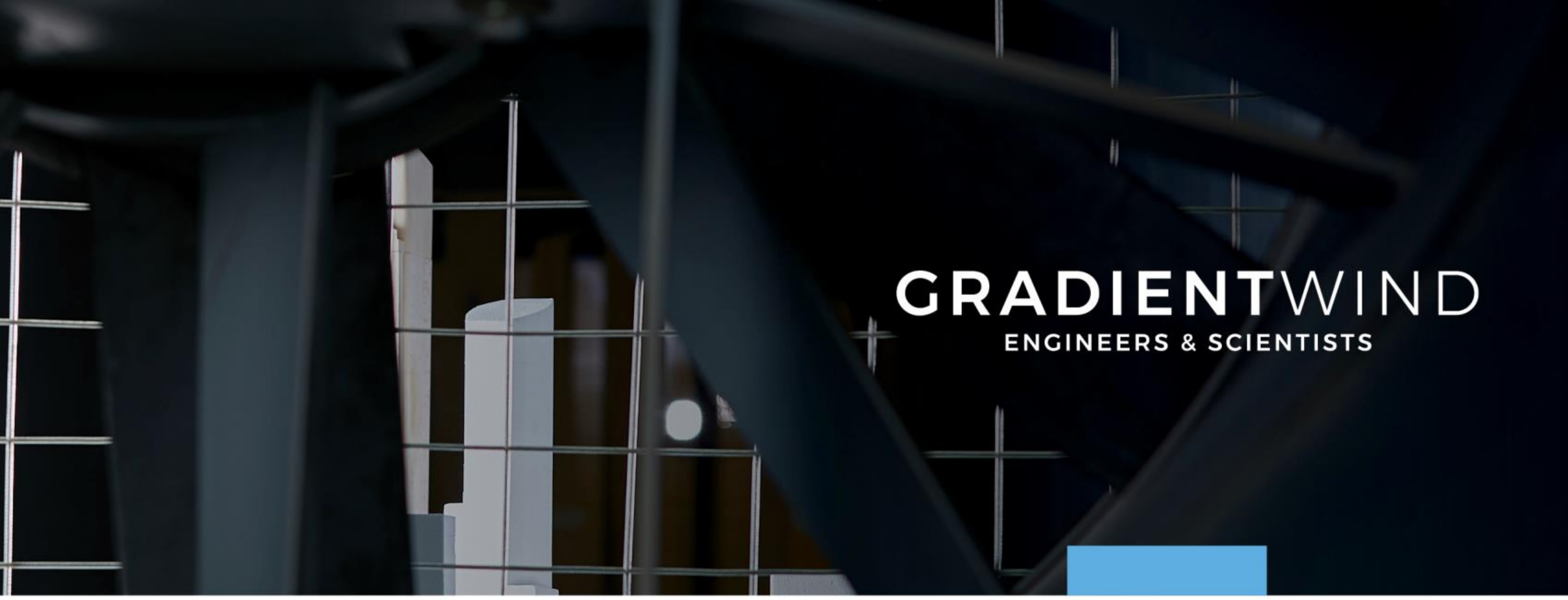

GRADIENTWIND
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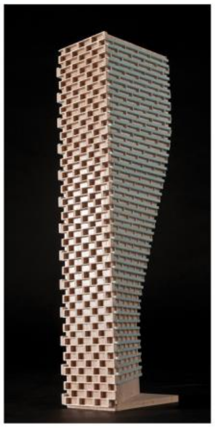
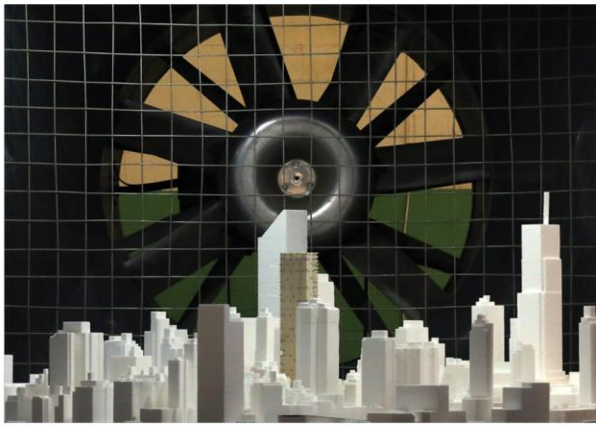
# PEDESTRIAN LEVEL WIND STUDY

91 and 93 Holland Avenue
Ottawa, Ontario

Report: 21-033-PLW





April 28, 2021



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# EXECUTIVE SUMMARY


This report describes a pedestrian level wind (PLW) study undertaken to satisfy the requirements for a Site Plan Control application submission for the proposed development located at 91 and 93 Holland Avenue in Ottawa (hereinafter referred to as "subject site" or "proposed development"). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, as required.

The study involves simulation of wind speeds for selected wind directions in a three-dimensional (3D) computer model using the computational fluid dynamics (CFD) technique, combined with meteorological data integration, to assess pedestrian wind comfort and safety within and surrounding the subject site according to City of Ottawa wind comfort and safety criteria. The results and recommendations derived from these considerations are detailed in the main body of the report (Section 5), illustrated in Figures 3A-8B, and summarized as follows:

1) All grade-level areas within and surrounding the subject site are predicted to be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, and nearby parking lots are considered acceptable for the intended pedestrian uses throughout the year.

2) Conditions over the common amenity terrace is predicted to be mostly suitable for sitting during the typical use period of late spring through early autumn with small regions of standing conditions located along the north and west perimeters of the terrace. Depending on the programming, the noted conditions may be considered acceptable. If necessary, the sitting conditions may be extended over the full terrace by installing a 1.5-metre-tall barrier, typically glazed, around the perimeter of the terrace.

3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas within and surrounding the subject site were found to experience conditions that could be considered dangerous or uncomfortable.

# TABLE OF CONTENTS

## 1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Tallis Project Management Inc., on behalf of Nicholson Gluckstein Lawyers, to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control application submission for the proposed development located at 91 and 93 Holland Avenue in Ottawa (hereinafter referred to as "subject site" or "proposed development"). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, as required.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings provided by Chmiel Architects Inc., in March 2021, 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 91 and 93 Holland Avenue on the east elevation of Holland Avenue, mid-block between Wellington Street West and Armstrong Street. Throughout this report, the Holland Avenue elevation is referred to as the west elevation.

*Rendering of Proposed Development, West Perspective (Courtesy of Chmiel Architects Inc.)*

The planned development comprises a 9-storey building plus mechanical penthouse. Above one level of underground parking, the grade level has a nearly square planform and comprises residential suites along the east elevation, commercial space fronting Holland Avenue at the southwest corner, and a residential lobby fronting Holland Avenue along the west elevation. Access to the underground parking is provided by a ramp at the northwest corner via Holland Avenue. Levels 2 through 9 comprise residential units with protruding balconies on all façades. Above Level 9, the mechanical penthouse level comprises mechanical space along the east elevation and an elevator lobby on the west elevation which opens to a rooftop amenity terrace.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) are characterized mostly low-rise buildings in all directions with taller buildings along Wellington Street West and Holland Avenue. Additionally, there are several taller buildings in development to the east of the subject site. Notably, there is a development to the immediate east of the subject site at 84-96 Hinton Avenue which comprises a 4-storey building and three 6-storey apartment buildings (Application # D07-12-14-0169). 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 the open exposure of Ottawa River, the mix of low- and high-rise massing of Tunney's Pasture campus, and a mix of mostly low- and mid-rise massing from the west clockwise to the northeast, by the open exposure of the Central Experimental Farm and a mix of mostly low- and mid-rise massing from the east-southeast clockwise to the south-southeast, and by a mix of mostly low- and mid-rise massing for the remaining compass directions. The Central Experimental Farm lies approximately 1.5 km to the southeast, the Tunney's Pasture campus lies approximately 500 m to the northwest, and the Ottawa River flows west-southwest to east-northeast approximately 1.3 km to the north-northwest.

Key areas under consideration include surrounding sidewalks, walkways, bus stops, and building access points. Site plans for the proposed and approved 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 pedestrian level wind comfort and safety conditions at key areas within and surrounding the development site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.

# 4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on CFD simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the Ottawa area wind climate, and synthesis of computational data with City of Ottawa wind comfort and safety criteria[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

## 4.1 Computer-Based Context Modelling

A computer based PLW study was performed to determine the influence of the wind environment on pedestrian comfort over the proposed development site. Pedestrian comfort predictions, based on the mechanical effects of wind, were determined by combining measured wind speed data from CFD simulations with statistical weather data obtained from Ottawa Macdonald-Cartier International Airport. The general concept and approach to CFD modelling is to represent building and topographic details in the immediate vicinity of the study site on the surrounding model, and to create suitable atmospheric wind profiles at the model boundary. The wind profiles are designed to have similar mean and turbulent wind properties consistent with actual site exposures.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative (i.e., windier) wind speed values.

