

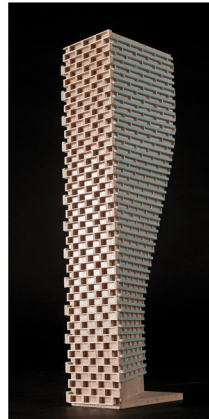
GRADIENTWIND

ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

320 McRae Avenue & 1976 Scott Street
Ottawa, Ontario

Report: 20-012-PLW



February 4, 2020

PREPARED FOR

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EXECUTIVE SUMMARY

This report describes a computer-based pedestrian level wind (PLW) study to satisfy the requirements for a site plan control application (SPA) submission for a proposed two-building development located at 320 McRae Avenue and 1976 Scott 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 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-7B, and summarized as follows:

- 1) Conditions at the retail entrances located at the northeast and northwest corners of Building A are not expected to meet the required comfort criterion during the two colder seasons. As such, we recommend either situating these entrances away from the building corners or recessing the entrances into the building façade by a minimum of 2 meters.
- 2) Conditions around the subject site at grade level, including at the bus stop on McRae Avenue, along sidewalks and walkways, within the proposed public park to the south of Building B, and at building entrances (excluding the two noted above) will be acceptable for their intended uses throughout the year.
- 3) Wind conditions within the rooftop terrace serving Building B will be suitable for sitting during the summer season, which is acceptable. Wind conditions at the northeast and northwest corners of the amenity terrace at Level 7 of Building A are not expected to meet the sitting comfort criterion during the summer season but are considered acceptable for a transition zone without seating. We recommend that the programming and landscape design for this terrace be designed with careful consideration of the wind comfort conditions near the corners.



- 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 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 GWL Realty Advisors Inc. to undertake a computer-based pedestrian level wind (PLW) study to satisfy the requirements for a site plan control application (SPA) submission for a proposed two-building development located at 320 McRae Avenue and 1976 Scott 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, architectural drawings provided by Neuf Architect(e)s in January 2020, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery via Google Earth Pro and the Copernicus Open Access Hub.

2. TERMS OF REFERENCE

The subject site is located at 320 McRae Avenue and 1976 Scott Street in Ottawa, and is situated on a parcel of land bordered by Scott Street to the north, McRae Avenue to the east, Tweedsmuir Avenue to the west, and existing developments to the south.

The subject site features a 26-storey building (Building A) fronting Scott Street, and a four-storey building (Building B) along McRae Avenue. The two buildings are connected by a 4-storey link, which is recessed from McRae Avenue. Building A comprises a roughly square planform at grade, which sets in at Level 2 at the centre of the south elevation. The building then sets back again at the southwest corner at Level 4. At Level 7 the building sets back on all elevations, revealing a common amenity terrace. The building then rises with a



*Perspective Rendering Looking Southwest
(Courtesy of Neuf Architect(e)s.)*



consistent rectangular planform to Level 26 and is topped by a mechanical penthouse. Building A features commercial retail space at grade along Scott Street, a lobby and leasing office at the southeast along McRae Avenue, and townhouses at the southwest, along Tweedsmuir Avenue. Levels 2-6 and 8-26 comprise residential units, while Level 7 features amenity space. Two levels of parking are provided below grade. Retail entrances are located at the northeast and northwest corners of the building, while the primary residential entrance is located on the east side of the building. A bus stop is located on McRae Avenue, immediately east of Building A.

Building B has an oblong planform, with the long axis along McRae Avenue and an east-west dimension that grows towards the south. The building is four storeys tall and comprises a mix of townhouses and apartment units. A common amenity area is provided on the roof, at Level 5. Entrances to the apartment units are located at the north and south of the west elevation, as well as at the centre of the north elevation. Private entrances to the townhouses are located along the east elevation. A public park is proposed to the south of Building B.

The near-field surroundings (defined as an area within 500 meters (m) of the subject site) are composed of a mix of low-rise residential dwellings and high-rise developments to the north and east (including some developments currently under construction) and a mix of open space and low- and mid-rise buildings in all other directions. The far-field surroundings (defined as an area beyond the near-field but within a 5 kilometer (km) radius of the subject site) contribute primarily suburban wind exposures from the northeast clockwise to west-southwest, and hybrid open-suburban exposures from the west-southwest to the northeast, owing to the proximity of the Ottawa River.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, walkways, building access points, nearby transit stops, and the amenity terraces serving the podium of Building A and on the roof of Building B. 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.

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



4.2 Wind Speed Measurements

The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 12 wind directions. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 1 km.

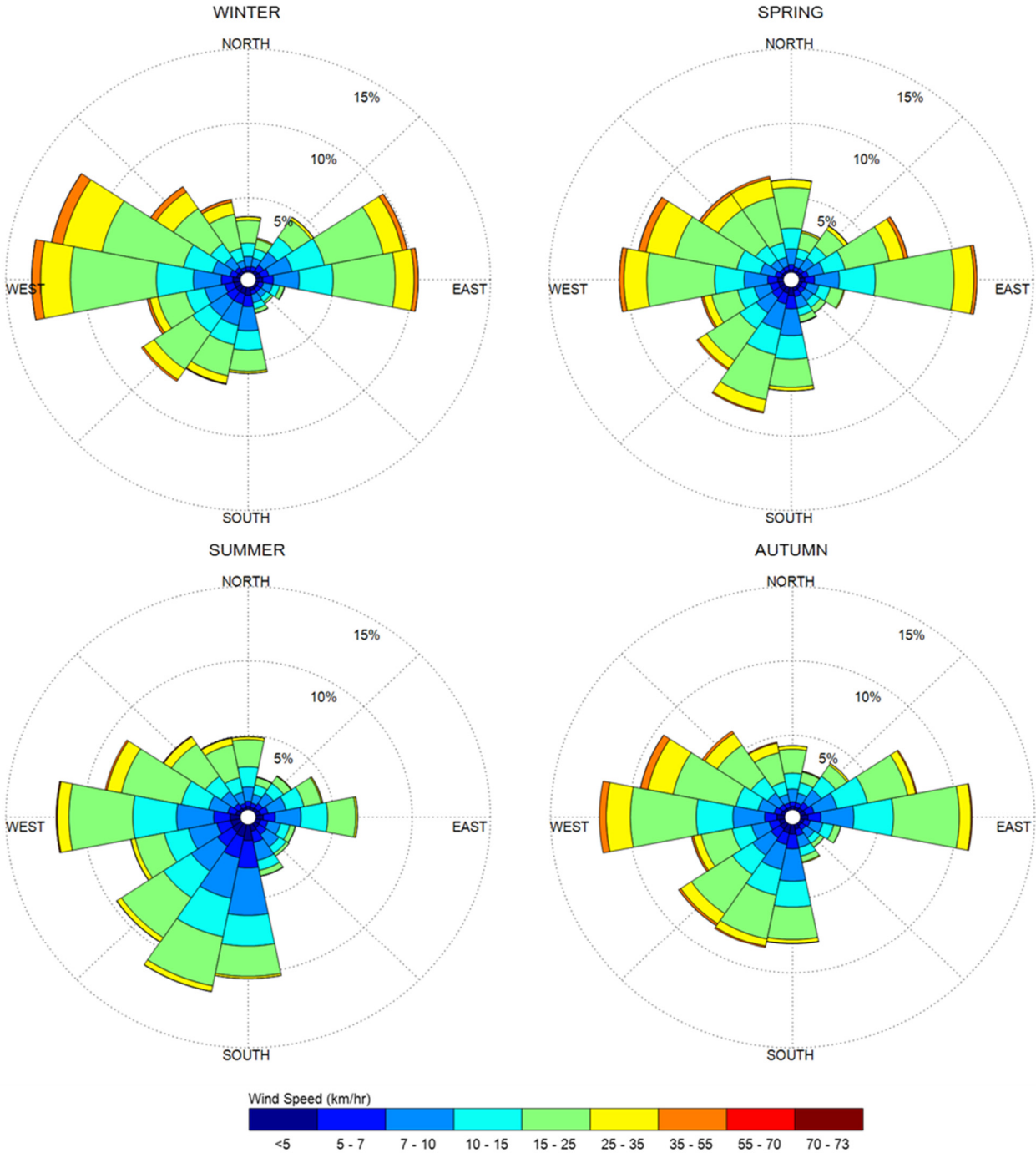
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade, and 1.5 m above the rooftop amenity terraces, were referenced 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. Appendices A and B provide greater detail of the theory behind wind speed measurements.

