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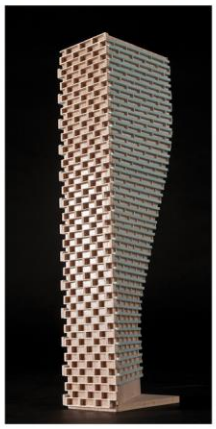
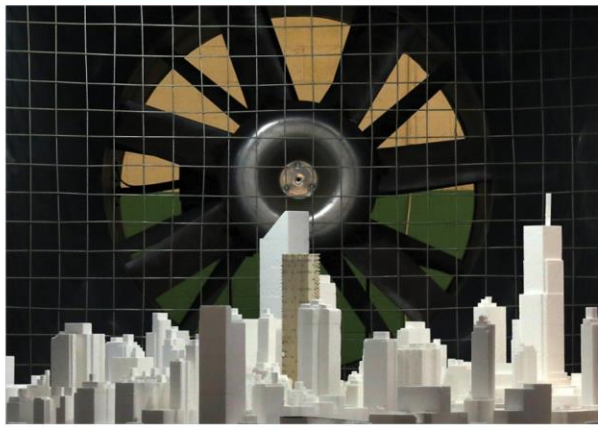
PEDESTRIAN LEVEL WIND STUDY

1047 Richmond Road
Ottawa, Ontario

Report: 21-416-PLW-2023





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PREPARED FOR

1047 Richmond Nominee Inc.
77 King Street W, Suite 3410
Toronto, ON M5K 2A1

PREPARED BY

Sunny Kang, B.A.S., Project Coordinator
David Huitema, M.Eng., 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 Official Plan Amendment (OPA) and Zoning By-law Amendment (ZBLA) application submission requirements for the proposed mixed-use residential development located at 1047 Richmond Road 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. This PLW study, using the computational fluid dynamics (CFD) technique, was conducted to satisfy concurrent OPA and ZBLA application resubmission requirements. The results and recommendations of this study will be confirmed in a PLW study based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

The study involves simulation of wind speeds for selected wind directions in a three-dimensional (3D) computer model using the 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-9, 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, transit stops, the existing parking lots to the north, the loading/service laneway to the north, walkways, and in the vicinity of building access points, are considered acceptable. Exceptions are as follows:

    a. The public sidewalks along New Orchard Avenue North, the existing parking lot to the east, and the central walkways along the drop-off courtyard, between Towers A and B, and between Tower A and Building C, are predicted to receive isolated regions of uncomfortable conditions during the winter season. The noted conditions may be considered satisfactory since the walking percentage exceedance is considered small at a maximum exceedance of 2% of the walking comfort class during the winter season.

b. During the typical use period, conditions over the park at the southwest corner of the subject site are predicted to be suitable for sitting to the north and east and suitable for standing elsewhere with an isolated region suitable for strolling near the northwest corner and conditions over the outdoor amenity to the east of Tower A are predicted to be suitable for sitting close to the building façade and suitable for standing elsewhere with an isolated region suitable for strolling to the southeast. During the same period, conditions over the P.O.P.S. to the east of Building C are predicted to be suitable for sitting over most of the area with standing conditions along the north and east elevations, and conditions over the P.O.P.S. to the west of Building C are predicted to be suitable for sitting to the east and suitable for standing elsewhere.

c. Conditions in the vicinity of the building access point at the northwest corner of Building C are predicted to be windy throughout the year, being suitable for walking, or better, with a region of conditions considered uncomfortable for walking during the winter.

d. Mitigation will be explored through wind tunnel testing. Regarding the P.O.P.S., outdoor amenity, and the park, local mitigation in the form of landscaping elements, such as tall wind screens (typically glazed), planters with coniferous plantings in dense arrangements, and/or strategically placed seating with high-back benches, will also be required to create calm conditions during the typical use period.

e. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

2) Wind conditions over the common amenity terraces serving the proposed development at Level 2, modelled with tall wind screens along their full perimeters, in place of standard height guards, are predicted to be suitable for mostly sitting during the typical use period. The noted conditions are considered acceptable.

3) Conditions during the typical use period over the Level 7 amenity terrace serving Tower B to the south, modelled with tall wind screens, in place of standard height guards, along the east, south, and west terrace perimeters, are predicted to be suitable for sitting over most of the area, with an isolated region suitable for standing to the east. Depending on the programming of the terrace, the noted conditions may be considered acceptable. Specifically, if the noted windier area within the terrace will not accommodate seating or lounging activities, the noted conditions would be considered acceptable. If required, sitting conditions may be extended over the full area by implementing a tall wind screen along the northeast elevation of the terrace in combination with targeted mitigation inboard of the perimeter of the terrace, which could take the form of wind barriers or clusters of coniferous plantings in dense arrangements, and/or canopies around designated seating areas.

4) Regarding the common amenity terrace serving Tower A at Level 7 and the terrace serving Tower B to the west at Level 7, which were modelled with tall wind screens along their full perimeters, in place of standard height guards, conditions are predicted to be windy during the typical use period and will require further mitigation to create calm wind conditions.

    a. Wind mitigation is expected to include tall perimeter wind screens (typically glazed) and mitigation inboard of the perimeter to protect sensitive areas. The noted terraces would also benefit from canopies extending outwards from the adjoining towers to protect the terraces from downwash incident on the northeast and southeast elevations of Tower A and the northwest elevation of Tower B. Additional details of the canopies are provided in Section 5.2.

    b. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

5) 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, with the exception of the Level 7 terrace serving Tower A, where there is a potential for the terrace to develop wind speeds that are in excess of the wind safety threshold of a 0.1% exceedance gust wind speed of 90 km/h on an annual basis and that may be considered dangerous. These conditions will be confirmed in the PLW study based on wind tunnel testing of a physical scale model of the proposed development in its surroundings. 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.

Addendum: The PLW study was completed based on architectural drawings that were prepared by IBI Group in early July 2023. Updated drawings were subsequently distributed to the consultant team with some changes to the proposed development. Notably, a floorplate setback has been introduced at Level 4 to the west of the podium serving Tower B. Additionally, the tower setback has increased from the east property line to a distance of 10 metres (m) compared to the previous 8.5 m. The noted changes are not expected to adversely influence pedestrian wind conditions at grade or within the amenity terraces serving the proposed development. The results and recommendations provided in this study are expected to be representative of the current architectural design.

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1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by 1047 Richmond Nominee Inc. to undertake a pedestrian level wind (PLW) study to satisfy concurrent Official Plan Amendment (OPA) and Zoning By-law Amendment (ZBLA) application resubmission requirements for the proposed mixed-use residential development located at 1047 Richmond Road in Ottawa, Ontario (hereinafter referred to as "subject site" or "proposed development"). A PLW study was conducted in December 2021 for the previous design of the proposed development[1]. 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. This PLW study, using the computational fluid dynamics (CFD) technique, was conducted to satisfy concurrent OPA and ZBLA application resubmission requirements. The results and recommendations of this study will be confirmed in a PLW study based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

Our work in this study is based on industry standard computer simulations using the CFD technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings prepared by IBI Group in July 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 at 1047 Richmond Road in Ottawa, situated to the north at the intersection of Richmond Road and New Orchard Avenue North, on a parcel of land bounded by Richmond Road to the southeast, New Orchard Avenue North to the southwest, a low-rise building to the northwest, and a high-rise residential building to the northeast. Throughout this report, Richmond Road is referred to as project south. The proposed development comprises three buildings identified as "Tower A" (40 storeys), "Tower B" (38 storeys), and "Building C" (six storeys) situated at the northwest corner, to the east, and to the south of the subject site, respectively. A park is provided at the southwest corner of the subject site. Tower A and Tower B are topped with a mechanical penthouse and all three buildings share three below-grade parking levels which are accessed by a parking ramp located to the north of Tower A via a

[1] Gradient Wind Engineering Inc., '*1047 Richmond Road – Pedestrian Level Wind Study*', [Dec 21, 2021]

loading/service laneway extending along the north elevation of the subject site from New Orchard Avenue North. A central drop-off courtyard is accessed from the noted laneway.

The ground floor of Tower A comprises a near 'L'-shaped planform and includes a residential lobby to the south with a main entrance at the southeast corner, an indoor amenity and a retail space at the southwest corner, townhouse units to the northwest, a garbage room and a loading area to the north, and townhouse units along the east elevation. An outdoor amenity and a privately-owned publicly accessible space (P.O.P.S.) are located to the south of Tower A. Level 2 includes an indoor amenity to the south and residential units throughout the remainder of the level. The building steps back from the south elevation to accommodate an amenity terrace at this level. Levels 3-6 are reserved for residential use. Level 7 includes an indoor amenity to the northeast and residential units throughout the remainder of the level. The building steps back from the east elevation to accommodate an amenity terrace at this level. Levels 8-40 rise with a typical residential planform.

The ground floor of Tower B comprises a near 'L'-shaped planform, with its short axis-oriented along the loading/service laneway and includes a central lobby with a residential main entrance to the west, townhouse units at the northwest corner, a garbage room and a loading area to the north, townhouse units along the east elevation, and an indoor amenity to the south. A P.O.P.S. is located at the southwest corner of Tower B. Level 2 includes an indoor amenity at the southwest corner of the short-axis of the building, lockers at the inner corner of the 'L'-shaped planform, and residential units throughout the remainder of the level. The building steps back at the southwest elevation of the short axis to accommodate an amenity terrace at this level. Levels 3-6 are reserved for residential use and the building steps back from the south elevation at Level 4 to accommodate private terraces. Level 7 includes an indoor amenity at the southwest corner and residential units throughout the remainder of the level. The building steps back from the west and south elevations to accommodate an amenity terrace at this level. Levels 8-38 rise with a typical residential planform.

The ground floor of Building C comprises a near trapezoidal planform and includes a residential lobby and main entrance and a loading area to the north, and retail space throughout the remainder of the level. Levels 2-6 are reserved for residential use. The building steps back from the south elevation at Level 4 to accommodate private terraces.

The near-field surroundings, defined as an area within 200-metres (m) of the subject site, include the Sir John A. Macdonald Parkway and the Trans-Canada Trail from the west-southwest clockwise to the northeast, high-rise residential buildings to the east-northeast and to the west-southwest, and mostly low-rise residential buildings for the remaining compass directions. Notably, there is a 28-storey apartment building to the immediate east of the subject site at 1025 Richmond Road and a 30-storey residential building has been approved (OPA and ZBLA) at 1071 Ambleside Drive, approximately 90 m to the west. Additionally, the Stage 2 Ottawa Light Rail Transit West Extension and the future New Orchard Station are currently under construction approximately 20 m to the south 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 the open exposure of the Ottawa River from the west-southwest clockwise to the northeast, and by mostly low-rise buildings with some isolated taller buildings for the remaining compass directions. The Britannia Conservation Area is situated approximately 1 km to the west, and Highway 417 runs southwest-northeast approximately 1.6 km to the southeast.

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 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 criteria[2]. 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.

[2] 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 proposed development, complete with surrounding massing within a radius of 545 m. The process was performed for two context massing scenarios, as noted in Section 2.

