

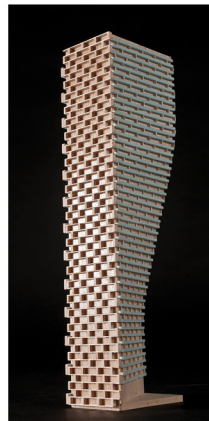
GRADIENTWIND

ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

3-33 Selkirk Street
Ottawa, Ontario

Report: 20-077-PLW



June 15, 2020

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 joint Official Plan Amendment (OPA) and Zoning By-Law Amendment (ZBA) application submission for a proposed development located at 3-33 Selkirk 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.

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-5, and summarized as follows:

- 1) Wind conditions at the nearby bus stop on the north side of Montreal Road will be suitable for standing during the summer and autumn, and suitable for strolling during the winter and spring. Since it is recommended that comfort conditions be suitable for standing, or better, throughout the year, the introduction of a bus shelter would provide the necessary relief to the more vulnerable members of the population during strong wind events.
- 2) If seating is desired within certain windier regions in the courtyard, mitigation will be required and could be coordinated during design development.
- 3) Except for items (1) and (2) above, all grade-level areas within and surrounding the subject site will be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, driveways, other bus stops in the immediate vicinity of the subject site, and within the courtyard, are considered acceptable for the intended pedestrian uses throughout the year.
- 4) Wind conditions within the north and northeast common rooftop terraces will be suitable for sitting during late spring through early autumn, which is considered acceptable.



- 5) Wind conditions within the northeast common rooftop terraces will be suitable for a mix of sitting and standing during the summer. To achieve conditions suitable for sitting during the summer season, we recommend installing tall (minimum 2 m) wind screens in place of standard height guardrails along the perimeter of the terrace. Since the terrace is large, local wind barriers inboard of the perimeter may also be required. Wind barriers may take the form of glass architectural wind screens positioned to protect designated seating areas, or a mix of wind screens and coniferous trees planted in dense arrangements. A mitigation strategy could be confirmed during design development.
- 6) 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.
- 7) 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.

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1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Selkirk & Main Developments Inc. to undertake a pedestrian level wind (PLW) study to satisfy the requirements for a joint Official Plan Amendment (OPA) and Zoning By-Law Amendment (ZBA) application submission for a proposed development located at 3-33 Selkirk 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.

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, preliminary drawings prepared by HOK Architects in June 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 planned multi-building mixed-use development is located on an irregular parcel of land at 3-33 Selkirk Street in Ottawa. The subject site is bounded by Montreal Road to the north, Montgomery Street to the east, Selkirk Street to the south, and North River Road to the west.



*Architectural Rendering, North Perspective
(Courtesy of HOK Architects)*

The subject site comprises three buildings with rectangular planforms at grade connected by a

1-storey podium. Building ‘A’, of 28 storeys, is located at the north of the site, with the long axis oriented along a Montgomery Street. Building ‘B’, of 22 storeys, is located at the east of the site with the long axis oriented perpendicular to Tower A. Building ‘C’, of 32 storeys, is located at the south of the site with the long axis oriented parallel to Montgomery Street.

The ground floor comprises various retail spaces, lobby space, and parking space. The mezzanine level comprises a continuation of the retail space and parking space. Level 2 comprises residential units and



parking space. Levels 3 and above comprise residential units. Main building entrances are located within the courtyard in the centre of the subject site, near the centre of the southeast elevation of Building A, near the centre of the northwest elevation of Building B, and near the centre of the northeast elevation of Building C. Within the courtyard there is a roundabout accessed from Montgomery Street and North River Road. At the centre of the roundabout is an entrance that gives access to the parking structures at the southeast and northeast corners of the site, which feature one below-grade and two above-grade parking levels. Dedicated parkland is located at the northwest, southwest, and southeast corners of the site. A bus stop is integrated within the dedicated parkland on North River Road, near Selkirk Street, which will include a bus shelter. Existing bus stops are also located on the north side of Montreal Road and on the west side of North River Road. The latter bus stop includes a bus shelter. Above the northwest section of the parking structure is a large rooftop terrace between Buildings A and C overlooking the dedicated parkland. Rooftop terraces are also located at Level 2 north of Building B and south of Building A.

The near-field surroundings (defined as an area within 500 metres (m) of the subject site) are composed of low-rise residential dwellings from the west clockwise to the east, as well as to the south, and a mix of low-rise residential dwellings and mid- and high-rise developments to the south-southeast and the southwest. To the west, the Rideau River provides for slightly more open exposures. The far-field surroundings (defined as an area beyond the near-field but within a 5 kilometre (km) radius of the subject site) contribute primarily suburban wind exposures from all directions, although southwesterly winds are affected by the Ottawa downtown core and westerly and northerly winds are affected by the Ottawa River.

Key areas under consideration include surrounding sidewalks, walkways, building access points, nearby transit stops, and the rooftop terraces. 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.



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.

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

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

grade and 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.

