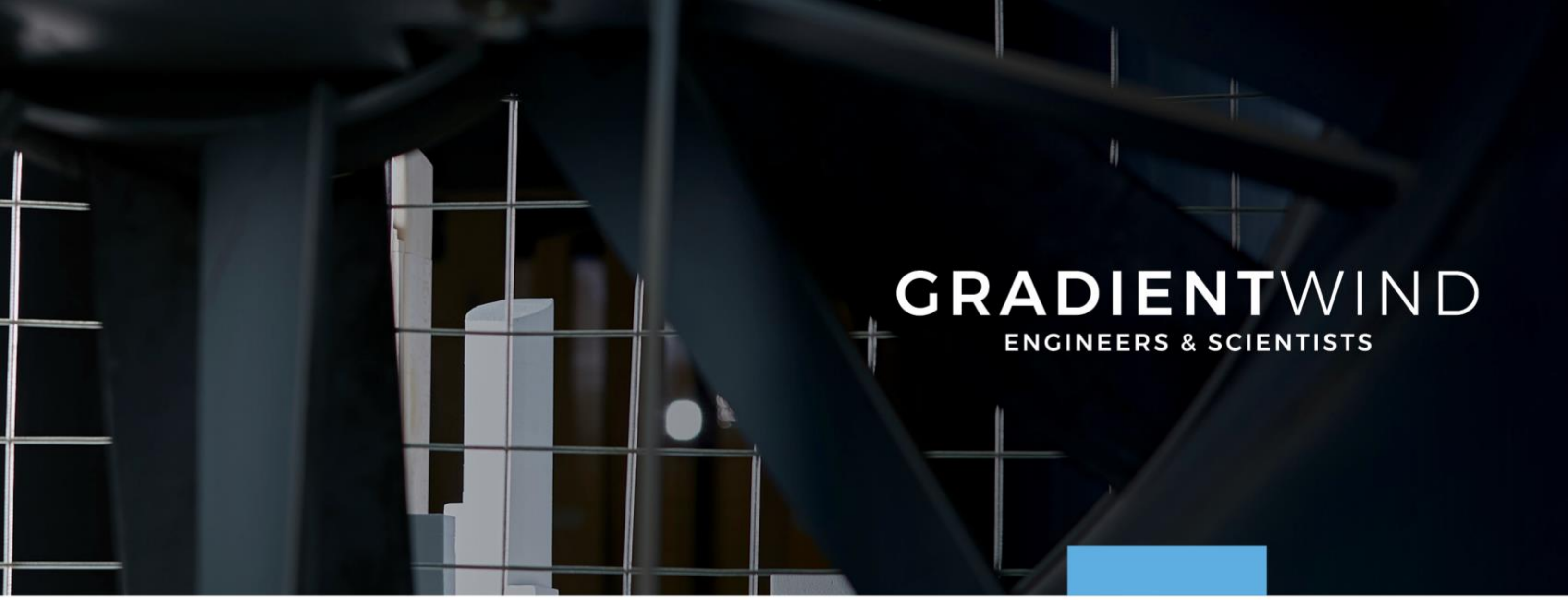
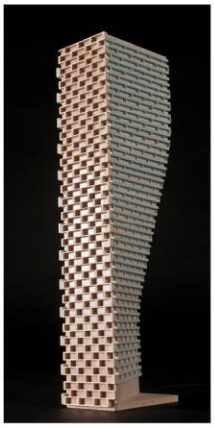
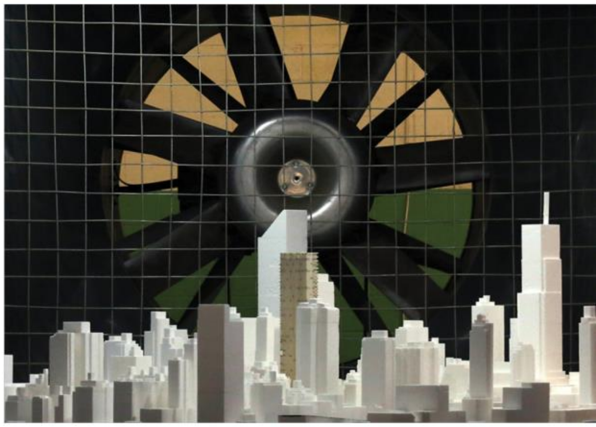


PEDESTRIAN LEVEL WIND STUDY

South Keys Redevelopment (Phase 1)
Ottawa, Ontario

Report: 21-330-PLW-2023





November 14, 2023

PREPARED FOR
Calloway REIT (South Keys) Inc.
3200 Highway 7
Vaughan, ON L4K 5Z5

PREPARED BY
Sunny Kang, B.A.S., Project Coordinator
Omar Rioseco, B.Eng., Junior Wind Scientist
Justin Ferraro, P.Eng., Principal

127 WALGREEN ROAD, OTTAWA, ON, CANADA K0A 1L0 | 613 836 0934
GRADIENTWIND.COM

EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy concurrent Zoning By-law Amendment and Site Plan Control application requirements for the proposed residential development known as the South Keys Redevelopment Project (Phase 1) in Ottawa, Ontario (hereinafter referred to as "subject site" or "proposed development"). Our mandate within this study is to investigate pedestrian wind conditions within and surrounding the subject site, and to identify areas where conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

The study involves simulation of wind speeds for selected wind directions in a three-dimensional (3D) computer model using the computational fluid dynamics (CFD) technique, combined with meteorological data integration, to assess pedestrian wind comfort and safety within and surrounding the subject site according to City of Ottawa wind comfort and safety criteria. The results and recommendations derived from these considerations are detailed in the main body of the report (Section 5), illustrated in Figures 3A-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 the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, walkways, surface parking, the Transitway, and in the vicinity of the building access points serving the proposed development are considered acceptable according to the City of Ottawa Terms of Reference.

2) Regarding the common amenity terraces serving the proposed development at Level 3 and Level 10, wind conditions during the typical use period are predicted to suitable for mostly sitting. The noted conditions are considered acceptable, inclusive of the run/walk path at Level 3.

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 Calloway REIT (South Keys) Inc. to undertake a pedestrian level wind (PLW) study to satisfy concurrent Zoning By-Law Amendment (ZBLA) and Site Plan Control application requirements for the proposed residential development known as the South Keys Redevelopment Project (Phase 1), located approximately 250 m to the north of the intersection of Hunt Club Road and the Transitway in Ottawa, Ontario (hereinafter referred to as "subject site" or "proposed development"). PLW studies have been previously conducted in October 2021[1] and May 2023[2] for the previous designs of the proposed development. Our mandate within this study is to investigate pedestrian wind conditions within and surrounding the subject site, and to identify areas where conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings prepared by RLA Architecture Inc. in October 2023, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery.

2. TERMS OF REFERENCE

The subject site is located approximately 250 metres (m) to the north of the intersection of Hunt Club Road and the Transitway, bounded by the Transitway to the west, the South Keys Walmart to the north, Dazé Street to the east, and the South Keys Cineplex Odeon to the south. The proposed development comprises a residential building, rising to 20 storeys above a 9-storey residential podium and a 2-storey parking podium. The proposed development forms the first phase of a multi-phase development which comprises seven buildings on four separate parcels.

The ground floor of the proposed development comprises commercial spaces along the north elevation, a residential lobby, rental offices, and an indoor amenity along the east elevation, shared building support

[1] Gradient Wind Engineering Inc., '*South Keys Redevelopment (Phase 1) –Pedestrian Level Wind Study*', [Oct 28, 2021]
[2] Gradient Wind Engineering Inc., '*South Keys Redevelopment (Phase 1) –Pedestrian Level Wind Study*', [May 16, 2023]

spaces along the south elevation, and covered parking throughout the remainder of the level. Level 2 comprises above grade parking throughout the level. At Level 3, the podium steps back from the south and west elevations to create an "L-shaped" planform that is open towards the west with its long axis parallel to the Transitway. Level 3 comprises residential units along the north and east elevations, and an indoor amenity at the south end of the "L-shaped" planform, adjoining an outdoor amenity terrace. Levels 4-9 comprise residential units. The building steps back from the east elevation at Level 8 and from the south elevation at Level 10. The noted setback at Level 10 accommodates an outdoor amenity terrace to the south of the tower floorplate. Level 10 includes an indoor amenity space at the southeast corner of the level, and residential units throughout the remainder of the level. The remaining levels rise with a uniform rectangular planform above the podium and are reserved for residential occupancy.

The near-field surroundings, defined as an area within 200-metres (m) of the subject site comprise low-rise commercial massing from the north-northwest clockwise to the south-southeast, and a mix of green space, the O-Train railway, and the Transitway for the remaining compass directions. 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 mostly green space from the southeast clockwise to the south-southwest and by a mix of low-rise buildings and green space for the remaining compass directions. Notably, the Sawmill Creek Reservoir is located approximately 300 m to the northwest.

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

3. OBJECTIVES

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

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on CFD simulations of wind speeds across the 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[3]. 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 stronger wind speeds.

[3] 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 radius of 480 m. The process was performed for two context massing scenarios, as noted in Section 2.

