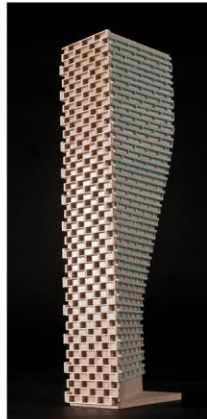


PEDESTRIAN LEVEL WIND STUDY

145 Loretta Avenue North
951 Gladstone Avenue
Ottawa, Ontario

Report: 18-075-PLW-2024



December 4, 2024

PREPARED FOR

TIP Gladstone by its General Partner TIP Gladstone GP Inc.
c/o CLV Group Developments Inc.
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PREPARED BY

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy Site Plan Control application submission requirements for the proposed development located at 145 Loretta Avenue North and 951 Gladstone Avenue in Ottawa, Ontario (hereinafter referred to as “subject site” or “proposed development”). Our mandate within this study is to investigate pedestrian wind conditions within and surrounding the subject site, and to identify areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

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

- 1) All grade-level areas within and surrounding the subject site are predicted to experience conditions that are considered acceptable for their intended pedestrian uses throughout the year. Specifically, conditions over the nearby public sidewalks, the Corso Italia O-Train station platform to the southeast of the site, the multi-use pathways to the northeast, nearby existing surface parking lots, loading areas, and in the vicinity of the building access points are considered acceptable.
- 2) Wind conditions during the typical use period (May to October, inclusive) within most of the exterior amenity terraces located at Level 5 are predicted to be suitable for sitting, with conditions suitable for standing along the north perimeter of the podium. Notably, a 1.8-m-tall wind screen was modelled along the full perimeter of the podium roof, which is recommended to provide shielding from direct winds.
 - a. In combination with the perimeter screens, inboard mitigation is recommended in the form of wind screens and clusters of coniferous plantings located adjacent to seating areas along the north perimeter.



- 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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Appendix A – Simulation of the Atmospheric Boundary Layer



1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by TIP Gladstone by its general partner TIP Gladstone GP Inc. c/o CLV Group Developments Inc, to undertake a pedestrian level wind (PLW) study to satisfy Site Plan Control application submission requirements for the proposed development located at 145 Loretta Avenue North and 951 Gladstone Avenue in Ottawa, Ontario (hereinafter referred to as “subject site” or “proposed development”). A PLW study and subsequent addenda for the Zoning By-Law Amendment (ZBLA) application submissions for the buildout of the subject site, comprising the three towers, were completed between 2018 and 2021^{1,2,3}. Our mandate within the current study is to investigate pedestrian wind conditions within and surrounding Tower A (Phase 1), and to identify areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings prepared by Linebox Studio in November 2024, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery.

2. TERMS OF REFERENCE

The subject site is located at 145 Loretta Avenue North and 951 Gladstone Avenue situated on the northern portion of a triangular parcel of land bounded by Loretta Avenue North to the west, the O-Train Line 2 to the northeast, and Gladstone Avenue to the south.

The proposed development comprises a 30-storey residential building topped with a mechanical penthouse (MPH). Above the below-grade parking, the ground floor of the proposed development comprises vestibules to the west and south providing access to amenity spaces that occupy the eastern

¹ Gradient Wind Engineering Inc., ‘Pedestrian Level Wind Study, 145 Loretta Avenue & 951 Gladstone Avenue,’ [Oct 18, 2018]

² Gradient Wind Engineering Inc., ‘Addendum to Pedestrian Level Wind Study, 145 Loretta Avenue & 951 Gladstone Avenue,’ [Aug 1, 2019]

³ Gradient Wind Engineering Inc., ‘Addendum to Pedestrian Level Wind Study, 145 Loretta Avenue & 951 Gladstone Avenue,’ [Apr 19, 2021]



and southern portions of the ground level. A loading area and a parking ramp are situated to the northwest, which provides vehicular access from Loretta Avenue North to the underground parking levels. The remainder of the level is reserved for shared building services. The building steps back from all elevations at Level 5, accommodating outdoor amenity areas atop the podium around the perimeter of the level, partially covered by a canopy extending from Level 6. Levels 6 to 30 are reserved for residential use, with an indoor amenity located to the east at Level 30.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) are characterized by mostly low-rise buildings in all directions. The O-Train Line 2 corridor runs northeast of the site, with the Corso Italia station to the southeast, over Gladstone Avenue. Notably, the Gladstone Village development comprising seven buildings ranging from 8 to 30 storeys is approved at 933 Gladstone, approximately 50 m to the northeast of the subject site.

The far-field surroundings (defined as an area beyond the near-field but within a 2-kilometre (km) radius of the subject site) are characterized by a mix of mostly low-rise massing, with isolated clusters of mid- and high-rise massing from the west-southwest clockwise to the west-northwest and to the southeast, and the edge of the Ottawa downtown core approximately 1.2 km to the northeast. LeBreton Flats is located to the north, followed by the Ottawa River, approximately 950 m from the subject site. Approximately 1 km from the subject site are Dow's Lake and the Central Experimental Farm, to the southeast and to the south, respectively.

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

3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind conditions at key areas within and surrounding the development site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.



4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on CFD simulations of wind speeds across the subject site within a virtual environment, meteorological analysis of the Ottawa area wind climate, and synthesis of computational data with City of Ottawa wind comfort and safety criteria⁴. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

4.1 Computer-Based Context Modelling

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

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly stronger wind speeds.

4.2 Wind Speed Measurements

The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 16 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a radius of 480 m. The process was performed for two context massing scenarios, as noted in Section 2.

⁴ City of Ottawa Terms of References: Wind Analysis
https://documents.ottawa.ca/sites/documents/files/wind_analysis_tor_en.pdf

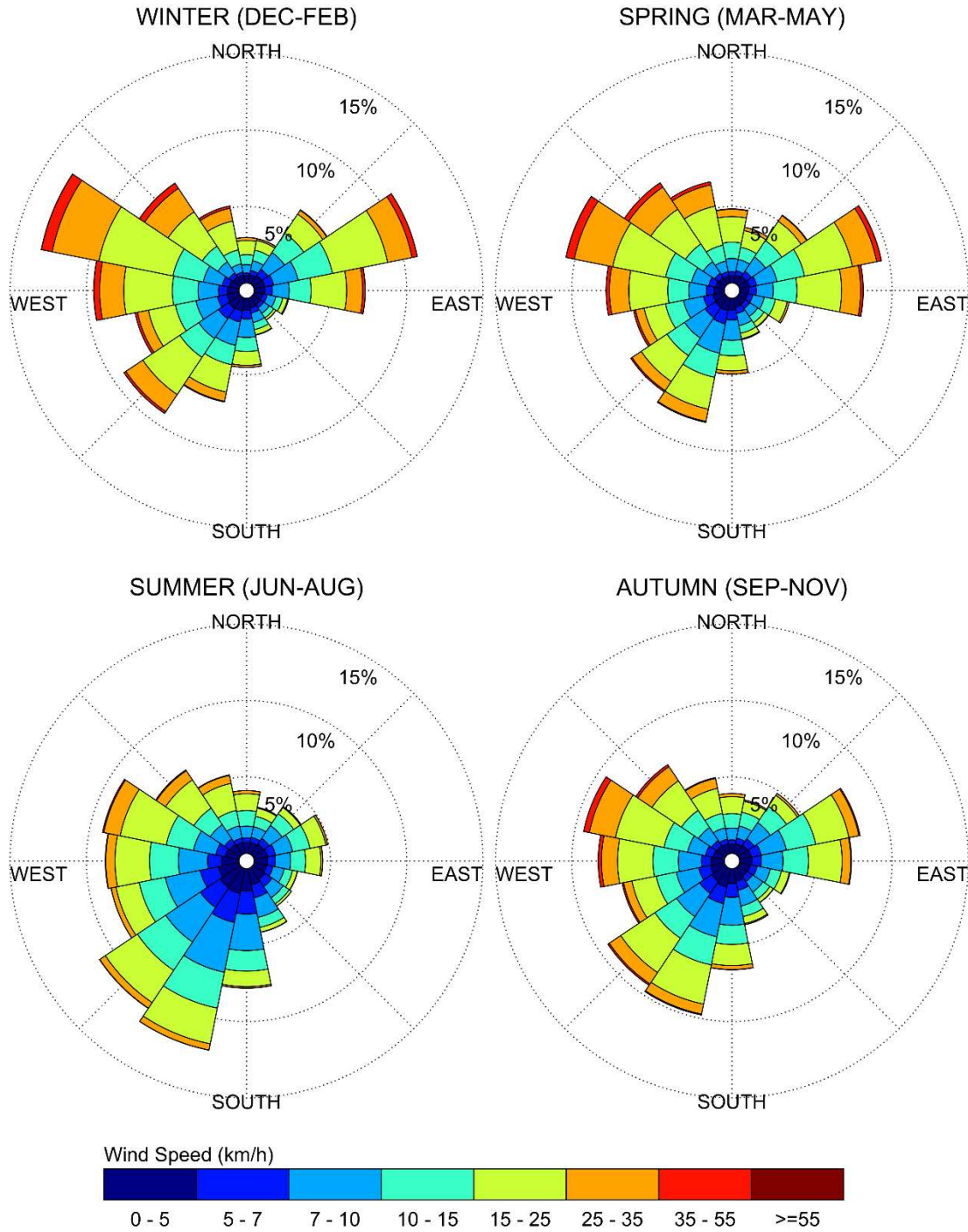
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the common amenity terrace serving the proposed development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

4.3 Historical Wind Speed and Direction Data

A statistical model for winds in Ottawa was developed from approximately 40 years of hourly meteorological wind data recorded at Ottawa Macdonald-Cartier International Airport and obtained from Environment and Climate Change Canada. Wind speed and direction data were analyzed during the appropriate hours of pedestrian usage (that is, between 06:00 and 23:00) and divided into four distinct seasons, as stipulated in the wind criteria. Specifically, the spring season is defined as March through May, the summer season is defined as June through August, the autumn season is defined as September through November, and the winter season is defined as December through February, inclusive.

