ATTACHMENT G

PEDESTRIAN LEVEL WIND STUDY

1400 Vancouver Street
Victoria, British Columbia

REPORT: GWE18-187-CFDPLW

November 26, 2018

PREPARED FOR
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EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed mixed-use development located at 1400 Vancouver Street in Victoria, British Columbia. 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.

Our work is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by AVRP Architecture in November 2018, surrounding street layouts and existing and approved future building massing information, 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 3-6 following the main text. Based on CFD test results, interpretation, and experience with similar developments, we conclude that wind conditions over all pedestrian sensitive grade-level locations within and surrounding the study site will be acceptable for the intended uses throughout the year.

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 conditions too windy for walking, or that could be considered unsafe.

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TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by 1153279 BC Ltd. to undertake a computer-based pedestrian level wind study for a mixed-use development to be located at 1400 Vancouver Street in Victoria, British Columbia. Our mandate within this study, as outlined in GWE proposal #18-304P, dated November 2, 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, where necessary.

Our work is based on industry standard computer simulations using the Computational Fluid Dynamics (CFD) technique and data analysis procedures, architectural drawings provided by AVRP Architecture in November 2018, surrounding street layouts and existing and approved future building massing information, as well as recent site imagery.

2. TERMS OF REFERENCE

The focus of this detailed pedestrian level wind study is a proposed mixed-use development at 1400 Vancouver Street in Victoria, British Columbia. The development is located at the northwest corner of Vancouver Street and Johnston Street, and retains an existing chapel at the east side of the study site.

The proposed development is a 15-storey residential building with mixed-uses at ground floor. The building features an irregular planform characterized by rectangular insets and diagonal walls. At grade, the building comprises retail units fronting Johnson Street and a lobby at the east side of the building, as well as indoor parking for vehicles and bicycles. A parking entrance at the southwest corner of the building provides access to grade-level parking as well as to a ramp to three levels of underground parking. The lobby entrances open to a gated area, between the study building and an existing adjacent chapel, that may contain seating areas. At Level 2, the floorplate sets back from the north side to create private decks and extends at the east and south sides to overhang entrances at ground floor. At Level 3, the floorplate neatly sets back from the north and south and extends at the east side. An inset at the southwest corner accommodates a rooftop amenity deck, and private rooftop decks are located at the south and north sides of the building. At Level 4, the floorplate largely concentrates towards the centre of the building while variably extending at all sides to partially overhang private and amenity roof decks at Level 3. At Levels 7 and 11, the floorplate slightly extends at the east side. At Level 15, the floorplate sets back neatly from the north and south sides and extends further east. The Level 15 setback at the south side of the building accommodates a public view deck bounded by private decks to the east and west, all partially covered by a canopy extending from the south and east sides of the roof.

Regarding wind exposures, the near-field surroundings of the development (defined as an area falling within a 200-metre radius of the site) are primarily characterized by a mix of low- and mid-rise developments in all directions. Additionally, the near-field contains a future proposed multi-tower high-rise development (989 Johnson Street) directly south across Johnson Street. The far-field surroundings (defined as the area beyond the near field and within a two-kilometer radius), are a continuation of the near-field, transitioning to include scattered taller buildings from east clockwise to the northwest.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, building access points, nearby transit stops, parking lots, and the potential grade-level outdoor amenity area. Figure 1 illustrates the study site and surrounding context. 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 wind comfort and safety conditions at key areas within and surrounding the development site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on CFD simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the Victoria area wind climate, and synthesis of computational data with industry-accepted guidelines. 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 was performed to determine the influence of the wind environment on pedestrian comfort over the proposed development site. Pedestrian comfort predictions, based on the mechanical effects of wind, were determined by combining measured wind speed data from CFD simulations with statistical weather data obtained from Victoria International Airport. The general concept and approach to CFD modelling is to represent building and topographic details in the immediate vicinity of the study site on the surrounding model, and to create suitable atmospheric wind profiles at the model boundary. The wind profiles are designed to have similar mean and turbulent wind properties consistent with actual site exposures.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative 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 study building, complete with surrounding massing within a diameter of approximately 840 metres.

