

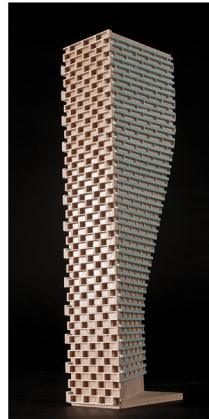
GRADIENTWIND

ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

1335-1339 Bank Street
Ottawa, Ontario

Report: 20-109-PLW



March 3, 2021

PREPARED FOR

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PREPARED BY

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control application submission for a proposed residential condominium development located at 1335-1339 Bank Street in Ottawa, Ontario (hereinafter referred to as “subject site”). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, as required and practical to implement.

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-5B, and summarized as follows:

- 1) All grade-level areas within and surrounding the subject site are predicted to be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, bus stops, and driveways are considered acceptable for the intended pedestrian uses throughout the year.
- 2) Regarding the amenity terrace at Level 7, it is recommended that a 1.8-m tall wind barrier, such as a glazed guard, serve the west perimeter of the space. With this wind barrier, it is expected that conditions during the typical use period of late spring through early autumn over most of the terrace will achieve the sitting comfort class, while the remainder of the terrace is expected to be suitable for sitting at least 75% of the time.
- 3) Regarding the amenity terrace at Level 26, it is recommended that a 2.0-m tall wind barrier, such as a glazed guard, serve the full perimeter of the space. Following the implementation of the wind barrier, wind conditions are expected to be suitable for sitting during the typical use period.



- 4) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level or within the common amenity terraces were found to experience conditions that could be considered uncomfortable or dangerous.
- 5) Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associate hardware.

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Appendix A – Simulation of the Atmospheric Boundary Layer



1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Riverside Development GP Inc. to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a Site Plan Control application submission for a proposed residential condominium development located at 1335-1339 Bank Street in Ottawa, Ontario (hereinafter referred to as “subject site”). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, as required and practical to implement.

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 Hobin Architecture Inc. in July 2020, 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 on the southwest half of a parcel of land bounded by Bank Street to the southwest, Riverside Drive (northbound) to the east, and Riverside Drive (southbound) to the northwest. Throughout this report, the Bank Street elevation is referred to as the west elevation. The proposed residential condominium development comprises a



*Rendering, West Perspective
(Courtesy of Hobin Architecture Inc.)*

26-storey tower with a 6-storey podium. The development includes two levels of underground parking, accessed by Riverside Drive (southbound) via a laneway along the east elevation that passes beneath the building podium. The ground floor provides two lobbies, a café/bar, and indoor amenity space. The floorplan steps back at Level 7 on all sides, with a larger step back at the southwest corner to



accommodate an outdoor amenity space, including a swimming pool. Level 7 also includes indoor amenity space and residential units. Above Level 7, the tower rises with a uniform floorplate to Level 26, where the floorplate steps back on the west elevation to provide outdoor amenity space. Level 26 also includes indoor amenity space and a mechanical penthouse. All other floors contain residential units.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) include the Rideau River, which flows southwest to northeast approximately 30 m to the northwest. As well, there is a 7-storey building to the immediate northeast, a 7-storey health care clinic and a 21-storey residential building to the southeast, and a cluster of mostly low-rise retail buildings across Bank Street to the southwest. The remainder of the nearfield surroundings are characterized by mostly open green space and parking lots. 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 primarily suburban exposures from the west clockwise to the south, by a mix of open green space, parking lots and low- and mid-rise developments from the south clockwise to the southwest, and by a mix of mid-rise and high-rise buildings from the Carleton University campus and the open exposure of Brewer Park from the southwest clockwise to the west. The Rideau River runs southwest to northeast approximately 30 m to the northwest of the subject site.

Key areas under consideration include surrounding sidewalks, walkways, bus stops, and building access points. Figure 1 illustrates the subject site and surrounding context, while Figures 2A-2D illustrate the computational model used to conduct the study.

3. OBJECTIVES

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



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 criteria¹. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

