Pedestrian Level Wind Study

Château Laurier Hotel Addition

Ottawa, Ontario

REPORT: GWE16-068-PLW

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EXECUTIVE SUMMARY

This report describes a Pedestrian Level Wind (PLW) study for the proposed hotel addition serving the Château Laurier, which is located at 1 Rideau Street in Ottawa, 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 subsequent report.

A complete summary of the predicted wind conditions across the study site is presented in Section 5 of this report. Based on CFD test results, interpretation, experience with similar developments, all grade-level areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal and annual basis. More specifically, surrounding sidewalks and building access points will continue to experience acceptable wind conditions throughout the year. Of particular importance, although wind conditions along Mackenzie Avenue are moderately windy they remain acceptable for the intended uses of the area.

Regarding the rooftop patio serving the planned 3-storey podium, we recommend incorporating a 2.4 m tall wind barrier along the north perimeter of the roof to ensure the terrace achieves conditions suitable for sitting specifically during the summer season when demand is anticipated to be high. Wind comfort predictions incorporating this mitigating feature achieve acceptable conditions for sitting during the summer and shoulder months during spring and autumn.

Excluding anomalous localized storm events such as tornadoes and downbursts, no areas over the study site were found to be uncomfortable or unsafe.

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1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by Larco Investments Ltd. to undertake a Pedestrian Level Wind (PLW) study for the Château Laurier Hotel Addition, which is located at 1 Rideau Street in Ottawa, Ontario. Our mandate in this study, as outlined in GWE proposal #16-100P, dated June 6, 2016, is to investigate pedestrian wind comfort and safety within and surrounding the development site.

Our work is based on industry standard Computational Fluid Dynamic (CFD) simulations and data analysis procedures, architectural drawings provided by architectsAlliance in September and November of 2016, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery.

2. TERMS OF REFERENCE

The focus of this PLW study is the proposed expansion of the Château Laurier, which is located at 1 Rideau Street in Ottawa, Ontario. The redevelopment will constitute substituting the existing parking garage to the north for a hotel addition. Surrounding the site are Major's Hill Park to the north, Mackenzie Avenue to the east, Rideau Street to the south, and the national historic Ottawa Locks / Rideau Canal to the west.

The proposed development comprises the addition of two buildings connected by a 3-storey podium with a rooftop terrace, a central courtyard at grade situated between the addition and the existing hotel, and five levels of below-grade parking including a dual loading bay with access from Mackenzie Avenue. The proposed buildings adjacent to the podium are identified as the 'West Wing' and 'East Wing' rising twelve (12) floors and eleven (11) floors respectively above grade. The upper floors of the West and East Wings are set-back from their perimeters for compatibility with the existing roofscape silhouette characterizing the existing Château Laurier. Extensive green roof areas are also planned for the upper roof surfaces serving the West and East Wings. A green roof is also planned for the south-most roof area serving the existing hotel, while a landscaped amenity area is planned for the north-most roof area.

Of particular importance for wind comfort, the ground floor plan includes a court plaza fronting onto Mackenzie Avenue, designated sitting areas serving the suites along the north side, as well as canal promenades and upper and lower terraces along the west side of the development.

Wind exposures affecting the site include the open fetch of green space and the Ottawa River from west to north, and low-density urban exposures for remaining wind directions. Figure 1 illustrates the study site and surrounding context, while Figures 2A and 2B illustrate the computational model used to conduct the study. It is noteworthy that in wind engineering wind direction refers to wind origin, so that a north wind blows from north to south.

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 Ottawa 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 Ottawa's 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.

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[1] City of Ottawa Terms of Reference: Wind Analysis

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 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 16 wind directions. The CFD simulation model was centered on the study building, complete with surrounding massing within a diameter of approximately 400 metres (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 roof 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.

