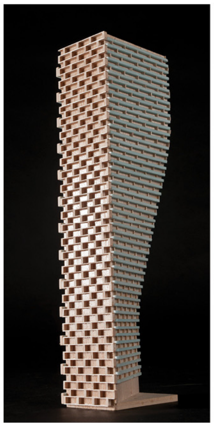
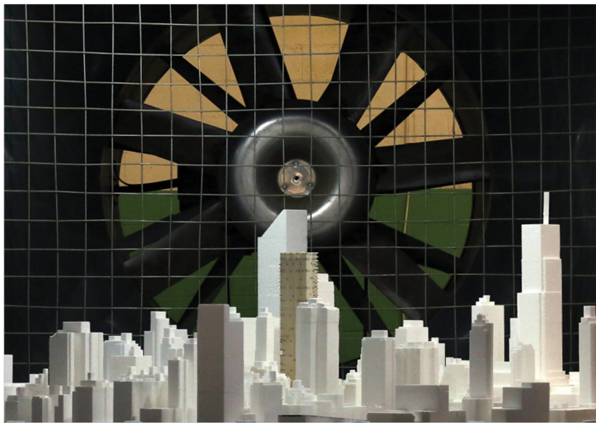
PEDESTRIAN LEVEL WIND STUDY

1140 Yonge Street
Toronto, Ontario

Report: 20-078-PLW





August 11, 2020

PREPARED FOR
1140 Yonge Inc.
31 Scarsdale Road, Unit 5
Toronto, ON M3R 2R2

PREPARED BY
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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study to satisfy Official Plan Amendment (OPA), Zoning By-law Amendment (ZBA), and Site Plan Control Application (SPA) requirements for the proposed mixed-use development located at 1140 Yonge Street in Toronto, Ontario (hereinafter referred to as the "subject site"). Our mandate within this study is to investigate pedestrian wind comfort 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 necessary.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, preliminary drawings prepared by Audax Architecture in May 2020, surrounding street layouts and existing and approved future building massing information obtained from the City of Toronto, as well as recent site imagery.

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

1) While wind speeds at the northeast corner of the subject site are predicted to accelerate within the general area during the spring and winter seasons on account of prominent westerly and easterly winds, pedestrian wind comfort is predicted to be suitable for a mix of standing and walking at the intersection of Marlborough Avenue and Yonge Street, which is considered acceptable for public sidewalks according to the comfort guidelines in Section 4.4.

2) Further to item (1), all other areas at grade will be suitable for their intended uses throughout the year. This includes building access points, nearby sidewalks, the drive aisle near the centre of the subject site, the landscaped area at the southwest of the subject site, the patio at the north of the subject site, and nearby bus stops.

3) The amenity terrace at Level 3 will be suitable for sitting during the typical use period of late spring to early autumn, which is acceptable.

4) 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.

5) 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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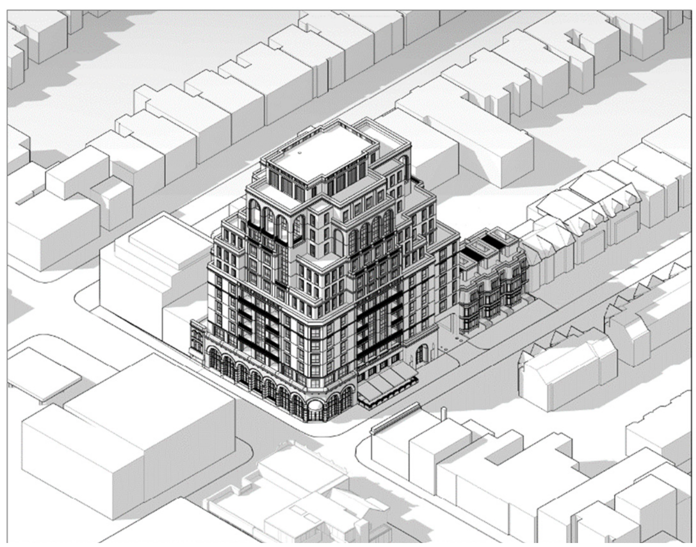
1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by 1140 Yonge Inc. to undertake a pedestrian level wind (PLW) study to satisfy Official Plan Amendment (OPA), Zoning By-law Amendment (ZBA), and Site Plan Control Application (SPA) requirements for the proposed mixed-use development located at 1140 Yonge Street in Toronto, Ontario (hereinafter referred to as "subject site" or "proposed development"). Our mandate within this study is to investigate pedestrian wind comfort 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 necessary.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, preliminary drawings prepared by Audax Architecture in May 2020, surrounding street layouts and existing and approved future building massing information obtained from the City of Toronto, as well as recent site imagery.

2. TERMS OF REFERENCE

The proposed development is located in the Summerhill neighbourhood of Toronto, at the northeast corner of a long rectangular parcel of land bordered by Yonge Street to the east, Marlborough Avenue to the north, and existing developments to the immediate west and south.



Axonometric Rendering, Northeast Perspective (Courtesy of Audax Architecture)

The subject site comprises a 13-storey mixed-use building and three 3-storey townhouses. At grade, the 13-storey building has an irregular planform, with a drive aisle separating it from the townhouses, which provides access to three levels of underground parking from Marlborough Avenue. At the south of the site, the planned building shares a wall with the existing building at 1134 Yonge Street. Levels 1 and 2 share a roughly consistent planform. Level 1 comprises amenity space, lobby space, and commercial space fronting Marlborough

Avenue and Yonge Street, while Level 2 comprises mostly commercial units. At Level 3 the building steps out along the west elevation and connects to the planned townhouses, while stepping back slightly from the east elevation. An indoor amenity space is located at the southwest of Level 3, which is connected to an outdoor amenity. The remainder of Level 3 and all levels above comprise residential units. From Level 8 and up the building features progressive setbacks from all elevations, which provide for private terraces. Private terraces are also located on the roof. The building is topped by a mechanical penthouse which may feature a green roof.

Also at grade level, a patio is located at the north of the building, which will be bordered by planter boxes. A landscaped area is located at the southwest of the subject site. Two bus stops are located to the southeast of the site at the intersection of Yonge Street and Macpherson Avenue.

Regarding wind exposures, the near-field surroundings of the development (defined as an area falling within a 200-metre (m) radius of the site) are characterized by low-rise buildings from the south clockwise to the north, and mix of low- and mid-rise developments from the north clockwise to south, including a planned 21-storey building located at 5 Scrivener Square (Scrivener Court). The far-field surroundings (defined as the area beyond the near field and within a 2 km radius) are characterized by primarily suburban buildings, with a collection of mid- and high-rise buildings to the north, along St. Clair Avenue, and the dense urban centre of Toronto to the south. A site plan is illustrated in Figure 1, 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 comparative pedestrian level wind comfort and safety conditions at key outdoor areas; (ii) identify areas where future 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 Greater Toronto Area (GTA) wind climate, and synthesis of computational data with industry-accepted guidelines[1]. The following sections describe the analysis procedures, including a discussion of the pedestrian comfort guidelines.

