# Pedestrian Level Wind Study

## 55 Port Street East

## Mississauga, Ontario

REPORT: GWE17-184-CFDPLW

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# EXECUTIVE SUMMARY

This document summarizes the results of a computer-based Pedestrian Level Wind (PLW) study in support of a joint Official Plan Amendment (OPA) and Zoning By-law Amendment (ZBA) application for a proposed condominium development located at 55 Port Street East in Mississauga, Ontario. The study is based on industry standard simulations using the Computational Fluid Dynamics (CFD) technique and associated data analysis procedures, City of Mississauga wind criteria, architectural drawings prepared by Giannone Petricone Associates Inc. Architects in December 2017, surrounding street layouts and contextual information, as well as recent site imagery.

A complete summary of the predicted wind conditions across the study site is presented in Section 5 of this report and illustrated in Figures 3A-4B (following the main text). Based on CFD test results, interpretation, and experience with similar developments, all grade-level areas within and surrounding the development site, including surrounding sidewalks, building access points, and the grade-level outdoor amenity area, as well as the St. Lawrence Park and Waterfront Trail, will be acceptable for the intended pedestrian uses on a seasonal and annual basis.

A comparison of existing versus future wind comfort over the study site indicates that the proposed development will have a generally neutral influence on existing grade-level wind conditions, which will remain acceptable for the anticipated pedestrian uses of the spaces.

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

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# 1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by FRAM + Slokker to undertake a computer-based Pedestrian Level Wind (PLW) study in support of a joint Official Plan Amendment (OPA) and Zoning By-law Amendment (ZBA) application for a proposed condominium development located at 55 Port Street East in Mississauga, Ontario. Our mandate within this study, as outlined in GWE proposal #17-276P, dated November 6, 2017, is to investigate pedestrian wind comfort and safety 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, where necessary.

Our work is based on industry-standard wind simulations using the Computational Fluid Dynamics (CFD) technique and associated data analysis procedures, City of Mississauga wind criteria, architectural drawings prepared by Giannone Petricone Associates Inc. Architects in December 2017, surrounding street layouts and contextual information, as well as recent site imagery.

# 2. TERMS OF REFERENCE

The focus of this PLW study is the proposed condominium development located at 55 Port Street East in Mississauga, Ontario. The development, located in the Port Credit neighbourhood, is situated on the southwest portion of a parcel of land bounded by Helene Street South to the southwest, Port Street East to the northwest, St. Lawrence Drive to the northeast, and the St. Lawrence Park to the southeast, beyond which is Lake Ontario. For ease of description, Port Street East is defined as project north.

The study site is generally surrounded in the near-field and far-field by a suburban mix of low- and mid-rise developments in all directions, except for the open exposure of Lake Ontario to the south. The proposed development is a 10-storey building with a single-storey podium. At Level 1 the floorplate features two extensions to the south. An outdoor amenity area is located between these extensions. Above the podium, the building rises uniformly with an irregular planform formed by a combination of straight and diagonal walls.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, potential building access points, and the grade-level outdoor amenity area, as well as the St. Lawrence Park and Waterfront Trail. Figures 1A illustrates the proposed development and surrounding context, while Figure

1B illustrates the existing context. Figures 2A and 2B illustrate the computational models used to conduct the study for both the proposed and existing massing scenarios, respectively.

## 3. OBJECTIVES

The principal objectives of this study are to: (i) determine pedestrian wind 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 Mississauga area wind climate, and synthesis of computational data with City of Mississauga wind criteria[1]. The following sections describe the analysis procedures, including a discussion of the pedestrian comfort criteria.

### 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 Toronto Island Billy Bishop 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 both wind tunnel and computer-based models due to the difficulty of providing accurate

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[1] City of Mississauga Urban Design Terms of Reference, Wind Comfort and Safety Studies, June 2014

seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative wind speed values.

## 4.2 Wind Speed Measurements

The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 12 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a diameter of approximately 1,640 meters (m).

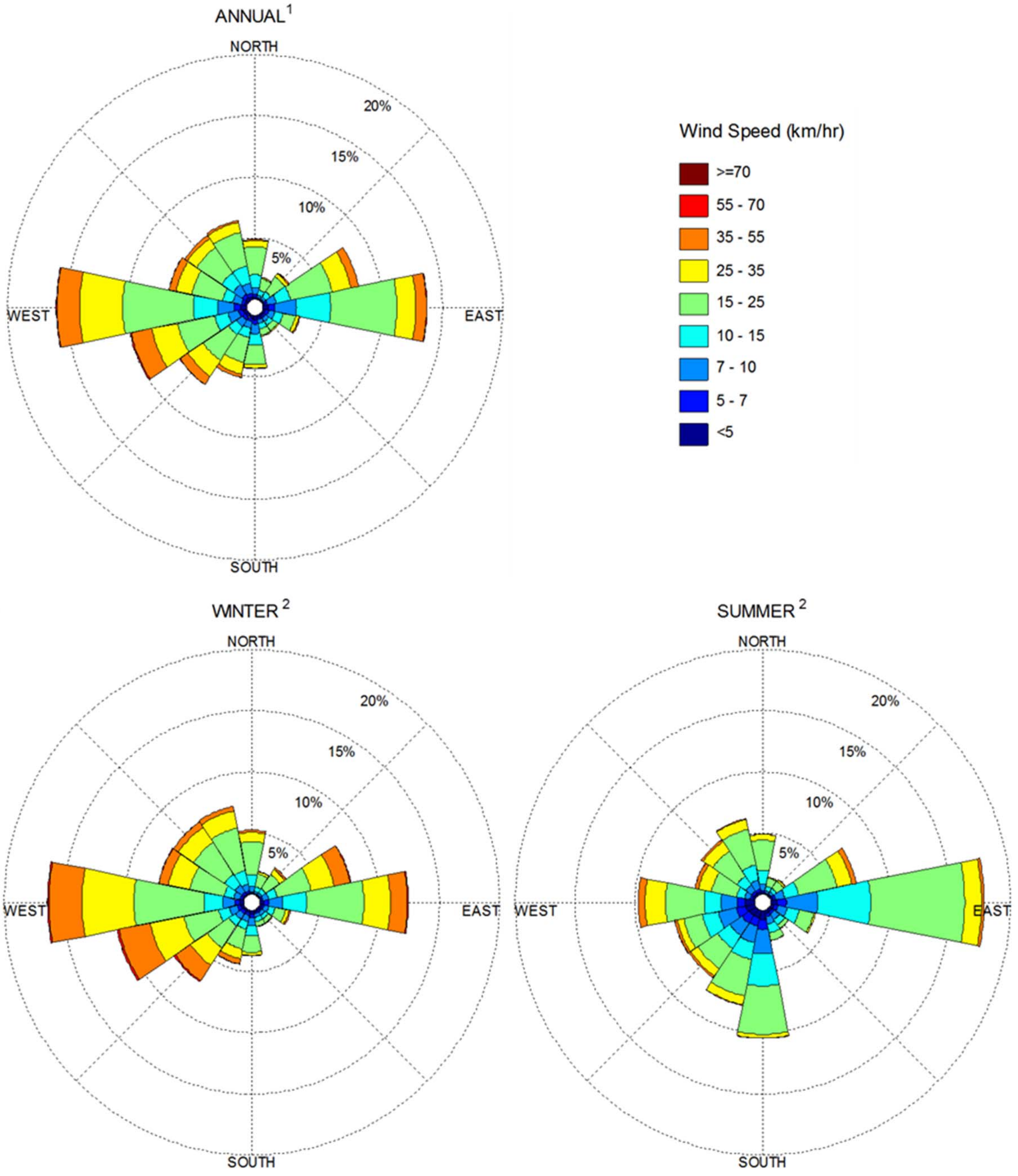
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade were referenced to the wind speed at gradient height to generate 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 Mississauga was developed from approximately 35-years of hourly meteorological wind data recorded at Toronto Island Billy Bishop Airport. Wind speed and direction data were analyzed during the appropriate hours of pedestrian usage (i.e., between 06:00 and 23:00) and divided into two distinct seasons, as stipulated in the noted City of Mississauga Urban Design Terms of Reference[1]. More specifically, the summer season is defined as May through October, while the winter season is defined as November through April, inclusive.