4.1 Computer-Based Context Modelling

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

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

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



4.2 Wind Speed Measurements

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

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

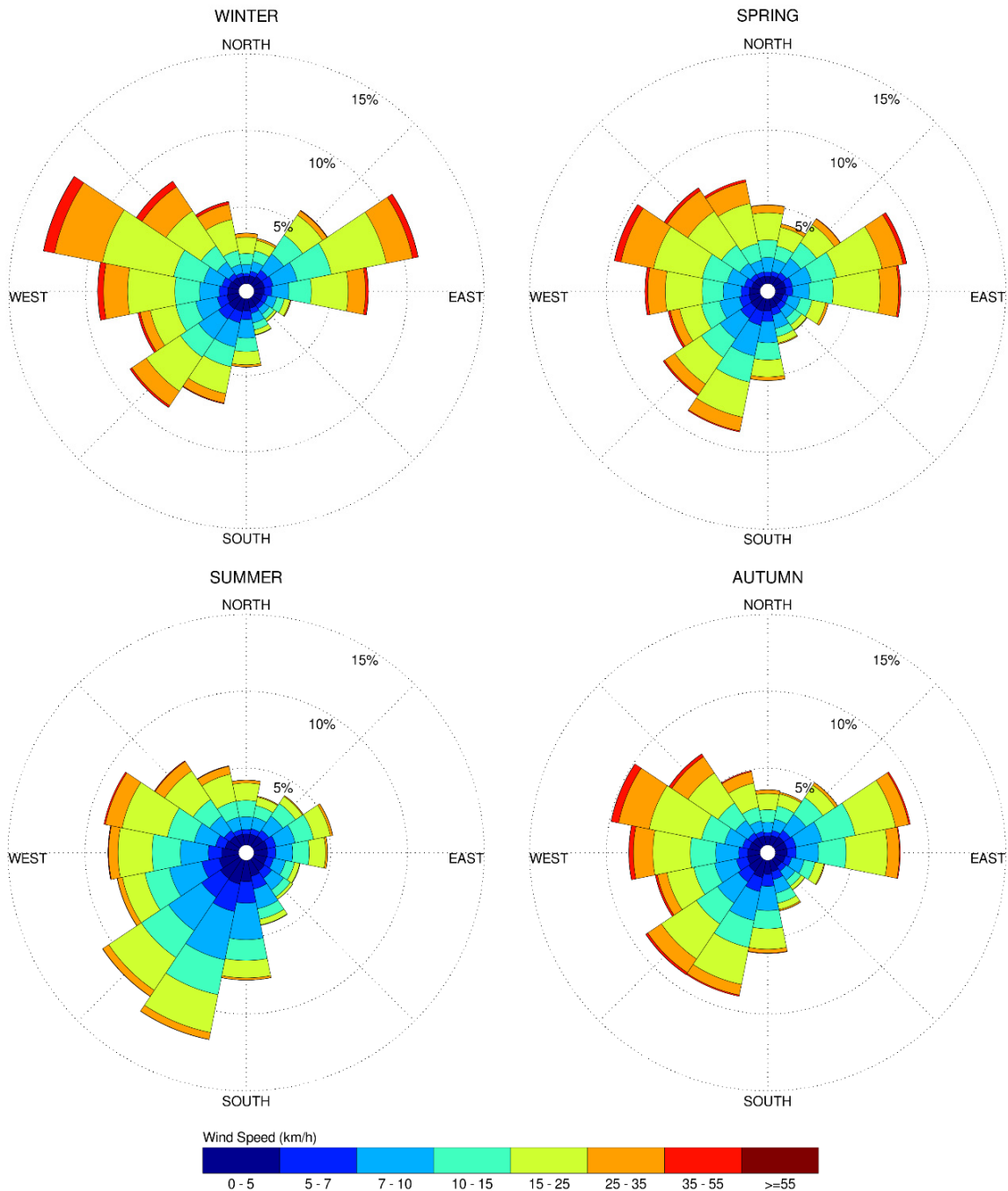
4.3 Meteorological Data Analysis

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

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



SEASONAL DISTRIBUTION OF WIND OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT



Notes:

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



4.4 Pedestrian Comfort and Safety Criteria – City of Ottawa

Pedestrian comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 20% non-exceedance mean wind speed ranges, which include (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

- 1) **Sitting:** Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 16 km/h.
- 2) **Standing:** Mean wind speeds no greater than 14 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 22 km/h.
- 3) **Strolling:** Mean wind speeds no greater than 17 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 27 km/h.
- 4) **Walking:** Mean wind speeds no greater than 20 km/h occurring at least 80% of the time. The equivalent gust wind speed is approximately 32 km/h.
- 5) **Uncomfortable:** Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.

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



THE BEAUFORT SCALE

Number	Description	Wind Speed (km/h)		Description
		Mean	Gust	
2	Light Breeze	6-11	9-17	Wind felt on faces
3	Gentle Breeze	12-19	18-29	Leaves and small twigs in constant motion; wind extends light flags
4	Moderate Breeze	20-28	30-42	Wind raises dust and loose paper; small branches are moved
5	Fresh Breeze	29-38	43-57	Small trees in leaf begin to sway
6	Strong Breeze	39-49	58-74	Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty
7	Moderate Gale	50-61	75-92	Whole trees in motion; inconvenient walking against wind
8	Gale	62-74	93-111	Breaks twigs off trees; generally impedes progress

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

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



DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

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

5. RESULTS AND DISCUSSION

The following discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-3D (following the main text) illustrating the seasonal wind conditions at grade level, and Figures 4A-4D illustrating the seasonal wind conditions within the common amenity terraces. The colour contours indicate various comfort classes predicted for certain regions. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by orange, and walking by blue. In addition, Figures 5A and 5B illustrate the percentage of time that areas at grade and within the elevated amenity terraces, respectively, are predicted to be suitable for sitting during the summer season. Pedestrian comfort is summarized below for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Sidewalk, Bus Stop, and Building Entrances along Bank Street: Conditions along the Bank Street sidewalk, including the nearby bus stop, are predicted to be suitable for mostly sitting during the summer, with some standing conditions near the northwest corner of the subject site, becoming suitable for a mix of mostly sitting and standing throughout the remainder of the year, with some strolling conditions near the northwest corner of the development. Owing to the protection of the façade, conditions at building



entrances are generally calmer than the adjacent sidewalk. Conditions in the vicinity of the building entrances along Bank Street are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

Sidewalk and Loading Area along Riverside Drive Southbound: Conditions along the Riverside Drive Southbound sidewalk 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. The walking conditions during the winter are located to the northeast corner of the subject site. Owing to the protection of the building overhang, conditions within the loading area are predicted to be suitable for standing, or better, during the spring, summer, and autumn, becoming suitable for strolling, or better, during the winter. The noted conditions are considered acceptable.

Laneway and Building Entrances Beneath Podium along East Elevation: Conditions beneath the podium along the east elevation 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 building entrances are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

Sidewalk and Parkette along Riverside Drive Northbound: Conditions along the Riverside Drive Northbound sidewalk are predicted to be suitable for mostly sitting during the summer, with some standing conditions near the southeast corner of the subject site, becoming suitable for a mix of sitting and standing during the spring and autumn, and for strolling, or better during the winter. The strolling conditions in the winter are located near the southeast corner of the development. Owing to the shelter from prominent northwest winds by the study building, conditions within the parkette are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.



5.2 Wind Comfort Conditions – Elevated Amenity Terraces

Level 7 Amenity Terrace: The elevated amenity terrace at Level 7 is predicted to be suitable for a mix of sitting and standing during the typical use period of late spring through to early autumn. As illustrated in Figure 5B, conditions over most of the terrace are predicted to be suitable for sitting at least 75% of the time. It is recommended that the west perimeter of the space include a solid wind barrier (e.g., glazed wind screen) rising 1.8 m above the local walking surface. With this wind barrier, it is expected that conditions during the typical use period over most of the terrace will be suitable for sitting, and over the remainder of the terrace will be suitable for sitting at least 75% of the time.