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 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 guidelines 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 gust equivalent mean 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 gust equivalent mean 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 gust equivalent mean 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 gust equivalent mean 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
2	Light Breeze	6-11	Wind felt on faces
3	Gentle Breeze	12-19	Leaves and small twigs in constant motion; Wind extends light flags
4	Moderate Breeze	20-28	Wind raises dust and loose paper; Small branches are moved
5	Fresh Breeze	29-38	Small trees in leaf begin to sway
6	Strong Breeze	39-49	Large branches in motion; Whistling heard in electrical wires; Umbrellas used with difficulty
7	Moderate Gale	50-61	Whole trees in motion; Inconvenient walking against wind
8	Gale	62-74	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 (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	Walking
Primary Public Sidewalk	Strolling
Secondary Public Sidewalk / Bicycle Path	Walking
Outdoor Amenity Space	Sitting / Standing / Strolling
Café / Patio / Bench / Garden	Sitting
Transit Stop	Sitting / Standing
Public Park / Plaza	Standing / Strolling
Garage / Service Entrance	Walking
Parking Lot	Strolling / Walking
Vehicular Drop-Off Zone	Standing / Strolling / Walking

5. RESULTS AND DISCUSSION

The following discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-3D (following the main text) illustrating the seasonal wind conditions at grade level, and Figures 4A/5A/6A/7A illustrating the seasonal wind conditions within the common amenity terraces. The colour contours indicate various comfort classes predicted for certain regions. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by orange, walking by blue, while uncomfortable conditions are represented by the colour magenta. In addition to the standard wind comfort class results, Figures 4B/5B/6B/7B illustrate the percentage of time the amenity terraces will be suitable for sitting on a seasonal basis. Pedestrian wind comfort is summarized below for each seasonal period.

5.1 Wind Comfort Conditions – Grade Level

Following the introduction of the subject site, wind conditions at grade level are predicted to be acceptable across the subject site throughout the year.

McRae Avenue: The sidewalks along the east side of McRae Avenue and near the northeast corner of the building are predicted to be suitable for standing during the summer, while the sidewalks on the west side of McRae Avenue are predicted to be suitable for sitting. During the spring and autumn, conditions will be suitable for strolling on the east sidewalks and near the northeast corner of the building, and suitable for standing along the west sidewalk. During the winter, conditions will be suitable for walking or better along the sidewalk. Conditions at the bus stop are predicted to be suitable for standing throughout the year. All noted wind conditions are considered acceptable.

Scott Street: During the summer, the sidewalks along Scott Street are predicted to be suitable for sitting, except near the building corners, where conditions will be suitable for standing. During the colder seasons, the sidewalk will be suitable for strolling near the building corners, and suitable for standing elsewhere. These conditions are considered acceptable.

Tweedsmuir Avenue: The sidewalks along Tweedsmuir Avenue are predicted to be suitable for a mix of sitting and standing during the summer and autumn seasons, becoming suitable for strolling or better during the spring and winter seasons. These conditions are considered acceptable.

Building entrances: The residential entrance serving Building A, as well as all entrances serving Building B will be suitable for sitting during the summer and suitable for standing during the remaining colder seasons, which is acceptable. The retail entrances at the northeast and northwest corners of Building A will be suitable for standing during the summer and autumn, becoming suitable for strolling during the spring and winter, which does not meet the recommended comfort criterion (standing) for a primary building access point. To achieve acceptable conditions during the two colder seasons, we recommend either situating these entrances away from the building corners or recessing the entrances into the building façade by a minimum of 2 m.

Park: The proposed public park to the south of Building B is predicted to be suitable for sitting throughout the year, which is acceptable.

5.2 Wind Comfort Conditions – Amenity Terraces

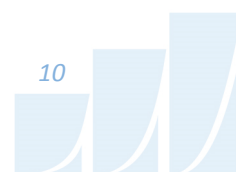
Building A Level 7 Terrace: During the summer season, wind conditions within the amenity terrace are expected to be suitable for standing near the northeast and northwest corners of the building, and suitable for sitting elsewhere. During the autumn season, these corners will be suitable for strolling, while walking conditions will develop near the corners during the spring and winter seasons. Apart from these corners, the terrace will experience wind conditions suitable for a mix of sitting and standing during the spring, autumn, and winter seasons. Conditions within the larger area at the southeast corner of the terrace are acceptable.

Wind conditions within the terrace on the north, east, and west sides of Building A are acceptable, except for localized areas at the northeast and northwest corners. We recommend that the programming and landscape design for this terrace be designed with careful consideration of the wind comfort conditions near building corners.

Building B Rooftop Terrace: Wind conditions within the terrace serving the roof of Building B are expected to be suitable for sitting during the summer and autumn (Figures 5A and 6A), suitable for a mix of sitting and standing during the spring (Figure 3A), and mostly suitable for standing during the winter (Figure 7A). In addition, Figures 3B and 7B illustrate that while the terrace will not meet the 80% non-exceedance criterion for the sitting comfort class during the spring and winter seasons, it will nevertheless be suitable for sitting at least 70% of the time during these seasons. Since the terrace is expected to be suitable for sitting during the typical use period, defined as late spring to early autumn, these conditions are considered acceptable.

5.3 Wind Comfort Conditions – Surrounding Area

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 and localized increases in the gustiness of the wind.

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-7B. 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) Conditions at the retail entrances located at the northeast and northwest corners of Building A are not expected to meet the required comfort criterion during the two colder seasons. As such, we recommend either situating these entrances away from the building corners or recessing the entrances into the building façade by a minimum of 2 m.
- 2) Conditions around the subject site at grade level, including at the bus stop on McRae Avenue, along sidewalks and walkways, within the proposed public park to the south of Building B, and at building entrances (excluding the two noted above) will be acceptable for their intended uses throughout the year.
- 3) Wind conditions within the rooftop terrace serving Building B will be suitable for sitting during the summer season, which is acceptable. Wind conditions at the northeast and northwest corners of the amenity terrace at Level 7 of Building A are not expected to meet the sitting comfort criterion during the summer season but are considered acceptable for a transition zone without seating. We recommend that the programming and landscape design for this terrace be designed with careful consideration of the wind comfort conditions near the corners.
- 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 were found to experience conditions that could be considered uncomfortable or dangerous.



