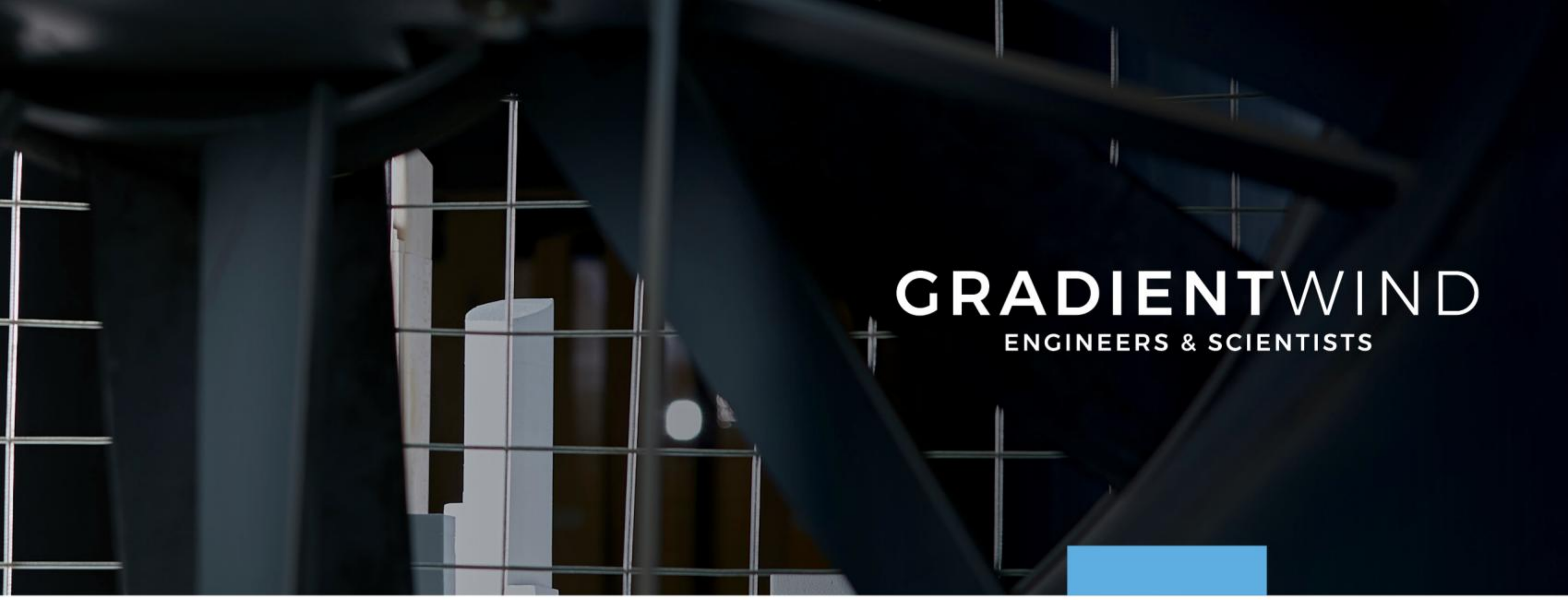
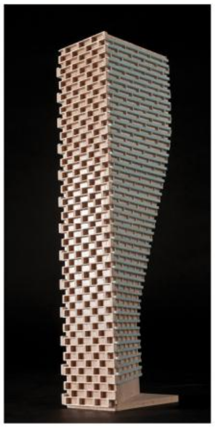
# Appendix E

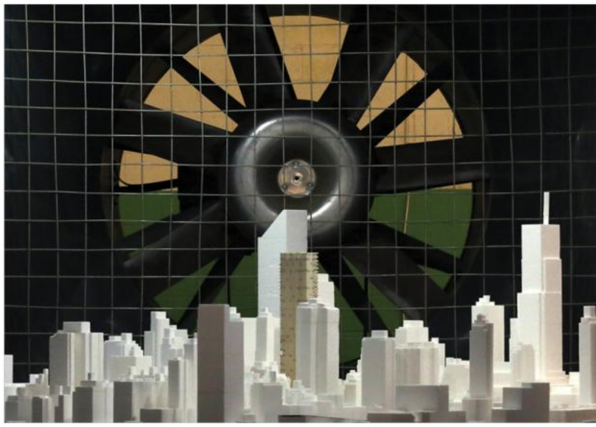



# PEDESTRIAN LEVEL WIND STUDY

143-153 Sackville Drive
Halifax, Nova Scotia

Report: 24-083-PLW





May 22, 2024

PREPARED FOR
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# EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy development agreement application submission requirements for the proposed mixed-use residential development located at 143-153 Sackville Drive in Halifax, Nova Scotia (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 areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

The study involves the simulation of wind speeds for sixteen (16) 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. Since the Sackville Drive community plan area does not specify wind criteria, the criteria in Regional Centre Land-use Bylaw were applied. A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-5B, and is summarized as follows:

1) Most 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, transit stops, Gate of Heaven Cemetery, neighbouring existing surface parking lots, proposed access routes, driveways, surface parking, and walkways, and in the vicinity of building access points are considered acceptable.

2) Wind comfort conditions over the landscaped garden to the west of the subject site are predicted to be suitable for mostly sitting, with an isolated region suitable for standing central to the garden during the summer season.

    a. Depending on the programming of the landscaped garden, the noted conditions may be considered acceptable. Specifically, if the noted windier area that is predicted to be suitable for standing will not accommodate seating or more sedentary activities, the noted conditions may be considered 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. 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 Stephen Adams Consulting Services Inc. to undertake a pedestrian level wind (PLW) study to satisfy development agreement application submission requirements for the proposed mixed-use residential development located at 143-153 Sackville Drive in Halifax, Nova Scotia (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 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, industry standard wind comfort and safety guidelines, architectural drawings prepared by Paul Skerry Architects Limited in April 2024, surrounding street layouts and existing and approved future building massing information obtained from the Halifax Regional Municipality, recent satellite imagery, and experience with numerous similar developments. Since the Sackville Drive community plan area does not specify wind criteria, the criteria in Regional Centre Land-use Bylaw were applied. These criteria are consistent with industry standards.

## 2. TERMS OF REFERENCE

The subject site is located at 143-153 Sackville Drive in Halifax, situated on a parcel of land to the southeast at the intersection of Sackville Drive and Hillcrest Avenue. Throughout this report, Sackville Drive is referred to as project west. The proposed development comprises two nominally rectangular towers: Tower 1 (13 storeys) and Tower 2 (14 storeys) rising to the south and north of the subject site, respectively. The two towers are connected by a single storey at grade level. Towers 1 and 2 share two underground parking levels accessed by a parking ramp at the southwest corner of Tower 1 via a driveway extending from Sackville Drive. Grade-level outdoor surface parking is provided to the east of the subject site and is accessed via an access route at the rear of the subject site that extends from Hillcrest Avenue. A landscaped garden serves the proposed development to the west along Sackville Drive.

Above the underground parking levels, the ground floor of Tower 1 includes a central residential lobby with main entrances to the east and west, commercial spaces to the west along Sackville Drive, a community space at the northeast corner, and indoor parking spaces to the southeast. The ground floor of Tower 2 includes a central residential lobby with main entrances to the north and south, commercial spaces to the west and at the northeast corner, and indoor parking spaces at the southeast corner. Towers 1 and 2 are reserved for residential occupancy from Levels 2-13 and 2-14, respectively. Tower 1 steps back from the east elevation at Level 2 and from the south, west, and north elevations at Level 3, while Tower 2 steps back from the southeast elevation at Level 2 and from the west, north, and east elevations at Level 4.