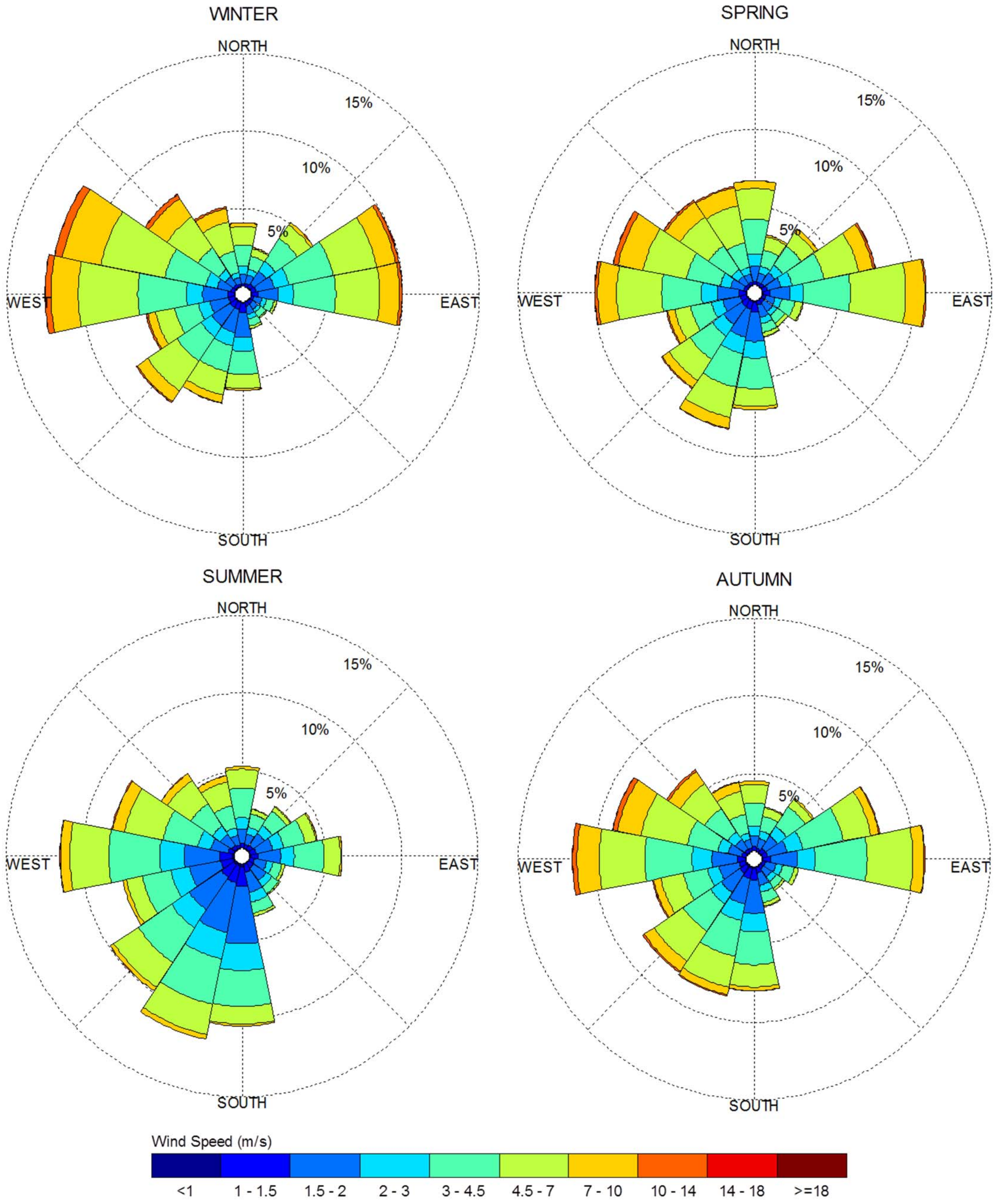
4.3 Meteorological Data Analysis

A statistical model for winds in Ottawa was developed from approximately 40-years of hourly meteorological wind data recorded at Macdonald-Cartier 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 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 metres per second (m/s). 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 10 m/s. The directional preference and relative magnitude of wind speed changes somewhat from season to season.

By convention 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 MACDONALD-CARTIER INTERNATIONAL AIRPORT, OTTAWA, ONTARIO



Notes:

1. Radial distances indicate percentage of time of wind events.
2. Mean hourly wind speeds in metres per second (m/s) measured at 10 m above the ground.
3. Apply a factor of 3.6 to convert m/s to km/h (e.g., 10 m/s is equivalent to 36 km/h).

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

(i) **Sitting:** Mean wind speeds less than or equal to 10 kilometres per hour (km/h), occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 14 km/h.

(ii) **Standing:** Mean wind speeds less than or equal to 14 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 20 km/h.

(iii) **Strolling:** Mean wind speeds less than or equal to 17 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 25 km/h.

(iv) **Walking:** Mean wind speeds less than or equal to 20 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 30 km/h.

(v) **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 guideline.

(vi) **Dangerous:** Gust equivalent mean wind speeds greater than or equal to 90 km/h, occurring more often 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.

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 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	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 20% 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
Major Building Entrances	Standing
Secondary Building Access Points	Strolling/Walking
Primary Public Sidewalks	Strolling/Walking
Secondary Public Sidewalks / Bicycle Paths	Walking
Outdoor Amenity Spaces	Sitting
Cafés / Patios / Benches / Gardens	Sitting
Transit Shelters	Standing
Public Parks / Plazas	Sitting/Standing
Garage / Service Entrances	Walking
Parking Lots	Walking
Vehicular Drop-Off Zones	Strolling/Walking

5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions for the study site is accompanied by Figures 3A through 6B (following the main text), which illustrate the seasonal wind conditions at both grade and roof levels. 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, strolling by orange, while conditions suitable for walking are represented by blue. The colour magenta indicates wind conditions considered uncomfortable for walking.

Rideau Street Sidewalk + Existing Lobby Entrance (Tags A and B): The large majority of the sidewalk area along Rideau Street, adjacent to the south side of the building (Tag A), will be comfortable for standing, or better, throughout the year, while conditions to the immediate southwest of the hotel will be mostly suitable for strolling during the three colder seasons. The main lobby entrance (Tag B) will be comfortable for sitting throughout the year. The noted conditions are acceptable for the intended uses of the spaces.

Mackenzie Avenue Sidewalk + Existing Secondary Entrances (Tags C and D): The sidewalk area along the east side of the building (Tag C) will be comfortable for strolling, or better, throughout the year, except during the winter and early spring seasons when this region will be comfortable for walking, or better. Conditions in close proximity to the two existing entrances fronting onto Mackenzie Avenue (Tag D), which are both equipped with vestibules, are predicted to be comfortable for strolling, or better, throughout the year. The noted conditions are acceptable for the intended uses of the spaces.

Court Plaza (Tag E): The planned plaza will be suitable for sitting during the summer and autumn seasons, and mostly suitable for sitting during the remaining colder seasons. The noted wind conditions are acceptable for plazas.

East Wing Lobby Entrance (Tag F): Wind conditions in the vicinity of the main entrance will be suitable for sitting during the summer and autumn seasons, becoming suitable for standing, or better, during the spring and winter seasons. The noted wind conditions are acceptable for entrances.

North Side Sitting Areas (Tag G): The sitting areas serving the suites along the north side of the development and fronting onto Major’s Hill Park will be suitable for sitting during the summer season, and mostly suitable for sitting during the autumn season with only small areas adjacent to the West Wing becoming suitable for standing. Conditions during the colder seasons of spring and winter will be largely suitable for standing. Since the typical use period is widely accepted as occurring from late spring through early autumn, the noted conditions are considered acceptable.

West Side Canal Promenade/Lower Terrace (Tag H): The existing pedestrian area is predicted to be suitable for sitting during the summer season, becoming suitable for standing during the remaining three colder seasons. The planned hotel addition does not influence pedestrian wind comfort within this area which remains acceptable.

West Side Canal Promenade/Upper Terrace (Tag I): The existing pedestrian area is predicted to be mostly suitable for standing throughout the year, becoming calmer and suitable for sitting closer to the building. Although conditions become windier at greater distances from the building, wind comfort remains suitable for strolling, or better, at all times during the year. Regarding the north end of the existing upper terrace, both the geometry and massing of the West Wing benefits pedestrian comfort in this area as it acts to reduce wind flow and therefore slightly improves wind comfort.

Amenity Green Roof Area serving Existing Hotel (Tag J): The existing roof area is protected from the statistically prominent winds by the new massing. As such, wind comfort within the north end will be suitable for standing during the summer and autumn seasons, becoming mostly suitable for standing during the spring season. Wind comfort during the winter season is suitable for strolling over approximately half the area and standing over the remaining half.