The statistical model of the Mississauga 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 Mississauga (south of the Queen Elizabeth Way), the most common winds concerning pedestrian comfort during the winter season occur for westerly wind directions, followed by those from the east. The most common winds during the summer season occur for easterly wind directions. The directional preference and relative magnitude of the wind speed varies somewhat from season to season. Also, by convection in microclimate studies, wind direction refers to the wind origin (e.g., a north wind blows from north to south).

# SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES
## TORONTO ISLAND BILLY BISHOP AIRPORT, TORONTO



**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 Criteria

Pedestrian comfort criteria are based on mechanical wind effects without consideration of other meteorological conditions (i.e., temperature and relative humidity). The criteria provide an assessment of comfort, assuming that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Since both mean and gust wind speeds affect pedestrian comfort, their combined effect is defined in the City of Mississauga Urban Design Terms of Reference[1]. More specifically, the criteria are defined as a Gust Equivalent Mean (GEM) wind speed, which is the greater of the mean wind speed or the gust wind speed divided by 1.85. The wind 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.

Five pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort, which include: (i) Sitting; (ii) Standing; (iii) Walking; (iv) Uncomfortable; and (v) Dangerous. More specifically, the comfort classes, wind speed ranges, and limiting criteria are summarized as follows:

(i) **Sitting** – GEM wind speeds below 10 km/h occurring more than 80% of the time would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – GEM wind speeds below 15 km/h occurring more than 80% of the time are acceptable for activities such as standing, strolling or more vigorous activities.

(iii) **Walking** – GEM wind speeds below 20 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 criterion.

(v) **Dangerous** – Wind speeds greater than 90 km/h, occurring more than 0.1% of the time on an annual basis, 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 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 GEM wind speeds of 10 km/h were exceeded for more than 20% of the time, most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if GEM wind speeds of 20 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As most of these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established 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 |
|---|---|
| Private Entrance | Standing |
| Primary Building Access | Standing |
| Secondary Building Access | Standing / Walking |
| Public Sidewalks / Pedestrian Walkways | Walking |
| Outdoor Amenity Spaces | Sitting / Standing |
| Cafés / Patios / Benches / Gardens | Sitting / Standing |
| Transit Shelters | Standing |
| Public Parks | Sitting / Walking |
| Garage / Service Entrances | Walking |
| Vehicular Drop-Off Zones | Walking |

## 5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions for the study site is accompanied by Figures 3A through 4B (following the main text), which illustrate the seasonal wind conditions at grade level for both the future site massing (Figures 3A and 3B) and the existing site massing (Figures 4A and 4B). The colour contours indicate predicted regions of the various comfort classes. Wind conditions comfortable for sitting are represented by the colour green, standing is represented by yellow, and areas suitable for walking are represented by blue.

**Port Street East Sidewalk including Building Access Points (Figures 3A-4B, Tag A):** The sidewalk along the north side of the building, including any potential building access points, will be comfortable for sitting during the summer season, becoming suitable for standing, or better, during the winter season. The noted conditions are acceptable for the intended pedestrian uses of the spaces.

Conditions along the sidewalk upon the introduction of the proposed development will generally remain similar to the existing conditions on a seasonal basis. A small region of the Port Street East sidewalk will be somewhat windier upon the introduction of the proposed development, with conditions changing from sitting to standing. However, conditions are considered acceptable for the anticipated pedestrian uses of the area.

**Helene Street South Sidewalk and Grade-Level Parking (Figures 3A-4B, Tags B and C):** The sidewalk along the west side of the building (Tag B) and the grade-level parking areas (Tag C) will be comfortable for sitting during the summer season and for standing during the winter season. The noted conditions are acceptable for the intended pedestrian uses of the spaces.

Conditions along the sidewalk and the grade-level parking areas upon the introduction of the proposed development are similar to the existing conditions during the summer season. During the winter season, conditions are somewhat windier upon the introduction of the proposed development, with conditions across the sidewalk and parking areas changing from sitting to standing. However, conditions are considered acceptable for the anticipated pedestrian uses of the areas.

**Grade-Level Outdoor Amenity Area (Figures 3A-4B, Tag D):** The outdoor amenity area to the south of the building will be comfortable for sitting throughout the year, which is acceptable.

