Pedestrian Level Wind Study

90-104 Queen Street East and 3 Mutual Street

Toronto, Ontario

REPORT: GWE18-172-PLW

Prepared For:

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EXECUTIVE SUMMARY

This report describes a computer-based pedestrian level wind study in support of a zoning by-law amendment (ZBA) application for the proposed single-tower development located at 90-104 Queen Street East and 3 Mutual Street in Toronto, Ontario. 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 development site. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report.

This study is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by IBI Group in November 2018, 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 conditions is provided in Section 5 of this report, and illustrated in Figures 3A-6B (following the main text). Based on CFD simulations, meteorological data analysis for Toronto, and experience with similar developments, we conclude that wind conditions at all grade-level locations within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal basis. More specifically, surrounding sidewalks and primary and secondary building access points will experience calm and acceptable wind conditions throughout the year.

The Level 4 common terraces will also be suitable for sitting conditions during the summer season when demand is assumed to be greatest. In general, the common areas will be suitable for sitting except for the southwest corner of the west terrace and the southeast corner of the east terrace, which are nonetheless suitable for standing during the three colder seasons. If sitting is required within these areas during the shoulder months of spring and autumn, it will be necessary to introduce perimeter wind screens. Mitigation strategies could be explored and confirmed for the Site Plan Control (SPA) application, if required.

Excluding anomalous localized storm events such as tornadoes and downbursts, no areas over the study site are considered uncomfortable or unsafe.

CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by QM Developments LP to undertake a computer-based pedestrian level wind (PLW) study in support of a zoning by-law (ZBA) amendment application for the proposed single-tower development located at 90-104 Queen Street East and 3 Mutual Street in Toronto. Our mandate, as outlined in GWE proposal #18-219P, dated August 28, 2018, is to investigate pedestrian wind comfort within and surrounding the development site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered. Our work is based on industry standard Computational Fluid Dynamics (CFD) simulations and data analysis procedures, architectural drawings provided by IBI Group in November 2018, 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 focus of this PLW study is the proposed single-tower development located at 90-104 Queen Street East and 3 Mutual Street in Toronto. The study site is located on the northeast corner at the intersection of Queen Street East and Mutual Street. The development will feature a single building comprising a rectangular planform with a 3-storey podium located on the south side of the building. Parts of the north, south, and west elevations of a heritage building will be retained. Various setbacks occur on Floors 4 through 32 on the south side to accommodate common amenity areas. A residential entrance is provided on Queen Street East, while retail entrances are provided on both Queen Street East and Mutual Street.

Regarding wind exposures, the near-field surroundings of the development (defined as an area falling within a 200-m radius from the subject site) comprise primarily of mid-rise developments in all directions except to the immediate north and west which include a collection of tall buildings. The far-field surroundings (defined as the area beyond the near-field and within a 2-km radius), are characterized by suburban low-rise residential developments and isolated tall residential towers from the north clockwise to the south, and dense urban massing from the south clockwise to the north.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, building access points, and the common amenity terraces at Level 4. A site plan is provided in Figure 1, while Figures 2A and 2B illustrate the computational model used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to: (i) determine pedestrian level comfort and safety conditions within and surrounding the development site; (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 Computational Fluid Dynamics (CFD) simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the Toronto area 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 study is 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, are determined by combining measured wind speed data from CFD simulations with statistical weather data obtained from 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 wind tunnel 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] Toronto Development Guide, Pedestrian Level Wind Study Terms of Reference, February 2012

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 840 m.

Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade, as well as 1.5 m above the Level 4 common amenity areas, 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.