Courtyard (Tag K): The central courtyard at grade, which is situated between the new addition and the existing hotel, is predicted to be suitable for sitting during the summer season. Conditions during the spring season are largely suitable for sitting with a smaller central area suitable for standing. Wind conditions during the autumn and winter seasons are similar to those predicted to occur during the spring season but with smaller and larger areas suitable for standing, respectively.

Rooftop Terrace atop 3-Storey Podium (Tag L): The north perimeter of the terrace includes a 2.4 m tall wind barrier, which protects the area from strong northwest winds. More specifically, conditions with the barrier are suitable for sitting during the summer season with only a small region closest to the south perimeter suitable for standing. Conditions during the remaining colder seasons become increasingly suitable for standing between the autumn, spring, and winter seasons. Additionally, strolling conditions are predicted to impact the south area of the terrace during the winter season. As a result, we recommend maintaining a 2.4 m tall wind barrier to ensure the terrace achieves the noted acceptable conditions.

Influence of the Proposed Development on Existing Wind Conditions: The introduction of the proposed hotel addition is expected to moderately influence pedestrian wind comfort over neighbouring areas at grade. However, although moderate changes to wind speeds may occur beyond the study site upon introduction of the proposed development, nearby building entrances, sidewalks, and other pedestrian areas will continue to experience wind conditions similar to those that presently exist without the proposed building in place.

Of particular importance and 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 unsafe.

6. SUMMARY AND RECOMMENDATIONS

This document summarizes the results of a pedestrian level wind study undertaken to assess wind comfort and safety conditions for the proposed expansion of Château Laurier, which is located at 1 Rideau Street in Ottawa, Ontario. This work is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by architectsAlliance in September and November of 2016, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery.

Based on CFD test results, interpretation, experience with similar developments, all grade-level areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal and annual basis. More specifically, surrounding sidewalks and building access points will continue to experience acceptable wind conditions throughout the year. Of particular importance, although wind conditions along Mackenzie Avenue are moderately windy they remain acceptable for the intended uses of the area.

Regarding the rooftop patio serving the planned 3-storey podium, we recommend incorporating a 2.4 m tall wind barrier along the north perimeter of the roof to ensure the terrace achieves conditions suitable for sitting specifically during the summer season when demand is anticipated to be high. Wind comfort predictions incorporating this mitigating feature achieve acceptable conditions for sitting during the summer and shoulder months of spring and autumn.

Excluding anomalous localized storm events such as tornadoes and downbursts, no areas over the study site were found to be uncomfortable or unsafe.

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

Sincerely,

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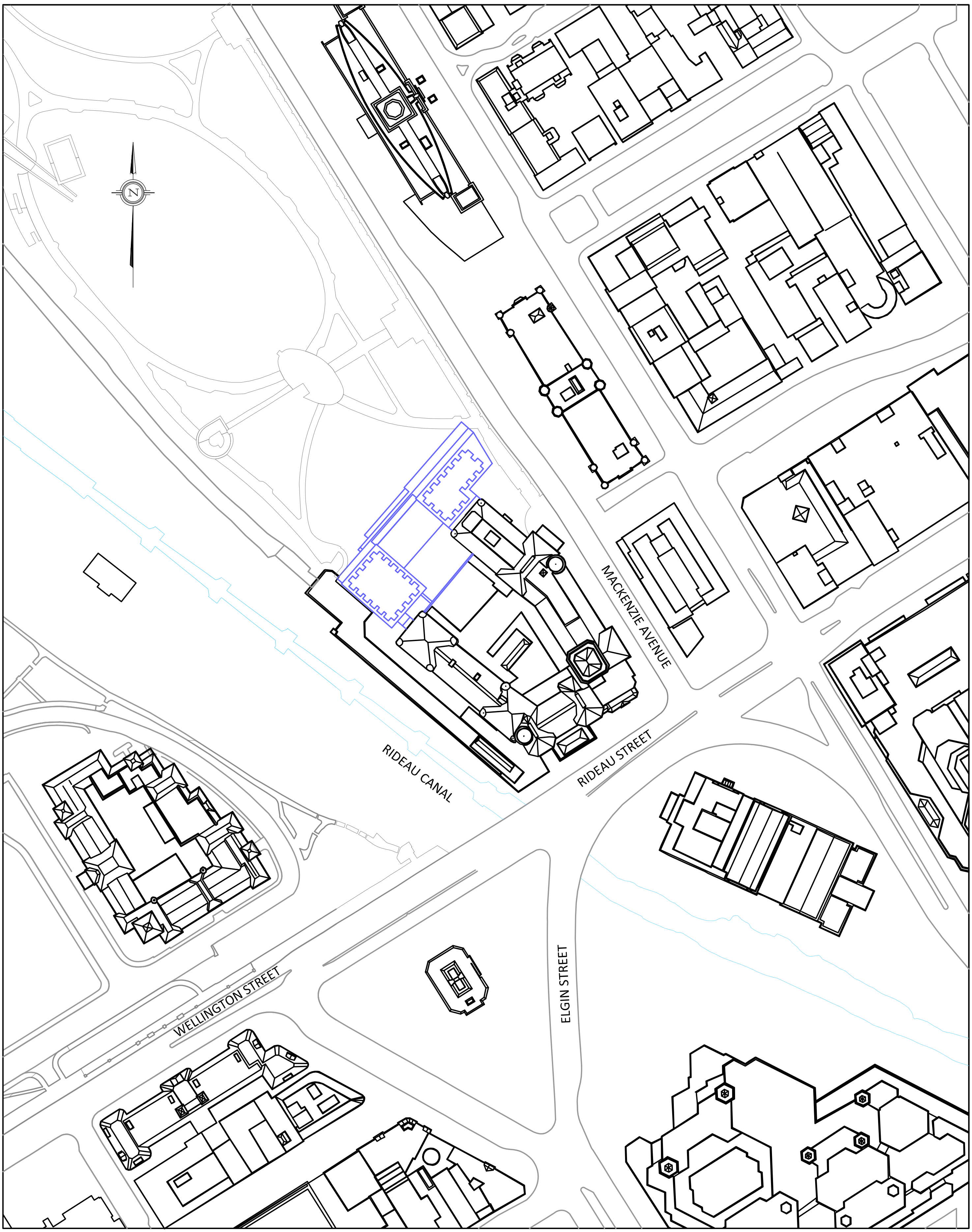

GRADIENT WIND
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PROJECT	CHATEAU LAURIER HOTEL ADDITION, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:2500 (APPROX.)	DRAWING NO.	GWE16-068-PLW-1
DATE	DECEMBER 9, 2016	DRAWN BY	B.J.