Regarding wind exposures, the near-field surroundings (defined as an area falling within a 200-metre (m) radius of the subject site) include the Gate of Heaven Cemetery from the south-southeast clockwise to the north-northwest and a mix of low-rise residential and commercial buildings and green space in the remaining directions. The far-field surroundings (defined as the area beyond the near field and within a 2-kilometre (km) radius) are characterized by mostly low-rise massing from the north-northwest clockwise to the east-southeast, and large green spaces and forested areas in the remaining directions. Notably, First Lake is located approximately 1.2 km to the northeast of the proposed development and the Harvest Highway (Highway 101) runs northwest-southeast approximately 300 m to the southwest.

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

## 3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind conditions at key areas within and surrounding the subject 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 Halifax area wind climate, and synthesis of computational data with industry standard wind comfort and safety guidelines. While Policy SS-4 (a)(d) of the Secondary Planning Strategy for the Sackville Drive community plan area specifies the consideration of pedestrian wind comfort and safety, the Sackville Drive community plan area does not stipulate the wind criteria for the evaluation[1]. In accordance with good engineering practice, the criteria described in the Pedestrian Wind Impact Assessment Protocol and Performance Standards in the Halifax Regional Centre Land Use By-Law[2] were considered for this study. The noted criteria are consistent with industry standards. 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 subject 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 CFB Shearwater Airport in Halifax, Nova Scotia. 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 proposed 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 stronger wind speed values.

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[1] Halifax, *Secondary Planning Strategy, Sackville Drive, Policy SS-4(a)(d)*
https://cdn.halifax.ca/sites/default/files/documents/about-the-city/regional-community-planning/sackvilledrive-sps-eff-23sep01-case24526-toclinked_0.pdf

[2] Halifax, *Halifax Regional Centre Land Use By-Law*
https://cdn.halifax.ca/sites/default/files/documents/about-the-city/regional-community-planning/regionalcentrelub-eff-22sep15-caserp16-16_1.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 subject site for 16 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a radius of approximately 480 m. The process was performed for two context massing scenarios, as noted in Section 2.

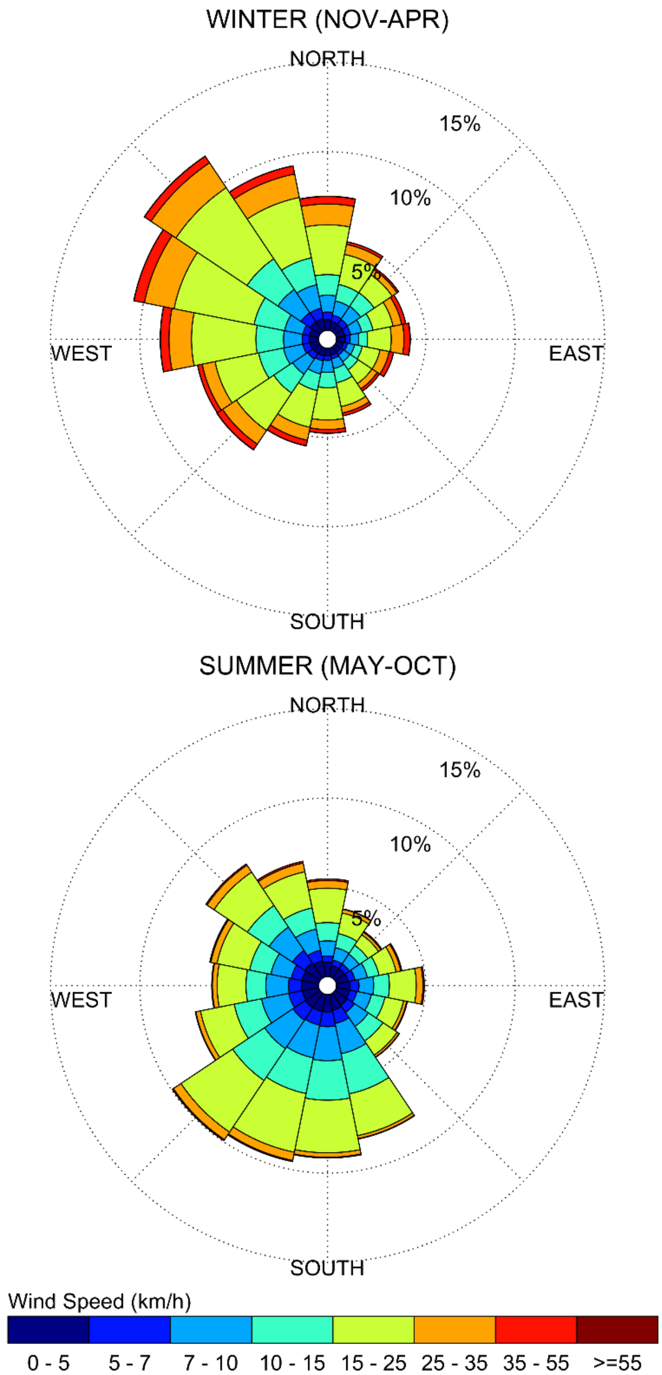
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade were referenced to the wind speed at gradient height to generate 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 Halifax was developed from 42 years (1982-2024) of hourly meteorological wind data recorded at CFB Shearwater Airport and obtained from Environment and Climate Change Canada. Wind speed and direction data were analyzed during the appropriate hours of pedestrian usage (that is, between 06:00 and 23:00) and divided into a summer season, defined as May to October, and a winter season, defined as November to April, inclusive.

The statistical model of the Halifax area wind climate, which indicates the directional character of local winds during the summer and winter seasons, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometres 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 Halifax, the most common winds concerning pedestrian wind comfort occur from the southwest clockwise to north, as well as those from the south. Southerly winds are common during the summer season, while westerly and northerly winds are common during the winter season. The directional preference and relative magnitude of wind speed varies somewhat between seasons, with the summer months displaying calmer winds relative to the winter season.

## SEASONAL DISTRIBUTION OF WIND
## CFB SHEARWATER AIRPORT, HALIFAX, NOVA SCOTIA




**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 – City of Halifax

Pedestrian wind comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (that is, temperature and relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Since both mean and gust wind speeds affect pedestrian comfort, their combined effect is defined in the Pedestrian Wind Impact Assessment Protocol and Performance Standards in the Halifax Regional Centre Land Use By-Law. Specifically, the criteria are defined as a Gust Equivalent Mean (GEM) wind speed, which is the greater of the mean wind speed or the gust wind speed divided by 1.85.

The wind speed ranges are based on the Beaufort scale, which describes the effects of forces produced by varying wind speed levels on objects. Five pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort: (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. Wind conditions suitable for sitting are represented by the colour blue, standing by green, strolling by yellow, and walking by orange; uncomfortable conditions are represented by the colour magenta. Specifically, the comfort classes, associated wind speed ranges, and limiting guidelines are summarized as follows:

**PEDESTRIAN WIND COMFORT CLASS DEFINITIONS**

| Wind Comfort Class | GEM Speed (km/h) | Description |
|---|---|---|
| SITTING | ≤ 10 | GEM wind speeds no greater than 10 km/h occurring at least 80% of the time would be considered acceptable for sedentary activities, including sitting. |
| STANDING | ≤ 14 | GEM wind speeds no greater than 14 km/h occurring at least 80% of the time are acceptable for activities such as standing or more vigorous activities. |
| STROLLING | ≤ 17 | GEM wind speeds no greater than 17 km/h occurring at least 80% of the time are acceptable for activities such as strolling or more vigorous activities. |
| WALKING | ≤ 20 | GEM wind speeds no greater than 20 km/h occurring at least 80% of the time are acceptable for walking or more vigorous activities. |
| UNCOMFORTABLE | > 20 | Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion. |

Regarding wind safety, gust wind speeds greater than 90 km/h, occurring more than 0.1% of the time on an annual basis (based on wind events recorded for 24 hours a day), are classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall.

