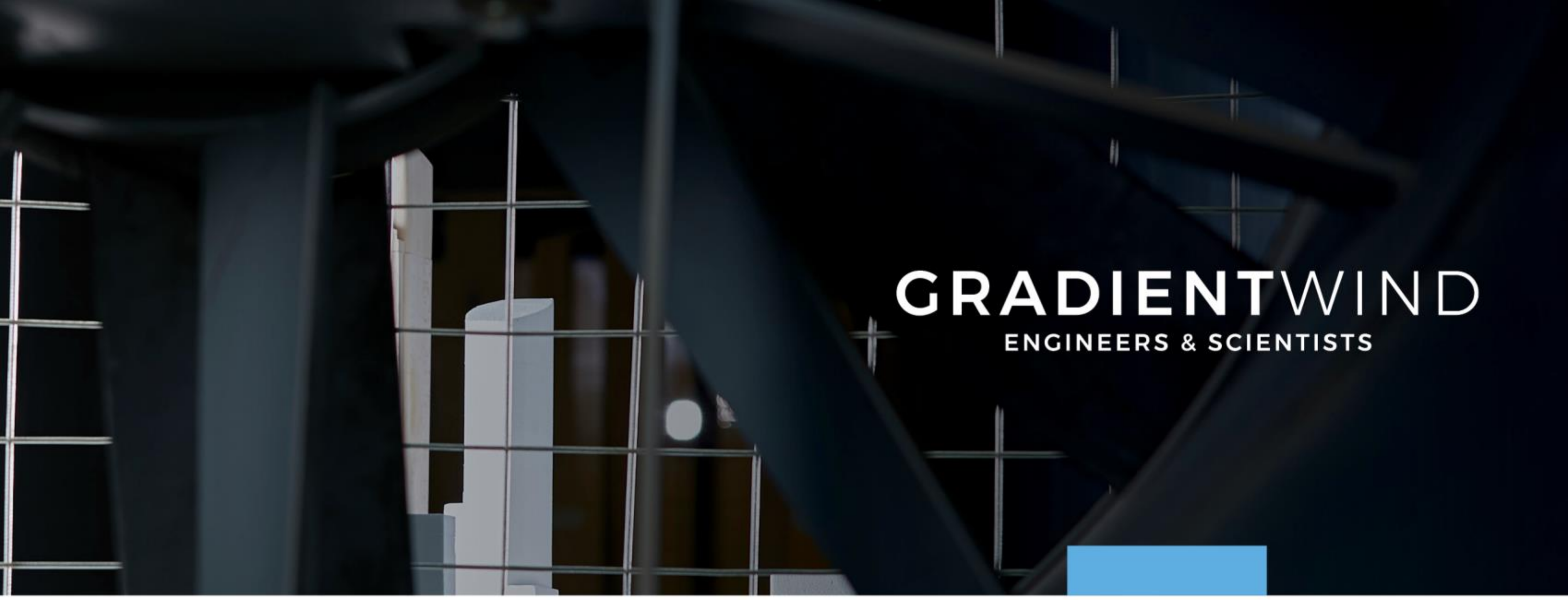
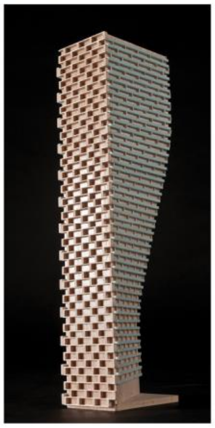
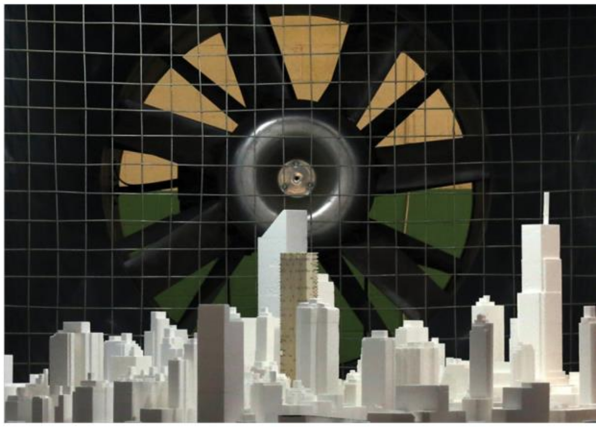


PEDESTRIAN LEVEL WIND STUDY

147 Spadina Avenue
Toronto, Ontario

Report: 21-032-PLW





August 18, 2021

PREPARED FOR
Hullmark
474 Wellington Street West, Suite 200
Toronto, ON M5V 1E3

PREPARED BY
Sacha Ruzzante, MASc, Wind Scientist
Justin Ferraro, P.Eng., Principal

EXECUTIVE SUMMARY

This report describes a comparative pedestrian level wind (PLW) study to satisfy Zoning By-law Amendment (ZBLA) application requirements for the proposed development located at 147 Spadina Avenue Road in Toronto, Ontario (hereinafter referred to as the "subject site" or "proposed development"). Our mandate within this study is to investigate 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. A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-7D, and is summarized as follows:

1) Following the introduction of the proposed development, all grade-level areas within and surrounding the subject site are predicted to continue to experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. While the introduction of the proposed development is predicted to increase wind speeds in some areas, conditions over the surrounding sidewalks and transit stops, and in the vicinity of all building access points, are predicted to be acceptable for the intended uses throughout the year.

2) Wind conditions on the outdoor amenity terraces at Level 3 of the proposed development are predicted to be suitable for sitting throughout the year, which is acceptable.

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 at grade or on the amenity terraces. During extreme weather events, (e.g., 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.

Addendum: The detailed PLW study was performed based on drawings provided in May 2021[1]. An updated design was distributed to the consultants in August 2021[2]. The previous architectural design included two common amenity terraces at Level 3: one at the midpoint of the north elevation and one at the midpoint of the east elevation. While the current design maintains the common amenity terrace on the east elevation, the amenity terrace on the north elevation has been relocated to the northeast corner of the floorplan. The terrace at the northeast corner of the building results from the introduction of a large notch that has been incorporated into the current architectural design. While the current design for the proposed development includes additional small changes, they are considered minor for the purpose of pedestrian wind comfort and safety. Additionally, since the wind conditions predicted in this study are considered acceptable following the introduction of the proposed development in all locations studied, the conclusions and recommendations of this study are applicable to the current site massing.

[1] Audax Architects Inc., '*147 Spadina Avenue – Issued for Coordination*', [May 7, 2021]
[2] Audax Architects Inc., '*147 Spadina Avenue – Issued for ZBA*', [Aug 10, 2021]

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Hullmark to undertake a comparative pedestrian level wind (PLW) study to satisfy Zoning By-law Amendment (ZBLA) application requirements for the proposed development located at 147 Spadina Avenue Road in Toronto, Ontario (hereinafter referred to as the "subject site" or "proposed development"). Our mandate within this study is to investigate 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, architectural drawings provided by Audax Architects Inc. in May 2021, surrounding street layouts and existing and approved future building massing information obtained from the City of Toronto, and recent site imagery.

2. TERMS OF REFERENCE

Architectural Rendering, Southwest Perspective
(Courtesy of Audax Architecture Inc.)

The subject site is situated at the northeast corner of the intersection of Spadina Avenue and Richmond Street West. The proposed development is a 25-storey mixed-use building with a rectangular floorplan at grade. At grade level, the building includes commercial space along Spadina Avenue and building services space over the eastern half of the floorplan. Commercial entrances are located along the west elevation and at the southeast corner, while the primary residential entrance is located near the centre of the south elevation.

Levels 2 and above comprise residential units, and amenity rooms. The building features setbacks at various levels from all elevations. Outdoor amenity terraces are located on the north and east sides of the building at Level 3 and connected to an indoor amenity room.

Regarding wind exposures, the near-field surroundings of the development (defined as an area falling within a 200-metre (m) radius of the site) comprise a mix of mid- and high-rise buildings from the east clockwise to the west, and a mix of low-rise and mid-rise buildings to the north. The far-field surroundings (defined as the area beyond the near field and within a 2-kilometre (km) radius) contribute a wide range of effective surface roughness, including the Toronto downtown core to the east and Lake Ontario approximately 1.3 km to the south. Site plans for the proposed and existing massing scenarios are illustrated in Figures 1A and 1B, respectively, while Figures 2A-2F illustrate the computational models used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to: (i) determine comparative pedestrian level wind comfort and safety conditions at key outdoor areas; (ii) identify areas where future 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 Greater Toronto Area (GTA) wind climate, and synthesis of computational data with industry-accepted guidelines[3]. The following sections describe the analysis procedures, including a discussion of the comfort guidelines.

[3] City of Toronto, Application Support Material: Terms of Reference

4.1 Computer-Based Context Modelling

A computer-based PLW wind 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 Lester B. Pearson 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 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 and two massing scenarios, as noted in Section 2. The CFD simulation models were centered on the subject site, complete with surrounding massing within a diameter of approximately 840 m.