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

SEASONAL DISTRIBUTION OF WIND OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT



Notes:

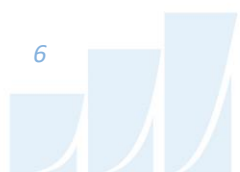
1. Radial distances indicate percentage of time of wind events.
2. Wind speeds are mean hourly in km/h, measured at 10 m above the ground.

4.4 Pedestrian Wind Comfort and Safety Criteria – City of Ottawa

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

PEDESTRIAN WIND COMFORT CLASS DEFINITIONS

Wind Comfort Class	Mean Speed (km/h)	Description
SITTING	≤ 10	Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 16 km/h.
STANDING	≤ 14	Mean wind speeds no greater than 14 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 22 km/h.
STROLLING	≤ 17	Mean wind speeds no greater than 17 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 27 km/h.
WALKING	≤ 20	Mean wind speeds no greater than 20 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 32 km/h.
UNCOMFORTABLE	> 20	Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.



Regarding wind safety, the pedestrian safety wind speed criterion is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of 90 km/h is classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall. Notably, pedestrians tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also create problems for pedestrians.

Experience and research on people's perception of mechanical wind effects has shown that if the wind speed levels are exceeded for more than 20% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if a mean wind speed of 10 km/h (equivalent gust wind speed of approximately 16 km/h) were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting. Similarly, if mean wind speed of 20 km/h (equivalent gust wind speed of approximately 32 km/h) at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

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

TARGET PEDESTRIAN WIND COMFORT CLASSES FOR VARIOUS LOCATION TYPES

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

5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-6B, which illustrate wind conditions at grade level for the proposed and existing massing scenarios, and by Figures 7A-7D, which illustrate conditions within the common amenity terraces serving the proposed development at Level 5. Conditions are presented as continuous contours of wind comfort throughout the subject site and correspond to the comfort classes presented in Section 4.4.

Wind comfort conditions are also reported for the typical use period, which is defined as May to October, inclusive. Figure 8 illustrate wind comfort conditions during this period over the noted common amenity terraces, consistent with the comfort classes illustrated in Section 4.4.

The details of these conditions are summarized in the following page for the areas of interest.

5.1 Wind Comfort Conditions – Grade Level

Sidewalks along Loretta Avenue North: Wind comfort conditions over the nearby public sidewalks along Loretta Avenue North under the existing massing are predicted to be suitable for sitting throughout the year. Following the introduction of the proposed development, conditions along the noted sidewalks are predicted to be suitable for a mix of mostly sitting and standing throughout the year, with isolated areas suitable for strolling and walking to the west and southwest of the proposed development during the colder seasons. While the introduction of the proposed development produces windier conditions over the nearby sidewalks along Loretta Avenue North in comparison to existing conditions, wind comfort conditions with the proposed development are nevertheless considered acceptable for public sidewalks.

Multi-Use Pathways: Wind conditions over the multi-use pathways along the O-Train corridor to the northeast of the subject site under the existing massing are predicted to be suitable for standing, or better, throughout the year. Following the introduction of the proposed development, conditions over the noted pathways are predicted to be suitable for mostly standing, or better, throughout the year, with strolling conditions during the colder months along the northeast perimeter of the subject site. While the introduction of the proposed development produces slightly windier conditions, wind comfort conditions with the proposed development are nevertheless considered acceptable for the multi-use pathways.

O-Train Station Platform to the Southeast: Under both massing scenarios, conditions in the vicinity of the nearby O-Train Station (Corso Italia Station) platform to the southeast of the subject site are predicted to be suitable for standing, or better, throughout the year. The noted conditions are considered acceptable.

Neighboring Parking Lot to the Northwest: Under both massing scenarios, wind comfort conditions over the neighbouring parking lot to the northwest of the subject site are predicted to be suitable for standing, or better, throughout the year. The noted conditions are considered acceptable.

Building Access Points: Owing to the protection of the building façade, wind conditions in the vicinity of the building access points serving the proposed development are predicted to be suitable for mostly standing, or better, throughout the year. The noted conditions are considered acceptable.



5.2 Wind Comfort Conditions – Common Amenity Terraces

Notably, the proposed common amenity terraces serving the proposed development at Level 5 were modelled with 1.8-m-tall wind screens along the full perimeter of the podium roof. As illustrated in Figure 8, wind conditions during the typical use period are predicted to be suitable for sitting over the southwestern terrace, mostly suitable for sitting over the southeastern terrace, and suitable for sitting to the north with standing conditions along the north perimeter. Where conditions are suitable for standing, they are also suitable for sitting at least 70% of the time during the same period, where the target is 80% to achieve the sitting comfort class.

In combination with the perimeter screens, inboard mitigation for the windier areas is recommended in the form of wind screens and clusters of coniferous plantings located adjacent to designated seating areas along the north perimeter of the terrace.

5.3 Wind Safety

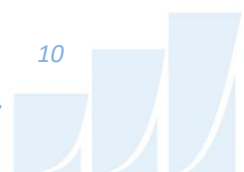
Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas within or surrounding the subject site are expected to experience conditions that could be considered dangerous, as defined in Section 4.4.

5.4 Applicability of Results

Pedestrian wind comfort and safety have been quantified for the specific configuration of existing and foreseeable construction around the subject site. Future changes (that is, construction or demolition) of these surroundings may cause changes to the wind effects in two ways, namely: (i) changes beyond the immediate vicinity of the subject site would alter the wind profile approaching the subject site; and (ii) development in proximity to the subject site would cause changes to local flow patterns.

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-8. Based on computer simulations using the CFD technique, meteorological data analysis of the Ottawa wind climate, City of Ottawa wind comfort and safety criteria, and experience with numerous similar developments, the study concludes the following:



- 1) All grade-level areas within and surrounding the subject site are predicted to experience conditions that are considered acceptable for their intended pedestrian uses throughout the year. Specifically, conditions over the nearby public sidewalks, the Corso Italia O-Train station platform to the southeast of the site, the multi-use pathways to the northeast, nearby existing surface parking lots, loading areas, and in the vicinity of the building access points are considered acceptable.
- 2) Wind conditions during the typical use period (May to October, inclusive) within most of the exterior amenity terraces located at Level 5 are predicted to be suitable for sitting, with conditions suitable for standing along the north perimeter of the podium. Notably, a 1.8-m-tall wind screen was modelled along the full perimeter of the podium roof, which is recommended to provide shielding from direct winds.
 - a. In combination with the perimeter screens, inboard mitigation is recommended in the form of wind screens and clusters of coniferous plantings located adjacent to seating areas along the north perimeter.
- 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.