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 GEM wind speeds 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 GEM wind speeds 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 subject site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for discrete regions within and surrounding the subject site. This step involves comparing the predicted comfort classes to the target comfort classes, which are dictated by the location type for each region (that is, a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their typical windiest target comfort classes are summarized below. Depending on the programming of a space, the desired comfort class may differ from this table.

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

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

# 5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-4B, which illustrate wind conditions at grade level for the proposed and existing massing scenarios. Conditions are presented as continuous contours of wind comfort within and surrounding the subject site and correspond to the various comfort classes noted in Section 4.4. The details of these conditions are summarized in the following sections for each area of interest.

## 5.1 Wind Comfort Conditions – Grade Level

**Sidewalks and Transit Stops along Sackville Drive:** Prior to the introduction of the proposed development, wind comfort conditions over the public sidewalks along Sackville Drive are predicted to be suitable for mostly standing during the summer, with small, isolated regions suitable for strolling, becoming suitable for a mix of standing and strolling during the winter, with isolated regions suitable for walking. The noted conditions remain practically unchanged following the introduction of the proposed development, and the wind conditions with the proposed development are nevertheless considered acceptable.

Following the introduction of the proposed development, wind comfort conditions in the vicinity of the nearby transit stops along Sackville Drive are predicted to be suitable for standing during the summer, becoming suitable for strolling during the winter. The noted conditions are considered acceptable.

Under the existing massing, conditions in the vicinity of the nearby northbound transit stop to the east of Sackville Drive are predicted to be suitable for standing during the summer, becoming suitable for strolling during the winter, while conditions in the vicinity of the nearby southbound transit stop to the west of Sackville Drive are predicted to be suitable for standing during the summer, becoming suitable for a mix of strolling and walking during the winter. Notably, the introduction of the proposed development is predicted to improve comfort levels over the nearby southbound transit stop along Sackville Drive in comparison to existing conditions and comfort levels over the northbound transit stop along Sackville Drive are predicted to be similar prior to and following the introduction of the proposed development. Nevertheless, the predicted wind conditions with the proposed development are considered acceptable.

**Gate of Heaven Cemetery**: Prior to the introduction of the proposed development, wind comfort conditions over the nearby areas of the Gate of Heaven Cemetery situated to the west across Sackville Drive are predicted to be suitable for strolling, or better, during the summer, becoming suitable for walking, or better, during the winter. The noted conditions remain mostly unchanged following the introduction of the proposed development, with conditions to the northwest of the subject site predicted to improve during the winter season. The wind conditions with the proposed development are considered acceptable.

**Neighbouring Existing Surface Parking Lot North of Subject Site:** Prior to the introduction of the proposed development, wind comfort conditions over the neighbouring existing surface parking lot to the north of the subject site are predicted to be suitable for mostly standing during the summer, becoming suitable for mostly strolling during the winter. The noted conditions remain unchanged following the introduction of the proposed development, and the wind conditions with the proposed development are considered acceptable.

**Sidewalks along Hillcrest Avenue:** Prior the introduction of the proposed development, wind comfort conditions over the public sidewalks along Hillcrest Avenue are predicted to be suitable for standing, or better, during the summer, becoming suitable for a mix of standing and strolling during the winter. The noted conditions remain unchanged following the introduction of the proposed development, and the wind conditions with the proposed development are considered acceptable.

**Landscaped Garden**: During the summer, wind comfort conditions over the landscaped garden to the west of the subject site are predicted to be suitable for mostly sitting, with an isolated region suitable for standing central to the garden. Where conditions are suitable for standing, they are also suitable for sitting for at least 75% of the time during the same period, where the target is 80% to achieve the sitting comfort class.

Depending on the programming of the landscaped garden, the noted conditions may be considered acceptable. Specifically, if the noted windier area that is predicted to be suitable for standing will not accommodate seating or more sedentary activities, the noted conditions may be considered acceptable.

**Proposed Access Route, Surface Parking, and Walkways**: Wind conditions over the access routes, surface parking, and walkways within the subject site are predicted to be suitable for standing, or better, during the summer, becoming suitable for strolling, or better, during the winter. The noted conditions are considered acceptable.

**Building Access Points**: Owing to the protection of the building façade, wind conditions in the vicinity of all building access points serving the proposed development are predicted to be suitable for sitting throughout the year, which is considered acceptable.

## 5.2 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.

## 5.3 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 (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 of this report and illustrated in Figures 3A-5B. Since the Sackville Drive community plan area does not specify wind criteria, the criteria in Regional Centre Land-use Bylaw were applied. Based on computer simulations using the CFD technique, meteorological data analysis of the Halifax wind climate, Halifax Regional Centre wind comfort and safety criteria, and experience with numerous similar developments, the study concludes the following:

1) Most 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, transit stops, Gate of Heaven Cemetery, neighbouring existing surface parking lots, proposed access routes, driveways, surface parking, and walkways, and in the vicinity of building access points are considered acceptable.

2) Wind comfort conditions over the landscaped garden to the west of the subject site are predicted to be suitable for mostly sitting, with an isolated region suitable for standing central to the garden during the summer season.

    a. Depending on the programming of the landscaped garden, the noted conditions may be considered acceptable. Specifically, if the noted windier area that is predicted to be suitable for standing will not accommodate seating or more sedentary activities, the noted conditions may be considered 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. 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.***

[redacted]

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

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DATE Dec. 12, 2024
[redacted]
12645
PROVINCE OF NOVA SCOTIA

