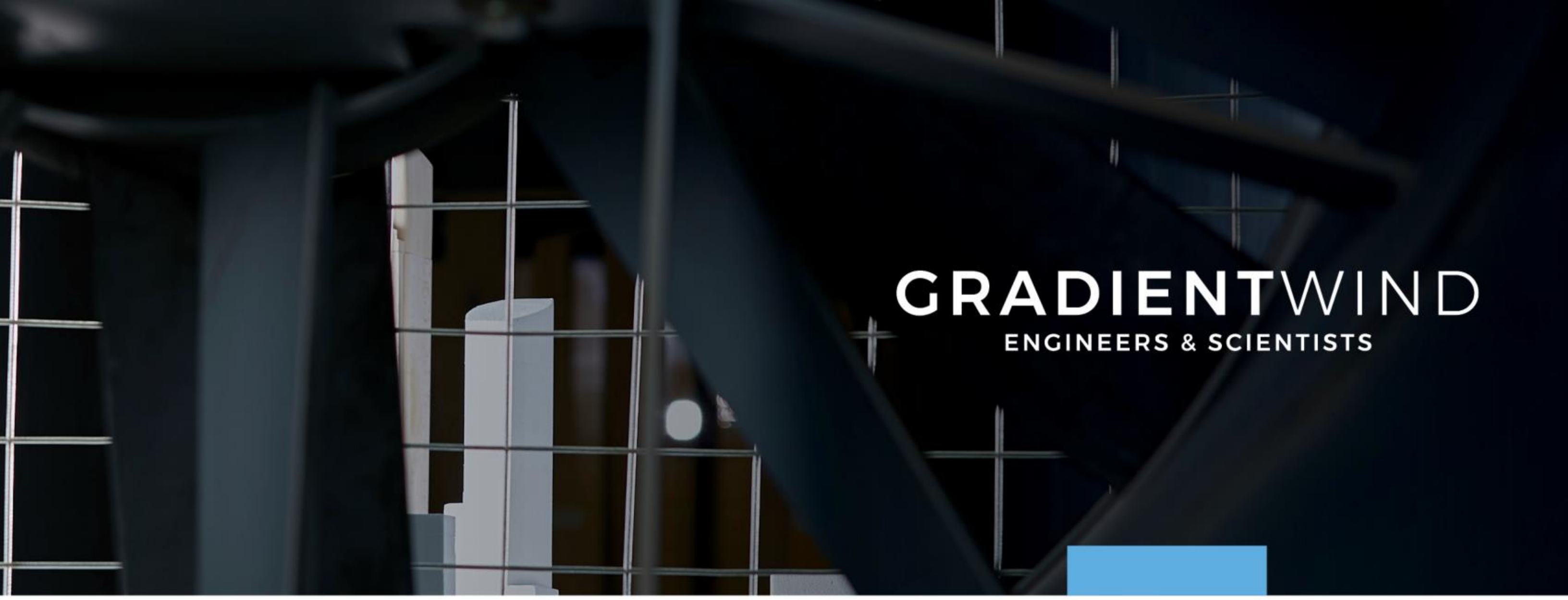
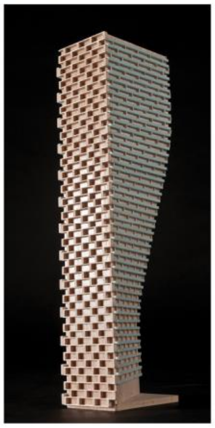


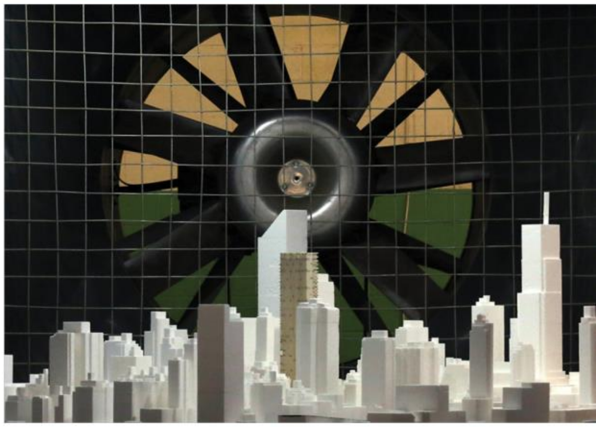
GRADIENTWIND
ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

1560 Scott Street
Ottawa, Ontario

Report: 20-229-PLW





December 15, 2021

PREPARED FOR
LaSalle Investment Management
22 Adelaide Street West, 26th Floor
Toronto, ON M5H 4E3

PREPARED BY
Sacha Ruzzante, MASc, Wind Scientist
Justin Ferraro, P.Eng., Principal

EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy Site Plan Control application requirements for a proposed mixed-use development at 1560 Scott Street in Ottawa, Ontario (hereinafter referred to as "subject site" or "proposed development"). 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, where required.

The study involves simulation of wind speeds for selected wind directions in a three-dimensional (3D) computer model using the computational fluid dynamics (CFD) technique, combined with meteorological data integration, to assess pedestrian wind comfort and safety within and surrounding the subject site according to City of Ottawa wind comfort and safety criteria. The results and recommendations derived from these considerations are detailed in the main body of the report, illustrated in Figures 3A-4D and 5A-5B, and summarized as follows:

1) All areas at grade will be suitable for their intended uses throughout the year. This includes all building access points, the loading docks, nearby sidewalks, and the pedestrian mall.

    a. The only exception involves the amenity space at grade, to the immediate south of the proposed development. We recommend installing 1.5-m-tall wind barriers around the full perimeter of the amenity patio to provide conditions suitable for sitting during the typical use period of late spring to early autumn. While solid glass barriers are commonly deployed, coniferous plantings in a dense arrangement could also be considered. An effective strategy would require direction from the landscape architect to ensure wind mitigation requirements were integrated with the overall programming of the area.

2) To achieve sitting conditions on the elevated amenity terrace at Level 5 during the typical use period, we recommend installing 1.8-m-tall wind barriers along the full perimeter of the terrace. Similarly, for the elevated amenity terrace at Level 29, we recommend installing 2-m-tall wind barriers along the full perimeter of the terrace.

3) 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 uncomfortable or dangerous.

Addendum: This addendum is provided at the request of LaSalle Investment Management to satisfy Site Plan Control application requirements for the proposed development.