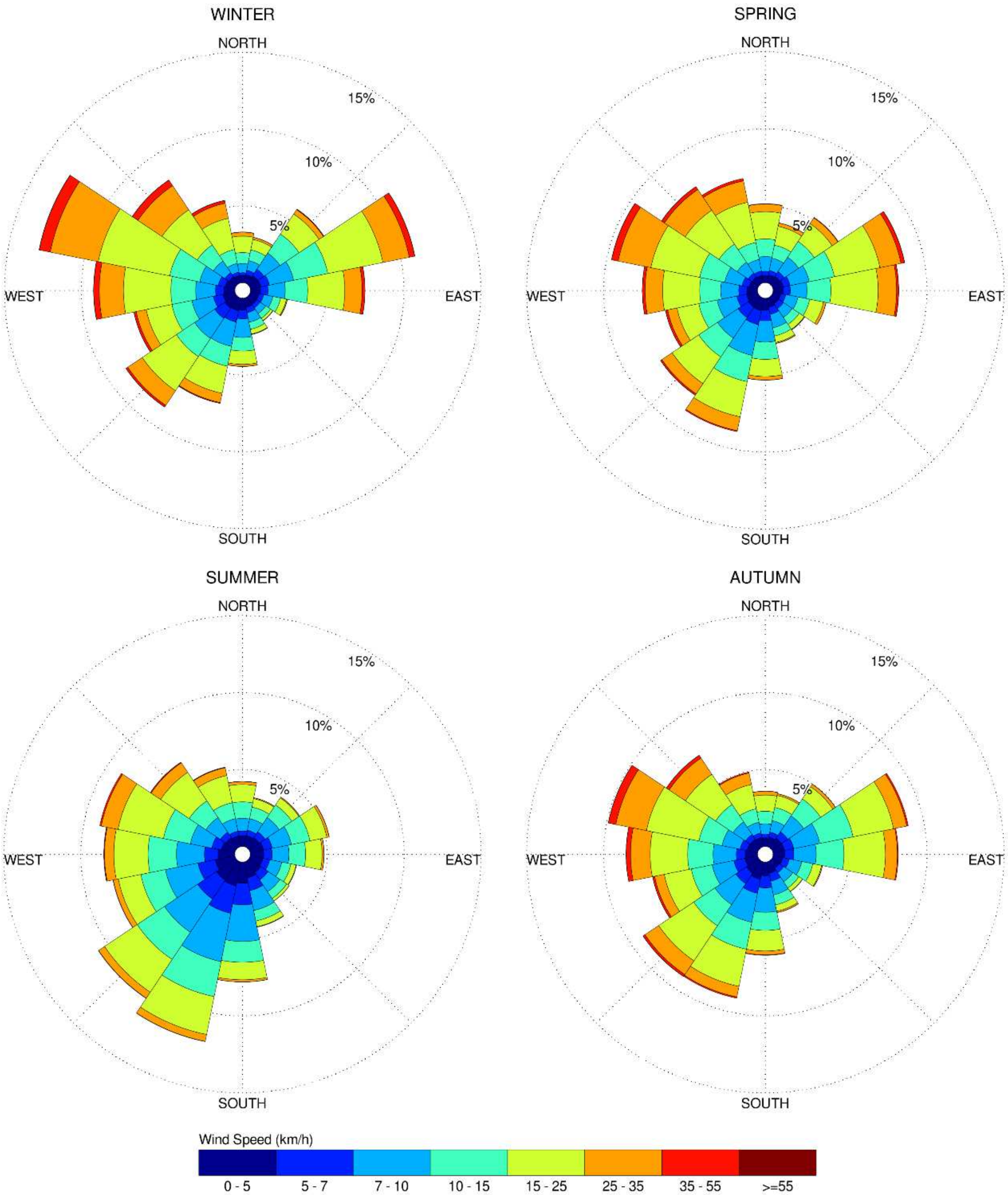
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the common amenity terraces serving the proposed development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

4.3 Historical Wind Speed and Direction Data

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

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

SEASONAL DISTRIBUTION OF WIND
OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT



Notes:

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

4.4 Pedestrian Wind Comfort and Safety Criteria – City of Ottawa

Pedestrian 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	GEM 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, illustrating wind conditions at grade level for the proposed and existing massing scenarios, and by Figures 7A-7D, which illustrate conditions over the common amenity terraces serving the proposed development at Levels 3 and 10. 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 over the noted common amenity terraces are also reported for the typical use period, which is defined as May to October, inclusive. Figure 8 illustrates comfort conditions over the common amenity terraces, consistent with the comfort classes in Section 4.4. The details of these conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Nearby Sidewalks and Walkways: Following the introduction of the proposed development, wind comfort conditions over the sidewalks and walkways adjacent to the proposed development along the north, east, and south elevations are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, throughout the remainder of the year with an isolated region suitable for walking near the northeast corner of the proposed development during the winter. The noted conditions are considered acceptable.

Wind conditions over the noted areas with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, throughout the remainder of the year. While the introduction of the proposed development produces windier conditions over the noted areas in comparison to the existing massing, conditions with the proposed development are nevertheless considered acceptable.

Nearby Surface Parking: Following the introduction of the proposed development, wind conditions over the adjacent surface parking lots are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, throughout the remainder of the year, with a limited area of walking conditions to the northeast of the proposed development. The noted conditions are considered acceptable.

Conditions over the adjacent parking lots with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, throughout the remainder of the year. While the introduction of the proposed development produces windier conditions over the noted areas in comparison to the existing massing, conditions are nevertheless considered acceptable.

Transitway: Following the introduction of the proposed development, wind conditions in the vicinity of the South Keys Transitway Station to the northwest of the subject site are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, throughout the remainder of the year. The noted conditions are considered acceptable.

Conditions over the noted areas with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for mostly standing throughout the remainder of the year. Notably, conditions over the noted areas with the proposed development are mostly similar to those under the existing massing and are considered acceptable.

Building Access Points: Owing to the protection of the building façades, conditions in the vicinity of the building access points serving the proposed development, as well as those serving the nearby existing buildings, are predicted to be suitable for standing, or better, throughout the year. The noted conditions are considered acceptable.

5.2 Wind Comfort Conditions – Common Amenity Terraces

Level 3, Podium Roof: During the typical use period, as illustrated in Figure 8, wind comfort conditions within the common amenity terrace serving the proposed development at Level 3 are predicted to be suitable for sitting. The noted conditions are considered acceptable, inclusive of the wind conditions over the run/walk pathway.

Level 10, Podium Roof: As illustrated in Figure 8, wind conditions within the common amenity terrace serving the proposed development atop the podium roof at Level 10 are predicted to be suitable for mostly sitting during the typical use period. The noted conditions are considered acceptable.

5.3 Wind Safety

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

5.4 Applicability of Results

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

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-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 the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, walkways, surface parking, the Transitway, and in the vicinity of the building access points serving the proposed development are considered acceptable according to the City of Ottawa Terms of Reference.

2) Regarding the common amenity terraces serving the proposed development at Level 3 and Level 10, wind conditions during the typical use period are predicted to suitable for mostly sitting. The noted conditions are considered acceptable, inclusive of the run/walk path at Level 3.

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,

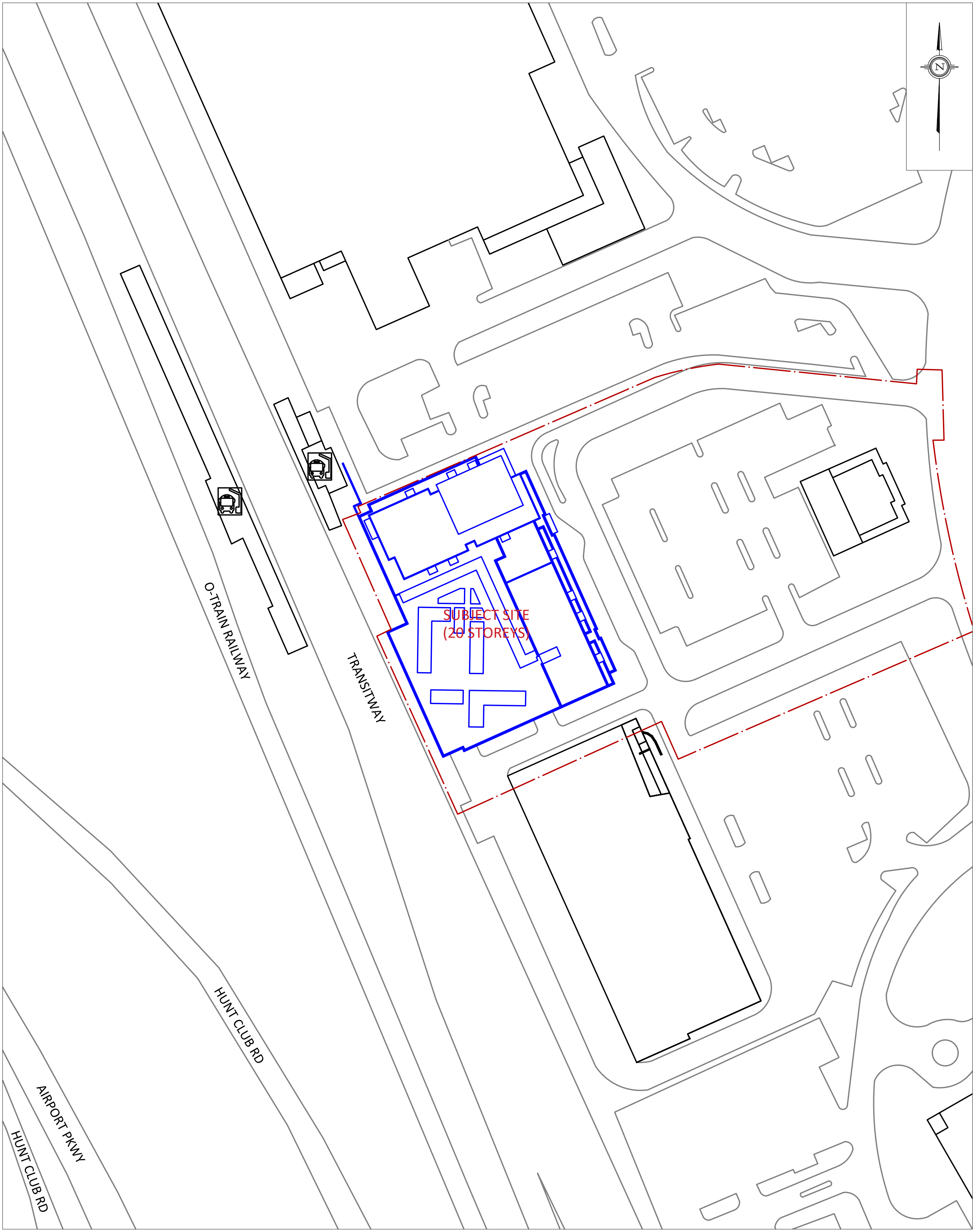
Gradient Wind Engineering Inc.