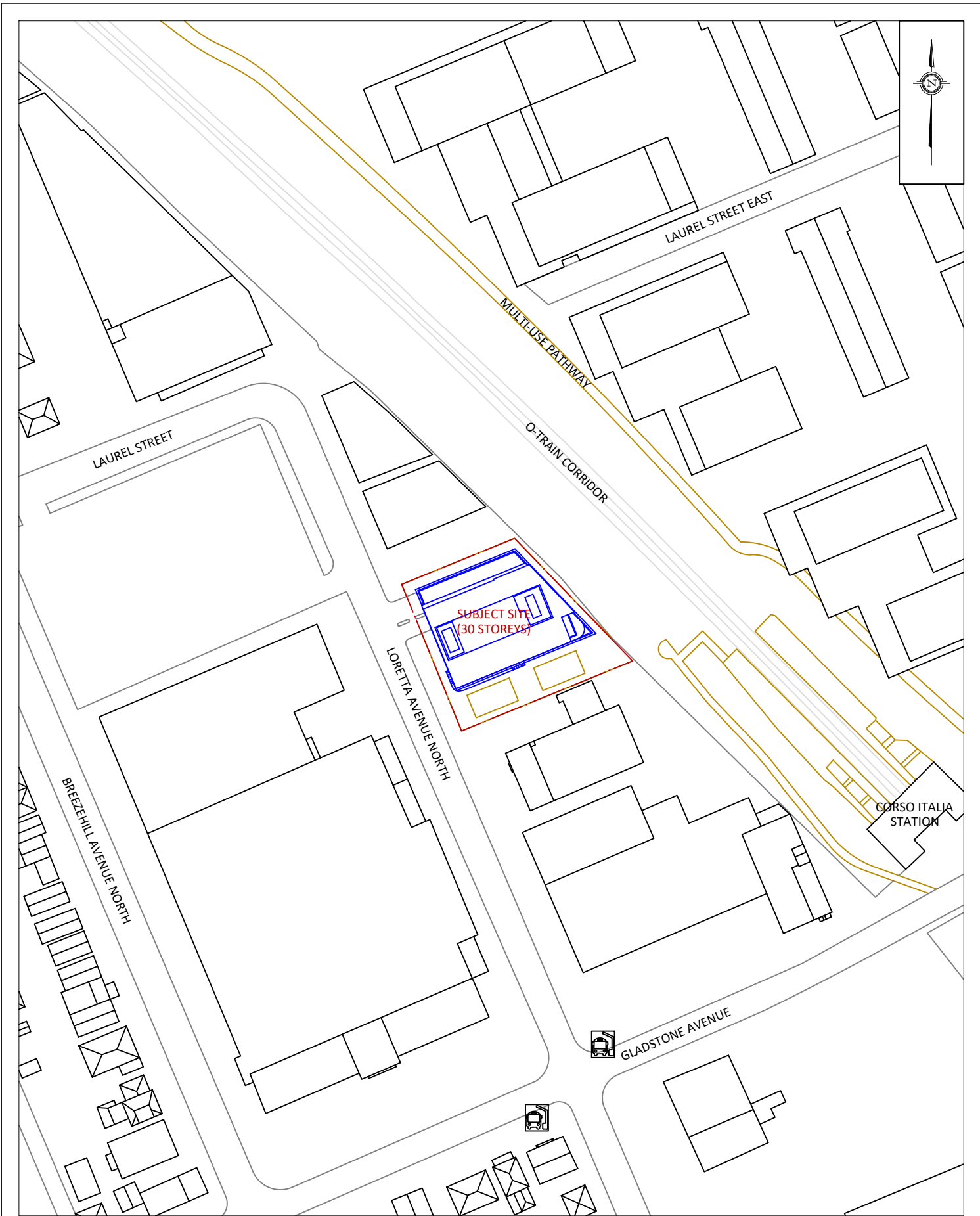


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GRADIENTWIND

ENGINEERS & SCIENTISTS

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PROJECT: 145 LORETTA AVE N AND 951 GLADSTONE AVE - PHASE 1, OTTAWA
PEDESTRIAN LEVEL WIND STUDY

SCALE: 1:1500

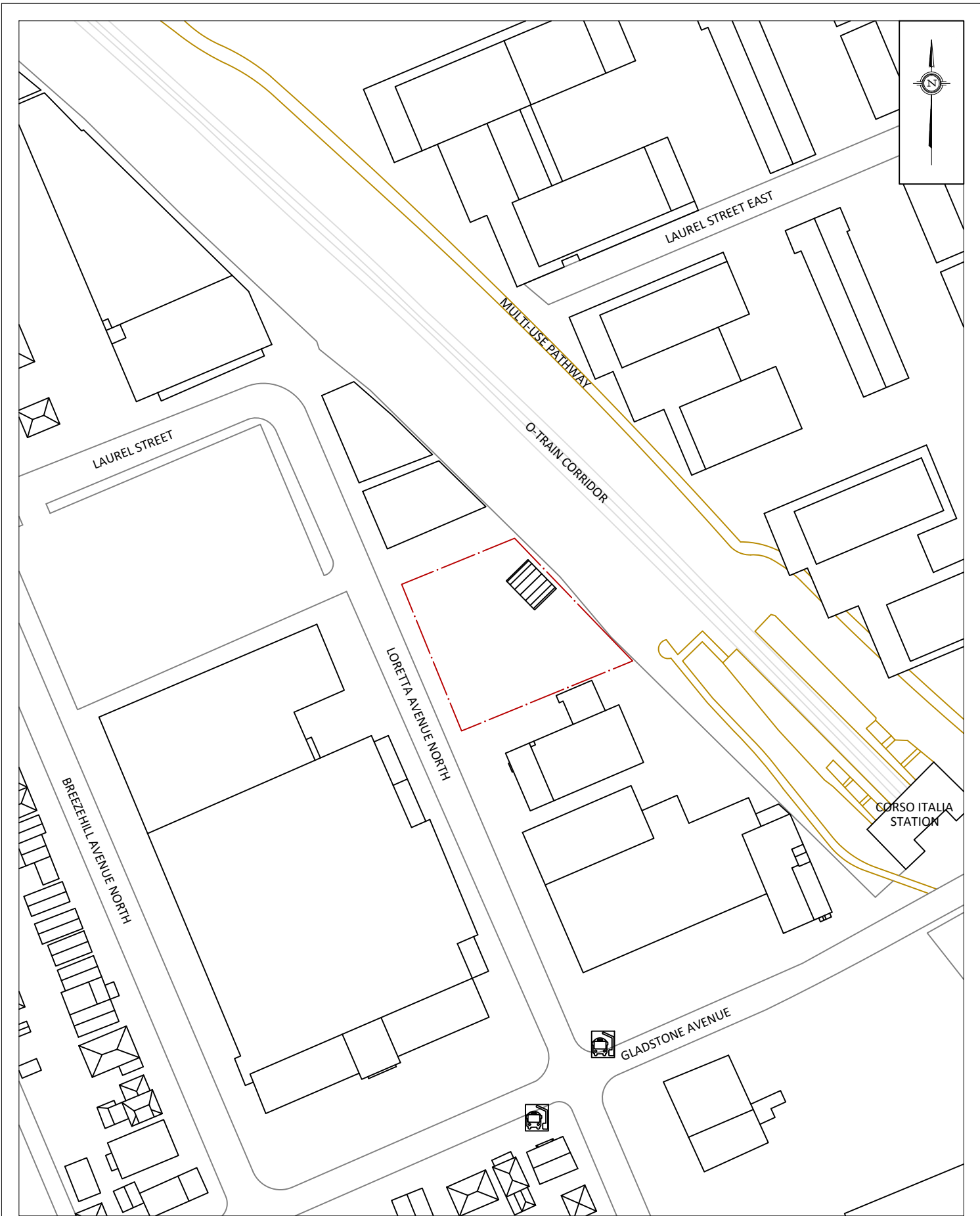
DATE: DECEMBER 4, 2024

DRAWING NO.: 18-075-PLW-2024-1A

DRAWN BY: S.K.

DESCRIPTION

FIGURE 1A:
PROPOSED SITE PLAN AND SURROUNDING CONTEXT



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PEDESTRIAN LEVEL WIND STUDY

SCALE: 1:1500

DATE: DECEMBER 4, 2024

DRAWING NO.: 18-075-PLW-2024-1B

DRAWN BY: S.K.