Following the completion of the PLW study, the design of the proposed development was reduced to 25 storeys (previously 29 storeys)[1]. While the footprint of the current design is similar to the design considered for the original PLW study, the long dimension of the typical tower floorplate is curved in the current design where previously it was linear. From a wind engineering perspective, the reduction in height is expected to result in somewhat calmer wind conditions around the subject site. Since wind conditions were determined to be acceptable across the subject site for the original taller massing, a formal update to the wind study is not recommended. Of particular importance, excluding anomalous localized storm events such as tornadoes and downbursts, no areas over the subject site are anticipated to be uncomfortable or dangerous for the current massing.

The original design included common amenity terraces along the east and west sides of the proposed development at Levels 5 and 29, respectively. While the current architectural design does not include any common amenity terraces above the ground floor, a large amenity area is provided at the ground floor along the south elevation of the proposed development. Based on the findings of the original study, conditions within the noted ground floor amenity area are predicted to be mostly suitable for sitting during the summer. As noted above, the reduction in tower height is expected to result in somewhat calmer wind conditions around the subject site, inclusive of the amenity area. These conditions would be considered acceptable according to the City of Ottawa wind criteria.

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[1] N45 Architecture Inc., '*Holland Cross Phase 3 Residential – Issued for Site Plan Application*', [Dec 8, 2021]

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by LaSalle Investment Management to undertake a pedestrian level wind (PLW) study to satisfy Site Plan Control application requirements for a proposed mixed-use development at 1560 Scott Street in Ottawa, Ontario (hereinafter referred to as "subject site" or "proposed development"). 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, where required.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings of the subject site provided by N45 Architecture in September 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 focus of this pedestrian level wind study is a proposed mixed-use building located at 1560 Scott Street in Ottawa, Ontario. The proposed development is bordered by Hamilton Avenue North to the east, and by a pedestrian mall to the south, and is located at the southeast corner of, and integrated with, the Holland Cross Development.

Architectural Rendering
Southeast Perspective
(Courtesy of N45 Architecture Inc.)

The proposed development comprises a 29-storey building with a roughly rectangular planform. The building steps back from the east elevation at Level 5, providing for a common amenity terrace. The building steps back again at Level 29, providing for another common amenity terrace. A grade-level amenity patio is located to the immediate south of the proposed building.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) include a mix of mid-and low-rise buildings, including the rest of the Holland Cross site to the north and west, 35 & 45 Holland Avenue to the south, and 320 Parkdale Avenue to the southeast. The proposed site of 250 and 274 Parkdale is situated to the northeast. The far-field surroundings (defined as an area beyond the near-field but within a 2-kilometre (km) radius of the subject site) include primarily low-rise buildings with isolated taller buildings, as well as undeveloped land, and the Ottawa River running from the northwest clockwise to northeast. Of note, the future Trinity Centre and Lebreton Flats sites lie approximately 1.1 km and 1.9 km to the northeast, respectively. The Ottawa Experimental Farm lies approximately 1.6 km to the south.

Key areas under consideration include surrounding sidewalks, the pedestrian mall, walkways, building access points and outdoor amenity areas. 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 subject 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.

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

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. 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 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 subject site for 12 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a diameter of approximately 820 m.

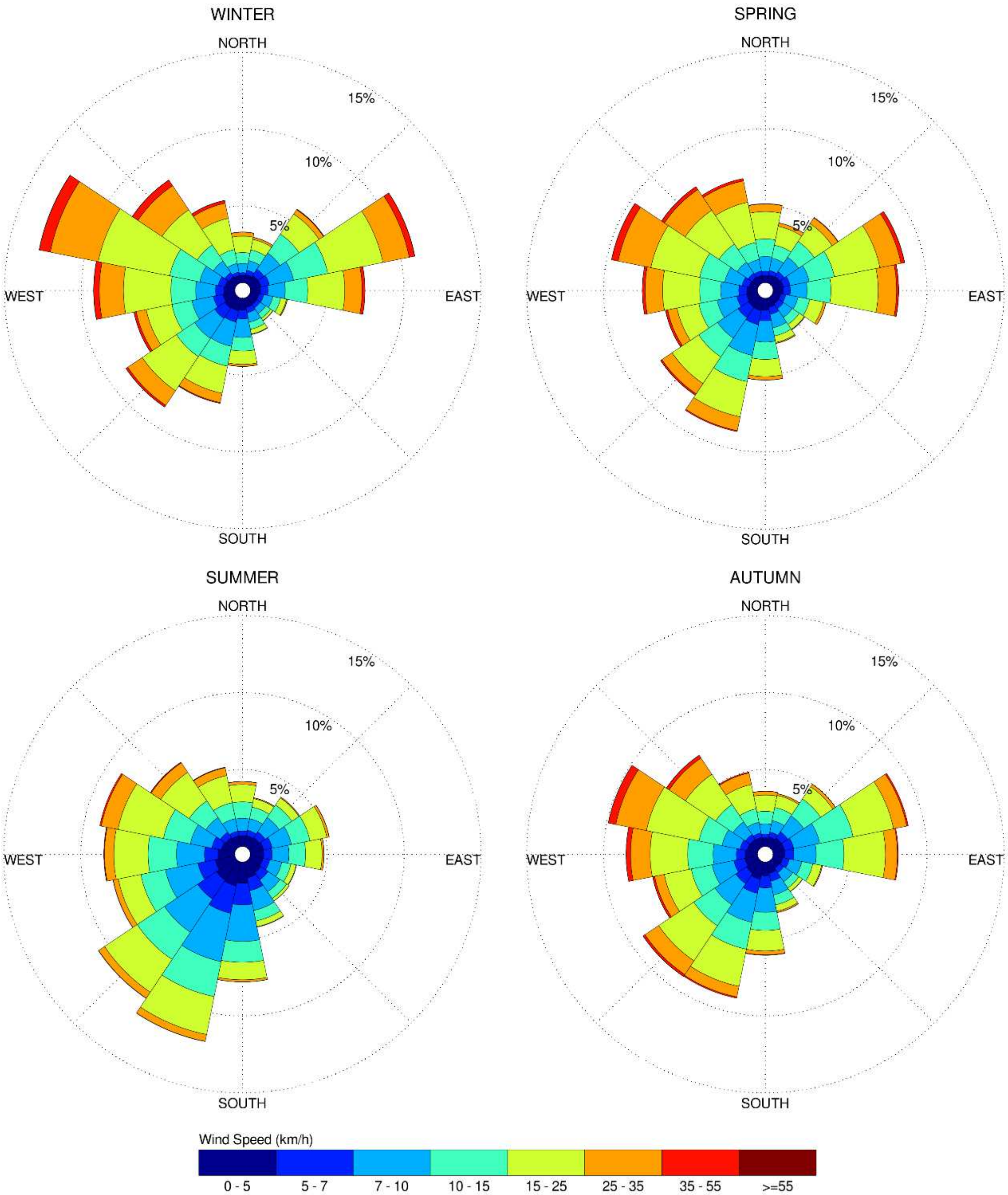
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds on a continuous measurement plane 1.5 m above local grade and above the elevated amenity terraces were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. The 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 CFD 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 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 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 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 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 and Figures 4A-4D (following the main text), illustrating seasonal wind comfort conditions at grade level and within the elevated amenity terrace, respectively. Wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site.