[1] City of Ottawa Terms of References: Wind Analysis
https://documents.ottawa.ca/sites/default/files/torwindanalysis_en.pdf

## 4.2 Wind Speed Measurements

The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 12 wind directions. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 820 m.

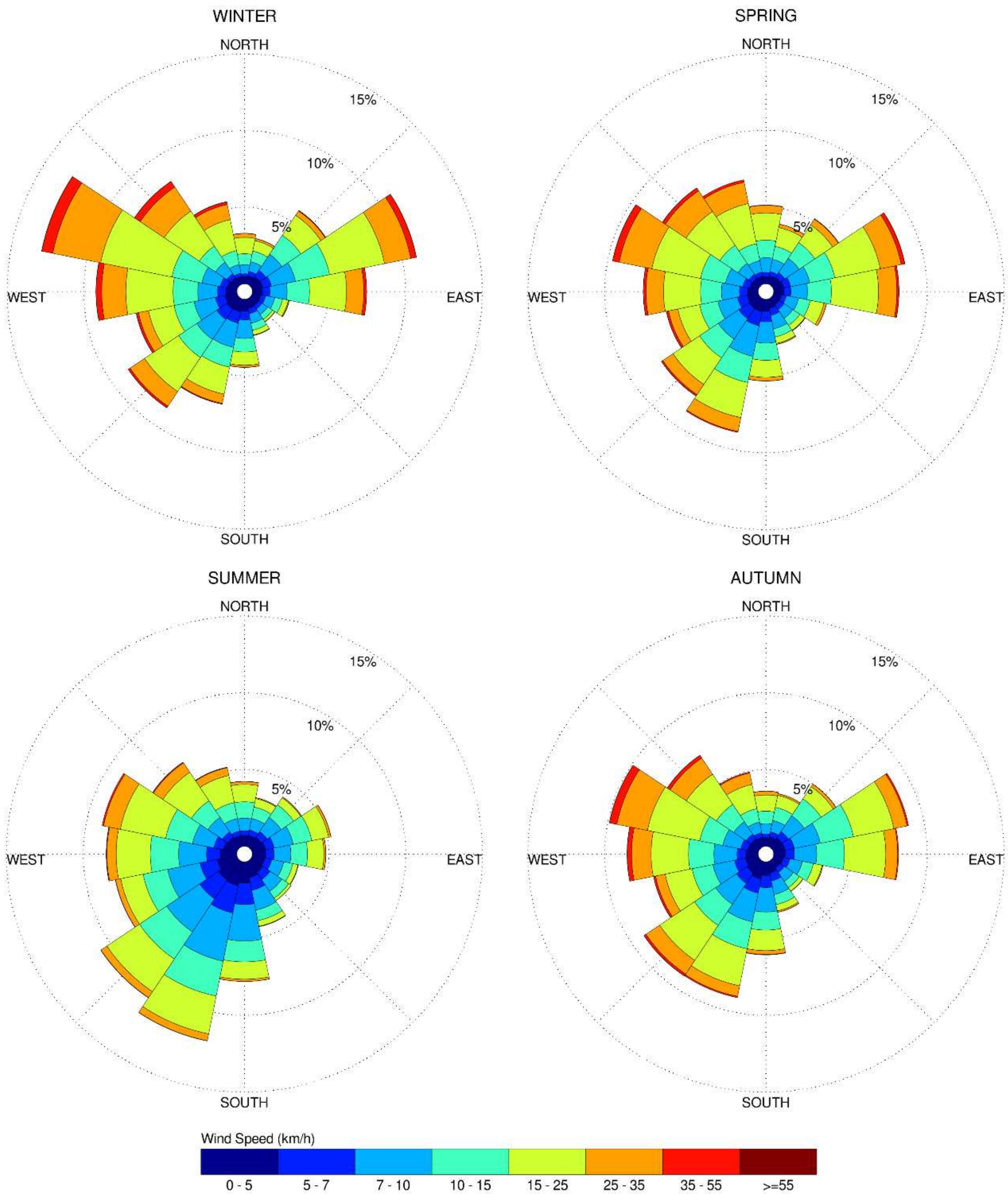
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the rooftop amenity terrace were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. Gradient height represents the theoretical depth of the boundary layer of the earth's atmosphere, above which the mean wind speed remains constant. Further details of the wind flow simulation technique are presented in Appendix A.

## 4.3 Meteorological Data Analysis

A statistical model for winds in Ottawa was developed from approximately 40 years of hourly meteorological wind data recorded at Ottawa Macdonald-Cartier International Airport and obtained from Environment and Climate Change Canada. Wind speed and direction data were analyzed for each month of the year to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns.

The statistical model of the Ottawa area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Ottawa, the most common winds occur for westerly wind directions, followed by those from the east, while the most common wind speeds are below 36 km/h. The directional preference and relative magnitude of wind speed changes somewhat from season to season.

**SEASONAL DISTRIBUTION OF WIND**
**OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT**




**Notes:**

1. Radial distances indicate percentage of time of wind events.
2. Wind speeds are mean hourly in km/h, measured at 10 m above the ground.

## 4.4 Pedestrian Comfort and Safety Criteria – City of Ottawa

Pedestrian comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 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 | Wind Speed (km/h) | | Description |
|---|---|---|---|---|
| | | Mean | Gust | |
| 2 | Light Breeze | 6-11 | 9-17 | Wind felt on faces |
| 3 | Gentle Breeze | 12-19 | 18-29 | Leaves and small twigs in constant motion; wind extends light flags |
| 4 | Moderate Breeze | 20-28 | 30-42 | Wind raises dust and loose paper; small branches are moved |
| 5 | Fresh Breeze | 29-38 | 43-57 | Small trees in leaf begin to sway |
| 6 | Strong Breeze | 39-49 | 58-74 | Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty |
| 7 | Moderate Gale | 50-61 | 75-92 | Whole trees in motion; inconvenient walking against wind |
| 8 | Gale | 62-74 | 93-111 | Breaks twigs off trees; generally impedes progress |

Experience and research on people's perception of mechanical wind effects has shown that if the wind speed levels are exceeded for more than 20% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if a mean wind speed of 10 km/h were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting. Similarly, if a mean wind speed of 20 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established throughout the site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for discrete regions within and surrounding the subject site. This step involves comparing the predicted comfort classes to the desired comfort classes, which are dictated by the location type for each region (i.e., a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their desired comfort classes are summarized on the following page.

**DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES**

| Location Types | Desired Comfort Classes |
|---|---|
| Primary Building Entrance | Standing |
| Secondary Building Access Point | Standing / Strolling / Walking |
| Primary Public Sidewalk | Strolling / Walking |
| Secondary Public Sidewalk / Bicycle Path | Walking |
| Outdoor Amenity Space | Sitting / Standing / Strolling |
| Café / Patio / Bench / Garden | Sitting |
| Transit Stop | Sitting / Standing |
| Public Park / Plaza | Standing / Strolling |
| Garage / Service Entrance | Walking |
| Parking Lot | Strolling / Walking |
| Vehicular Drop-Off Zone | Standing / Strolling / Walking |

## 5. RESULTS AND DISCUSSION

The following discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-6B, which illustrate seasonal wind conditions at grade level for the proposed and approved massing scenarios, and Figures 7A-7D, which illustrate seasonal wind conditions over the rooftop amenity terrace serving the proposed development. Wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site. The colour contours indicate various wind comfort classes predicted for certain regions, which correspond to the City of Ottawa wind comfort criteria in Section 4.4. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by orange, and walking by blue. Uncomfortable conditions are represented by magenta.

Regarding the rooftop amenity terrace, Figures 8A and 8B illustrate wind comfort conditions and the percentage of time the roof areas are predicted to be suitable for sitting during the typical use period, defined as May to October, inclusive. Figure 8A represents wind comfort based on the definitions in Section 4.4, as noted above, while Figure 8B represents sitting percentages. Pedestrian conditions are summarized in the following pages for each area of interest.

## 5.1 Wind Comfort Conditions – Grade Level

Following the introduction of the proposed development, the sidewalks around the subject site are predicted to be suitable for sitting during the spring, summer, and autumn, becoming suitable for a mix of sitting and standing during the winter. Conditions in the vicinity of building entrances serving the subject site are also predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable according to the City of Ottawa wind comfort criteria.

The introduction of the proposed development results in mostly similar conditions, with some areas being slightly windier and some areas being slightly calmer along the surrounding sidewalks, in comparison to existing conditions. Conditions over the surrounding sidewalks with the approved massing are predicted to be suitable for sitting during the summer and autumn, becoming suitable for a mix of sitting and standing during the winter.