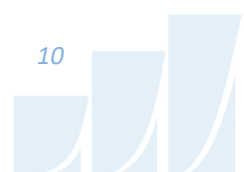
Level 26 Amenity Terrace: The elevated amenity terrace at Level 26 is predicted to be suitable for a mix of sitting and standing during the typical use period. It is recommended that the full perimeter of the space include a solid wind barrier (e.g., glazed wind screen) rising 2.0 m above the local walking surface to ensure conditions are suitable for sitting during the typical use period.

5.3 Wind Safety

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

5.4 Applicability of Results

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

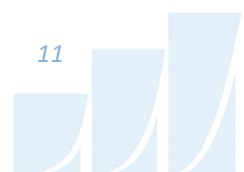


Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associated hardware.

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind comfort and safety conditions is provided in Section 5 and illustrated in Figures 3A-4D. Based on computer simulations using the CFD technique, meteorological data analysis of the Ottawa wind climate, City of Ottawa wind comfort and safety criteria, and experience with numerous similar developments in Ottawa, we conclude the following:

- 1) All grade-level areas within and surrounding the subject site are predicted to be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, bus stops, and driveways are considered acceptable for the intended pedestrian uses throughout the year.
- 2) Regarding the amenity terrace at Level 7, it is recommended that a 1.8-m tall wind barrier, such as a glazed guard, serve the west perimeter of the space. With this wind barrier, it is expected that conditions during the typical use period of late spring through early autumn over most of the terrace will achieve the sitting comfort class, while the remainder of the terrace is expected to be suitable for sitting at least 75% of the time.
- 3) Regarding the amenity terrace at Level 26, it is recommended that a 2.0-m tall wind barrier, such as a glazed guard, serve the full perimeter of the space. Following the implementation of the wind barrier, wind conditions are expected to be suitable for sitting during the typical use period.
- 4) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level or within the common amenity terraces were found to experience conditions that could be considered uncomfortable or dangerous.
- 5) Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associate hardware.



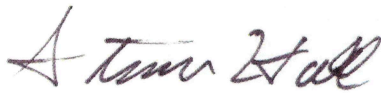
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This concludes our PLW study and report. Please advise the undersigned of any questions or comments.

Sincerely,

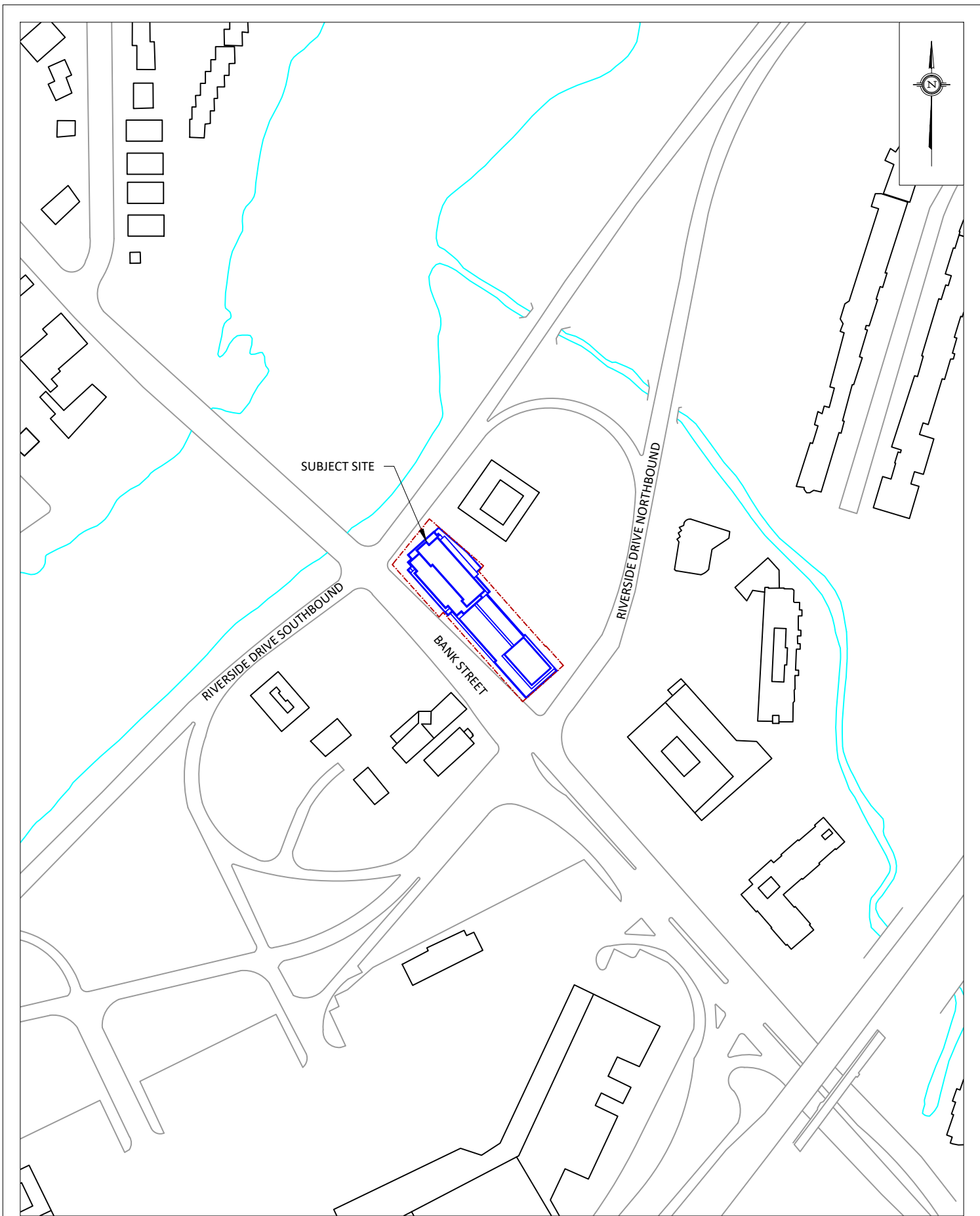
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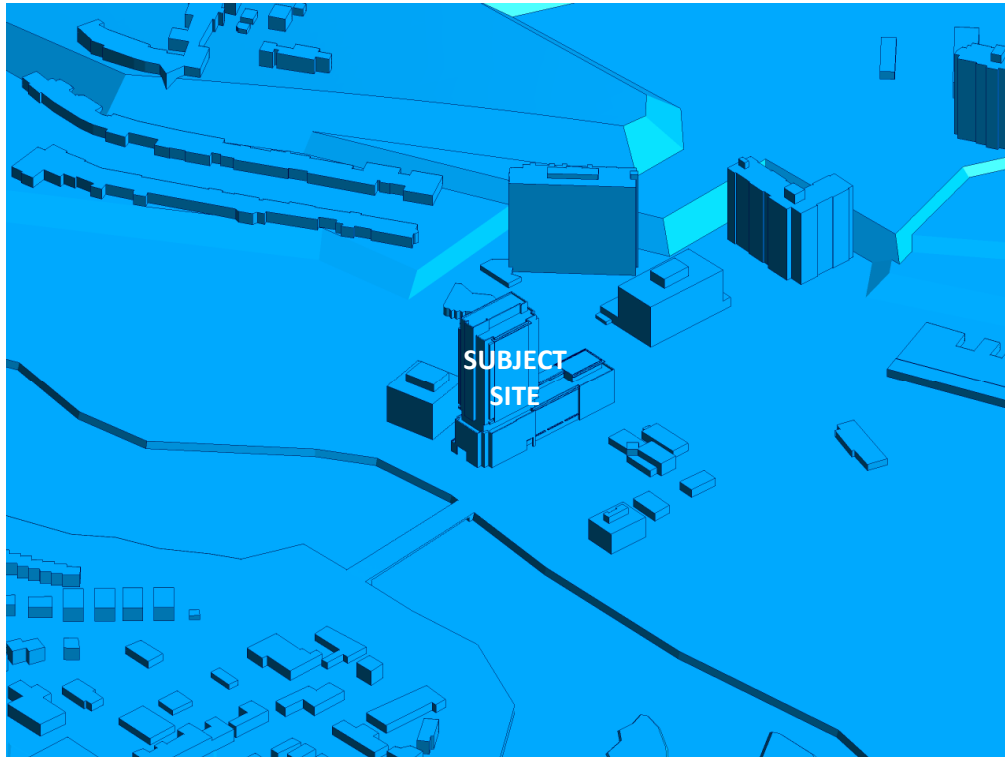