Nov 14, 2023

Omar Rioseco, B.Eng.
Junior Wind Scientist

Justin Ferraro, P.Eng.
Principal

Sunny Kang, B.A.S.
Project Coordinator



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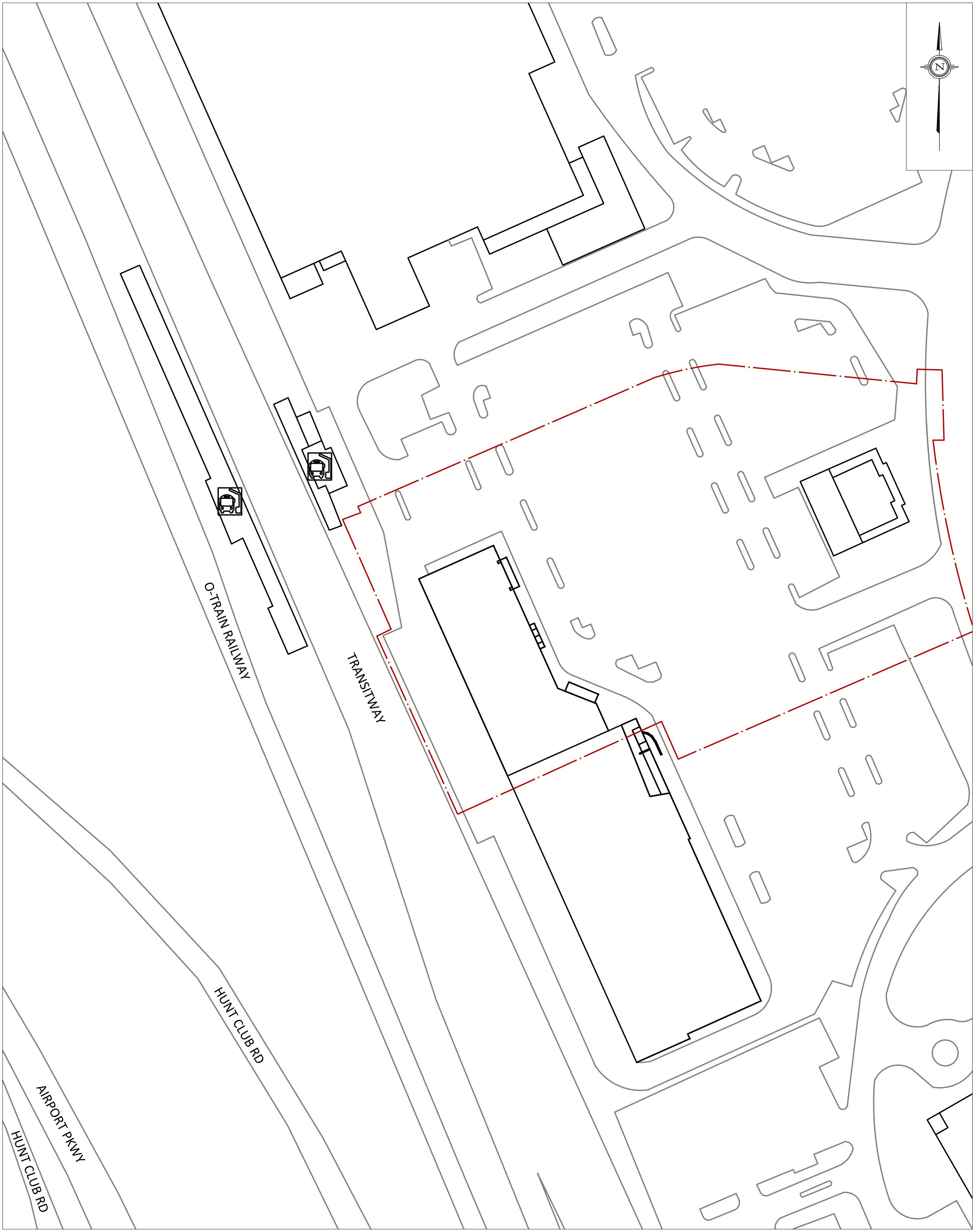
PROJECT		DESCRIPTION
SOUTH KEYS REDEVELOPMENT PHASE 1, OTTAWA PEDESTRIAN LEVEL WIND STUDY		FIGURE 1A: PROPOSED SITE PLAN AND SURROUNDING CONTEXT
SCALE: 1:1500	DRAWING NO.: 21-330-PLW-2023-1A	
DATE: NOVEMBER 8, 2023	DRAWN BY: T.K.	



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PROJECT	SOUTH KEYS REDEVELOPMENT PHASE 1, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1500
DRAWING NO.	21-330-PLW-2023-1B
DATE	NOVEMBER 8, 2023
DRAWN BY	T.K.
DESCRIPTION	FIGURE 1B: EXISTING SITE PLAN AND SURROUNDING CONTEXT