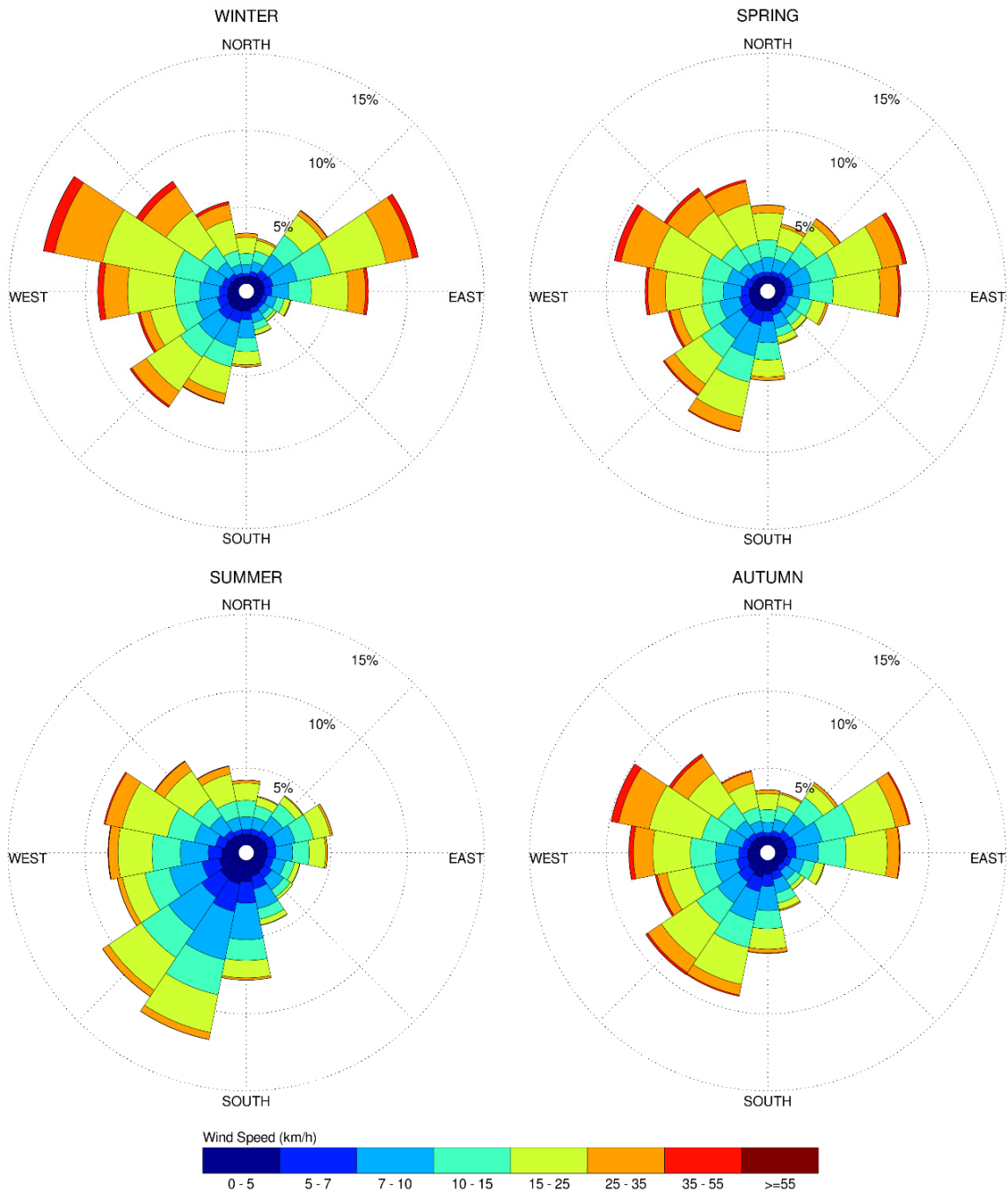
4.3 Meteorological Data Analysis

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 in order to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns. Based on this portion of analysis, the four seasons are represented by grouping data from consecutive months based on similarity of weather patterns, and not according to the traditional calendar method. The winter season is defined as December-March, spring as April-May, summer as June-September, and autumn as October-November.

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 80% 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 mean gust speed ranges are selected based on 'The Beaufort Scale', which describes the effect of forces produced by varying wind speeds on levels on objects.

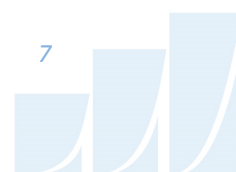


THE BEAUFORT SCALE

Number	Description	Wind Speed (km/h)		Description
		Mean	Gust (Peak)	
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 80% 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 (gust equivalent mean wind speed of 16 km/h) was 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 (gust equivalent mean wind speed of 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 most of 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 at tested locations, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type represented by the sensor. 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	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 Figure 4A-4D illustrating seasonal wind conditions on the elevated 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, walking by blue, while uncomfortable conditions are represented by the colour magenta. Further, Figure 5 illustrates the percentage of time the elevated amenity terraces will be suitable for sitting during the summer. Pedestrian comfort is summarized below for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Montgomery Street: The sidewalks along Montgomery Street are predicted to be suitable for sitting during the summer, transitioning to standing near the northeast building corners. During the spring, autumn, the sidewalk will be suitable for a mix of sitting and standing, with strolling conditions developing near the northeast building corners. Walking conditions will develop near the northeast corner of Building B during the winter. These conditions are considered acceptable.



Selkirk Street: The sidewalks along Selkirk Street are predicted to be suitable for a mix of sitting and standing during the summer, with windier conditions concentrated towards the west. During the three colder seasons, the sidewalks will be suitable for a mix of sitting, standing, and strolling. These conditions are considered acceptable.

North River Road: The sidewalks along North River Road are predicted to be mostly suitable for standing during the summer, with sitting conditions directly adjacent to the subject site. During the remaining colder seasons, the sidewalk will be suitable for standing, with strolling conditions developing near the intersection of North River Road and Selkirk Street. These conditions are considered acceptable.

Montreal Road: The sidewalks along Montreal Road are predicted to be mostly suitable for standing during the summer, becoming suitable for a mix of standing and strolling during the remaining colder seasons. These conditions are considered acceptable.

Courtyard: The courtyard and driveway entrances will be suitable for a mix sitting and standing during the summer, becoming suitable for a mix of standing and strolling during spring and autumn, with an isolated walking region that is predicted to form near the east entrance during the winter season. These conditions are considered acceptable. If seating areas will be provided over windier areas between the buildings, a comprehensive mitigation strategy comprising vertical wind barriers and/or canopies would be recommended and coordinated as the design evolves.

Dedicated Parkland Areas: The dedicated parkland areas are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for a mix of standing and strolling during the remaining colder seasons. If seating areas will be provided over windier areas, a comprehensive mitigation strategy comprising vertical wind barriers (wind screens and coniferous plantings in dense arrangements) would be recommended and coordinated as the design evolves.

Bus Stops, North River Road: The bus stops on either side of North River Road are predicted to be suitable for standing or better throughout the year, which is acceptable.



Bus Stop, North Side of Montreal Road: The bus stop on the north side of Montreal Road is predicted to be suitable for standing during the summer and autumn, and suitable for strolling during the spring and winter seasons. Since it is recommended that comfort conditions be suitable for standing, or better, the introduction of a bus shelter would provide the necessary relief to the more vulnerable members of the population during strong wind events.

Building Entrances: All primary building entrances will be suitable for standing or better throughout the year, which is acceptable.

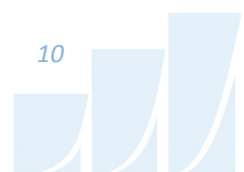
5.2 Wind Comfort Conditions – Rooftop Terraces

Northwest Rooftop Terrace: Wind conditions within the northeast common rooftop terrace will be suitable for a mix of sitting and standing during the summer season, becoming suitable for a mix of standing and strolling during the spring and autumn seasons, and with an isolated region suitable for walking during the coldest months of the year. Figure 5 illustrates that during the summer the majority of the terrace will be suitable for sitting at least 75% of the time with an isolated region near the west perimeter becoming suitable for sitting at least 70% of the time.