DESCRIPTION

FIGURE 1:
SITE PLAN AND SURROUNDING CONTEXT

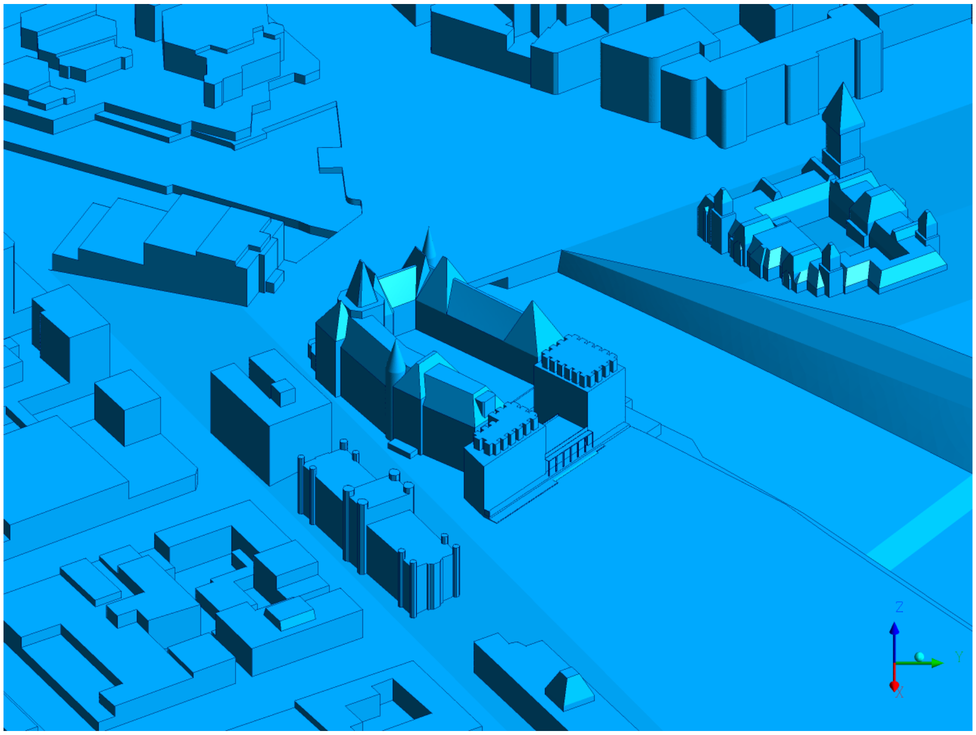

FIGURE 2A: COMPUTATIONAL MODEL, NORTHEAST PERSPECTIVE

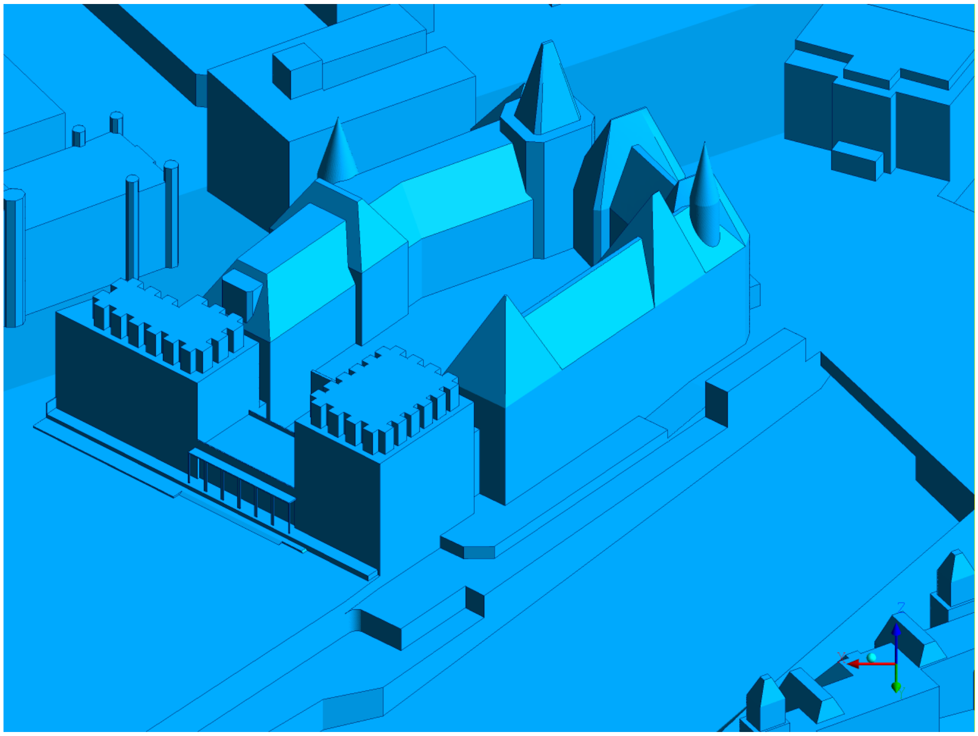

FIGURE 2B: COMPUTATIONAL MODEL, NORTHWEST PERSPECTIVE

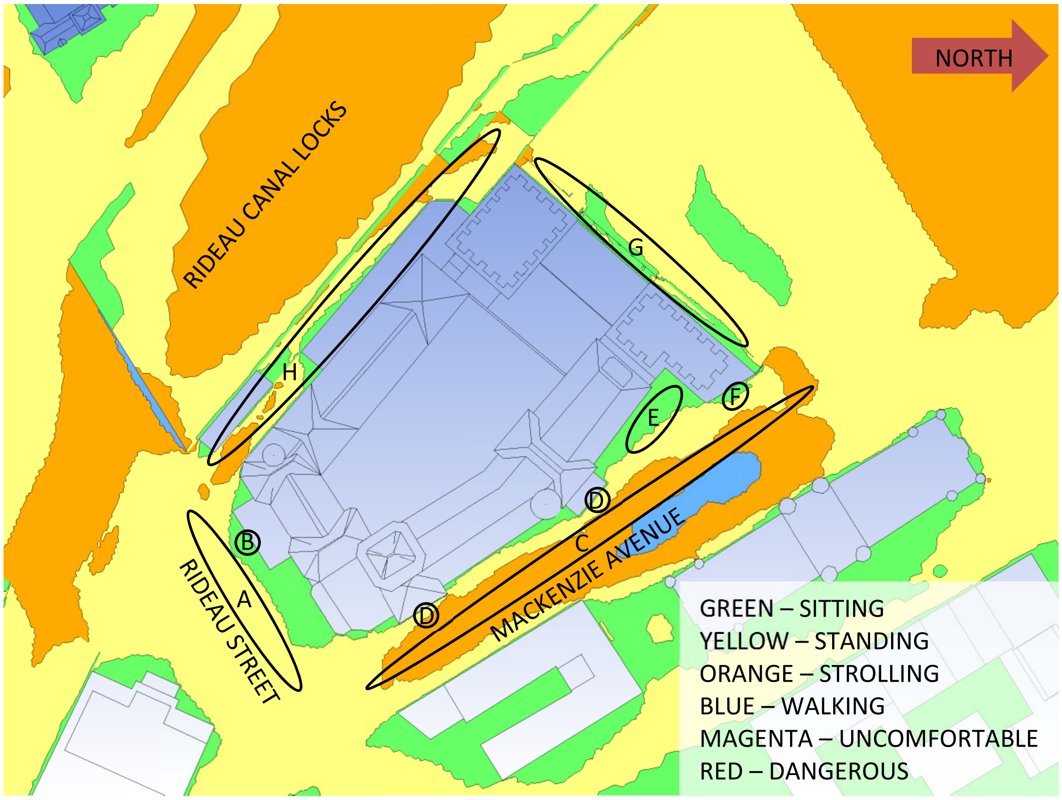