The colour contours indicate various wind comfort classes predicted for certain regions, which correspond to the City of Ottawa wind comfort criteria in Section 4.4. 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. Uncomfortable conditions are represented by magenta. Pedestrian comfort is summarized below for each area of interest. In addition, Figures 5A and 5B illustrate the percentage of time during the summer season that the grade level and elevated amenity terraces, respectively, are predicted to be suitable for sitting.

5.1 Wind Comfort Conditions – Grade Level

Hamilton Avenue North and Bullman Street: Conditions along Hamilton Avenue North and Bullman Street will be mostly suitable for standing during the summer, with calmer conditions, suitable for sitting, farther south on Hamilton Avenue North and along part of Bullman Street. During the autumn, conditions will be suitable for strolling near the intersection of the two roads, suitable for standing along Bullman Street and along part of Hamilton Avenue North, and suitable for sitting farther south along Hamilton Avenue North. During the winter and spring, conditions will be suitable for walking, or better, along both streets. Conditions are generally windiest near the northeast corner of the proposed building, around which northeast and northwest winds are expected to accelerate. Nevertheless, the conditions are considered acceptable according to the wind comfort criteria in Section 4.4.

Pedestrian Mall: Conditions along the pedestrian mall to the south of the subject site are expected to be mostly suitable for standing during the summer, becoming suitable for strolling, or better, during the remaining colder seasons. Windy conditions along the mall are caused primarily by acceleration of easterly and westerly winds. Nevertheless, the conditions are considered acceptable according to the wind comfort criteria in Section 4.4.

Grade-Level Amenity Patio: The grade-level amenity to the south of the proposed building will be suitable for a mix of sitting and standing during the summer, mostly suitable for standing during the spring and autumn, and suitable for a mix of standing and strolling during the winter. Further, Figure 5A illustrates that the area will be suitable for sitting at least 75% of the time during the summer season.

To provide conditions suitable for sitting during the typical use period of late spring to early autumn, we recommend installing 1.5 m tall wind barriers (solid, typically glass) along the full perimeter of the patio. Coniferous plantings in a dense arrangement could also be considered to shelter the area and increase wind comfort; an effective strategy would require direction from the landscape architect to ensure wind mitigation requirements were integrated with the overall programming of the area.

Loading Docks: The loading docks to the north of the proposed building will be suitable for a mix of sitting and standing during the summer, and suitable for strolling, or better, during the remaining colder seasons. These conditions are considered acceptable.

Primary Building Entrances: Wind conditions in the immediate vicinity of all primary building entrances serving the proposed development are expected to be suitable for standing, or better, throughout the year. These conditions are considered acceptable according to the wind comfort criteria in Section 4.4.

5.2 Wind Comfort Conditions – Common Elevated Amenity Terraces

Level 5 Amenity Terrace: The common terrace at Level 5 of the proposed building will be mostly suitable for sitting during the summer, although standing conditions are predicted to develop near the northeast and southeast corners. Further, Figure 5B illustrates that the area will be suitable for sitting at least 75% of the time during the summer season. Conditions during the autumn will be suitable for strolling, or better, while conditions during the winter and spring will be suitable for walking, or better.

To ensure conditions will be suitable for sitting during the typical use period, we recommend installing tall (minimum 1.8 m) wind barriers along the full perimeter of the terrace.

Level 29 Amenity Terrace: The common terrace at Level 29 of the proposed building will be suitable for standing during the summer, suitable for a mix of standing and strolling during the spring and autumn, and suitable for walking, or better, during the winter.

To ensure conditions will be suitable for sitting during the typical use period of late spring to early autumn, we recommend installing tall (minimum 2.0 m) wind barriers along the full perimeter of the terrace.

5.3 Wind Safety

Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level or on the elevated amenity terraces 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 and 5A-5B (following the main text). 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) All areas at grade will be suitable for their intended uses throughout the year. This includes all building access points, the loading docks, nearby sidewalks, and the pedestrian mall.

    a. The only exception involves the amenity space at grade, to the immediate south of the proposed development. We recommend installing 1.5 m tall wind barriers around the full perimeter of the amenity patio to provide conditions suitable for sitting during the typical use period. While solid glass barriers are commonly deployed, coniferous plantings in a dense arrangement could also be considered. An effective strategy would require direction from the landscape architect to ensure wind mitigation requirements were integrated with the overall programming of the area.

2) To achieve sitting conditions on the elevated amenity terrace at Level 5 during the typical use period, we recommend installing 1.8 m tall wind barriers along the full perimeter of the terrace. Similarly, for the elevated amenity terrace at Level 29, we recommend installing 2.0 m tall wind barriers along the full perimeter of the terrace.

3) 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 uncomfortable or dangerous.

Sincerely,

Gradient Wind Engineering Inc.

LICENSED PROFESSIONAL ENGINEER
J. D. FERRARO
100158495
Dec 15, 2021
PROVINCE OF ONTARIO

Sacha Ruzzante, MASc
Wind Scientist

Justin Ferraro, P.Eng.
Principal

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PROJECT: 1560 SCOTT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
SCALE: 1:2000	DRAWING NO.: 20-229-PLW-1	
DATE: NOVEMBER 3, 2020	DRAWN BY: E.K.	