DESCRIPTION

FIGURE 1B:
EXISTING SITE PLAN AND SURROUNDING CONTEXT

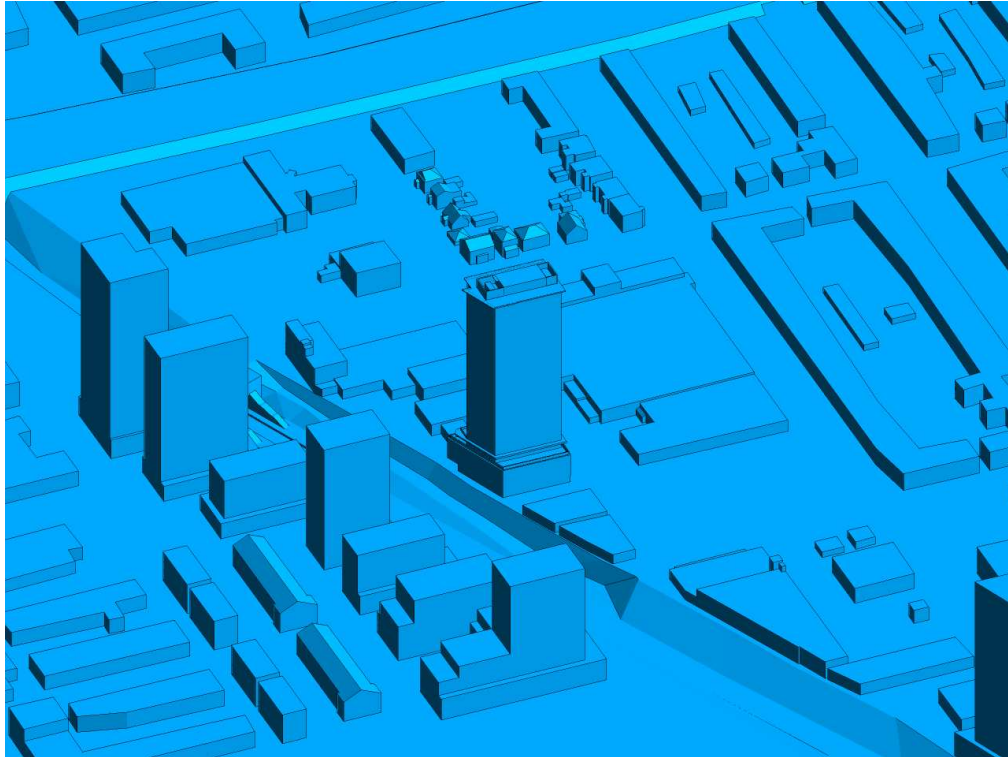


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTH PERSPECTIVE

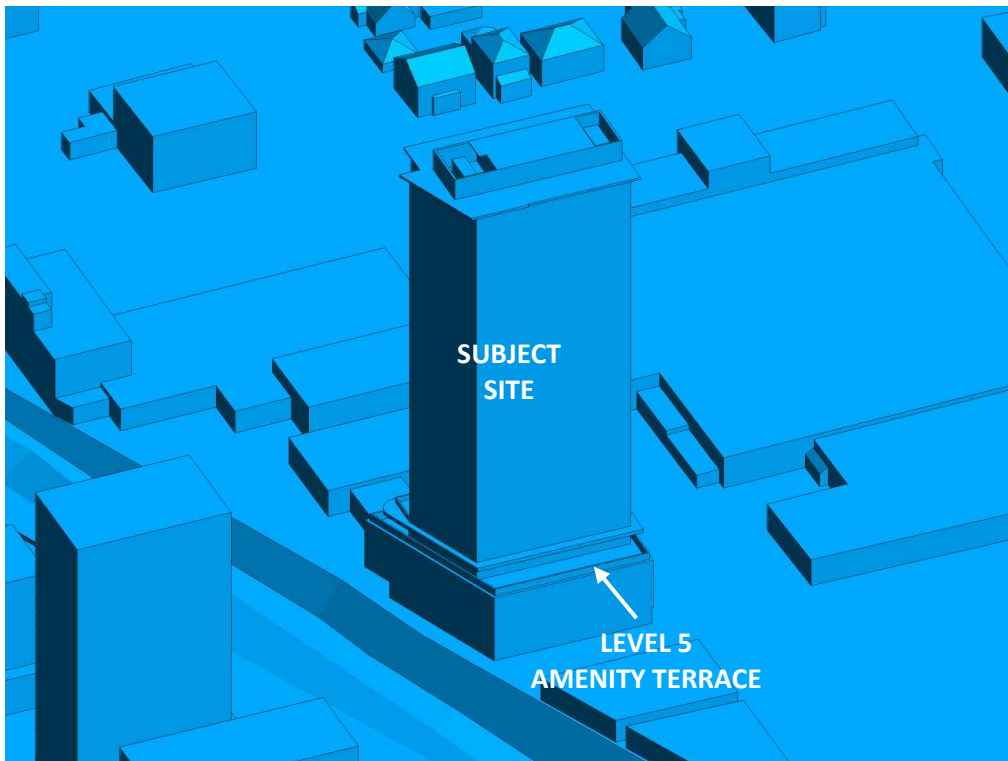


FIGURE 2B: CLOSE UP OF FIGURE 2A



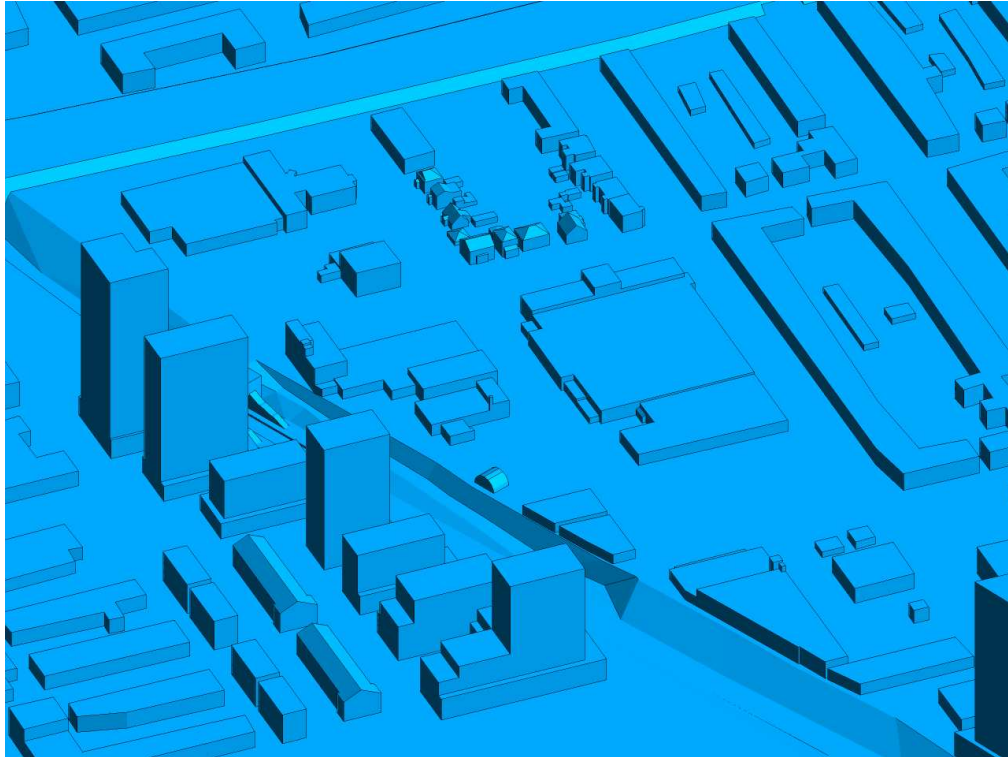


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, NORTH PERSPECTIVE

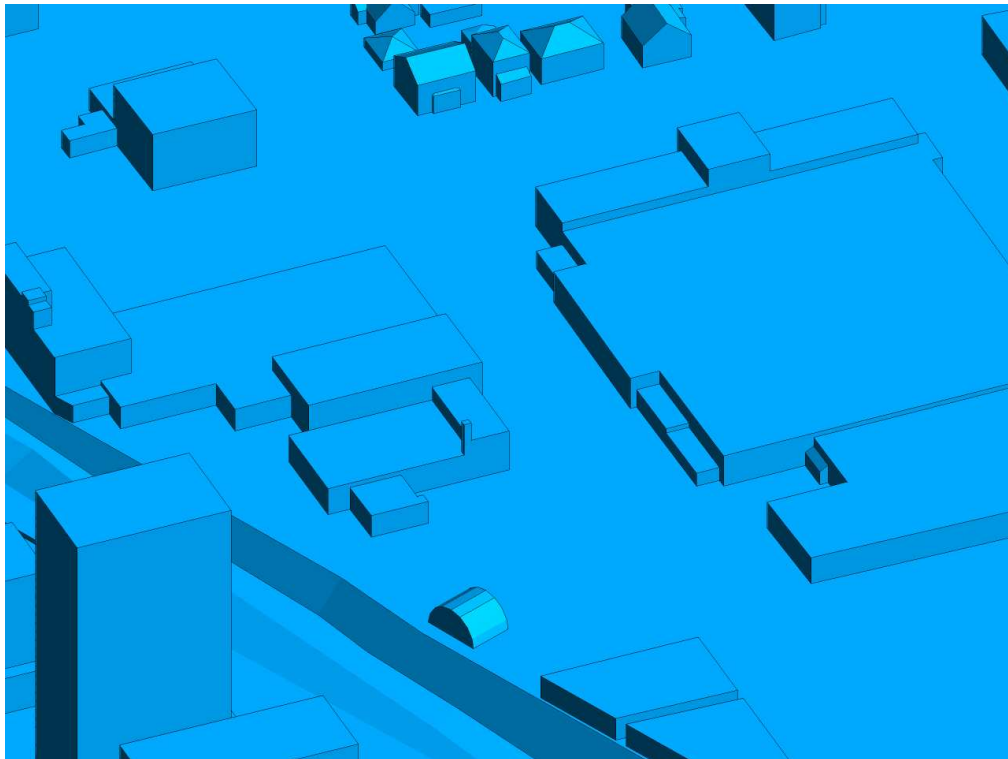


FIGURE 2D: CLOSE UP OF FIGURE 2C



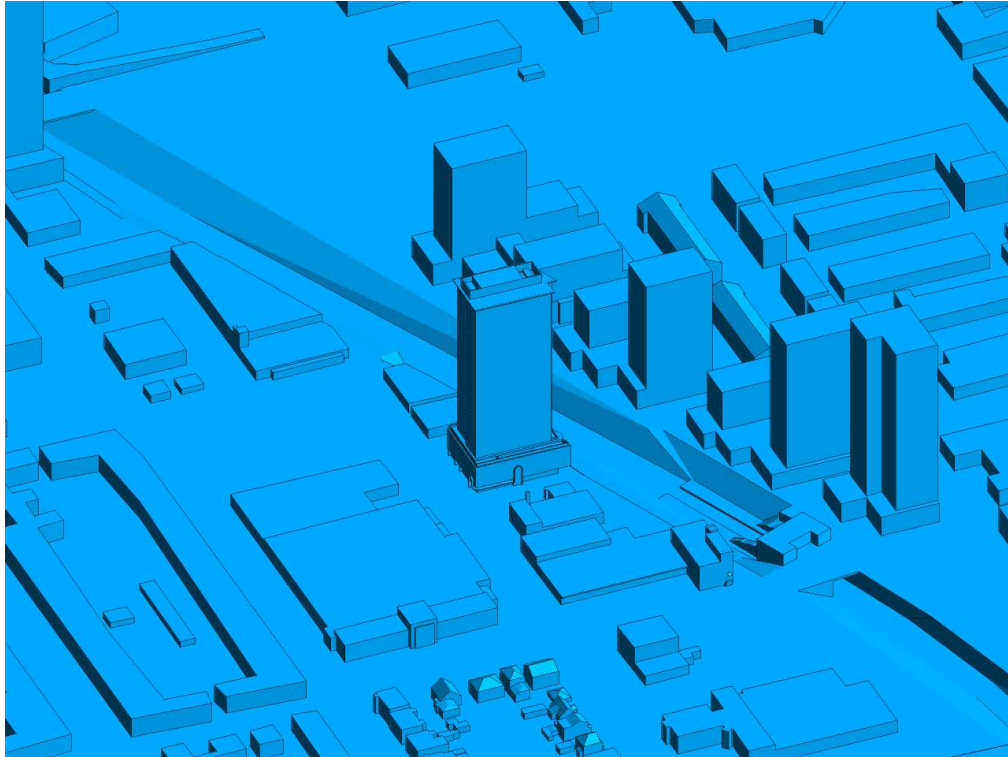


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTH PERSPECTIVE

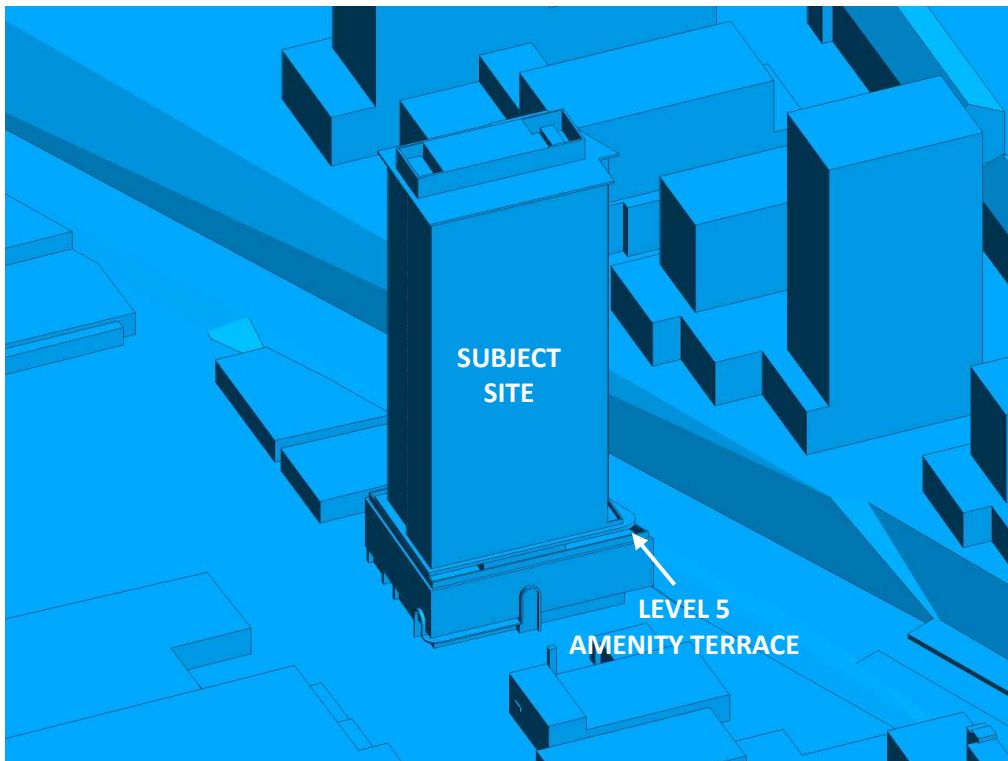


FIGURE 2F: CLOSE UP OF FIGURE 2E



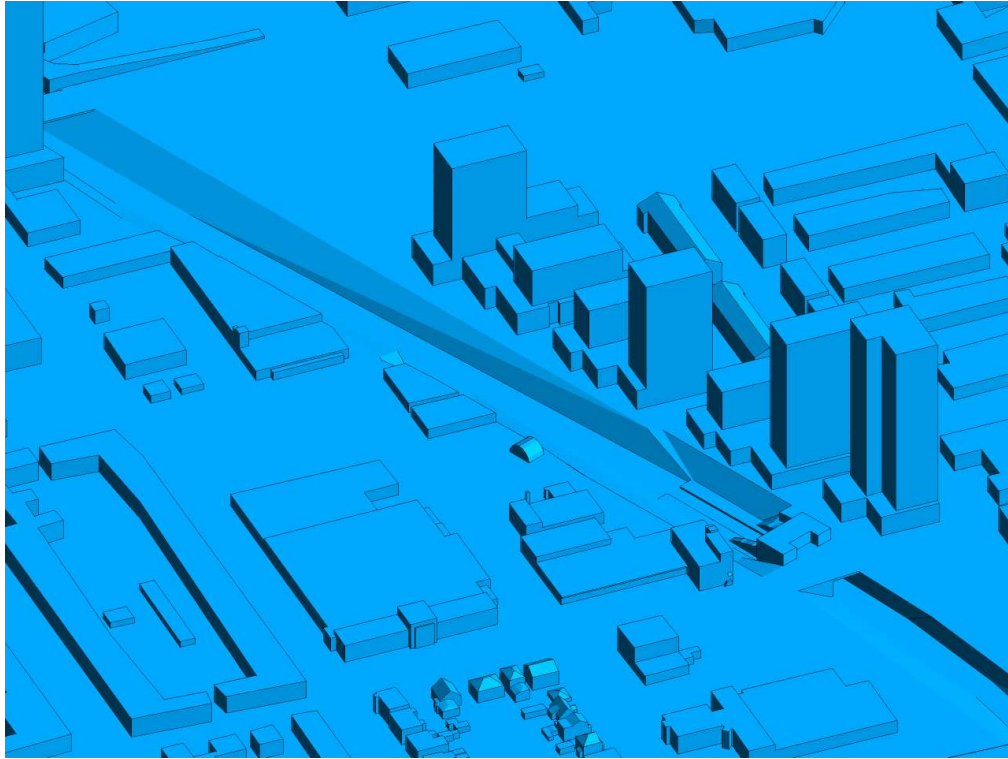


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, SOUTH PERSPECTIVE