Justin Ferraro, MBA, P.Eng.
Principal

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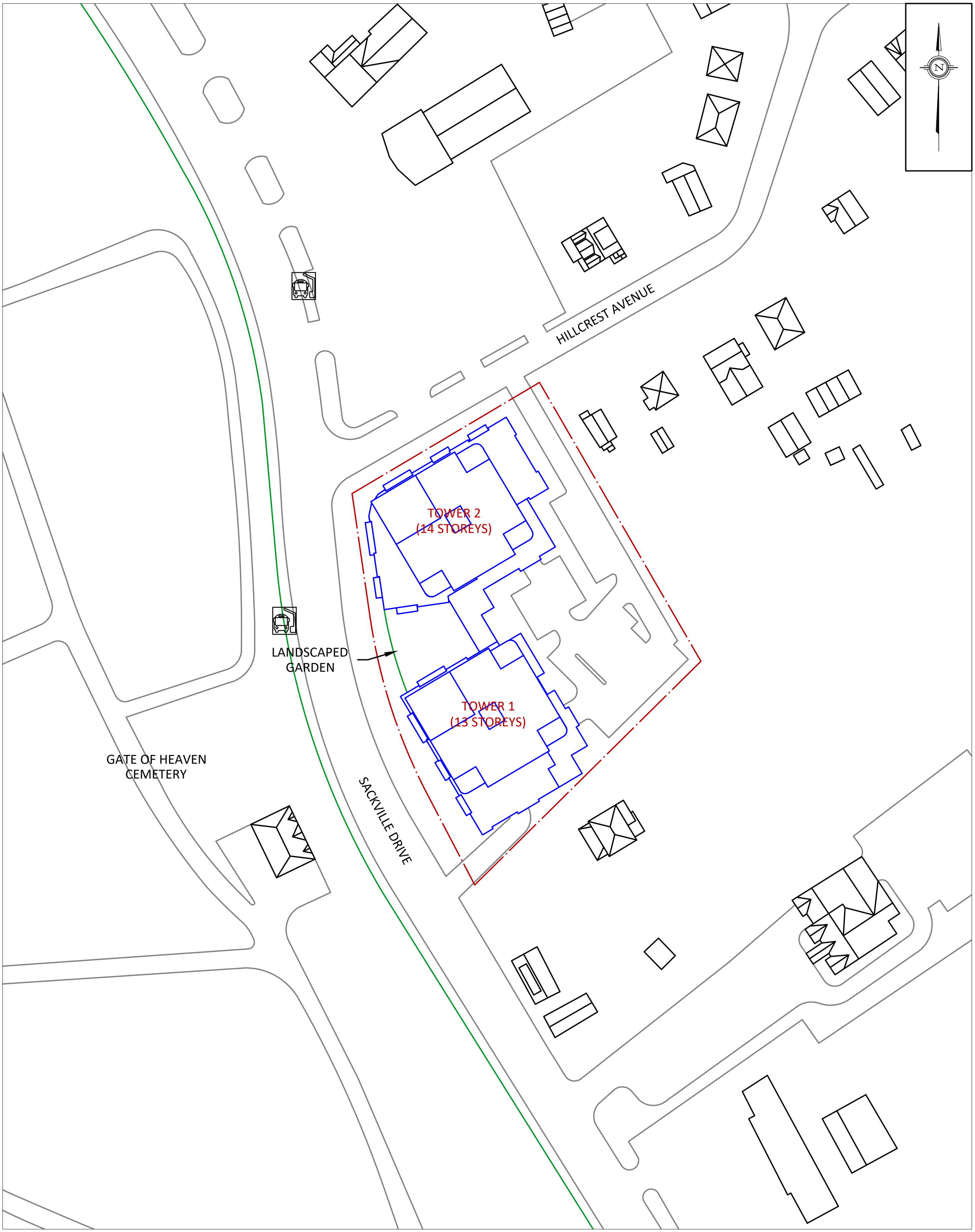
Junior Wind Scientist

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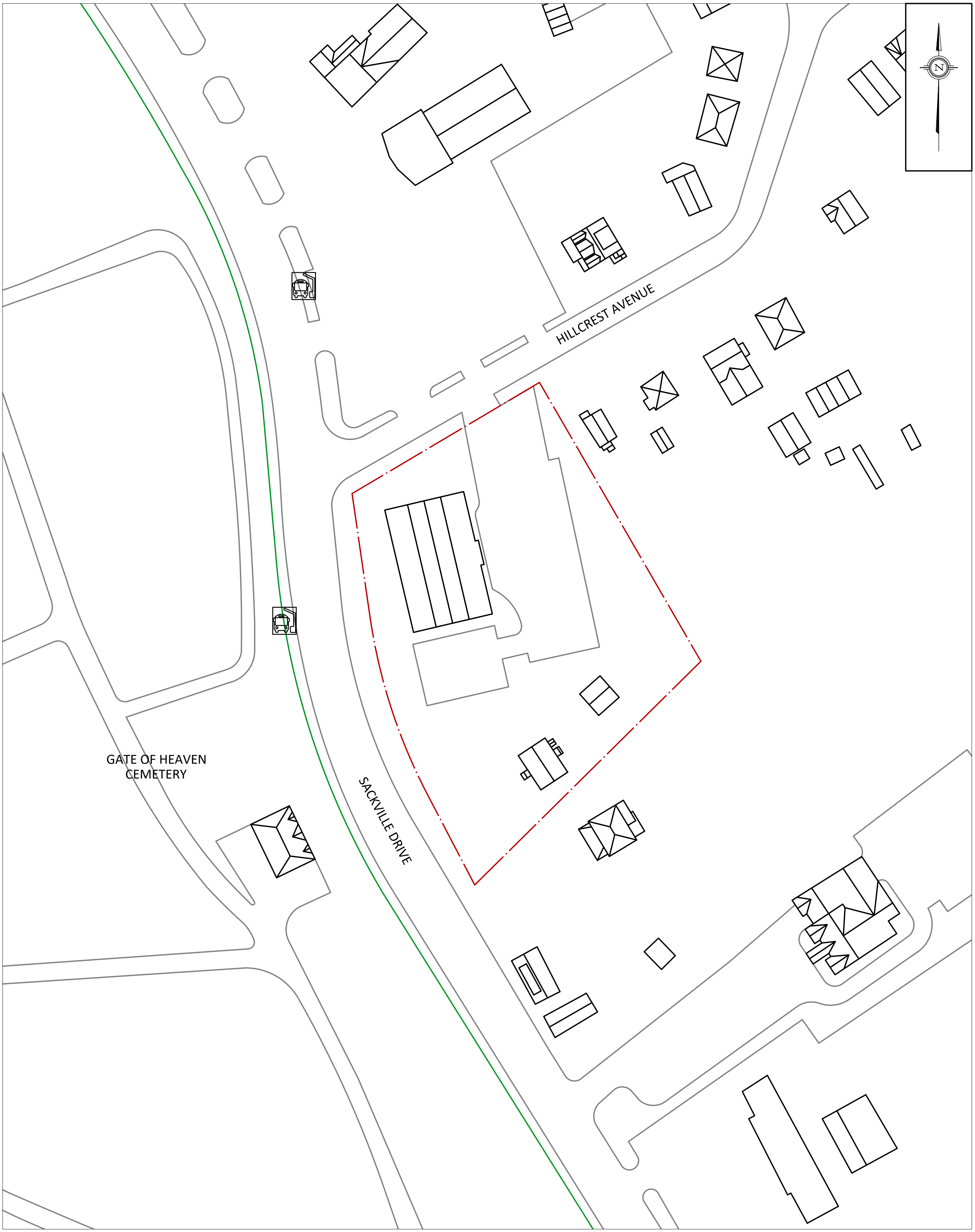
| | | |
|---|---|---|
| PROJECT: 143-153 SACKVILLE DRIVE, HALIFAX<br>PEDESTRIAN LEVEL WIND STUDY | | DESCRIPTION: FIGURE 1A:<br>PROPOSED SITE PLAN AND SURROUNDING CONTEXT |
| SCALE: 1:1500 | DRAWING NO.: 24-083-PLW-1A | |
| DATE: MAY 22, 2024 | DRAWN BY: S.K. | |

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| | | | |
|---|---|---|---|
| PROJECT: 143-153 SACKVILLE DRIVE, HALIFAX PEDESTRIAN LEVEL WIND STUDY | | | DESCRIPTION: FIGURE 1B: EXISTING SITE PLAN AND SURROUNDING CONTEXT |
| SCALE: 1:1500 | DRAWING NO.: 24-083-PLW-1B | | |
| DATE: MAY 22, 2024 | DRAWN BY: S.K. | | |