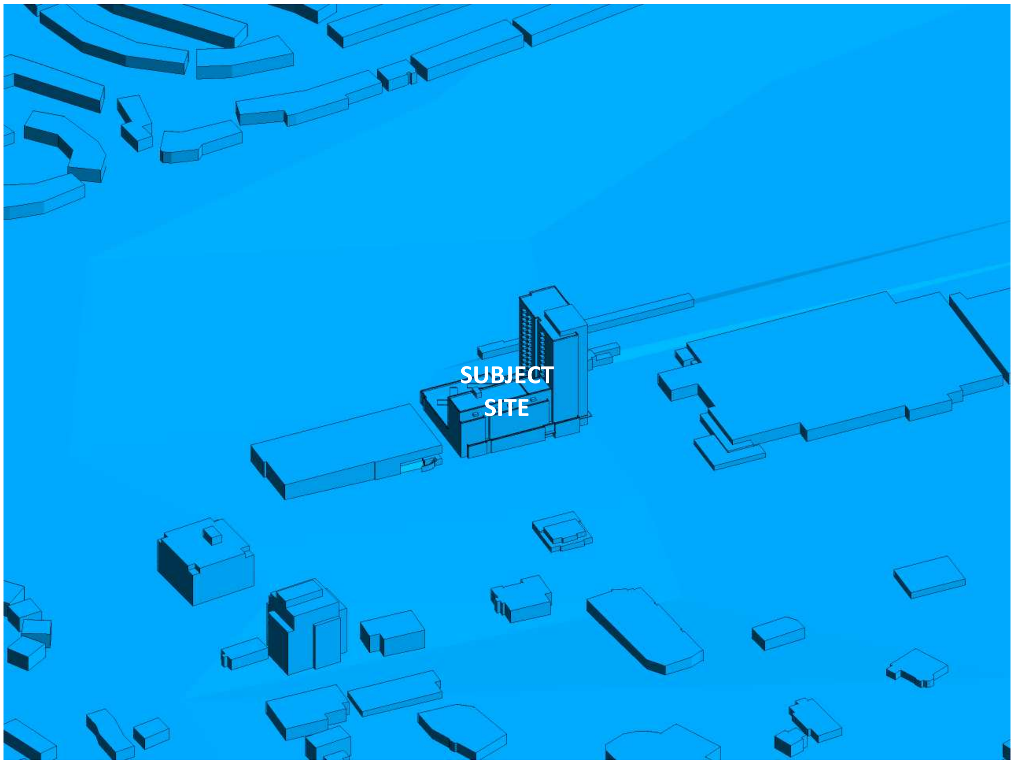


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, EAST PERSPECTIVE

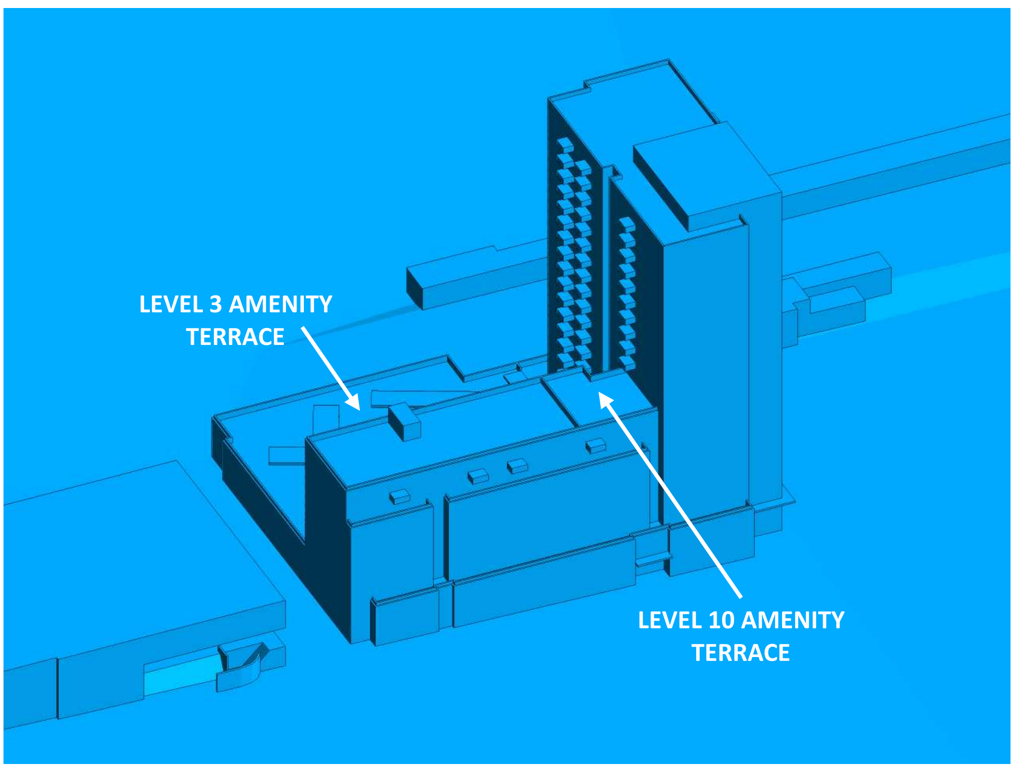


FIGURE 2B: CLOSE UP OF FIGURE 2A

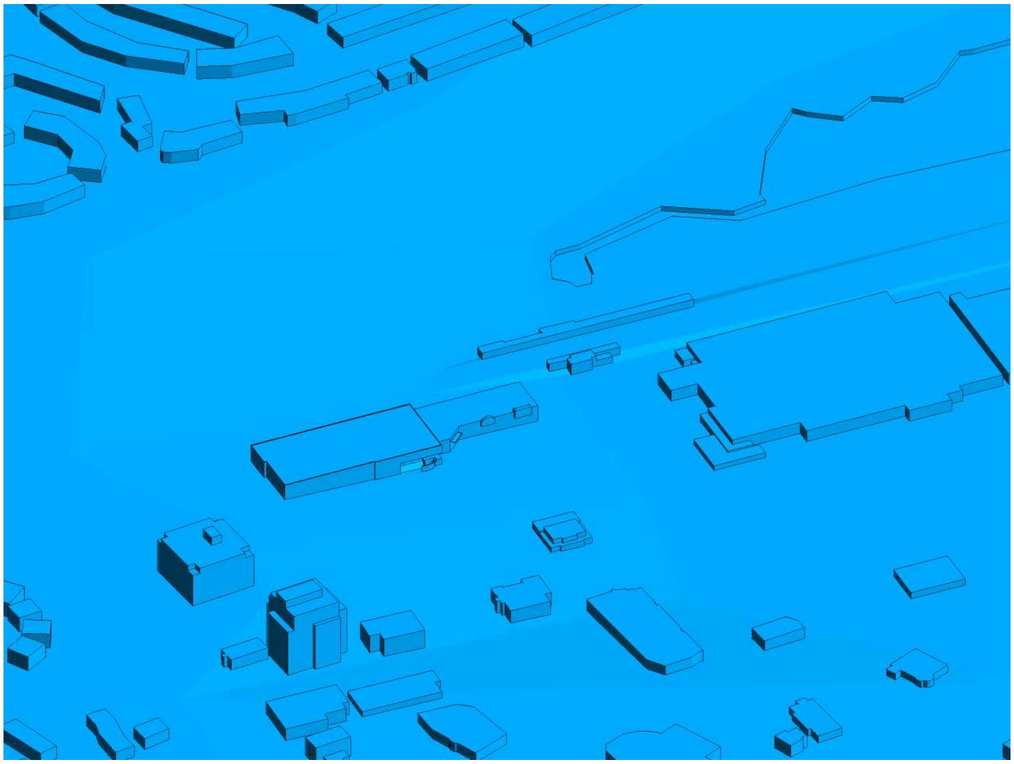


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, EAST PERSPECTIVE

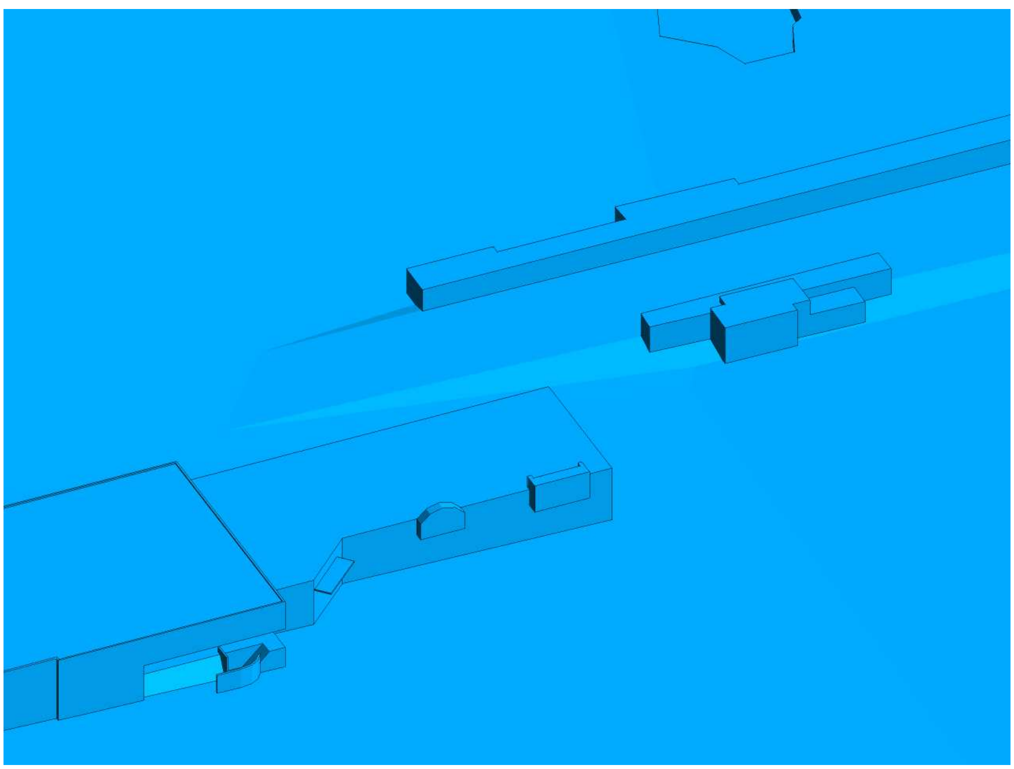


FIGURE 2D: CLOSE UP OF FIGURE 2C

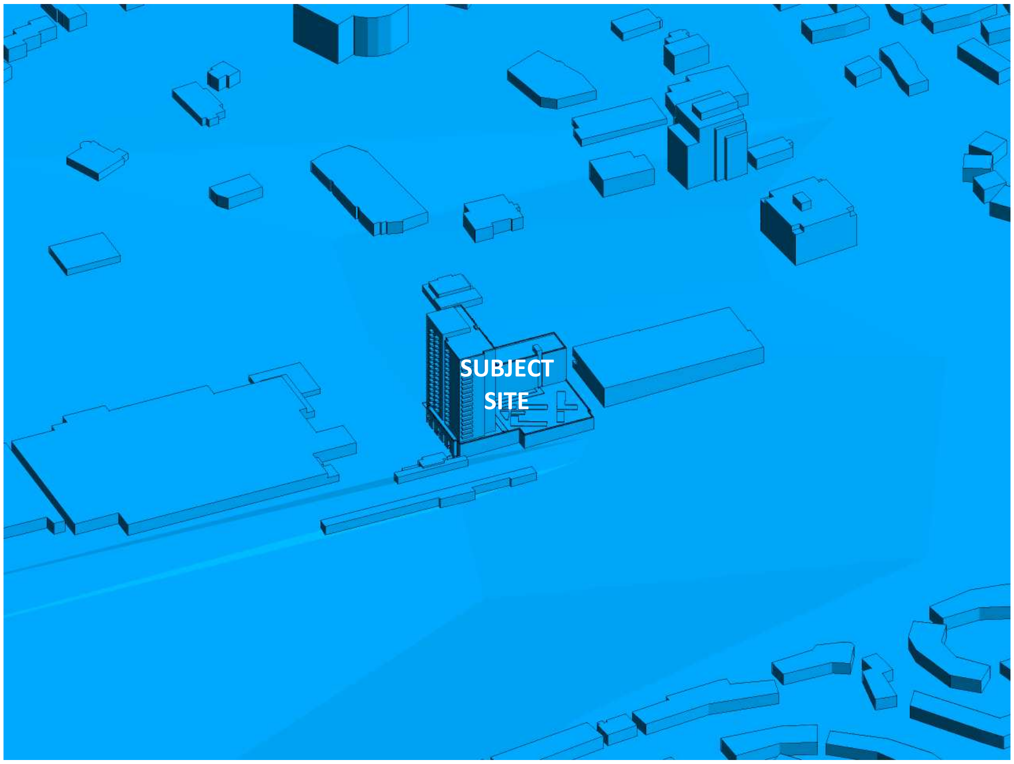


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, WEST PERSPECTIVE

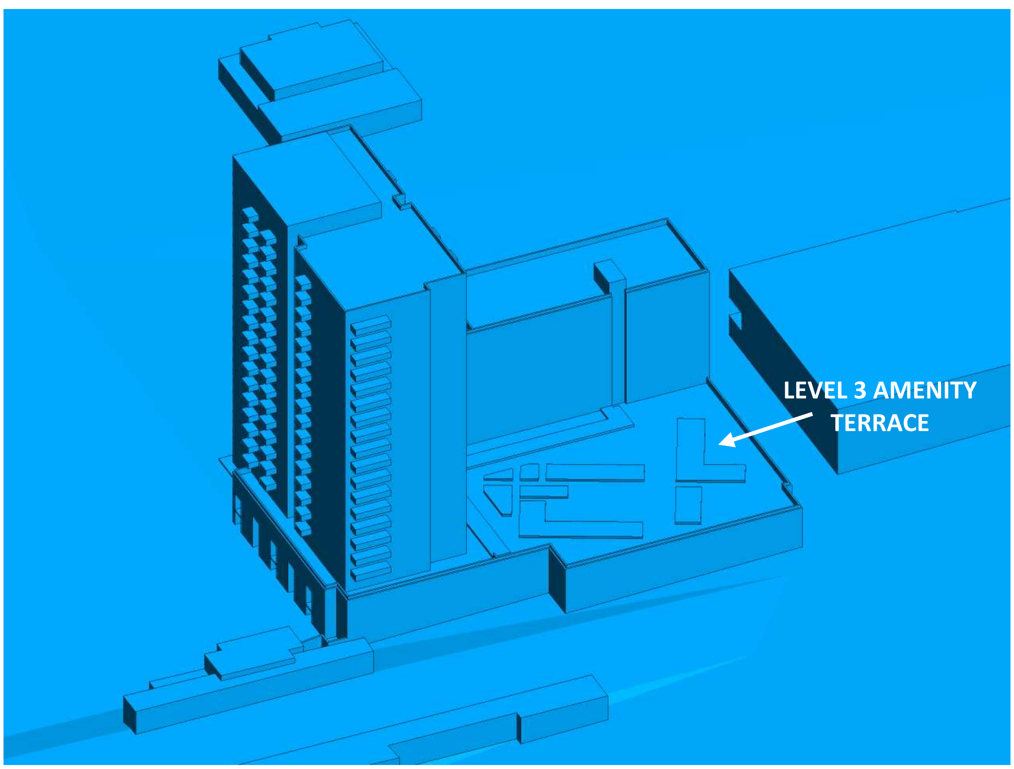


FIGURE 2F: CLOSE UP OF FIGURE 2E

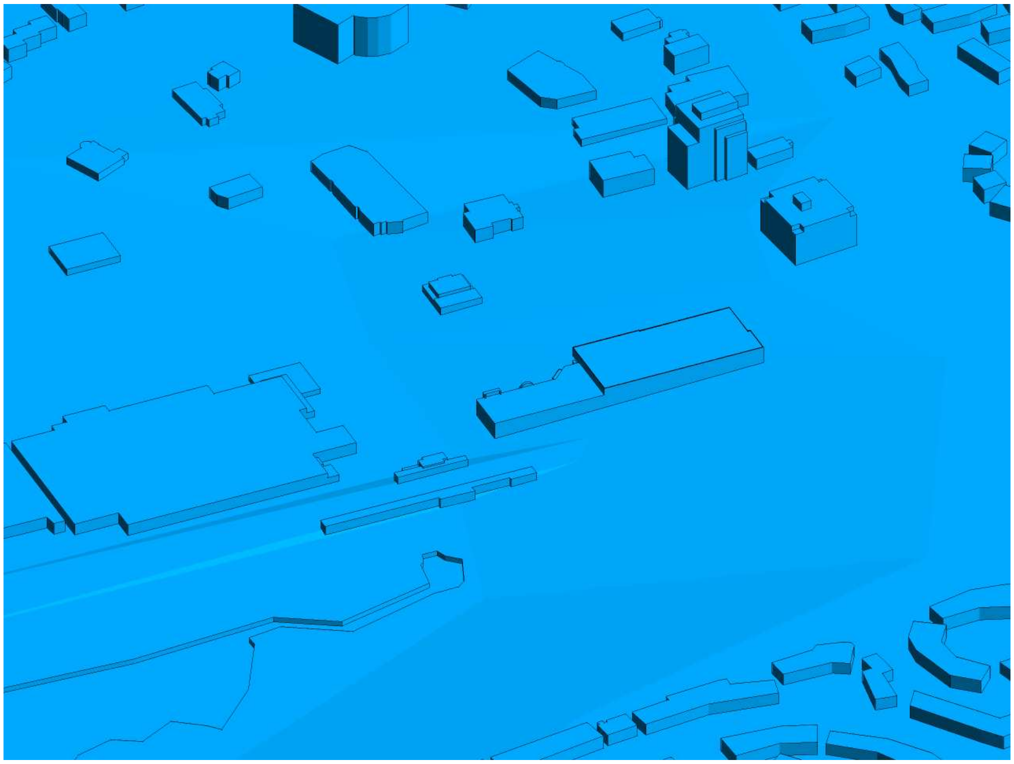


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, WEST PERSPECTIVE