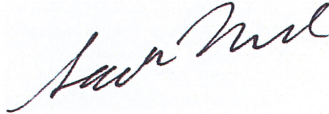
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This concludes our pedestrian level wind study and report. Please advise the undersigned of any questions or comments.

Sincerely,

Gradient Wind Engineering Inc.



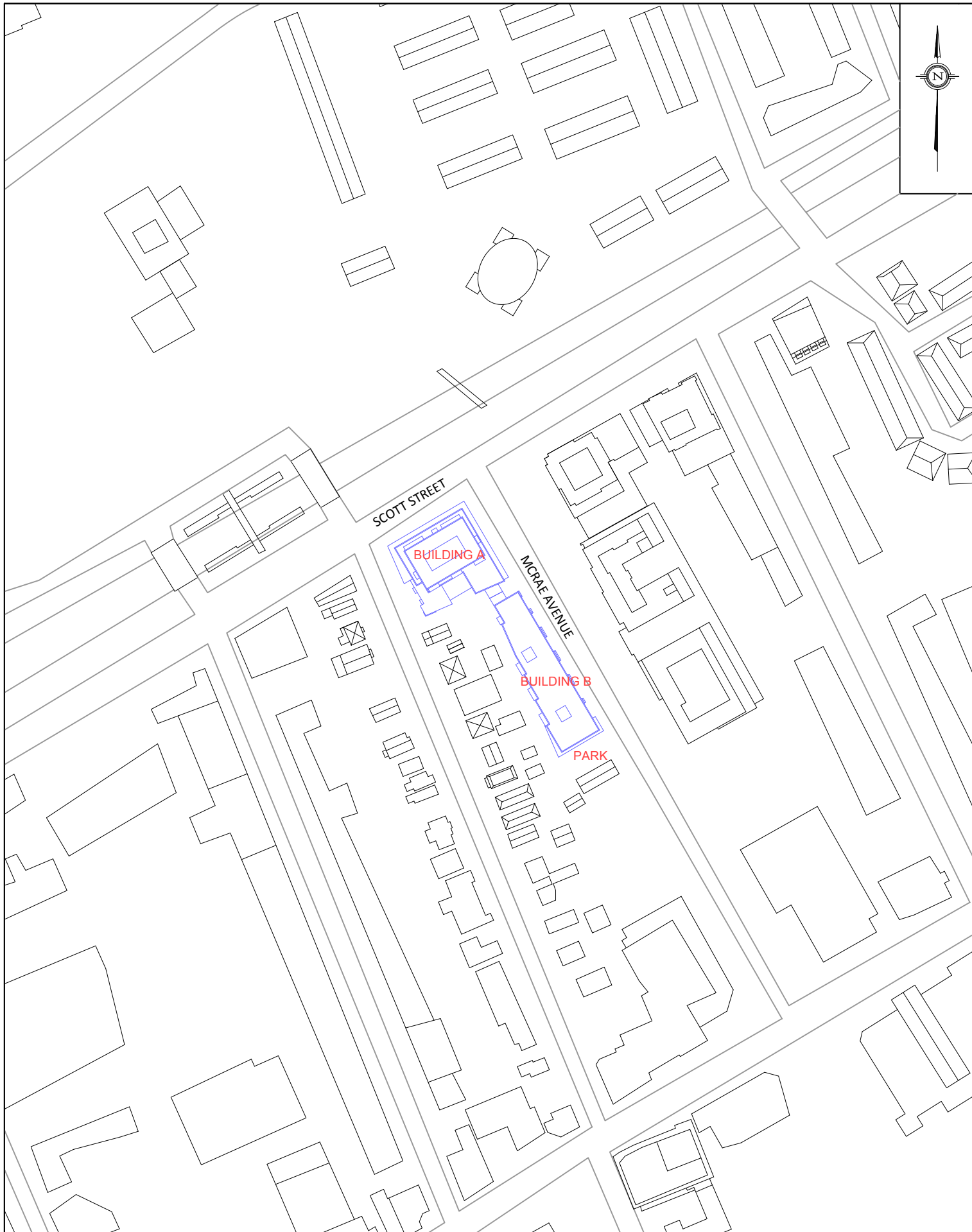
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PROJECT	320 MCRAE & 1976 SCOTT ST, ONTARIO PEDESTRIAN LEVEL WIND STUDY	
SCALE	1:2500 (APPROX.)	DRAWING NO. 20-012-PLW-1
DATE	JANUARY 31, 2020	DRAWN BY C.E.

DESCRIPTION	FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
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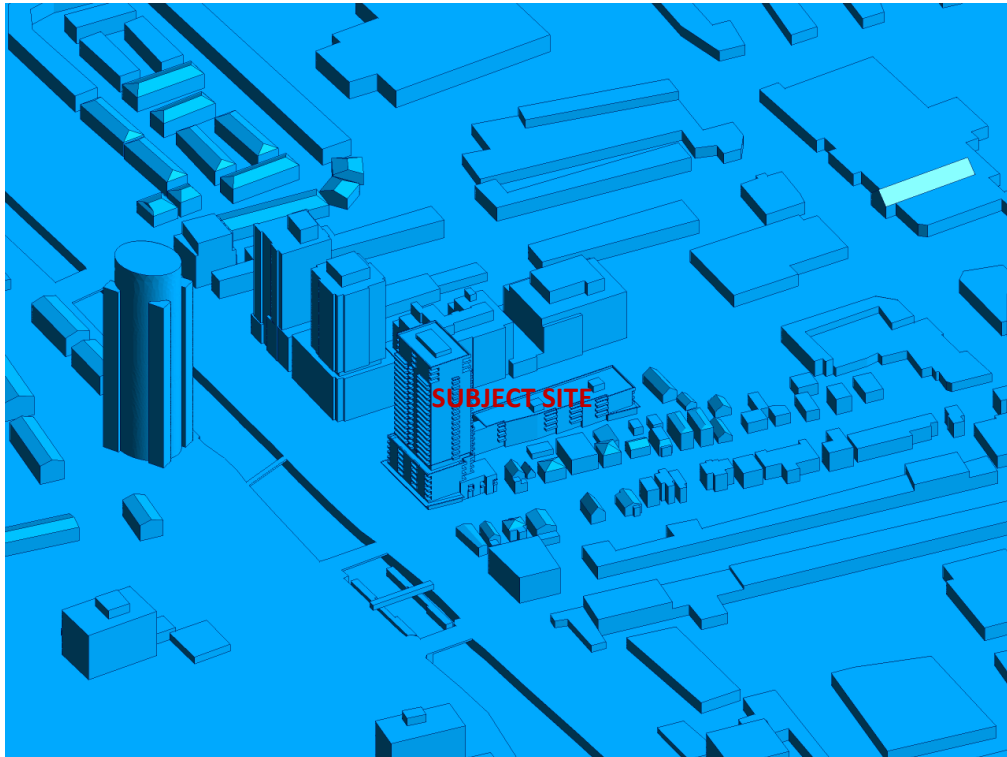