**St. Lawrence Park and Waterfront Trail (Figures 3A-4B, Tags E and F):** The park (Tag E) and noted trail (Tag F) to the south of the development will be comfortable for sitting during the summer season and for standing, or better, during the winter season. The noted conditions are acceptable for the intended pedestrian uses of the spaces.

Conditions across the park and waterfront trail upon the introduction of the proposed development will remain similar to the existing conditions on a seasonal basis, which are considered acceptable.

**Influence of the Proposed Development on Existing Wind Conditions beyond the Study Site:** Wind conditions over surrounding sidewalks beyond the development site, as well as at nearby building entrances, will be comfortable for their intended pedestrian uses during each seasonal period upon the introduction of the proposed development at 55 Port Street East in Mississauga.

**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 document summarizes the results of a computer-based PLW study in support of a joint OPA and ZBA application for a proposed condominium development located at 55 Port Street East in Mississauga, Ontario. This study is based on industry standard simulations using the Computational Fluid Dynamics (CFD) technique and associated data analysis procedures, City of Mississauga wind criteria, architectural drawings prepared by Giannone Petricone Associates Inc. Architects in December 2017, surrounding street layouts and contextual information, as well as recent site imagery.

A complete summary of the predicted wind conditions across the study site is presented in Section 5 of this report and illustrated in Figures 3A-4B (following the main text). Based on CFD test results, interpretation, and experience with similar developments, all grade-level areas within and surrounding the development site, including surrounding sidewalks, building access points, and the grade-level outdoor amenity area, as well as the St. Lawrence Park and Waterfront Trail, will be acceptable for the intended pedestrian uses on a seasonal and annual basis.

A comparison of existing versus future wind comfort over the study site indicates that the proposed development will have a generally neutral influence on existing grade-level wind conditions, which will remain acceptable for the anticipated pedestrian uses of the spaces.

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

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

Sincerely,

***Gradient Wind Engineering Inc.***

Nicolas Pratt

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Managing Principal

Justin Ferraro
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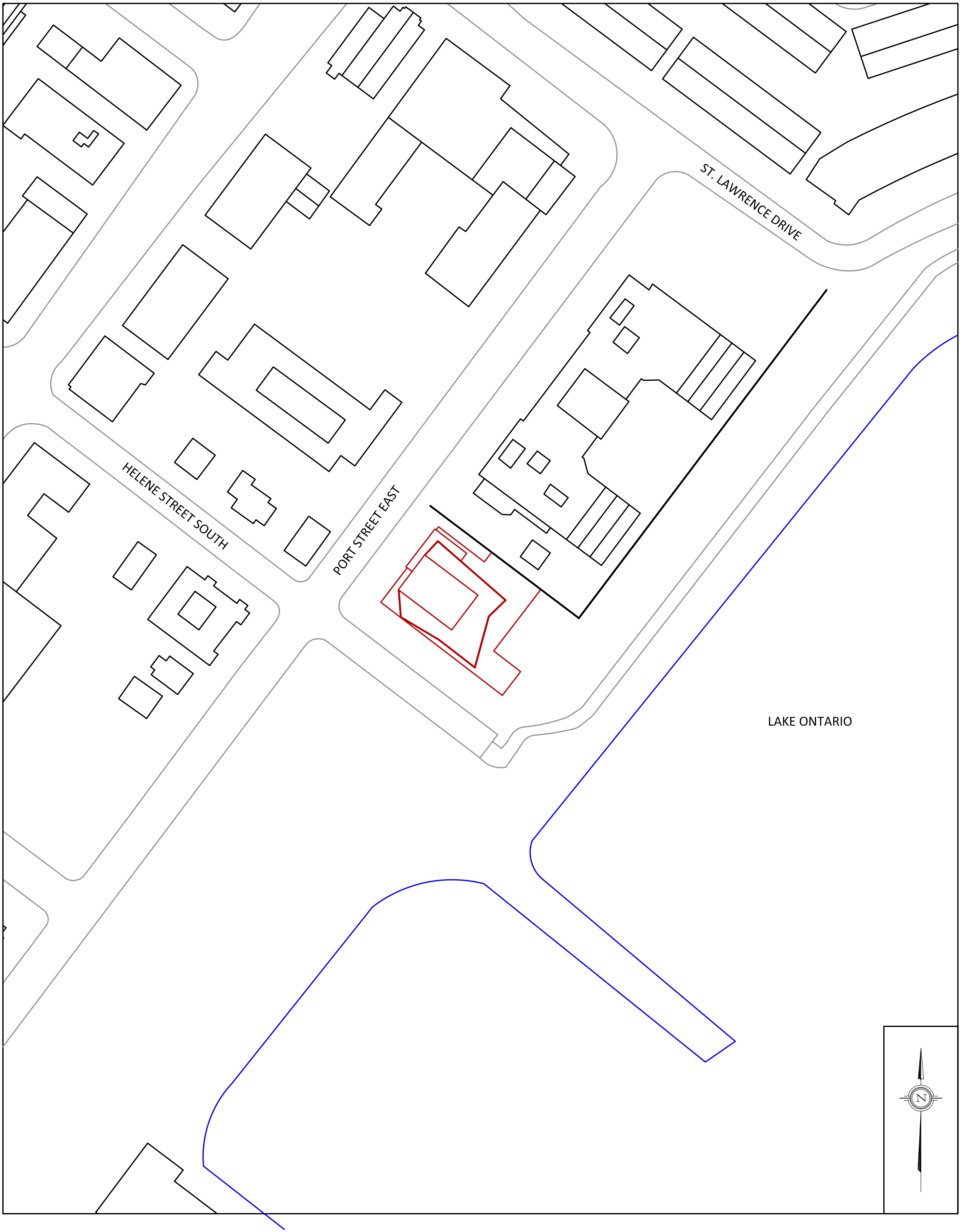

