A: AUTUMN – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

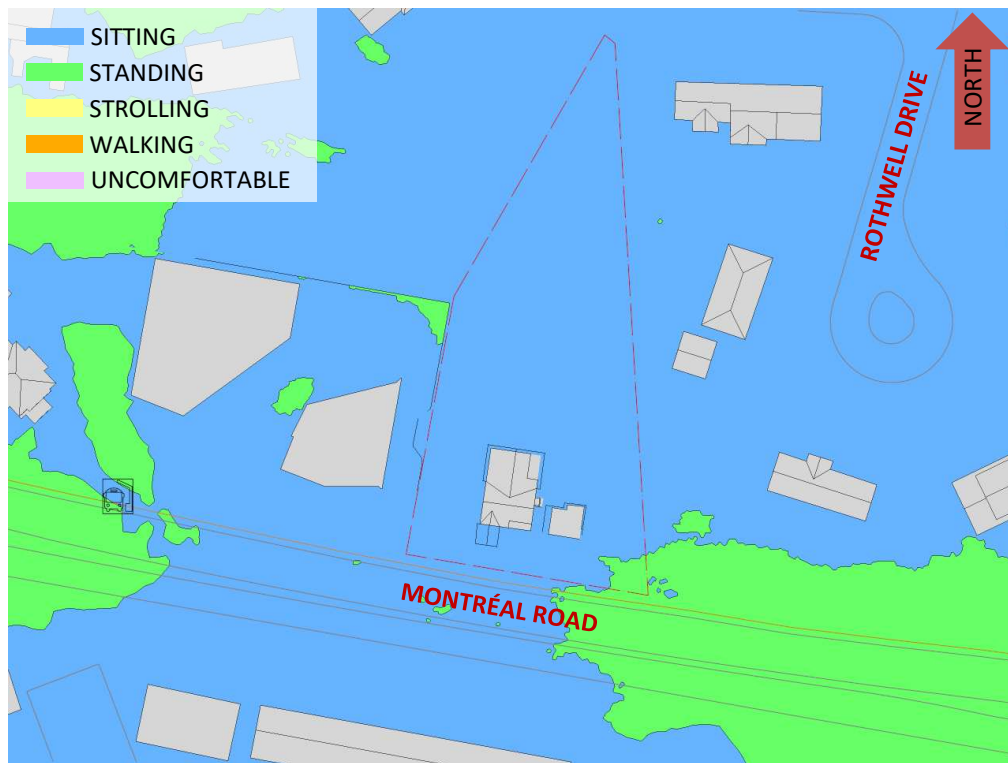


FIGURE 5B: AUTUMN – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



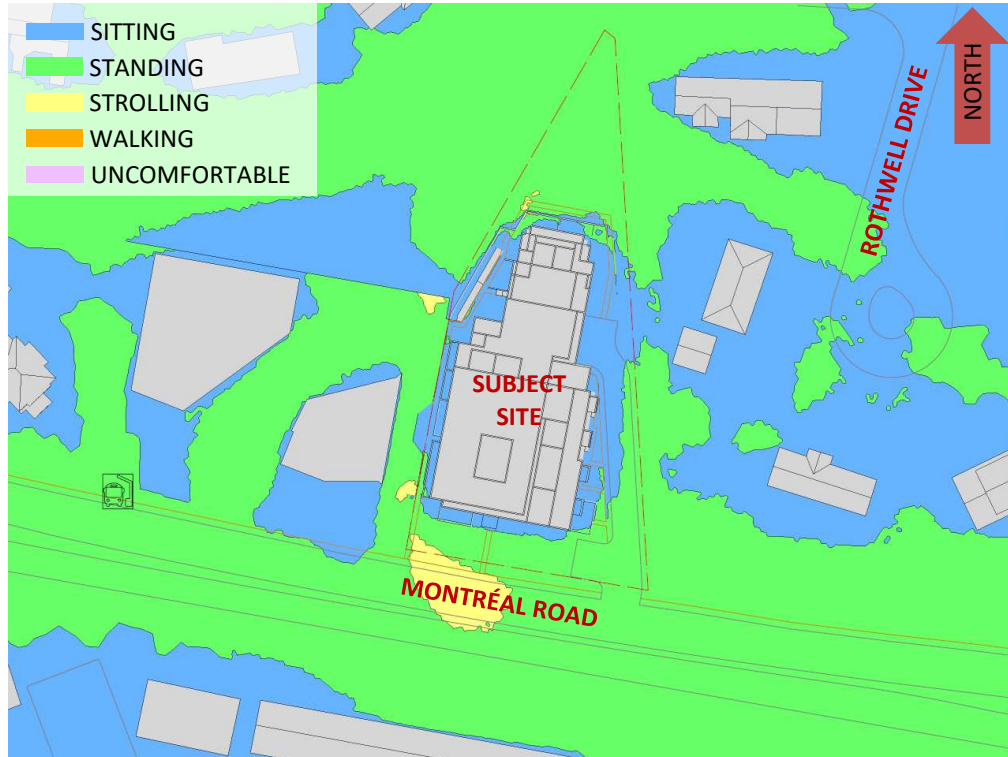


FIGURE 6A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

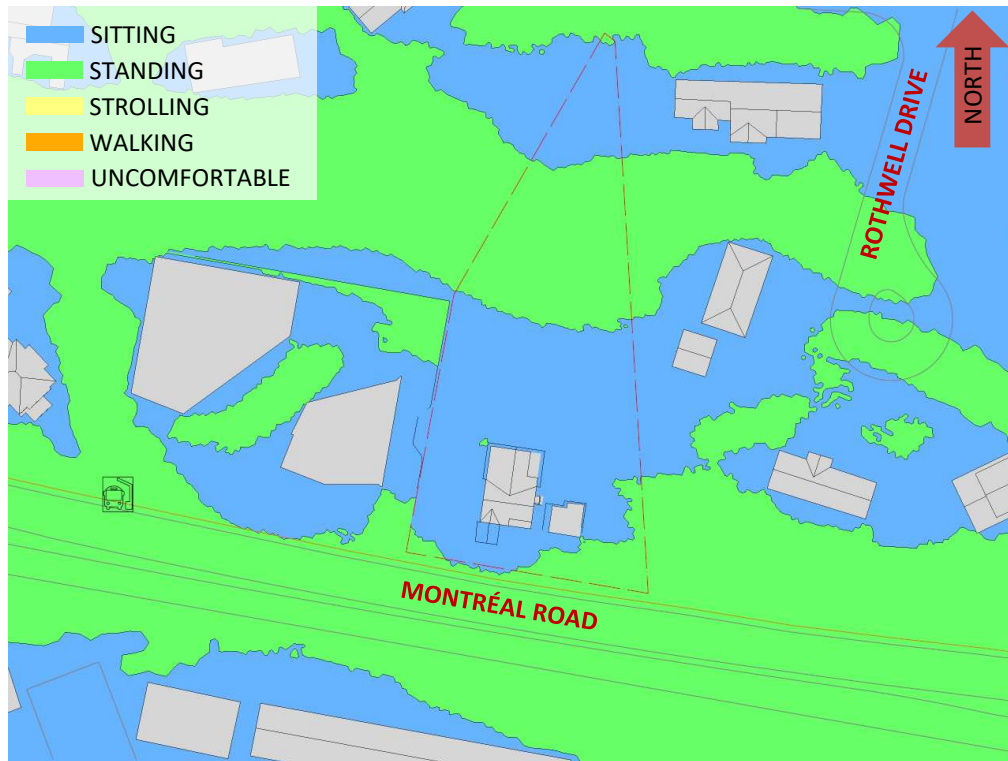


FIGURE 6B: WINTER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



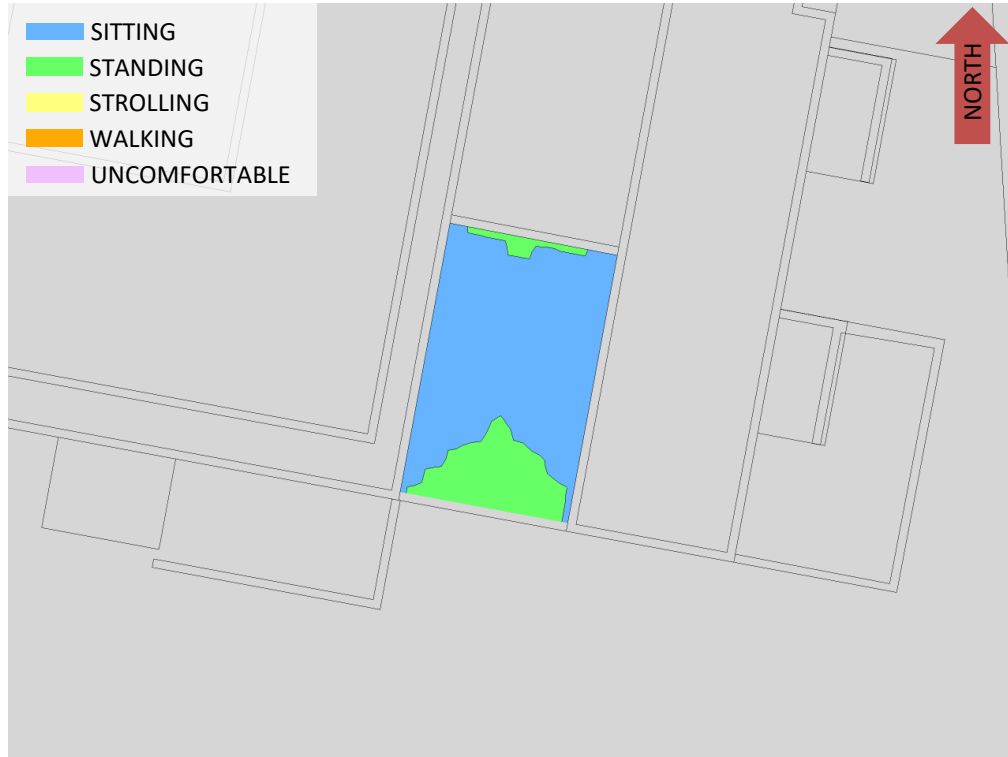