FIGURE 2A: COMPUTATIONAL MODEL, WEST PERSPECTIVE

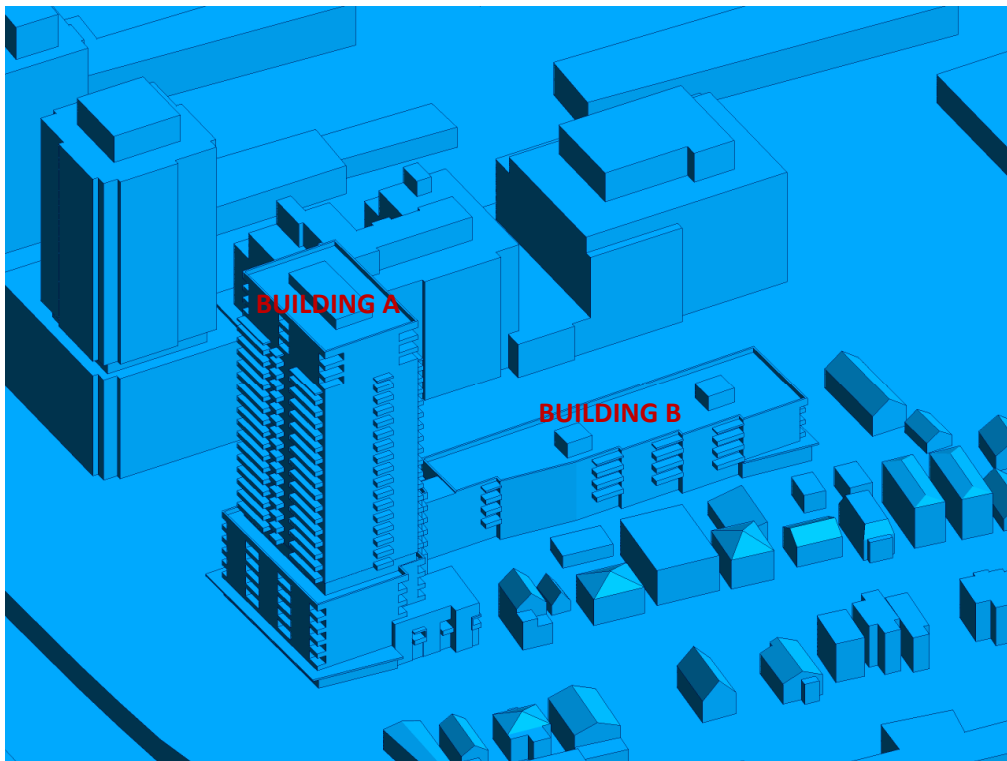


FIGURE 2B: CLOSE UP OF FIGURE 2A

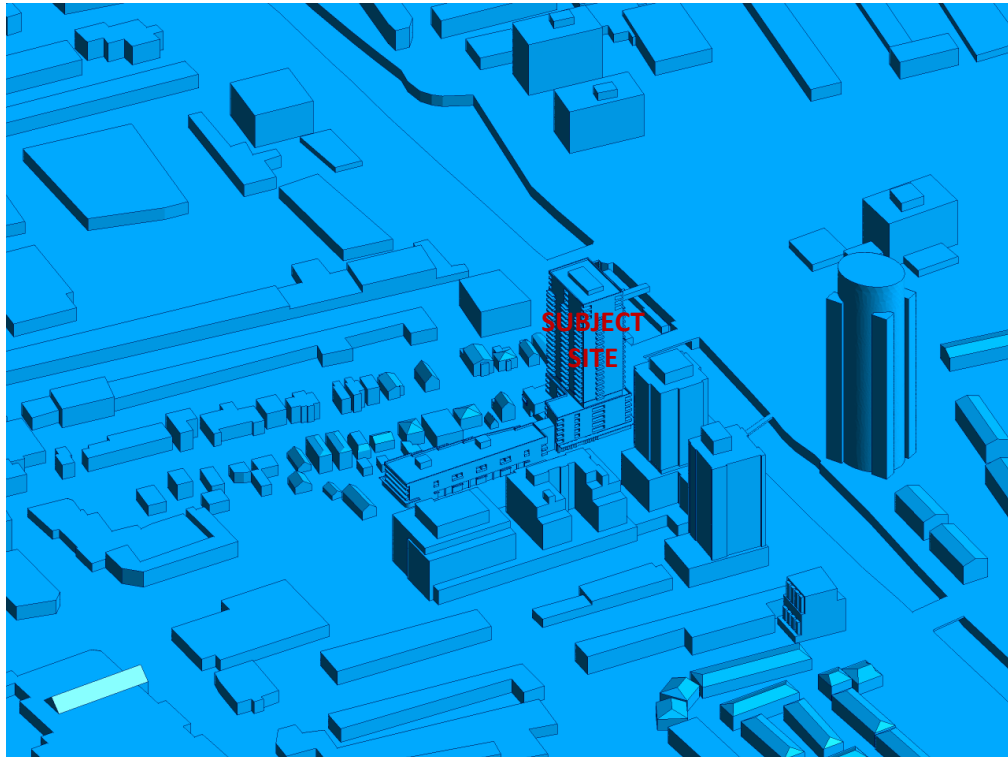


FIGURE 2C: COMPUTATIONAL MODEL, EAST PERSPECTIVE

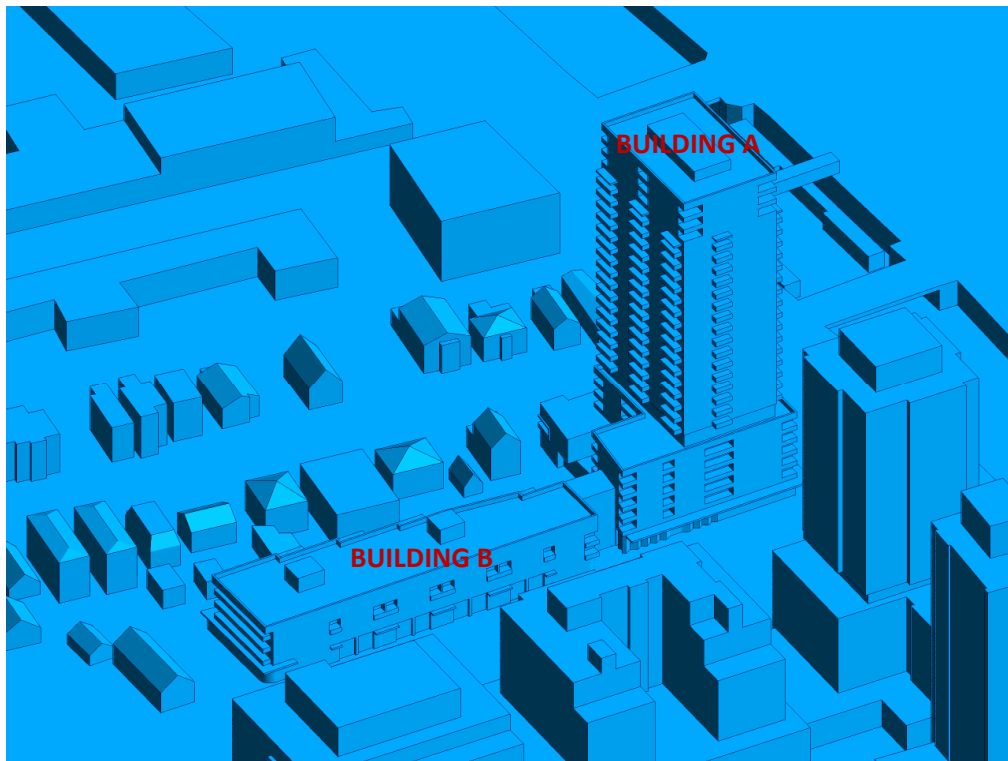


FIGURE 2D: CLOSE UP OF FIGURE 2C

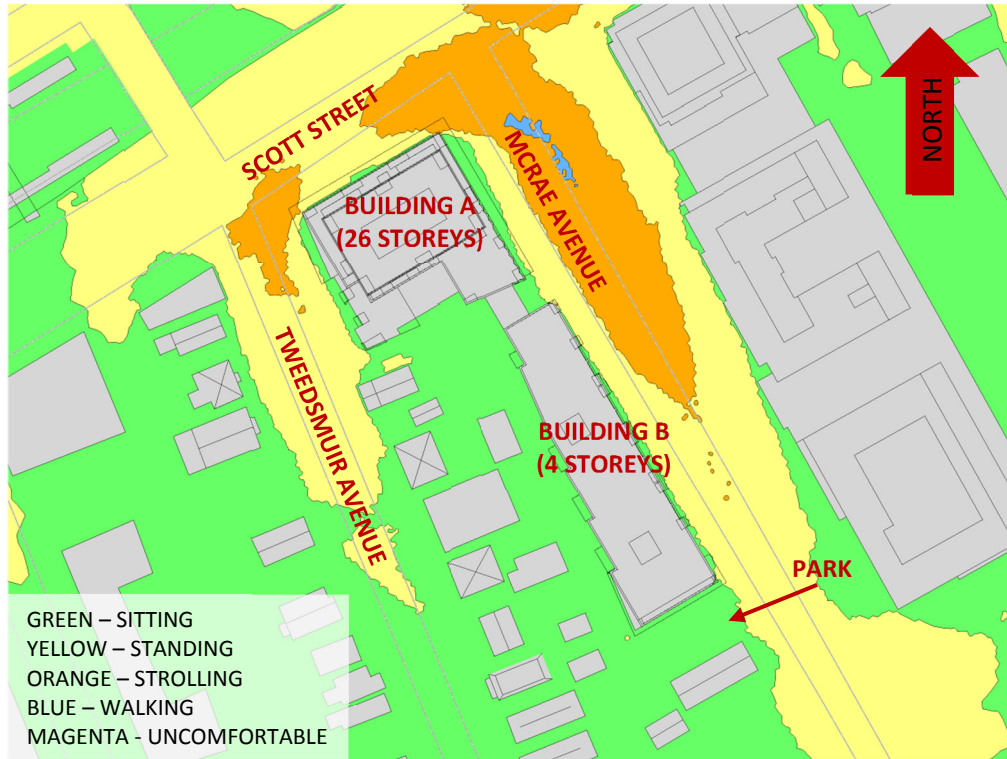


FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

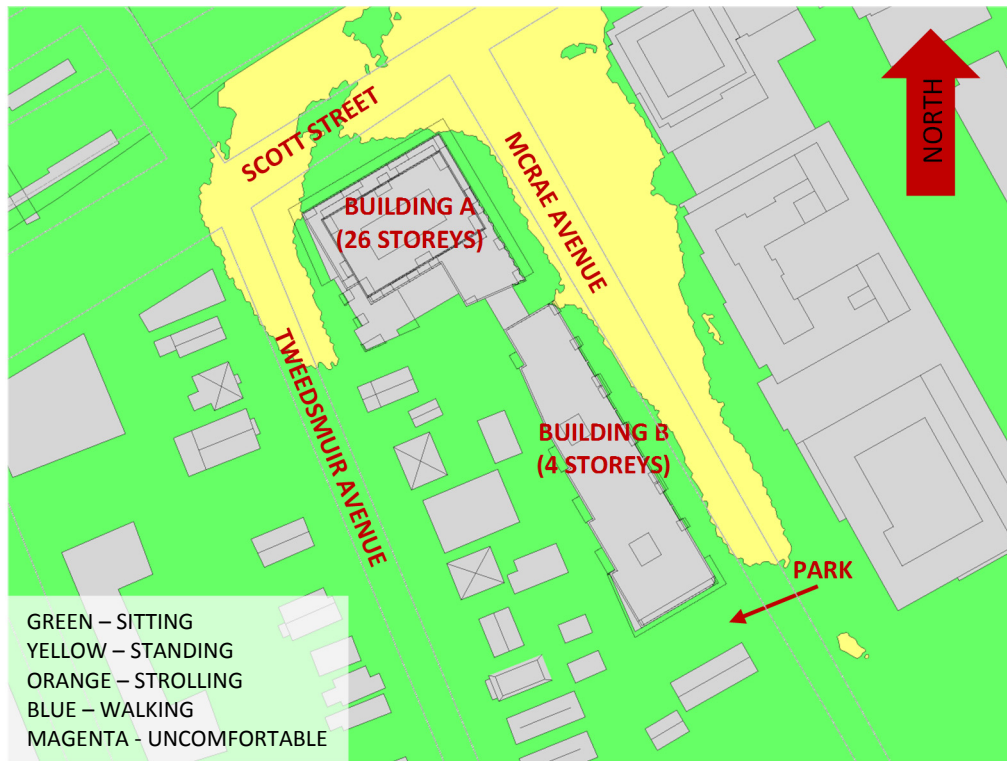


FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL

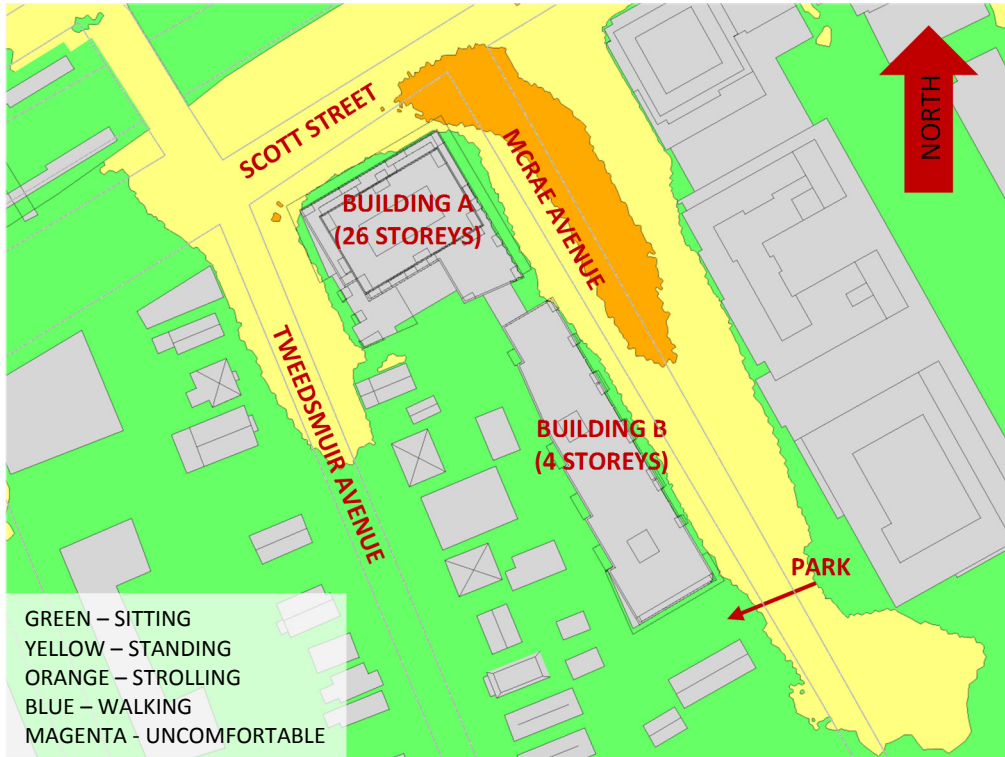


FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL



FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL

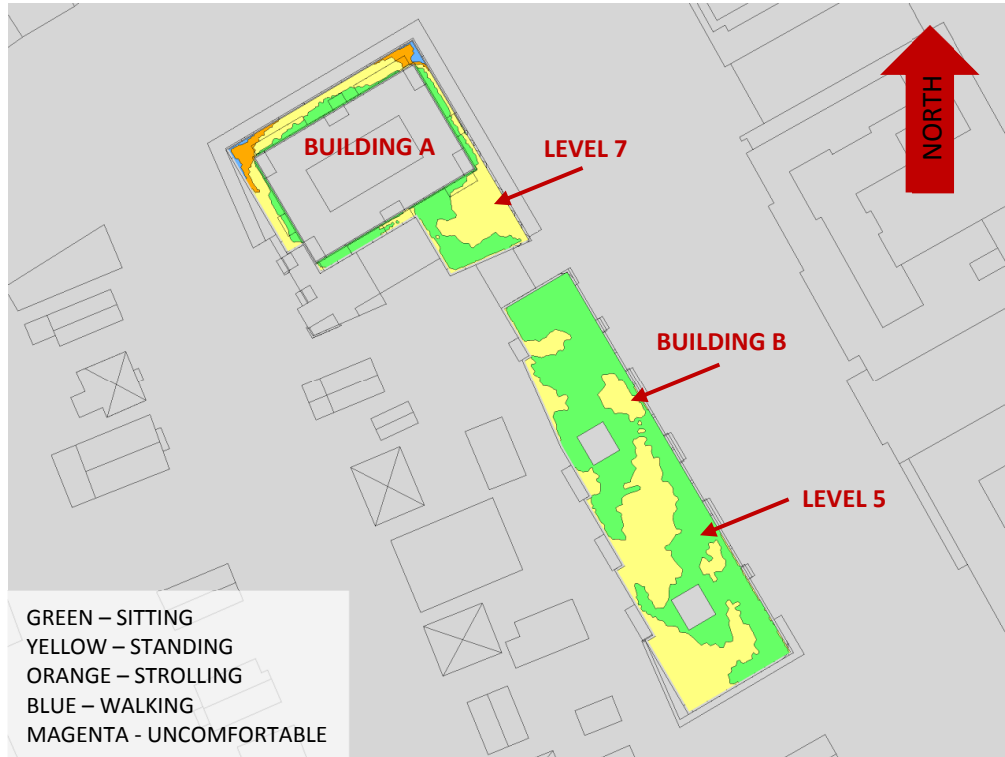


FIGURE 4A: SPRING – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES



FIGURE 4B: SPRING – PERCENTAGE OF TIME SUITABLE FOR SITTING WITHIN TERRACES