The windier conditions on the terrace are caused by a combination of wind channeling between Buildings A and C, and acceleration of prominent westerly and easterly winds around the building corners. As such, we recommend installing tall (minimum 2 m) wind screens in place of standard height guardrails along the perimeter of the terrace. Since the terrace is large, local wind barriers inboard of the perimeter may also be required. Wind barriers may take the form of glass architectural wind screens positioned to protect designated seating areas, or a mix of wind screens and coniferous trees planted in dense arrangements. A mitigation strategy could be confirmed during design development.

North Rooftop Terrace: Wind conditions within the common rooftop terrace to the south of Building A are predicted to be suitable for sitting during the summer and autumn, becoming suitable for a mix of sitting and standing during the two colder seasons. These conditions are considered acceptable.

Northeast Rooftop Terrace: Wind conditions within the common rooftop terrace are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing during the remaining three colder seasons. These conditions are considered acceptable.



5.3 Applicability of Results

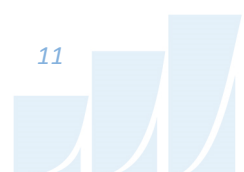
Wind conditions over surrounding sidewalks beyond the subject site, as well as at nearby primary building entrances, will be acceptable for their intended pedestrian uses during each seasonal period upon the introduction of the subject site. Pedestrian wind comfort and safety have been quantified for 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-3D, Figures 4A-4D, and Figure 5. 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 similar developments in Ottawa, we conclude the following:

- 1) Wind conditions at the nearby bus stop on the north side of Montreal Road will be suitable for standing during the summer and autumn, and suitable for strolling during the winter and spring. Since it is recommended that comfort conditions be suitable for standing, or better, throughout the year, the introduction of a bus shelter would provide the necessary relief to the more vulnerable members of the population during strong wind events.
- 2) If seating is desired within certain windier regions in the courtyard, mitigation will be required and could be coordinated during design development.



- 3) Except for items (1) and (2) above, all grade-level areas within and surrounding the subject site will be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, building access points, driveways, other bus stops in the immediate vicinity of the subject site, and within the courtyard, are considered acceptable for the intended pedestrian uses throughout the year.
- 4) Wind conditions within the north and northeast common rooftop terraces will be suitable for sitting during late spring through early autumn, which is considered acceptable.
- 5) Wind conditions within the northeast common rooftop terraces will be suitable for a mix of sitting and standing during the summer. To achieve conditions suitable for sitting during the summer season, we recommend installing tall (minimum 2 m) wind screens in place of standard height guardrails along the perimeter of the terrace. Since the terrace is large, local wind barriers inboard of the perimeter may also be required. Wind barriers may take the form of glass architectural wind screens positioned to protect designated seating areas, or a mix of wind screens and coniferous trees planted in dense arrangements. A mitigation strategy could be confirmed during design development.

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.

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

Sincerely,

Gradient Wind Engineering Inc.

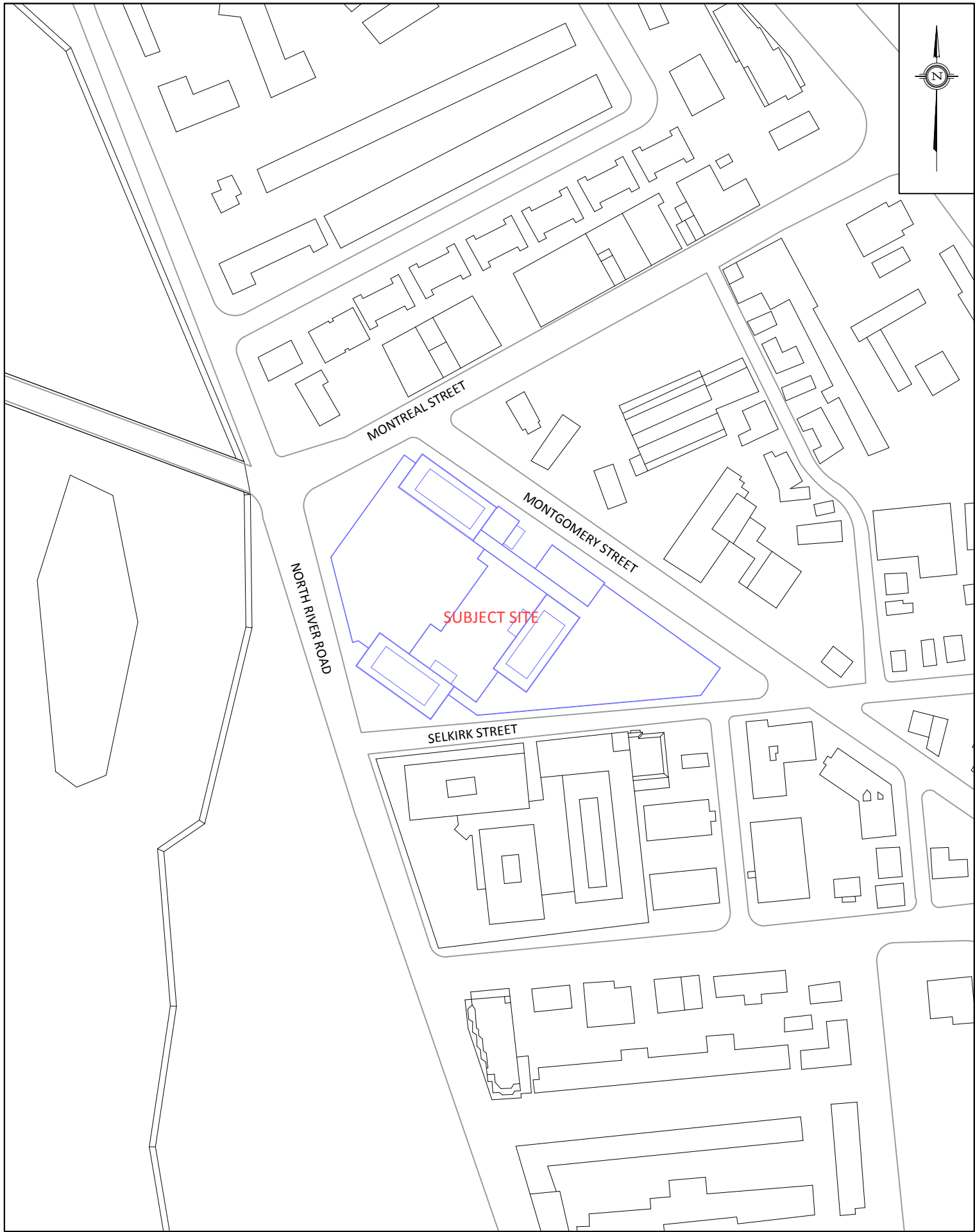
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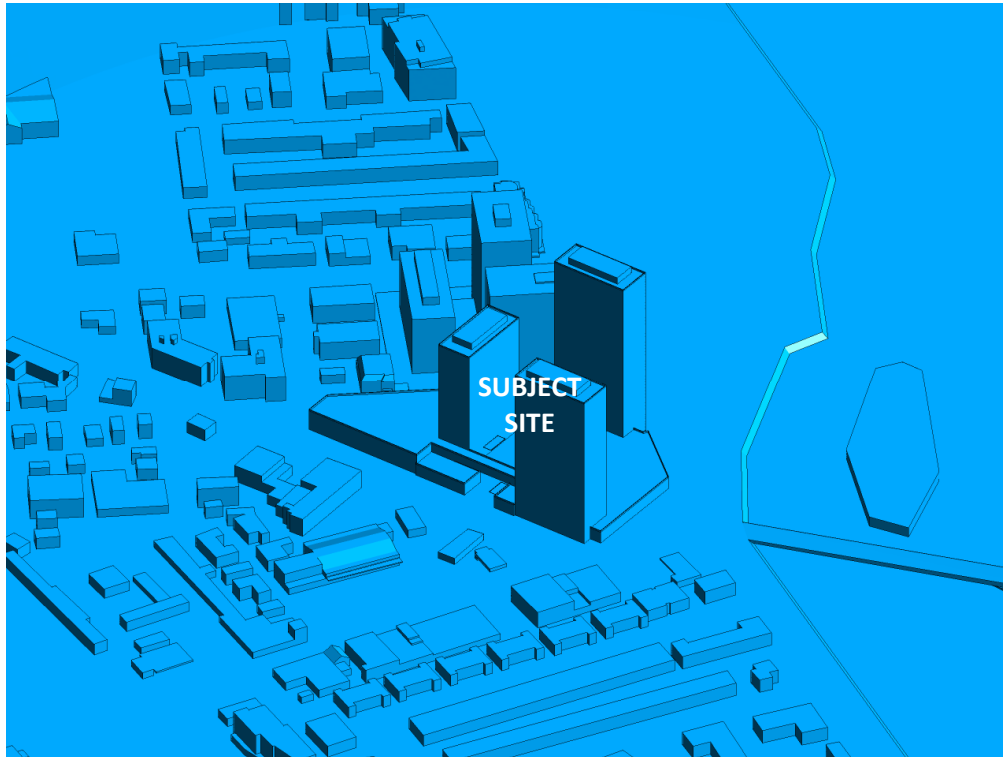