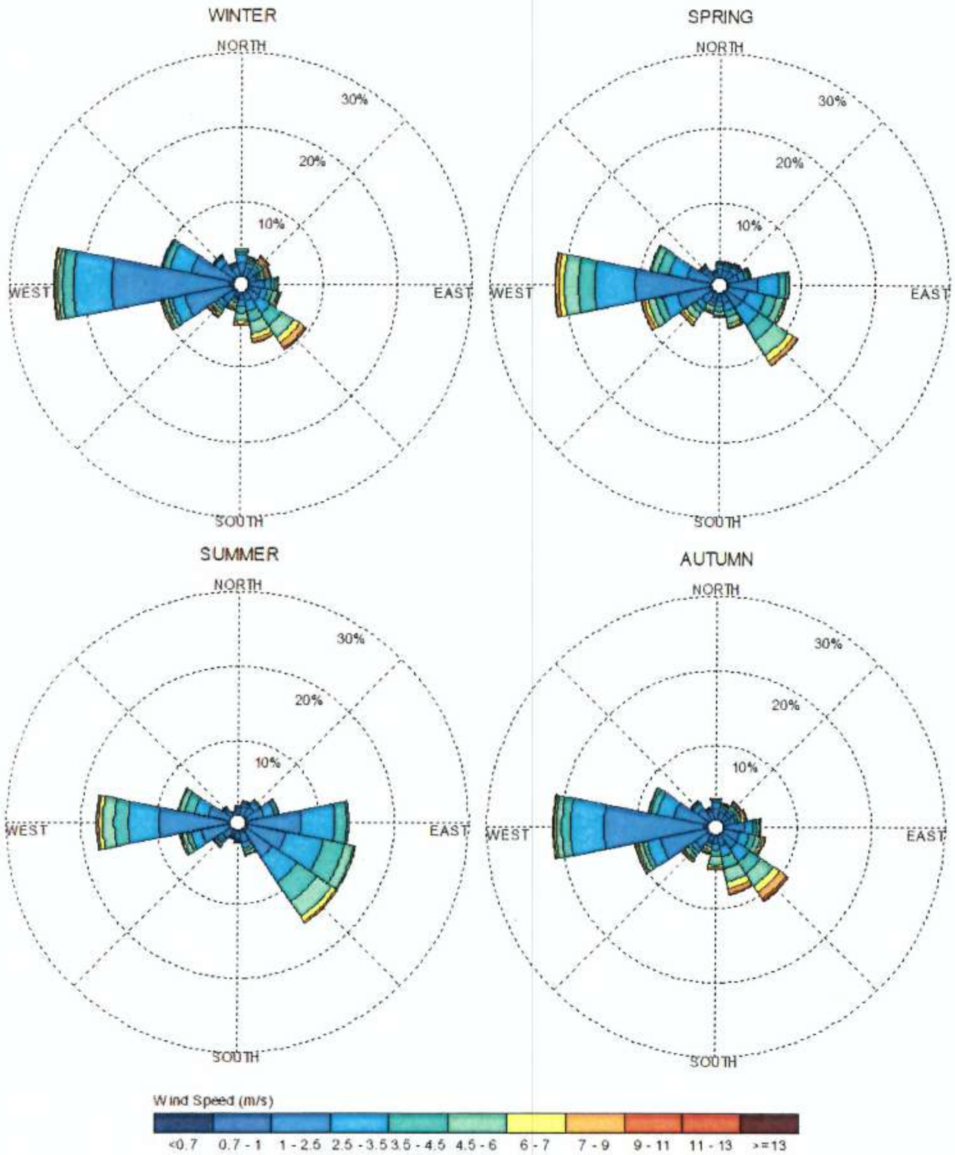
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 metres above local grade were referenced to the wind speed at gradient height to generate 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 Victoria was developed from approximately 40-years of hourly meteorological wind data recorded at Victoria 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 Victoria 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 meters 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 Victoria, the most common winds concerning pedestrian comfort occur from the east clockwise to the south-southeast, as well as those from the west. 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
VICTORIA INTERNATIONAL AIRPORT, VICTORIA, BC



Notes:

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

4.4 Pedestrian Comfort and Safety Guidelines

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

(i) **Sitting** – A wind speed below 16 km/h (i.e. 0 – 16 km/h) would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – A wind speed below 22 km/h (i.e. 16 km/h – 22 km/h) is acceptable for activities such as standing or leisurely strolling.