FIGURE 2A: COMPUTATIONAL MODEL, WEST PERSPECTIVE

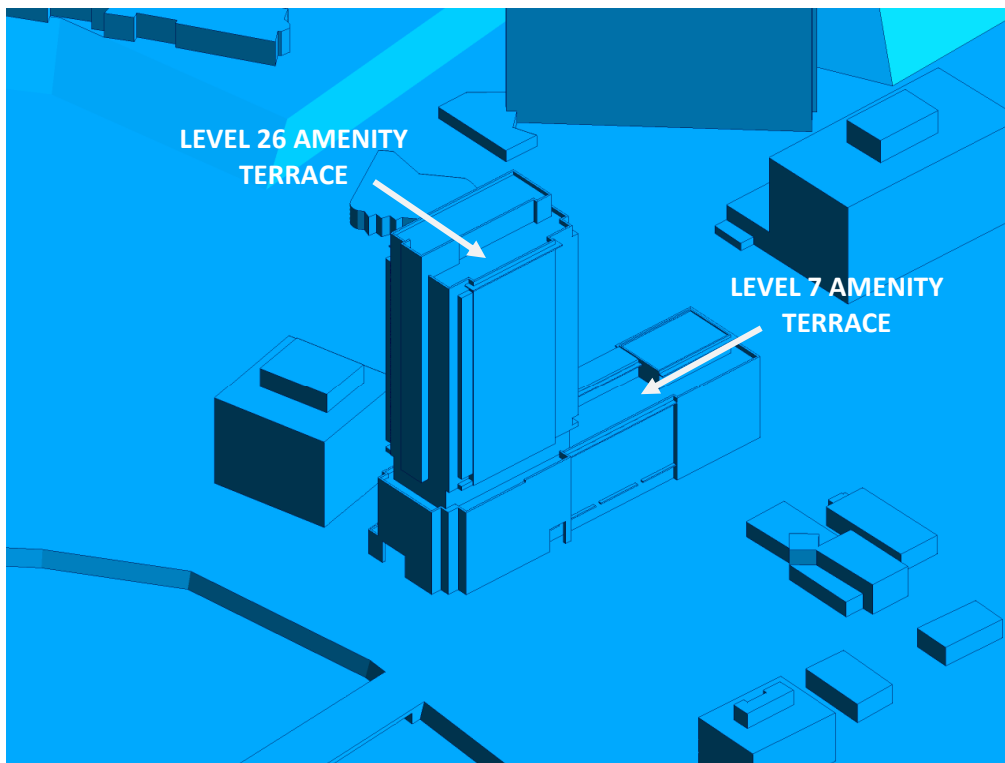


FIGURE 2B: CLOSE UP OF FIGURE 2A



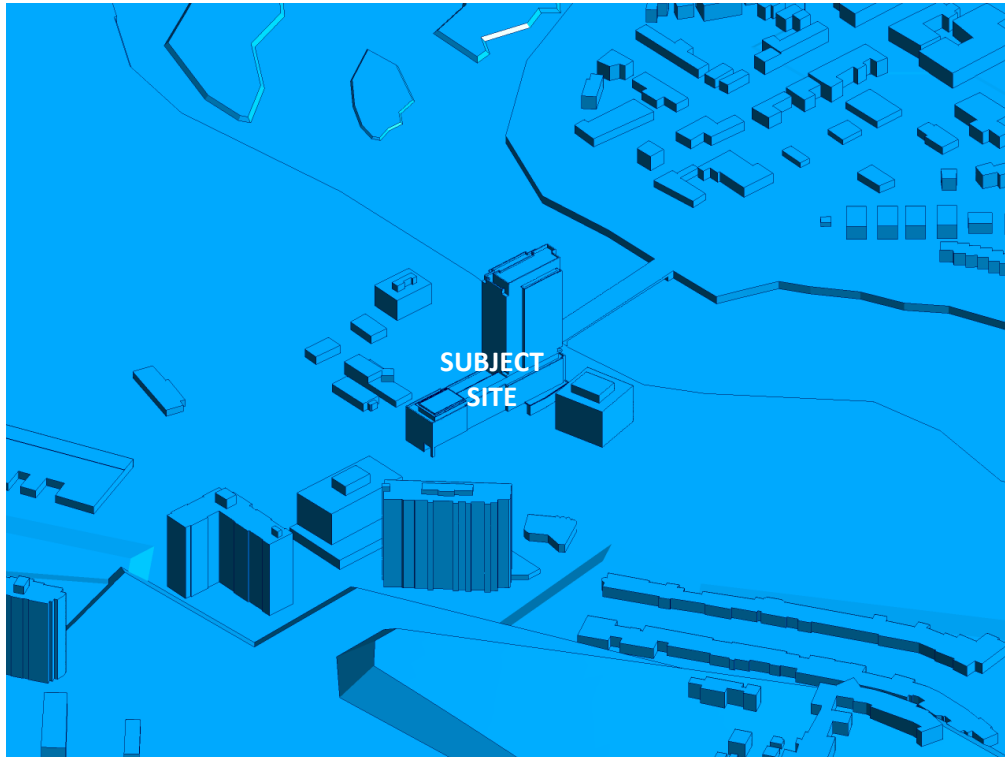


FIGURE 2C: COMPUTATIONAL MODEL, EAST PERSPECTIVE

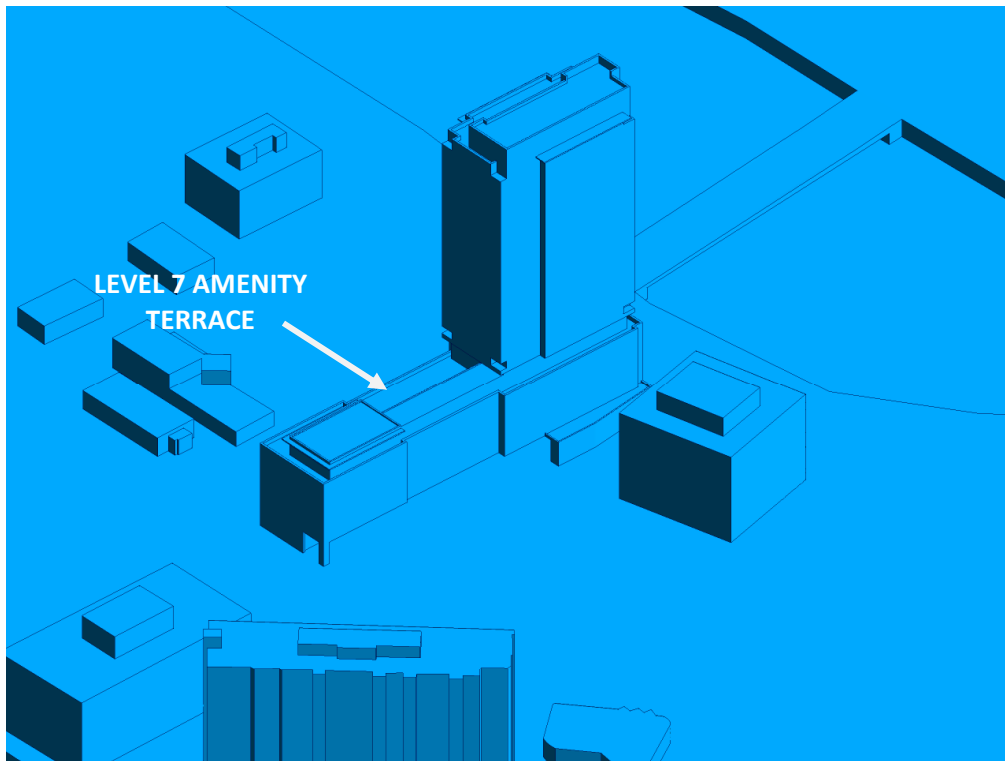


FIGURE 2D: CLOSE UP OF FIGURE 2C



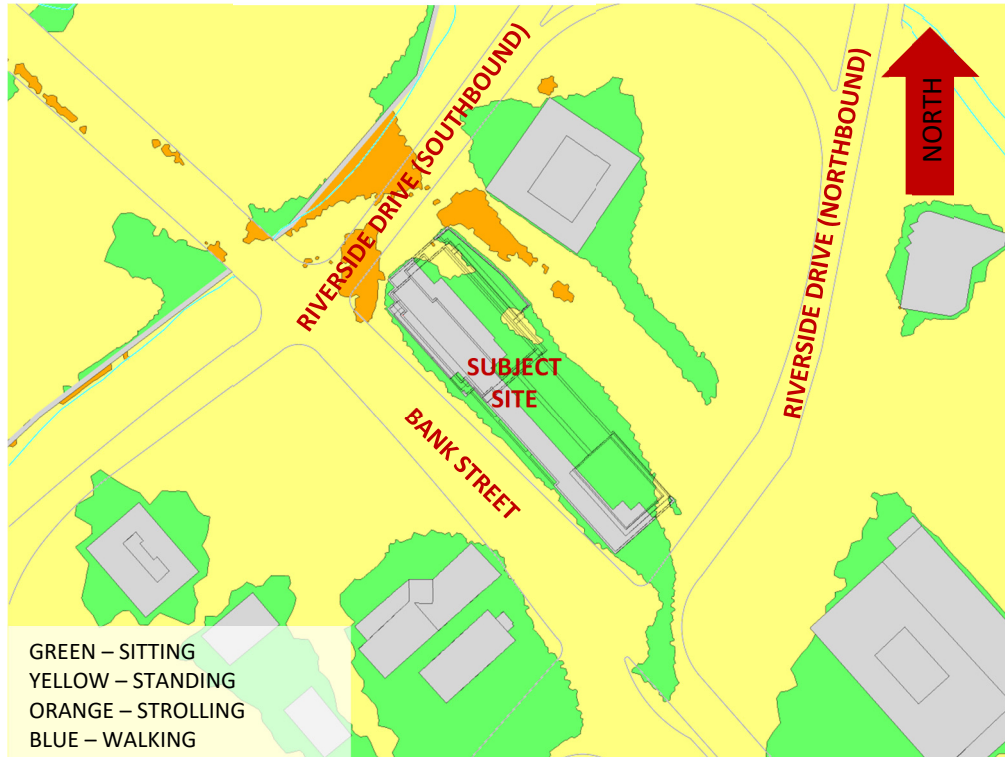


FIGURE 3A: SPRING – WIND CONDITIONS, GRADE LEVEL



FIGURE 3B: SUMMER – WIND CONDITIONS, GRADE LEVEL





FIGURE 3C: AUTUMN – WIND CONDITIONS, GRADE LEVEL