FIGURE 7A: SPRING – WIND COMFORT, LEVEL 2 COMMON AMENITY TERRACE



FIGURE 7B: SUMMER – WIND COMFORT, LEVEL 2 COMMON AMENITY TERRACE

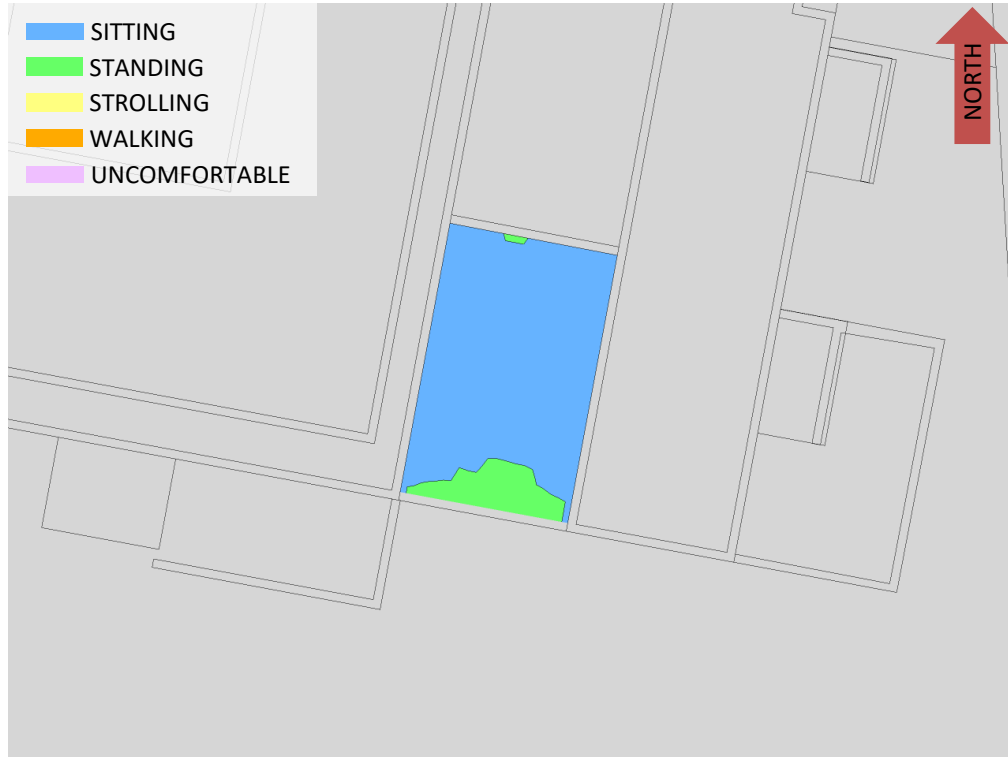


FIGURE 7C: AUTUMN – WIND COMFORT, LEVEL 2 COMMON AMENITY TERRACE

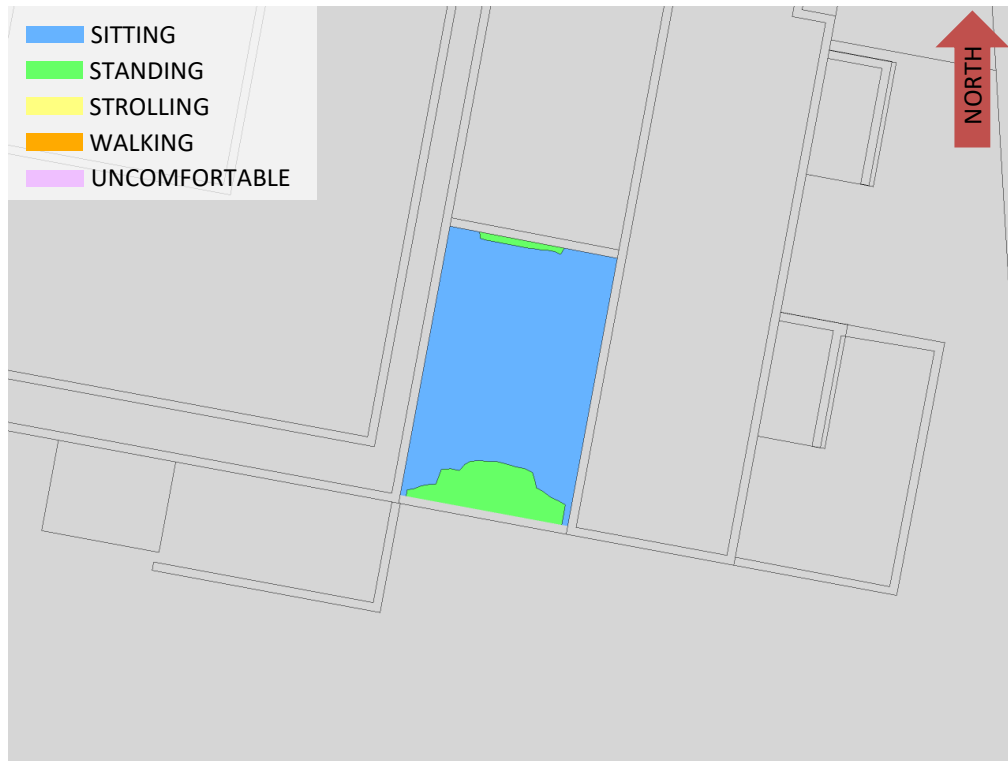


FIGURE 7D: WINTER – WIND COMFORT, LEVEL 2 COMMON AMENITY TERRACE



FIGURE 8: TYPICAL USE PERIOD – WIND COMFORT, LEVEL 2 COMMON AMENITY TERRACE

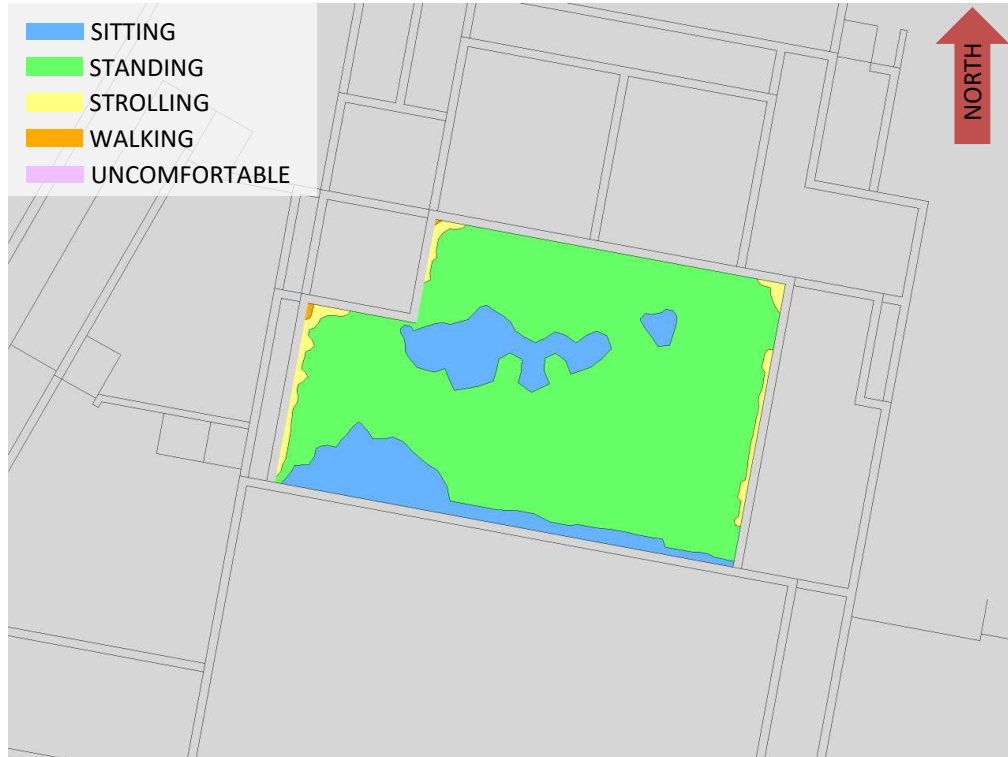