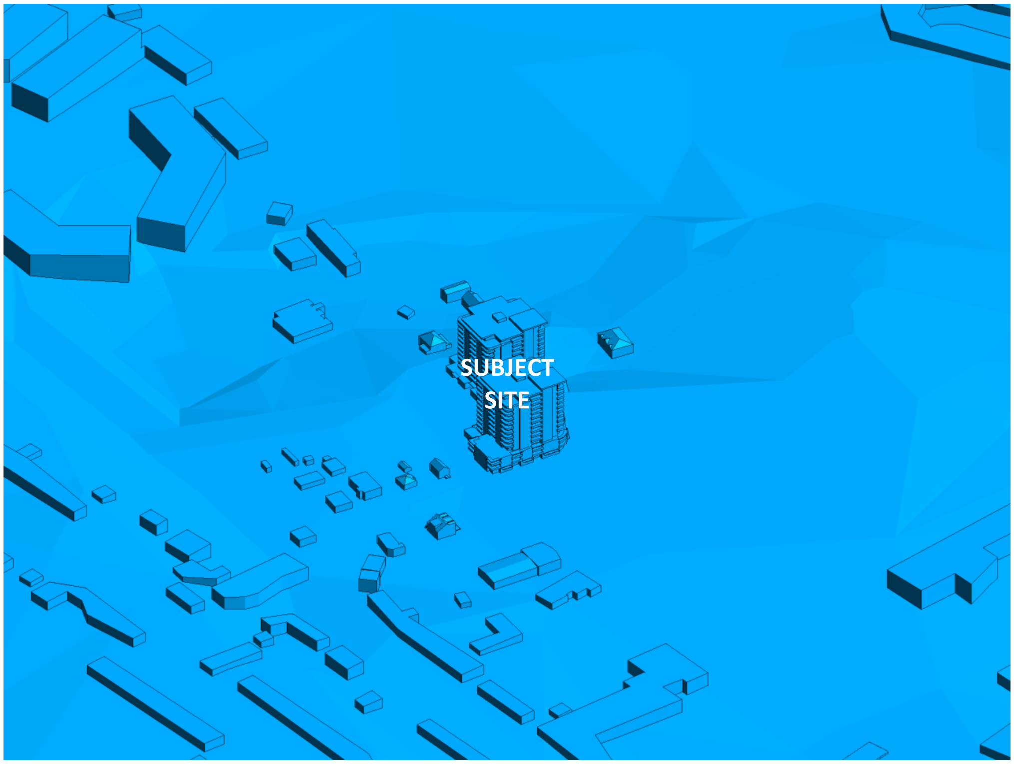



**FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTH PERSPECTIVE**


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

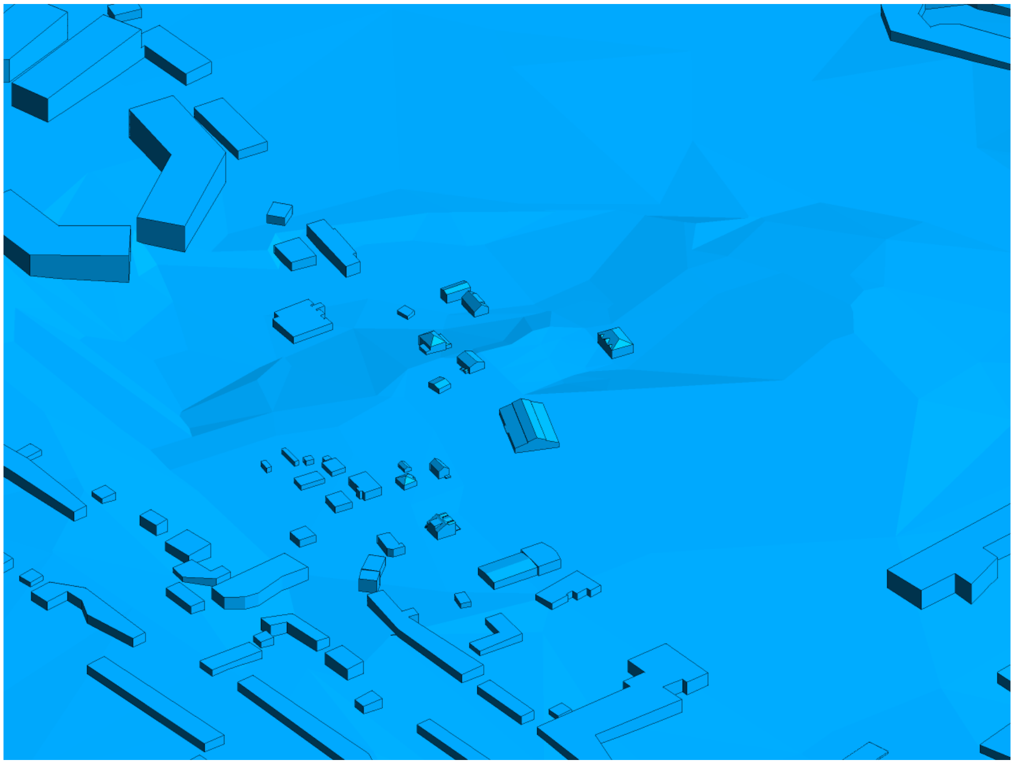


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, NORTH PERSPECTIVE

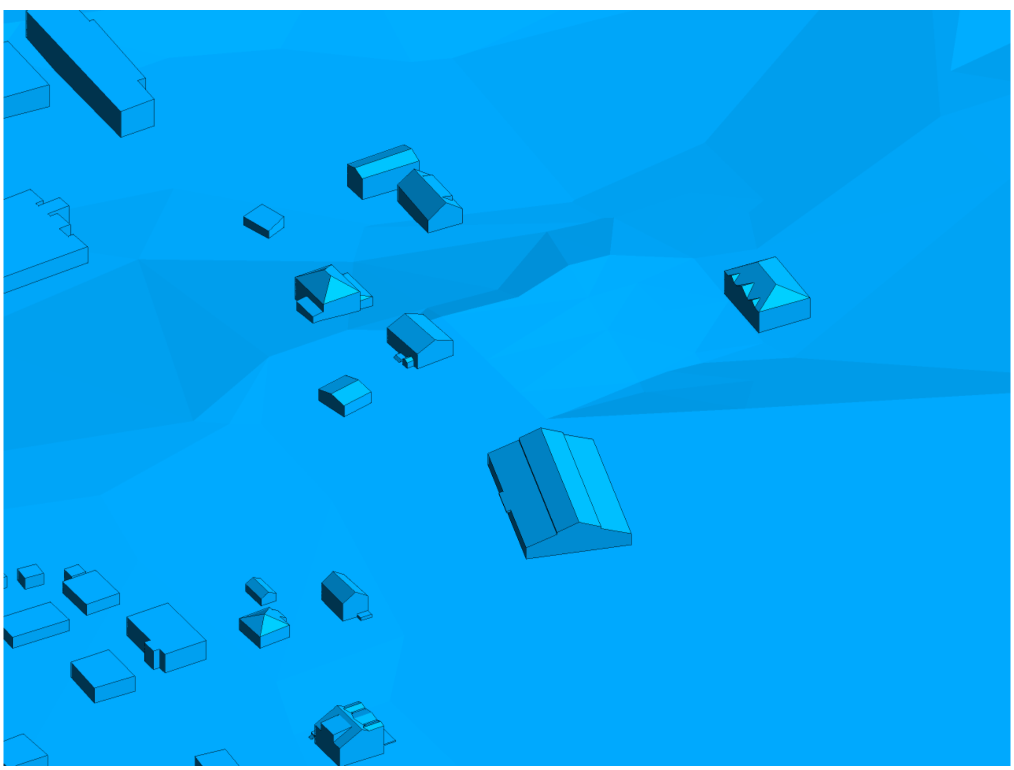


FIGURE 2D: CLOSE-UP VIEW OF FIGURE 2C


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

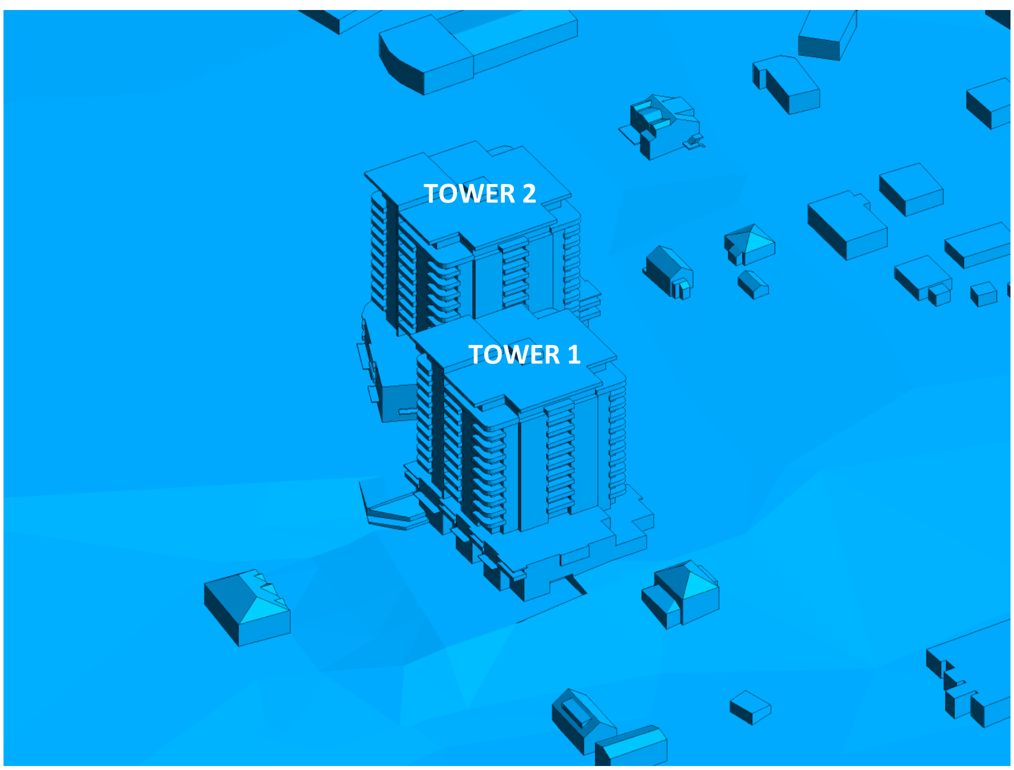



FIGURE 2F: CLOSE-UP VIEW OF FIGURE 2E

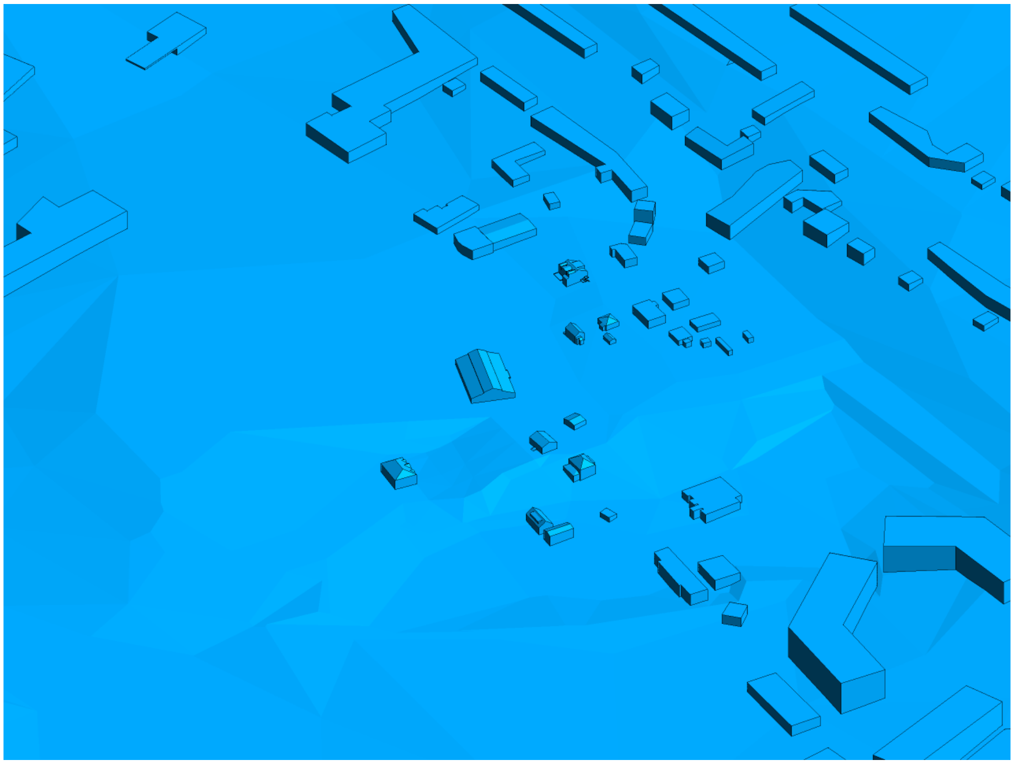


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, SOUTH PERSPECTIVE