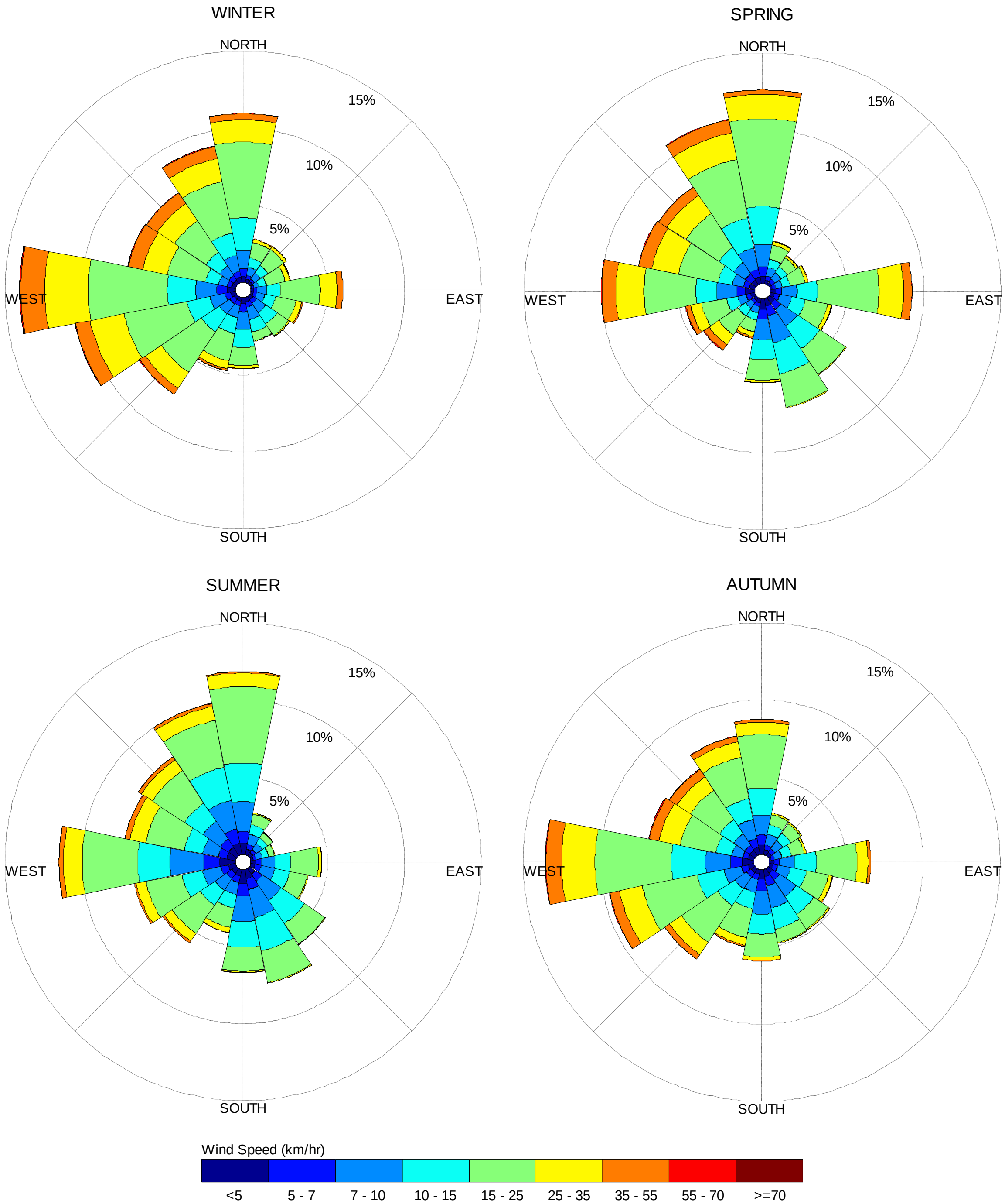
4.3 Meteorological Data Analysis

A statistical model for winds in Toronto was developed from approximately 40-years of hourly meteorological wind data recorded at Pearson International Airport, and obtained from the local branch of Atmospheric Environment Services of Environment 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 the 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 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, 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 WINDS FOR VARIOUS PROBABILITIES
PEARSON INTERNATIONAL AIRPORT, TORONTO, ONTARIO



Notes:

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

4.4 Pedestrian Comfort Guidelines

Pedestrian comfort guidelines are based on mechanical wind effects without consideration of other meteorological conditions (i.e., temperature, relative humidity). The guidelines provide an assessment of comfort, assuming that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Four pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort, which include: (i) Sitting; (ii) Standing; (iii) Walking; and (iv) Uncomfortable. More specifically, the comfort classes, associated wind speed ranges, and limiting guidelines are summarized as follows:

(i) **Sitting** – Wind speeds no greater than 14 km/h occurring at least 80% of the time would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – Wind speeds no greater than 22 km/h occurring at least 80% of the time are acceptable for activities such as standing, strolling or more vigorous activities.

(iii) **Walking** – Wind speeds no greater than 30 km/h occurring more than 80% of the time are acceptable for walking or more vigorous activities.

(iv) **Uncomfortable** – Uncomfortable conditions are characterized by predicted values that fall below the 80% criterion for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this target.

** **Dangerous** – Wind speeds greater than 90 km/h, occurring more than 0.1% of the time, are classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall.

The wind speeds associated with the above categories are gust wind speeds. Corresponding mean wind speeds are approximately calculated as gust wind speed divided by 1.5. Gust speeds are used in the guidelines because people 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 cause problems for pedestrians. The gust speed ranges 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.