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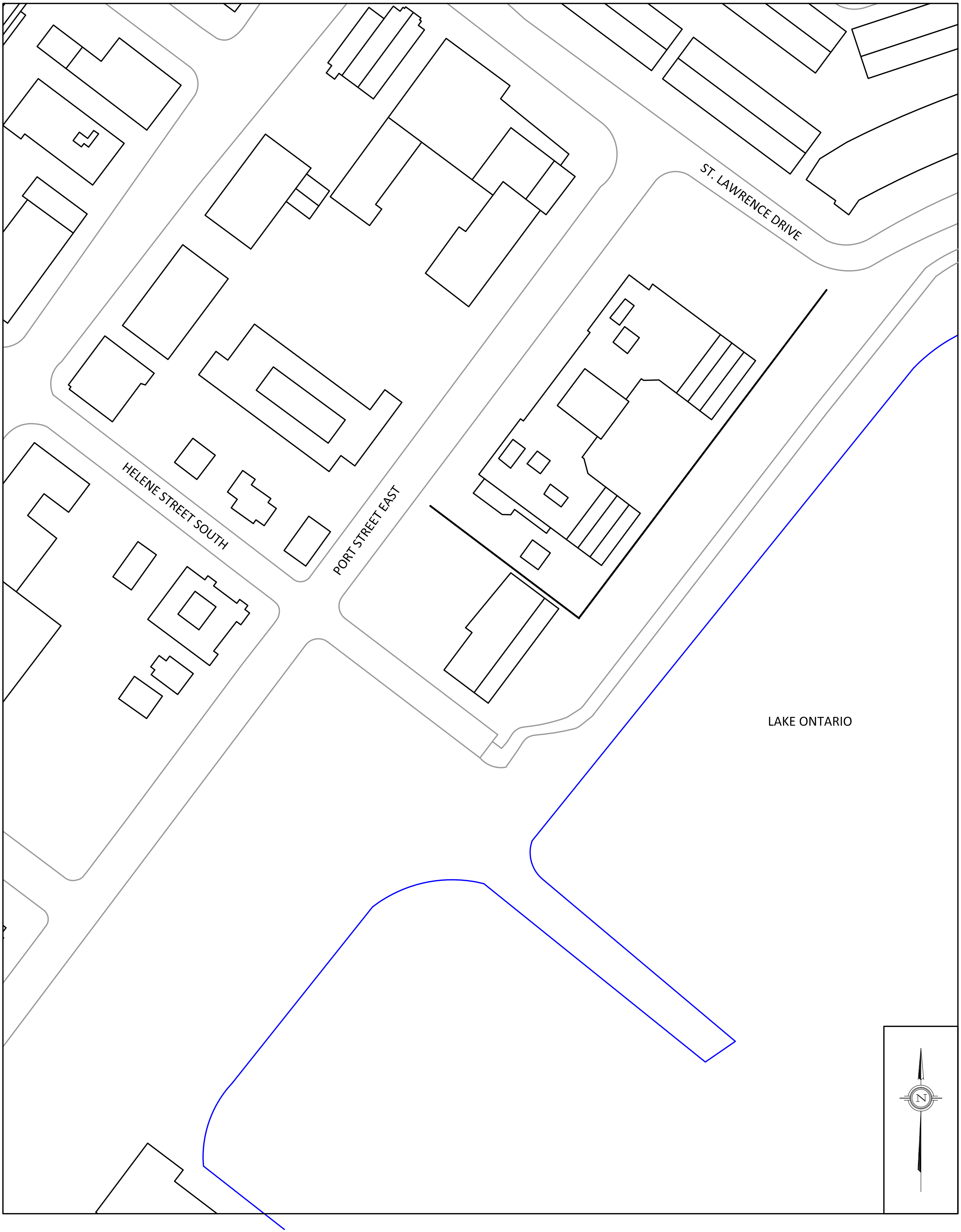
| | |
|---|---|
| PROJECT | 55 PORT STREET EAST, MISSISSAUGA<br>PEDESTRIAN LEVEL WIND STUDY |
| SCALE | 1:1600 (APPROX.) |
| DRAWING NO. | GWE17-184-PLW-1A |
| DATE | JANUARY 2, 2018 |
| DRAWN BY | B.J. |
| DESCRIPTION | FIGURE 1A:<br>PROPOSED BUILDING<br>WITH SURROUNDING CONTEXT |



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| | |
|---|---|
| PROJECT | 55 PORT STREET EAST, MISSISSAUGA<br>PEDESTRIAN LEVEL WIND STUDY |
| SCALE | 1:1600 (APPROX.) |
| DRAWING NO. | GWE17-184-PLW-1B |
| DATE | JANUARY 2, 2018 |
| DRAWN BY | B.J. |
| DESCRIPTION | FIGURE 1B:<br>EXISTING BUILDING<br>WITH SURROUNDING CONTEXT |