FIGURE 3A: SPRING – GRADE LEVEL PEDESTRIAN WIND CONDITIONS

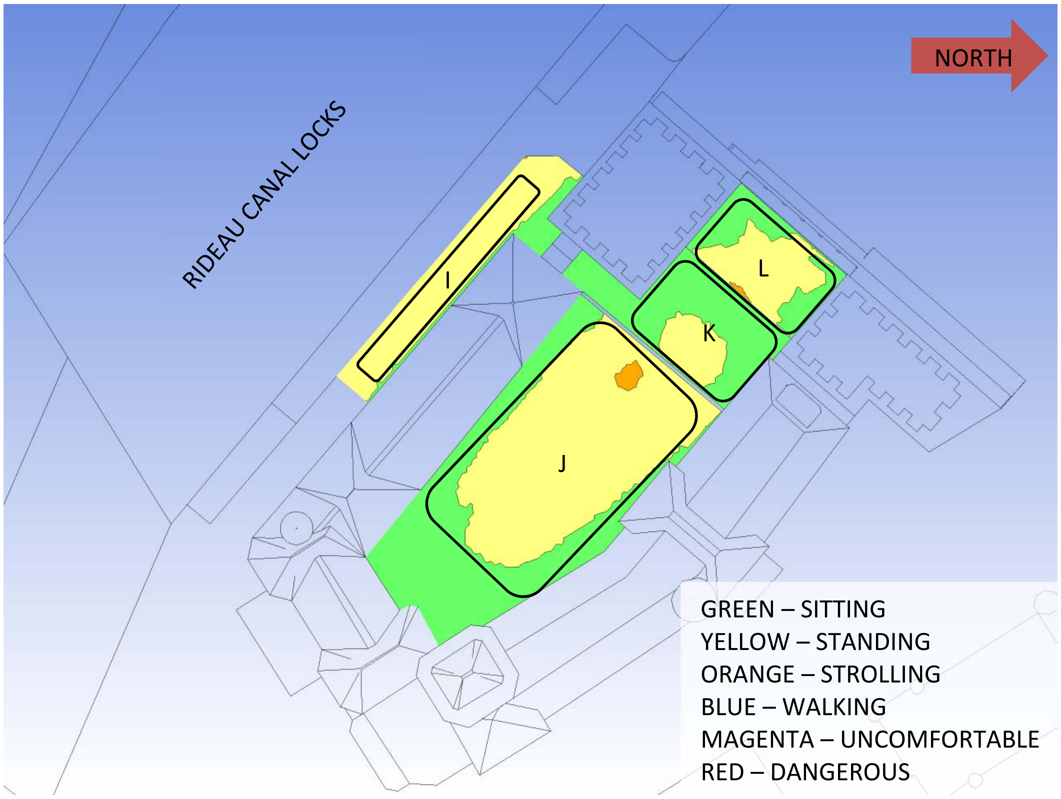

FIGURE 3B: SPRING –ROOF LEVEL PEDESTRIAN WIND CONDITIONS

FIGURE 4A: SUMMER – GRADE LEVEL PEDESTRIAN WIND CONDITIONS

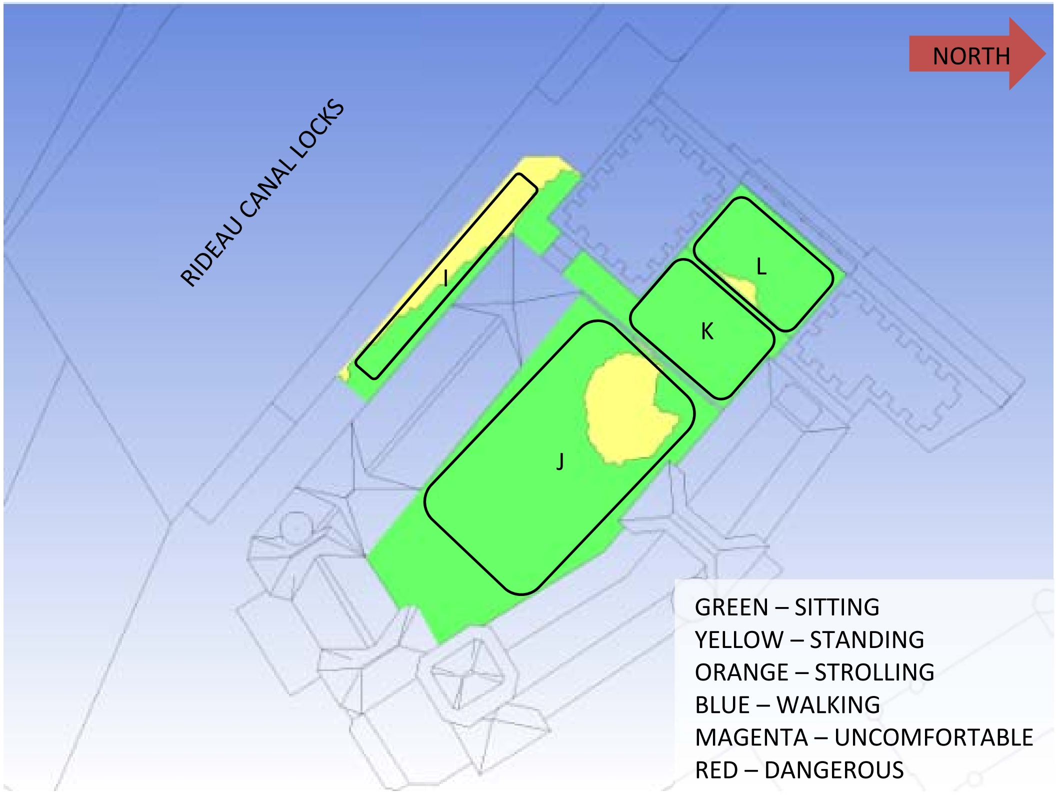