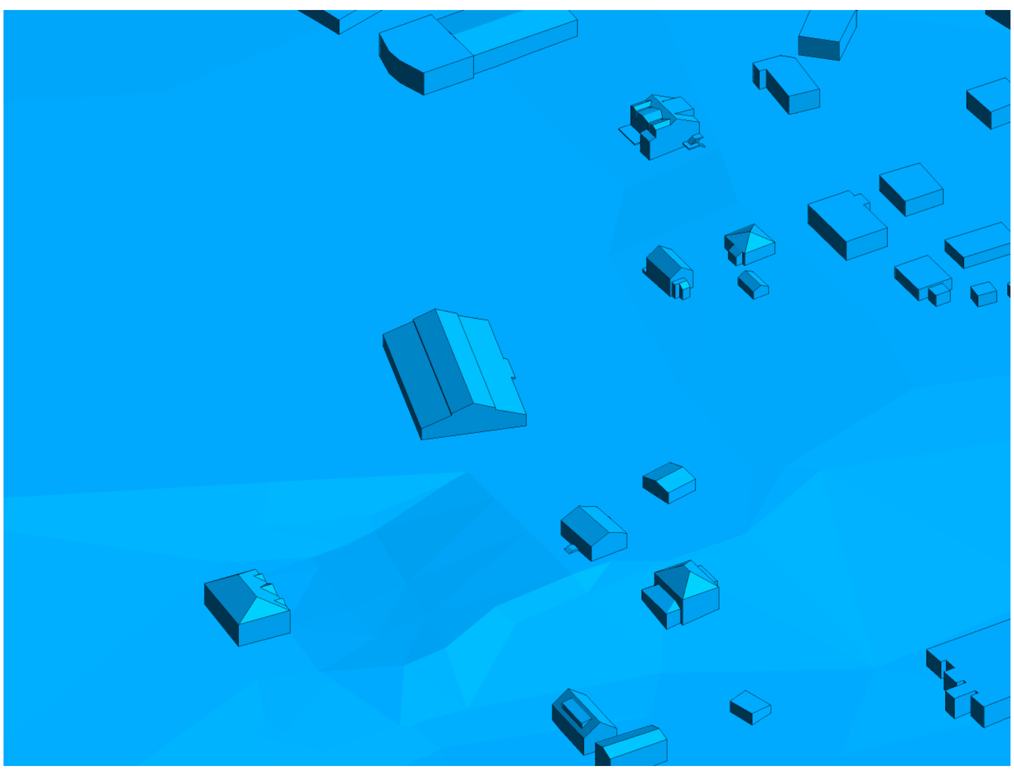


FIGURE 2H: CLOSE-UP VIEW OF FIGURE 2G

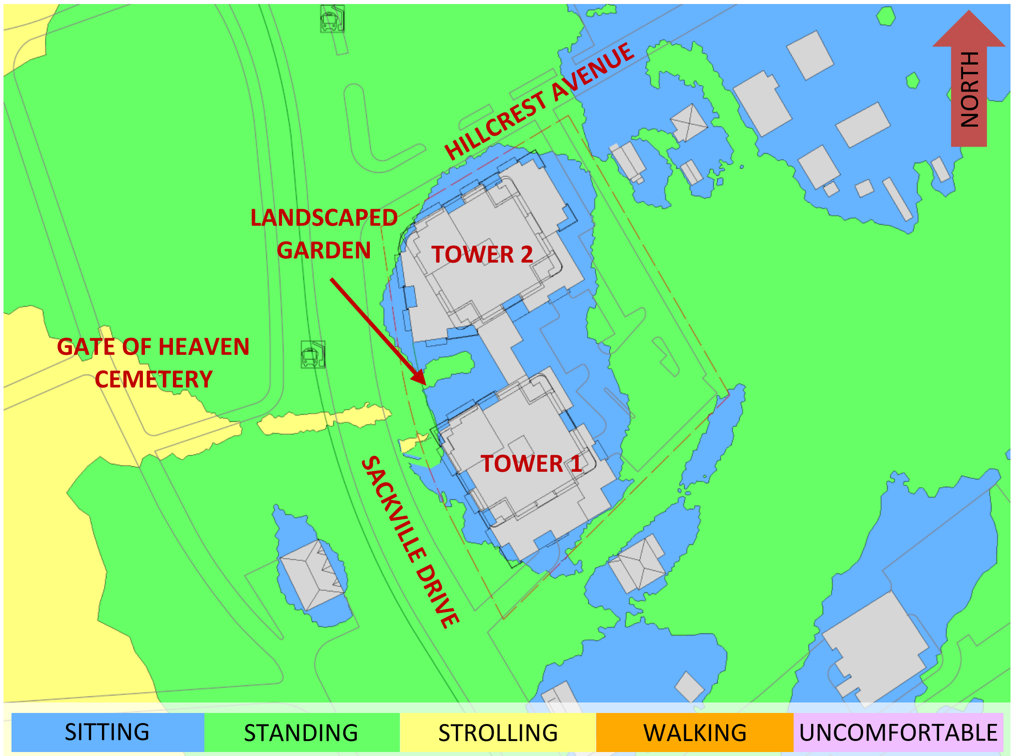



**FIGURE 3A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING**

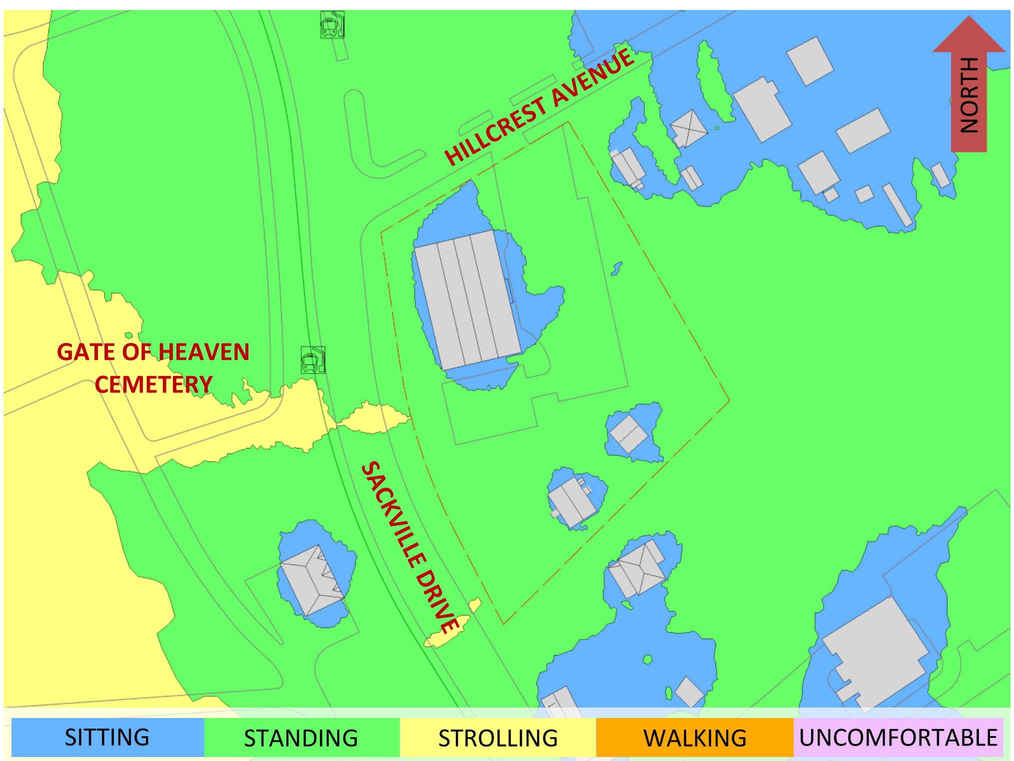



**FIGURE 3B: SUMMER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING**

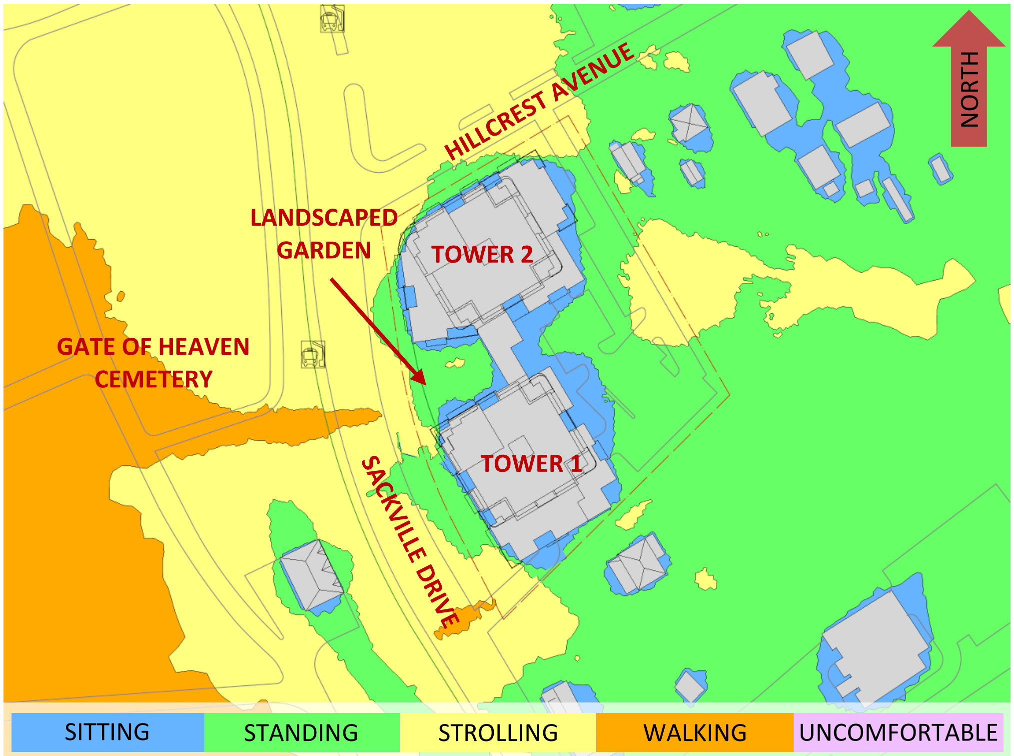



**FIGURE 4A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING**

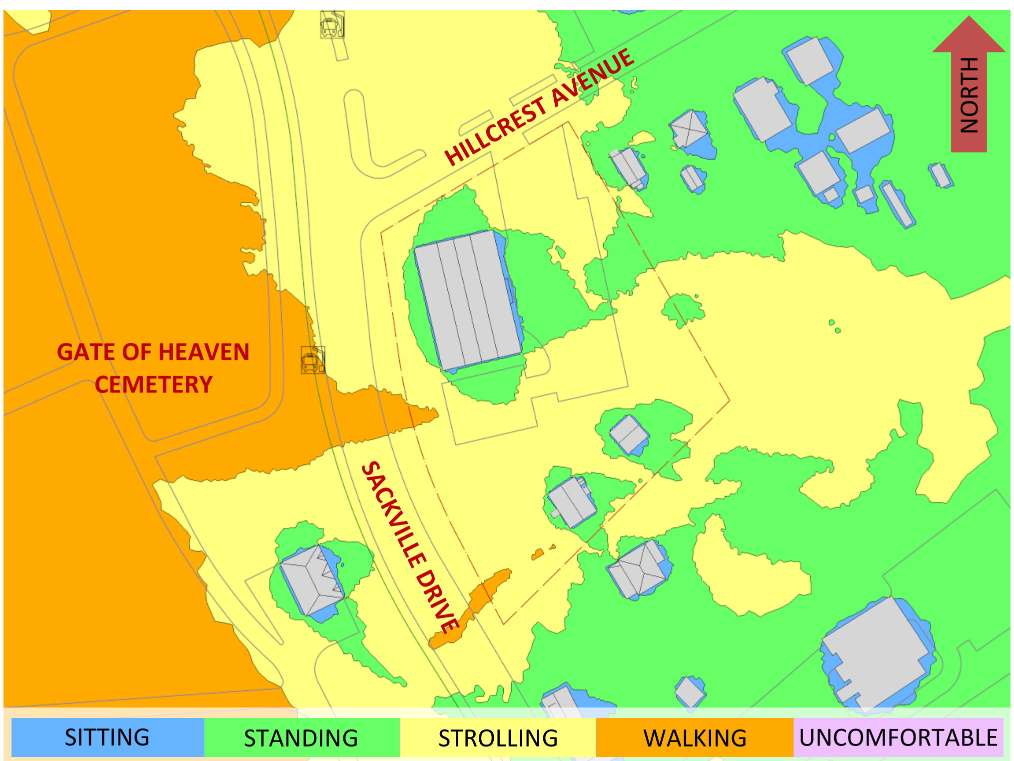
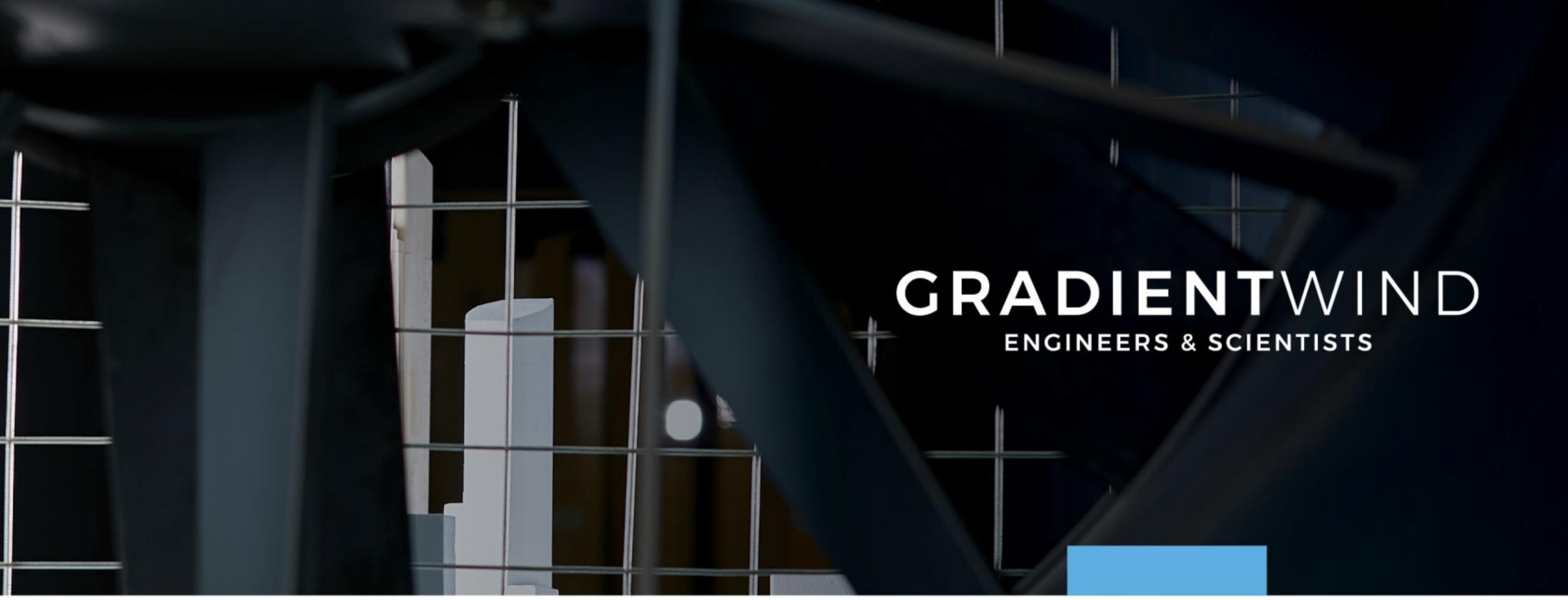



**FIGURE 4B: WINTER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING**




**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 $\alpha$ 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 40% mean wind speed for Halifax based on historical climate data and statistical analyses. When the results are normalized by this velocity, they are relatively insensitive to the selection of gradient wind speed.

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

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

Table 1 presents the values of 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 |
| 22.5 | 0.22 |
| 45 | 0.22 |
| 67.5 | 0.22 |
| 90 | 0.22 |
| 112.5 | 0.20 |
| 135 | 0.20 |
| 157.5 | 0.20 |
| 180 | 0.19 |
| 202.5 | 0.19 |
| 225 | 0.19 |
| 247.5 | 0.19 |
| 270 | 0.19 |
| 292.5 | 0.22 |
| 315 | 0.24 |
| 337.5 | 0.24 |

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

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

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

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

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, $\boldsymbol{I}$ = turbulence intensity, $\boldsymbol{L_t}$ = turbulence length scale, $\boldsymbol{Z}$ = 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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