FIGURE 3D: WINTER – WIND CONDITIONS, GRADE LEVEL



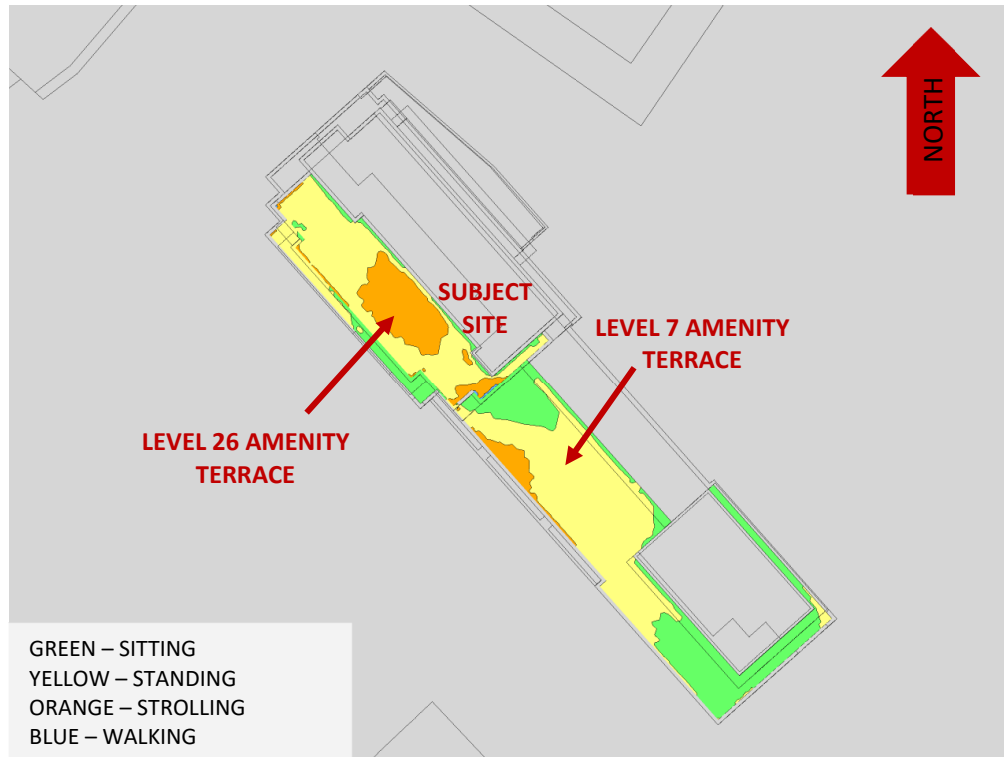


FIGURE 4A: SPRING – WIND CONDITIONS, COMMON AMENITY TERRACES

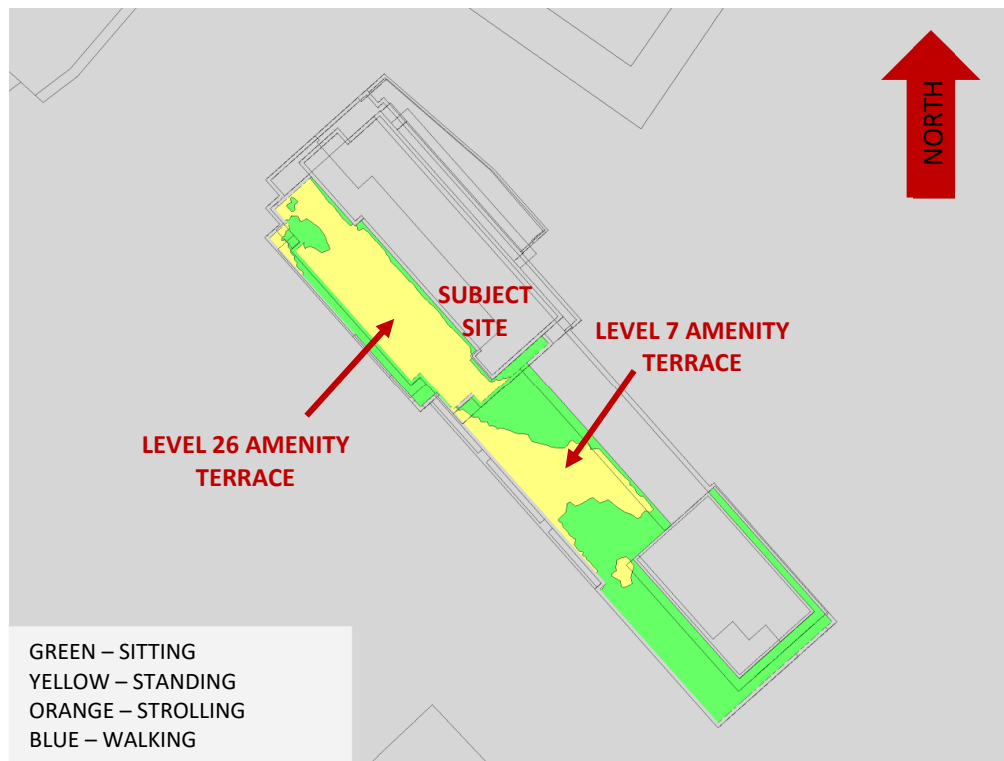


FIGURE 4B: SUMMER – WIND CONDITIONS, COMMON AMENITY TERRACES



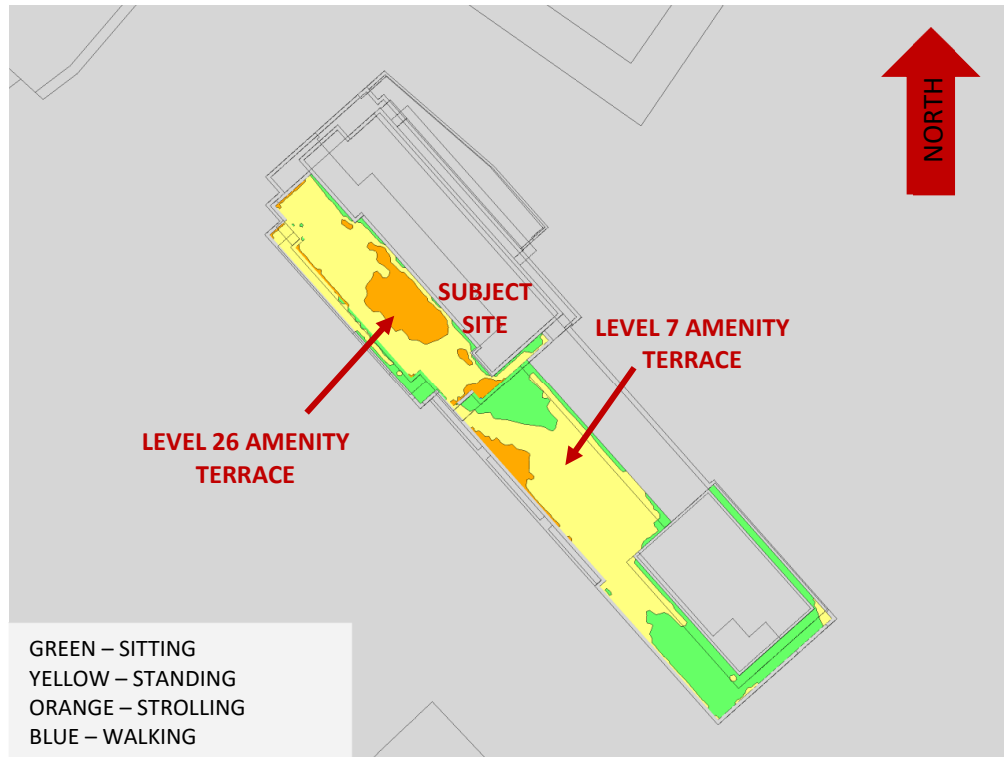


FIGURE 4C: AUTUMN – WIND CONDITIONS, COMMON AMENITY TERRACES

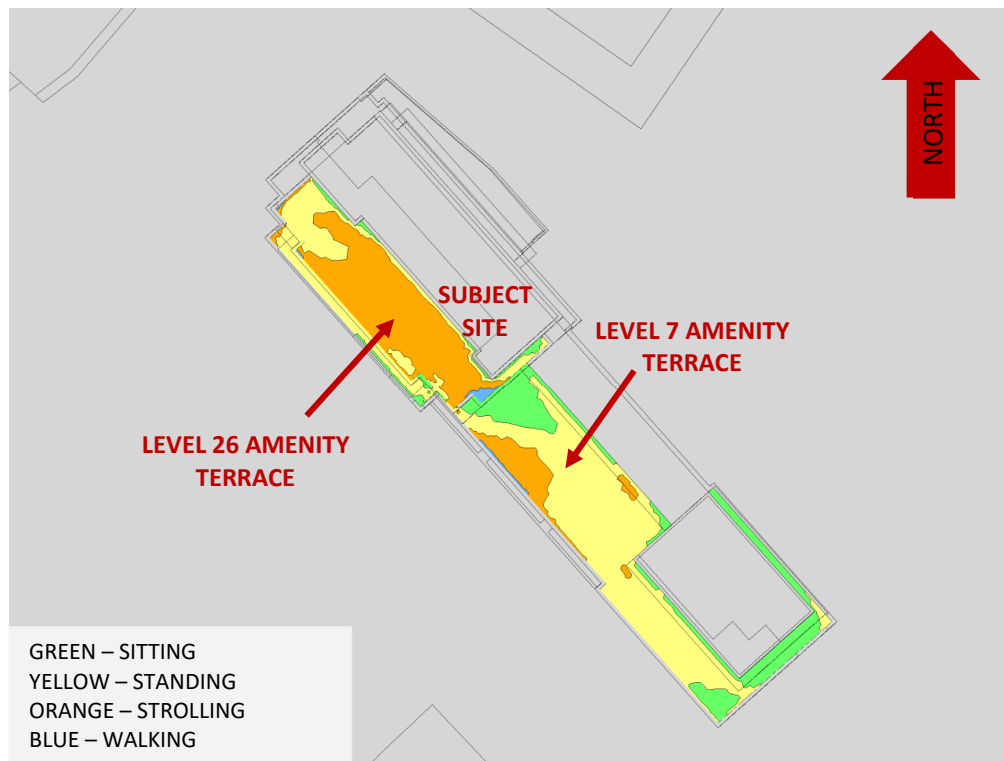


FIGURE 4D: WINTER – WIND CONDITIONS, COMMON AMENITY TERRACES