FIGURE 4B: SUMMER –ROOF LEVEL PEDESTRIAN WIND CONDITIONS

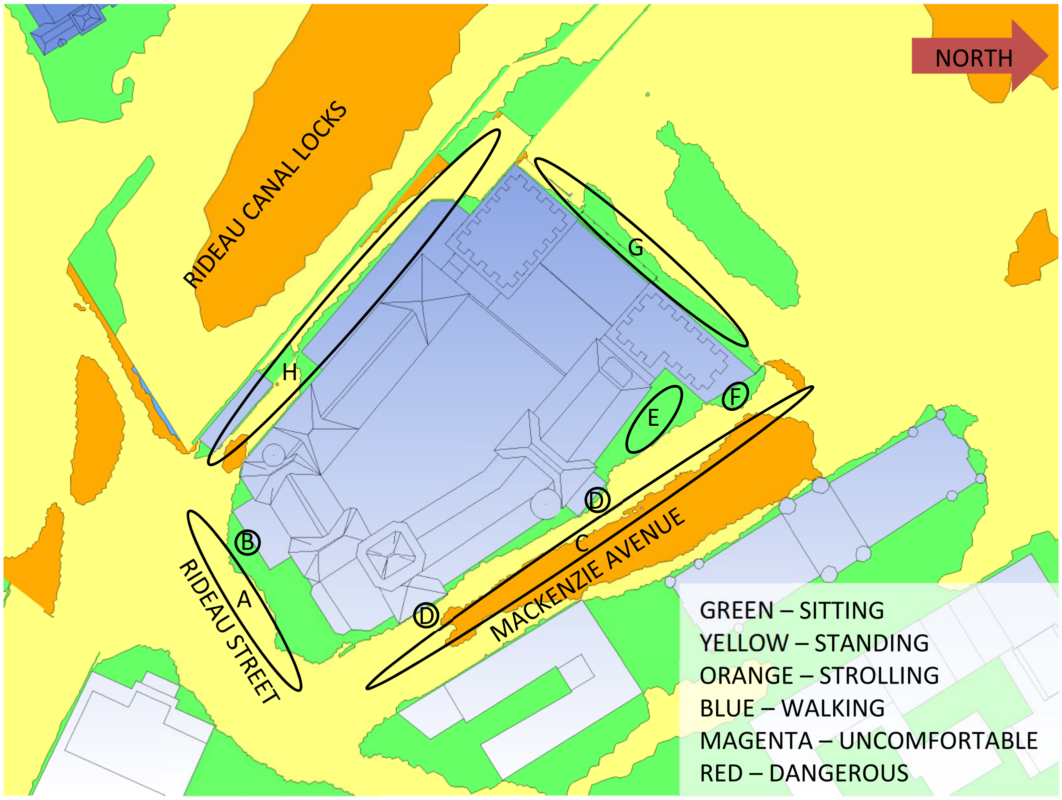

FIGURE 5A: AUTUMN – GRADE LEVEL PEDESTRIAN WIND CONDITIONS

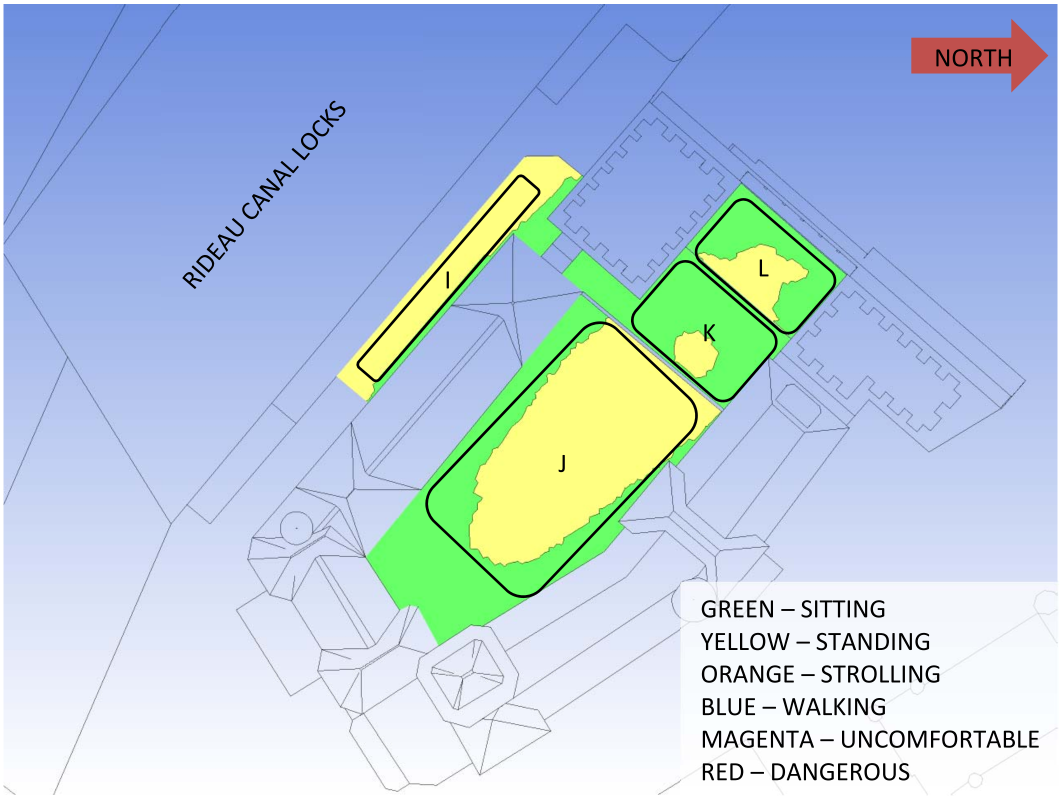

FIGURE 5B: AUTUMN –ROOF LEVEL PEDESTRIAN WIND CONDITIONS

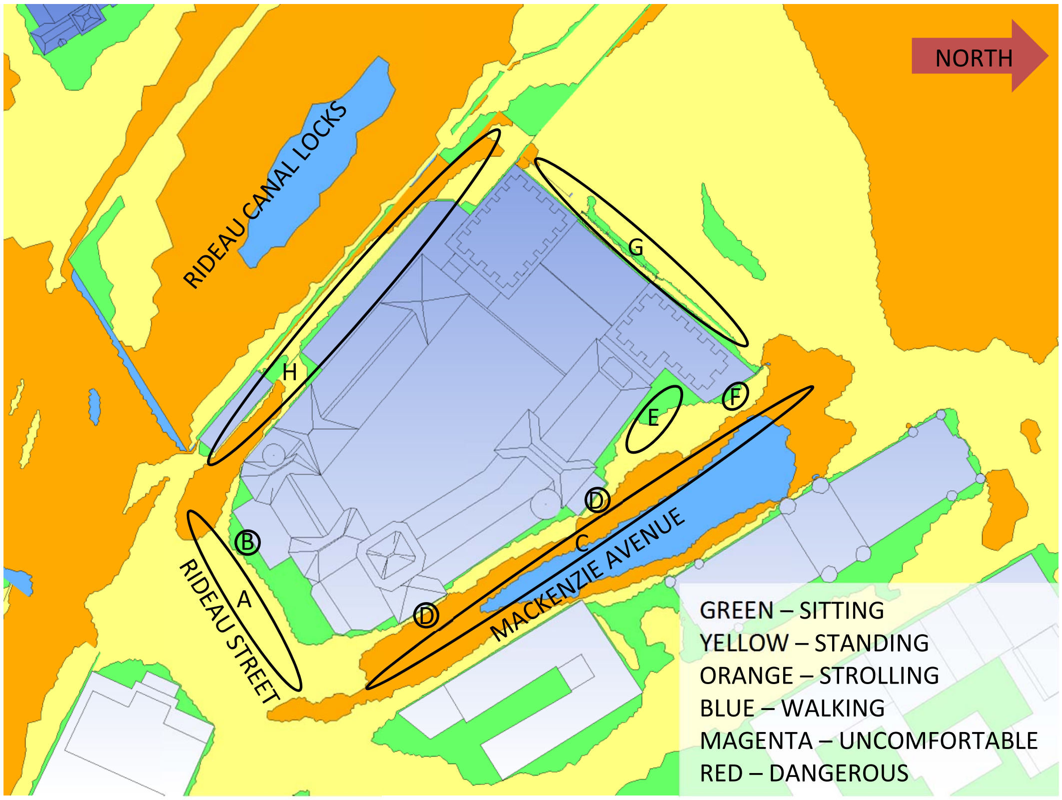