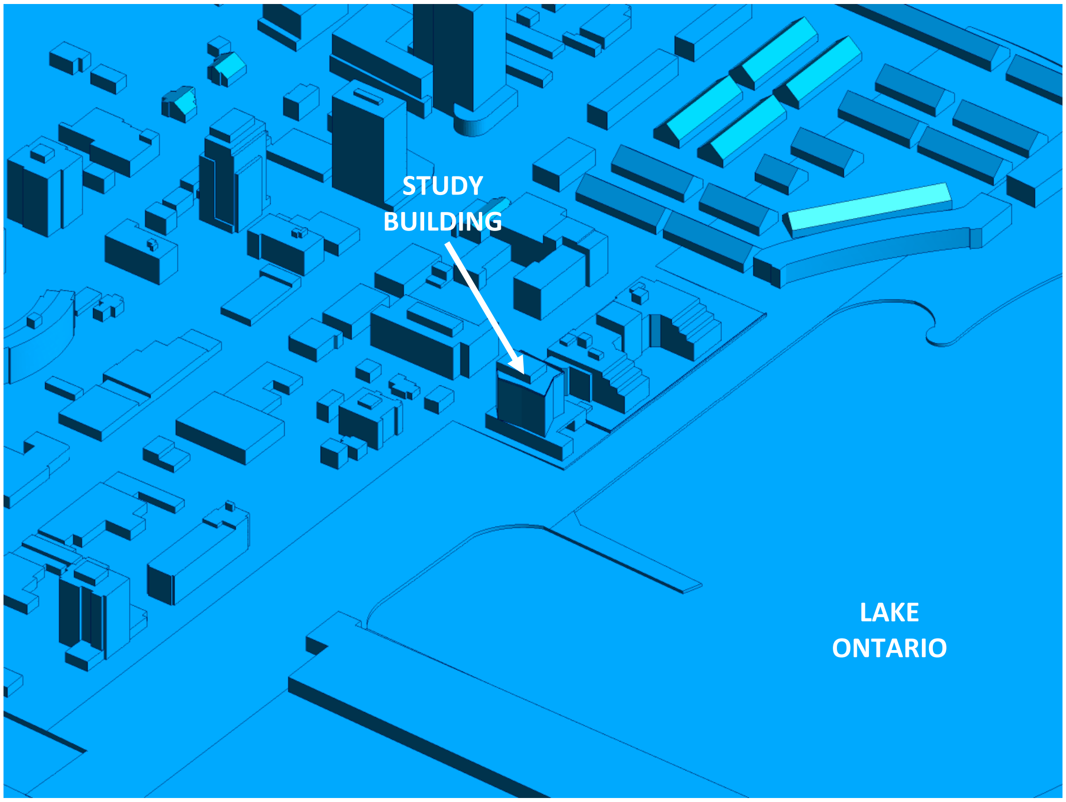


FIGURE 2A: COMPUTATIONAL MODEL FOR PROPOSED CONDITIONS, SOUTH PERSPECTIVE

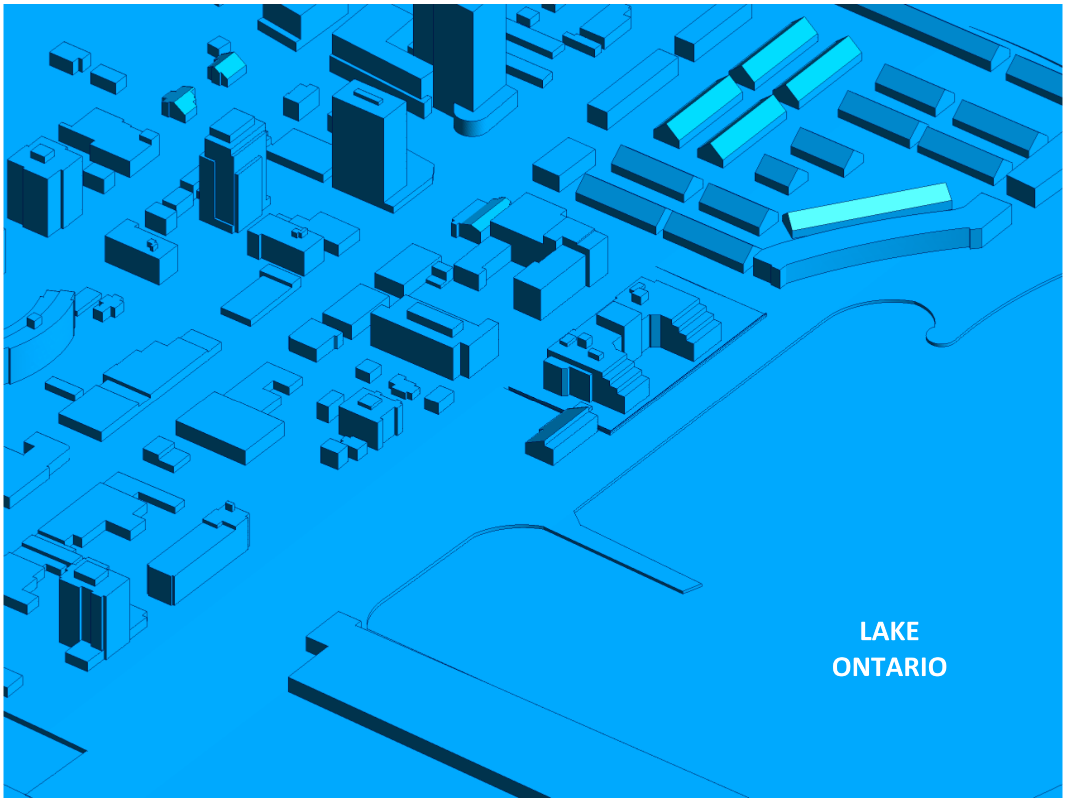
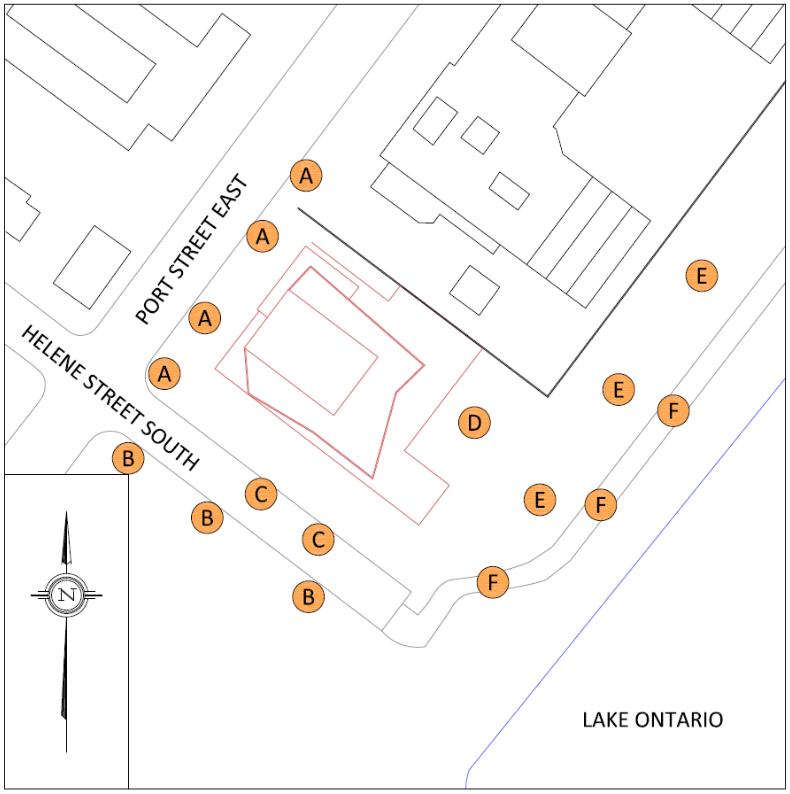