FIGURE 5A: SUMMER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES

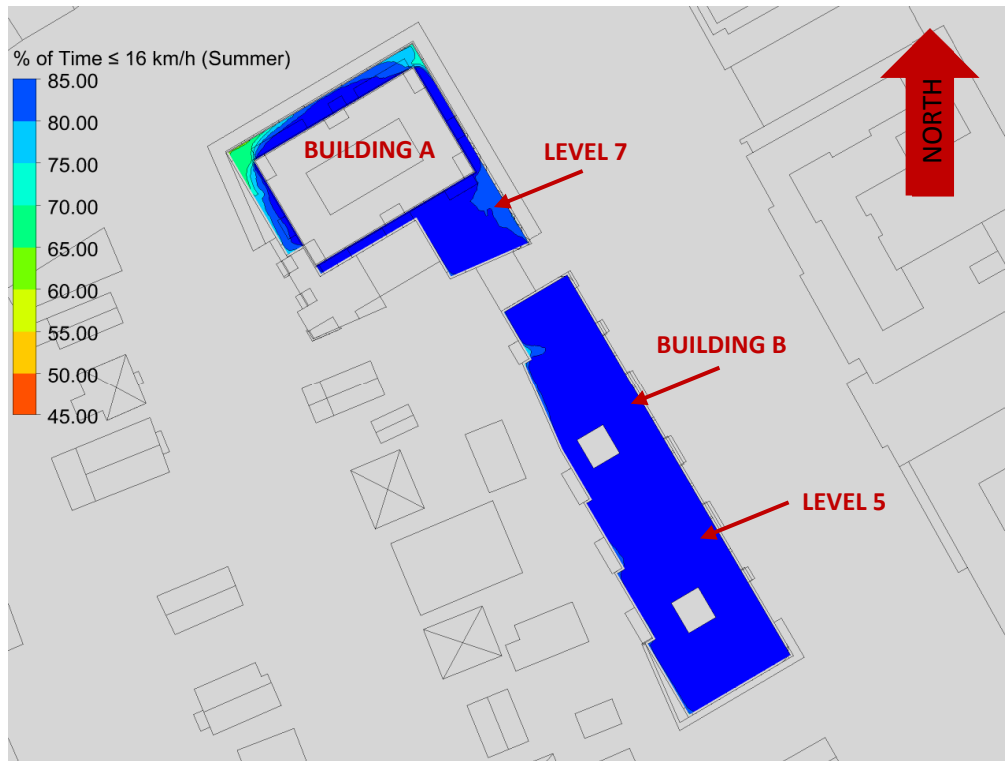


FIGURE 5B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING WITHIN TERRACES



FIGURE 6A: AUTUMN – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES



FIGURE 6B: AUTUMN – PERCENTAGE OF TIME SUITABLE FOR SITTING WITHIN TERRACES



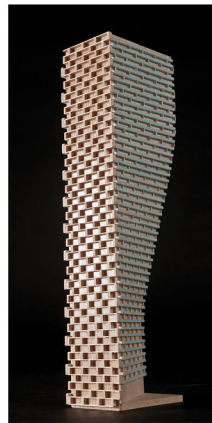
FIGURE 7A: WINTER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACES



FIGURE 7B: WINTER – PERCENTAGE OF TIME SUITABLE FOR SITTING WITHIN TERRACES

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APPENDIX A

SIMULATION OF THE NATURAL WIND

The information contained within this appendix is offered to provide a greater understanding of the relationship between the physical wind tunnel testing method and virtual computer-based simulations

SIMULATION OF THE NATURAL WIND

Wind flowing over the surface of the earth develops a boundary layer due to the drag produced by surface features such as vegetation and man-made structures. Within this boundary layer, the mean wind speed varies from zero at the surface to the gradient wind speed at the top of the layer. The height of the top of the boundary layer is referred to as the gradient height, above which the velocity remains more-or-less constant for a given synoptic weather system. The mean wind speed is taken to be the average value over one hour. Superimposed on the mean wind speed are fluctuating (or turbulent) components in the longitudinal (i.e. along wind), vertical and lateral directions. Although turbulence varies according to the roughness of the surface, the turbulence level generally increases from nearly zero (smooth flow) at gradient height to maximum values near the ground. While for a calm ocean the maximum could be 20%, the maximum for a very rough surface such as the center of a city could be 100%, or equal to the local mean wind speed. The height of the boundary layer varies in time and over different terrain roughness within the range of 400 metres (m) to 600 m.

Simulating real wind behaviour in a wind tunnel, or by computational simulations (CFD), requires simulating the variation of mean wind speed with height, simulating the turbulence intensity, and matching the typical length scales of turbulence. It is the ratio between wind tunnel turbulence length scales and turbulence scales in the atmosphere that determines the geometric scales that models can assume in a wind tunnel. Hence, when a 1:200 scale model is quoted, this implies that the turbulence scales in the wind tunnel and the atmosphere have the same ratios. Some flexibility in this requirement has been shown to produce reasonable wind tunnel predictions compared to full scale. In model scale the mean and turbulence characteristics of the wind are obtained with the use of spires at one end of the tunnel and roughness elements along the floor of the tunnel. The fan is located at the model end and wind is pulled over the spires, roughness elements and model. It has been found that, to a good approximation, the mean wind profile can be represented by a power law relation, shown below, giving height above ground versus wind speed.

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

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.

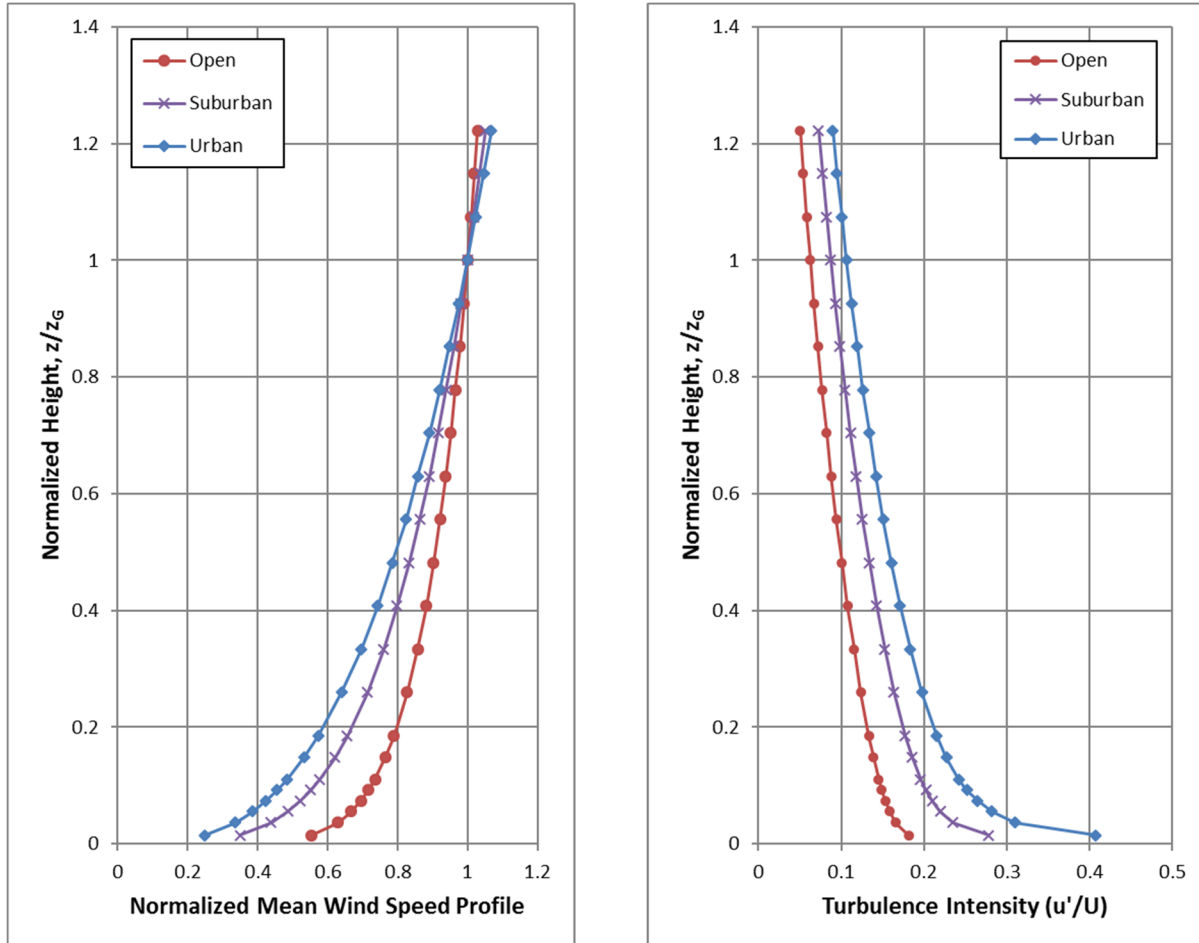
Figure A1 on the following page plots three velocity profiles for open country, and suburban and urban exposures. The exponent α varies according to the type of upwind terrain; α ranges from 0.14 for open country to 0.33 for an urban exposure. Figure A2 illustrates the theoretical variation of turbulence for open country, suburban and urban exposures.

The integral length scale of turbulence can be thought of as an average size of gust in the atmosphere. Although it varies with height and ground roughness, it has been found to generally be in the range of 100 m to 200 m in the upper half of the boundary layer. Thus, for a 1:300 scale, the model value should be between 1/3 and 2/3 of a metre. Integral length scales are derived from power spectra, which describe the energy content of wind as a function of frequency. There are several ways of determining integral length scales of turbulence. One way is by comparison of a measured power spectrum in model scale to a non-dimensional theoretical spectrum such as the Davenport spectrum of longitudinal turbulence. Using the Davenport spectrum, which agrees well with full-scale spectra, one can estimate the integral scale by plotting the theoretical spectrum with varying L until it matches as closely as possible the measured spectrum:

$$f \times S(f) = \frac{4(Lf)^2}{U_{10}^2} \left[1 + \frac{4(Lf)^2}{U_{10}^2} \right]^{-\frac{4}{3}}$$

Where, f is frequency, S(f) is the spectrum value at frequency f, U10 is the wind speed 10 m above ground level, and L is the characteristic length of turbulence.