4.1 Computer-Based Context Modelling

A computer based PLW wind 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 Lester B. Pearson 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 and two massing scenarios, as noted in Section 2. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 840 m.

[1] City of Toronto, Application Support Material: Terms of Reference

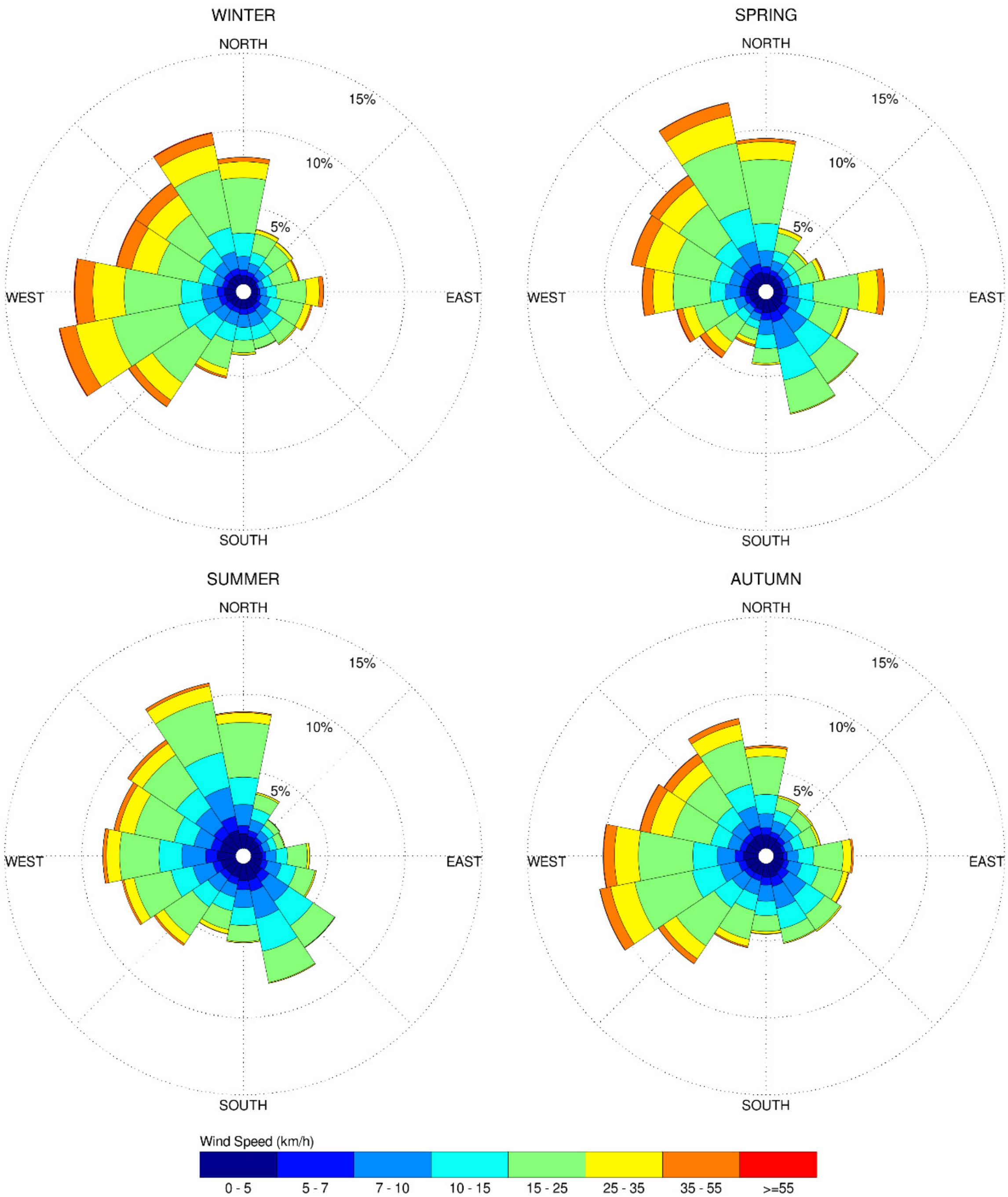
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds on a continuous measurement plane 1.5 m above local grade, and 1.5 m above the amenity terrace at Level 3, 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 Meteorological Data Analysis

A statistical model for winds in Toronto was developed from approximately 40-years of hourly meteorological wind data recorded at Lester B. Pearson 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. 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; spring is defined as April-May, summer as June-September, autumn as October-November, and winter as December-March.

The statistical model of the Toronto 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 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 Toronto, representative of the GTA, the most common winds concerning pedestrian comfort occur from the southwest clockwise to the north, as well as those from the east. The directional preference and relative magnitude of the wind speed varies somewhat from season to season, with the summer months displaying the calmest winds relative to the remaining seasonal periods.

SEASONAL DISTRIBUTION OF WIND
LESTER B. PEARSON INTERNATIONAL AIRPORT, MISSISSAUGA, ONTARIO



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 Guidelines

Pedestrian comfort and safety guidelines are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Four pedestrian comfort classes are based on 80% non-exceedance gust wind speed ranges, which include (i) Sitting; (ii) Standing; (iii) Walking; and (iv) Uncomfortable. More specifically, the comfort classes and associated gust wind speed ranges are summarized as follows:

(i) **Sitting** – A wind speed no greater than 16 km/h is considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – A wind speed greater than 16 km/h but no greater than 22 km/h is considered acceptable for activities such as standing or leisurely strolling.

(iii) **Walking** – A wind speed greater than 22 km/h but no greater than 30 km/h is considered acceptable for walking or more vigorous activities.

(iv) **Uncomfortable** – A wind speed greater than 30 km/h is classified as uncomfortable from a pedestrian comfort standpoint. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this comfort class.

The pedestrian safety wind speed guideline 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 greater than 90 km/h is classified as dangerous. The wind speeds associated with the above categories are gust wind speeds. 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	
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 wind speeds of 16 km/h were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if 30 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 / Walking
Public Sidewalks / Pedestrian Walkways	Walking
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens	Sitting / Standing
Plazas	Sitting / Standing / Walking
Transit Stops	Sitting / Standing
Public Parks	Sitting / Standing / Walking
Garage / Service Entrances	Walking
Vehicular Drop-Off Zones	Standing / Walking
Laneways / Loading Zones	Walking

5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-3D, which illustrate seasonal wind conditions at grade level, and Figures 4A-4D, which illustrate seasonal wind conditions on the Level 3 elevated amenity terrace. The wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site.