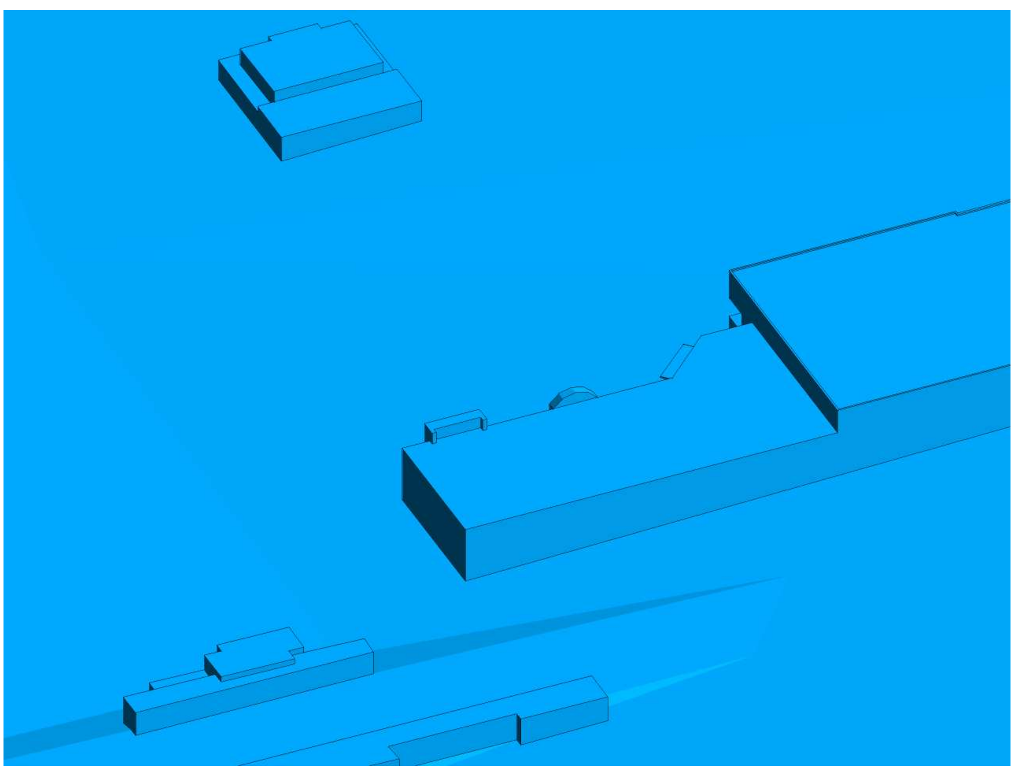


FIGURE 2H: CLOSE UP OF FIGURE 2G

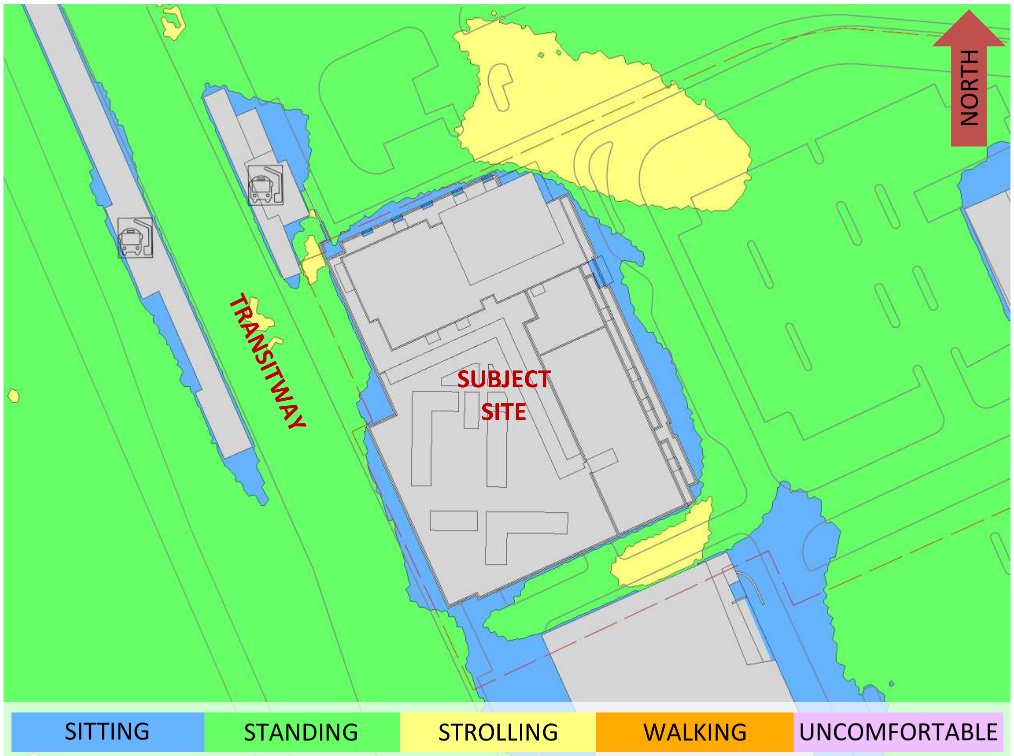


FIGURE 3A: SPRING – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

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

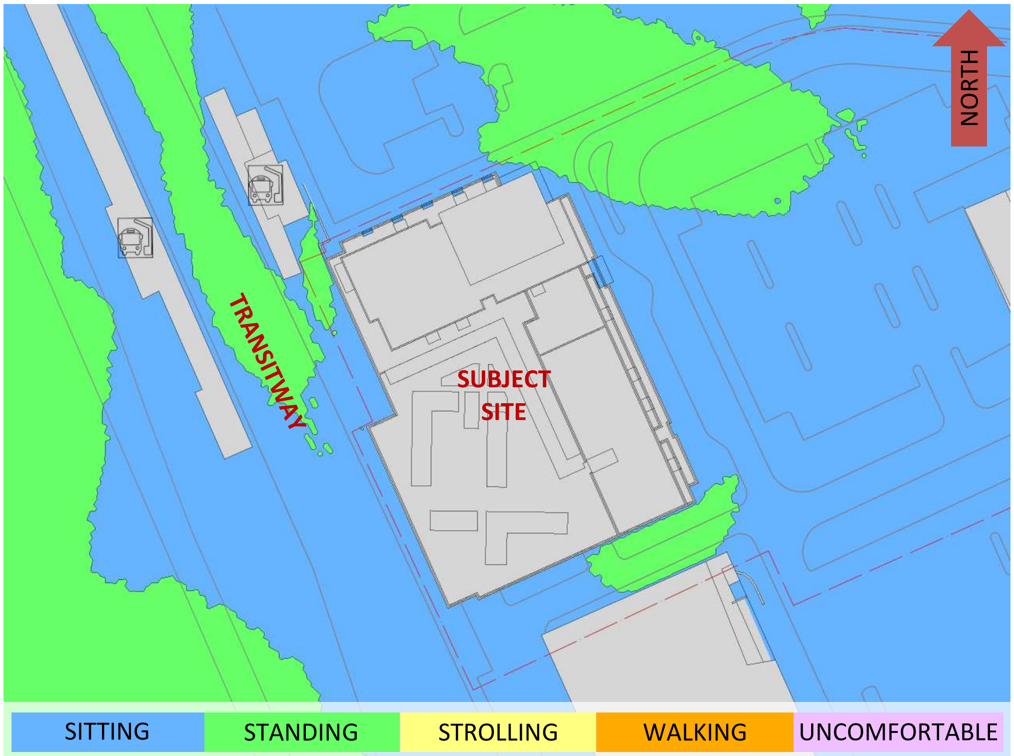


FIGURE 4A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

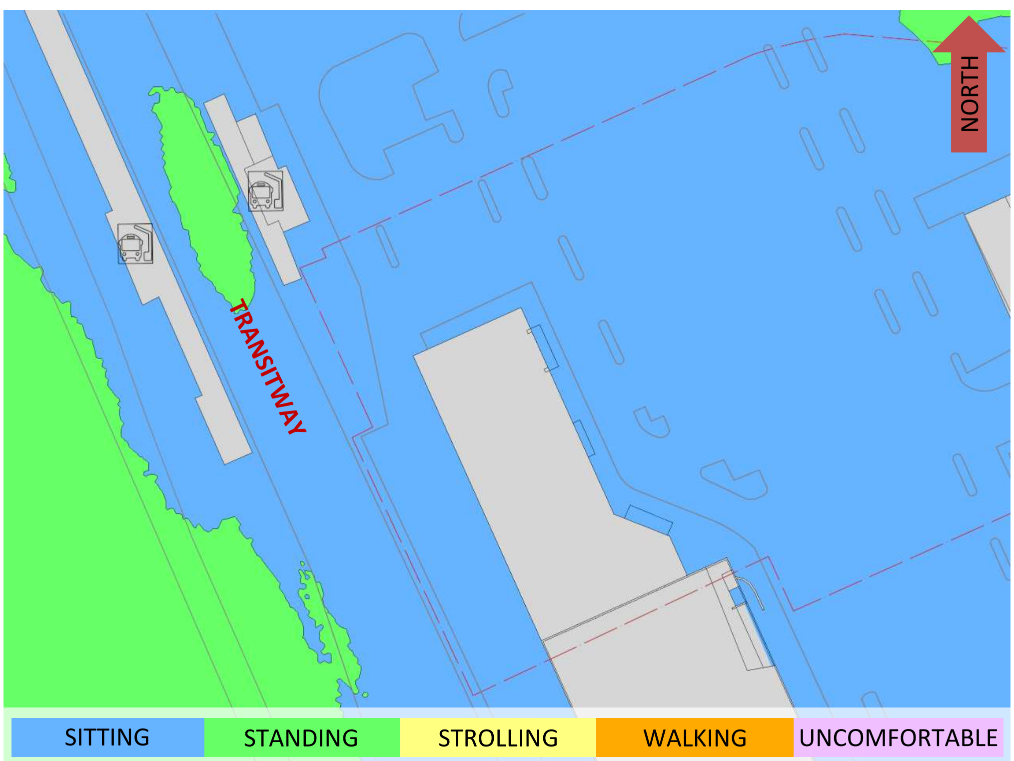


FIGURE 4B: SUMMER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

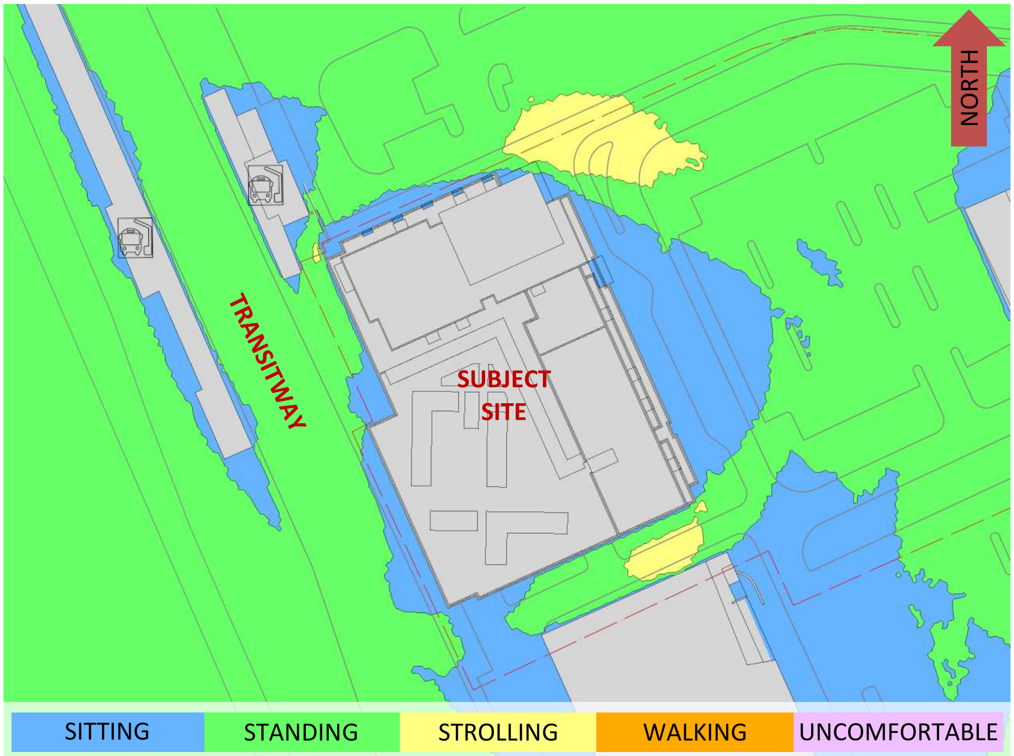


FIGURE 5A: AUTUMN – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

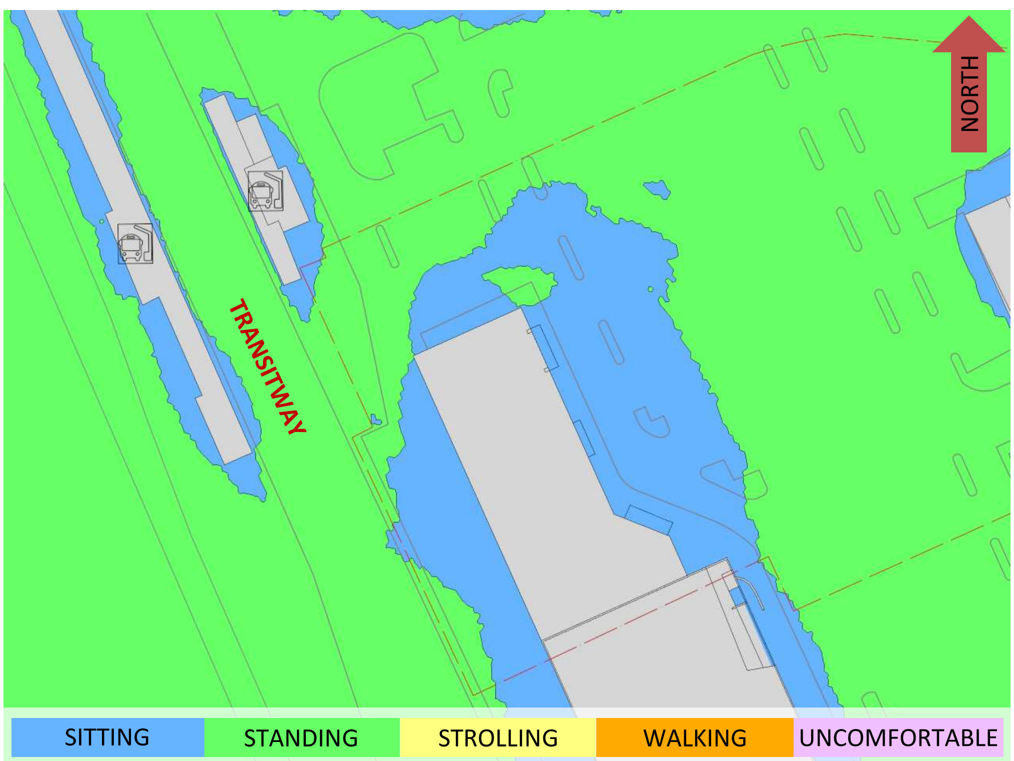


FIGURE 5B: AUTUMN – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

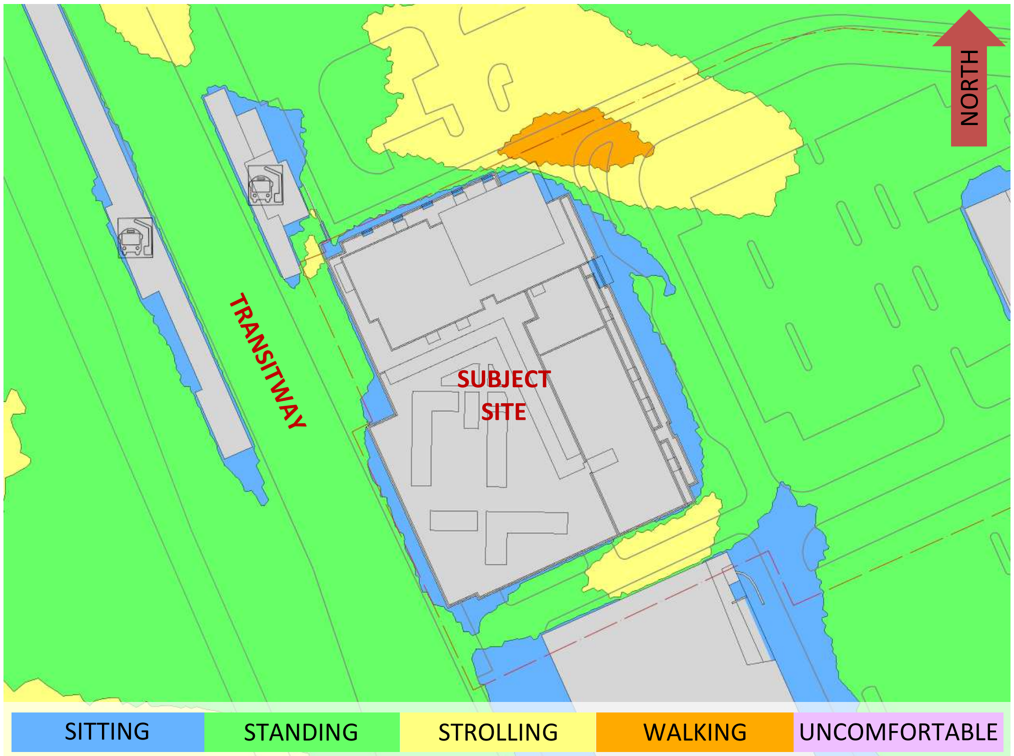