Once the wind simulation is correct, the model, constructed to a suitable scale, is installed at the centre of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel center-line axis.



**FIGURE A1 (LEFT): MEAN WIND SPEED PROFILES;
FIGURE A2 (RIGHT): TURBULENCE INTENSITY PROFILES**

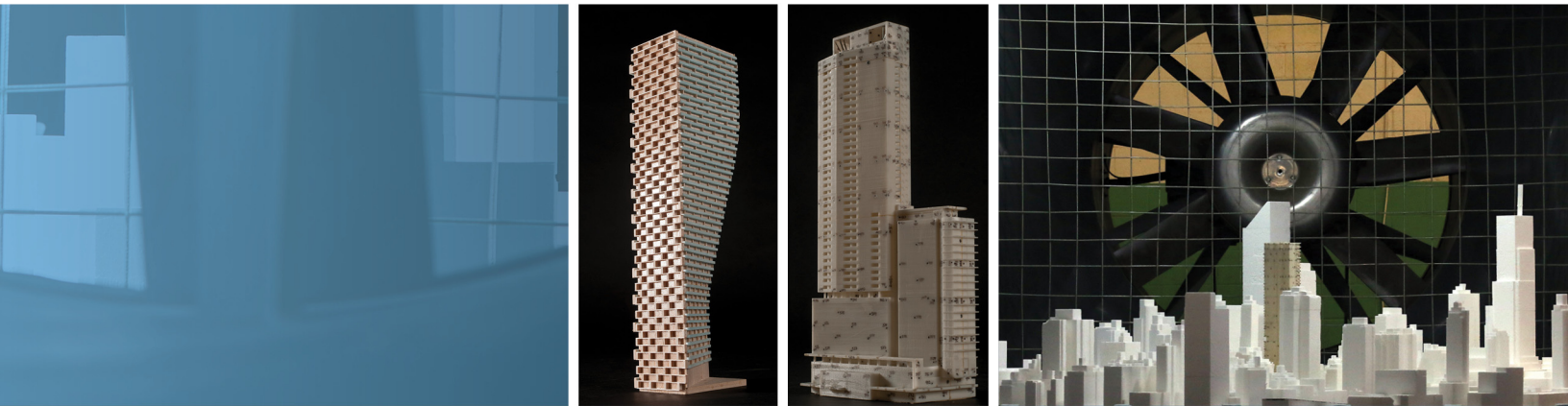
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APPENDIX B

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

The information contained within this appendix is offered to provide a greater understanding of the relationship between the physical wind tunnel testing method and virtual computer-based simulations

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

Pedestrian level wind studies are performed in a wind tunnel on a physical model of the study buildings at a suitable scale. Instantaneous wind speed measurements are recorded at a model height corresponding to 1.5 m full scale using either a hot wire anemometer or a pressure-based transducer. Measurements are performed at any number of locations on the model and usually for 36 wind directions. For each wind direction, the roughness of the upwind terrain is matched in the wind tunnel to generate the correct mean and turbulent wind profiles approaching the model.

The hot wire anemometer is an instrument consisting of a thin metallic wire conducting an electric current. It is an omni-directional device equally sensitive to wind approaching from any direction in the horizontal plane. By compensating for the cooling effect of wind flowing over the wire, the associated electronics produce an analog voltage signal that can be calibrated against velocity of the air stream. For all measurements, the wire is oriented vertically so as to be sensitive to wind approaching from all directions in a horizontal plane.

The pressure sensor is a small cylindrical device that measures instantaneous pressure differences over a small area. The sensor is connected via tubing to a transducer that translates the pressure to a voltage signal that is recorded by computer. With appropriately designed tubing, the sensor is sensitive to a suitable range of fluctuating velocities.

For a given wind direction and location on the model, a time history of the wind speed is recorded for a period of time equal to one hour in full-scale. The analog signal produced by the hot wire or pressure sensor is digitized at a rate of 400 samples per second. A sample recording for several seconds is illustrated in Figure B1. This data is analyzed to extract the mean, root-mean-square (rms) and the peak of the signal. The peak value, or gust wind speed, is formed by averaging a number of peaks obtained from sub-intervals of the sampling period. The mean and gust speeds are then normalized by the wind tunnel gradient wind speed, which is the speed at the top of the model boundary layer, to obtain mean and gust ratios. At each location, the measurements are repeated for 36 wind directions to produce normalized polar plots, which will be provided upon request.

In order to determine the duration of various wind speeds at full scale for a given measurement location the gust ratios are combined with a statistical (mathematical) model of the wind climate for the project site. This mathematical model is based on hourly wind data obtained from one or more meteorological stations (usually airports) close to the project location. The probability model used to represent the data is the Weibull distribution expressed as:

$$P(> U_g) = A_{\theta} \cdot \exp \left[\left(-\frac{U_g}{C_{\theta}} \right)^{K_{\theta}} \right]$$

Where,

$P(> U_g)$ is the probability, fraction of time, that the gradient wind speed U_g is exceeded; θ is the wind direction measured clockwise from true north, A , C , K are the Weibull coefficients, (Units: A - dimensionless, C - wind speed units [km/h] for instance, K - dimensionless). A_{θ} is the fraction of time wind blows from a 10° sector centered on θ .

Analysis of the hourly wind data recorded for a length of time, on the order of 10 to 30 years, yields the A_{θ} , C_{θ} and K_{θ} values. The probability of exceeding a chosen wind speed level, say 20 km/h, at sensor N is given by the following expression:

$$P_N(> 20) = \sum_{\theta} P \left[\frac{(> 20)}{\left(\frac{U_N}{U_g} \right)} \right]$$

$$P_N(> 20) = \sum_{\theta} P \{ > 20 / (U_N / U_g) \}$$

Where, U_N / U_g is the gust velocity ratios, where the summation is taken over all 36 wind directions at 10° intervals.

If there are significant seasonal variations in the weather data, as determined by inspection of the C_{θ} and K_{θ} values, then the analysis is performed separately for two or more times corresponding to the groupings of seasonal wind data. Wind speed levels of interest for predicting pedestrian comfort are based on the comfort guidelines chosen to represent various pedestrian activity levels as discussed in the main text.

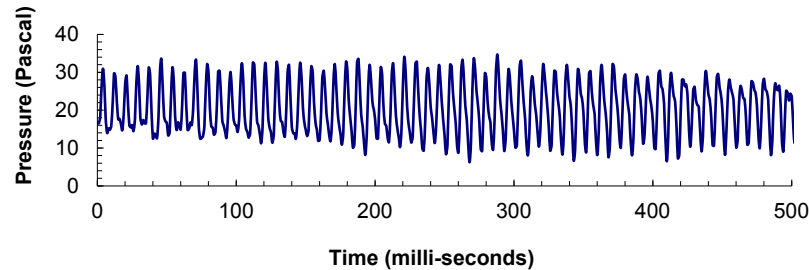


FIGURE B1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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