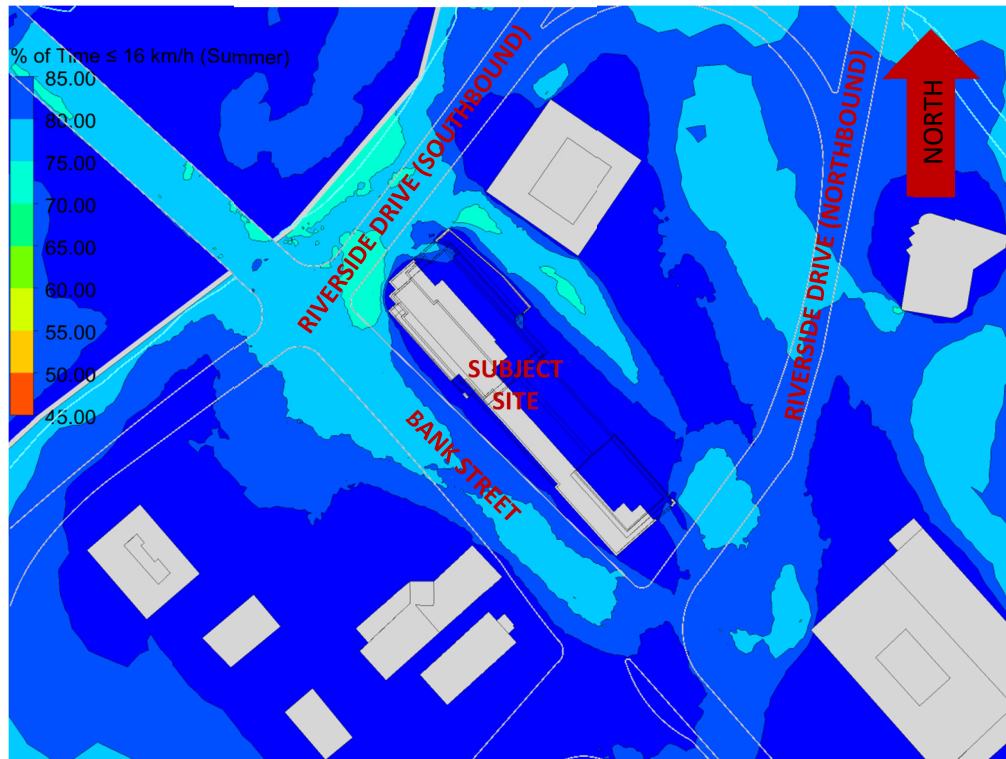


FIGURE 5A: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING, GRADE LEVEL

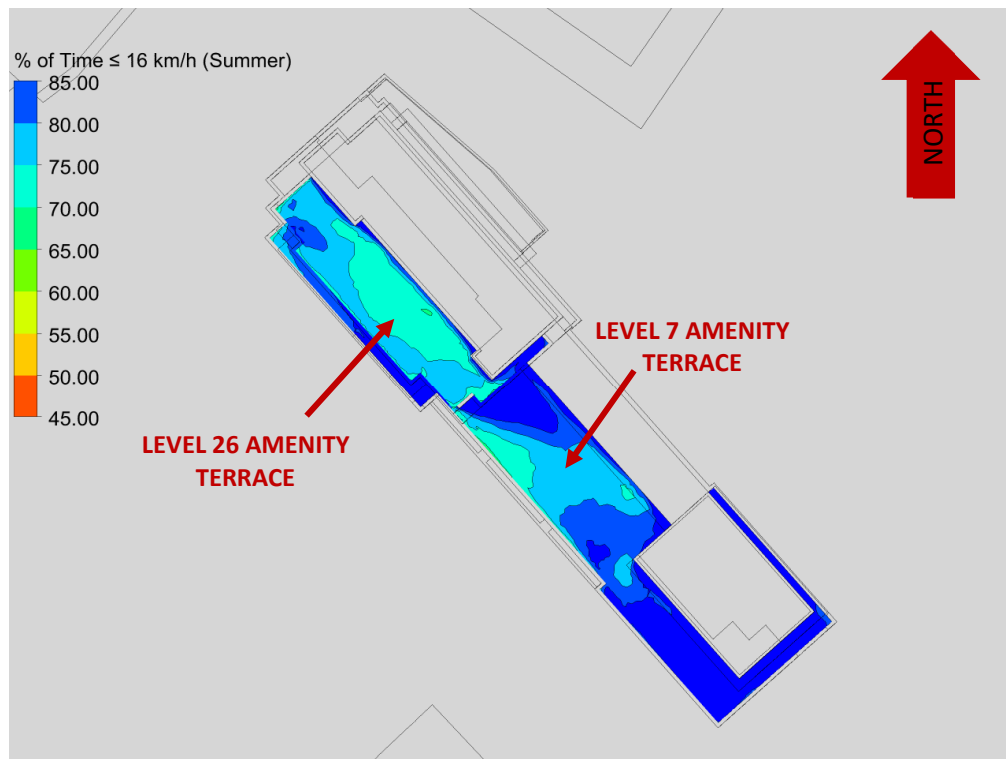
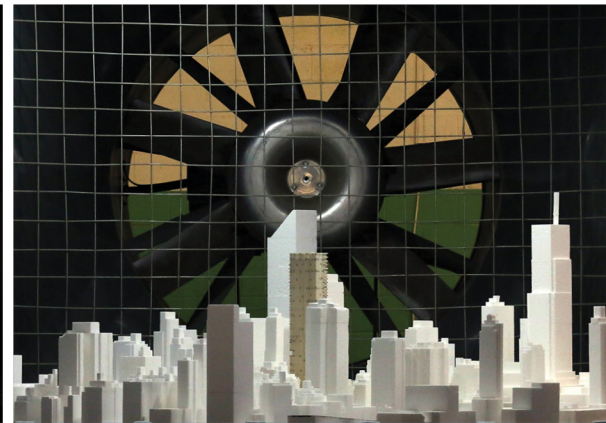
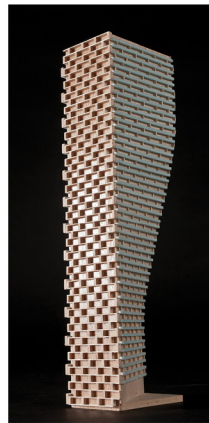


FIGURE 5B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING, AMENITY TERRACES



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APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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

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

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

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

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

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

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

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

Wind Direction (Degrees True)	Alpha Value (α)
0	0.25
49	0.23
74	0.24
103	0.24
167	0.24
197	0.20
217	0.21
237	0.21
262	0.22
282	0.23
302	0.26
324	0.27

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

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

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

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

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

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

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

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