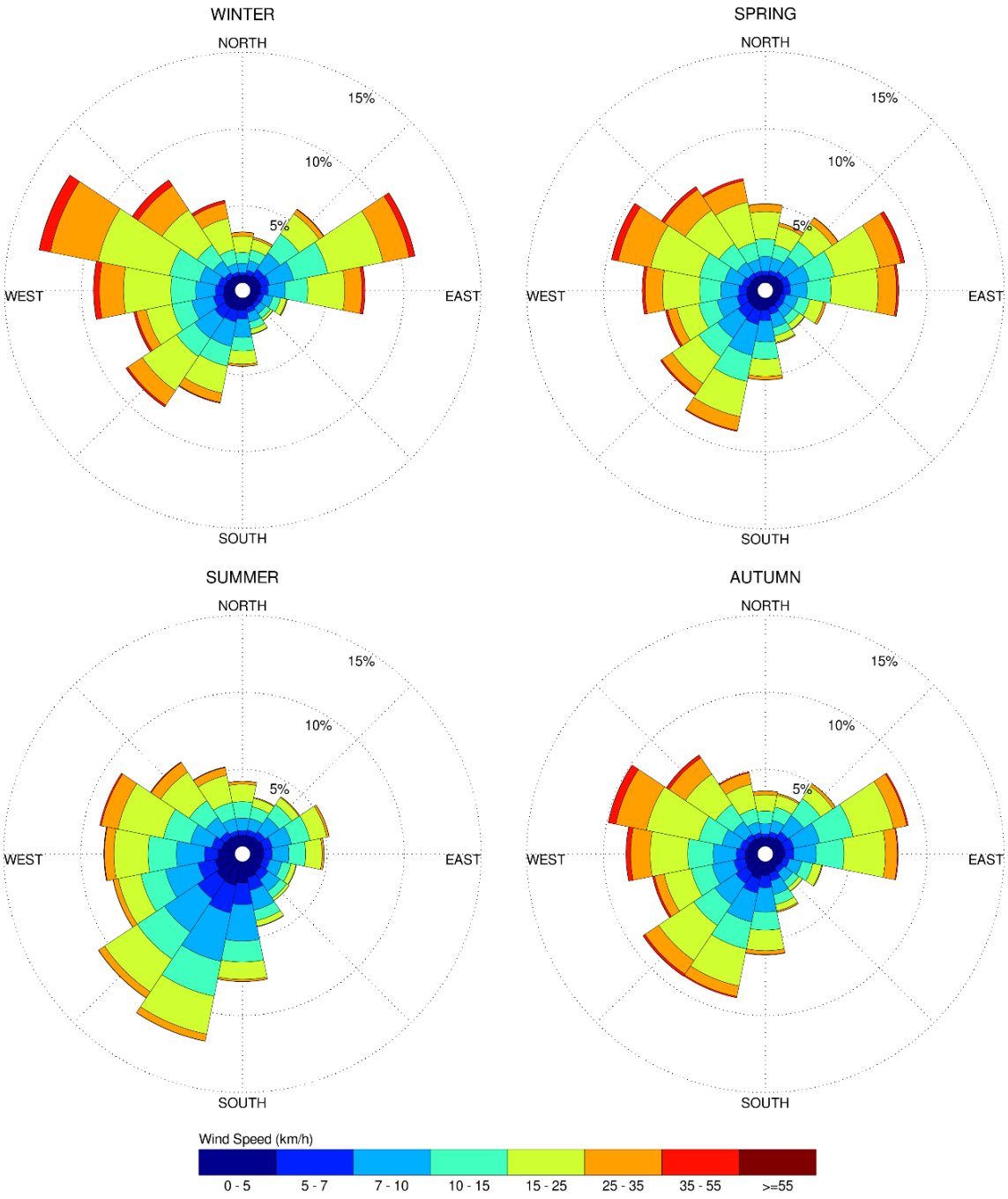
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the common amenity terraces serving the proposed development 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 comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (that is, temperature, relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 20% non-exceedance mean wind speed ranges, which include (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

1) **Sitting:** Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 16 km/h.

2) **Standing:** Mean wind speeds no greater than 14 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 22 km/h.

3) **Strolling:** Mean wind speeds no greater than 17 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 27 km/h.

4) **Walking:** Mean wind speeds no greater than 20 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 32 km/h.

5) **Uncomfortable:** Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.

The pedestrian safety wind speed criterion is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of 90 km/h is classified as dangerous. The gust speeds, and equivalent mean speeds, are selected based on 'The Beaufort Scale', presented on the following page, which describes the effects of forces produced by varying wind speed levels on objects. Gust speeds are included because pedestrians tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also create problems for pedestrians.

THE BEAUFORT SCALE

Number	Description	Gust Wind Speed (km/h)	Description
2	Light Breeze	9-17	Wind felt on faces
3	Gentle Breeze	18-29	Leaves and small twigs in constant motion; wind extends light flags
4	Moderate Breeze	30-42	Wind raises dust and loose paper; small branches are moved
5	Fresh Breeze	43-57	Small trees in leaf begin to sway
6	Strong Breeze	58-74	Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty
7	Moderate Gale	75-92	Whole trees in motion; inconvenient walking against wind
8	Gale	93-111	Breaks twigs off trees; generally impedes progress

Experience and research on people's perception of mechanical wind effects has shown that if the wind speed levels are exceeded for more than 20% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if 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 site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for discrete regions within and surrounding the subject site. This step involves comparing the predicted comfort classes to the desired comfort classes, which are dictated by the location type for each region (that is, a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their typical windiest desired comfort classes are summarized on the following page. Depending on the programming of a space, the desired comfort class may differ from this table.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired 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 8A-8D, illustrating wind conditions over the common amenity terraces serving Towers A and B at Levels 2 and 7. Conditions are presented as continuous contours of wind comfort throughout the subject site and correspond to the comfort classes presented in Section 4.4. 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.

Wind comfort conditions are also reported for the typical use period, which is defined as May to October, inclusive. Figures 7 and 9 illustrate comfort conditions at grade level and over the noted amenity terraces serving the proposed development, respectively, 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

Sidewalks along New Orchard Avenue North and Bus Stop along Ambleside Drive: Following the introduction of the proposed development, wind comfort conditions over the public sidewalks along New Orchard Avenue North are predicted to be suitable for standing, or better, during the summer, becoming suitable for a mix of standing and strolling with an isolated region suitable for walking during the autumn, and suitable for a mix of standing, strolling, and walking during the winter and spring. An isolated region is predicted to be uncomfortable for walking during the winter near the southwest corner of Tower A. Conditions within the noted region are also predicted to be suitable for walking at least 79% of the time during the winter, where the target is 80% to achieve the walking comfort criterion. Since the walking percentage exceedance is considered small (1% of the time during the winter), and the uncomfortable conditions are located mostly over the roadway, the noted conditions may be considered satisfactory.

Conditions over the bus stop located near the subject site along Ambleside Drive, adjacent to the intersection with New Orchard Avenue North, are predicted to be suitable for standing during the summer, strolling during the autumn and spring, and walking during the winter. The bus stop is served by a typical shelter, which provides pedestrians with a means to seek protection from the elements, including during periods of strong wind activity. As such, the noted wind conditions are considered acceptable.

Conditions over the sidewalks along New Orchard Avenue North with the existing massing are predicted to be suitable mostly for sitting during the summer, becoming suitable for a mix of sitting and standing during the autumn, and suitable for standing with isolated regions suitable for strolling during the winter and spring. Conditions over the noted bus stop with the existing massing are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for standing throughout the remainder of the year.

Existing Parking Lot North of Subject Site: Following the introduction of the proposed development, wind comfort conditions over the existing parking lots to the north of the subject site are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for standing, or better, during the spring and autumn with isolated regions suitable for strolling during the spring, and suitable for a mix of standing and strolling during the winter. The noted conditions are considered acceptable.

Conditions over the parking lots to the north with the existing massing are predicted to be suitable for standing, or better, during the summer and autumn, suitable for strolling, or better during the spring, and suitable for a mix of standing and strolling during the winter. Notably, conditions following the introduction of the proposed development over the noted parking lots are predicted to be similar to those under the existing massing, and wind conditions with the proposed development are nevertheless considered acceptable.

Existing Parking Lot East of Subject Site: Following the introduction of the proposed development, conditions over the existing parking lot to the east of the subject site serving 1025 Richmond Road are predicted to be suitable for standing during the summer, becoming suitable for a mix of standing, strolling, and walking during the autumn, and suitable for a mix of strolling and walking during the winter and spring. An isolated region is predicted to be uncomfortable for walking during the winter. Conditions within the noted region are also predicted to be suitable for walking at least 78% of the time during the winter, where the target is 80% to achieve the walking comfort criterion. Since the walking percentage exceedance is considered small (2% of the time during the winter), the noted conditions may be considered satisfactory.

Conditions over the parking lot to the east with the existing massing are predicted to be suitable for standing during the summer, becoming suitable for strolling during the autumn, and suitable for walking, or better, during the spring and winter.

Sidewalks along Richmond Road: Following the introduction of the proposed development, conditions over the public sidewalks along Richmond Road are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, during the autumn, and suitable for walking, or better, during the winter and spring. The calmest winds are predicted along the north sidewalk adjacent to Building C due to the combination of Towers A and B shielding the adjacent area from prominent westerly winds, creating an area of conditions predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

Conditions over the sidewalks along Richmond Road with the existing massing are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, during the spring and autumn, and suitable for walking, or better, during the winter. While the introduction of the

proposed development produces windier conditions in comparison to existing conditions, wind conditions with the proposed development are nevertheless considered acceptable for public sidewalks.

Transit Stops along Richmond Road, New Orchard Station: While two bus stops are located near the subject site along Richmond Road, they will be relocated within the construction scope of the Light Rail Transit New Orchard Station, associated with Stage 2 of the Confederation Line Extension[3]. The new bus stops are illustrated in Figures 1A and 1B; one bus stop is located to the immediate south of the proposed development, while the other bus stop is included within the plaza at the west end of New Orchard Station. The new bus stops are expected to be served by a typical shelter.

Following the introduction of the proposed development, wind comfort conditions in the vicinity of the nearby transit stop situated to the northeast at the intersection of Richmond Road and New Orchard Avenue North, immediately adjacent to the proposed park, are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for a mix of standing and strolling throughout the remainder of the year. Conditions in the vicinity of the transit stop situated within the plaza serving New Orchard Station are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, during the spring and autumn, and suitable for strolling, or better, during the winter. Since both transit stops are expected to be served by a typical shelter, which provides pedestrians a means to seek protection from the elements, including during periods of strong wind activity, the noted wind conditions are considered acceptable.

With the existing massing, conditions in the vicinity of the nearby transit stop immediately adjacent to the proposed park are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing throughout the remainder of the year. Conditions in the vicinity of the transit stop situated within the plaza serving New Orchard Station are predicted to be suitable for sitting during the summer and autumn, becoming suitable for a mix of sitting and standing during the winter and spring. While the introduction of the proposed development produces windier conditions in comparison to existing conditions, wind comfort conditions are nevertheless considered acceptable.

[3] City of Ottawa, 'Overview: Stage 2 Light Rail Transit Project', (published Sep 29, 2020), <*https://ottawa.ca/en/planning-development-and-construction/major-projects/stage-2-light-rail-transit-project/overview* > (accessed July 6, 2023)

Prior to the introduction of the proposed development, wind comfort conditions in the vicinity of the main entrance along the west elevation of the New Orchard Station are predicted to be suitable for sitting throughout the year. The noted conditions remain unchanged following the introduction of the proposed development, and the wind conditions with the proposed development are considered acceptable.

Walkways, Laneways, and Drop-off Courtyard: Wind comfort conditions over the walkways along the laneway situated along the north elevation of the subject site are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for a mix of standing and strolling throughout the remainder of the year with isolated regions suitable for walking during the winter and spring. The noted conditions are considered acceptable.

The walkways along the laneway between Towers A and B, the drop-off courtyard, and the walkways between Tower A and Building C are predicted to be windy on account of horizontal winds that accelerate through the area between Towers A and B and Tower A and Building C from several prominent compass directions. Conditions over the noted walkways and over the central drop-off courtyard are predicted to be suitable for standing during the summer, becoming suitable for strolling, or better, with isolated regions suitable for walking during the autumn, and suitable for a mix of standing, strolling, and walking during the winter and spring. Three isolated regions between the two podia and near the northwest corner of Building C are predicted to be uncomfortable for walking during the winter. Conditions within the noted regions are also predicted to be suitable for walking at least 78% of the time during the winter, where the target is 80% to achieve the walking comfort criterion. Since the walking percentage exceedance is considered small (2% of the time or less during the winter), the noted conditions may be considered satisfactory.