The colour contours indicate predicted regions of the various comfort classes noted in Section 4.4. Wind conditions suitable for sitting are represented by the colour green, standing by yellow, walking by blue, while conditions considered uncomfortable for walking are represented by the colour magenta.

5.1 Wind Comfort and Safety Conditions – Grade Level

Yonge Street: Conditions along Yonge Street are predicted to be mostly suitable for sitting during the summer, with standing conditions developing near the intersection of Marlborough Avenue and Yonge Street. During the autumn, conditions along the sidewalks are predicted to be suitable for a mix of sitting and standing, with the windier conditions located near the northeast of the subject site and near the intersection of Yonge Street and Macpherson Avenue. During the remaining two colder seasons, conditions are predicted to be suitable for walking near the northeast corner of the subject site, and suitable for a mix of sitting and standing elsewhere along Yonge Street. Wind conditions along the sidewalks on the west side of Yonge Street are generally calmer than those along the east side, owing to the blockage of prominent westerly winds provided by the proposed building. The noted conditions are considered acceptable.

Marlborough Avenue: Conditions along Marlborough Avenue are expected to be suitable for a mix of sitting and standing during the summer, mostly suitable for standing during the autumn, and suitable for a mix of standing and walking during the winter and spring seasons. In general, the windier conditions are predicted to occur near the east end of Marlborough Avenue, near Yonge Street, where northwesterly winds are predicted to accelerate around the northeast corner of the proposed building. These conditions are considered acceptable.

Price Street: Conditions along Price Street are predicted to be affected by the planned 21-storey building at 5 Scrivener Square. Conditions are predicted to be mostly suitable for standing during the summer, with isolated regions suitable for sitting. During the remaining seasons, conditions are expected to be suitable for a mix of standing and walking. The windier conditions are located near the intersection of Price Street and Yonge Street, as well as farther east, along the south elevation of the planned building at 5 Scrivener Square. Although moderately windy, these conditions are nevertheless considered acceptable.

Macpherson Avenue: Conditions along Macpherson Avenue are predicted to be mostly suitable for sitting during the spring, summer, and autumn, although certain isolated regions are predicted to be suitable for standing during the spring and autumn. During the winter season, the sidewalks along Macpherson Avenue are expected to be mostly suitable for standing. These conditions are considered acceptable.

Drive Aisle: The drive aisle, which provides access from Marlborough Avenue to the landscaped area at the southwest of the subject site, and to the underground parking, will be suitable for a mix of sitting and standing during the summer and autumn, and mostly suitable for standing during the winter and spring. These conditions are considered acceptable.

Landscaped Area: The landscaped area at the southwest of the subject site is expected be suitable for sitting throughout the year, which is a result of the landscape wall along the west and south perimeters of the property. These conditions are considered acceptable.

Patio: The patio at the north of the subject site, fronting Marlborough Avenue, which will be surrounded by planter boxes, will be suitable for sitting during the summer, and mostly suitable for sitting during the spring and autumn. During the colder months, a small region at the north of the patio is predicted to be suitable for standing. These conditions are considered acceptable for the typical use period of late spring to early autumn.

Building Entrances: All building access points on and around the subject site are predicted to experience conditions suitable for standing, or better, throughout the year, which is acceptable.

Bus Stops: The two nearby bus stops, at the northwest and southwest corners of the intersection of MacPherson Avenue and Yonge Street, will be suitable for standing, or better, throughout the year, which is considered acceptable.

5.2 Wind Comfort and Safety Conditions – Elevated Amenity Terrace

Level 3 Amenity Terrace: Wind conditions over the elevated amenity terrace at Level 3 will be suitable for sitting during the summer. During the spring and autumn, small regions near the south and west perimeters of the terrace will become suitable for standing. During the winter, conditions will be suitable for a mix of sitting and standing over the entire terrace. These conditions are considered acceptable for the typical use period.

5.3 Applicability of Results

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 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. SUMMARY AND RECOMMENDATIONS

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

1) While wind speeds at the northeast corner of the subject site are predicted to accelerate within the general area during the spring and winter seasons on account of prominent westerly and easterly winds, pedestrian wind comfort is predicted to be suitable for a mix of standing and walking at the intersection of Marlborough Avenue and Yonge Street, which is considered acceptable for public sidewalks according to the comfort guidelines in Section 4.4.

2) Further to item (1), all other areas at grade will be suitable for their intended uses throughout the year. This includes building access points, nearby sidewalks, the drive aisle near the centre of the subject site, the landscaped area at the southwest of the subject site, the patio at the north of the subject site, and nearby bus stops.

3) The amenity terrace at Level 3 will be suitable for sitting during the typical use period of late spring to early autumn, which is acceptable.

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.

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

Sincerely,

Gradient Wind Engineering Inc.