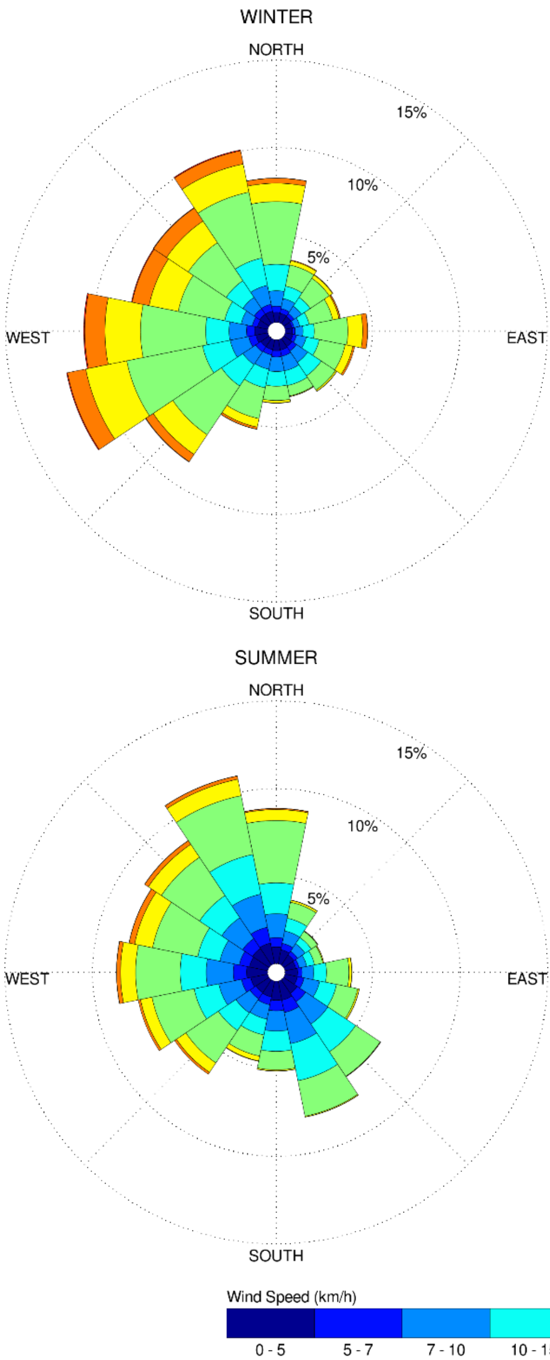
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds on a continuous measurement plane 1.5 m above local grade and the common amenity terraces were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. The 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 CFD wind flow simulation technique are presented in Appendix A.

4.3 Meteorological Data Analysis

A statistical model for winds in the Greater Toronto Area (GTA) was developed from approximately 40 years of hourly wind data recorded at Lester B. Pearson International Airport in Mississauga 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 GTA 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 km/h. Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction shows the frequency distribution of wind speeds for each wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Toronto the most common winds concerning pedestrian comfort occur from the southwest clockwise to the north, as well as those from the east. The directional preference and relative magnitude of the wind speed varies somewhat from season to season, with the summer months displaying the calmest winds relative to the remaining seasonal periods.

SEASONAL DISTRIBUTION OF WIND
LESTER B. PEARSON INTERNATIONAL AIRPORT, MISSISSUAGA, ONTARIO



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 Guidelines

Pedestrian comfort and safety guidelines are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Four pedestrian comfort classes are based on 20% non-exceedance gust wind speed ranges, which include (i) Sitting; (ii) Standing; (iii) Walking; and (iv) Uncomfortable. More specifically, the comfort classes and associated gust wind speed ranges are summarized as follows:

(i) **Sitting** – A gust wind speed no greater than 16 km/h is considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – A gust wind speed greater than 16 km/h but no greater than 22 km/h is considered acceptable for activities such as standing or leisurely strolling.

(iii) **Walking** – A gust wind speed greater than 22 km/h but no greater than 30 km/h is considered acceptable for walking or more vigorous activities.

(iv) **Uncomfortable** – A gust wind speed greater than 30 km/h is classified as uncomfortable from a pedestrian comfort standpoint. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this comfort class.

The pedestrian safety wind speed guideline 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 greater than 90 km/h is classified as dangerous. The wind speeds associated with the above categories are gust wind speeds. 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 wind speeds of 16 km/h were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if 30 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 guidelines 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 / Walking
Public Sidewalks / Pedestrian Walkways	Walking
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens	Sitting / Standing
Plazas	Sitting / Standing / Walking
Transit Stops	Sitting / Standing
Public Parks	Sitting / Standing / Walking
Garage / Service Entrances	Walking
Vehicular Drop-Off Zones	Standing / Walking
Laneways / Loading Zones	Walking

5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-6B, which illustrate seasonal wind conditions at grade level for the proposed and existing massing scenarios, and Figures 7A-7D, which illustrate seasonal wind conditions on the elevated amenity terraces at Level 3. Conditions are presented as continuous contours of wind comfort within and surrounding the subject site. The colour contours indicate predicted regions of the various comfort classes noted in Section 4.4. Wind conditions suitable for sitting are represented by the colour green, standing by yellow, and walking by blue; uncomfortable conditions are represented by the colour magenta.

In all locations studied, the wind conditions are predicted to be acceptable following the introduction of the proposed development. The details of these conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions

Sidewalks: Following the introduction of the proposed development, the sidewalks along Spadina Ave and Richmond Street West, adjacent to the subject site, are predicted to be suitable for sitting during the summer season, and suitable for standing or better during the remaining colder seasons. Conditions on the noted sidewalk areas under the existing massing scenario are estimated to be suitable for sitting throughout the year.

Although the introduction of the proposed development is expected to somewhat increase wind speeds in this area, wind conditions under both massing scenarios are considered acceptable with respect to the wind comfort guidelines provided in Section 4.4.

Transit Stops: Wind conditions at nearby transit stops are predicted to be suitable for standing or better throughout the year, both prior to and following the introduction of the proposed building. These conditions are considered acceptable with respect to the wind comfort guidelines provided in Section 4.4.

Building Entrances: Conditions in the immediate vicinity of all primary building entrances within and surrounding the subject site are predicted to be suitable for standing, or better, throughout the year, which is acceptable according to the comfort guidelines in Section 4.4.

Elevated Amenity Terraces: The outdoor amenity terraces serving the proposed building at Level 3 are predicted to be suitable for sitting throughout the year, which is considered acceptable according to the comfort guidelines in Section 4.4.

5.2 Wind Safety

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 at grade and on the amenity terraces. During extreme weather events, (e.g., 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.

5.3 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 (i.e., construction or demolition) of these surroundings may cause changes to the wind effects in two ways, namely: (i) changes beyond the immediate vicinity of the site would alter the wind profile approaching the site; and (ii) development in proximity to the site would cause changes to local flow patterns. In general, development in urban centers creates reduction in the mean wind speeds and localized increases in the gustiness of the wind.

6. SUMMARY AND RECOMMENDATIONS

A complete summary of the predicted wind conditions is provided in Section 5 of this report and illustrated in Figures 3A-7D. Based on computer simulations using the CFD technique, meteorological data analysis, and experience with numerous similar developments, this study concludes the following:

1) Following the introduction of the proposed development, all grade-level areas within and surrounding the subject site are predicted to continue to experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. While the introduction of the proposed development is predicted to increase wind speeds in some areas, conditions over the surrounding sidewalks and transit stops, and in the vicinity of all building access points, are predicted to be acceptable for the intended uses throughout the year.

2) Wind conditions on the outdoor amenity terraces at Level 3 of the proposed development are predicted to be suitable for sitting throughout the year, which is acceptable.

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 at grade or on the amenity terraces. During extreme weather events, (e.g., 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.