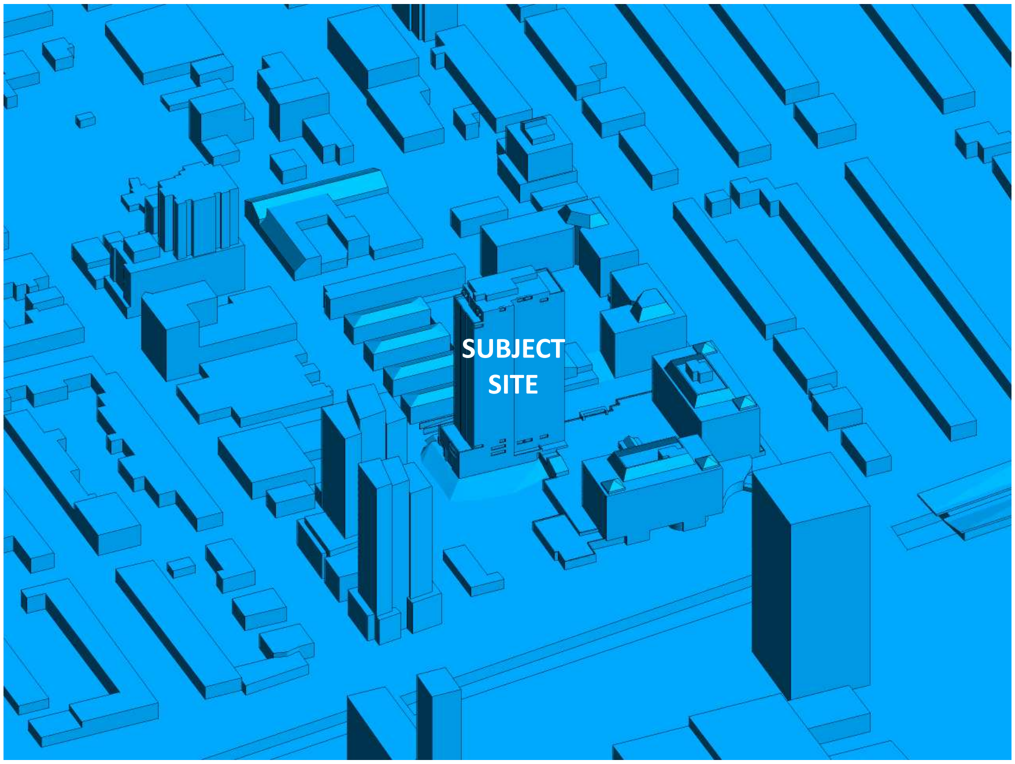


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

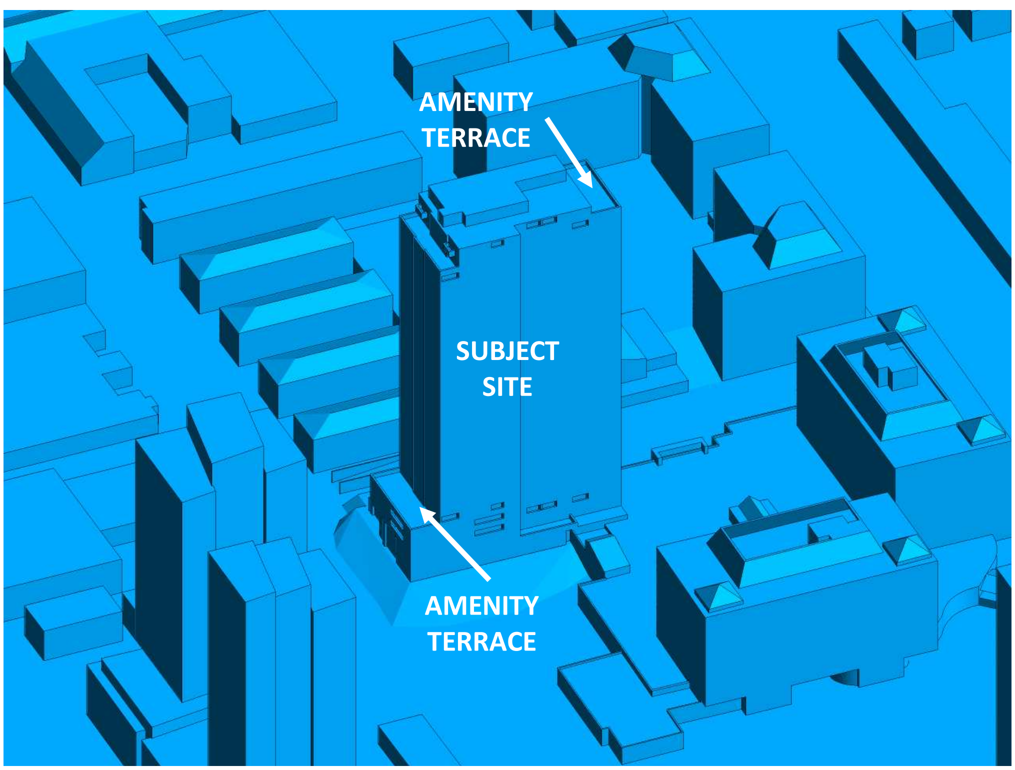


FIGURE 2B: CLOSE UP OF FIGURE 2A

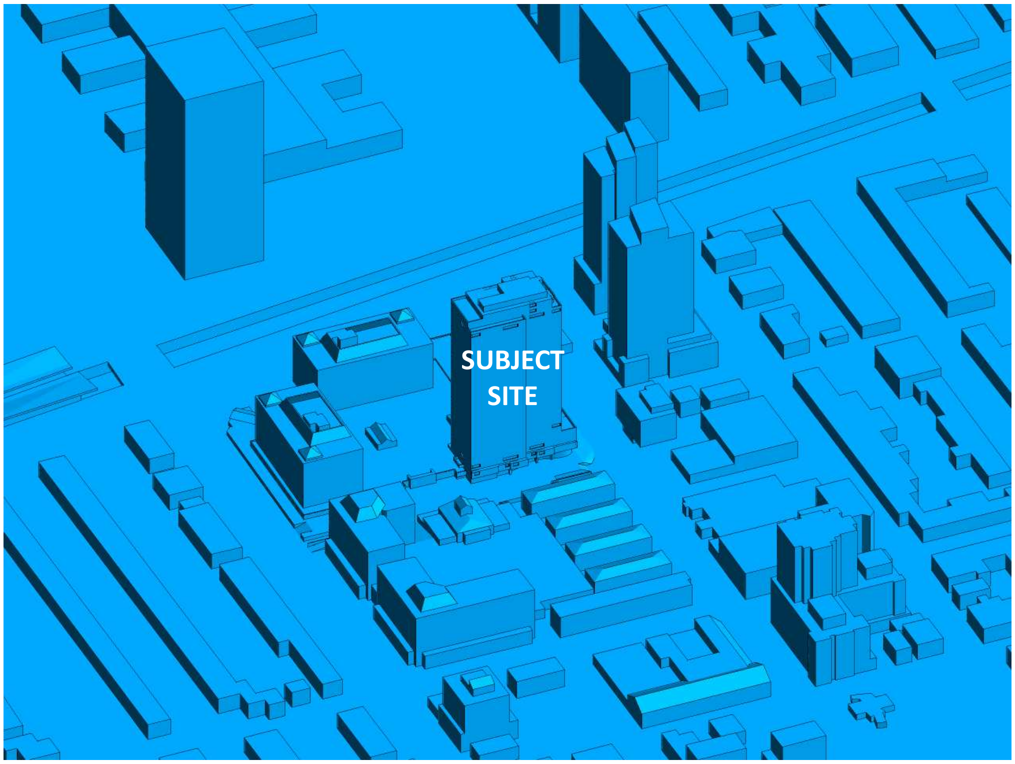


FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

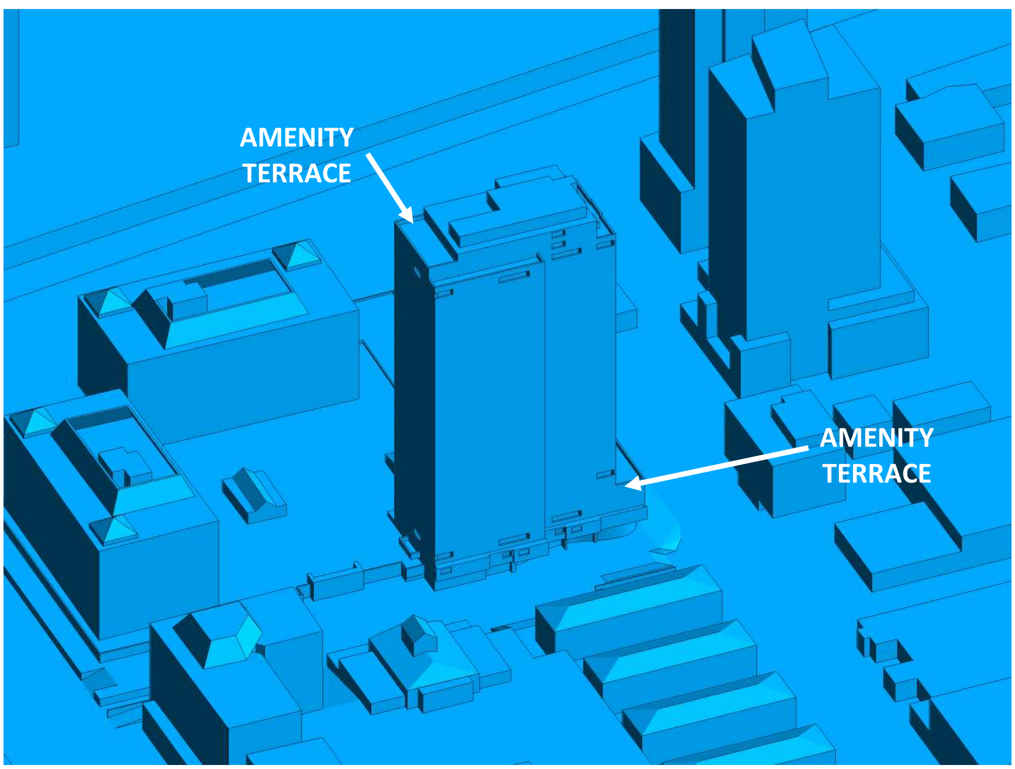


FIGURE 2D: CLOSE UP OF FIGURE 2C

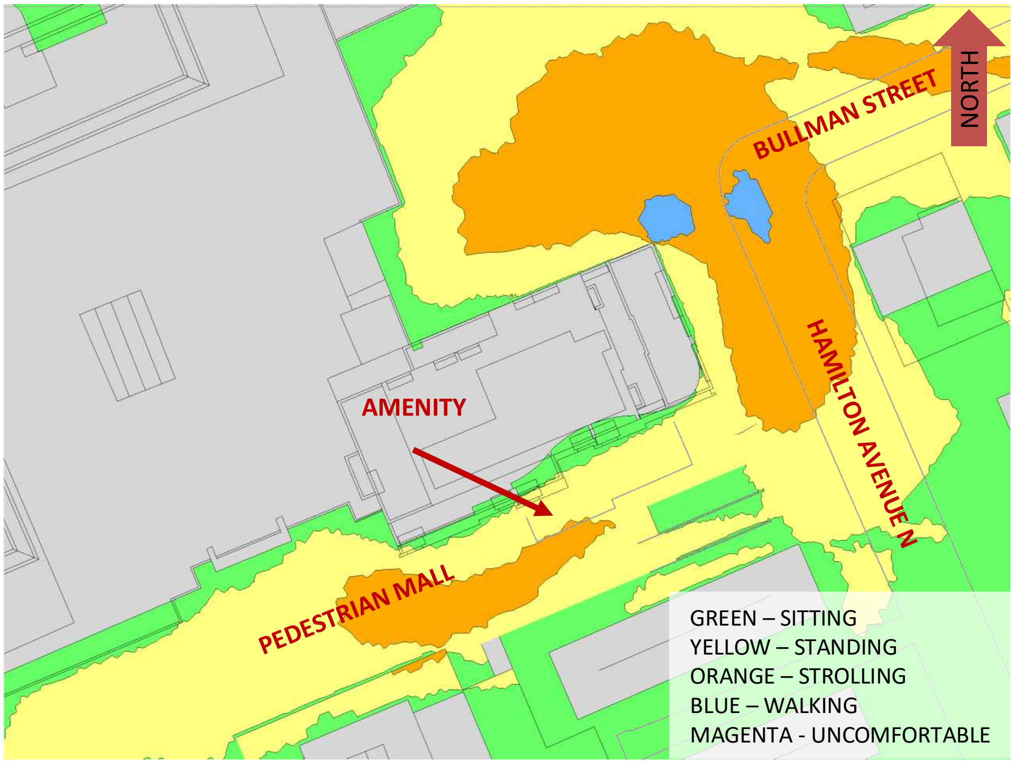


FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

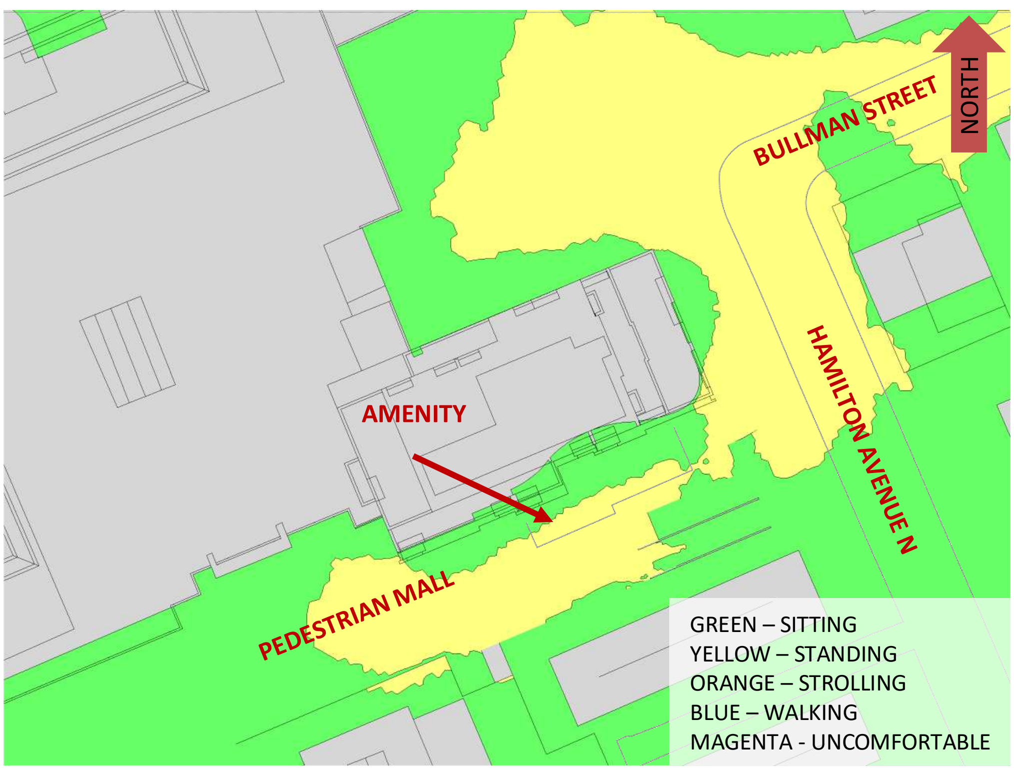


FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL

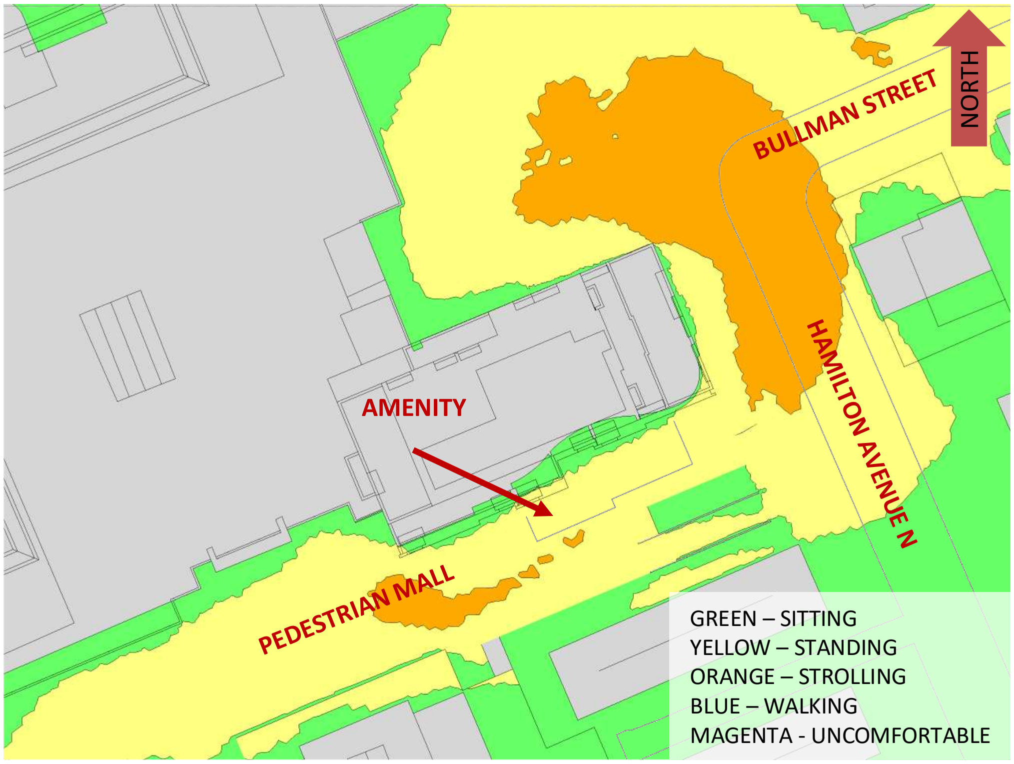


FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

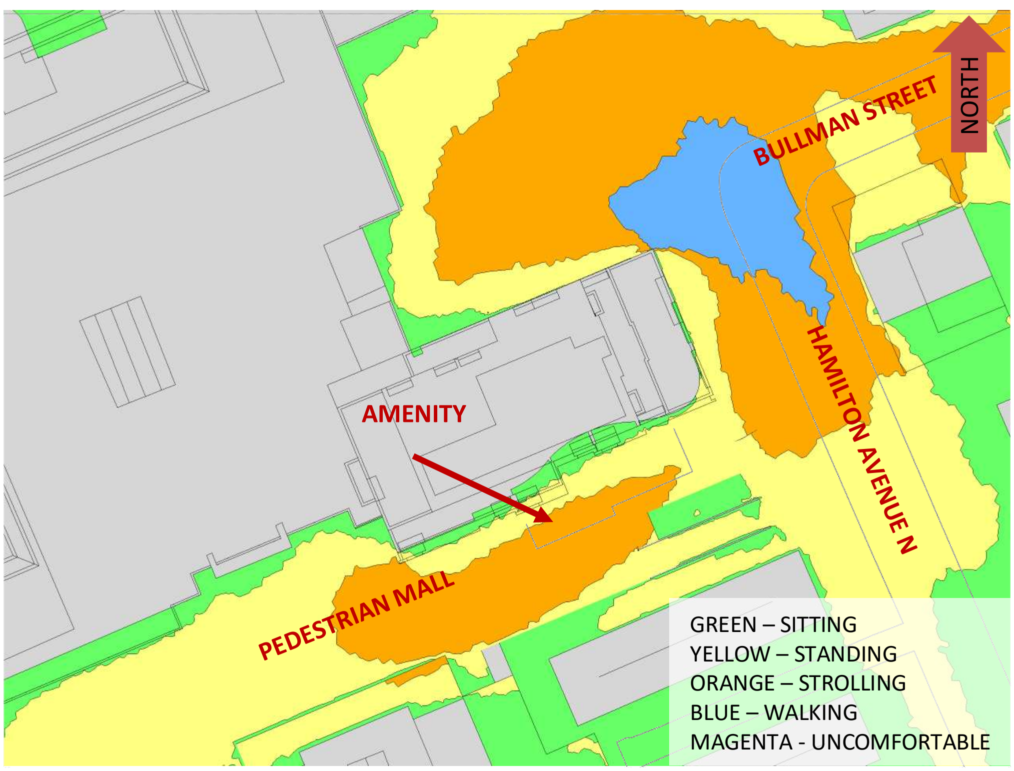


FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL

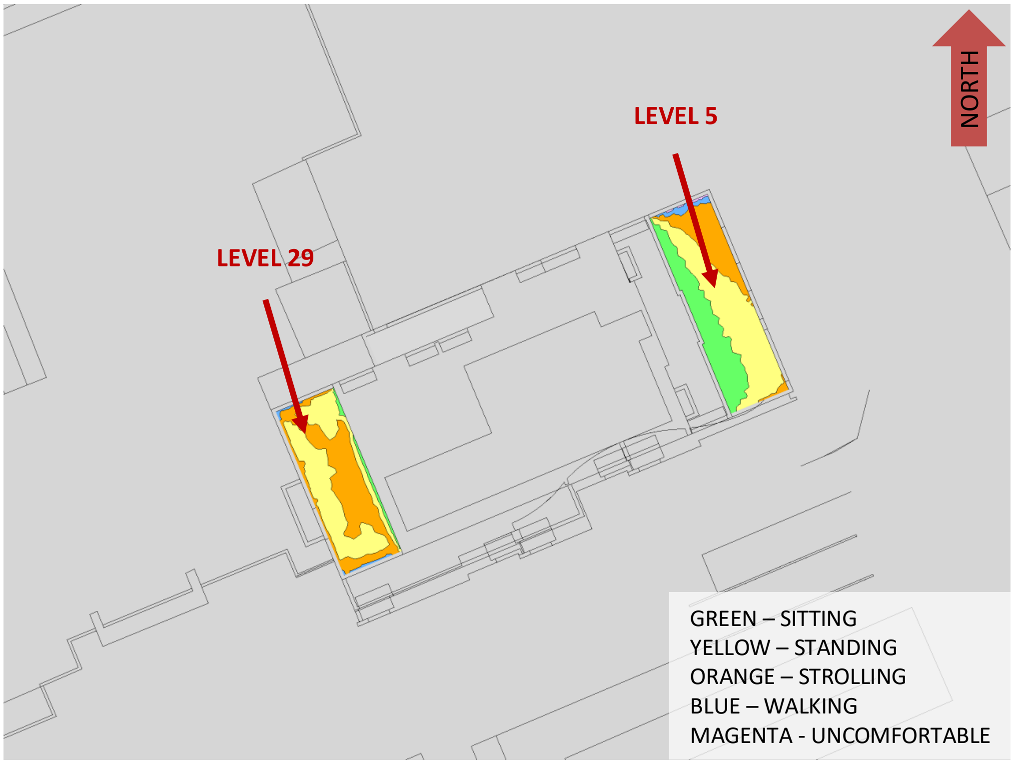