## 5.2 Wind Comfort Conditions – Common Amenity Terrace

The rooftop amenity terrace is predicted to be mostly suitable for sitting during the typical use period with small regions of standing conditions located along the north and west perimeters of the terrace. Depending on the programming, the noted conditions may be considered acceptable according to the City of Ottawa wind comfort criteria. If necessary, the sitting conditions may be extended over the full terrace by installing a 1.5-m-tall barrier, typically glazed, around the perimeter of 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 surrounding the subject site at grade level or on the common amenity terraces were found to experience conditions that could be considered dangerous, as defined in Section 4.4.

### 5.4 Applicability of Results

Wind conditions over surrounding sidewalks beyond the subject site, as well as at nearby primary building entrances, will be acceptable for their intended pedestrian uses during each seasonal period upon the introduction of the subject site. Pedestrian wind comfort and safety have been quantified for the specific configuration of existing and foreseeable construction around the study site. Future changes (i.e., construction or demolition) of these surroundings may cause changes to the wind effects in two ways, namely: (i) changes beyond the immediate vicinity of the site would alter the wind profile approaching the site; and (ii) development in proximity to the site would cause changes to local flow patterns. In general, development in urban centers generally creates reduction in the mean wind speeds and localized increases in the gustiness of the wind.

Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associated hardware.

## 6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-8B. 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 in Ottawa, the study concludes the following:

1) All grade-level areas within and surrounding the subject site are predicted to be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, and nearby parking lots are considered acceptable for the intended pedestrian uses throughout the year.

2) Conditions over the common amenity terrace is predicted to be mostly suitable for sitting during the typical use period of late spring through early autumn with small regions of standing conditions located along the north and west perimeters of the terrace. Depending on the programming, the noted conditions may be considered acceptable. If necessary, the sitting conditions may be extended over the full terrace by installing a 1.5-m-tall barrier, typically glazed, around the perimeter of the terrace.

3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas within and surrounding the subject site were found to experience conditions that could be considered dangerous or uncomfortable.

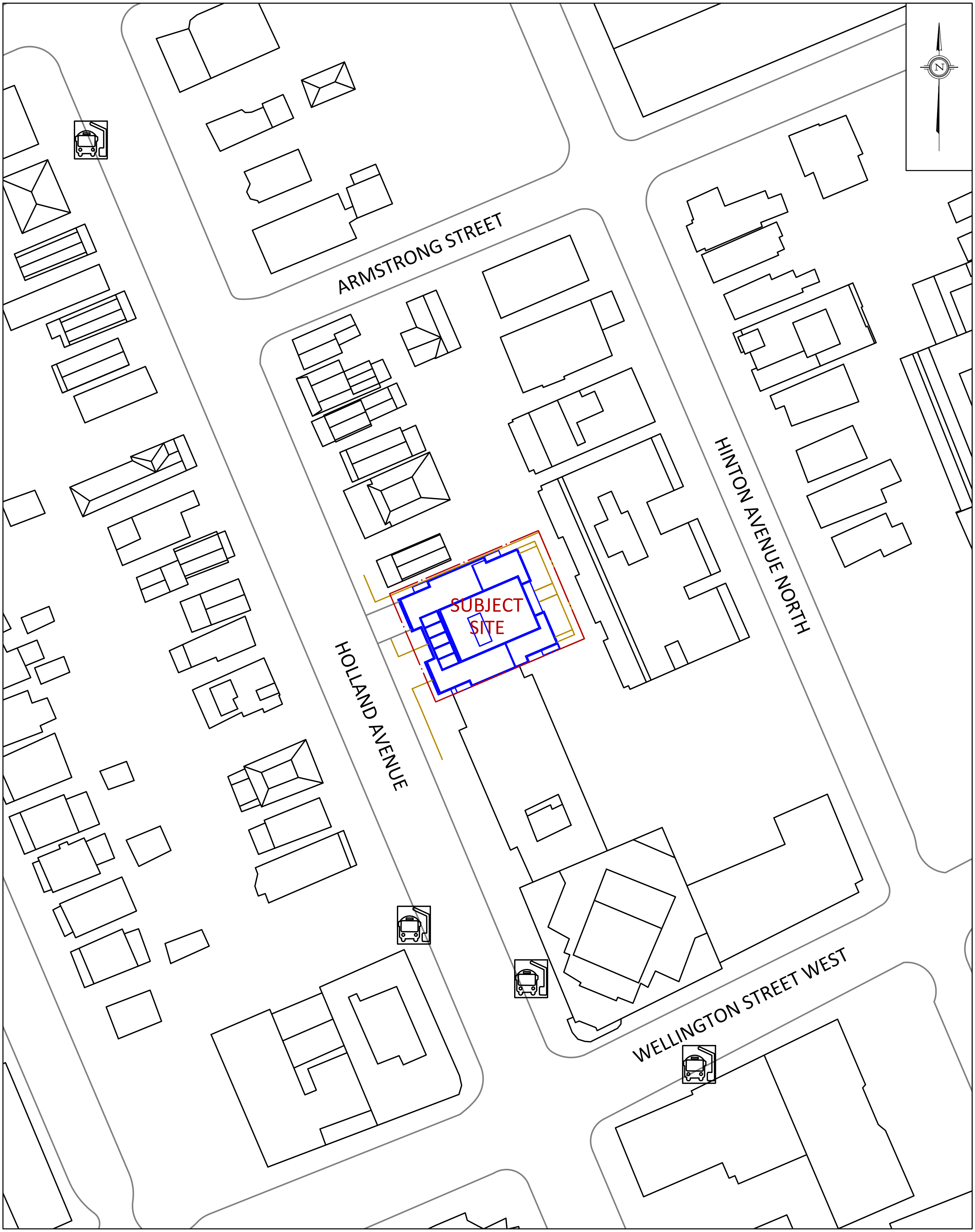
Sincerely,

***Gradient Wind Engineering Inc.***



Daniel Davalos, MESc.
Junior Wind Scientist

Steven Hall, M.A.Sc., P.Eng.
Senior Wind Engineer

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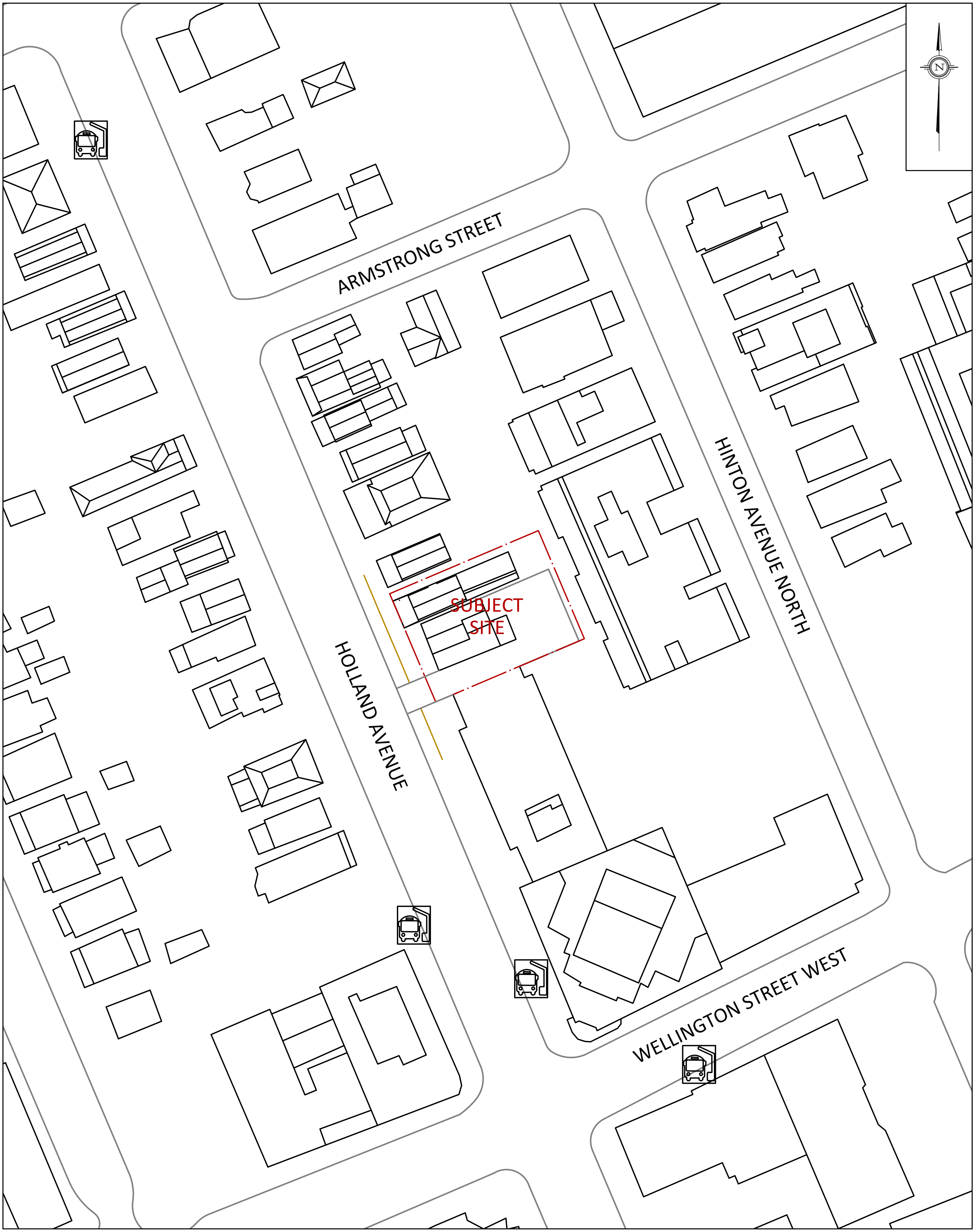
| | | |
|---|---|---|
| PROJECT: 91 AND 93 HOLLAND AVENUE, OTTAWA PEDESTRIAN LEVEL WIND STUDY | | DESCRIPTION: FIGURE 1A: PROPOSED SITE PLAN AND SURROUNDING CONTEXT |
| SCALE: 1:1000 | DRAWING NO.: 21-033-PLW-1A | |
| DATE: APRIL 28, 2021 | DRAWN BY: N.M.P. | |