Mitigation will be explored through wind tunnel testing. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

Conditions over the remaining walkways within 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 with isolated regions suitable for walking during the winter and spring. The noted conditions are considered acceptable.

Park, Outdoor Amenity, and P.O.P.S.: During the typical use period, wind comfort conditions over the park situated at the southwest corner of the subject site are predicted to be suitable for sitting to the north and east and suitable for standing elsewhere with an isolated region suitable for strolling near the northwest corner of the park, as illustrated in Figure 7.

During the typical use period, wind comfort conditions over the outdoor amenity situated to the south of Tower A are predicted to be suitable for sitting close to the building façade and suitable for standing elsewhere with an isolated region suitable for strolling to the southeast of the outdoor amenity.

Conditions during the typical use period over the P.O.P.S. situated to the east of Building C are predicted to be suitable for sitting over most of the area with regions predicted to be suitable for standing along the north and east elevations. Conditions over the P.O.P.S. situated to the west of Building C are predicted to be suitable for sitting to the east and suitable for standing elsewhere during the typical use period.

To shield the noted areas from prominent winds and to improve comfort levels within the park, outdoor amenity, and P.O.P.S., it is recommended that landscaping features such as tall wind barriers in the form of wind screens and dense arrangements of coniferous plantings be installed around sensitive areas, in combination with strategically placed seating with high-back benches and other local wind mitigation. The extent of mitigation measures is dependent on the programming of the noted spaces. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

Building Access Points: Owing to the recessing of the entrances into the building façades, conditions in the vicinity of the primary building entrances fronting the laneway from the drop-off courtyard to the loading/service laneway are predicted to be suitable for sitting throughout the year. Wind conditions in the vicinity of the entrances to the Tower A, Tower B, and Building C residential lobbies are predicted to

be suitable for sitting during the summer, becoming suitable for standing, or better, throughout the remainder of the year. Wind conditions in the vicinity of the secondary building access at the northeast corner of Building C are predicted to be suitable for walking, or better, throughout the year. The noted conditions are considered acceptable.

Wind conditions in the vicinity of the secondary building access point at the northwest corner of Building C are predicted to be windy, being suitable for standing during the summer, strolling, or better, during the autumn, and walking, or better, during the spring and winter, with conditions uncomfortable for walking in the vicinity of the building access point during the winter. Mitigation measures to address the windy conditions through the central areas of the subject site are expected to improve conditions along the elevations fronting the central laneway and drop-off courtyard. Mitigation strategies will be developed and confirmed in collaboration with the design team in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

Wind comfort conditions in the vicinity of the remaining building access points serving the proposed development 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

The proposed development is served by several common amenity terraces, which were modelled with tall wind screens along their perimeters, in place of standard height guards. Wind comfort conditions within the amenity terraces during the typical use period and recommendations regarding mitigation, where required, are described as follows:

Tower A, Level 2 Common Amenity Terrace: With the noted mitigation, wind comfort conditions within the common amenity terrace serving Tower A at Level 2 are predicted to be suitable for sitting over most of the area with a small, isolated region predicted to be suitable for standing to the west, as illustrated in Figure 9. The noted conditions are considered acceptable.

Tower A, Level 7 Common Amenity Terrace: With the noted mitigation, conditions within the common amenity terrace serving Tower A at Level 7 are predicted to be suitable for sitting close to the tower façade

and at the northeast corner, suitable for standing to the west, east, and south, and suitable for strolling central to the terrace (Figure 9).

To improve comfort levels within the terrace, it is recommended that taller wind screens be implemented along the full perimeter of the terrace to shield the area from prominent winds, in combination with targeted mitigation inboard of the terrace perimeter, which could take the form of wind barriers or clusters of coniferous plantings in dense arrangements, and/or canopies to shield designated seating areas. Additionally, conditions could also be improved by introducing a canopy along the elevation of Tower A, extending outward from the façade by at least 3 m. The underside of the canopy should have a clear height not exceeding 5 m as measured from the walking surface of the terrace. The canopy is expected to deflect downwash winds incident on the northeast and southeast elevations of Tower A, including vortices that are predicted to form at the northeast corner of Tower A, away from the terrace.

Tower B, Level 2 Common Amenity Terrace: With the noted mitigation, conditions within the common amenity terrace serving Tower B at Level 2 are predicted to be suitable for sitting (Figure 9). The noted conditions are considered acceptable.

Tower B, South Level 7 Common Amenity Terrace: With the noted mitigation, conditions within the common amenity terrace serving Tower B at Level 7 to the south are predicted to be suitable for sitting over most of the area with an isolated region suitable for standing to the east (Figure 9). 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.

Depending on the programming of the terrace, the noted conditions may be considered acceptable. Specifically, if the noted windier area within the terrace will not accommodate seating or lounging activities, the noted conditions would be considered acceptable. If required by programming, sitting conditions may be extended over the full terrace area by implementing a tall wind screen along the northeast elevation of the terrace, between the private terraces and the common amenity terrace, in combination with targeted mitigation inboard of the perimeter of the terrace, which could take the form of wind barriers or clusters of coniferous plantings in dense arrangements, and/or canopies around designated seating areas.

Tower B, West Level 7 Common Amenity Terrace: With the noted mitigation, wind conditions within the common amenity terrace serving Tower B at Level 7 to the west are predicted to be suitable for sitting close to the tower façade and along the south, west, and northwest terrace elevations, and suitable for standing elsewhere (Figure 9). Where conditions are predicted to be suitable for standing, they are also predicted to be suitable for sitting for at least 72% of the time during the same period, where the target is 80% to achieve the sitting comfort class.

The implementation of a taller wind screen, typically glazed, along the north and west perimeters of the terrace is recommended to shield the area from prominent winds, in combination with mitigation inboard of the perimeter of the terrace, which could take the form of wind barriers or clusters of coniferous plantings in dense arrangements, and/or canopies around designated seating areas. Conditions could also be improved to achieve the sitting comfort class by introducing a canopy at the northwest corner of Tower B, extending outward from the façade by at least 3 m. The underside of the canopy should have a clear height not exceeding 5 m as measured from the walking surface of the terrace. The canopy is expected to deflect downwash winds incident on the northwest elevation of Tower B away from the terrace.

The extent of mitigation measures is dependent on the programming of the noted amenity terraces. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

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, with the exception of the Level 7 terrace serving Tower A, where there is a potential for the terrace to develop wind speeds that are in excess of the wind safety threshold of a 0.1% exceedance gust wind speed of 90 km/h on an annual basis and that may be considered dangerous. These conditions will be confirmed in the PLW study based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

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

This PLW study, using the CFD technique, was conducted to satisfy concurrent OPA and ZBLA application resubmission requirements. The results and recommendations of this study will be confirmed in a PLW study based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-9. 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, transit stops, the existing parking lots to the north, the loading/service laneway to the north, walkways, and in the vicinity of building access points, are considered acceptable. Exceptions are as follows:

    a. The public sidewalks along New Orchard Avenue North, the existing parking lot to the east, and the central walkways along the drop-off courtyard, between Towers A and B, and between Tower A and Building C, are predicted to receive isolated regions of uncomfortable conditions during the winter season. The noted conditions may be considered satisfactory since the walking percentage exceedance is considered small at a maximum exceedance of 2% of the walking comfort class during the winter season.

b. During the typical use period, conditions over the park at the southwest corner of the subject site are predicted to be suitable for sitting to the north and east and suitable for standing elsewhere with an isolated region suitable for strolling near the northwest corner and conditions over the outdoor amenity to the east of Tower A are predicted to be suitable for sitting close to the building façade and suitable for standing elsewhere with an isolated region suitable for strolling to the southeast. During the same period, conditions over the P.O.P.S. to the east of Building C are predicted to be suitable for sitting over most of the area with standing conditions along the north and east elevations, and conditions over the P.O.P.S. to the west of Building C are predicted to be suitable for sitting to the east and suitable for standing elsewhere.

c. Conditions in the vicinity of the building access point at the northwest corner of Building C are predicted to be windy throughout the year, being suitable for walking, or better, with a region of conditions considered uncomfortable for walking during the winter.

d. Mitigation will be explored through wind tunnel testing. Regarding the P.O.P.S., outdoor amenity, and the park, local mitigation in the form of landscaping elements, such as tall wind screens (typically glazed), planters with coniferous plantings in dense arrangements, and/or strategically placed seating with high-back benches, will also be required to create calm conditions during the typical use period.

e. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

2) Wind conditions over the common amenity terraces serving the proposed development at Level 2, modelled with tall wind screens along their full perimeters, in place of standard height guards, are predicted to be suitable for mostly sitting during the typical use period. The noted conditions are considered acceptable.

3) Conditions during the typical use period over the Level 7 amenity terrace serving Tower B to the south, modelled with tall wind screens, in place of standard height guards, along the east, south, and west terrace perimeters, are predicted to be suitable for sitting over most of the area, with an isolated region suitable for standing to the east. Depending on the programming of the terrace, the noted conditions may be considered acceptable. Specifically, if the noted windier area within the terrace will not accommodate seating or lounging activities, the noted conditions would be considered acceptable. If required, sitting conditions may be extended over the full area by implementing a tall wind screen along the northeast elevation of the terrace in combination with targeted mitigation inboard of the perimeter of the terrace, which could take the form of wind barriers or clusters of coniferous plantings in dense arrangements, and/or canopies around designated seating areas.

4) Regarding the common amenity terrace serving Tower A at Level 7 and the terrace serving Tower B to the west at Level 7, which were modelled with tall wind screens along their full perimeters, in place of standard height guards, conditions are predicted to be windy during the typical use period and will require further mitigation to create calm wind conditions.

    a. Wind mitigation is expected to include tall perimeter wind screens (typically glazed) and mitigation inboard of the perimeter to protect sensitive areas. The noted terraces would also benefit from canopies extending outwards from the adjoining towers to protect the terraces from downwash incident on the northeast and southeast elevations of Tower A and the northwest elevation of Tower B. Additional details of the canopies are provided in Section 5.2.

    b. Mitigation strategies will be developed and confirmed in collaboration with the design team as the design progresses and in preparation of the future Site Plan Control application submission, which requires the development of pedestrian wind conditions based on wind tunnel testing of a physical scale model of the proposed development in its surroundings.

5) 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, with the exception of the Level 7 terrace serving Tower A, where there is a potential for the terrace to develop wind speeds that are in excess of the wind safety threshold of a 0.1% exceedance gust wind speed of 90 km/h on an annual basis and that may be considered dangerous. These conditions will be confirmed in the PLW study based on wind tunnel testing of a physical scale model of the proposed development in its surroundings. 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.