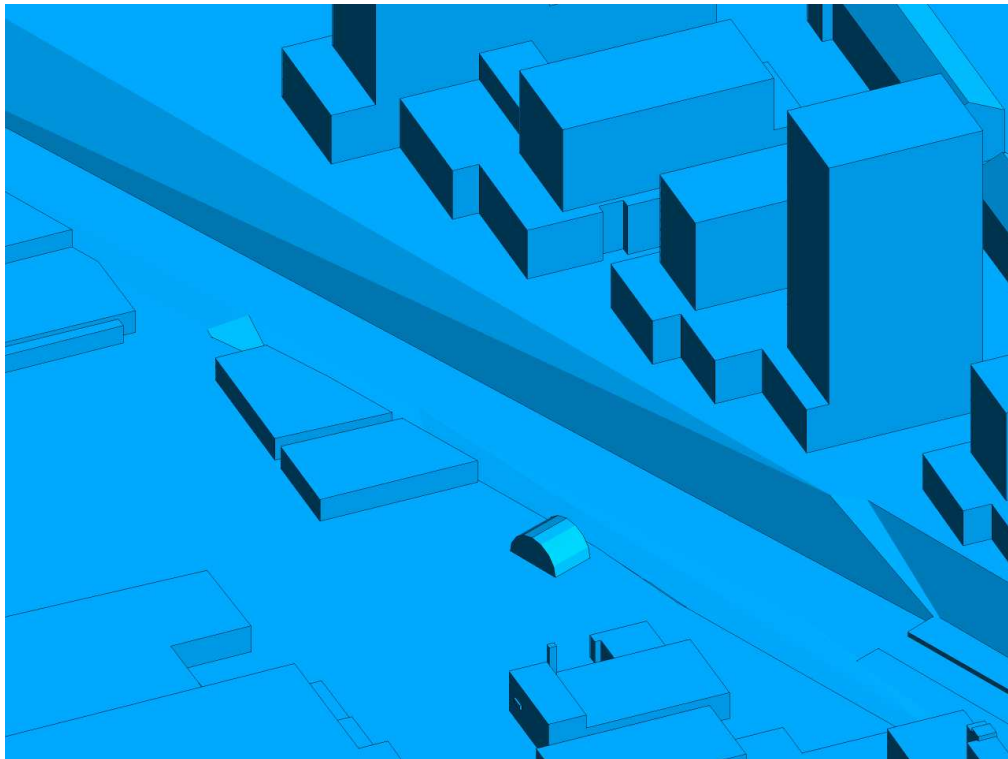


FIGURE 2H: CLOSE UP OF FIGURE 2G



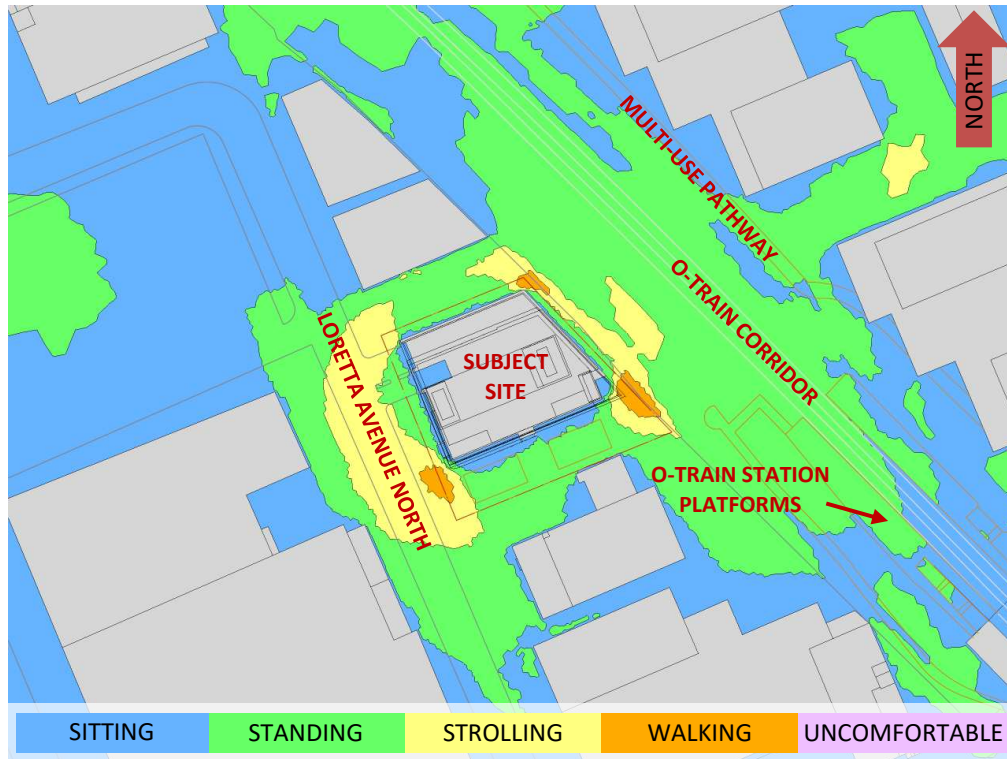


FIGURE 3A: SPRING – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

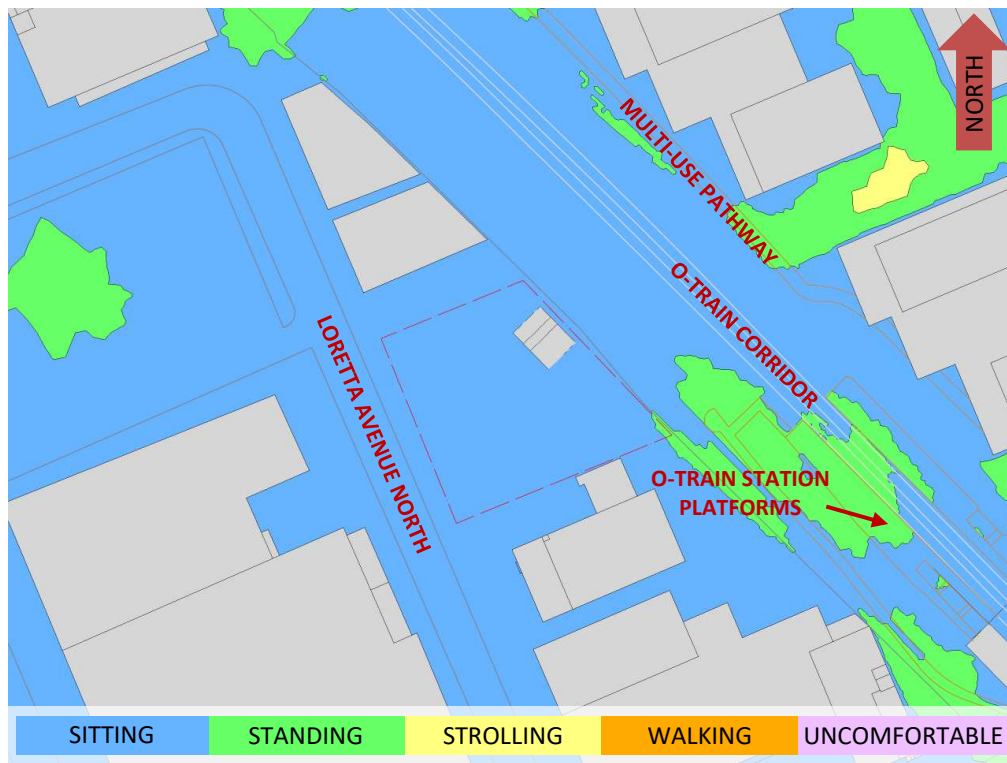


FIGURE 3B: SPRING – WIND COMFORT, GRADE LEVEL– EXISTING MASSING



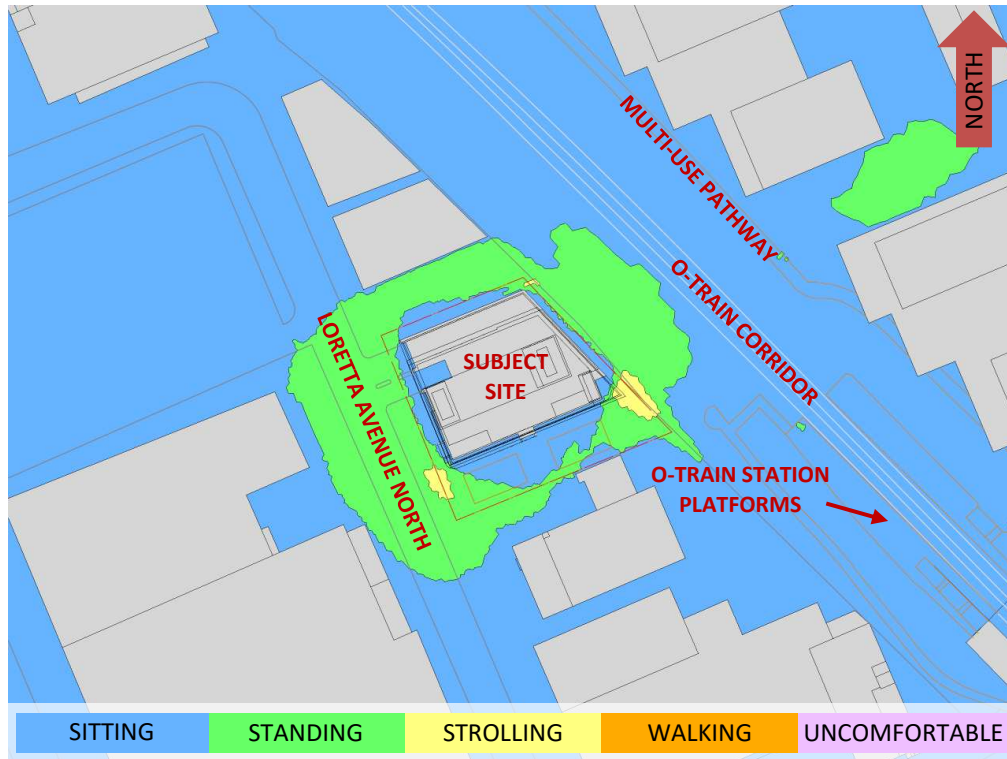


FIGURE 4A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

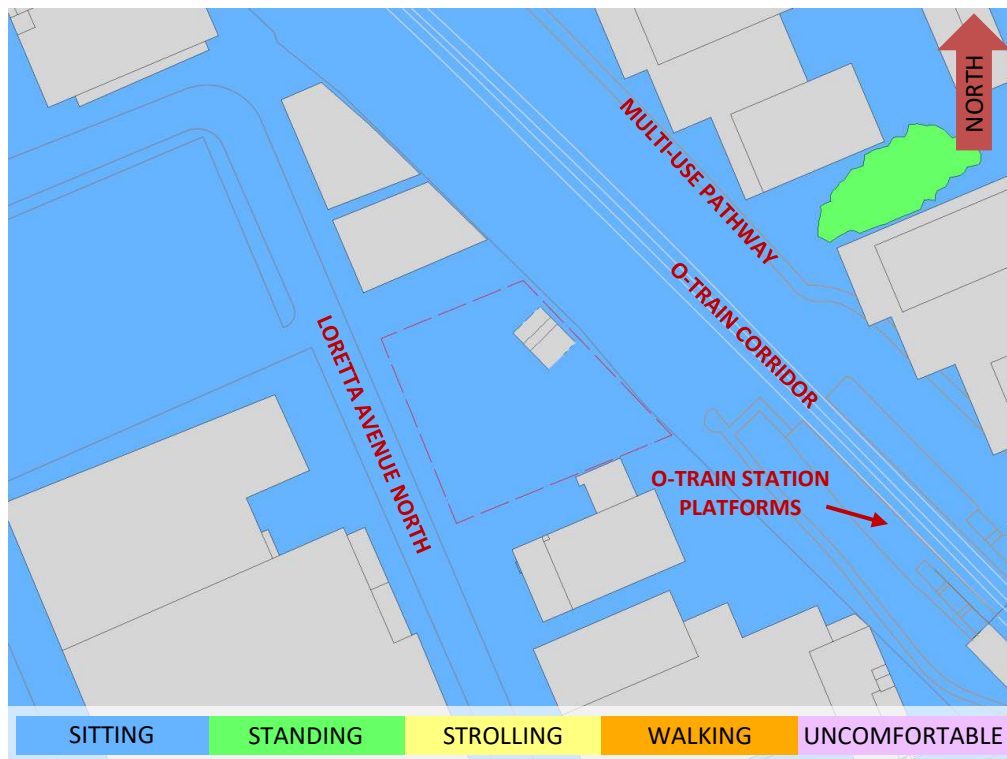


FIGURE 4B: SUMMER – WIND COMFORT, GRADE LEVEL– EXISTING MASSING



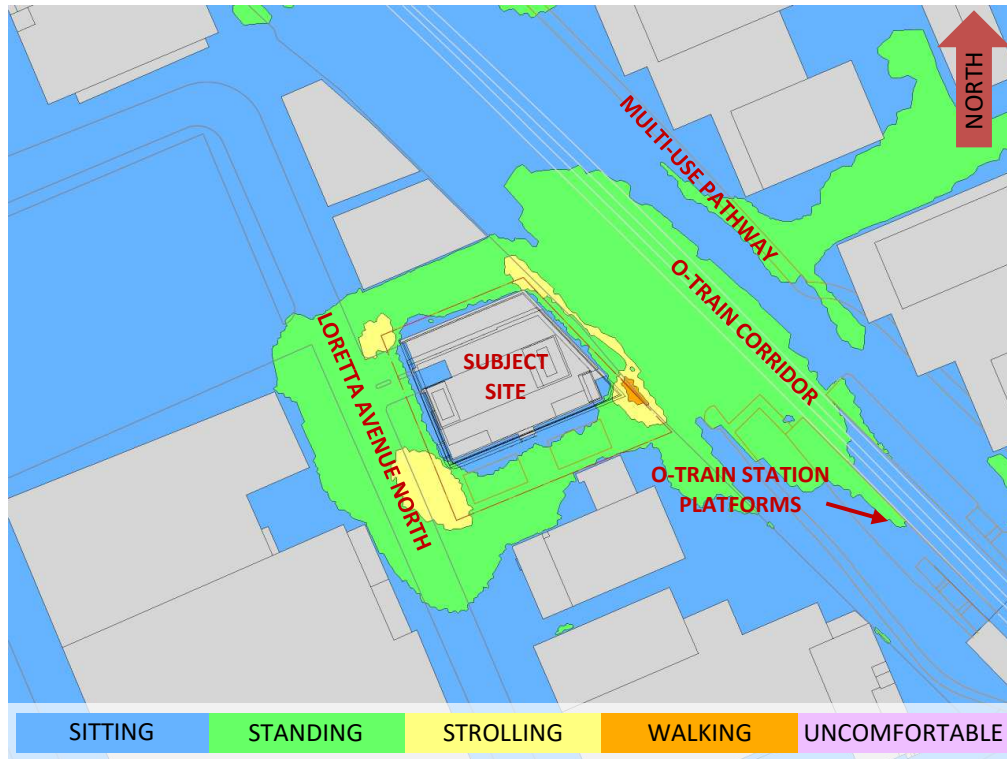


FIGURE 5A: AUTUMN – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

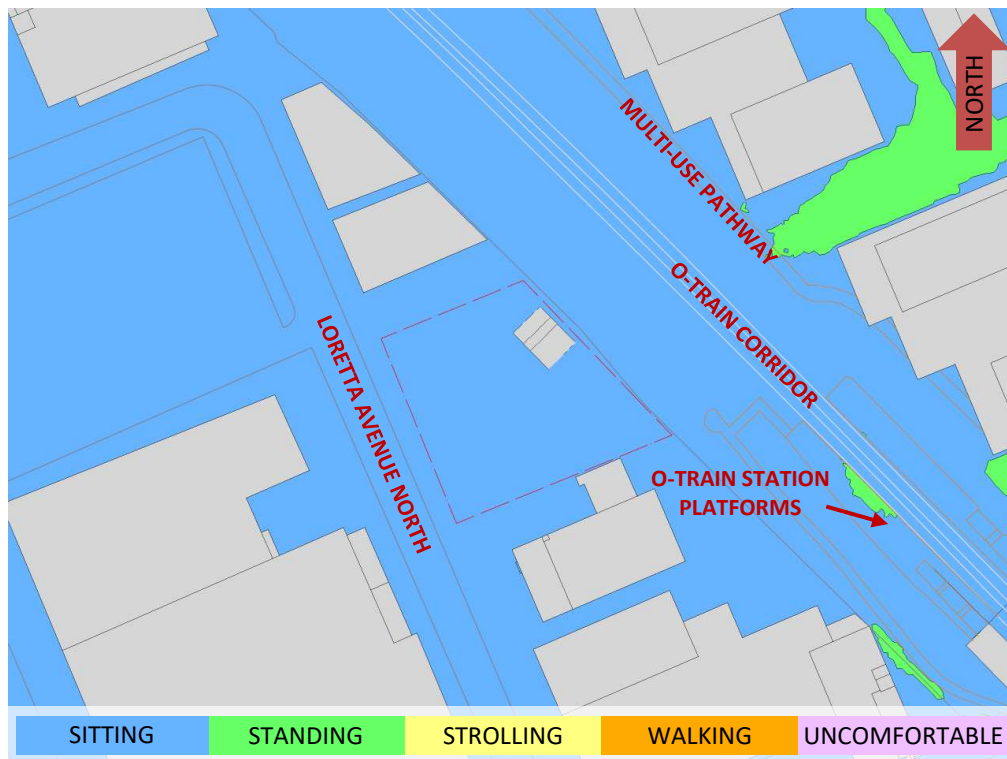


FIGURE 5B: AUTUMN – WIND COMFORT, GRADE LEVEL– EXISTING MASSING