FIGURE 4A: SPRING – WIND COMFORT CONDITIONS, AMENITY TERRACES

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

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

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

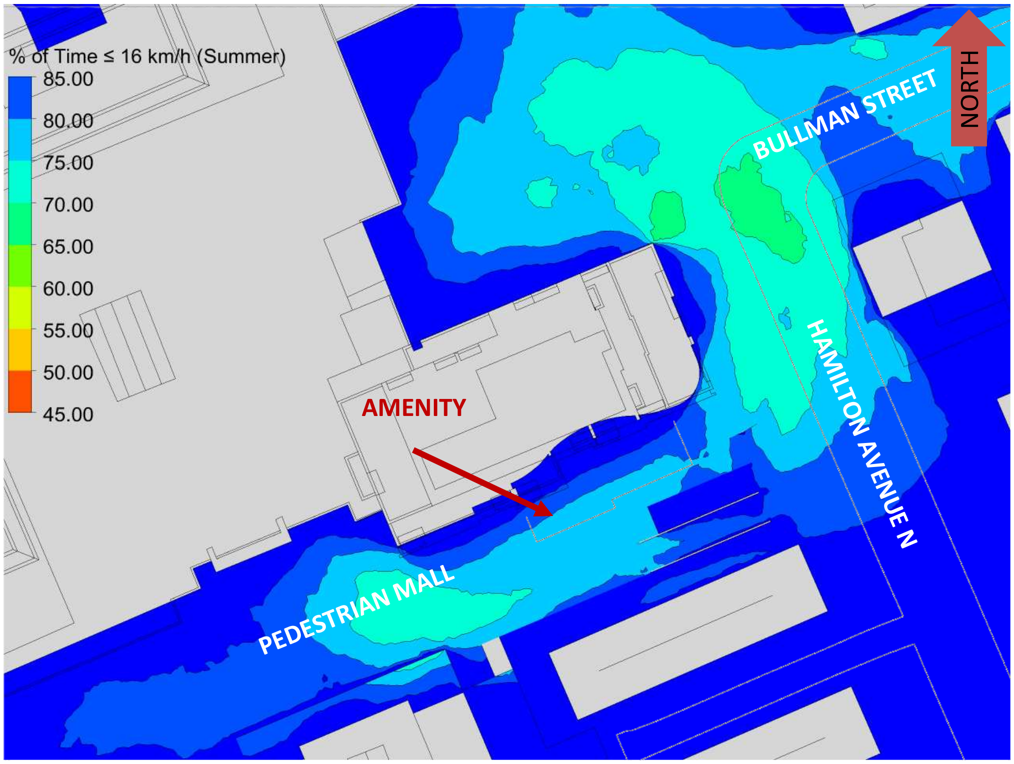


FIGURE 5A: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING, GRADE LEVEL

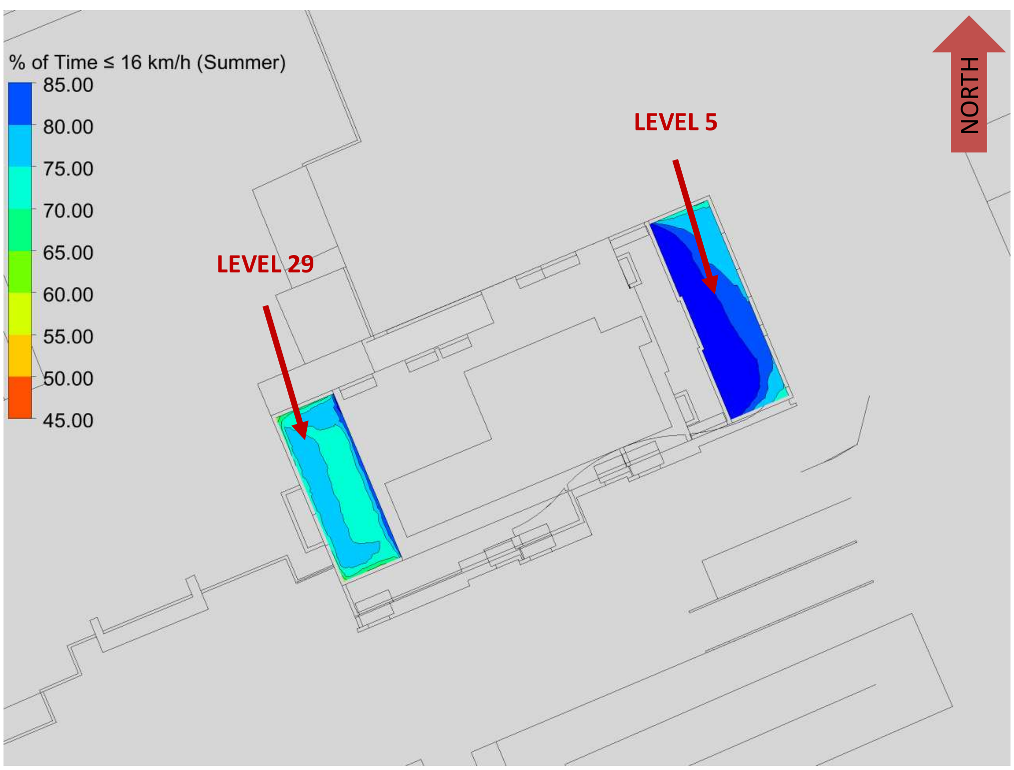
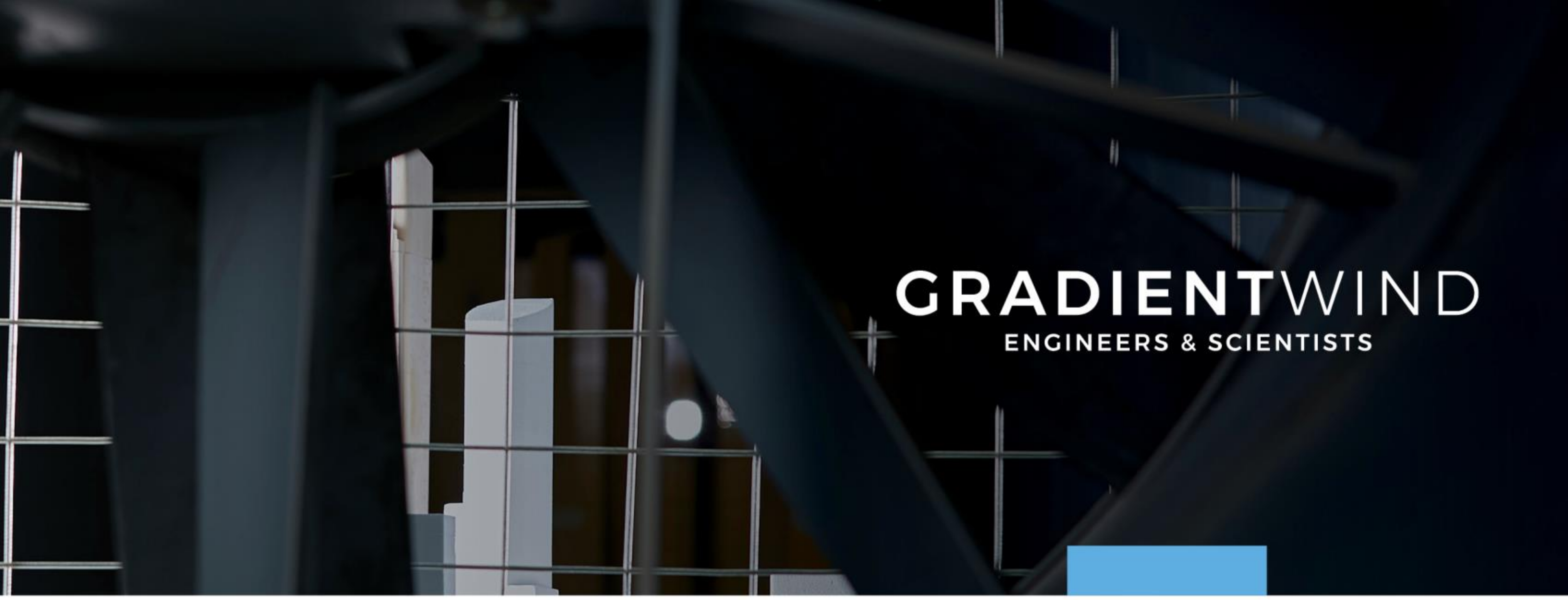