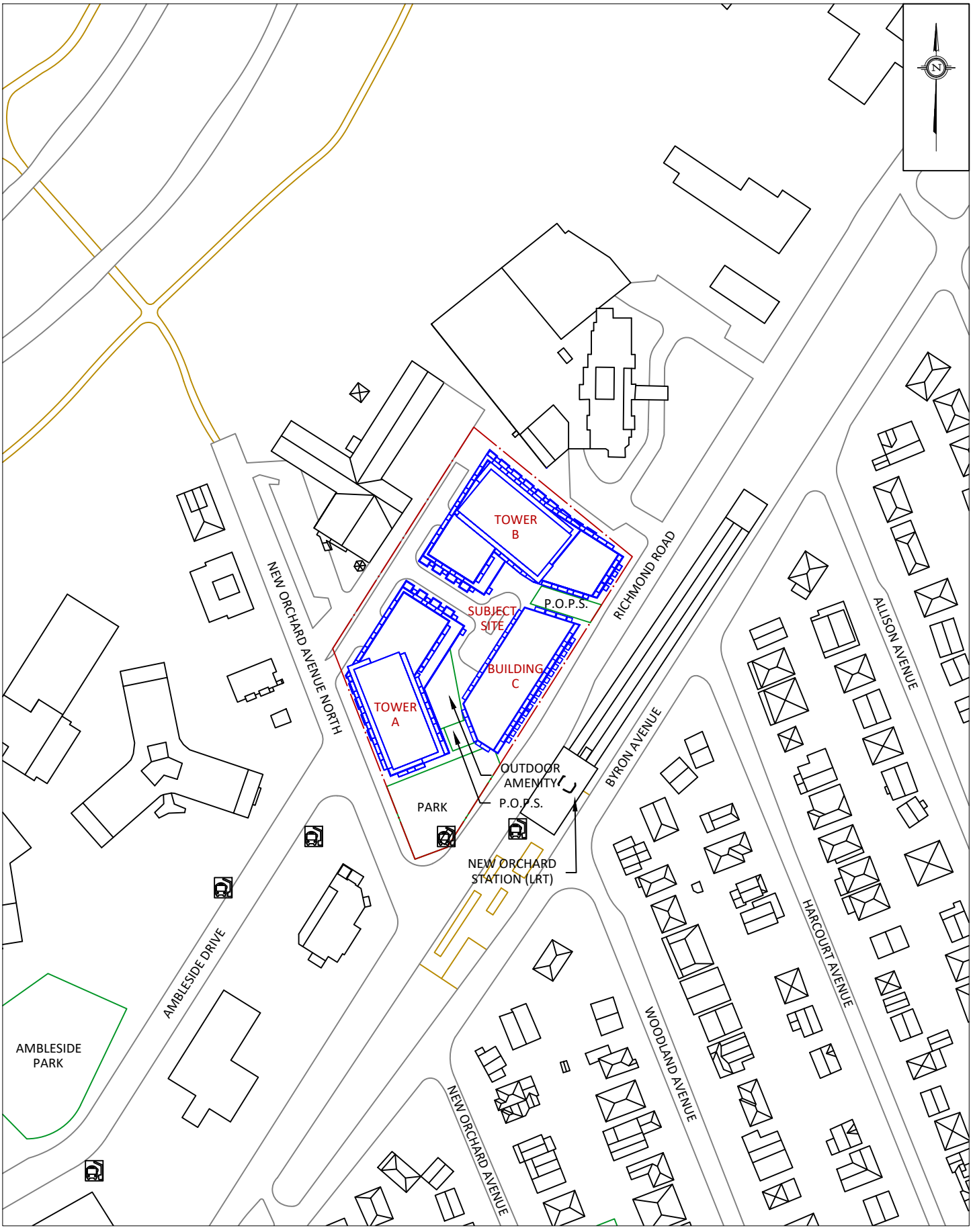
Sincerely,

Gradient Wind Engineering Inc.

David Huitema, M.Eng.
Wind Scientist

Justin Ferraro, P.Eng.
Principal

Sunny Kang, B.A.S.
Project Coordinator



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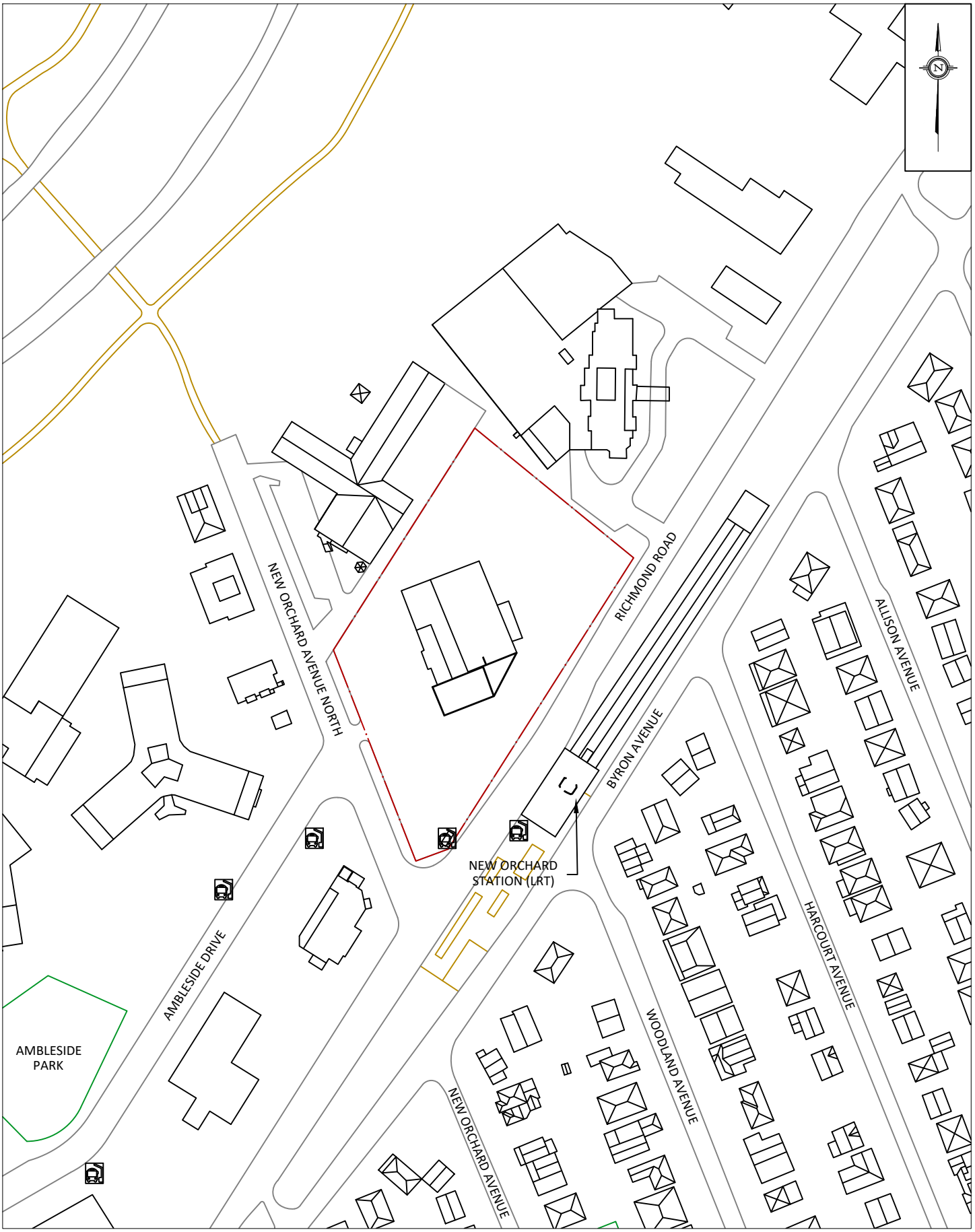
SCALE	1:2000
DRAWING NO.	21-416-PLW-2023-1A
DATE	JULY 7, 2023
DRAWN BY	S.K.

DESCRIPTION

FIGURE 1A:
PROPOSED SITE PLAN AND SURROUNDING CONTEXT



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PROJECT	1047 RICHMOND ROAD, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:2000
DRAWING NO.	21-416-PLW-2023-1B
DATE	JULY 7, 2023
DRAWN BY	S.K.