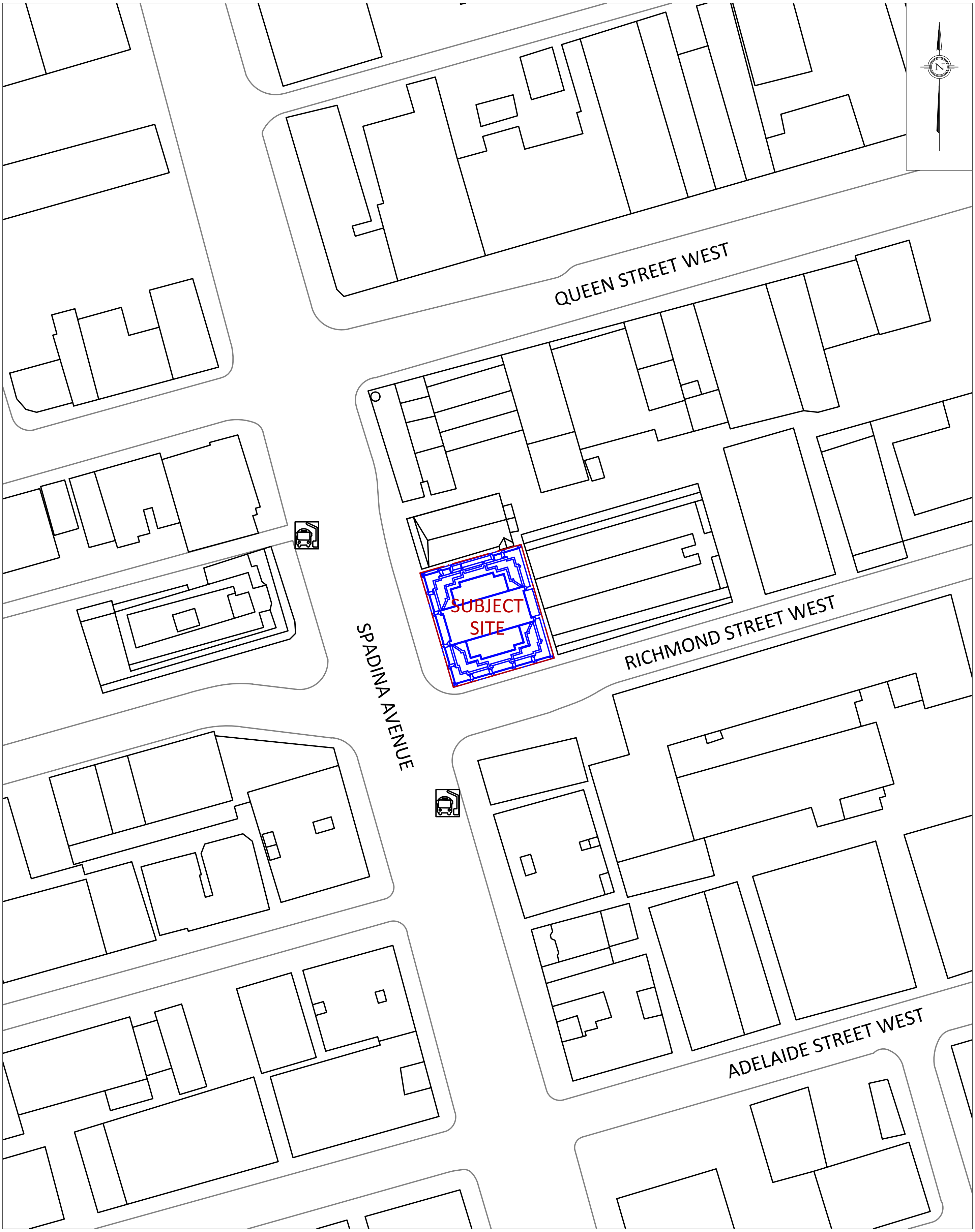
Sincerely,

Gradient Wind Engineering Inc.

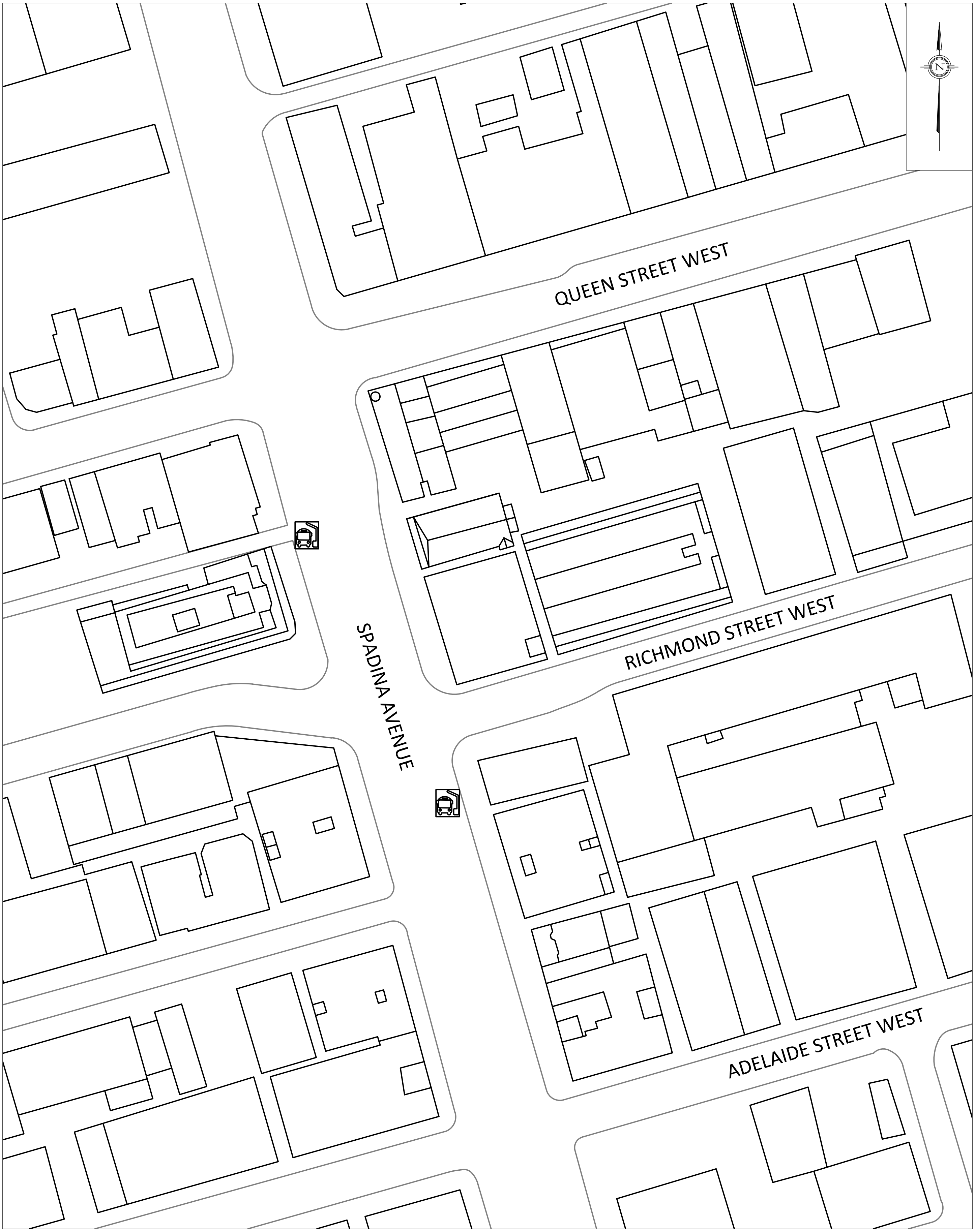
LICENSED PROFESSIONAL ENGINEER
J. D. FERRARO
100158495
Aug 18, 2021
PROVINCE OF ONTARIO

Sacha Ruzzante, MASc
Wind Scientist

Justin Ferraro, P.Eng.
Principal



GRADIENTWIND ENGINEERS & SCIENTISTS	PROJECT 147 SPADINA AVENUE, TORONTO PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION
127 WALGREEN ROAD, OTTAWA, ON 613 836 0934 • GRADIENTWIND.COM	SCALE 1:1500	DRAWING NO. 21-032-PLW-1A	FIGURE 1A: PROPOSED SITE PLAN AND SURROUNDING CONTEXT
	DATE MAY 27, 2021	DRAWN BY O.R.	



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ENGINEERS & SCIENTISTS
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PROJECT		DESCRIPTION
147 SPADINA AVENUE, TORONTO PEDESTRIAN LEVEL WIND STUDY		FIGURE 1B: APPROVED SITE PLAN AND SURROUNDING CONTEXT
SCALE 1:1500	DRAWING NO. 21-032-PLW-1B	
DATE MAY 27, 2021	DRAWN BY O.R.	