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

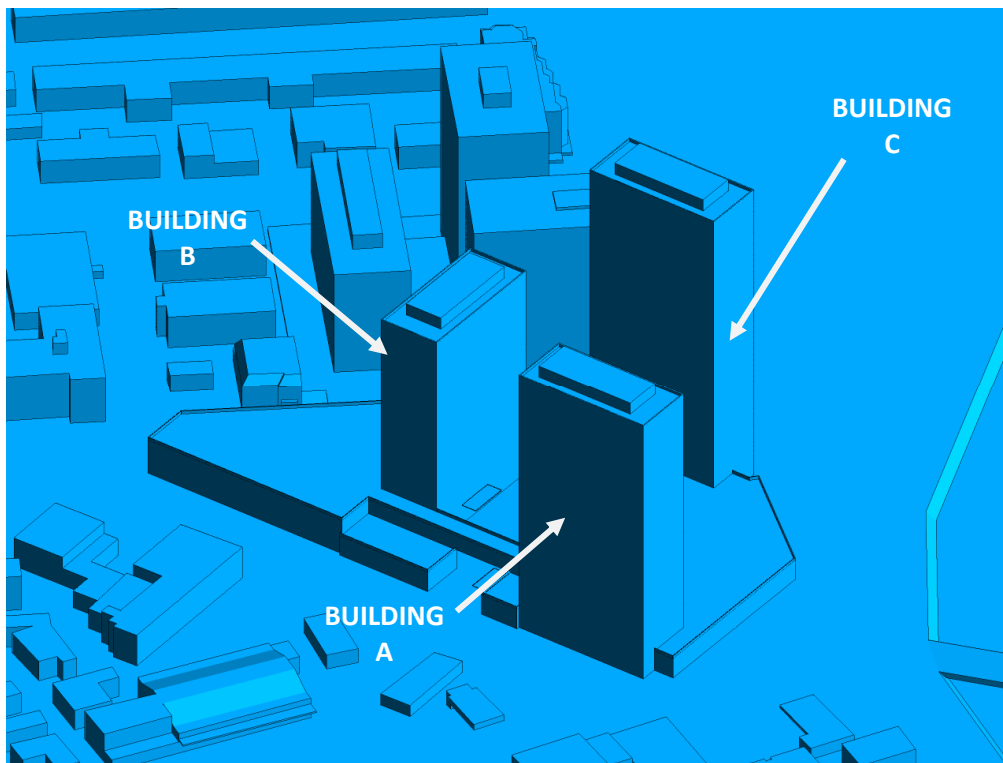


FIGURE 2B: CLOSE UP OF FIGURE 2A



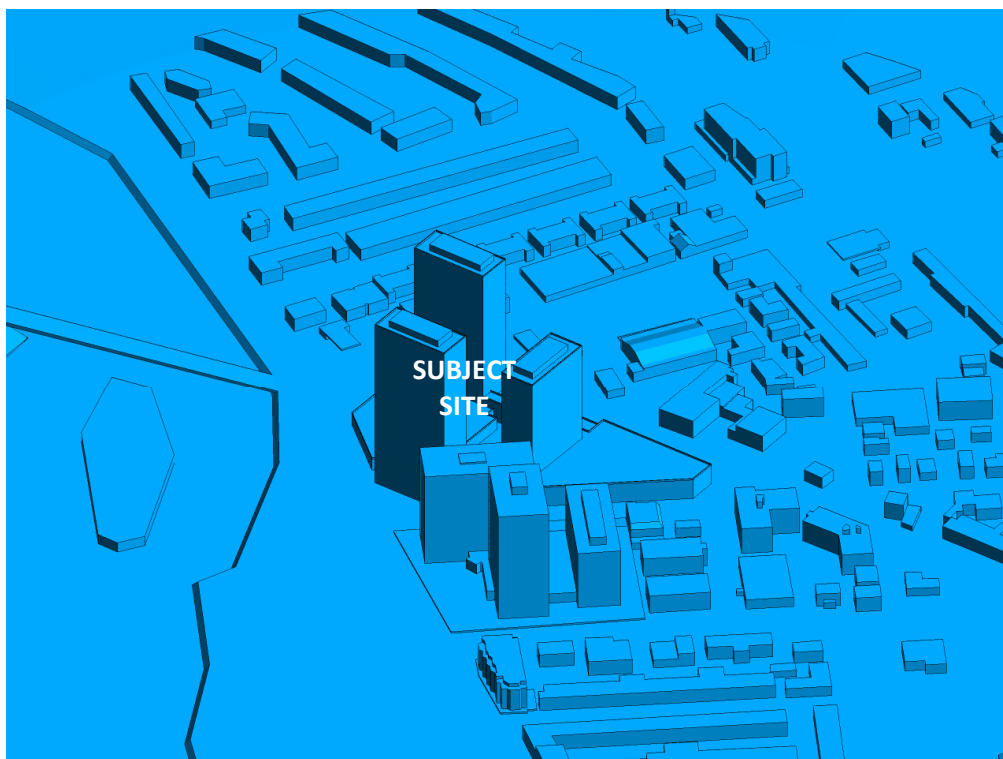


FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

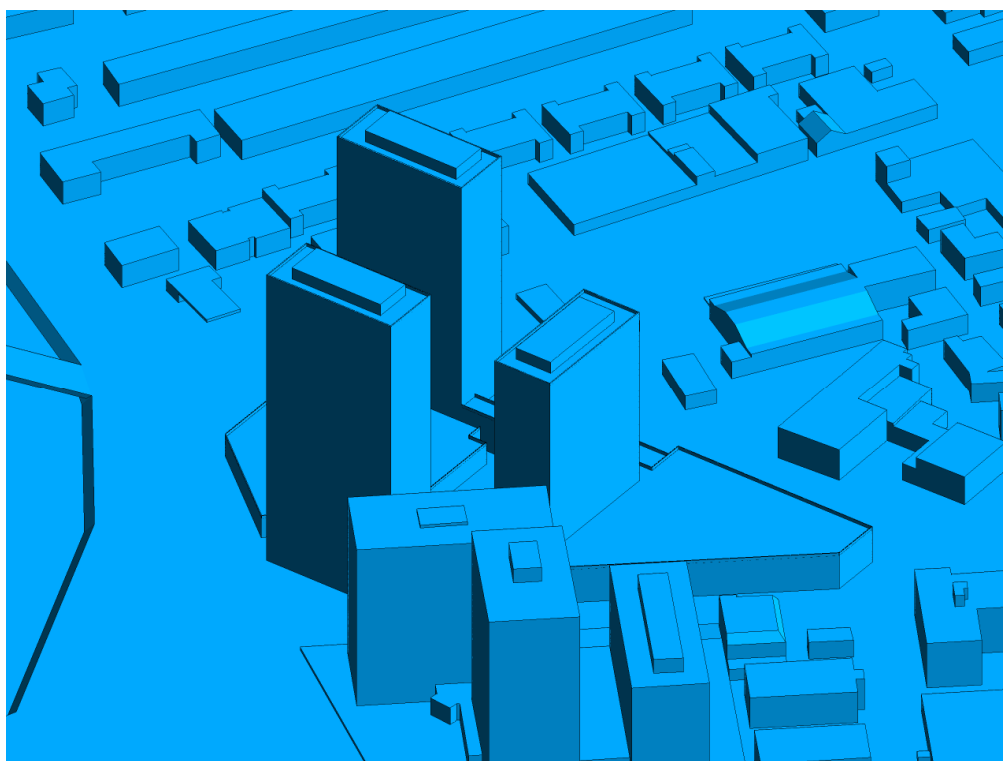


FIGURE 2D: CLOSE UP OF FIGURE 2C