LICENSED PROFESSIONAL ENGINEER
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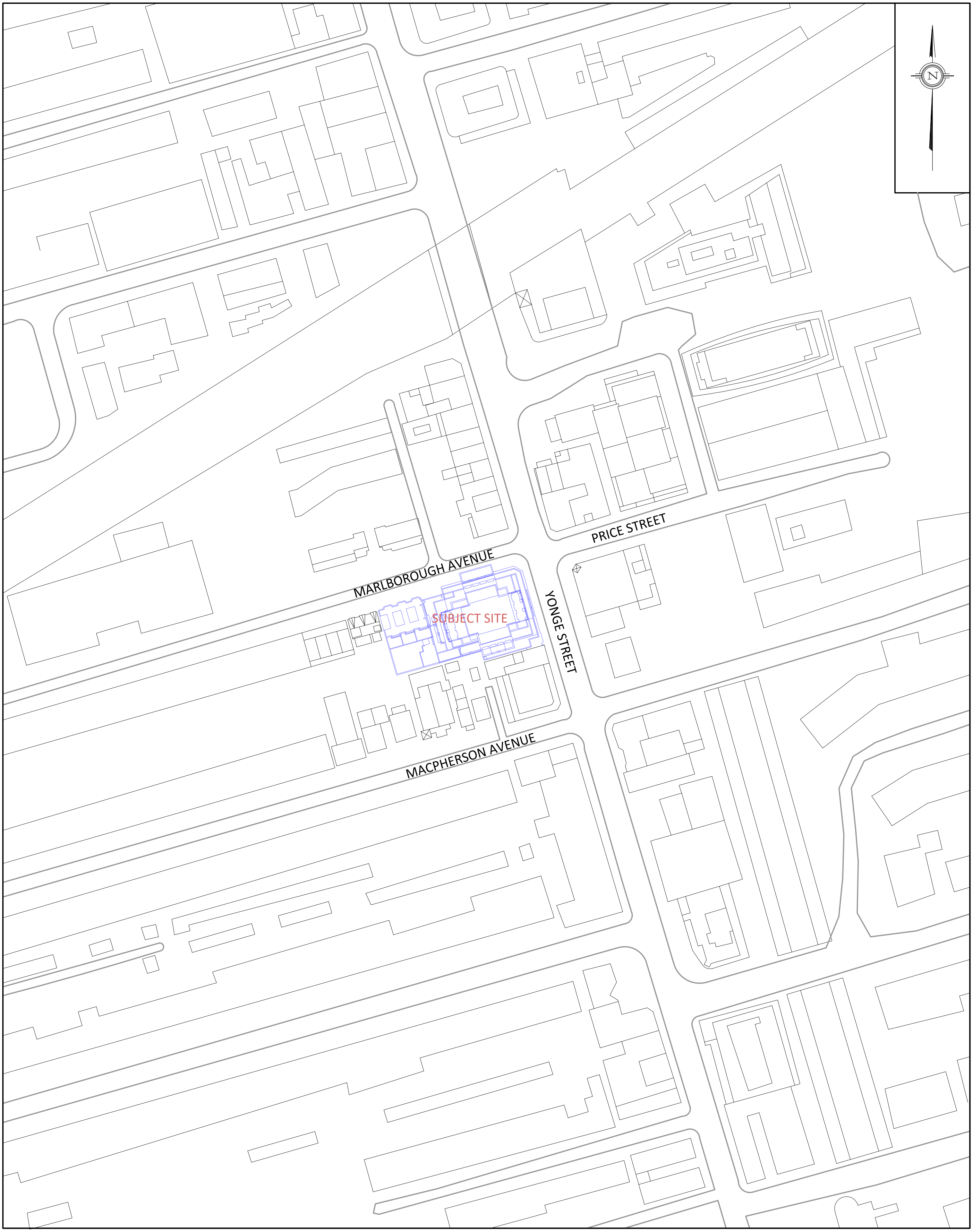

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PROJECT	1140 YONGE STREET, TORONTO PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION
SCALE	1:2500 (APPROX.)	DRAWING NO. 20-078-PLW-1	FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
DATE	JUNE 29, 2020	DRAWN BY S.R.	

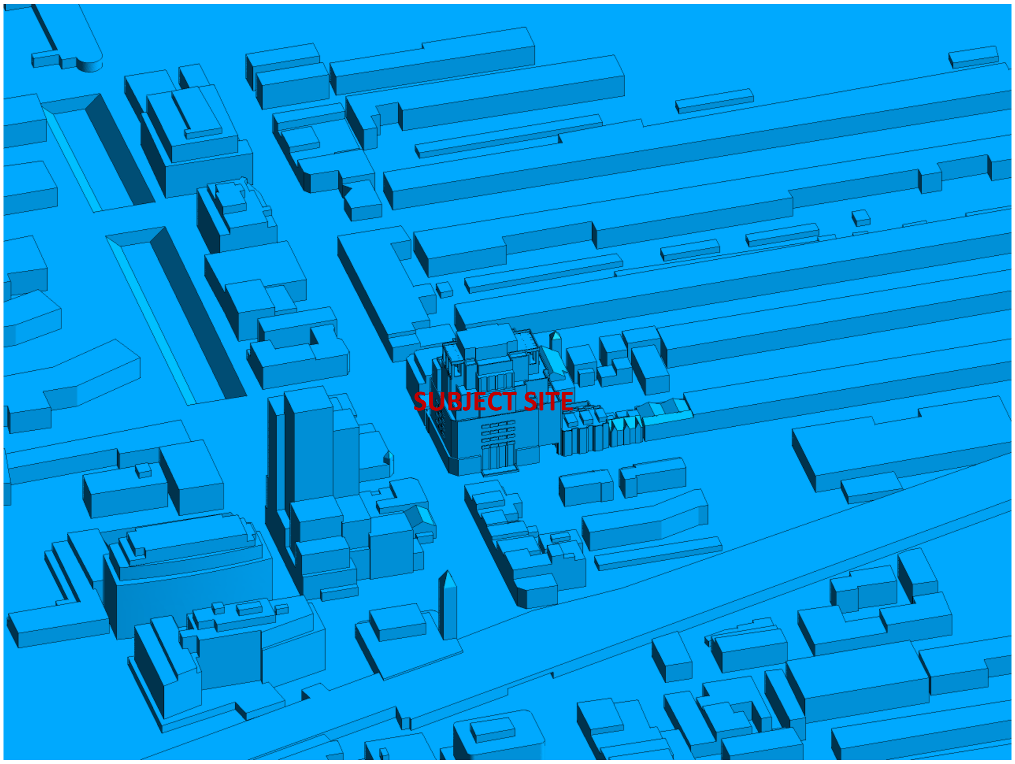


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

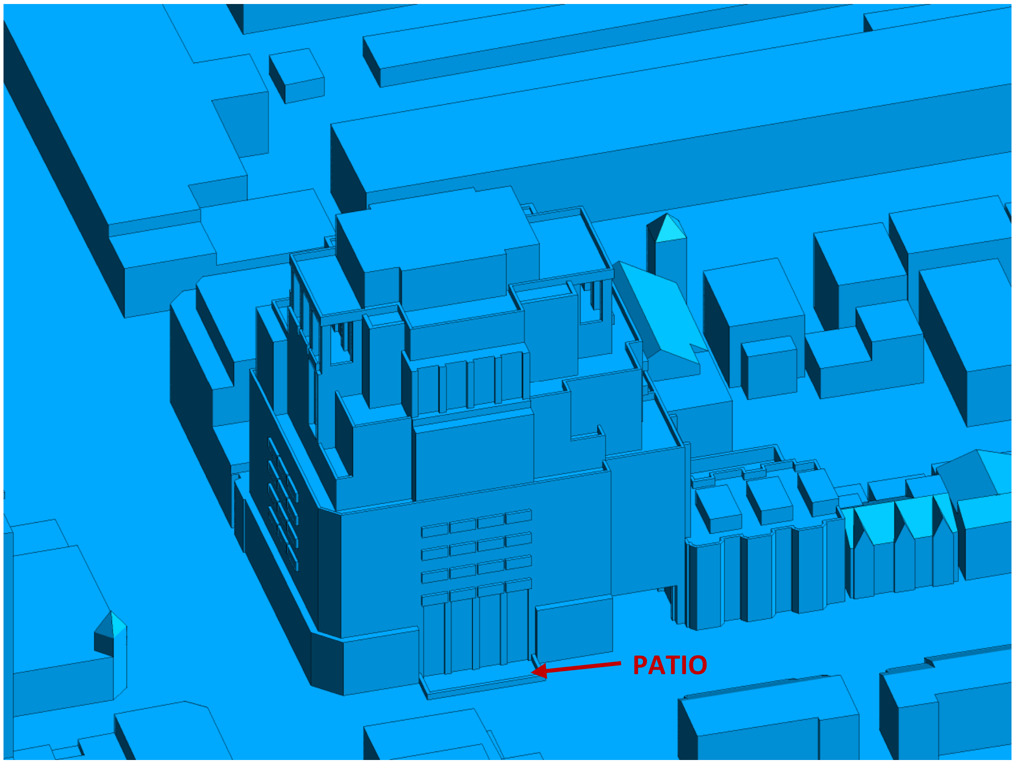


FIGURE 2B: COMPUTATIONAL MODEL, NORTH PERSPECTIVE (CLOSE-UP VIEW)