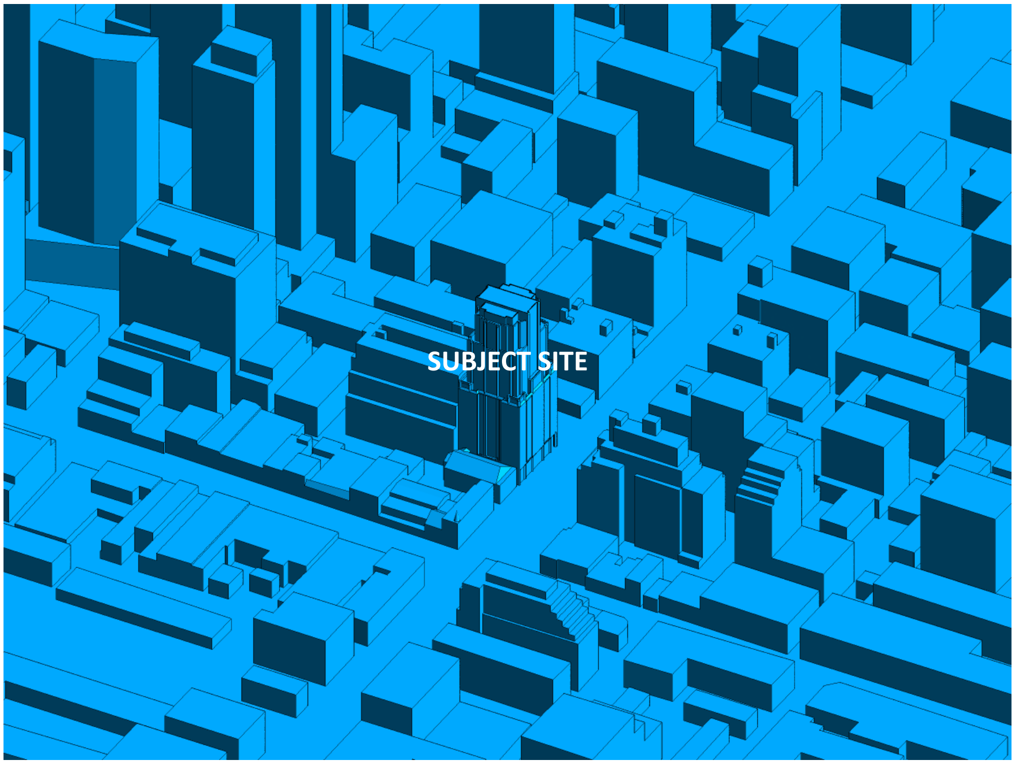


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTHWEST PERSPECTIVE

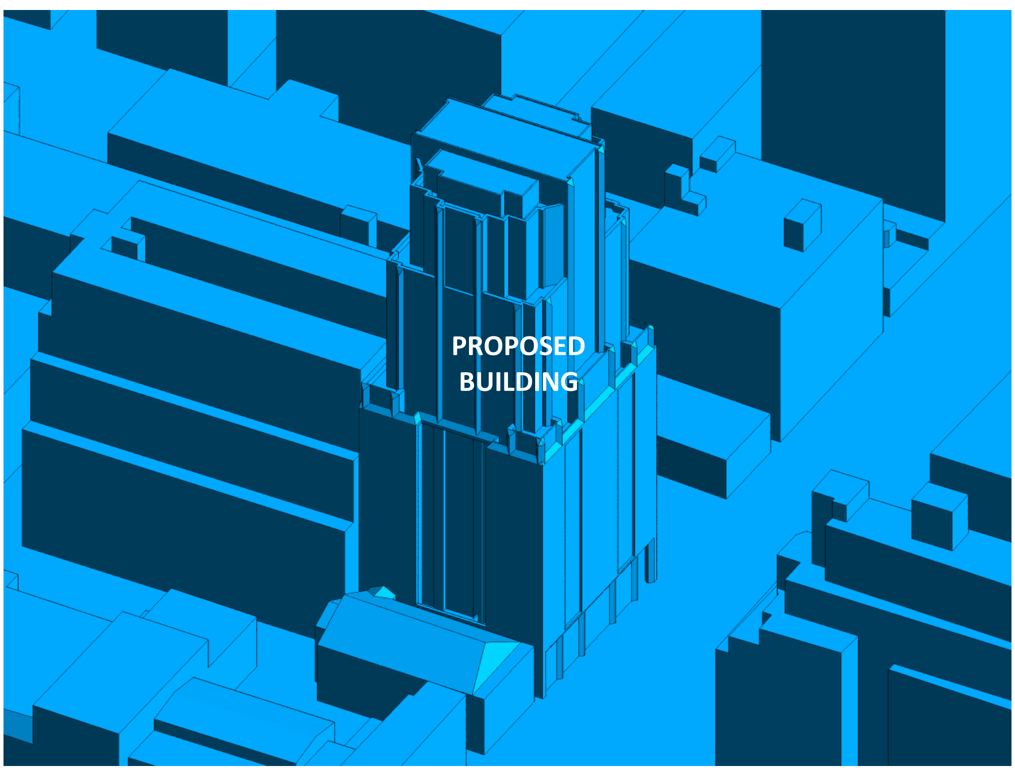


FIGURE 2B: CLOSE-UP VIEW OF FIGURE 2A

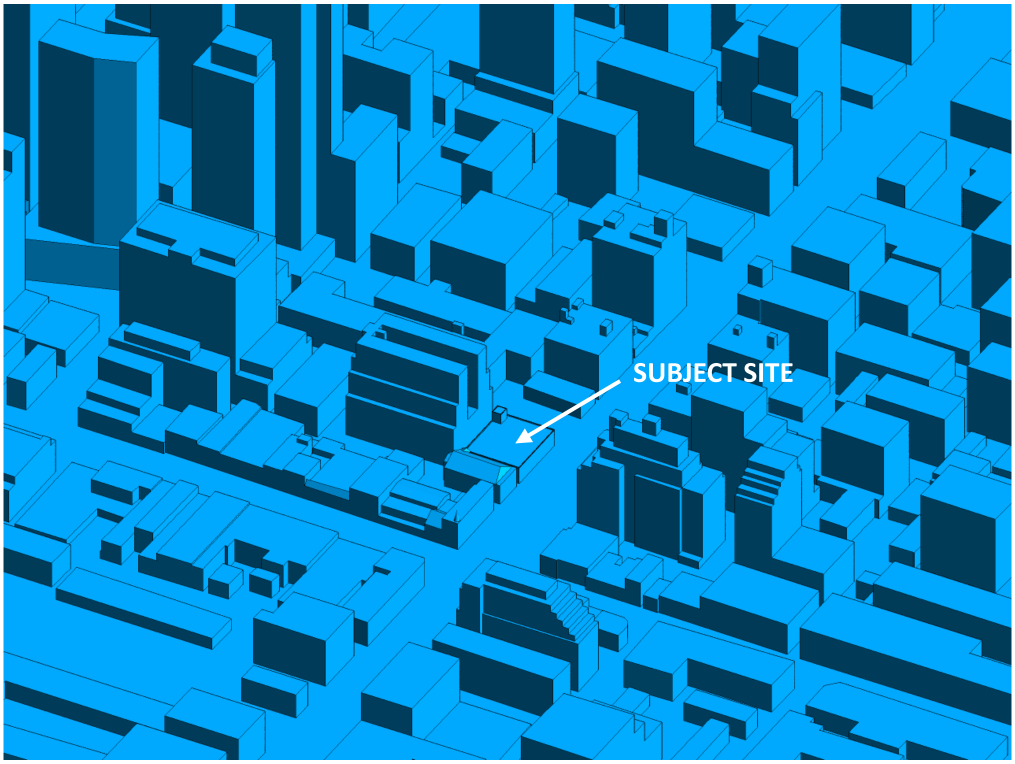


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, NORTHWEST PERSPECTIVE

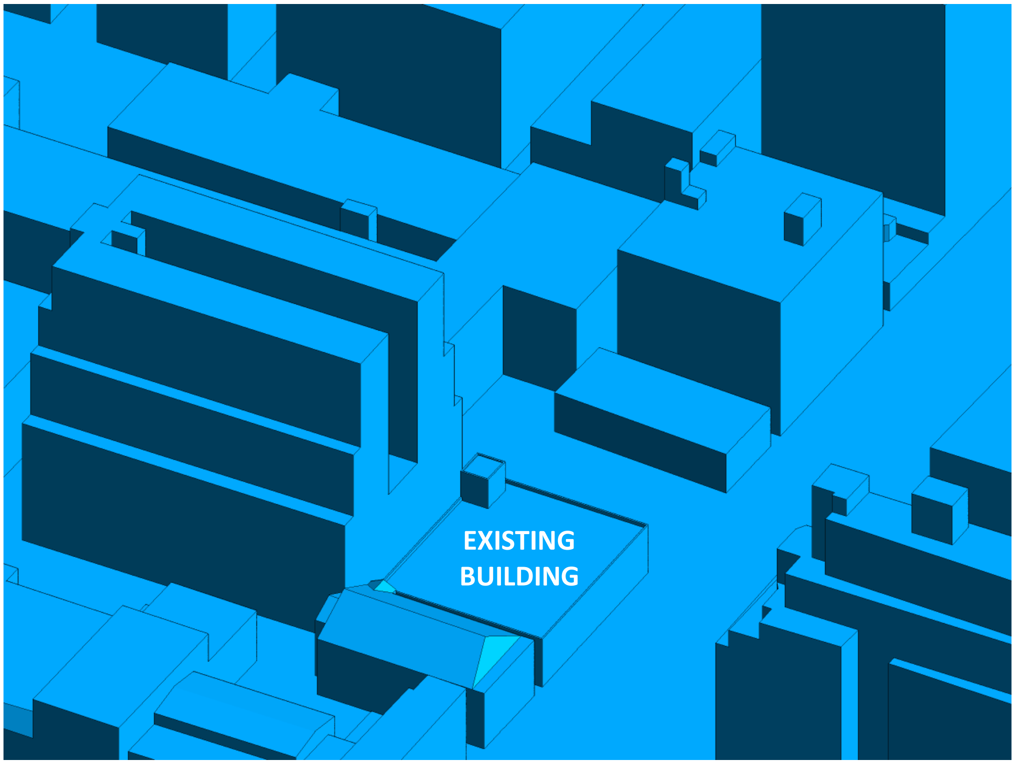


FIGURE 2D: CLOSE-UP VIEW OF FIGURE 2C

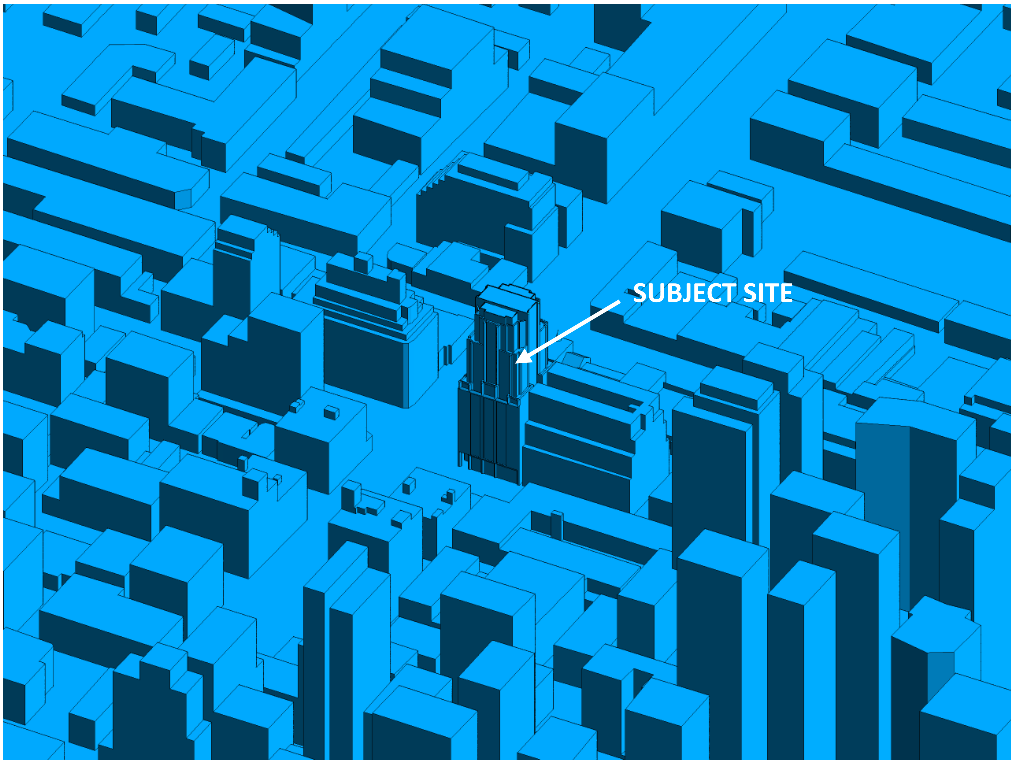


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTHEAST PERSPECTIVE

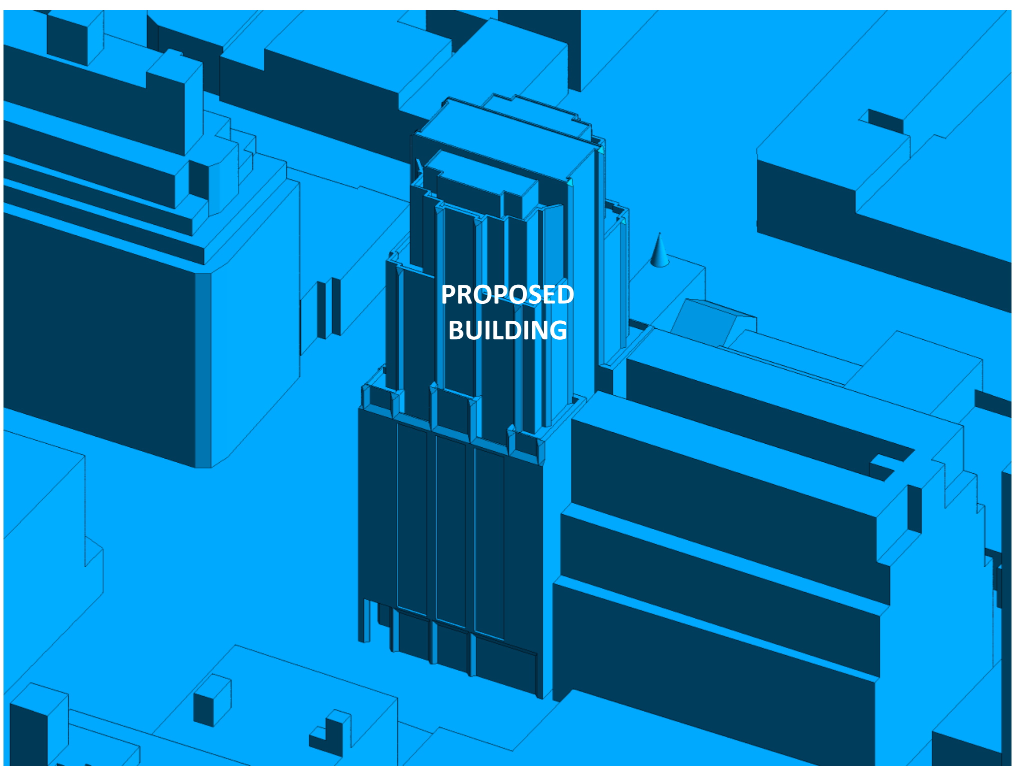


FIGURE 2F: CLOSE-UP VIEW OF FIGURE 2E

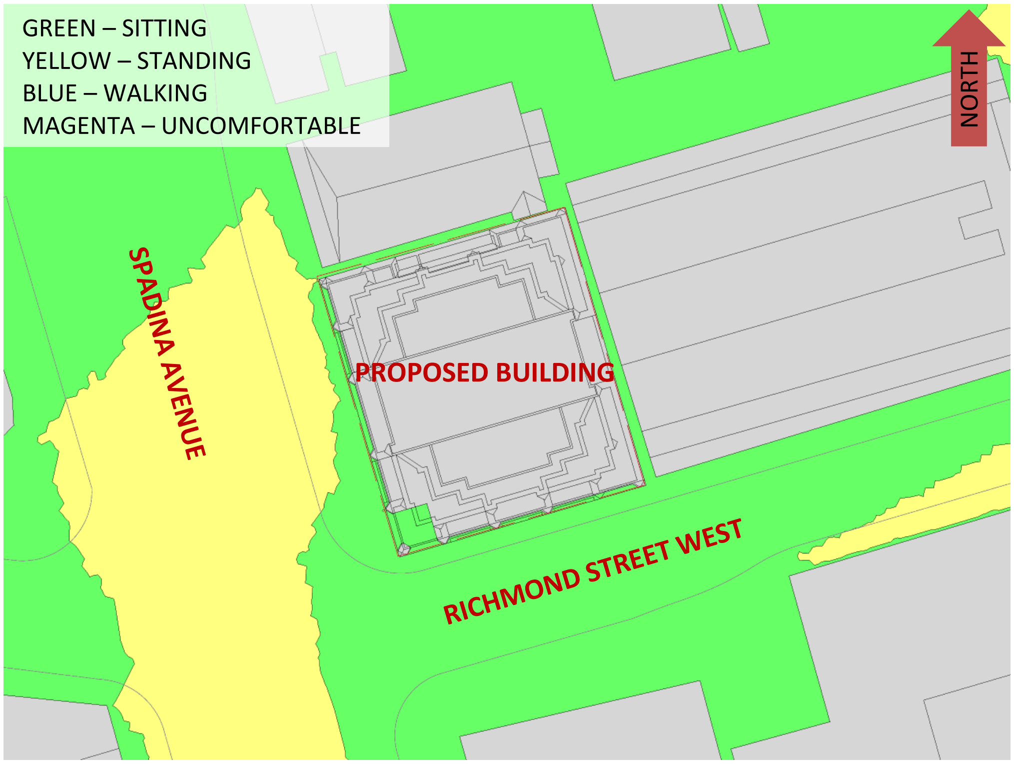


FIGURE 3A: SPRING – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

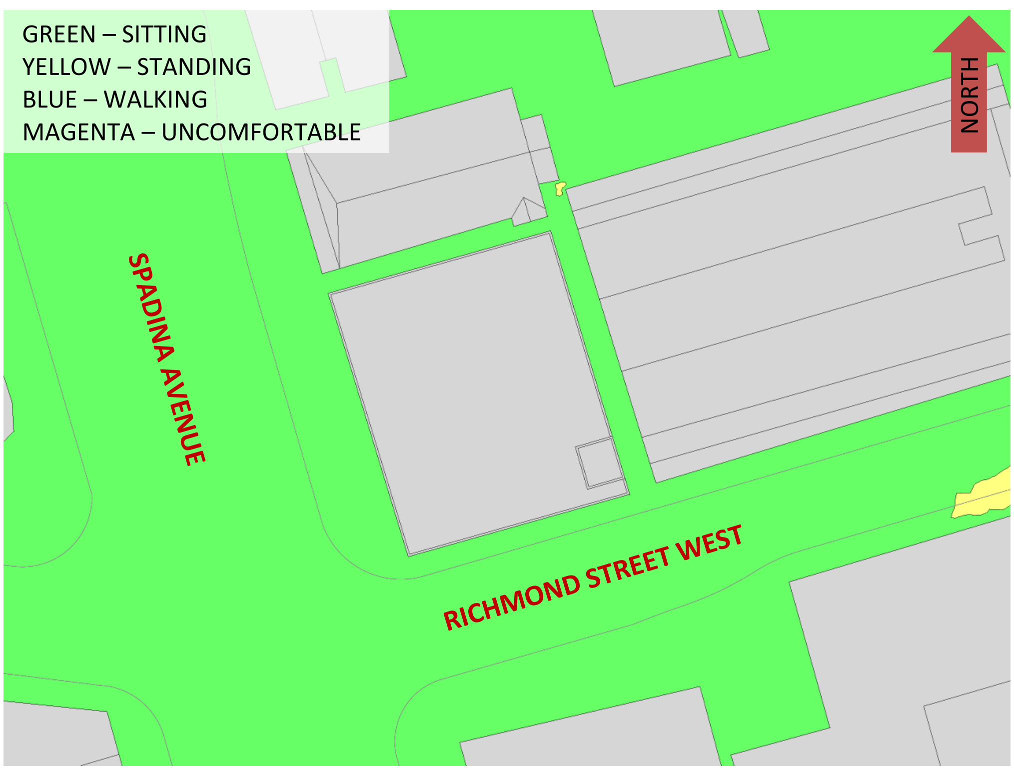