DESCRIPTION

FIGURE 1B:
EXISTING SITE PLAN AND SURROUNDING CONTEXT

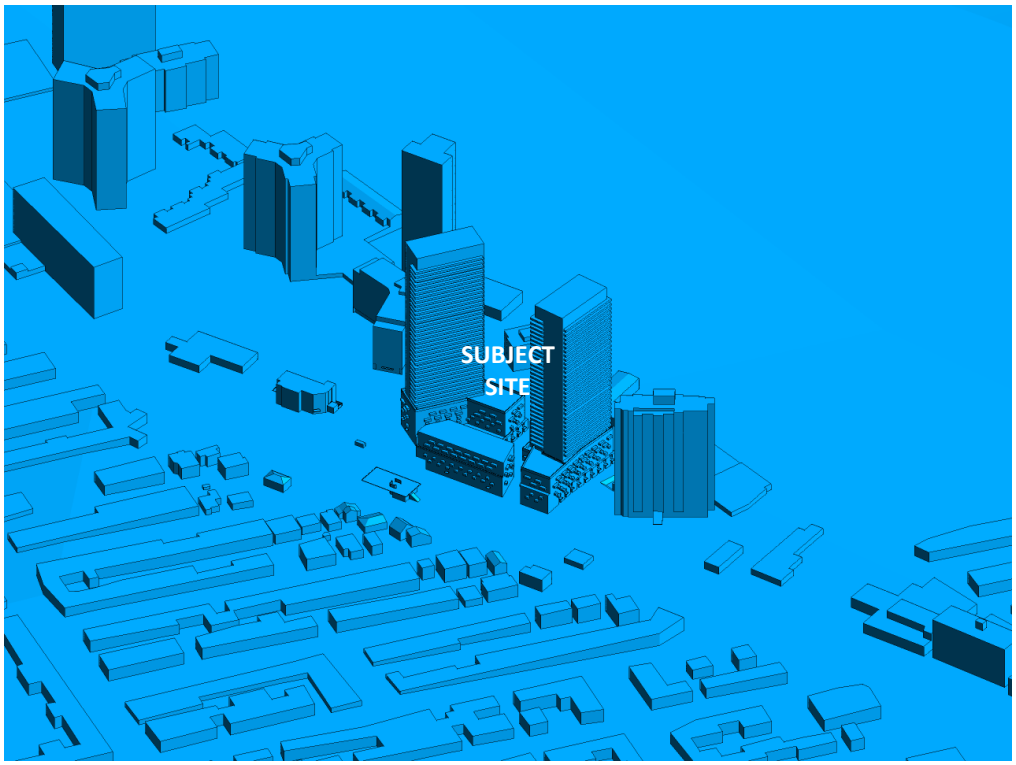


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, EAST PERSPECTIVE

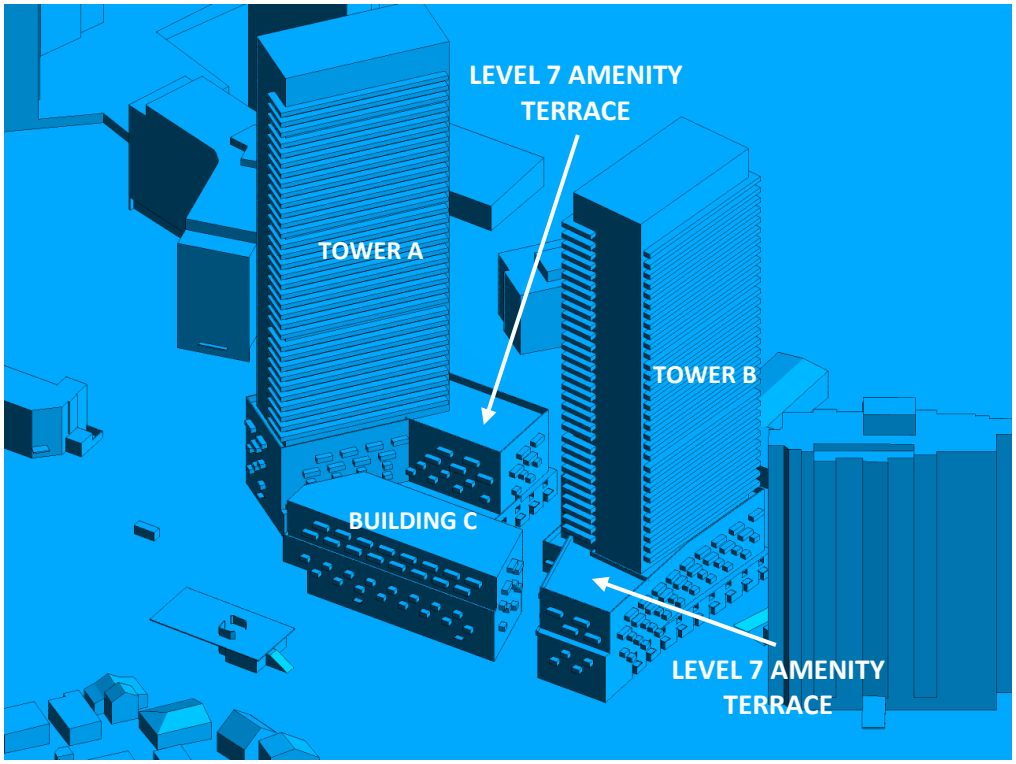


FIGURE 2B: CLOSE UP OF FIGURE 2A

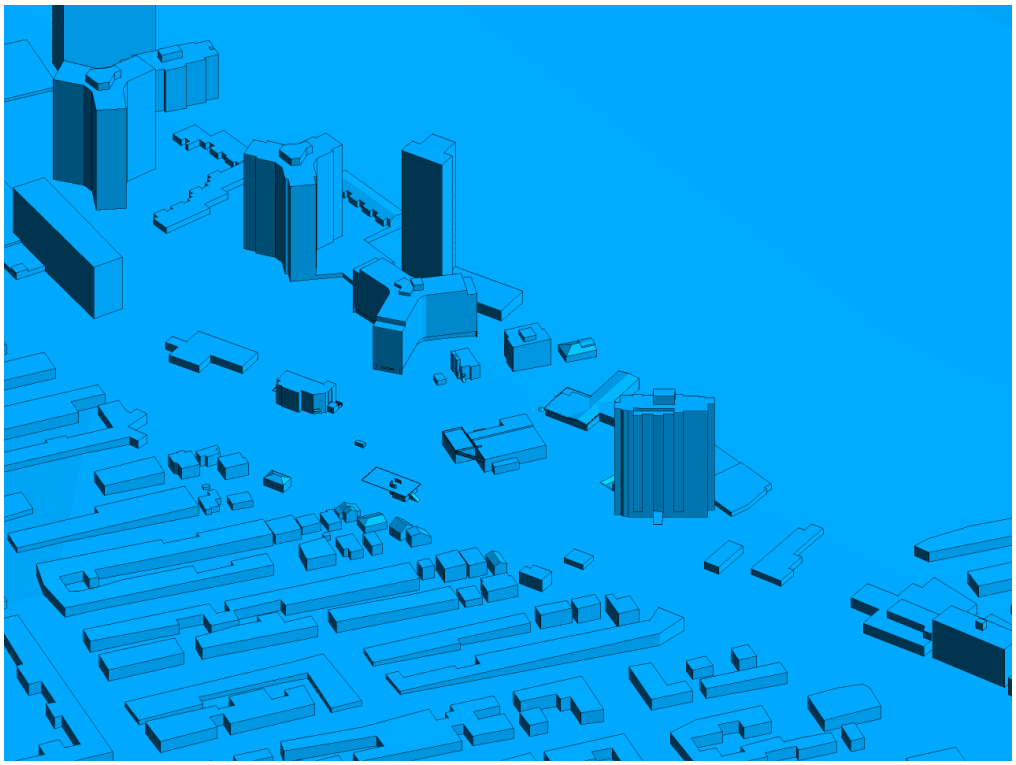


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, EAST PERSPECTIVE

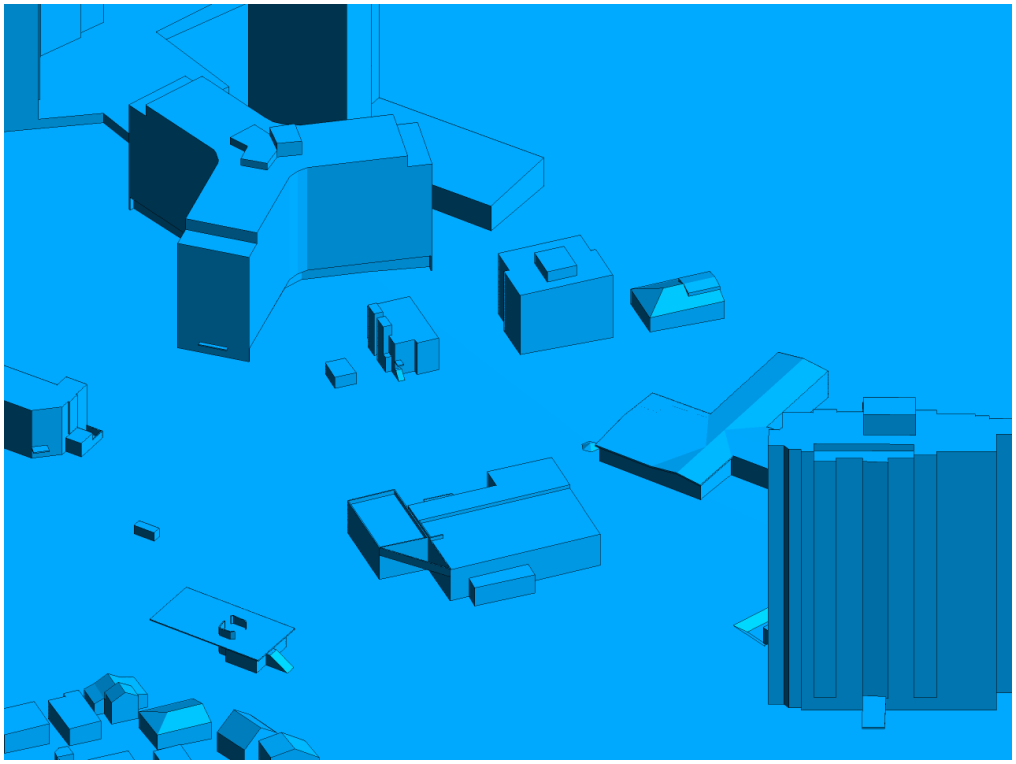


FIGURE 2D: CLOSE UP OF FIGURE 2C

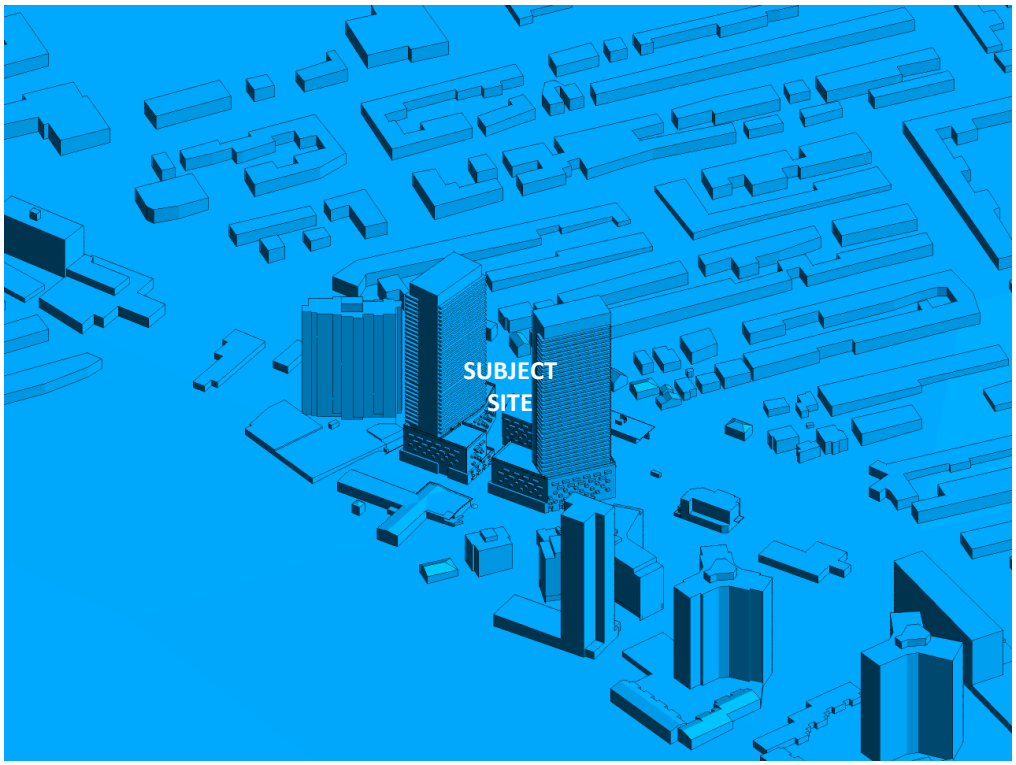


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, WEST PERSPECTIVE

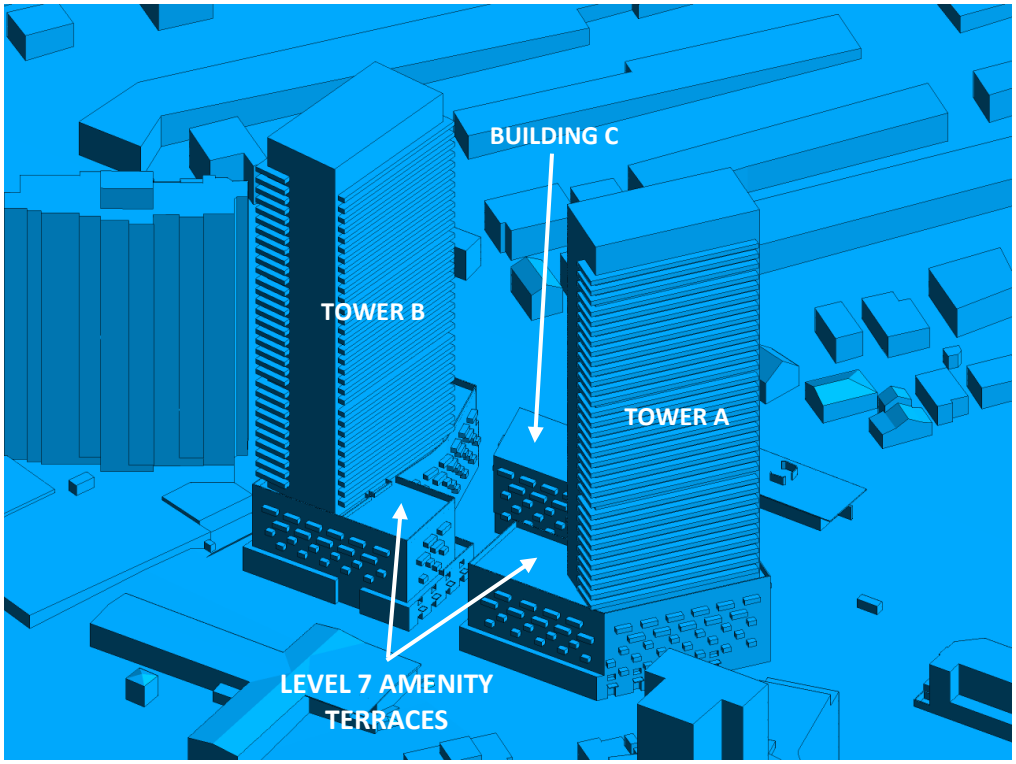


FIGURE 2F: CLOSE UP OF FIGURE 2E

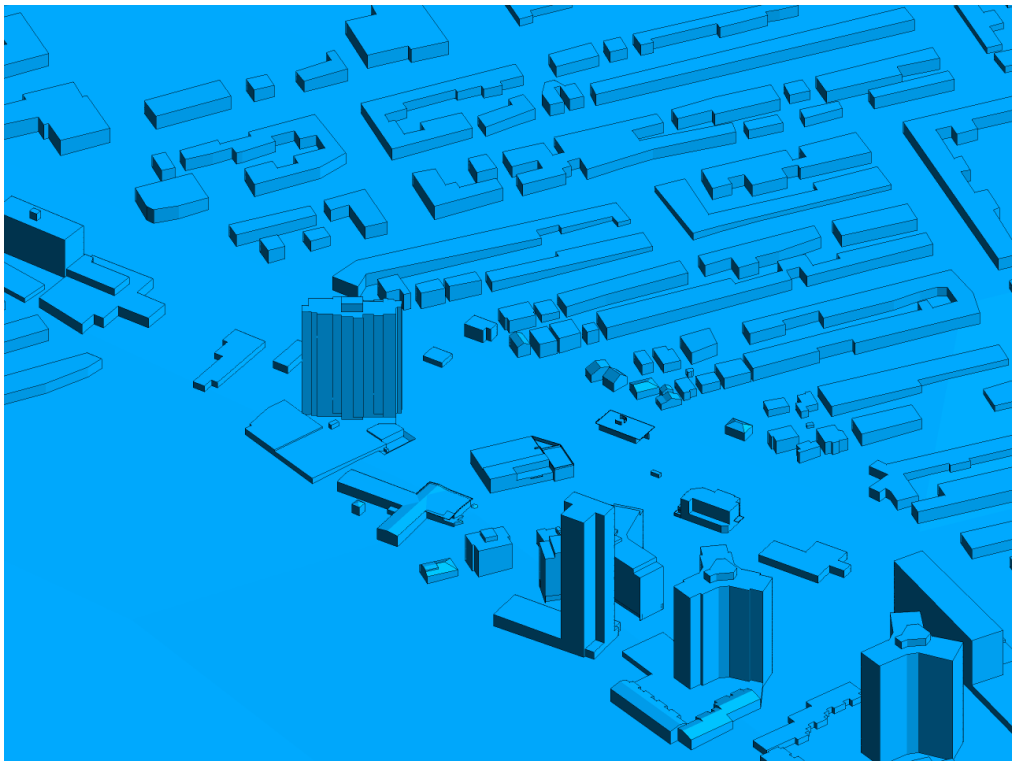


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, WEST PERSPECTIVE

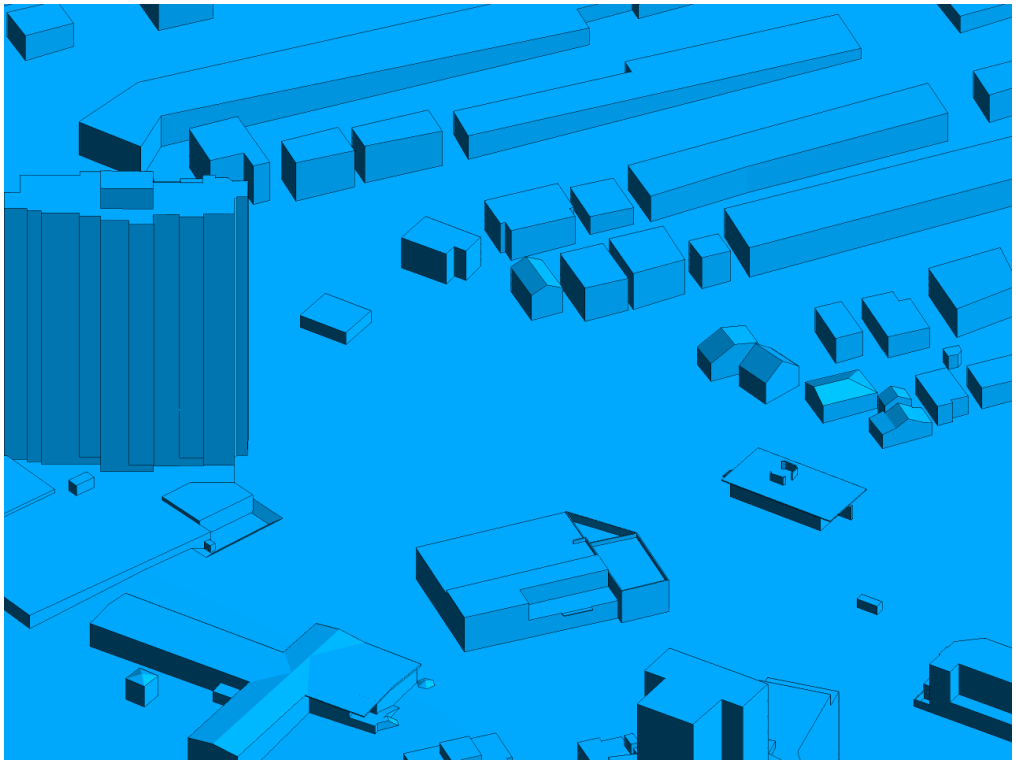


FIGURE 2H: CLOSE UP OF FIGURE 2G