(iii) **Walking** – A wind speed below 30 km/h (i.e. 22 km/h– 30 km/h) is acceptable for walking or more vigorous activities.

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

The pedestrian safety wind speed guideline is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of greater than 90 km/h is classified as dangerous.

The wind speeds associated with the above categories are gust wind speeds. Corresponding mean wind speeds are approximately calculated as gust wind speed minus 1.5 times the root-mean-square (rms) of the wind speed measurements. 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 16 km/h were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if 30 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As most of these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established at tested locations, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type represented by the sensor (i.e. a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their desired comfort classes are summarized on the following page.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired Comfort Classes
Primary Building Entrance	Standing
Secondary Building Access Point	Walking
Public Sidewalks / Pedestrian Walkways	Walking
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens	Sitting / Standing
Plazas	Standing / Walking
Transit Stops	Standing
Public Parks	Sitting / Walking
Garage / Service Entrances	Walking
Vehicular Drop-Off Zones	Walking
Laneways / Loading Zones	Walking

5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions is accompanied by Figures 3 through 6 (following the main text) illustrating the seasonal wind conditions at grade level areas. The colour contours indicate various comfort classes predicted for certain regions. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green and conditions suitable for standing are represented by yellow.

Johnson Street and Vancouver Street Sidewalks, Including All Adjacent Entrances (Tags A & B): The Johnson Street sidewalk to the south of the building (Tag A) and the Vancouver Street sidewalk to the east (Tag B), as well as all adjacent entrances serving the study building, will be suitable for sitting throughout the year. These conditions are acceptable for the intended uses.

Transit Stops and Parking Lots Surrounding the Study Side (Tags C & D): The transit stops located along Johnson Avenue to the southeast and southwest of the study building (Tag C), as well as all neighboring parking lots (Tag D) will be suitable for sitting throughout the year, which is acceptable.

Potential Grade-Level Amenity Area (Tags E): The gated area between the study building and the existing chapel may serve as a potential outdoor amenity area. This area will be suitable for sitting throughout the year without mitigation, which is acceptable.

Influence of the Proposed Development on Existing Wind Conditions near 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.

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 unsafe.

6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the methodology, results, and recommendations related to a pedestrian level wind study for the proposed mixed-use development located at 1400 Vancouver Street in Victoria, British Columbia. The study was performed in accordance with the scope of work described in GWE proposal #18-304P, dated November 2, 2018, as well as industry standard CFD simulation and data analysis procedures.

A complete summary of the predicted wind conditions is provided in Section 5 of this report and illustrated in Figures 3-6 following the main text. Based on CFD test results, meteorological data analysis of the Victoria wind climate, and experience with similar developments in Victoria, we conclude that wind conditions over all pedestrian sensitive grade-level locations within and surrounding the study site will be acceptable for the intended uses throughout the year.

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 conditions too windy for walking, or that could be considered unsafe.