FIGURE 3B: SPRING – EXISTING MASSING – WIND COMFORT, GRADE LEVEL

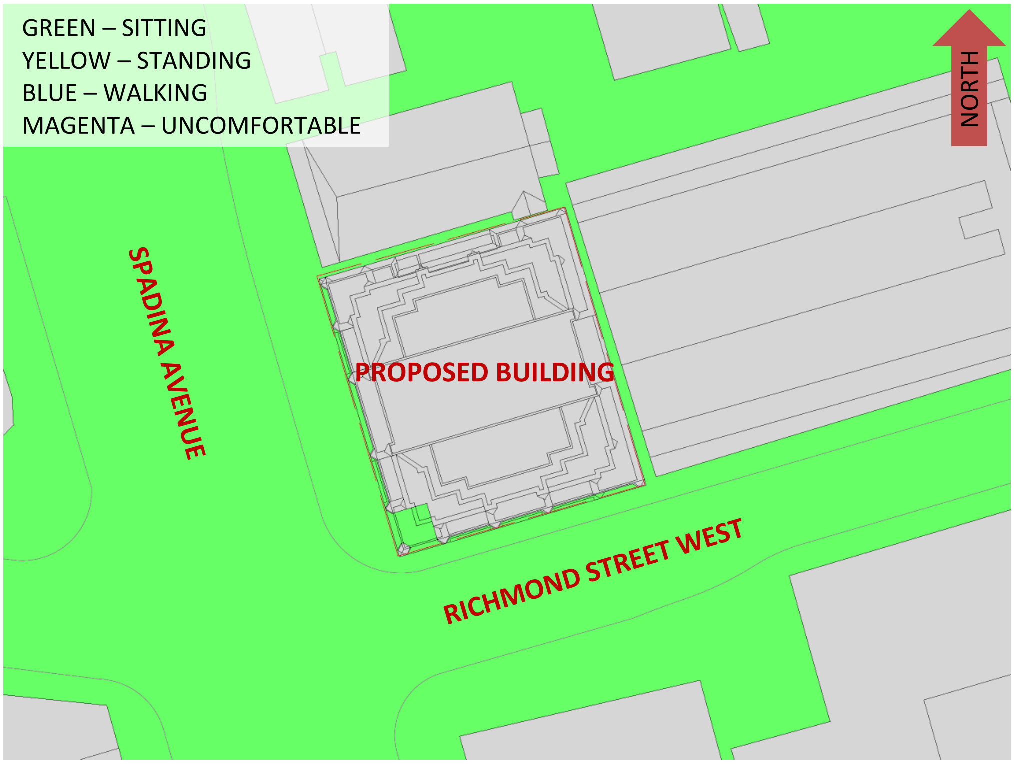


FIGURE 4A: SUMMER – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

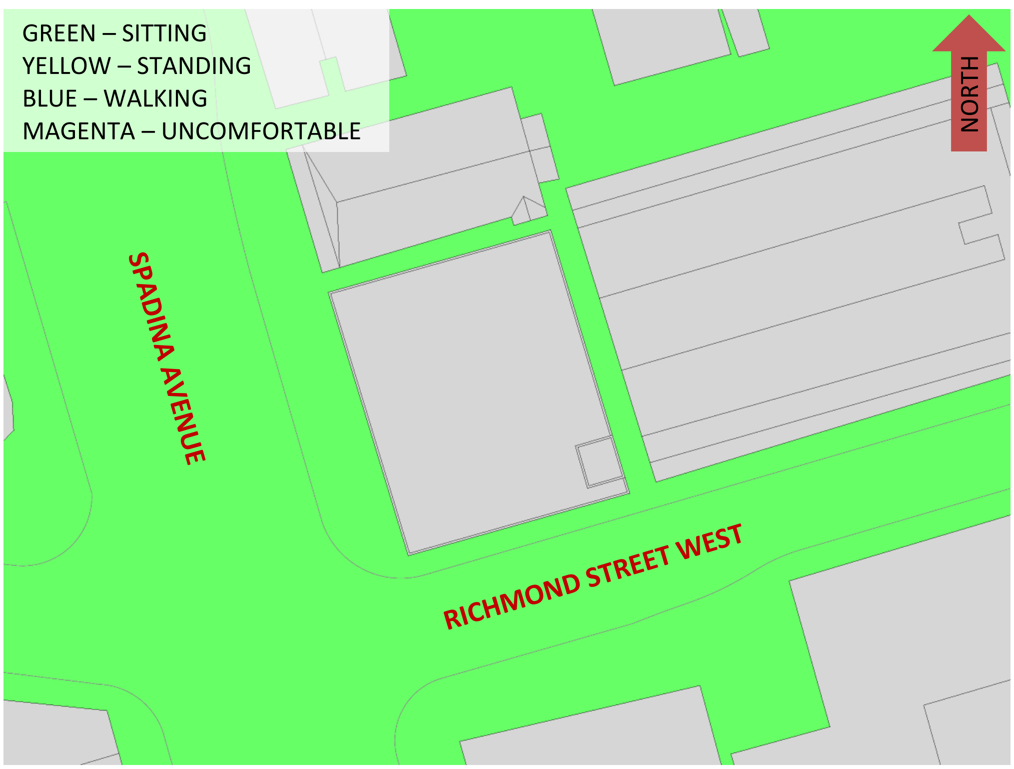


FIGURE 4B: SUMMER – EXISTING MASSING – WIND COMFORT, GRADE LEVEL

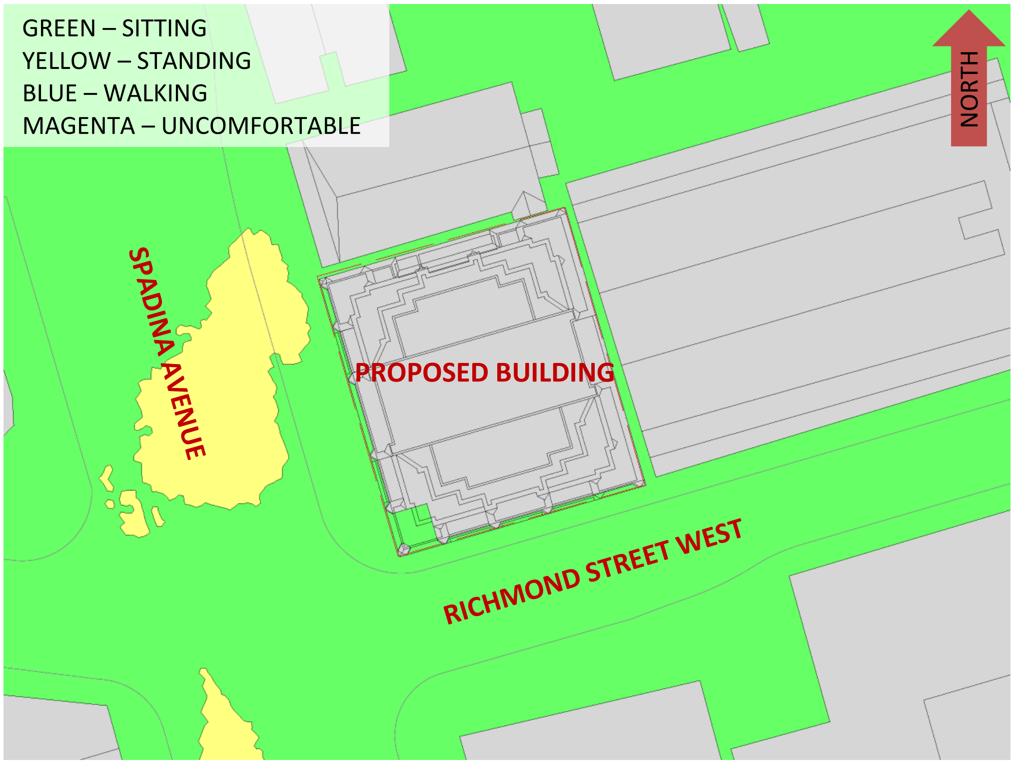


FIGURE 5A: AUTUMN – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

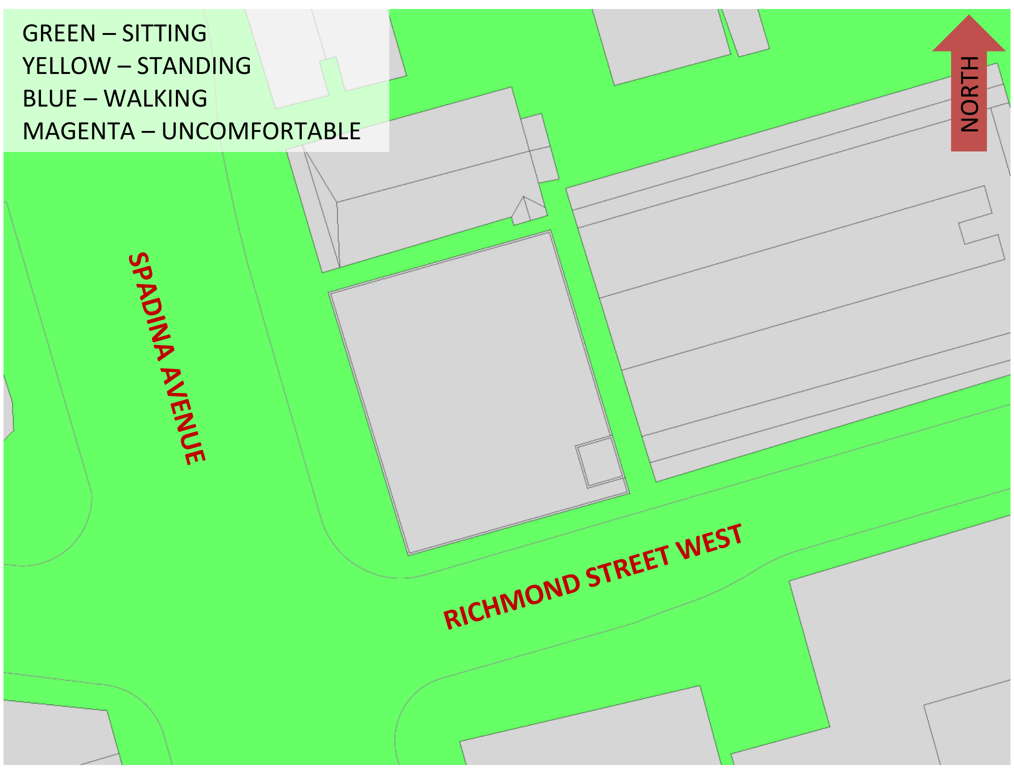


FIGURE 5B: AUTUMN – EXISTING MASSING – WIND COMFORT, GRADE LEVEL

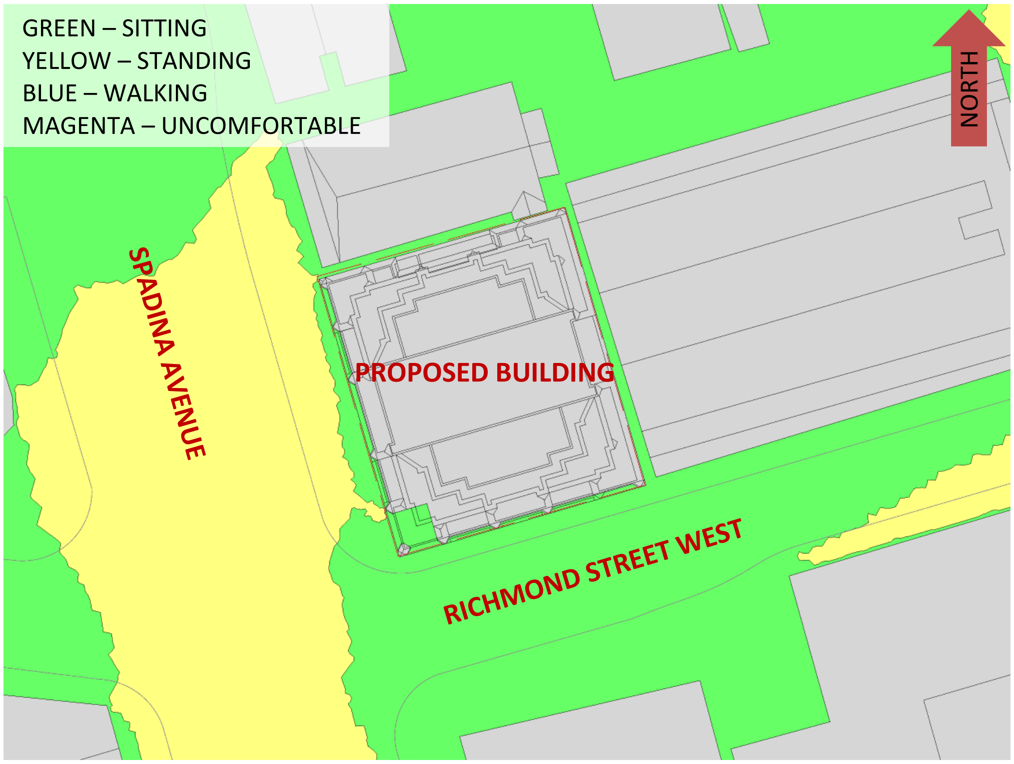


FIGURE 6A: WINTER – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

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

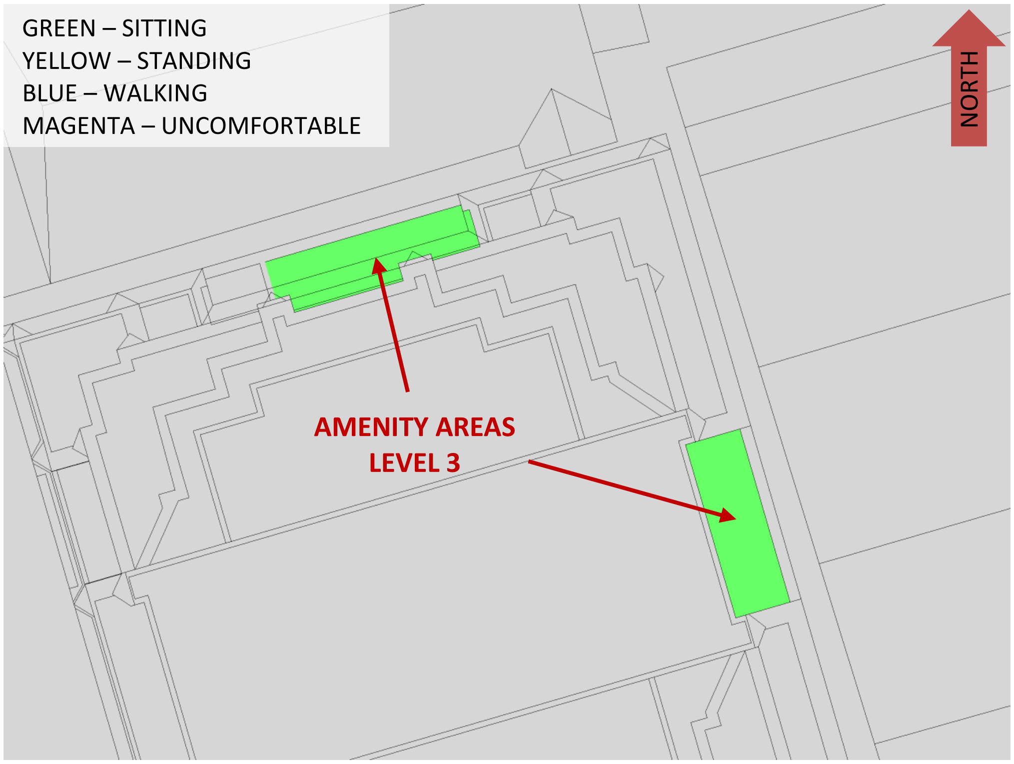


FIGURE 7A: SPRING – WIND COMFORT, AMENITY TERRACES