FIGURE 2B: COMPUTATIONAL MODEL FOR EXISTING CONDITIONS, SOUTH PERSPECTIVE

FIGURE 3A: SUMMER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS FOR PROPOSED DEVELOPMENT



55 PORT STREET EAST - REFERENCE MARKER LOCATIONS

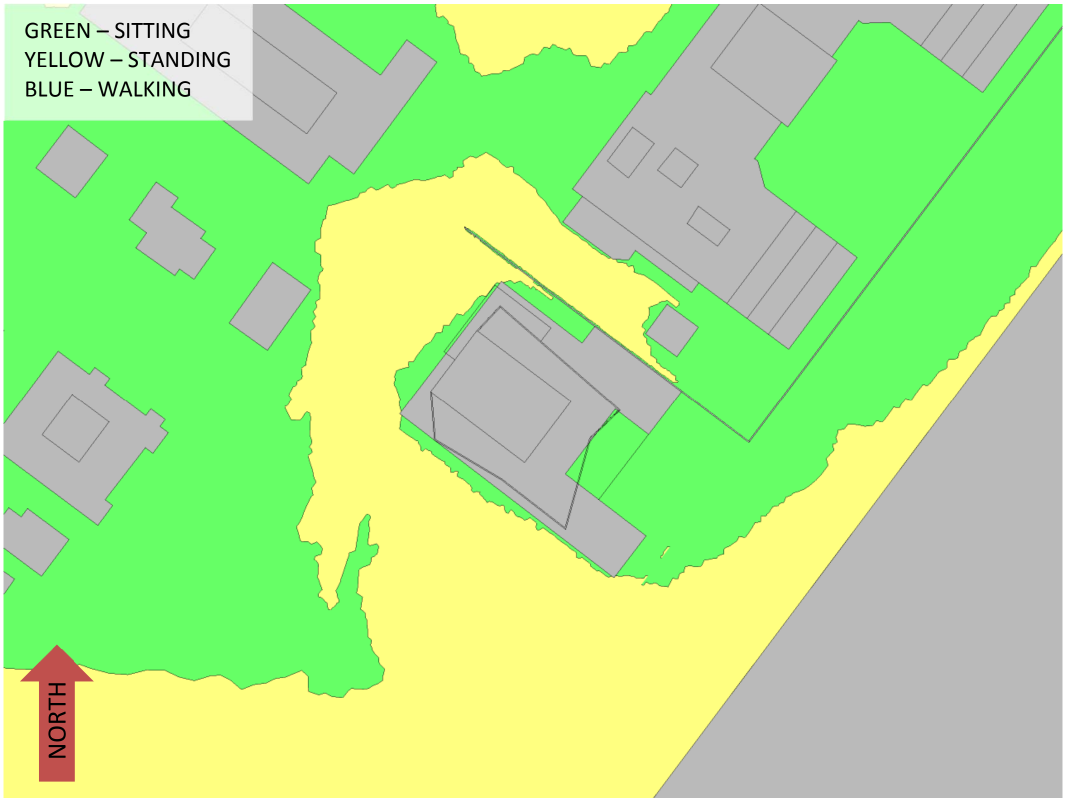
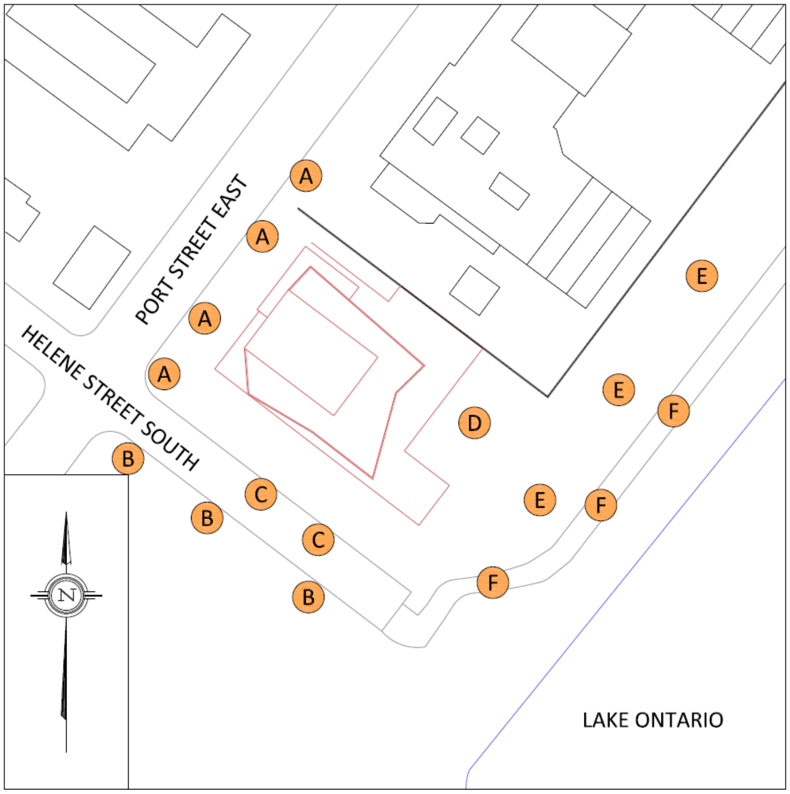
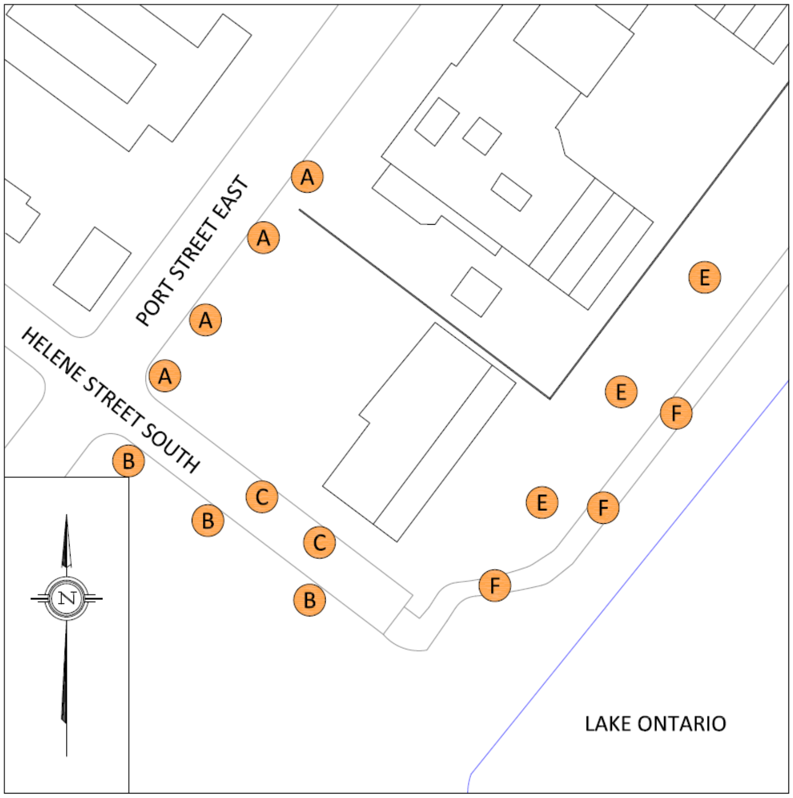