THE BEAUFORT SCALE

Number	Description	Wind Speed (km/h)	Description
2	Light Breeze	4-8	Wind felt on faces.
3	Gentle Breeze	8-15	Leaves and small twigs in constant motion; Wind extends light flags.
4	Moderate Breeze	15-22	Wind raises dust and loose paper; Small branches are moved.
5	Fresh Breeze	22-30	Small trees in leaf begin to sway.
6	Strong Breeze	30-40	Large branches in motion; Whistling heard in electrical wires; Umbrellas used with difficulty.
7	Moderate Gale	40-50	Whole trees in motion; Inconvenient walking against wind.
8	Gale	50-60	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 14 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 guidelines 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 across the study site, 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. 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
Building Access	Standing
Public Sidewalks / Pedestrian Walkways	Standing / Walking
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens	Sitting / Standing
Transit Shelters	Standing
Public Parks	Sitting / Standing / Walking
Vehicular Drop-Off Areas	Standing / Walking

5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions for the study site is accompanied by Figures 3A-6B illustrating the seasonal wind conditions at grade level and within the Level 4 common terraces. The colour contours indicate predicted regions of the various comfort classes. Wind conditions comfortable for sitting are represented by the colour green, standing by yellow, and walking by blue.

Sidewalks along Queen Street East, Mutual Street, Richard Bigley Lane, and Jarvis Street; Building Access Points (Figures 3A/4A/5A/6A): The sidewalks along Queen Street East and Mutual Street will be suitable for sitting during the summer and autumn seasons, and suitable for standing, or better, during the spring and winter seasons. The noted conditions are considered acceptable. Calmer conditions are predicted to occur along Richard Bigley Lane and Jarvis Street, in the immediate vicinity of the proposed development, while wind conditions adjacent to all building access points will be suitable for sitting throughout the year.

Level 4 Common Terraces (Figures 3B/4B/5B/6B): The desired pedestrian comfort class is sitting during the summer season when demand is assumed to be greatest, which is achieved outright at all locations within both the east and west terraces. In general, the common areas will be suitable for sitting except for the southwest corner of the west terrace and the southeast corner of the east terrace, which are nonetheless suitable for standing during the three colder seasons. If sitting is required within these areas during the shoulder months of spring and autumn, it will be necessary to introduce perimeter wind screens. Mitigation strategies could be explored and confirmed for the Site Plan Control (SPA) application, if required.

Wind Safety: Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas over the study site were found to experience wind conditions that are considered uncomfortable or unsafe.

6. SUMMARY AND RECOMMENDATIONS

This report summarizes the results of a computer-based pedestrian level wind study in support of a zoning by-law amendment (ZBA) application for the proposed single-tower mixed-use development located at 90-104 Queen Street East and 3 Mutual Street in Toronto, Ontario. Based on CFD simulations, meteorological data analysis for Toronto, and experience with similar developments, we conclude that wind conditions at all grade-level locations within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal basis. More specifically, surrounding sidewalks and primary and secondary building access points will experience calm and acceptable wind conditions throughout the year.

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

Sincerely,

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GRADIENTWIND ENGINEERS & SCIENTISTS 127 WALGREEN ROAD , OTTAWA, ON 613 836 0934 • GRADIENTWIND.COM	PROJECT 90-104 QUEEN STREET EAST & 3 MUTUAL STREET, TORONTO PEDESTRIAN LEVEL WIND STUDY	DESCRIPTION FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
	SCALE 1:2500 (APPROX.)	DRAWING NO. GWE18-172-PLW-1
	DATE DECEMBER 3, 2018	DRAWN BY K.A.