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| PROJECT: 91 AND 93 HOLLAND AVENUE, OTTAWA PEDESTRIAN LEVEL WIND STUDY | | DESCRIPTION: FIGURE 1B: APPROVED SITE PLAN AND SURROUNDING CONTEXT |
| SCALE: 1:1000 | DRAWING NO.: 21-033-PLW-1B | |
| DATE: APRIL 28, 2021 | DRAWN BY: N.M.P. | |

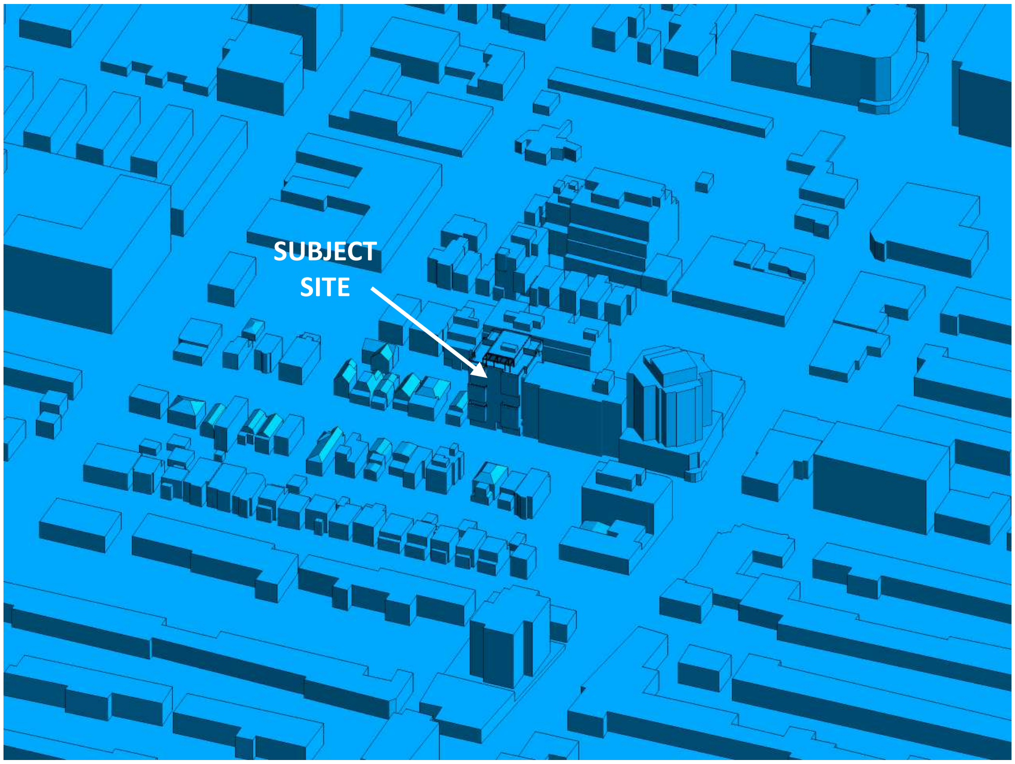



**FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTHWEST PERSPECTIVE**

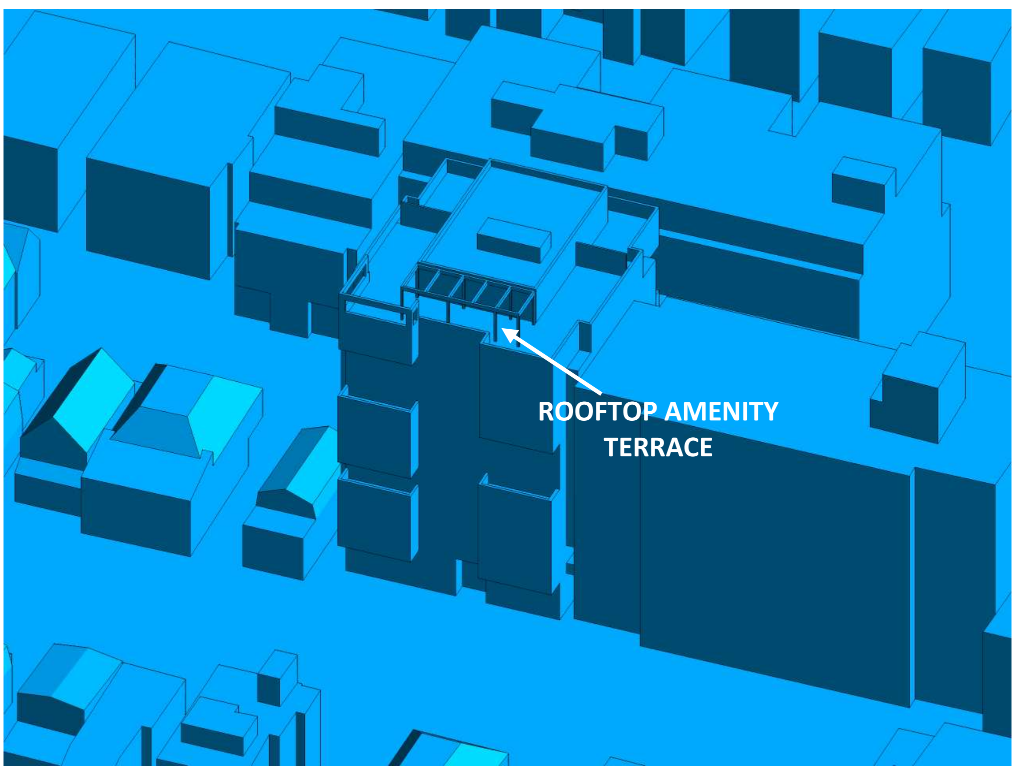



**FIGURE 2B: CLOSE UP OF FIGURE 2A**

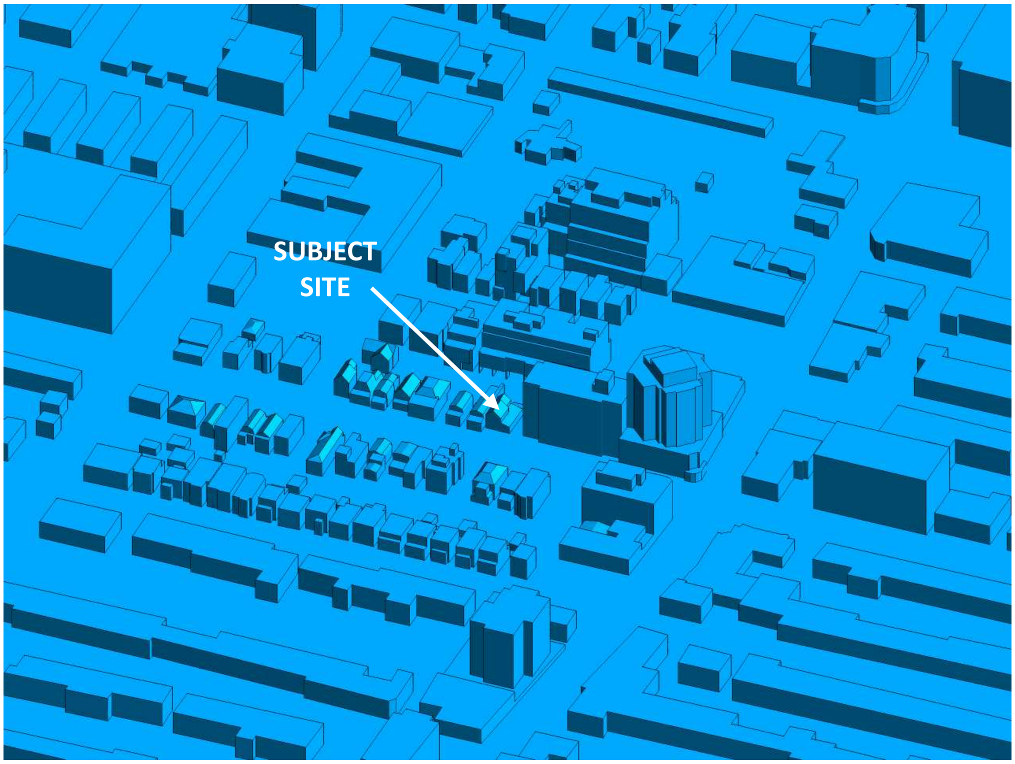



**FIGURE 2C: COMPUTATIONAL MODEL, APPROVED MASSING, SOUTHWEST PERSPECTIVE**

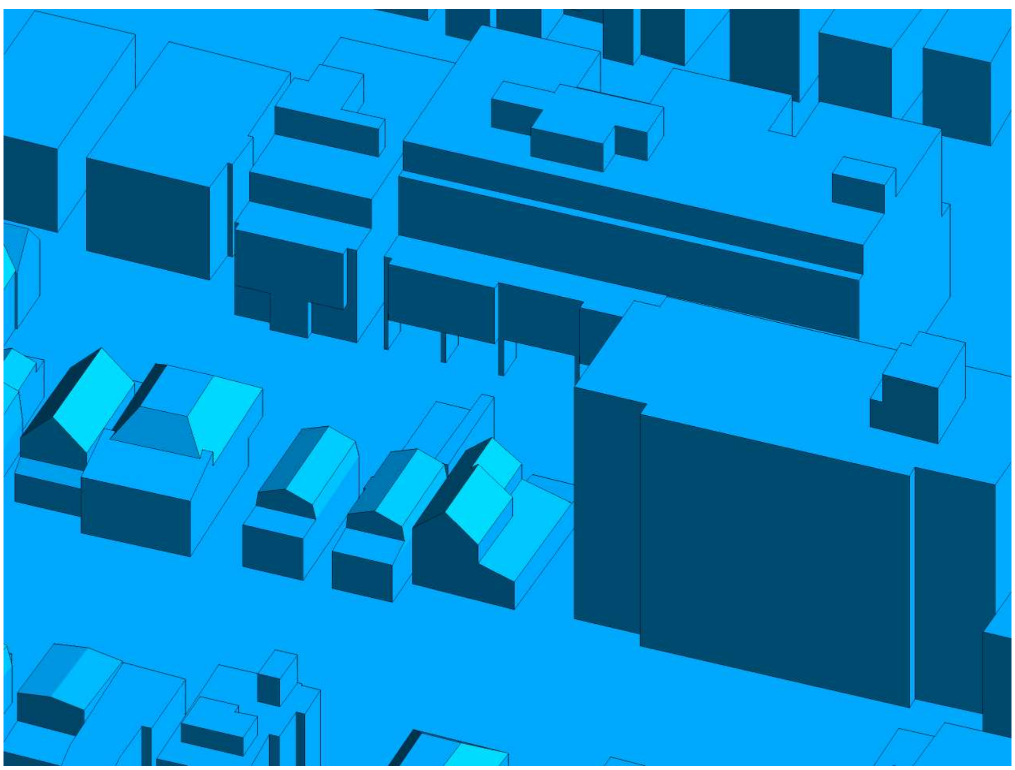


**FIGURE 2D: CLOSE-UP VIEW OF FIGURE 2C**

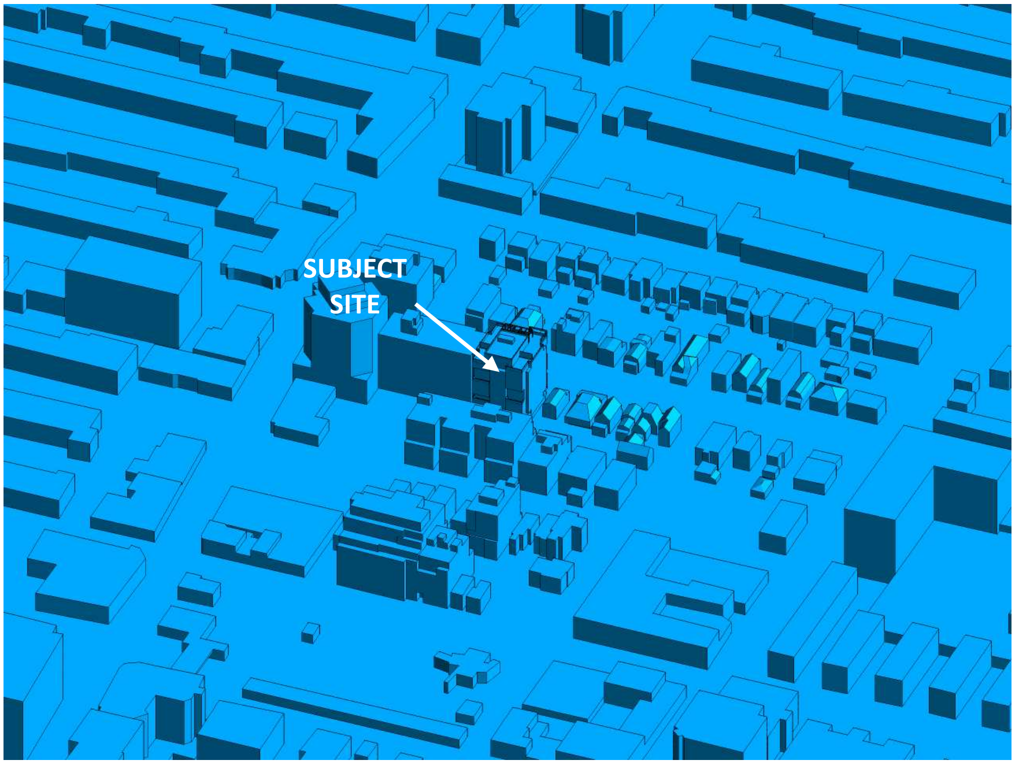



**FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTHEAST PERSPECTIVE**

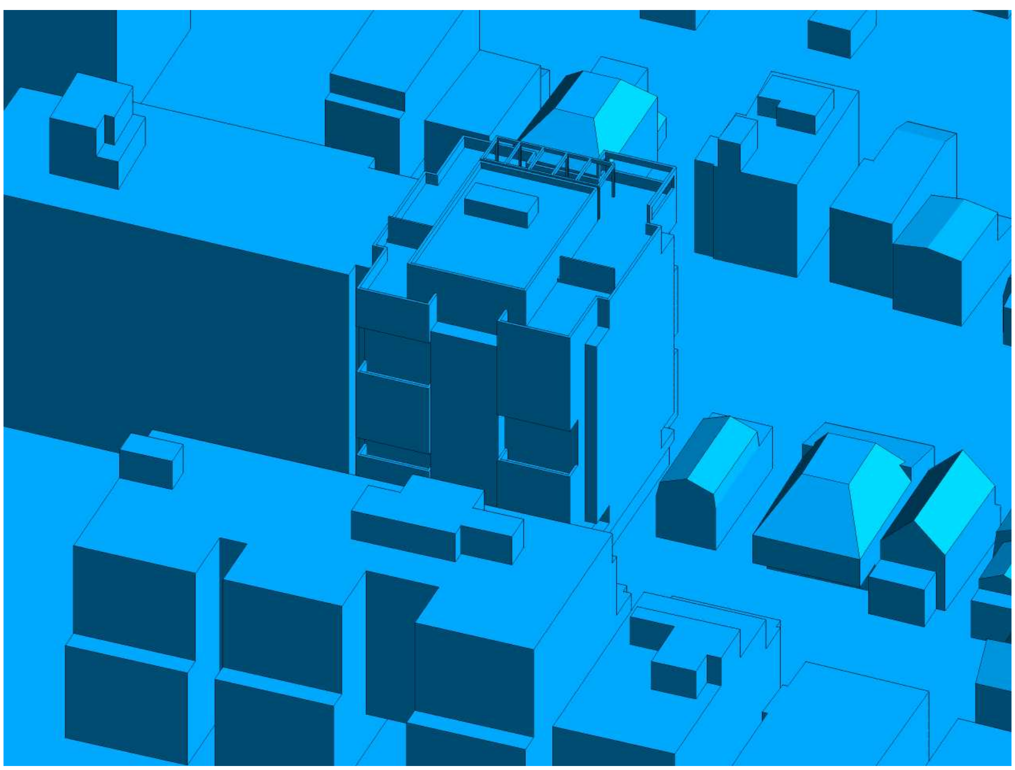


**FIGURE 2F: CLOSE UP OF FIGURE 2C**

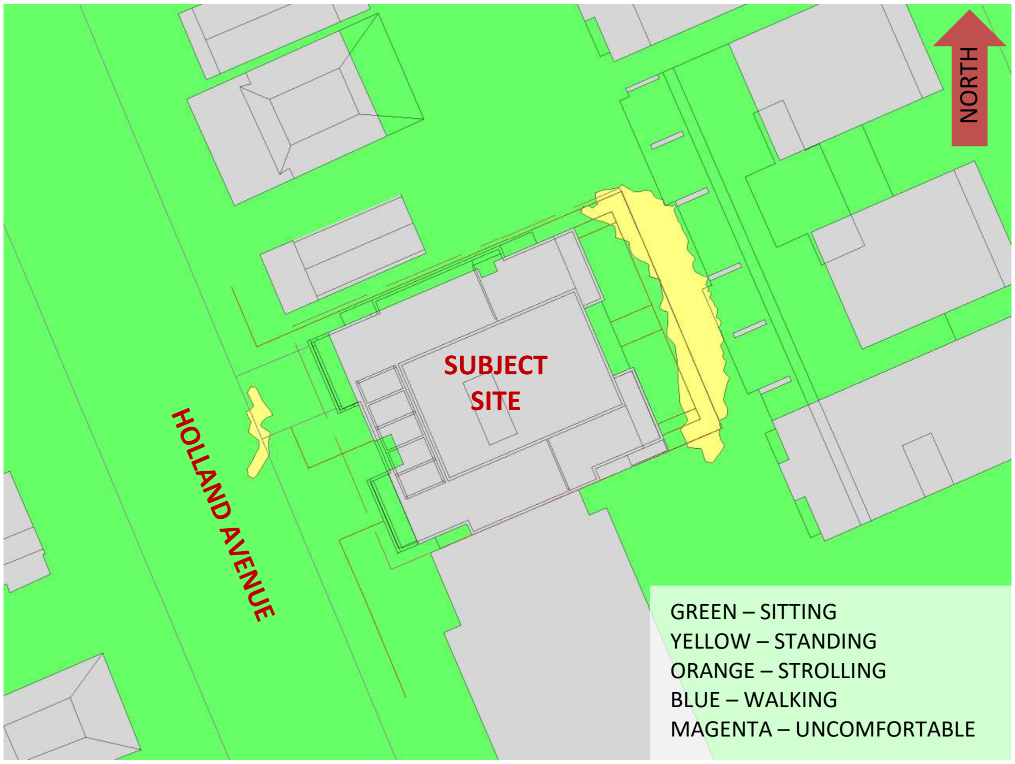



**FIGURE 3A: SPRING – PROPOSED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**

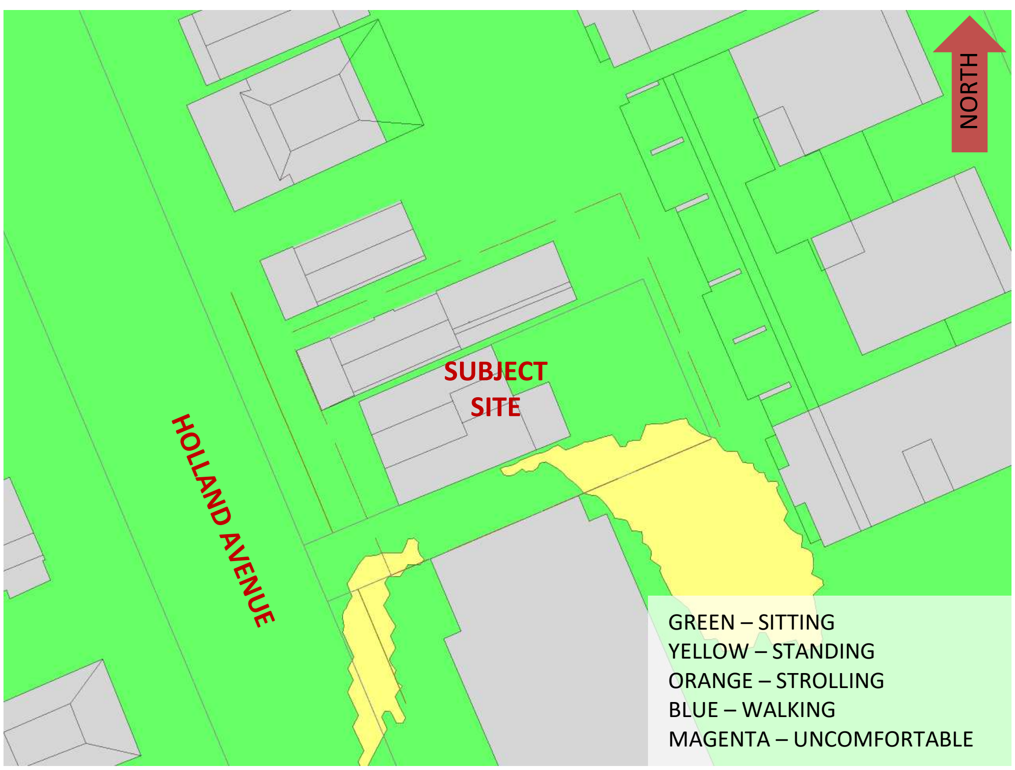



**FIGURE 3B: SPRING – APPROVED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**

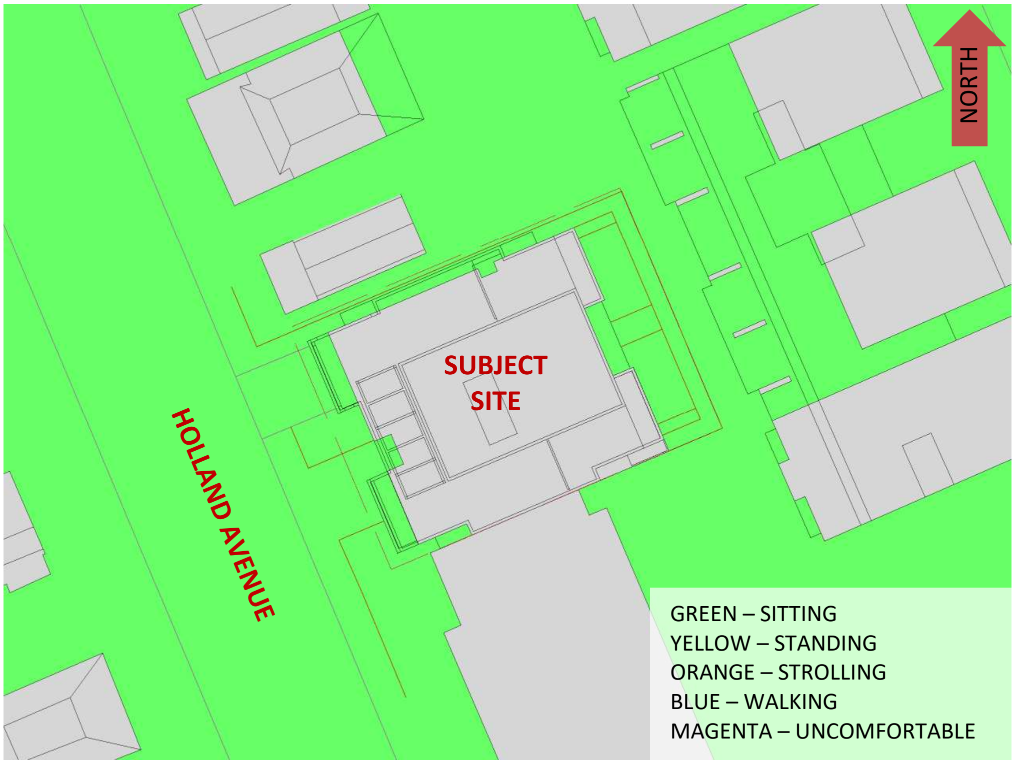



**FIGURE 4A: SUMMER – PROPOSED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**

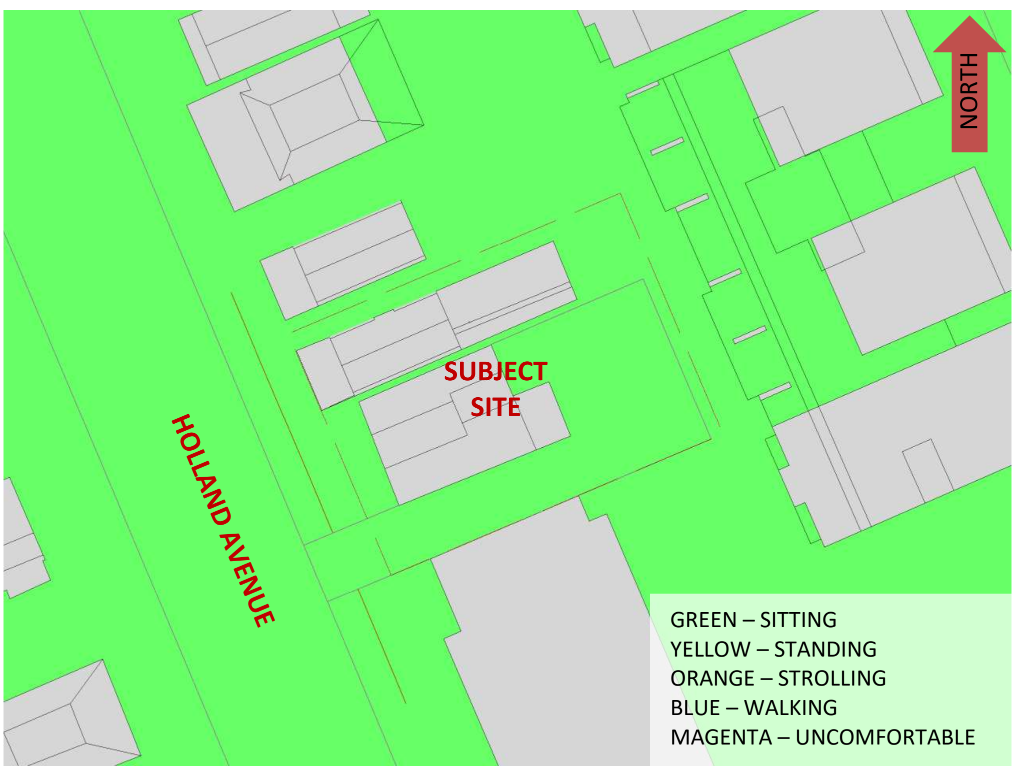



**FIGURE 4B: SUMMER – APPROVED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**

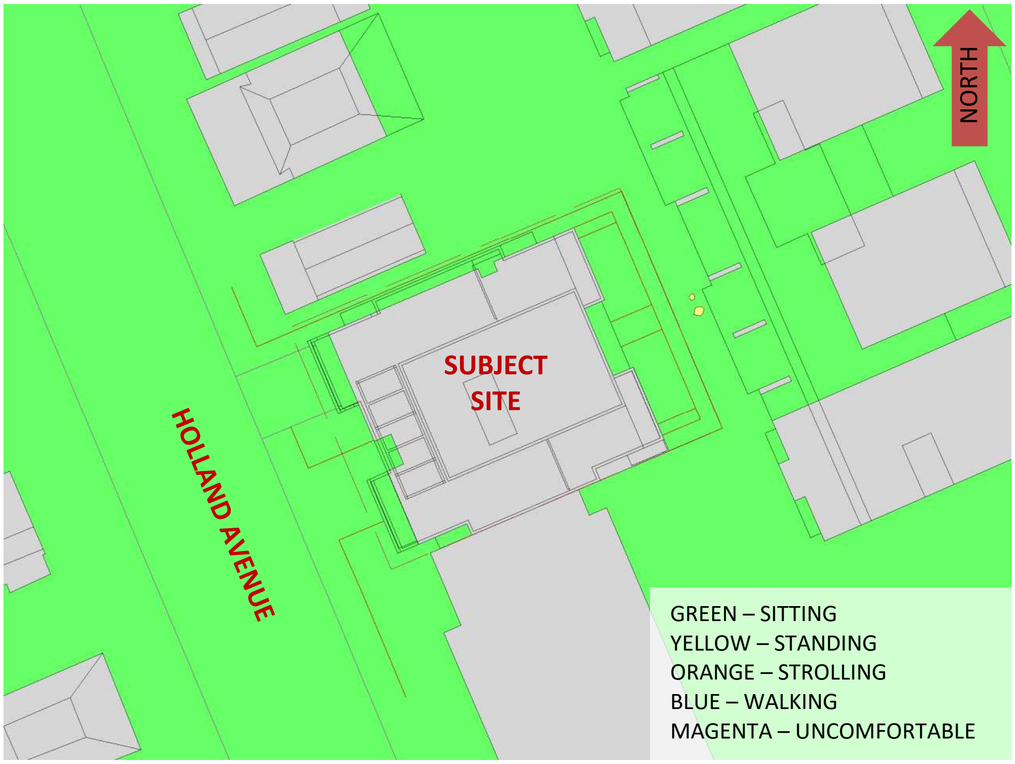