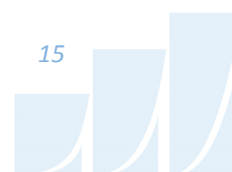




FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

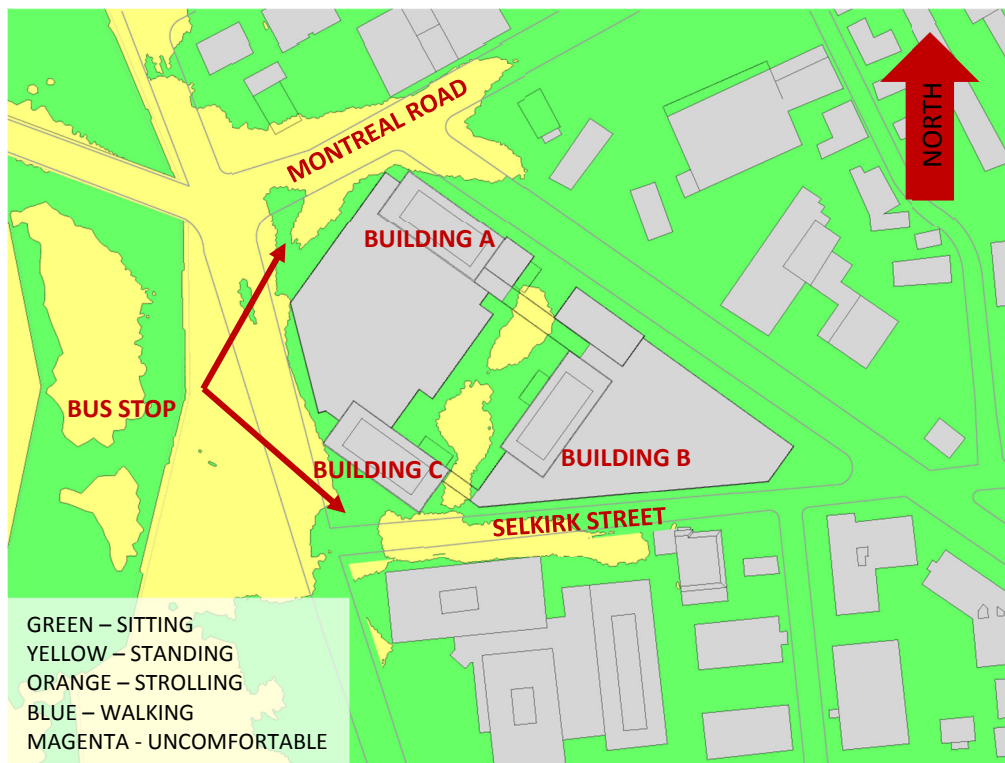


FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL



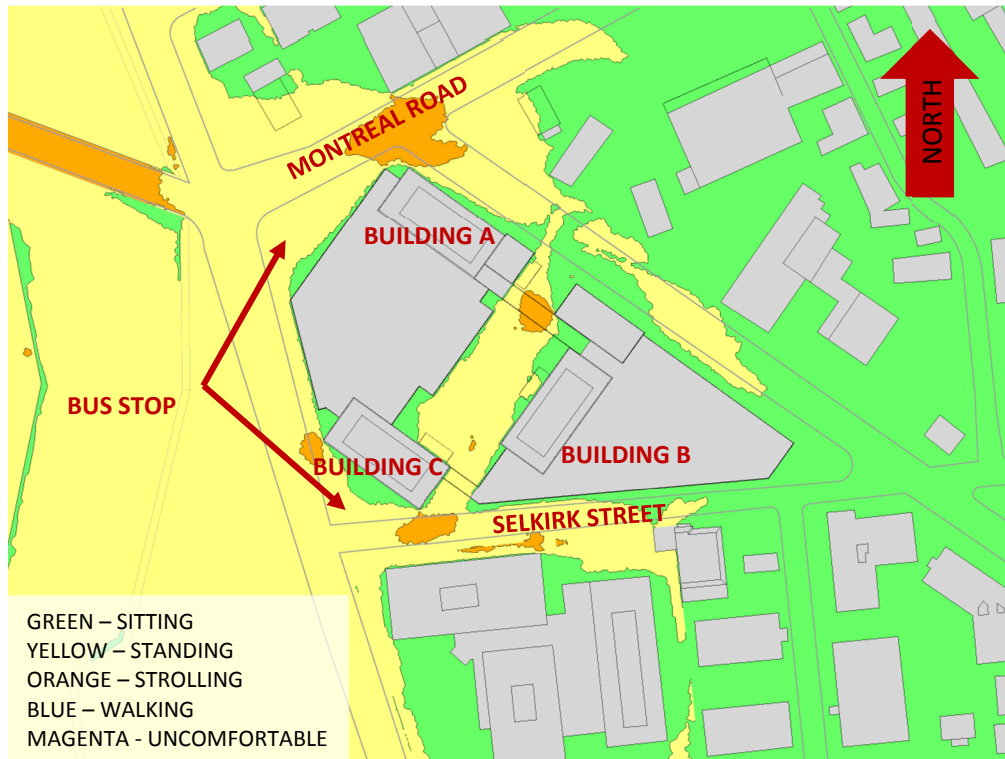


FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

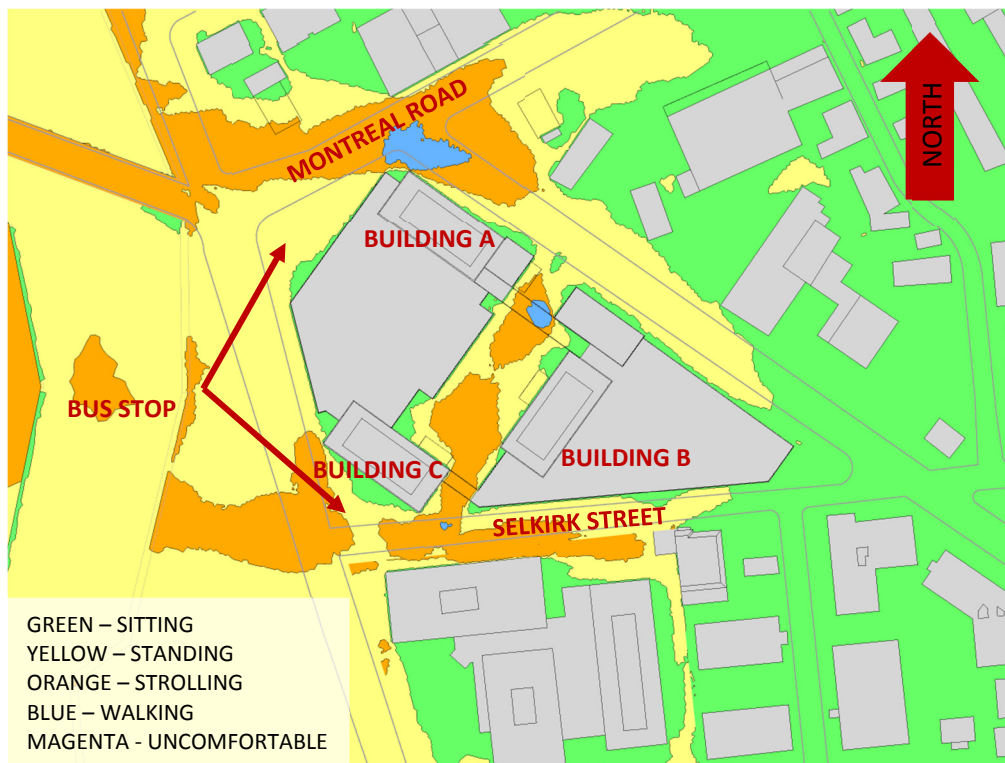


FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL



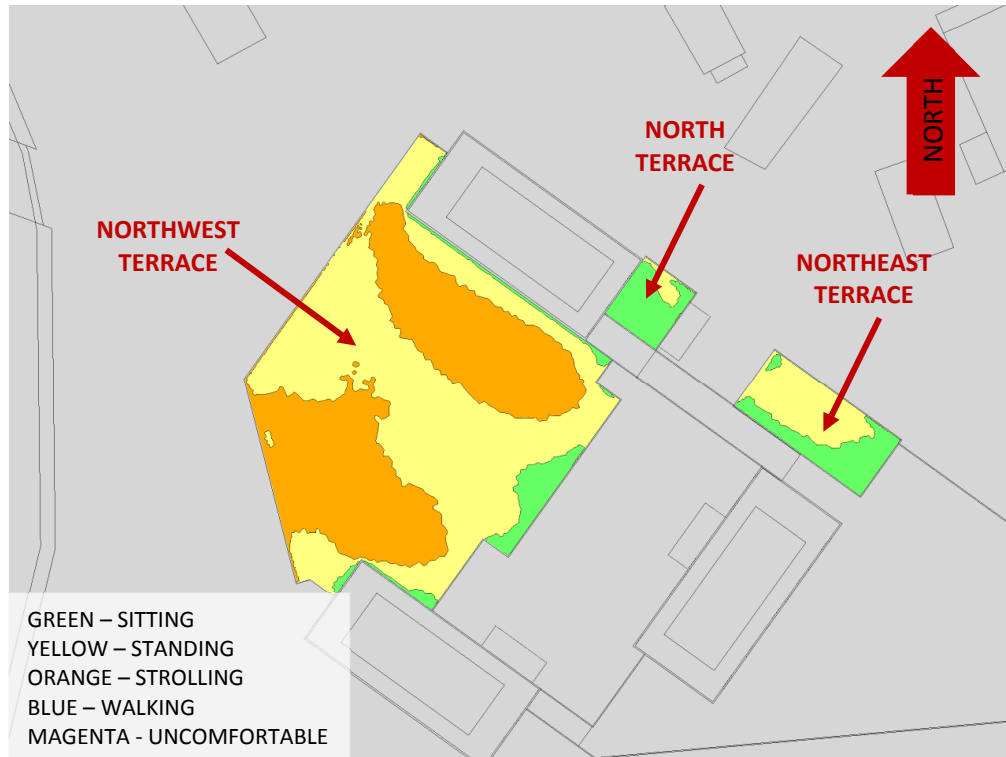


FIGURE 4A: SPRING – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES

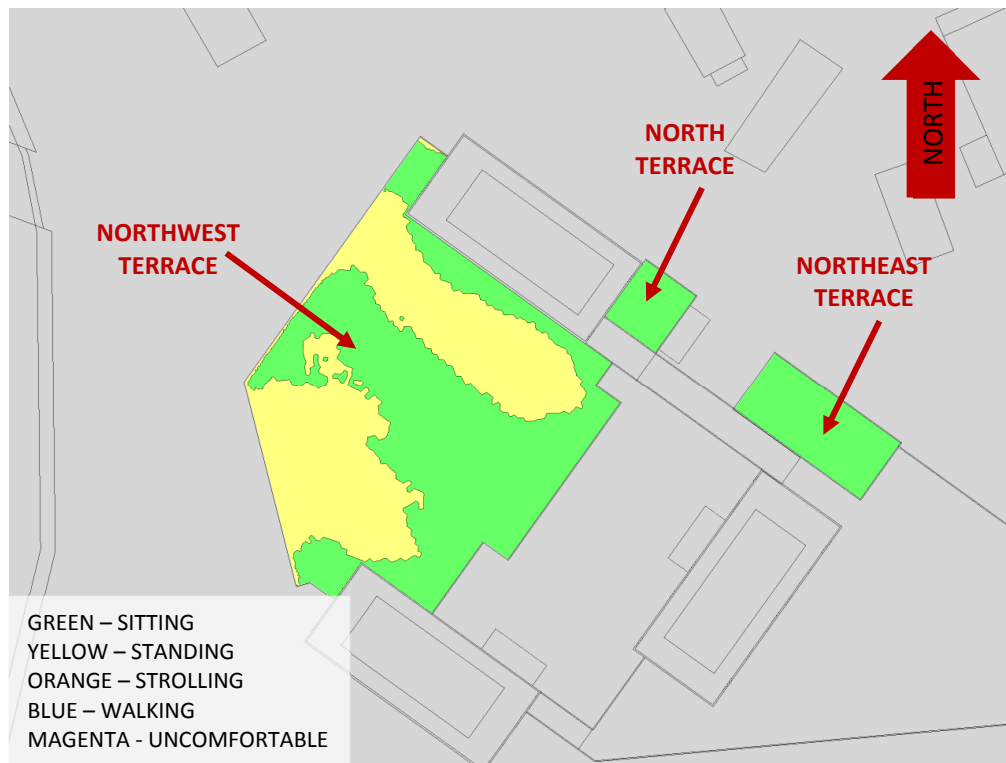


FIGURE 4B: SUMMER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES



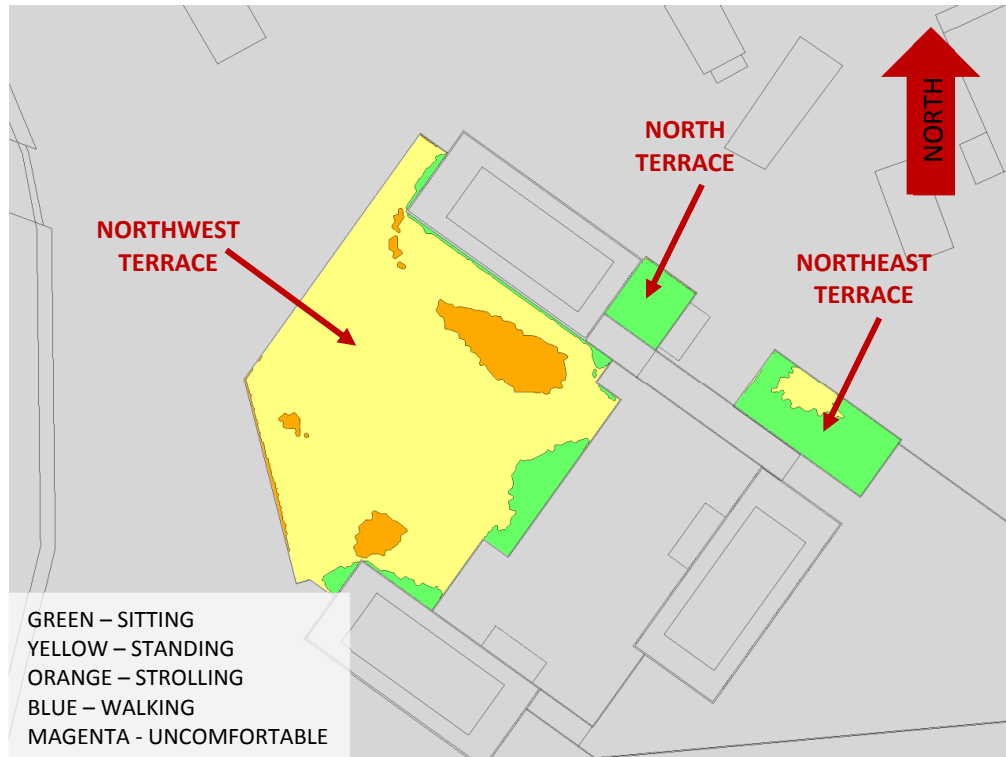