FIGURE 9A: SPRING – WIND COMFORT, LEVEL 7 COMMON AMENITY TERRACE



FIGURE 9B: SUMMER – WIND COMFORT, LEVEL 7 COMMON AMENITY TERRACE





FIGURE 9C: AUTUMN – WIND COMFORT, LEVEL 7 COMMON AMENITY TERRACE

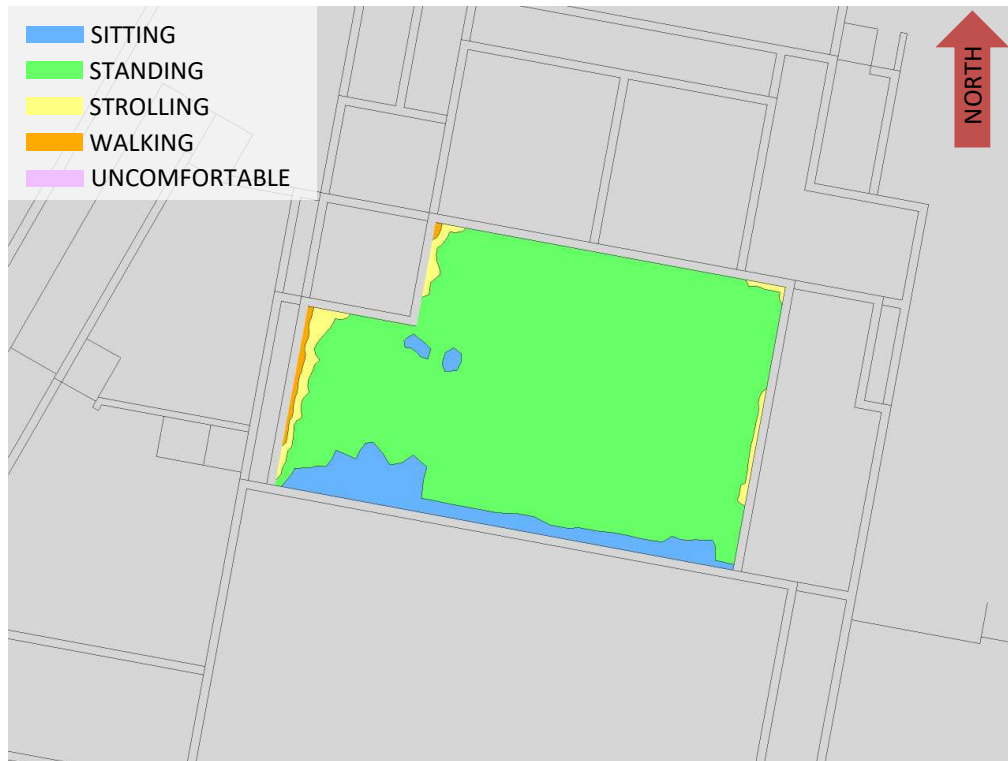


FIGURE 9D: WINTER – WIND COMFORT, LEVEL 7 COMMON AMENITY TERRACE



FIGURE 10: TYPICAL USE PERIOD – WIND COMFORT, LEVEL 7 COMMON AMENITY TERRACE

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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 α is the power law exponent.

For the model, U_g is set to 6.5 metres per second, 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 (that is, the area that it not captured within the simulation model).

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

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

Wind Direction (Degrees True)	Alpha Value (α)
0	0.23
49	0.23
74	0.22
103	0.21
167	0.21
197	0.24
217	0.24
237	0.23
262	0.24
282	0.24
301	0.23
324	0.23

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

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

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

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

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

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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