**FIGURE 3B: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS FOR PROPOSED DEVELOPMENT**



**55 PORT STREET EAST - REFERENCE MARKER LOCATIONS**

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



55 PORT STREET EAST - REFERENCE MARKER LOCATIONS

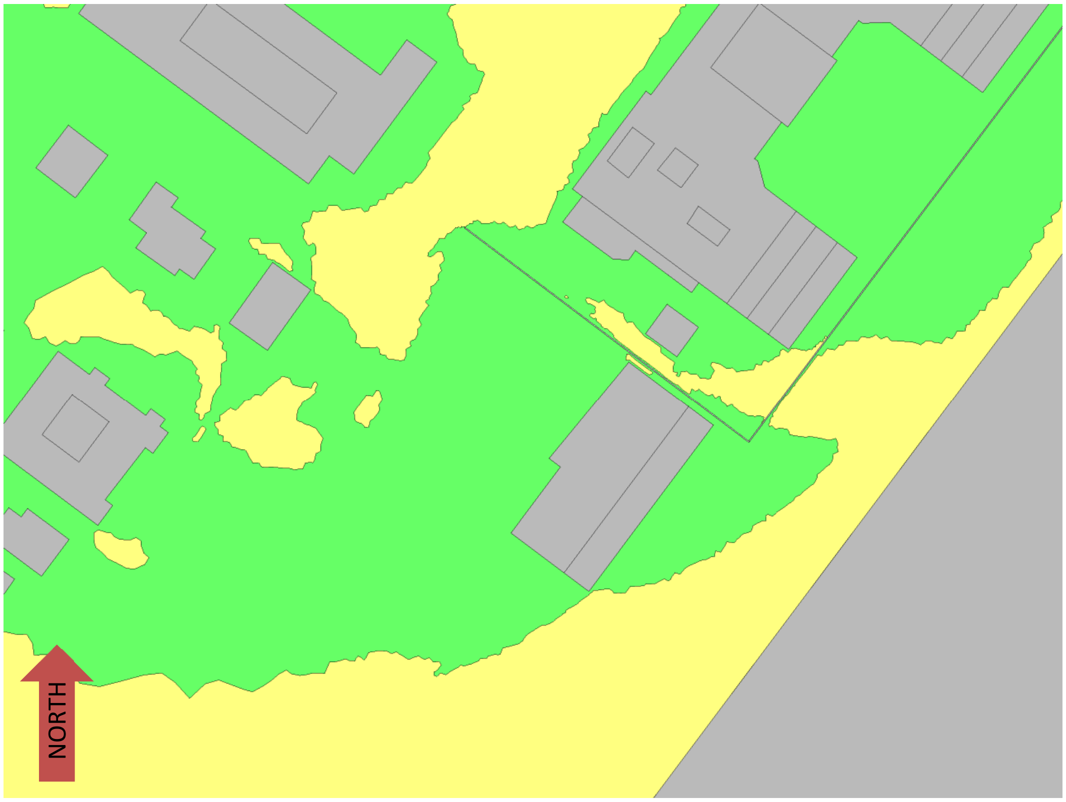
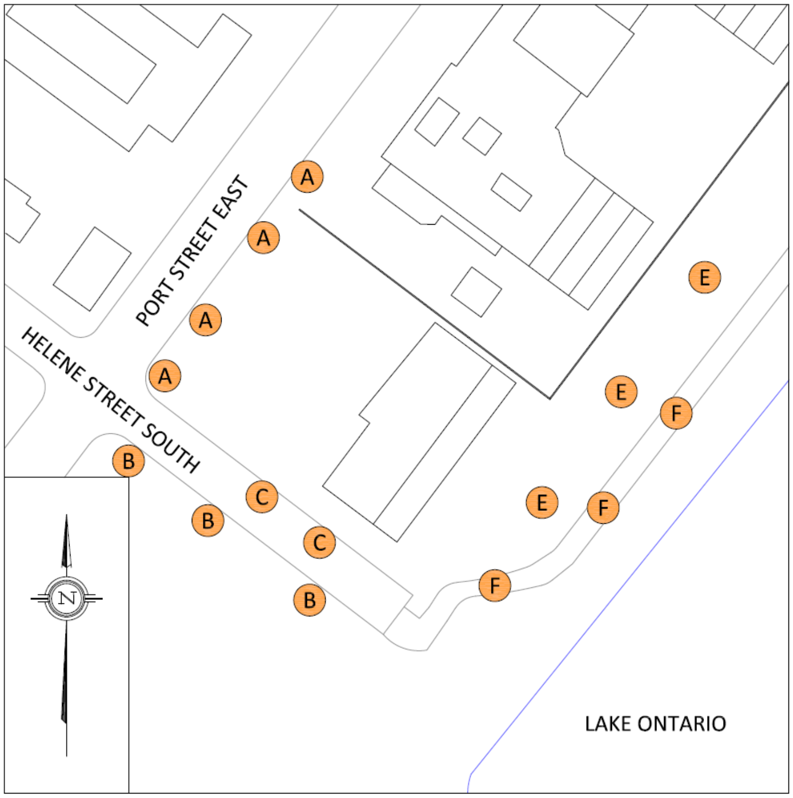


FIGURE 4B: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS FOR EXISTING CONDITIONS



55 PORT STREET EAST - REFERENCE MARKER LOCATIONS

# 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 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.

Where; $U$ = mean wind speed, $U_g$ = gradient wind speed, $Z$ = height above ground, $Z_g$ = depth of the boundary layer (gradient height) and $\alpha$ is the power law exponent.