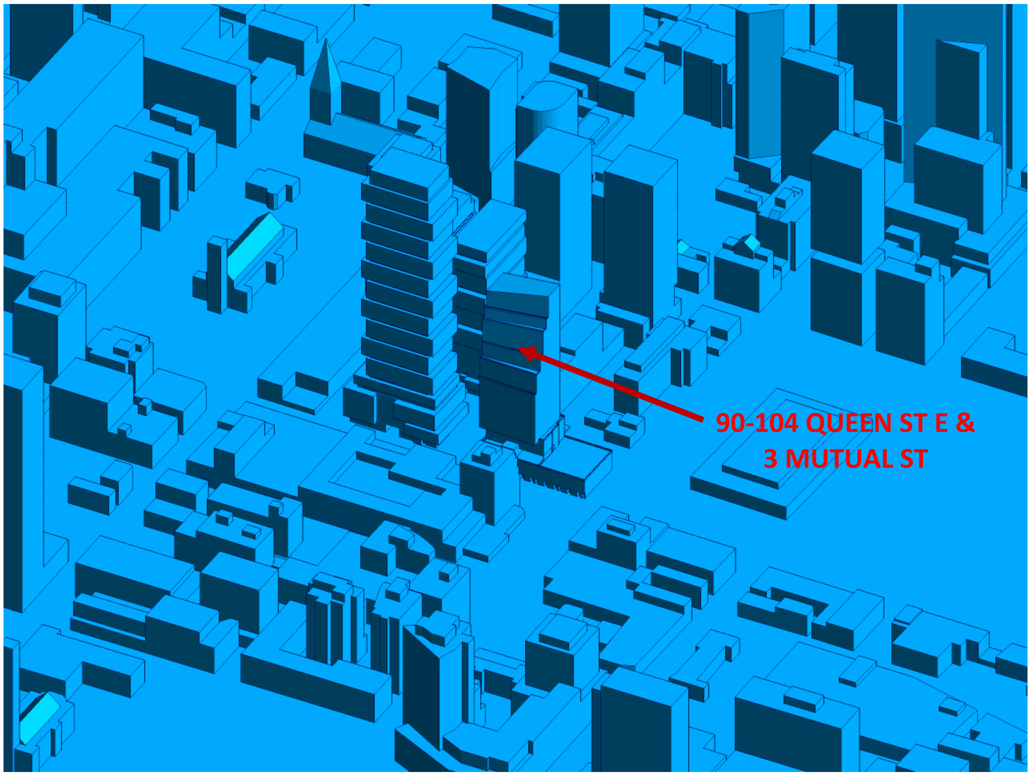

FIGURE 2A: COMPUTATIONAL MODEL, SOUTHEAST PERSPECTIVE (135° TRUE)