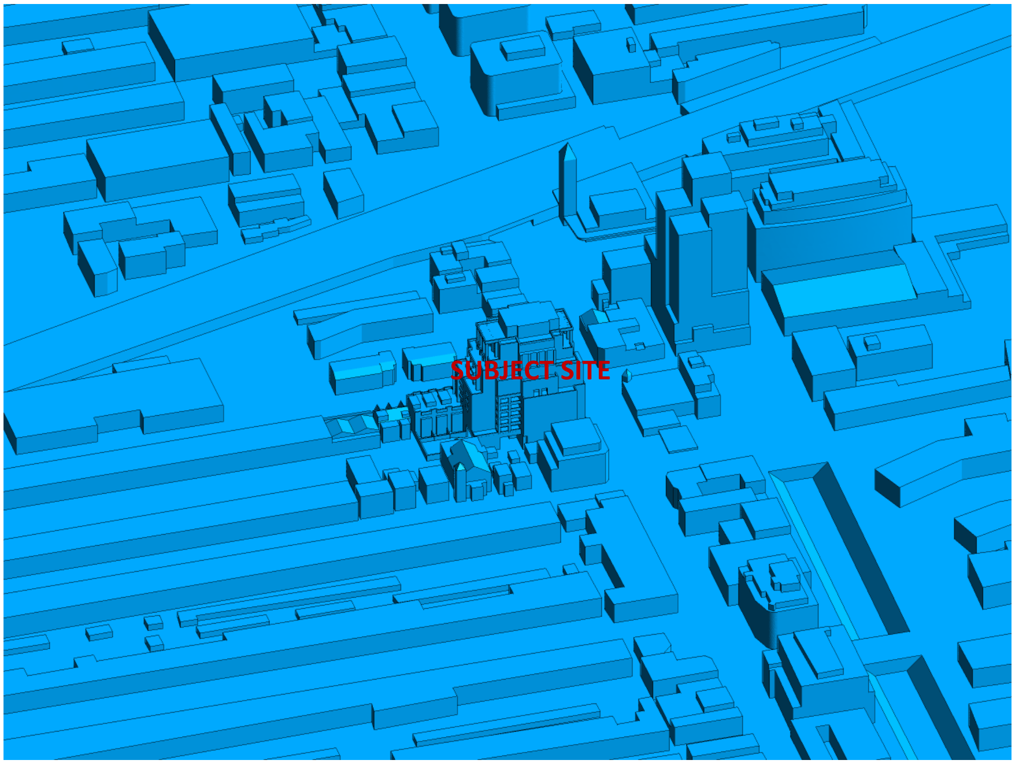


FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

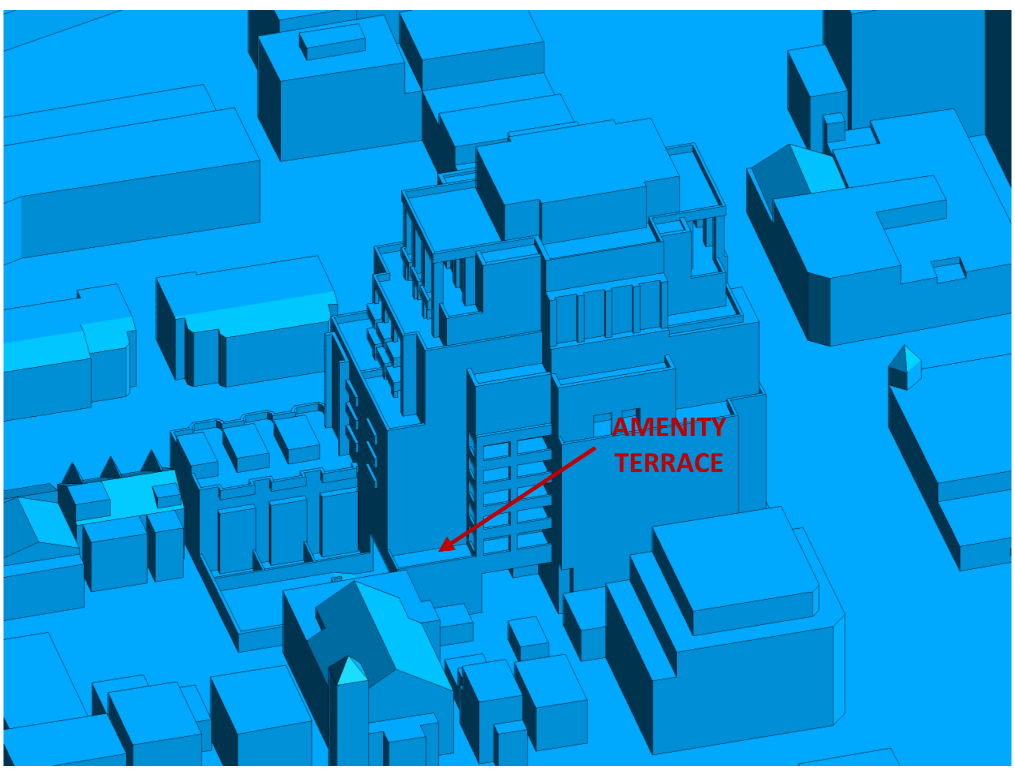


FIGURE 2D: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE (CLOSE-UP VIEW)