FIGURE 6A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

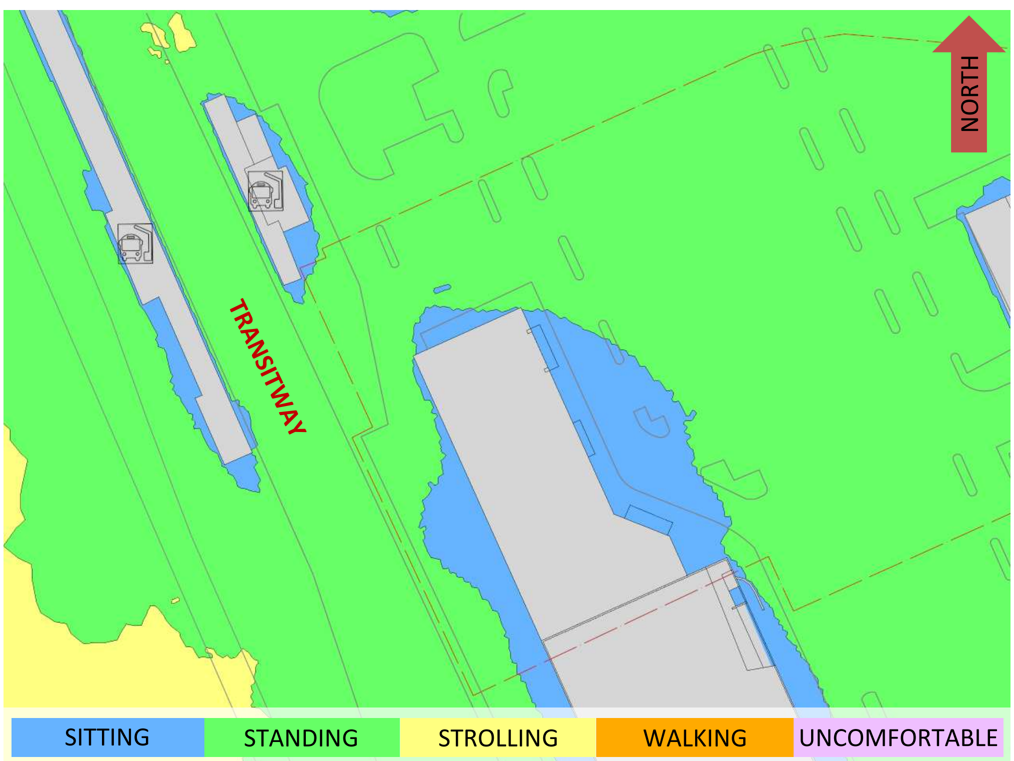


FIGURE 6B: WINTER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

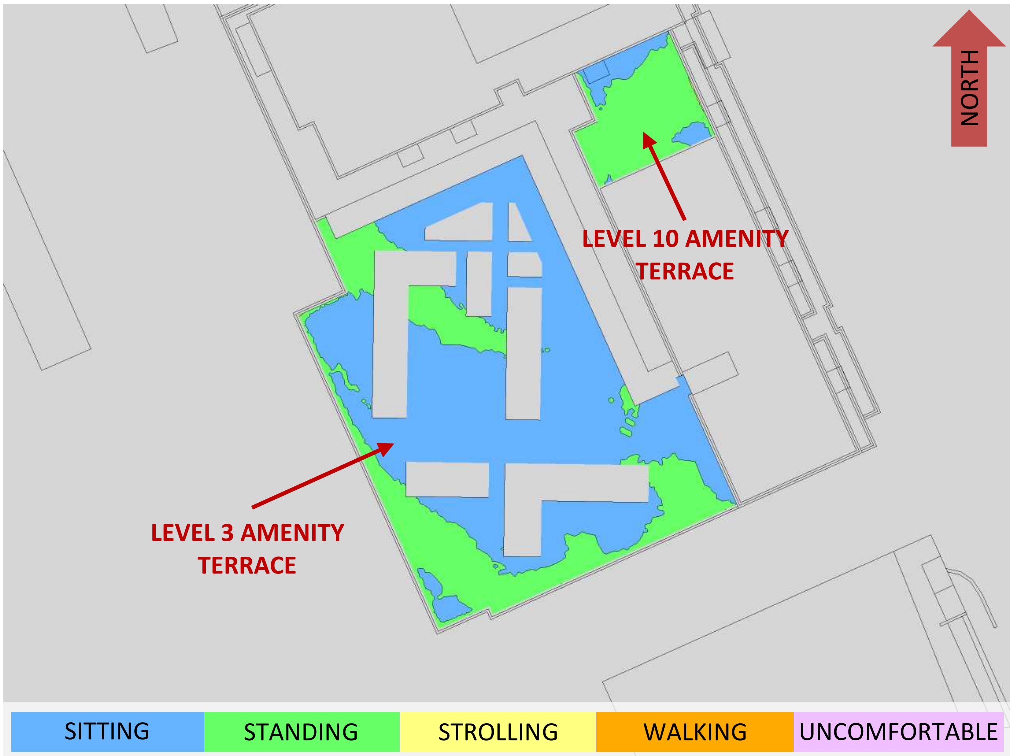


FIGURE 7A: SPRING – WIND COMFORT, COMMON AMENITY TERRACES

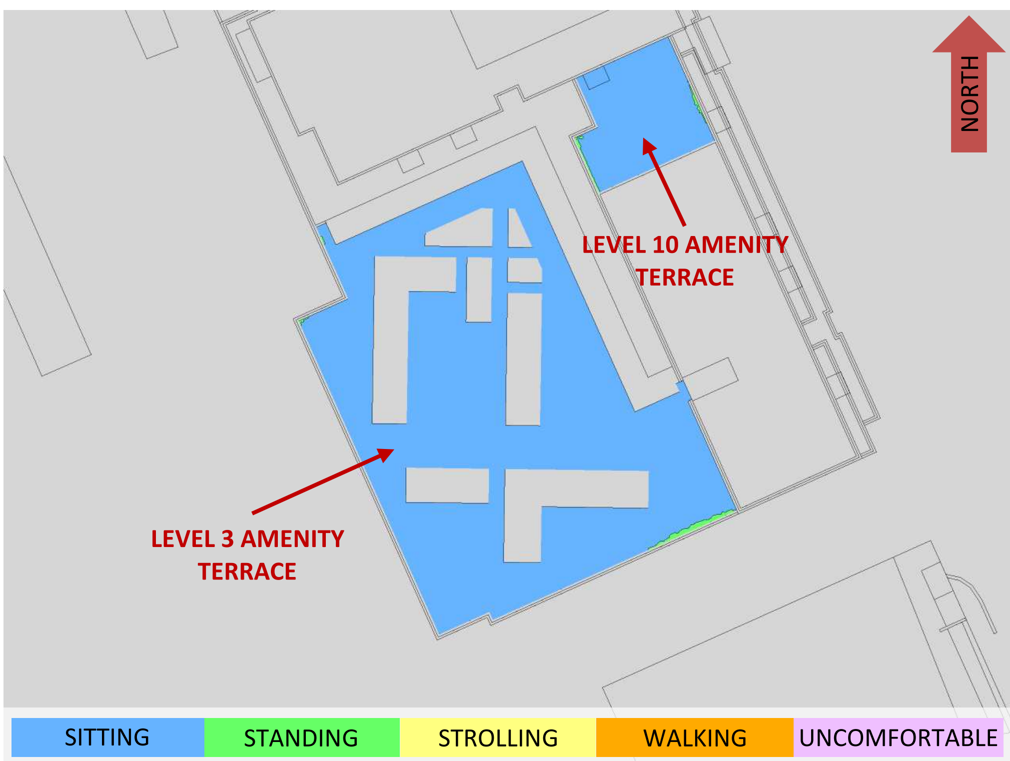


FIGURE 7B: SUMMER – WIND COMFORT, COMMON AMENITY TERRACES

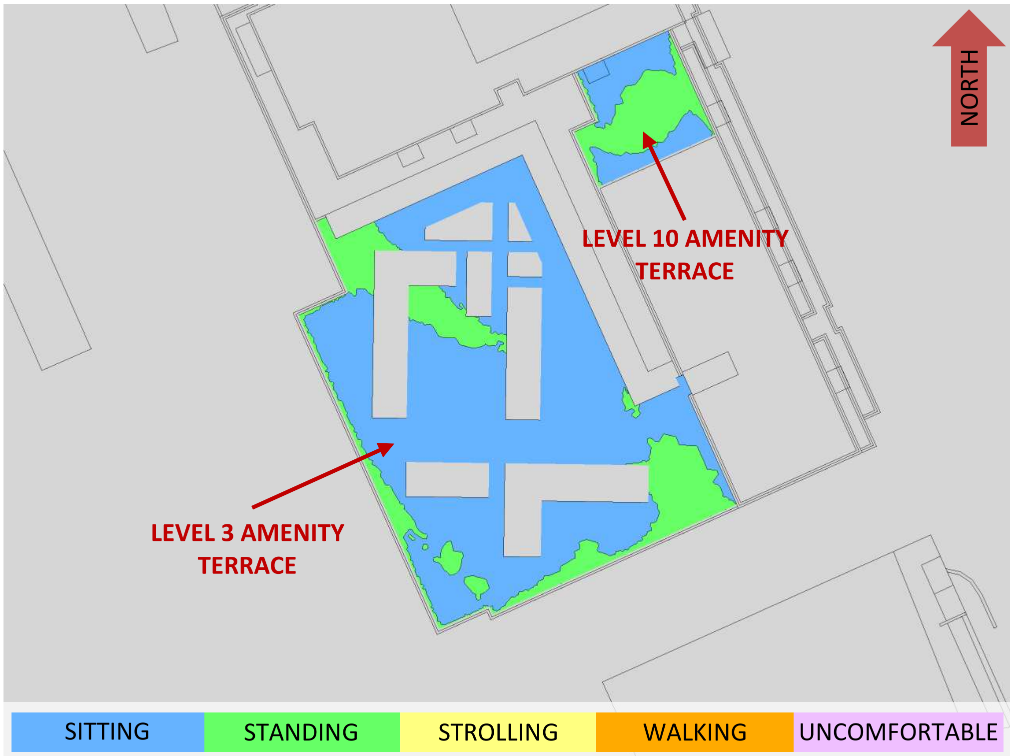


FIGURE 7C: AUTUMN – WIND COMFORT, COMMON AMENITY TERRACES

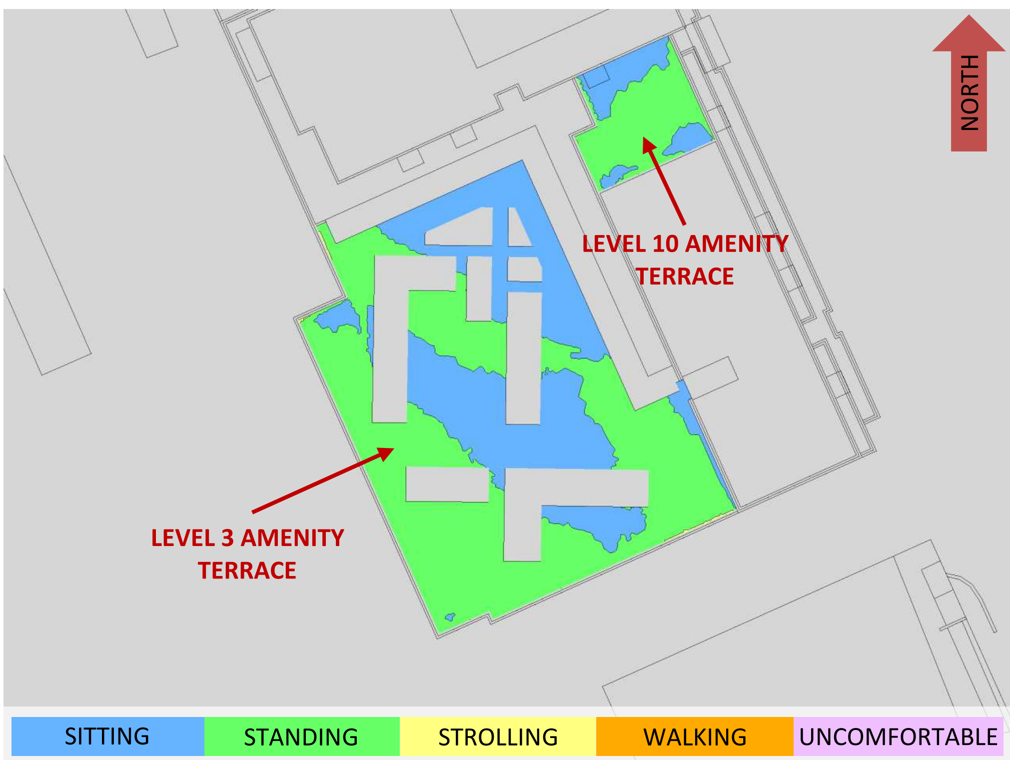


FIGURE 7D: WINTER – WIND COMFORT, COMMON AMENITY TERRACES

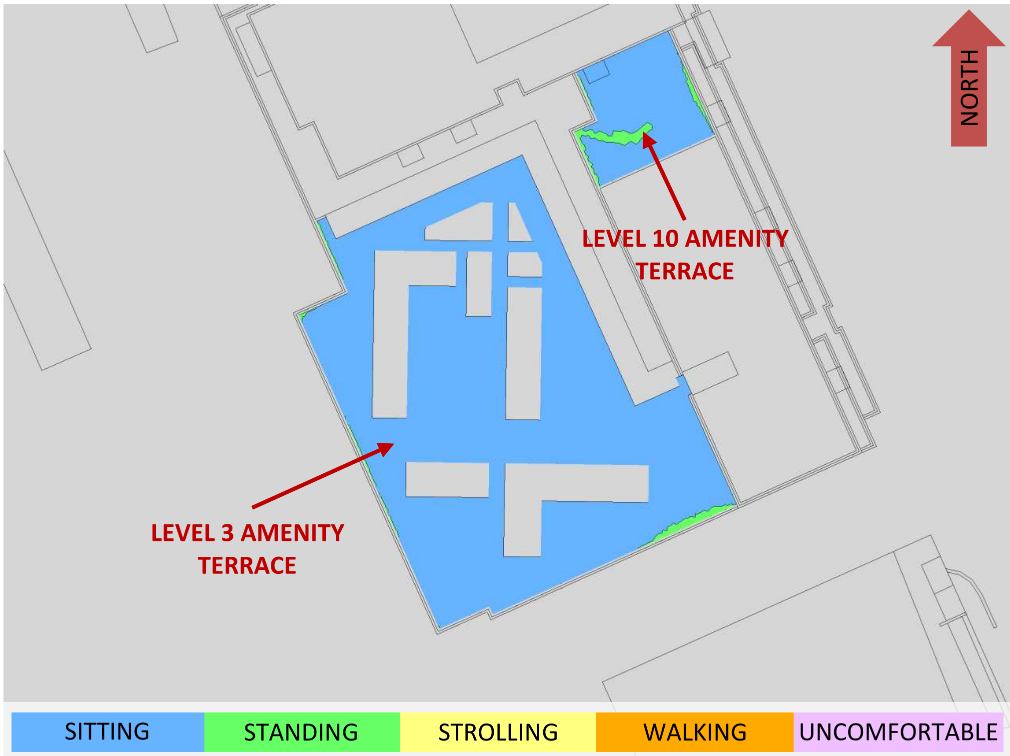
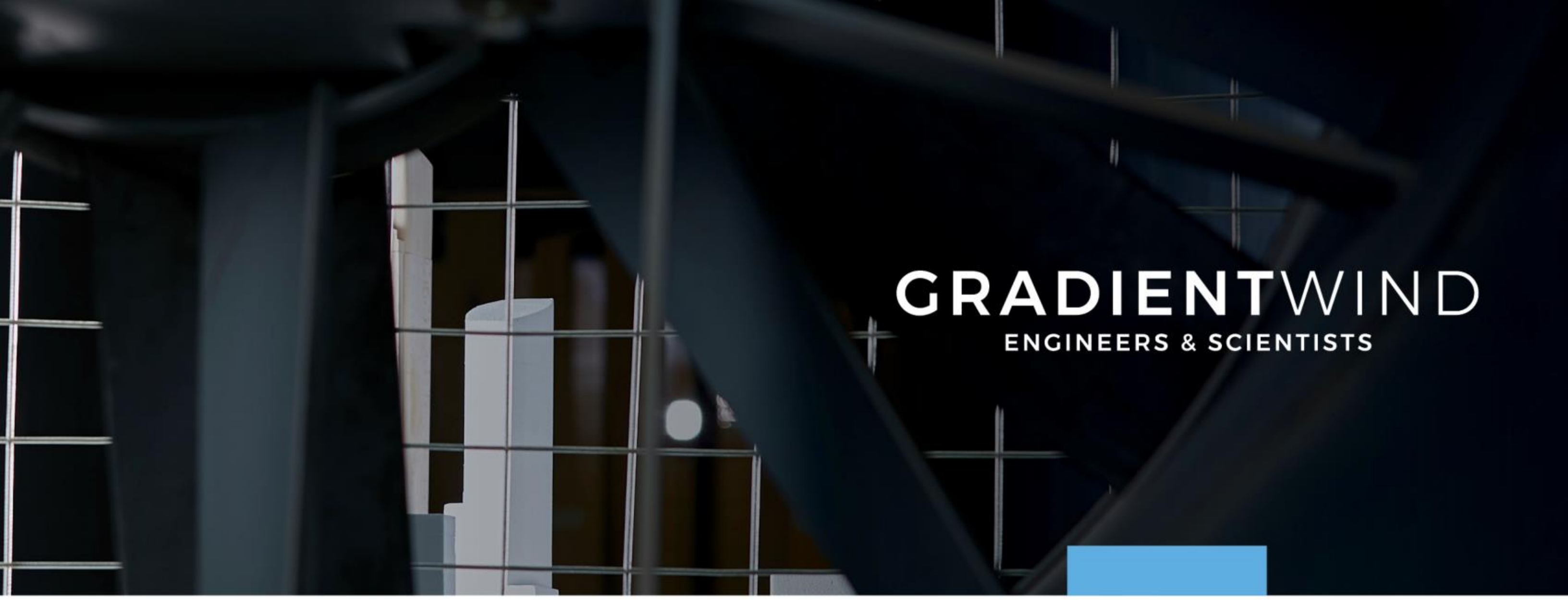
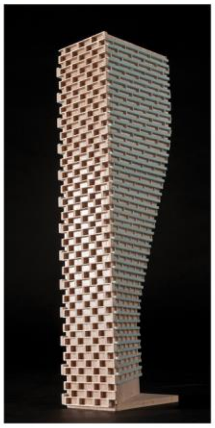