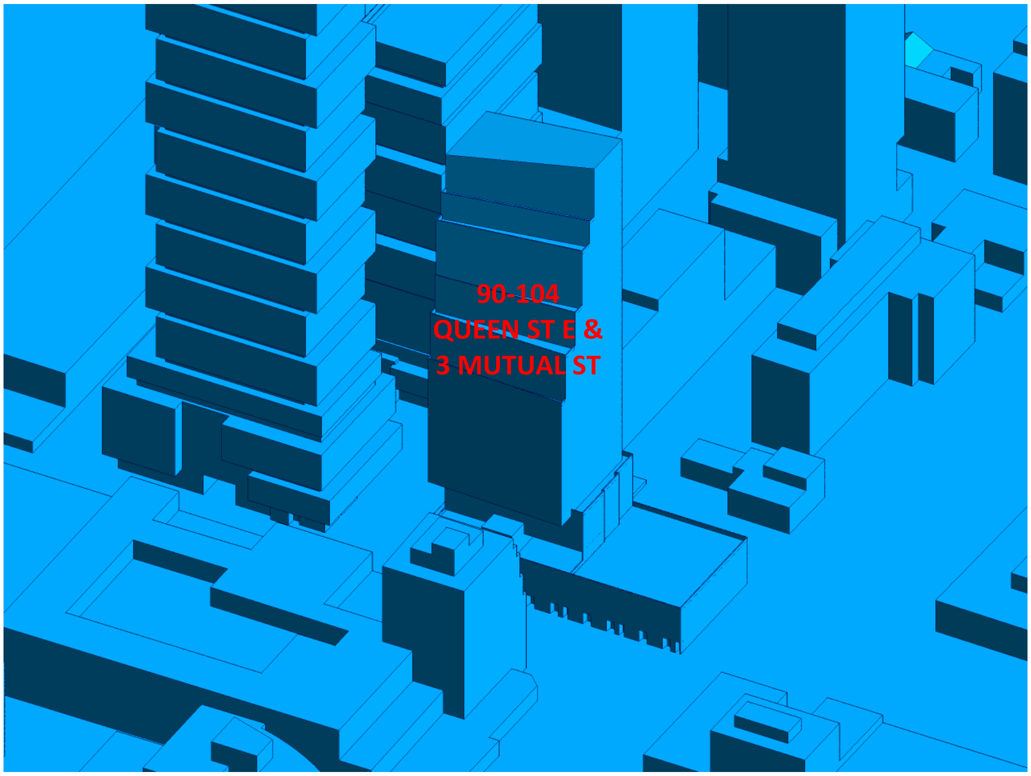

FIGURE 2B: CLOSE-UP VIEW OF FIGURE 2A

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

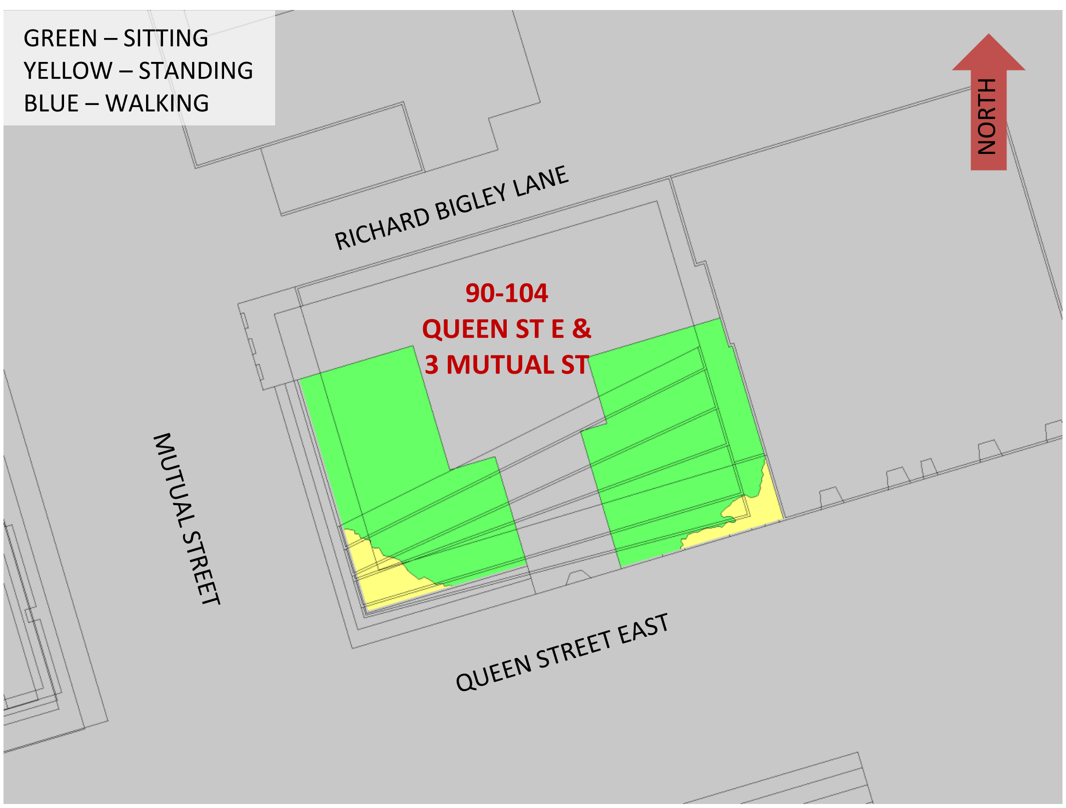

FIGURE 3B: SPRING – LEVEL 4 COMMON TERRACES, PEDESTRIAN WIND CONDITIONS

FIGURE 4A: SUMMER – GRADE-LEVEL, PEDESTRIAN WIND CONDITIONS

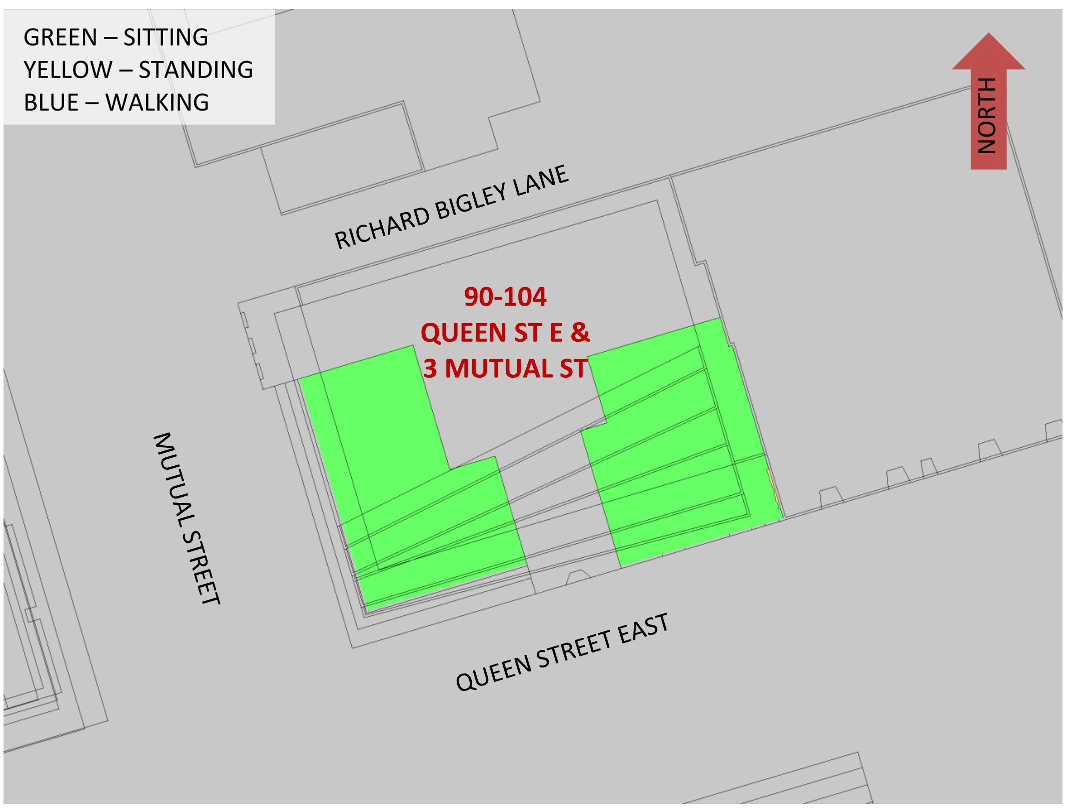

FIGURE 4B: SUMMER – LEVEL 4 COMMON TERRACES, PEDESTRIAN WIND CONDITIONS

FIGURE 5A: AUTUMN – GRADE-LEVEL, PEDESTRIAN WIND CONDITIONS

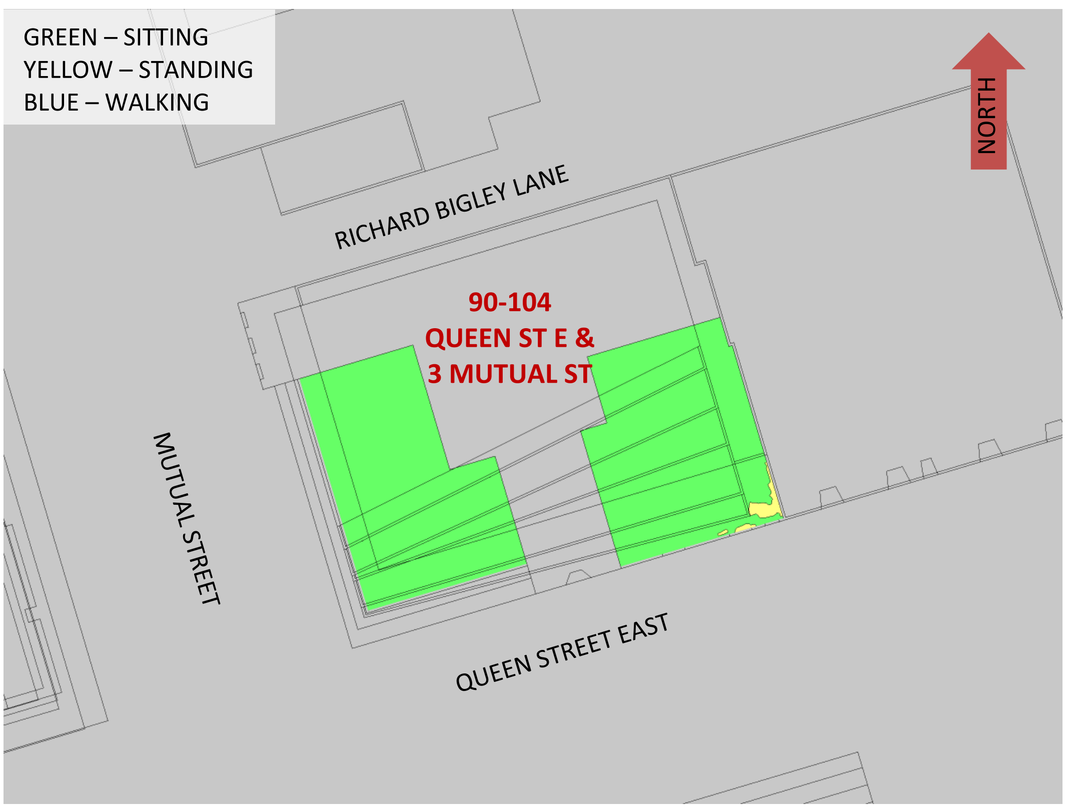

FIGURE 5B: AUTUMN – LEVEL 4 COMMON TERRACES, PEDESTRIAN WIND CONDITIONS