FIGURE 6A: WINTER – GRADE LEVEL PEDESTRIAN WIND CONDITIONS

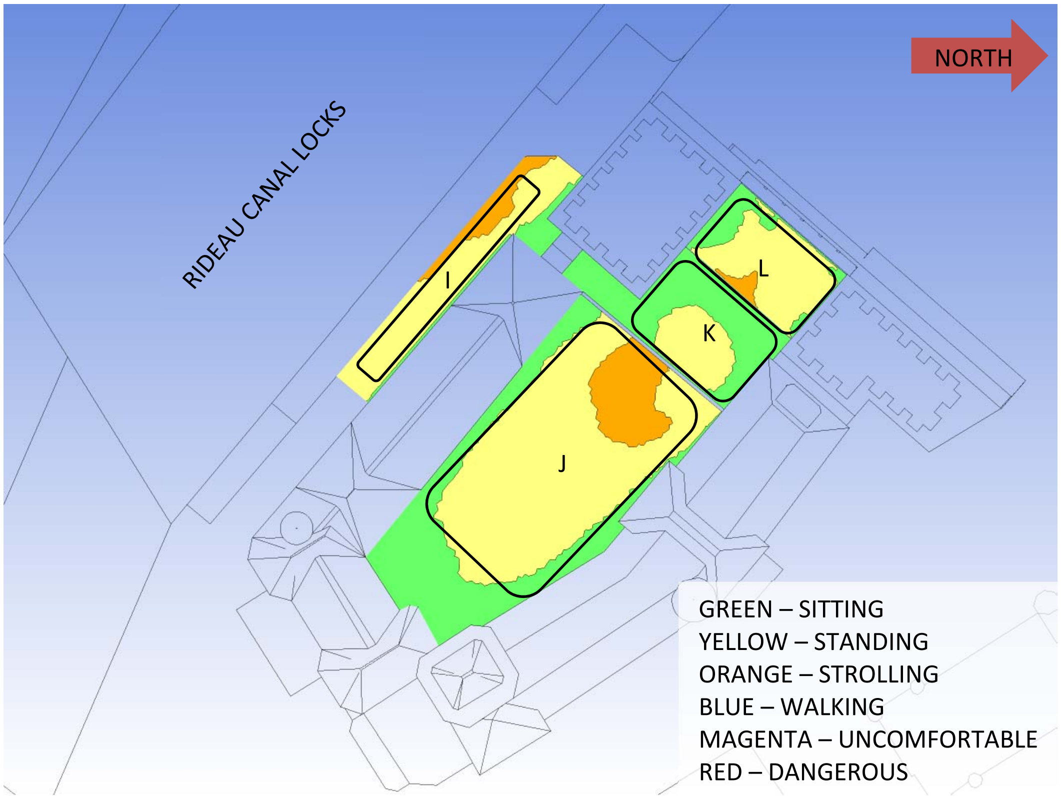

FIGURE 6B: WINTER –ROOF LEVEL PEDESTRIAN WIND CONDITIONS

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 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 center-line axis.