**FIGURE 5A: AUTUMN – PROPOSED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**


**FIGURE 5B: AUTUMN – APPROVED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**

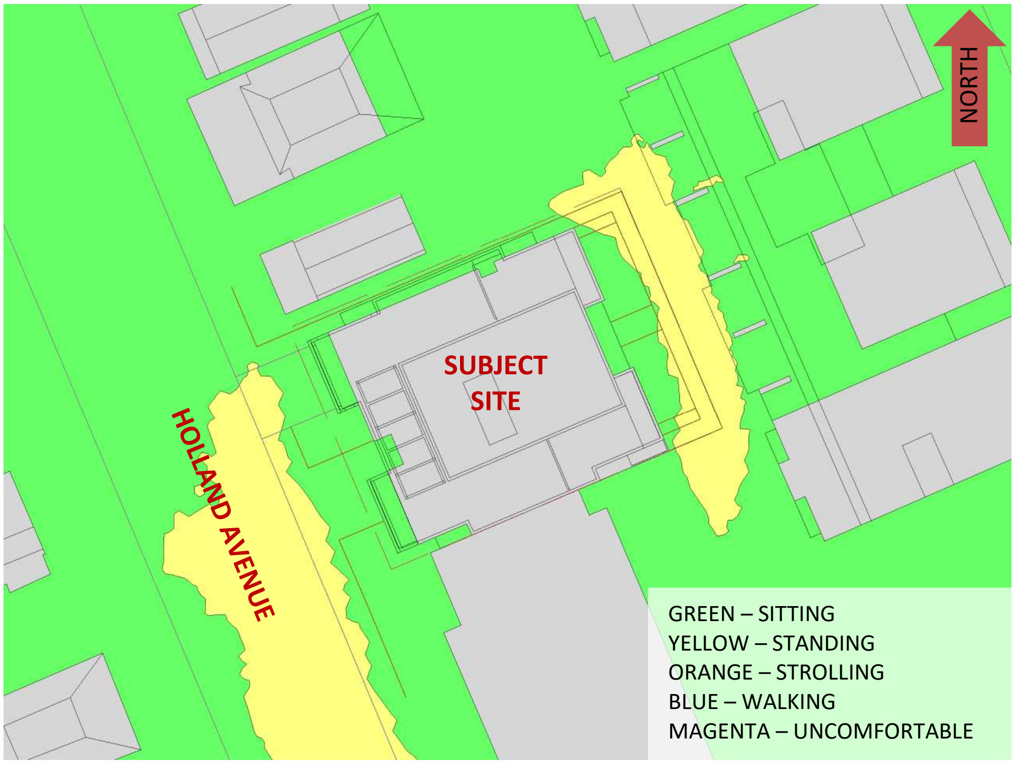



**FIGURE 6A: WINTER – PROPOSED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**

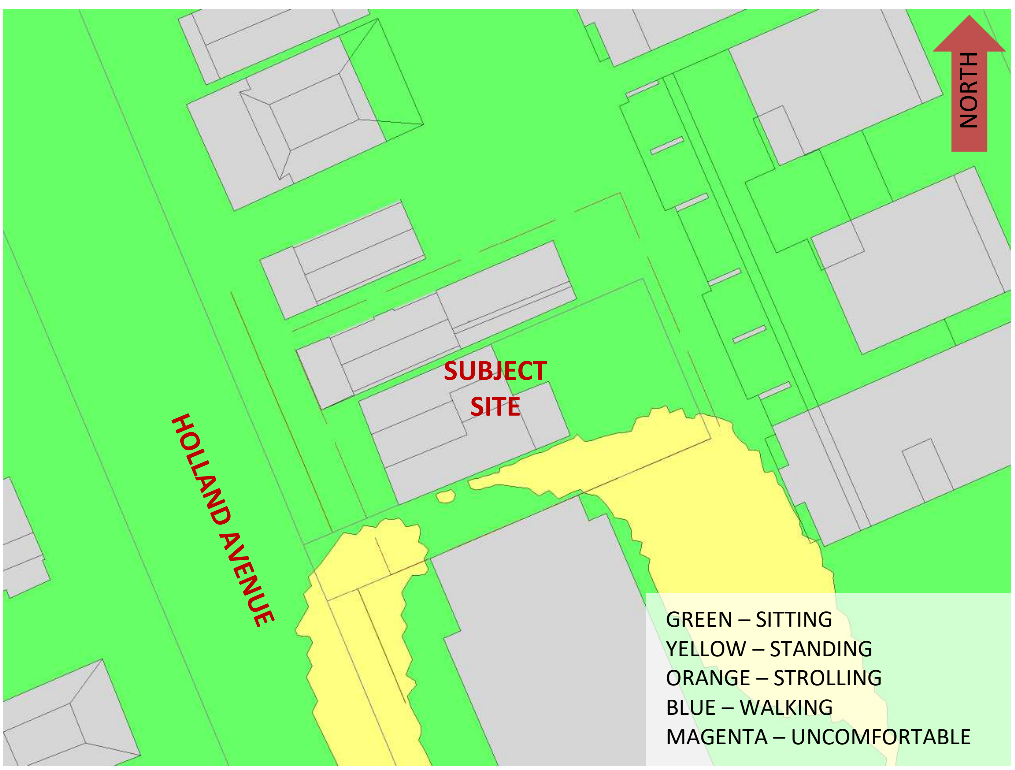



**FIGURE 6B: WINTER – APPROVED MASSING – WIND COMFORT CONDITIONS, GRADE LEVEL**


**FIGURE 7A: SPRING – WIND COMFORT, ROOFTOP AMENITY TERRACE**


**FIGURE 7B: SUMMER – WIND COMFORT, ROOFTOP AMENITY TERRACE**


**FIGURE 7C: AUTUMN – WIND COMFORT, ROOFTOP AMENITY TERRACE**


**FIGURE 7D: WINTER – WIND COMFORT, ROOFTOP