FIGURE 6A: WINTER – GRADE-LEVEL, PEDESTRIAN WIND CONDITIONS

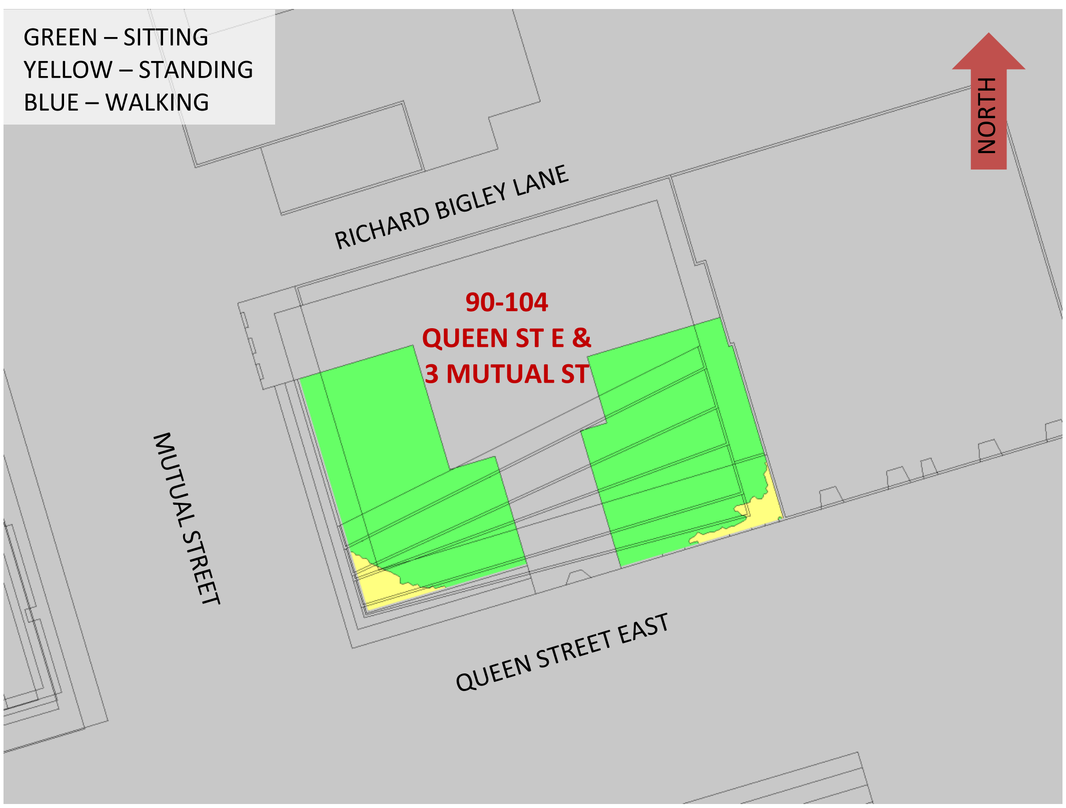

FIGURE 6B: WINTER – LEVEL 4 COMMON TERRACES, PEDESTRIAN WIND CONDITIONS

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

WIND TUNNEL 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 meters (m) to 600 m.

Simulating real wind behaviour in a wind tunnel, or by computer models (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; $\boldsymbol{U}$ = 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.

Figure A1 plots three such profiles for the open country, suburban and urban exposures. The exponent α varies according to the type of terrain; α = 0.14, 0.25 and 0.33 for open country, suburban and urban exposures respectively. Figure A2 illustrates the theoretical variation of turbulence in full scale and some wind tunnel measurement for comparison.

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. For a 1:300 scale, for example, 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:

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

Where, f is frequency, $S(f)$ is the spectrum value at frequency f, U_{10} 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 center of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel centre-line axis.