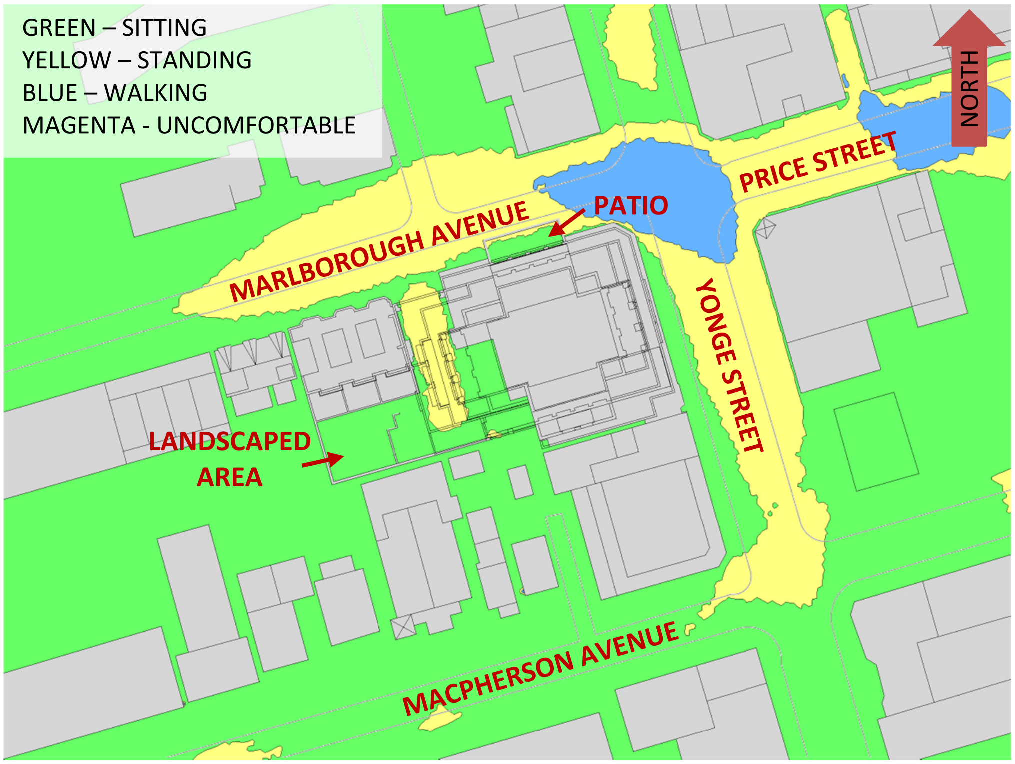


FIGURE 3A: SPRING – PEDESTRIAN WIND COMFORT CONDITIONS, GRADE LEVEL

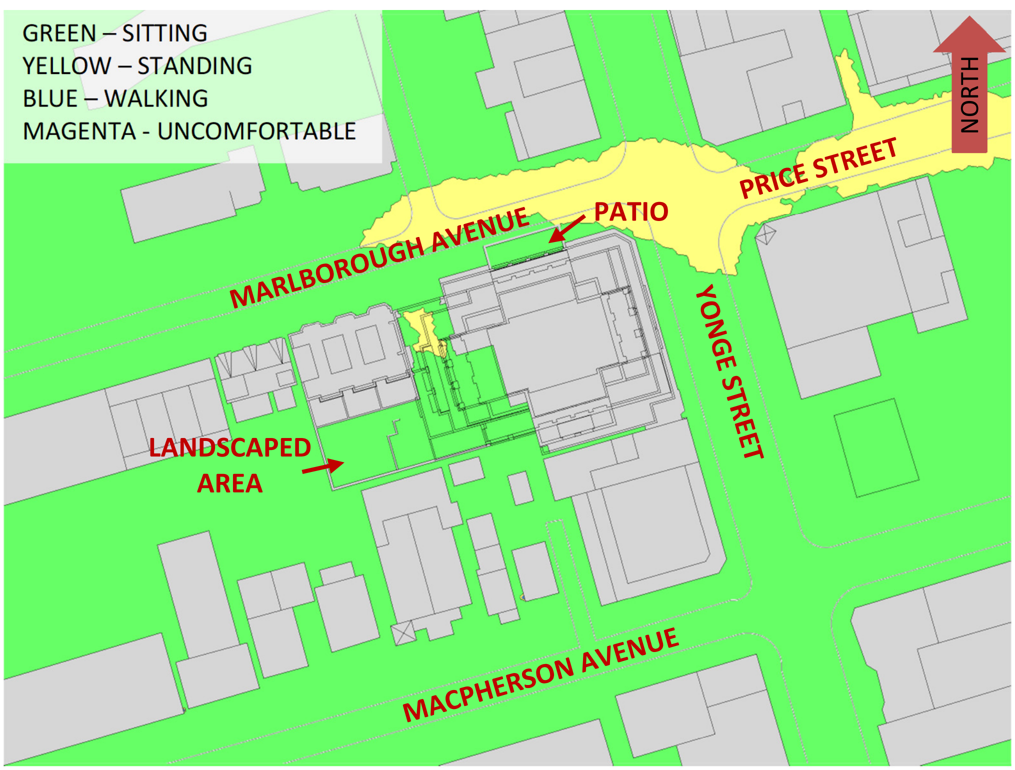


FIGURE 3B: SUMMER – PEDESTRIAN WIND COMFORT CONDITIONS, GRADE LEVEL

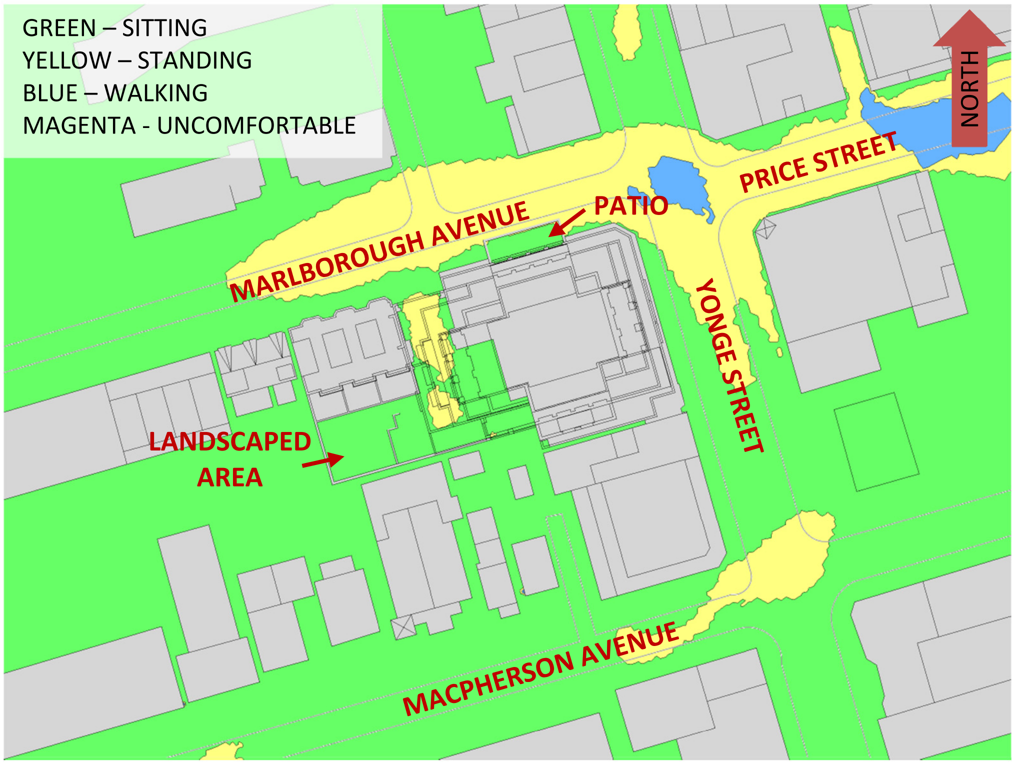


FIGURE 3C: AUTUMN – PEDESTRIAN WIND COMFORT CONDITIONS, GRADE LEVEL

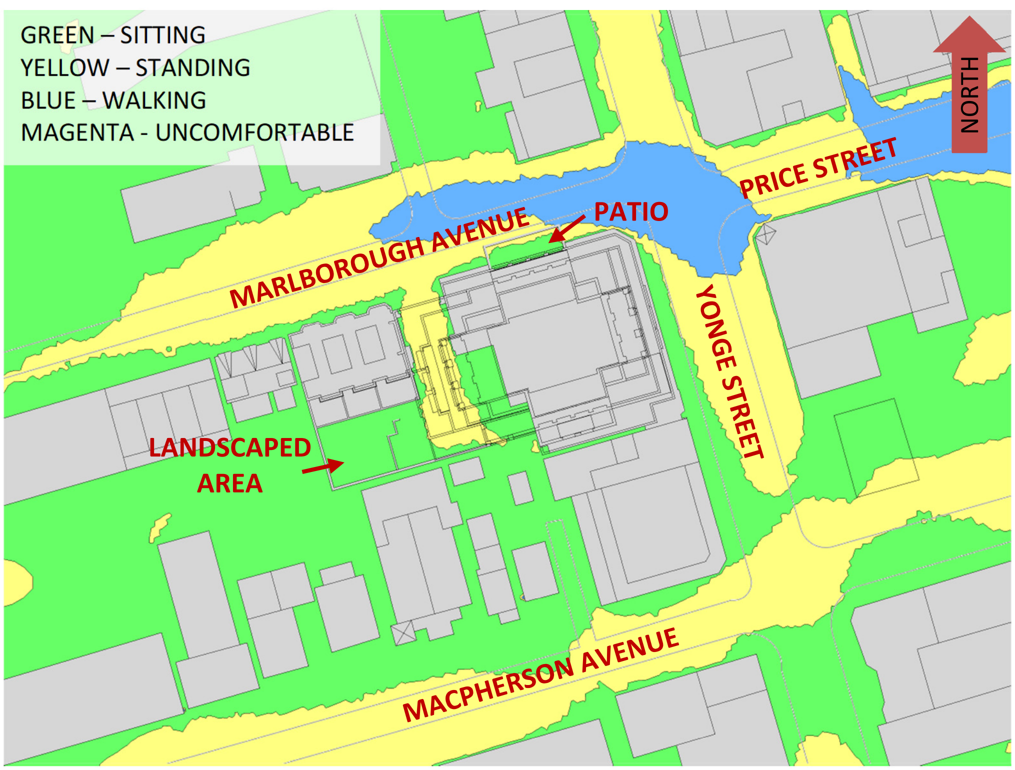


FIGURE 3D: WINTER – PEDESTRIAN WIND COMFORT CONDITIONS, GRADE LEVEL

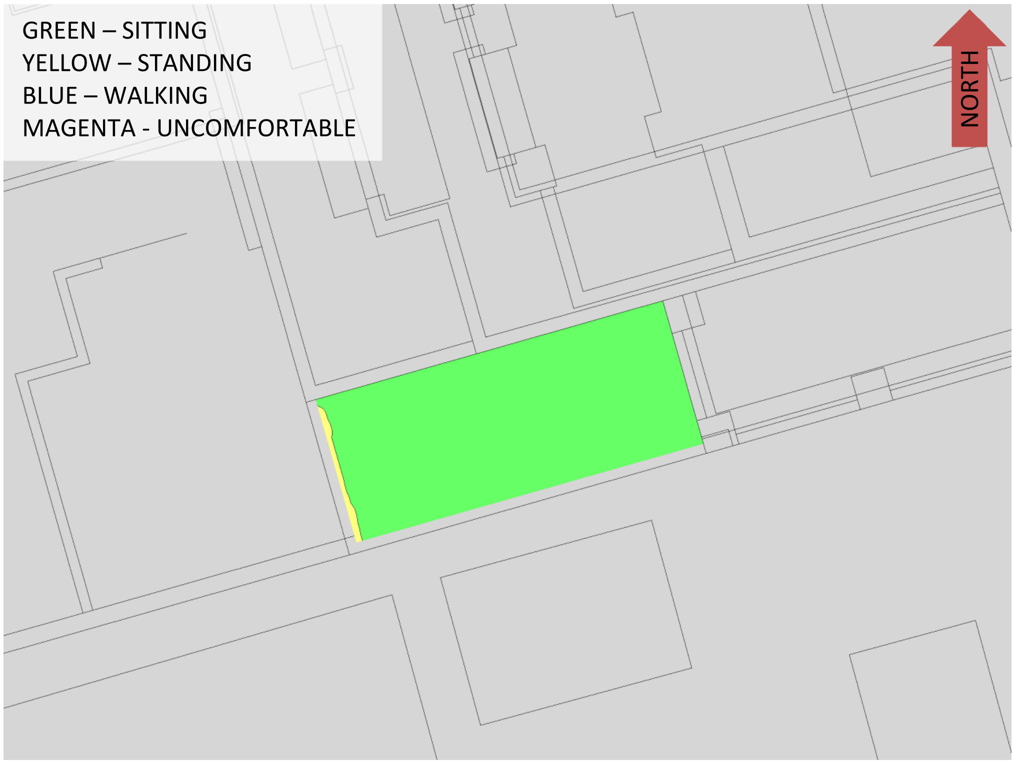