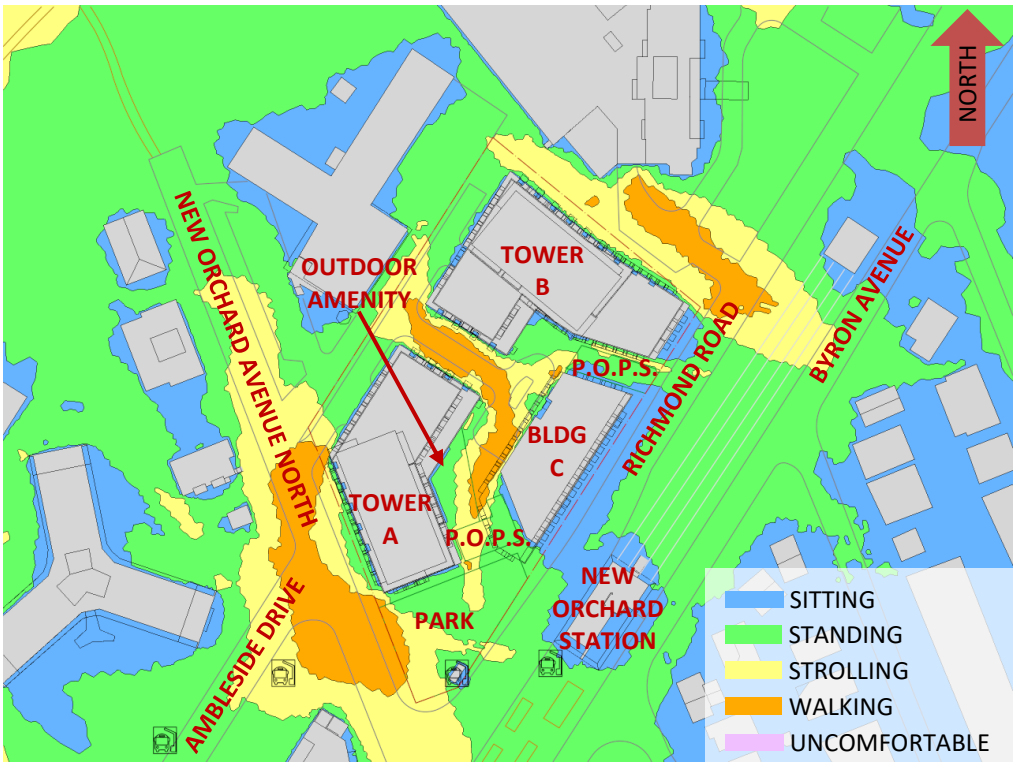


FIGURE 3A: SPRING – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

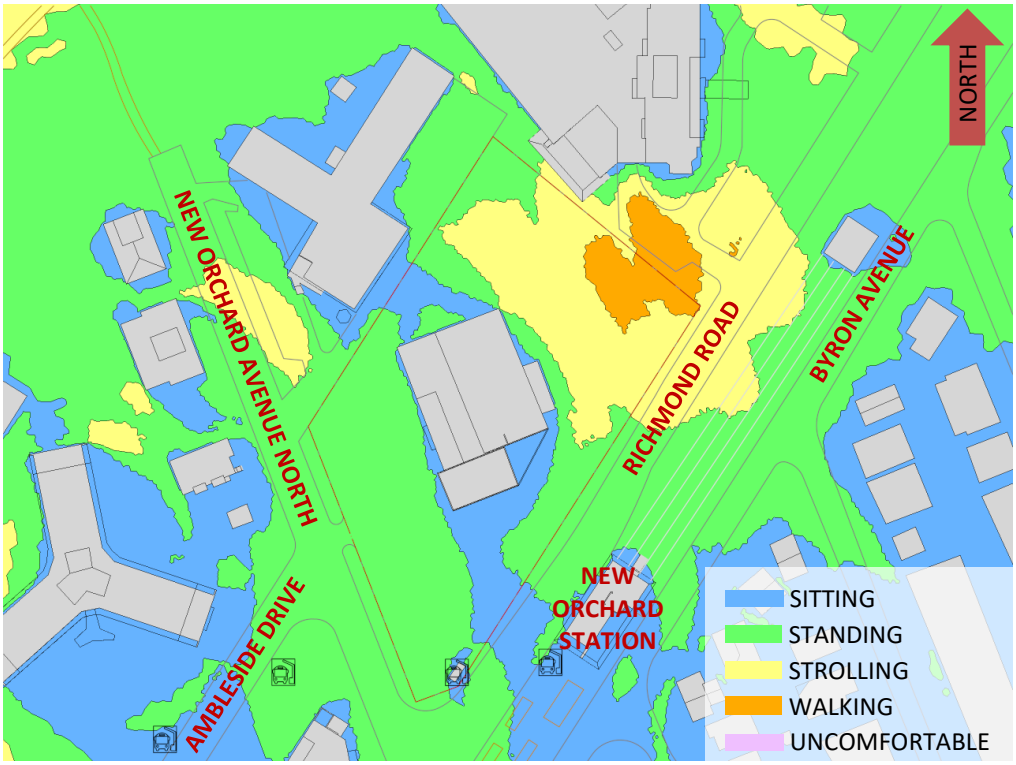


FIGURE 3B: SPRING – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

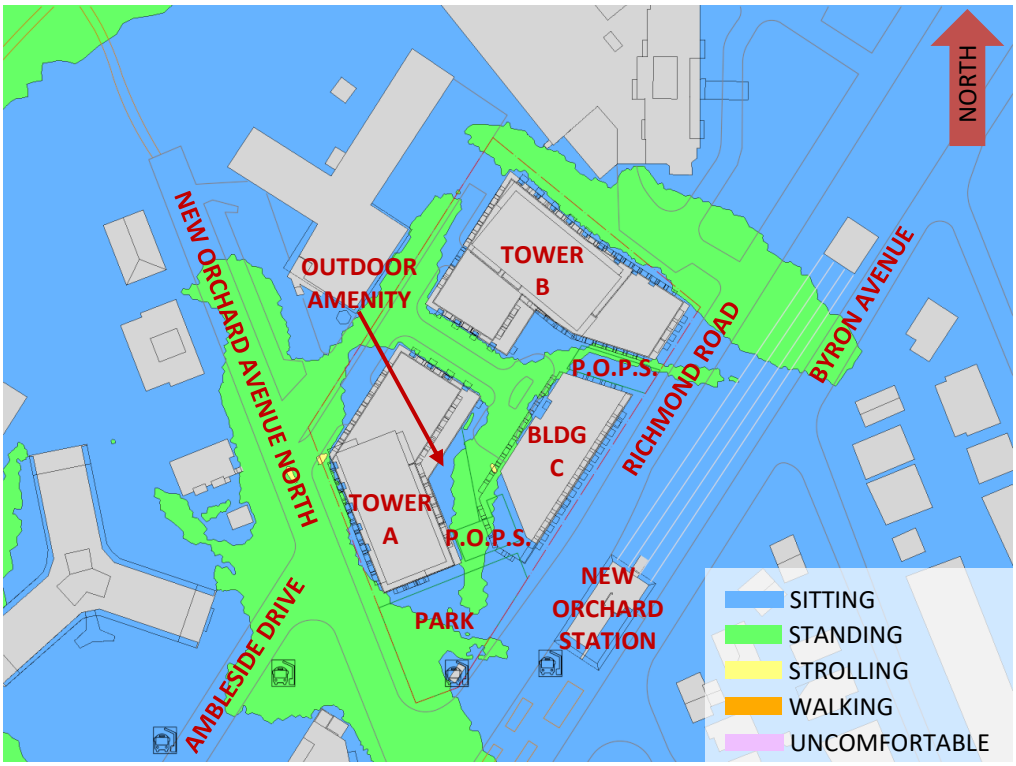


FIGURE 4A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

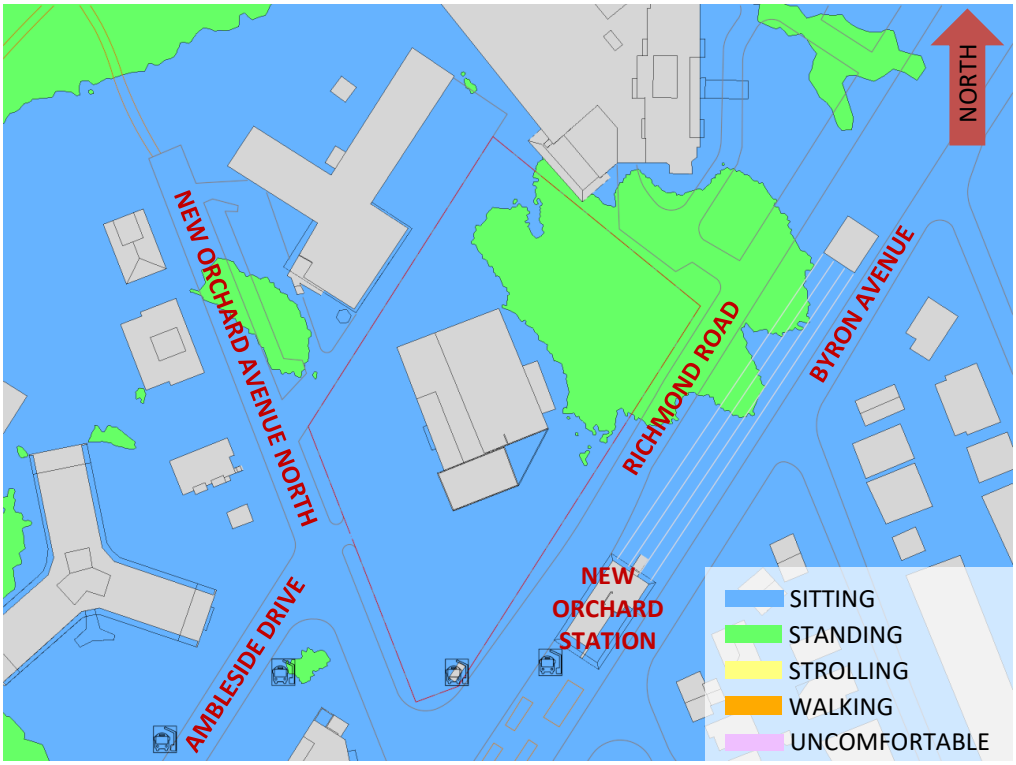


FIGURE 4B: SUMMER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

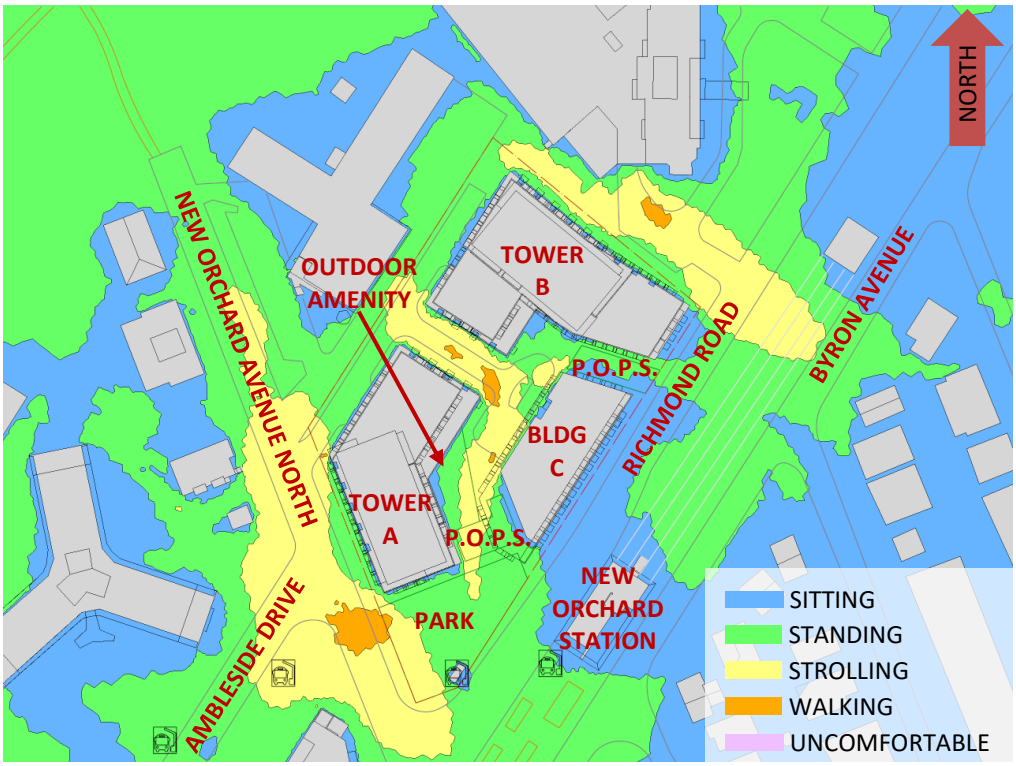


FIGURE 5A: AUTUMN – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

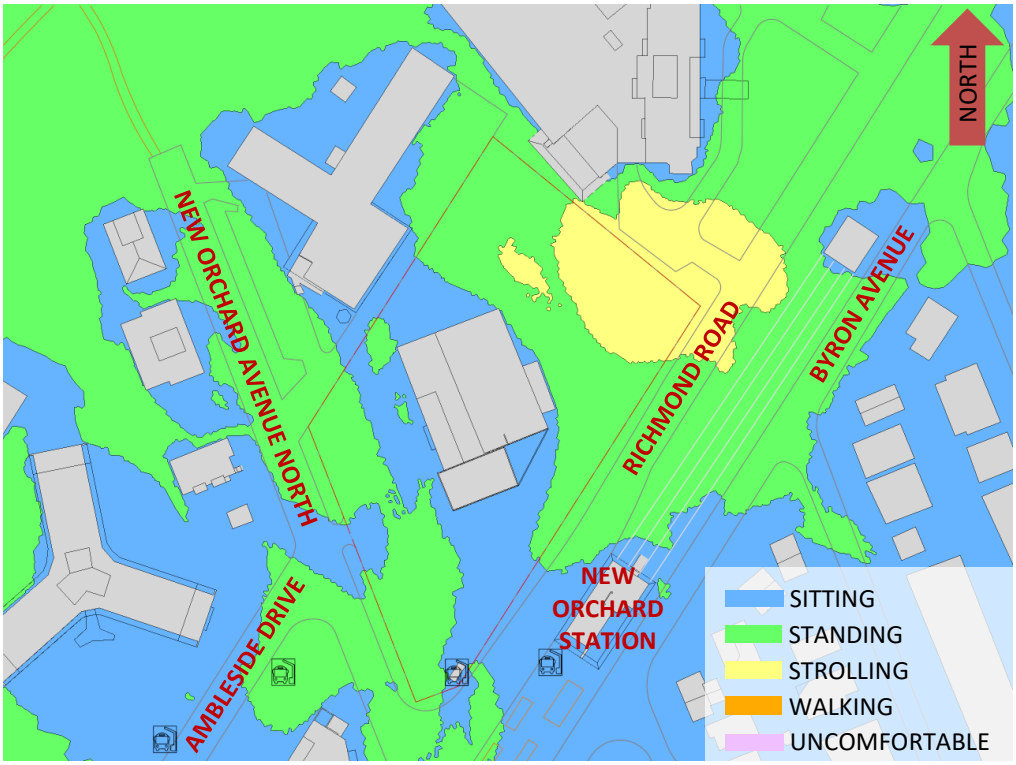


FIGURE 5B: AUTUMN – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

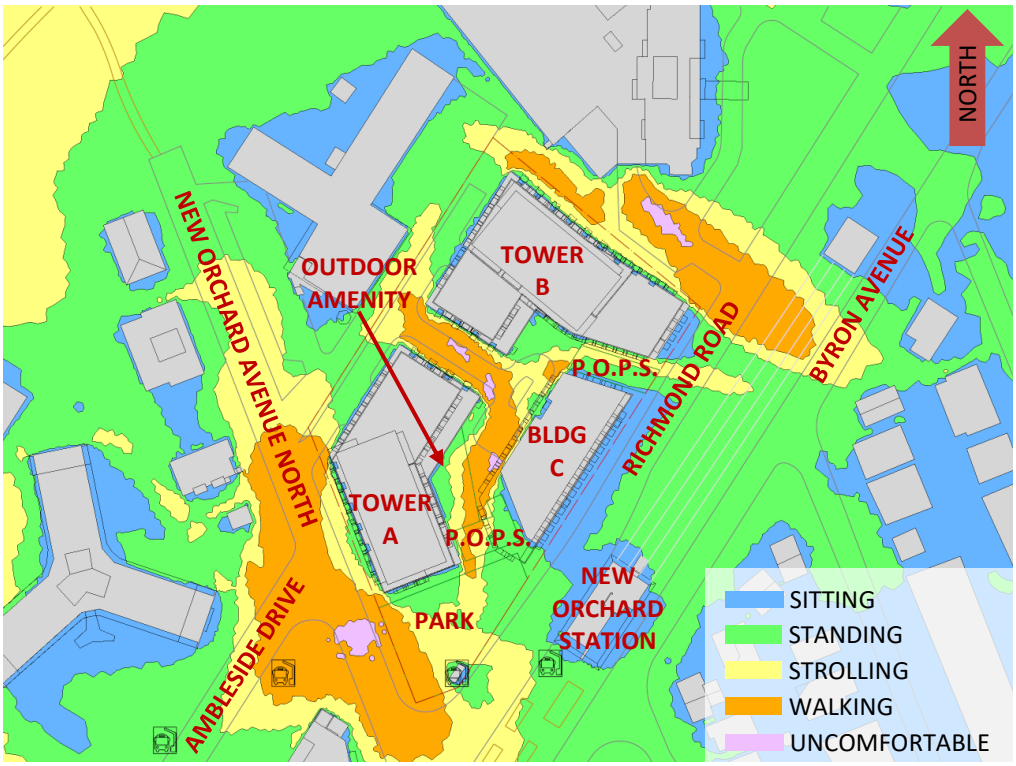


FIGURE 6A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