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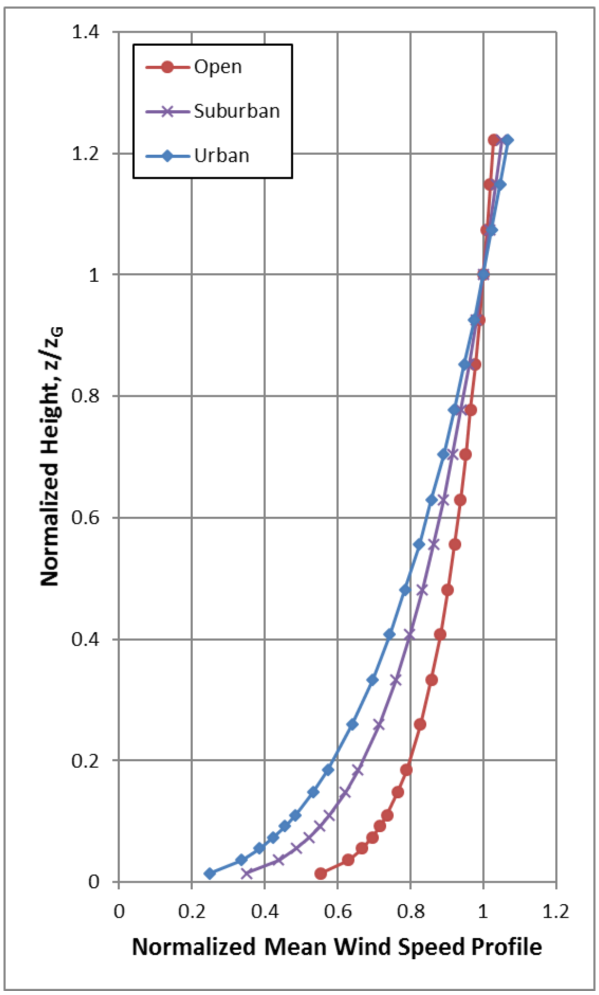


Figure A1: Mean Wind Speed Profiles

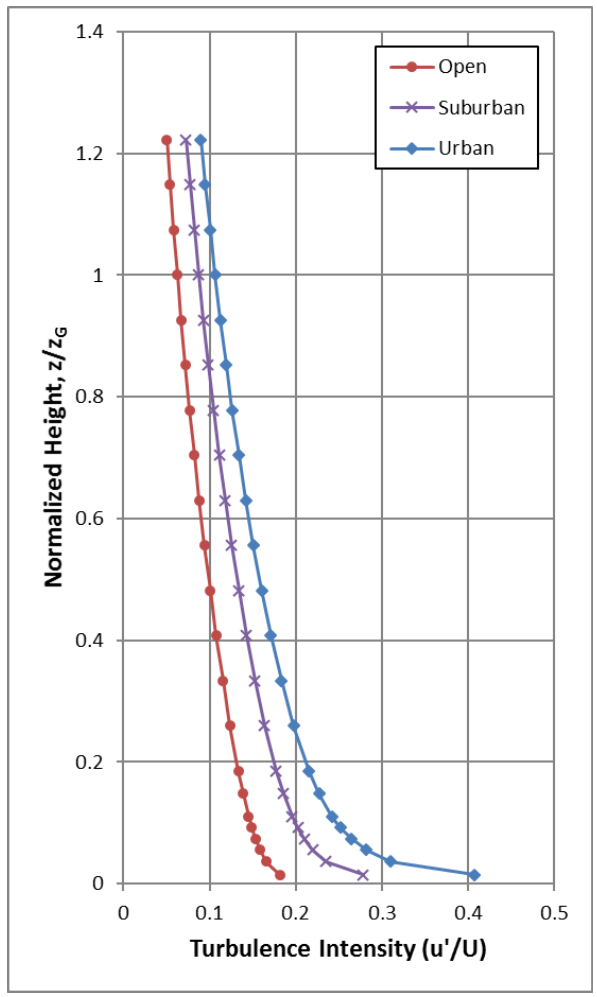


Figure A2: Turbulence Intensity Profiles

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 meters (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 B. 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:

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

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:

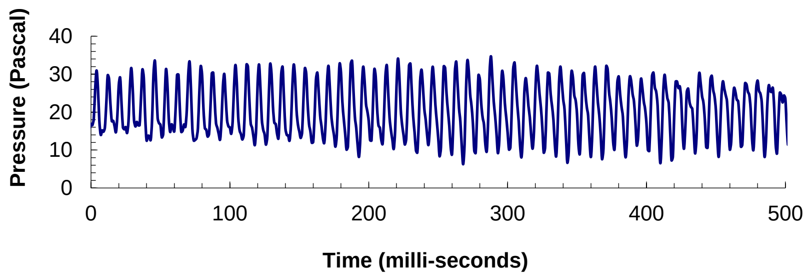
$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

$$P_N\ (>20) \quad = \quad \Sigma_\theta P\ \{>20/(U_N/Ug)\}$$

Where, U_N/U_g is the aforementioned normalized 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 B: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR



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