Figure A1 plots three such profiles for the open country, suburban and urban exposures. The exponent $\alpha$ varies according to the type of terrain; $\alpha$ = 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 center-line axis.

## REFERENCES

1. Teunissen, H.W., '*Characteristics Of The Mean Wind And Turbulence In The Planetary Boundary Layer*', Institute For Aerospace Studies, University Of Toronto, UTIAS # 32, Oct. 1970

2. Flay, R.G., Stevenson, D.C., '*Integral Length Scales In An Atmospheric Boundary Layer Near The Ground*', 9th Australian Fluid Mechanics Conference, Auckland, Dec. 1966

3. ESDU, '*Characteristics of Atmospheric Turbulence Near the Ground*', 74030

4. Bradley, E.F., Coppin, P.A., Katen, P.C., '*Turbulent Wind Structure Above Very Rugged Terrain*', 9th Australian Fluid Mechanics Conference, Auckland, Dec. 1966

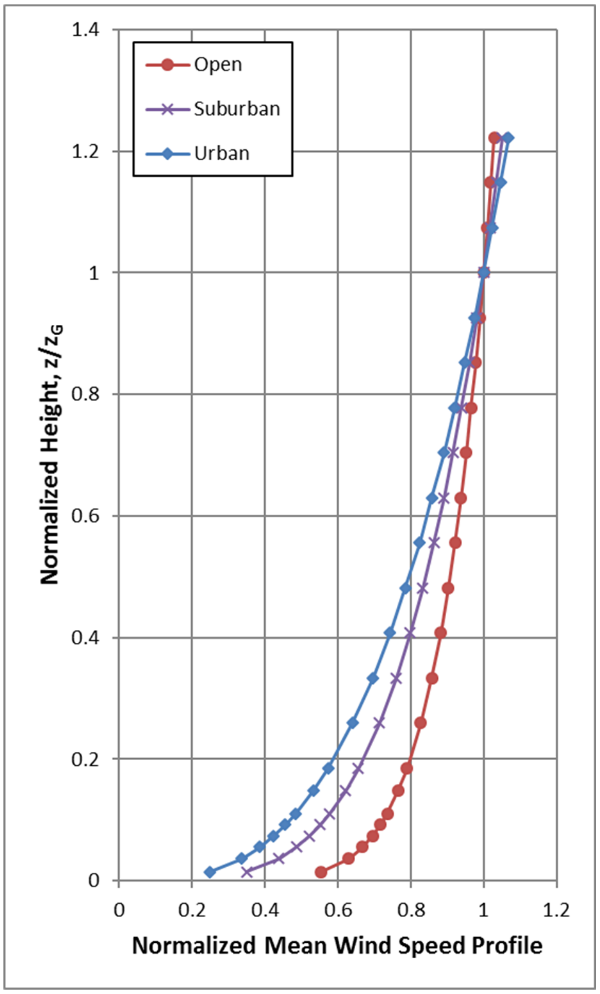


**Figure A1: Mean Wind Speed Profiles**

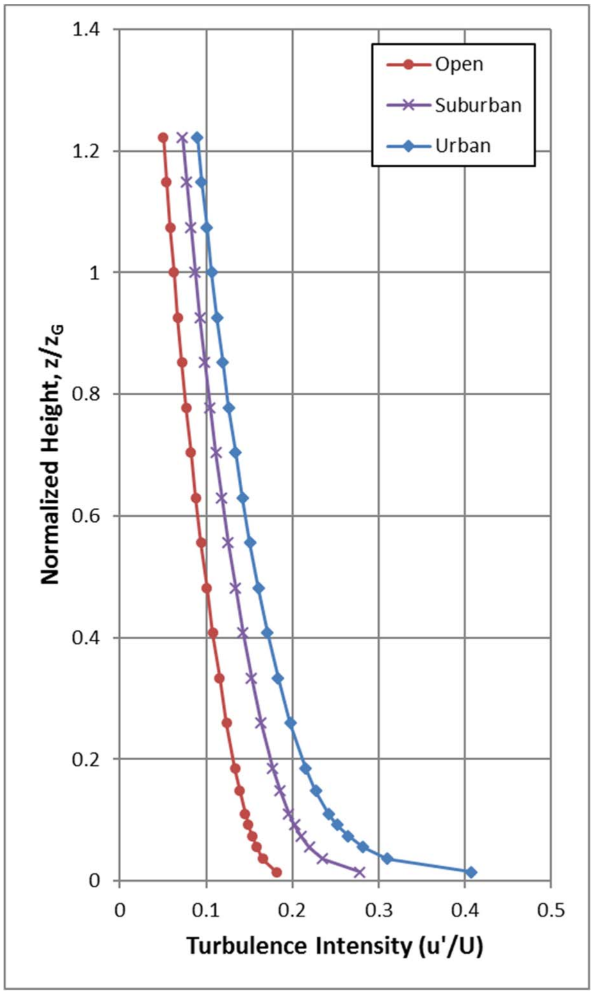


**Figure A2: Turbulence Intensity Profiles**

# 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 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; **$\theta$** 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). **$A_\theta$** is the fraction of time wind blows from a 10° sector centered on **$\theta$**.

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

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

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

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 **$C_\theta$** and **$K_\theta$** 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.

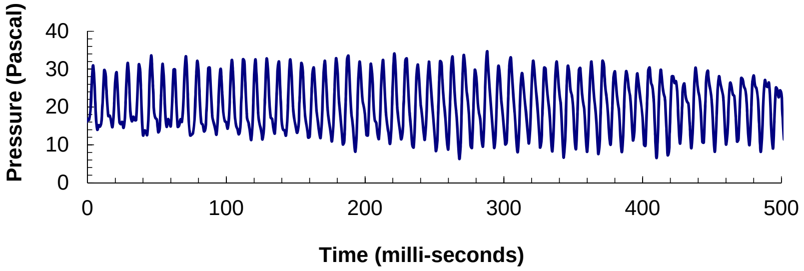


**FIGURE B: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR**

## REFERENCES

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