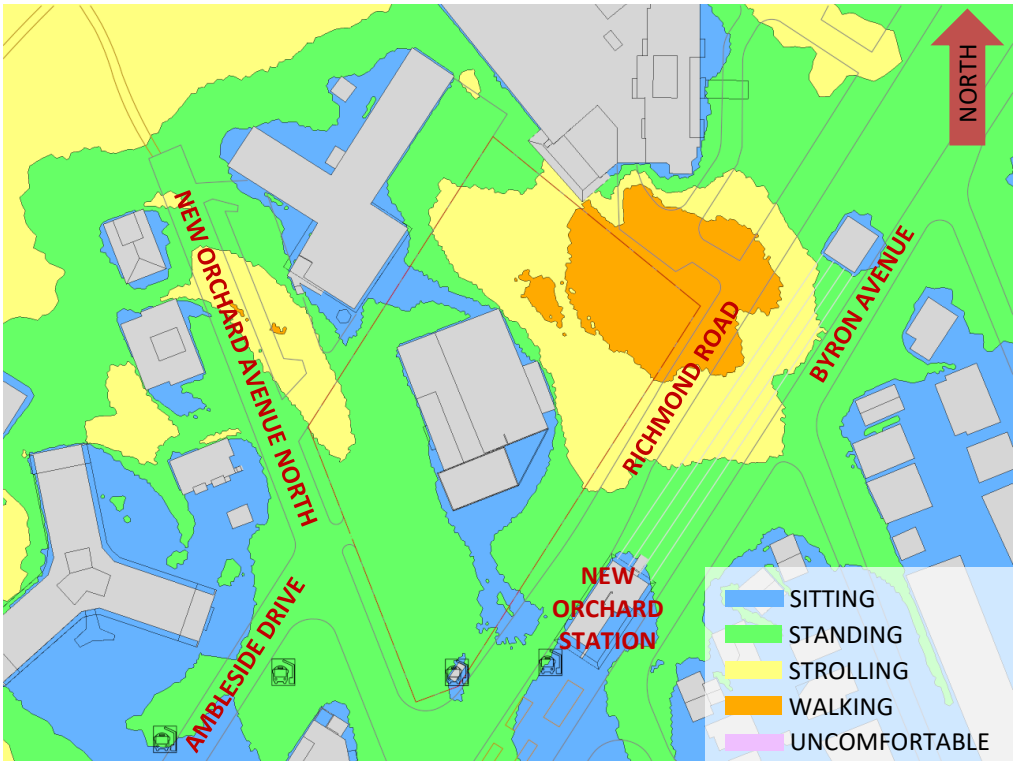


FIGURE 6B: WINTER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

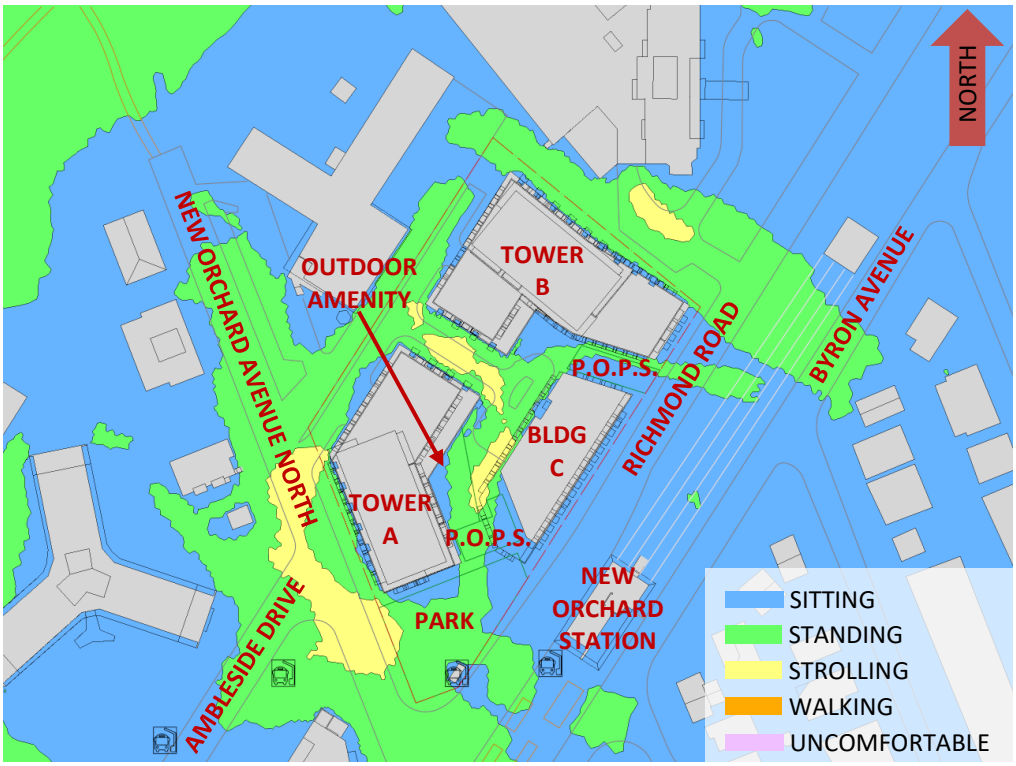


FIGURE 7: TYPICAL USE PERIOD – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

FIGURE 8A: SPRING – WIND COMFORT, COMMON AMENITY TERRACES

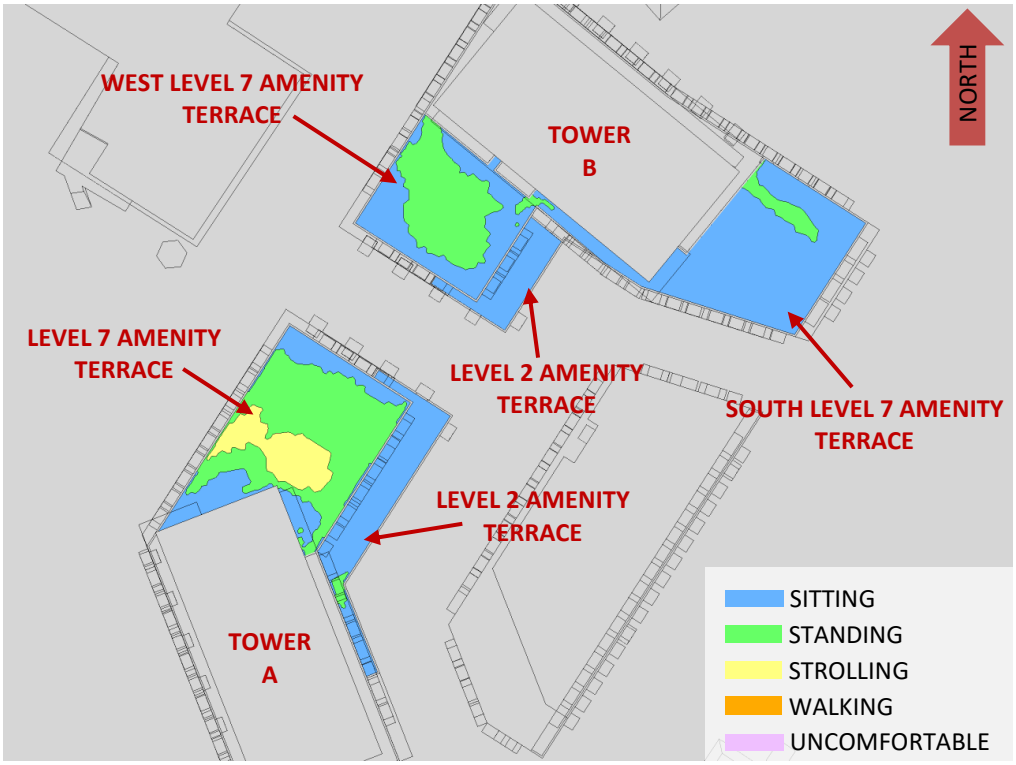
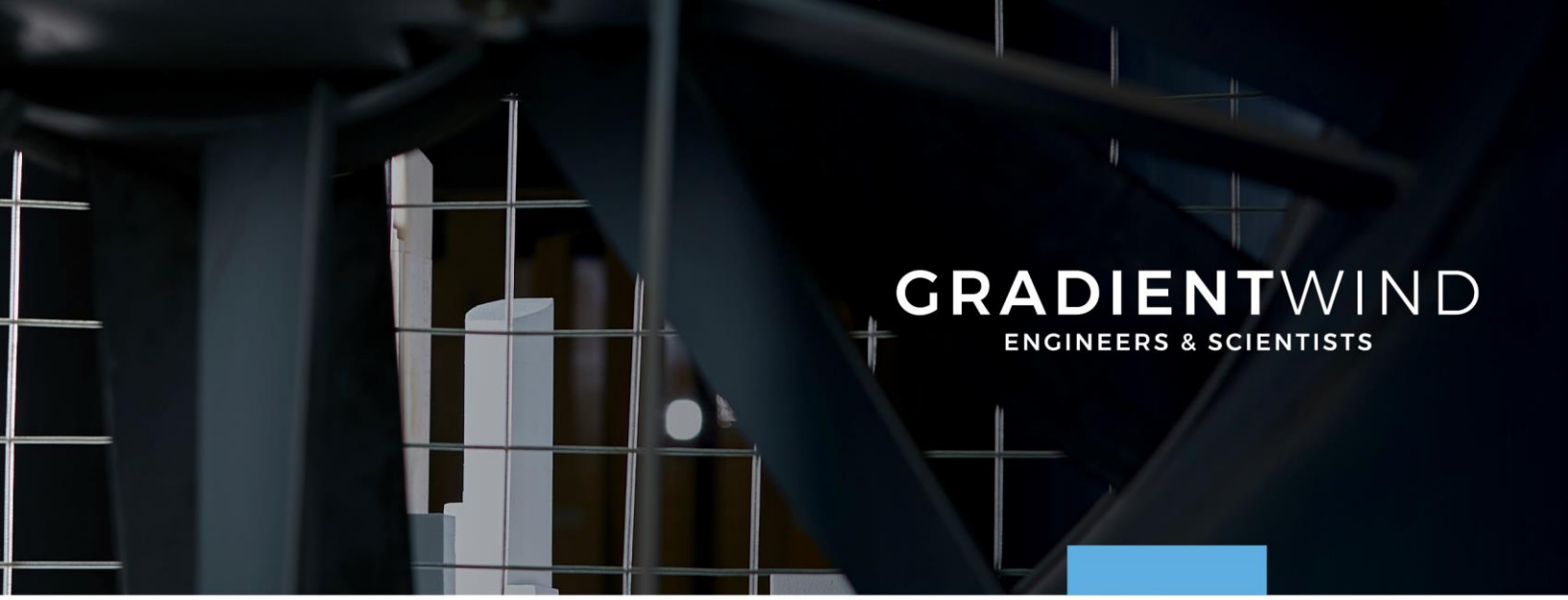


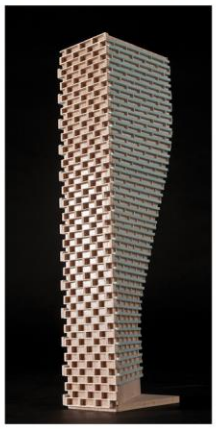
FIGURE 8B: SUMMER – WIND COMFORT, COMMON AMENITY TERRACES

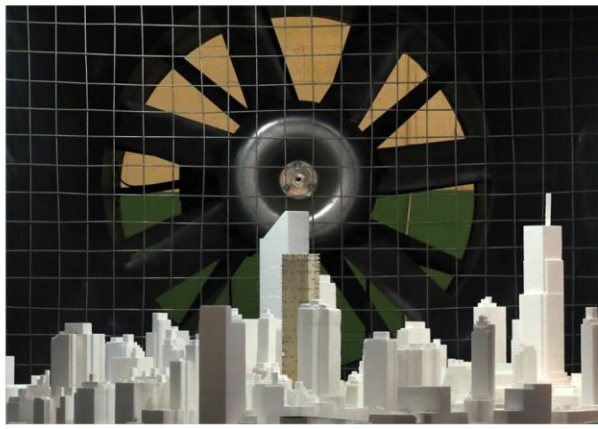
FIGURE 8C: AUTUMN – WIND COMFORT, COMMON AMENITY TERRACES

FIGURE 8D: WINTER – WIND COMFORT, COMMON AMENITY TERRACES

FIGURE 9: TYPICAL USE PERIOD – WIND COMFORT, COMMON AMENITY TERRACES







APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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

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

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

For the model, U_g is set to 6.5 metres per second, 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	0.17
49	0.24
74	0.24
103	0.24
167	0.24
197	0.24
217	0.24
237	0.21
262	0.18
282	0.17
301	0.18
324	0.18

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).

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

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

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.

REFERENCES

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

[2] S. A. Hsu, E. A. Meindl and D. B. Gilhousen, "Determining the Power-Law Wind Profile Exponent under Near-neutral Stability Conditions at Sea," vol. 33, no. 6, 1994.

[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.