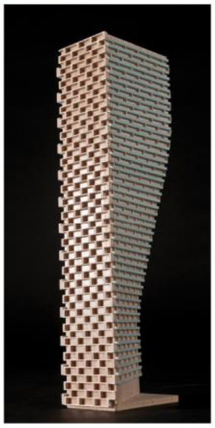
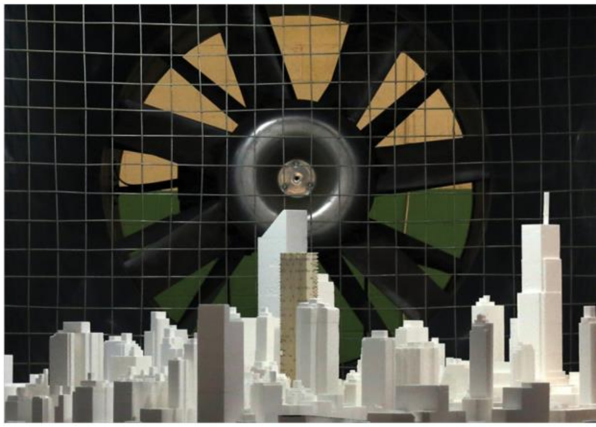


FIGURE 5B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING, AMENITY TERRACES





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 (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	0.23
49	0.26
74	0.25
103	0.25
167	0.25
197	0.25
217	0.25
237	0.24
262	0.20
282	0.20
302	0.21
324	0.21

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

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

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

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

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

where, ***I*** = turbulence intensity, $\boldsymbol{L_t}$ = 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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