FIGURE 4C: AUTUMN – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES

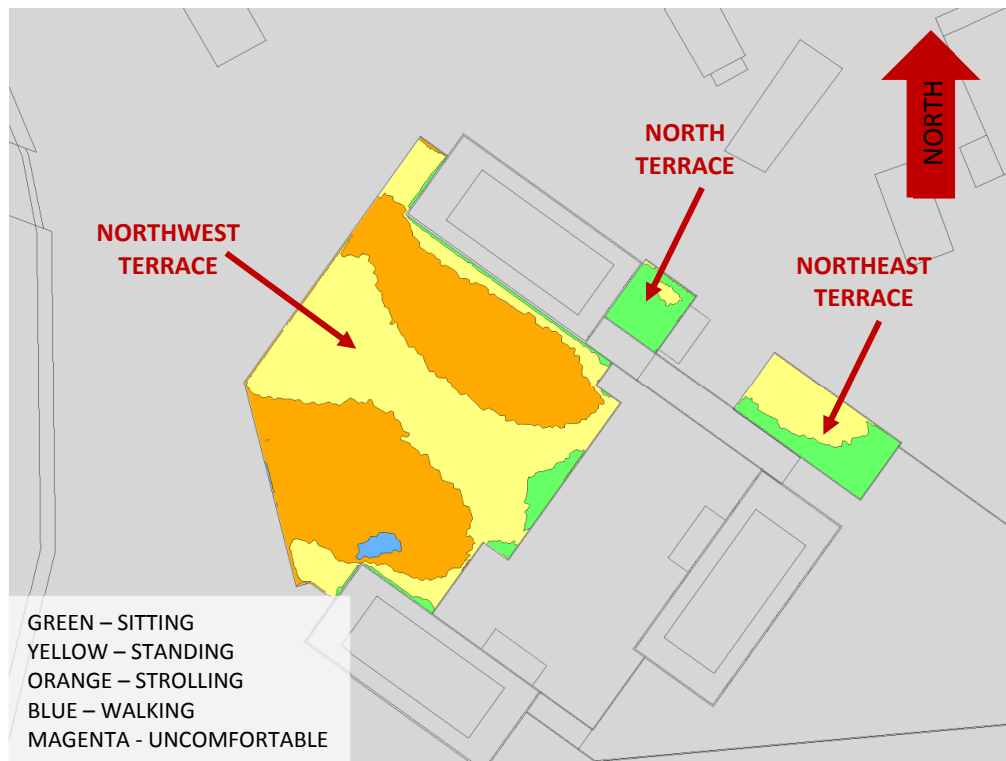


FIGURE 4D: WINTER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES



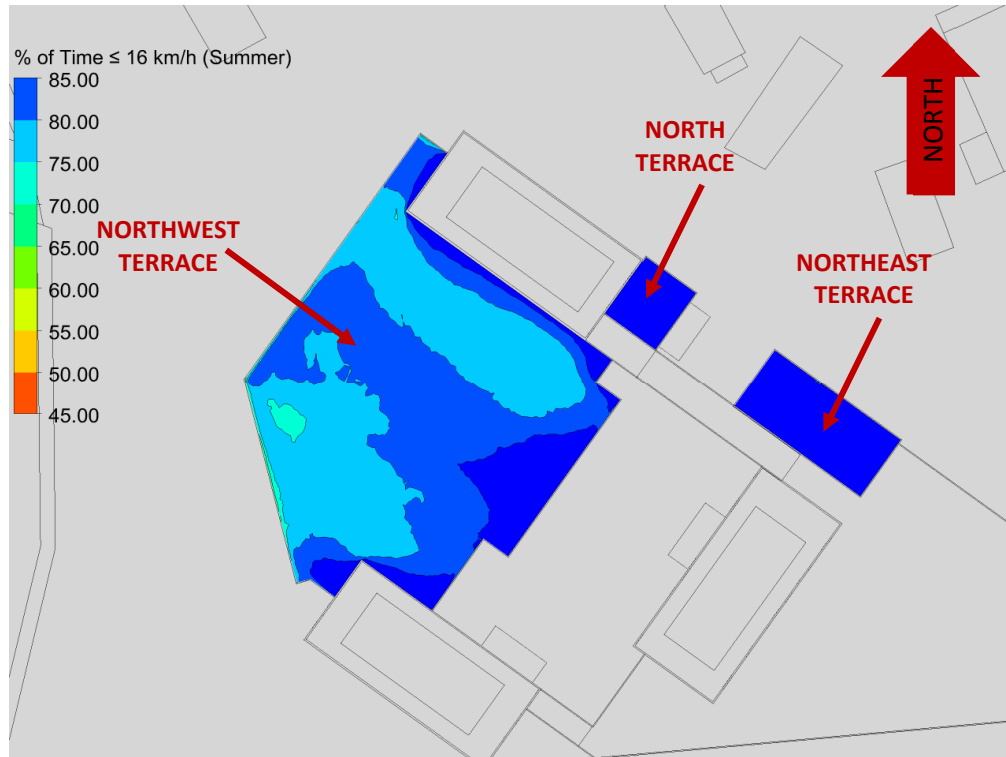
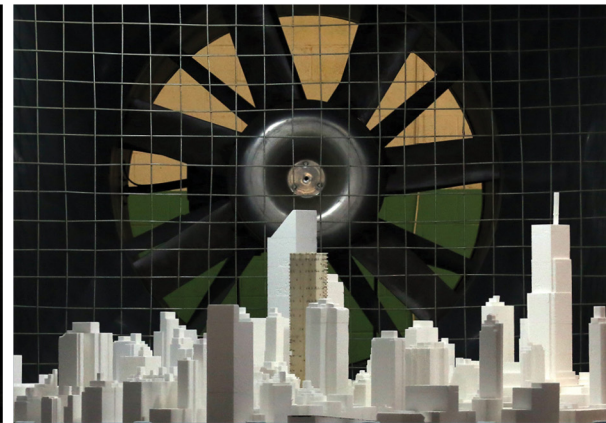
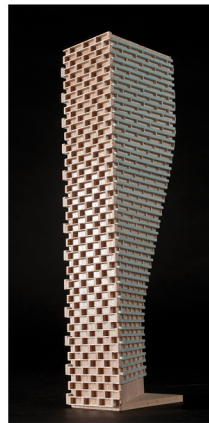


FIGURE 5: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING (TERRACES)



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

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

Upstream Exposure Type	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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