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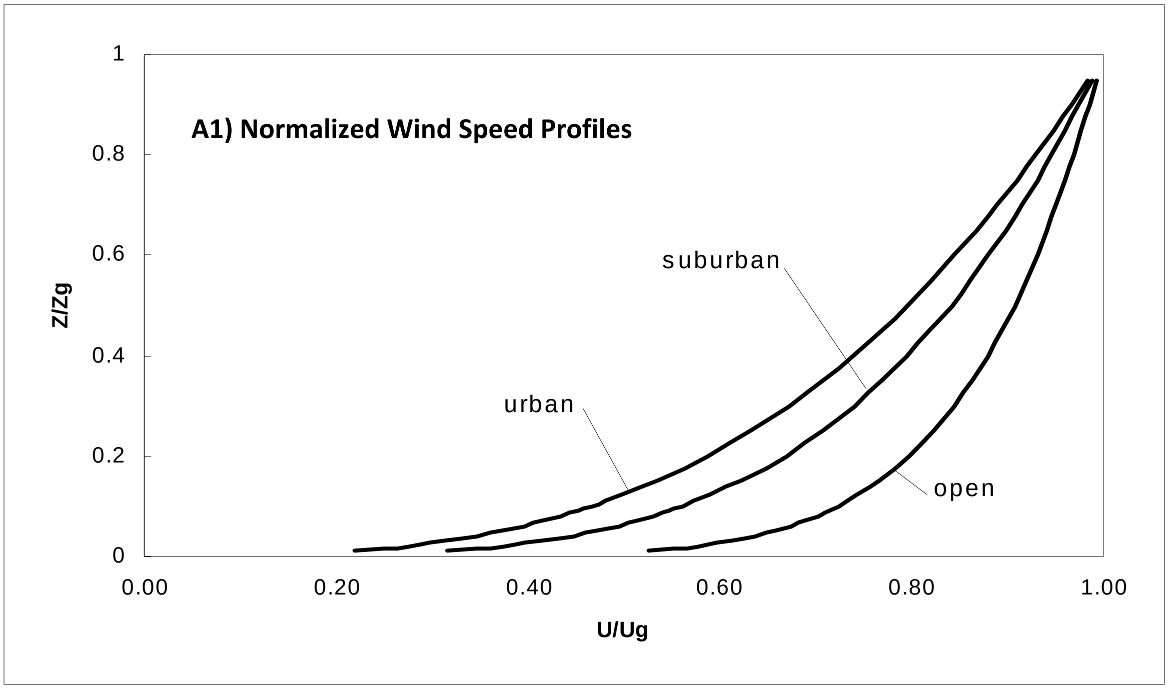


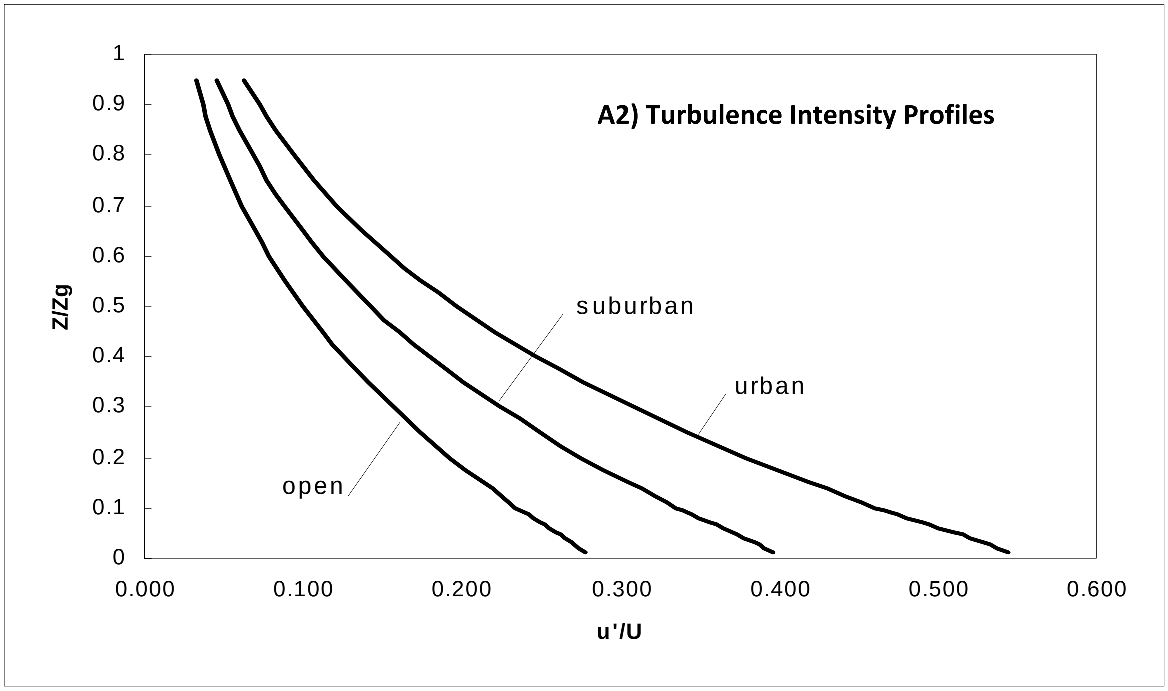


Figure A1 (Top): Mean Wind Speed Profiles

Figure A2 (Bottom): Turbulence Intensity Profiles (u' = fluctuation of mean velocity)

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; 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:

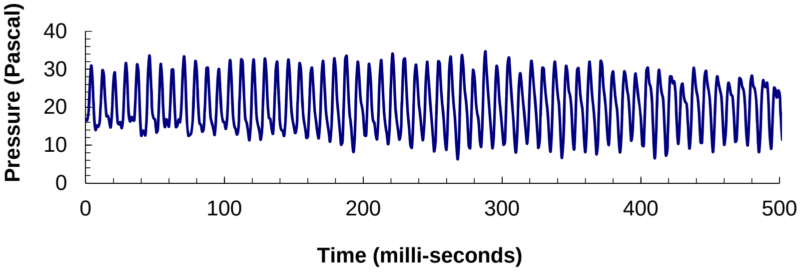
$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

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

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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