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

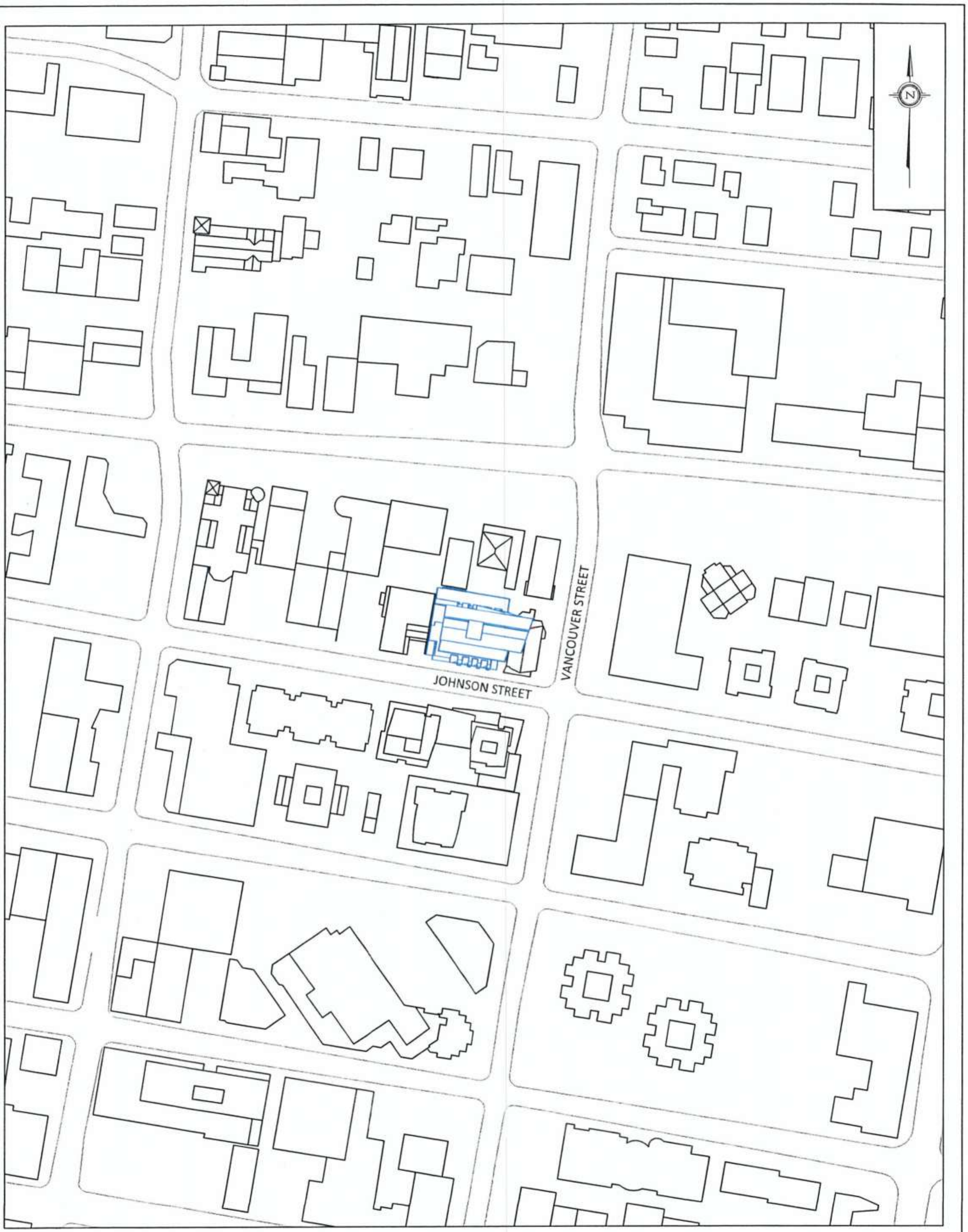
Sincerely,

Gradient Wind Engineering Inc.

Megan Prescott, MESc.,
Project Manager

GWE18-187-CFDPLW

Andrew Sliasas, M.A.Sc., P.Eng.,
Principal



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PROJECT	1400 VANCOUVER STREET, VICTORIA PEDESTRIAN LEVEL WIND STUDY	
SCALE 1:2500 (APPROX.)	DRAWING NO. GWE18-187-CFDPLW-1	DESCRIPTION FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
DATE NOVEMBER 23, 2018	DRAWN BY B.J.	