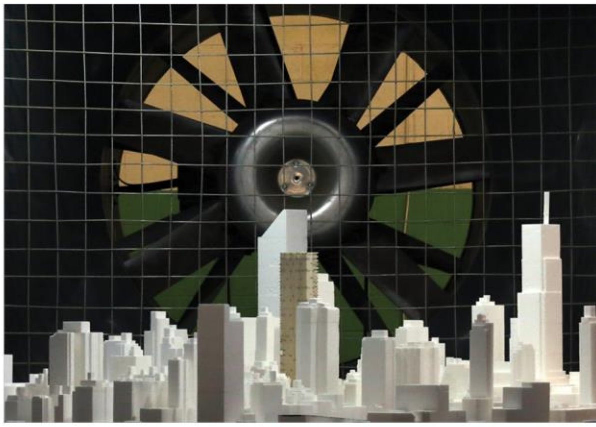


FIGURE 8: TYPICAL USE PERIOD – WIND COMFORT, COMMON AMENITY TERRACES







APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

127 WALGREEN ROAD, OTTAWA, ON, CANADA K0A 1L0 | 613 836 0934
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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).

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

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

For the model, U_g is set to 6.5 metres per second, 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	0.24
49	0.24
74	0.23
103	0.23
167	0.20
197	0.20
217	0.21
237	0.22
262	0.23
282	0.23
301	0.23
324	0.23

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

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

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

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

Equation (2)

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

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.

REFERENCES

[1] P. Arya, "Chapter 10: Near-neutral Boundary Layers," in *Introduction to Micrometeorology*, San Diego, California, Academic Press, 2001.

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[3] Y. Tamura, H. Kawai, Y. Uematsu, K. Kondo and T. Okhuma, "Revision of AIJ Recommendations for Wind Loads on Buildings," in *The International Wind Engineering Symposium, IWES 2003*, Taiwan, 2003.