FIGURE 4A: SPRING – PEDESTRIAN WIND COMFORT, LEVEL 3 AMENITY TERRACE

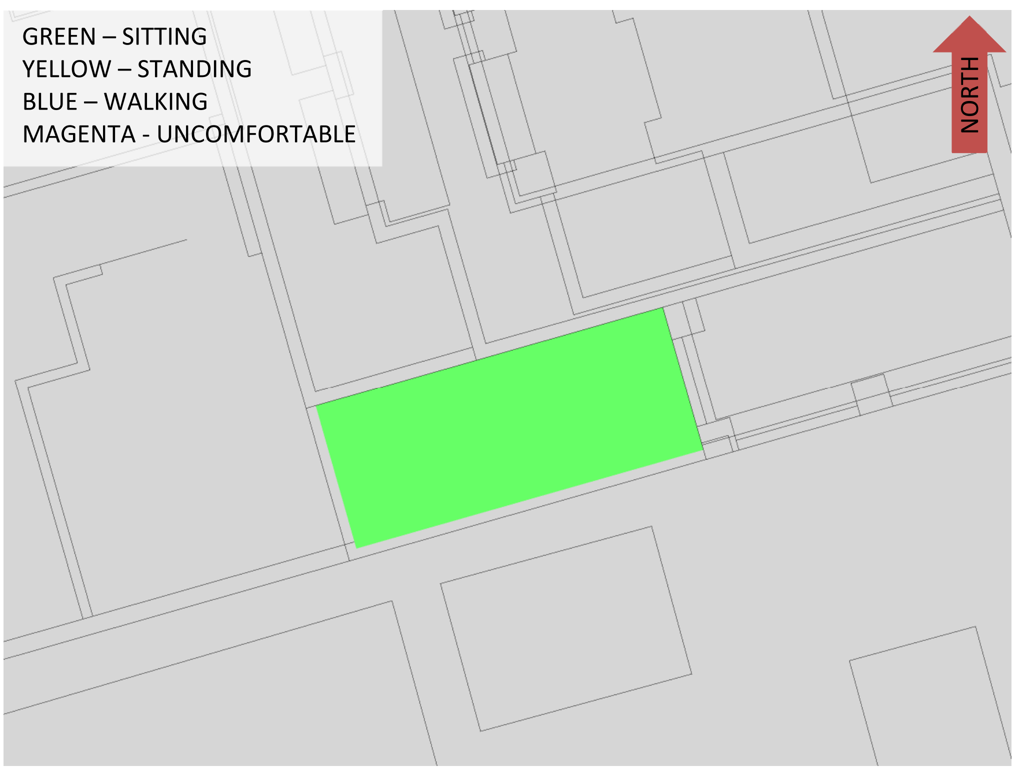


FIGURE 4B: SUMMER – PEDESTRIAN WIND COMFORT, LEVEL 3 AMENITY TERRACE

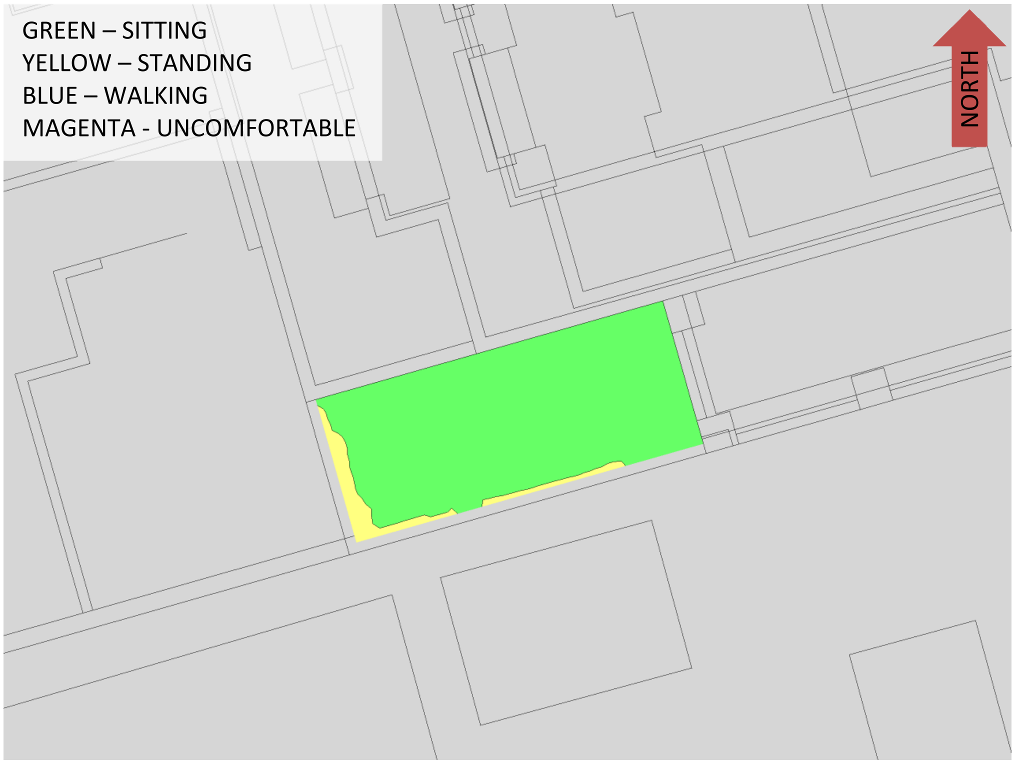
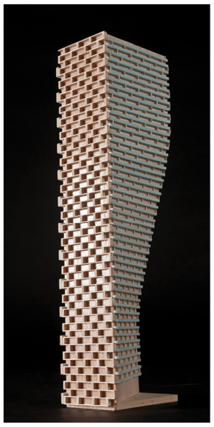
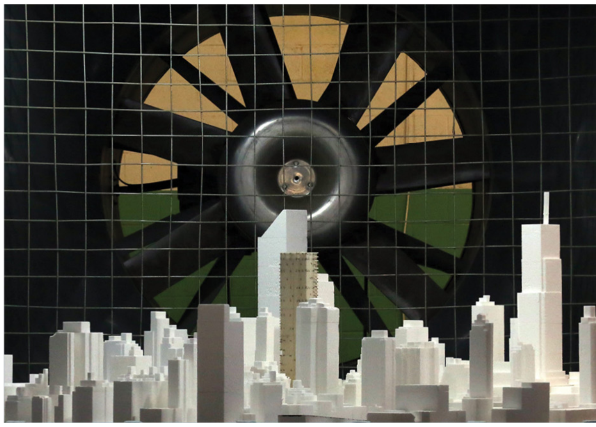


FIGURE 4C: AUTUMN – PEDESTRIAN WIND COMFORT, LEVEL 3 AMENITY TERRACE

FIGURE 4D: WINTER – PEDESTRIAN WIND COMFORT, LEVEL 3 AMENITY TERRACE





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].

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

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

For the model, U_g is set to 6.5 metres per second (m/s), which approximately corresponds to the 50% mean wind speed for Toronto 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	0.29
40	0.24
97	0.24
136	0.27
170	0.31
210	0.27
237	0.26
258	0.25
278	0.25
300	0.26
322	0.27
341	0.28

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].

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

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