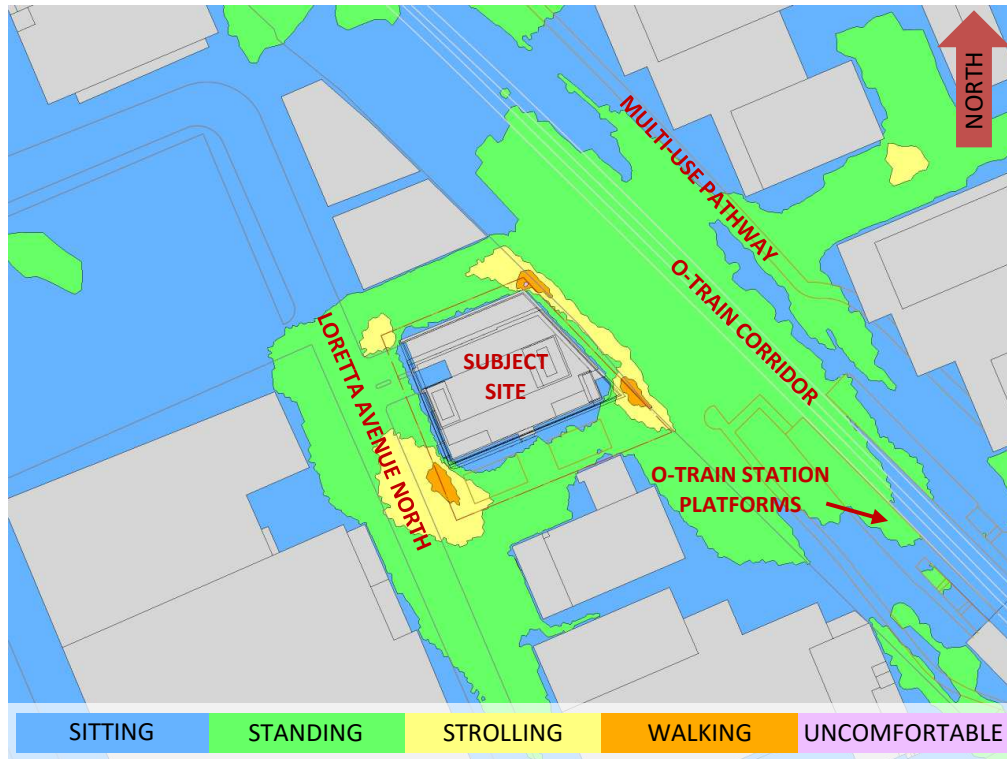


FIGURE 6A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

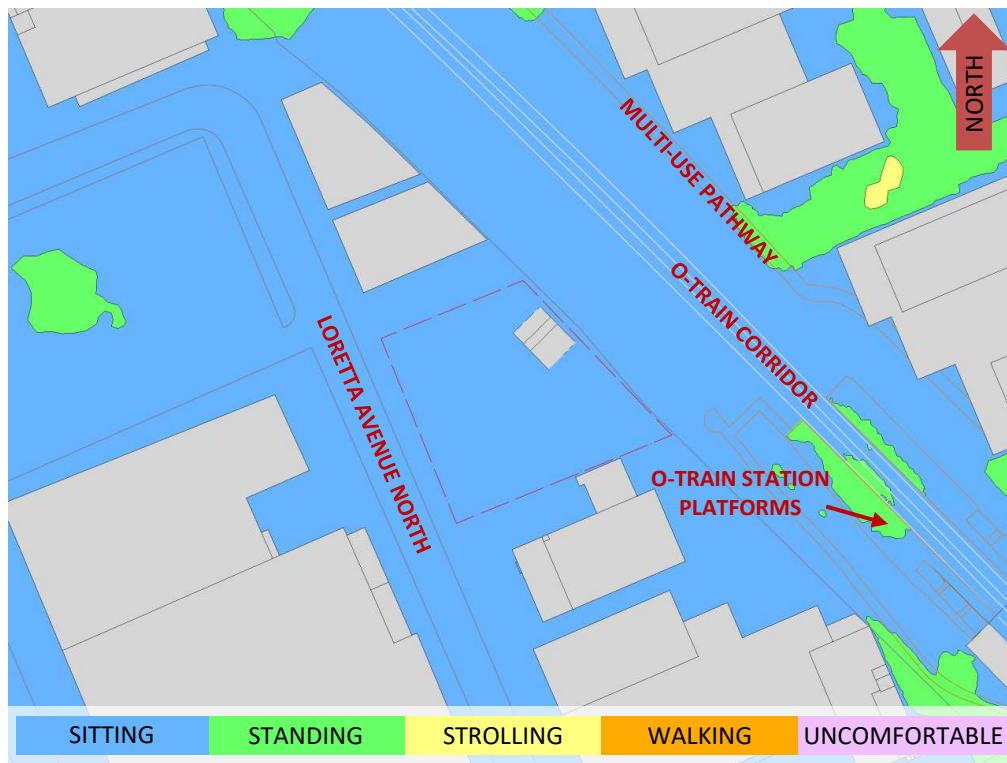


FIGURE 6B: WINTER – WIND COMFORT, GRADE LEVEL– EXISTING MASSING



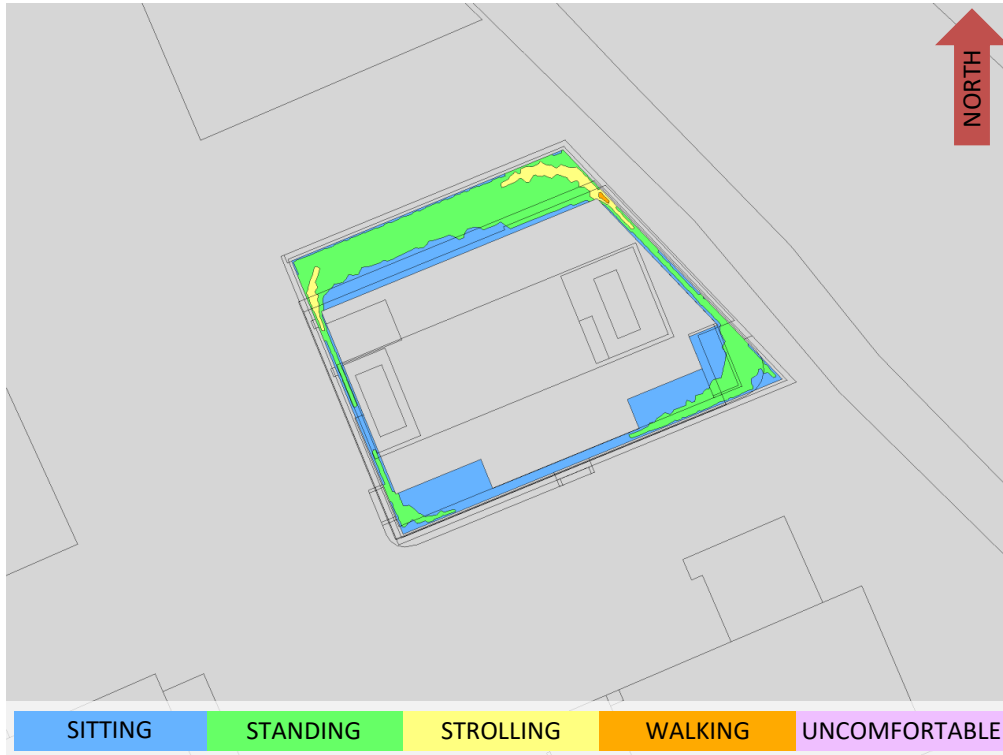


FIGURE 7A: SPRING – WIND COMFORT, LEVEL 5 COMMON AMENITY TERRACES

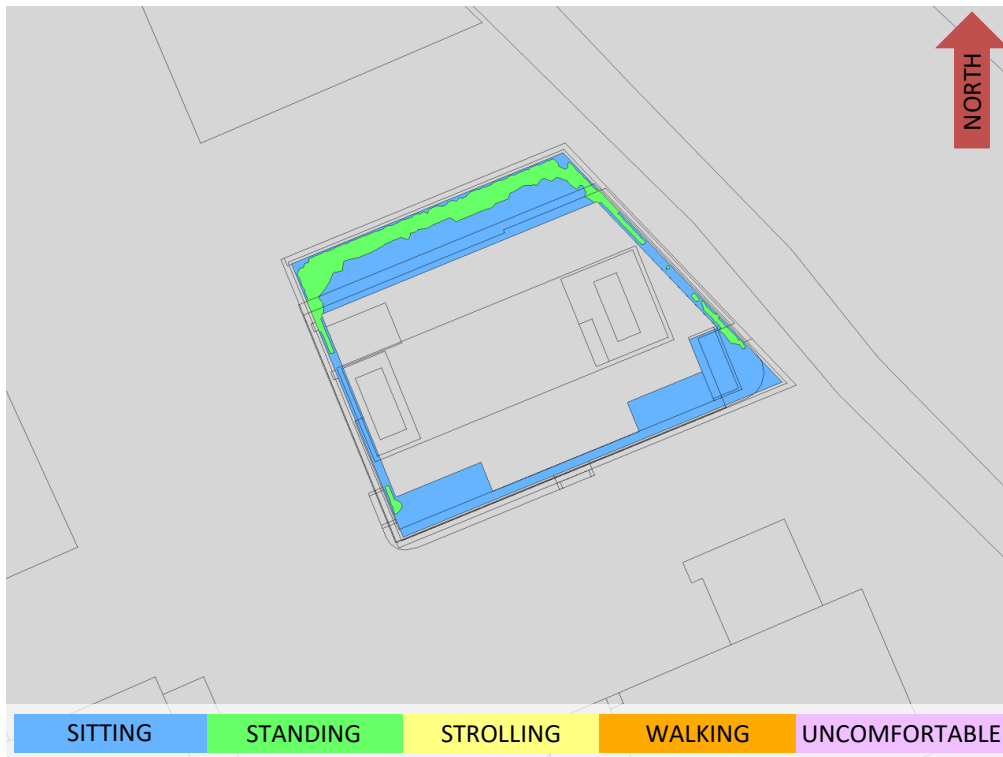


FIGURE 7B: SUMMER – WIND COMFORT, LEVEL 5 COMMON AMENITY TERRACES





FIGURE 7C: AUTUMN – WIND COMFORT, LEVEL 5 COMMON AMENITY TERRACES

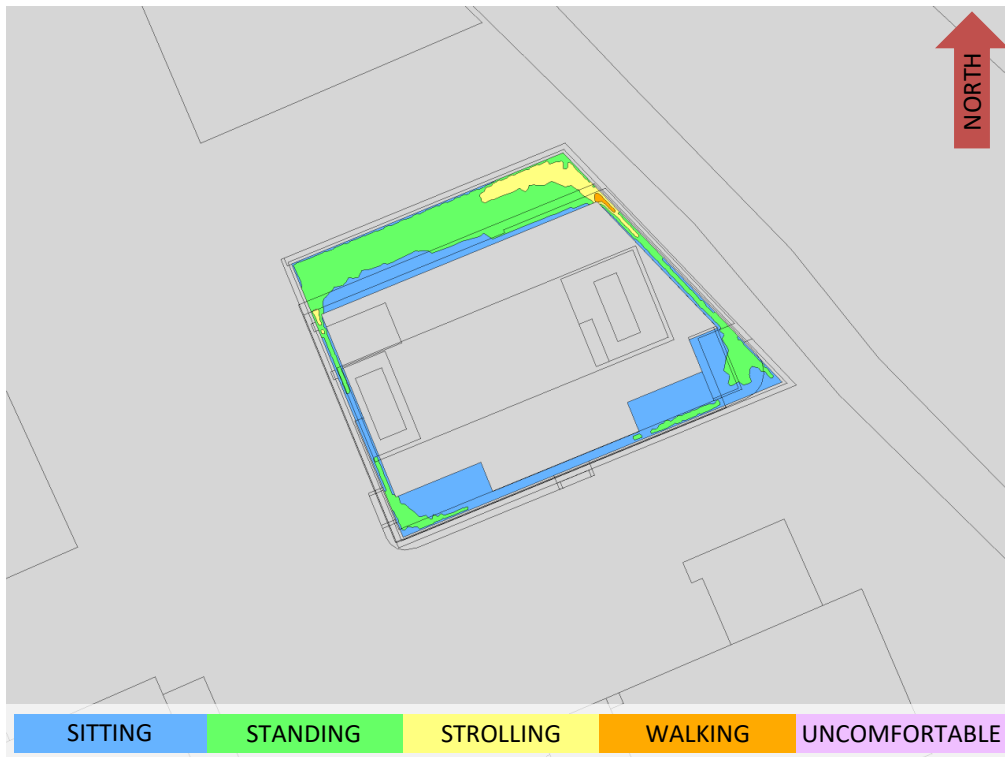


FIGURE 7D: WINTER – WIND COMFORT, LEVEL 5 COMMON AMENITY TERRACES





FIGURE 8: TYPICAL USE PERIOD – WIND COMFORT, LEVEL 5 COMMON AMENITY TERRACES



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APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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

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

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

For the model, U_g is set to 6.5 metres per second (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.

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

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

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

Wind Direction (Degrees True)	Alpha Value (α)
0	0.23
22.5	0.25
45	0.26
67.5	0.25
90	0.25
112.5	0.26
135	0.25
157.5	0.24
180	0.23
202.5	0.24
225	0.25
247.5	0.25
270	0.25
292.5	0.24
315	0.22
337.5	0.22

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

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

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

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

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

where, I = turbulence intensity, L_t = turbulence length scale, Z = height above ground, and α is the power law exponent used for the velocity profile in Equation (1).

Boundary conditions on all other domain boundaries are defined as follows: the ground is a no-slip surface; the side walls of the domain have a symmetry boundary condition; the top of the domain has a specified shear, which maintains a constant wind speed at gradient height; and the outlet has a static pressure boundary condition.

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