AMENITY TERRACE**


**FIGURE 8A: TYPICAL USE PERIOD – WIND COMFORT, ROOFTOP AMENITY TERRACE**

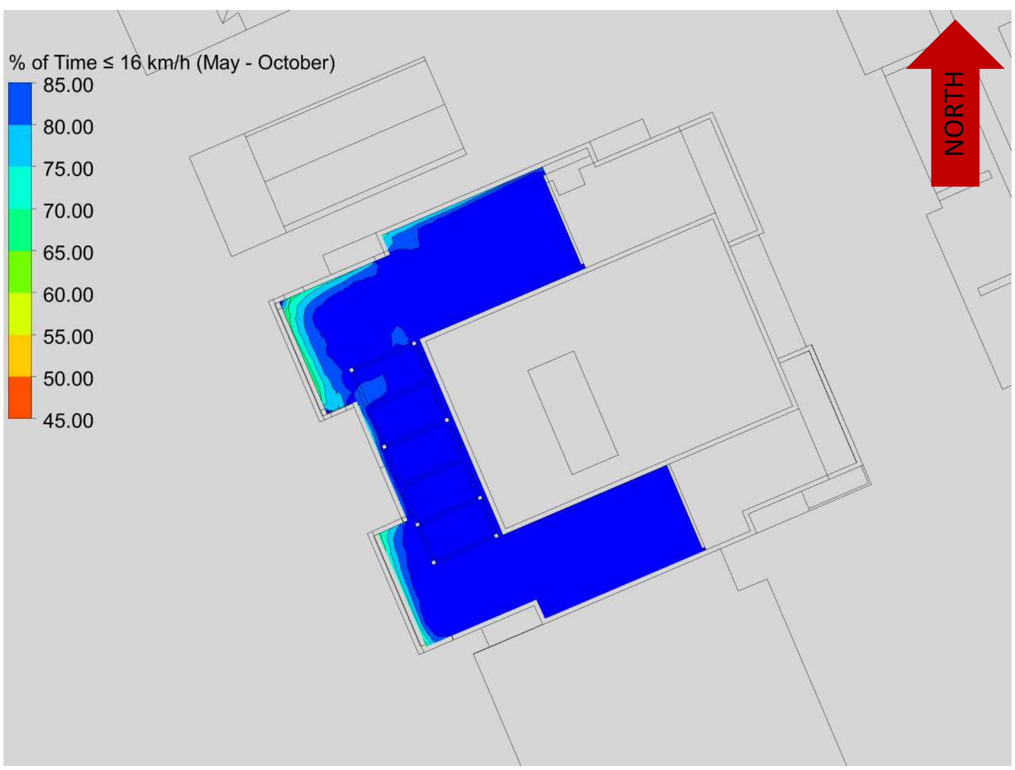
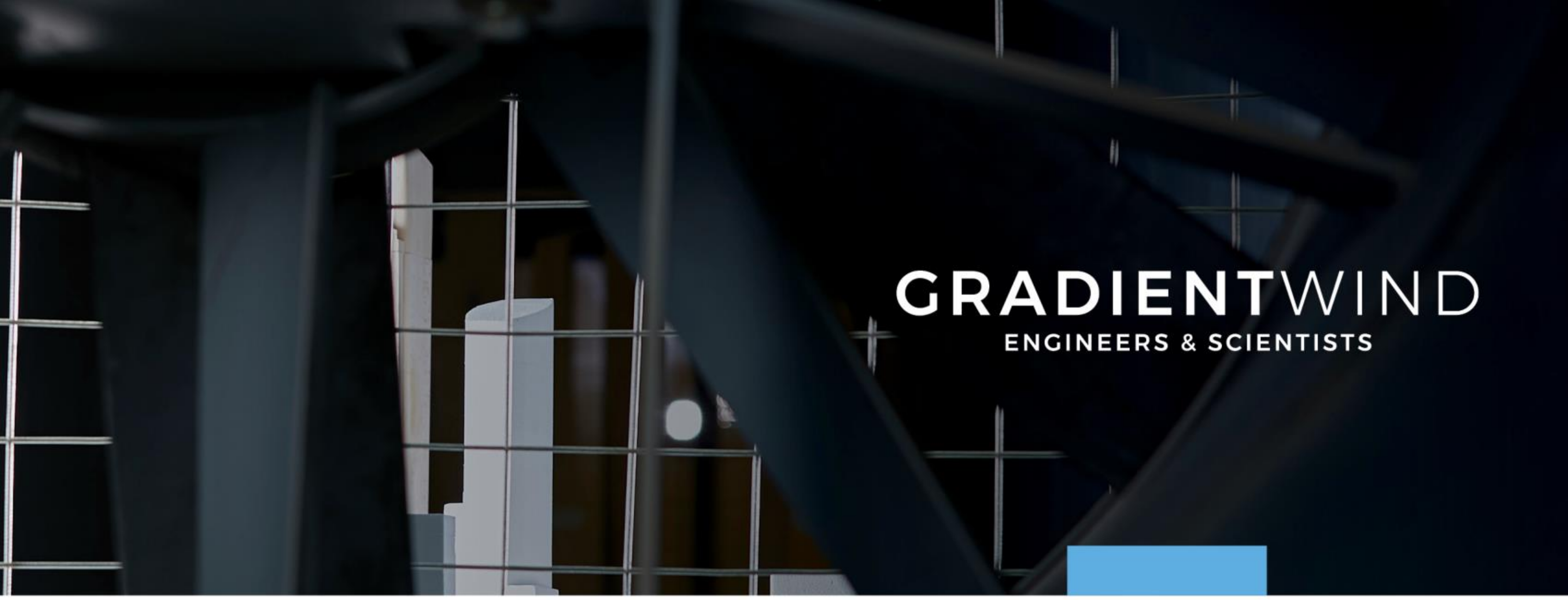
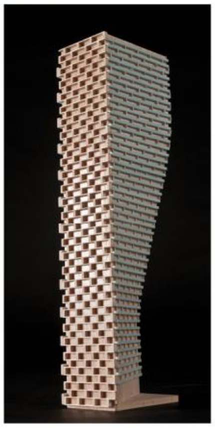
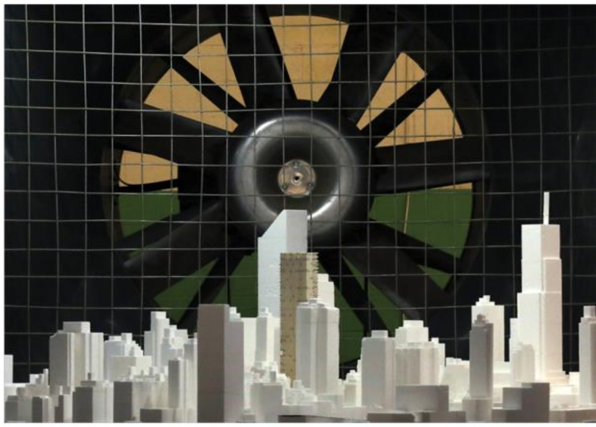



**FIGURE 8B: TYPICAL USE PERIOD – PERCENTAGE OF TIME SUITABLE FOR SITTING, TERRACE**





## 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].

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

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 $\alpha$ is the power law exponent.

For the model, $U_g$ is set to 6.5 metres per second (m/s), which approximately corresponds to the 60% mean wind speed for Ottawa based on historical climate data and statistical analyses. When the results are normalized by this velocity, they are relatively insensitive to the selection of gradient wind speed.

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

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

Table 1 presents the values of 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 | 0.25 |
| 49 | 0.26 |
| 74 | 0.25 |
| 103 | 0.24 |
| 167 | 0.23 |
| 197 | 0.24 |
| 217 | 0.24 |
| 237 | 0.24 |
| 262 | 0.24 |
| 282 | 0.24 |
| 302 | 0.23 |
| 324 | 0.24 |

**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 **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.

# REFERENCES

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