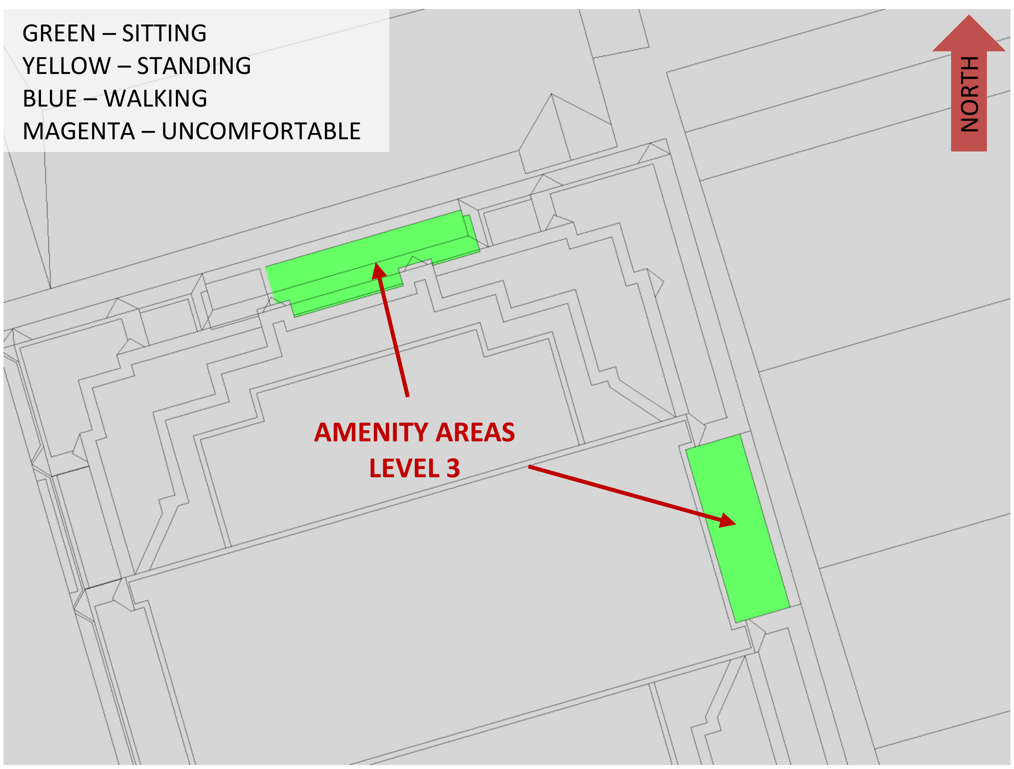


FIGURE 7B: SUMMER – WIND COMFORT, AMENITY TERRACES

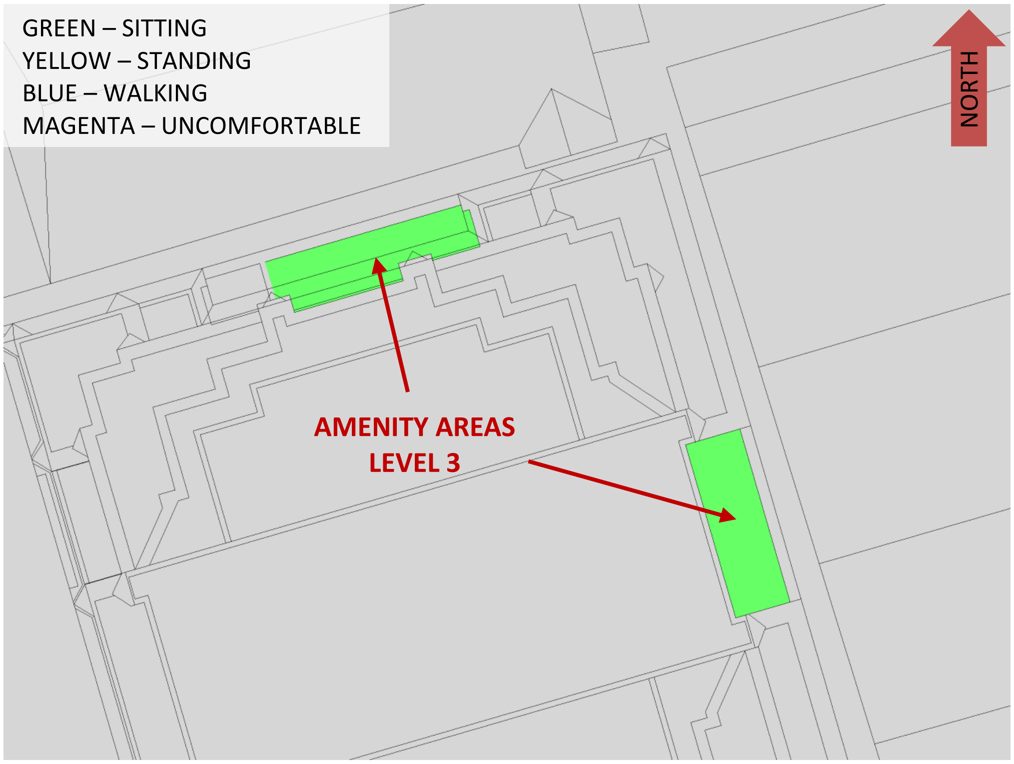


FIGURE 7C: AUTUMN – WIND COMFORT, AMENITY TERRACES

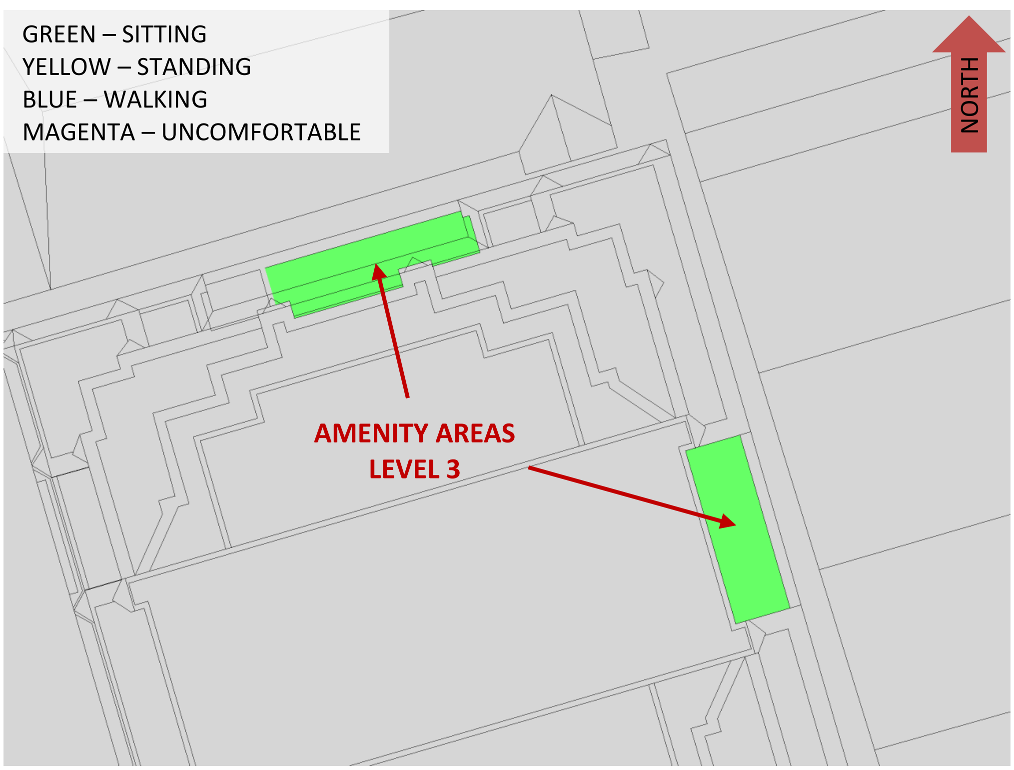
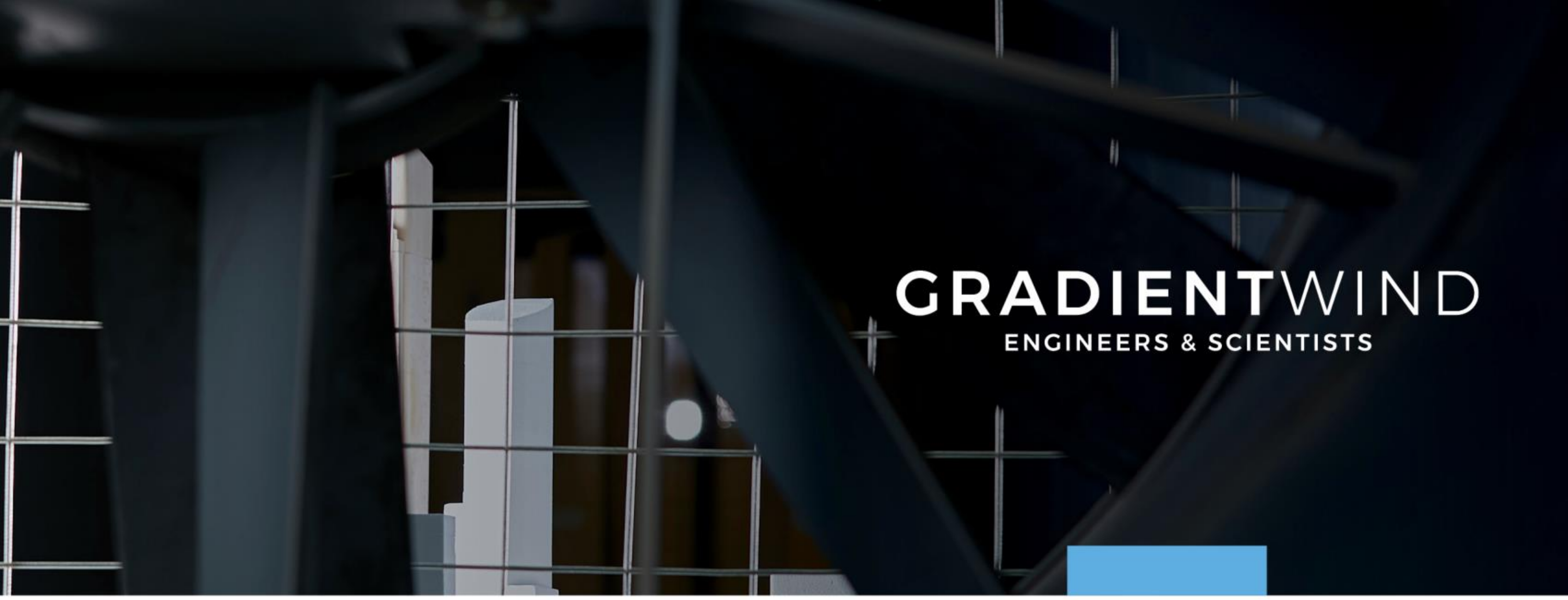
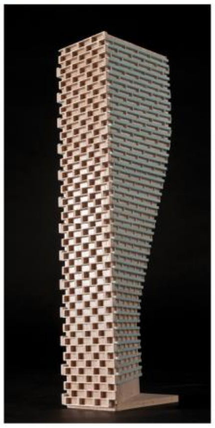
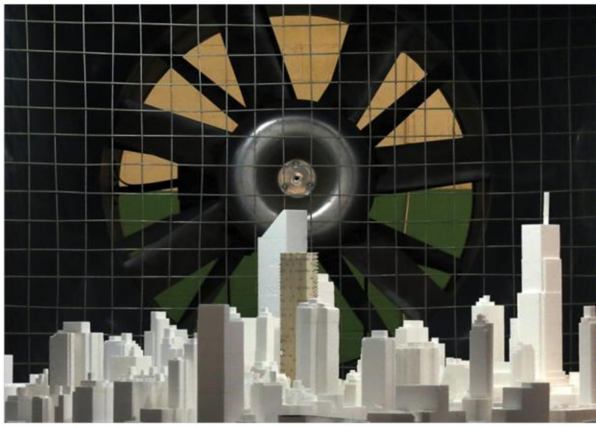


FIGURE 7D: WINTER – WIND COMFORT, AMENITY TERRACES







APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

The atmospheric boundary layer (ABL) is defined by the velocity and turbulence profiles according to industry standard practices. The mean wind profile can be represented, to a good approximation, by a power law relation, Equation (1), giving height above ground versus wind speed [1], [2].

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

where, $\boldsymbol{U}$ = mean wind speed, $\boldsymbol{U_g}$ = gradient wind speed, $\boldsymbol{Z}$ = height above ground, $\boldsymbol{Z_g}$ = depth of the boundary layer (gradient height), and α is the power law exponent.

For the model, U_g is set to 6.5 metres per second (m/s), which approximately corresponds to the 50% mean wind speed for Toronto based on historical climate data and statistical analyses. When the results are normalized by this velocity, they are relatively insensitive to the selection of gradient wind speed.

Z_g is set to 540 m. The selection of gradient height is relatively unimportant, so long as it exceeds the building heights surrounding the subject site. The value has been selected to correspond to our physical wind tunnel reference value.

α is determined based on the upstream exposure of the far-field surroundings (i.e., the area that it not captured within the simulation model).

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

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

Wind Direction (Degrees True)	Alpha Value (α)
0	0.26
40	0.28
97	0.33
136	0.31
170	0.28
210	0.27
237	0.26
258	0.25
278	0.25
300	0.25
322	0.25
341	0.26

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].

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

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

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

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