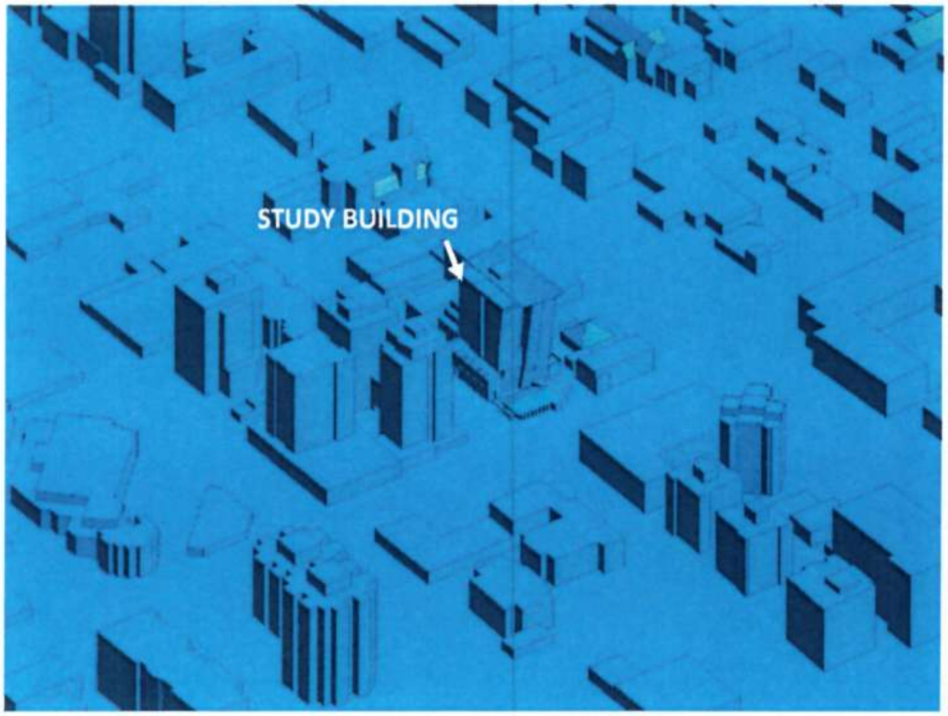


FIGURE 2A: COMPUTATIONAL MODEL, LOOKING NORTHWEST

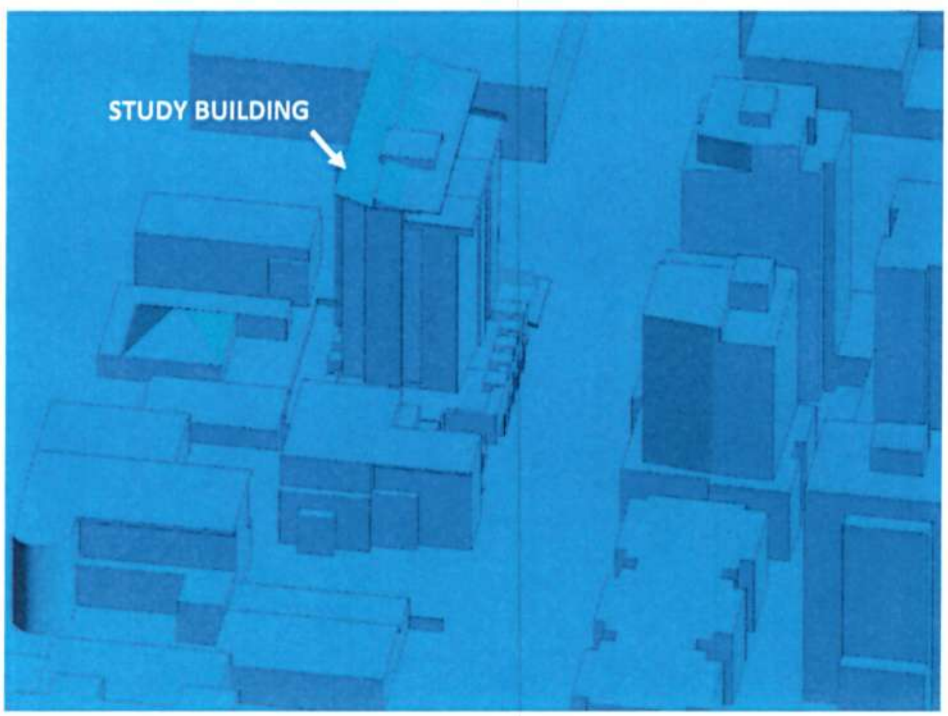
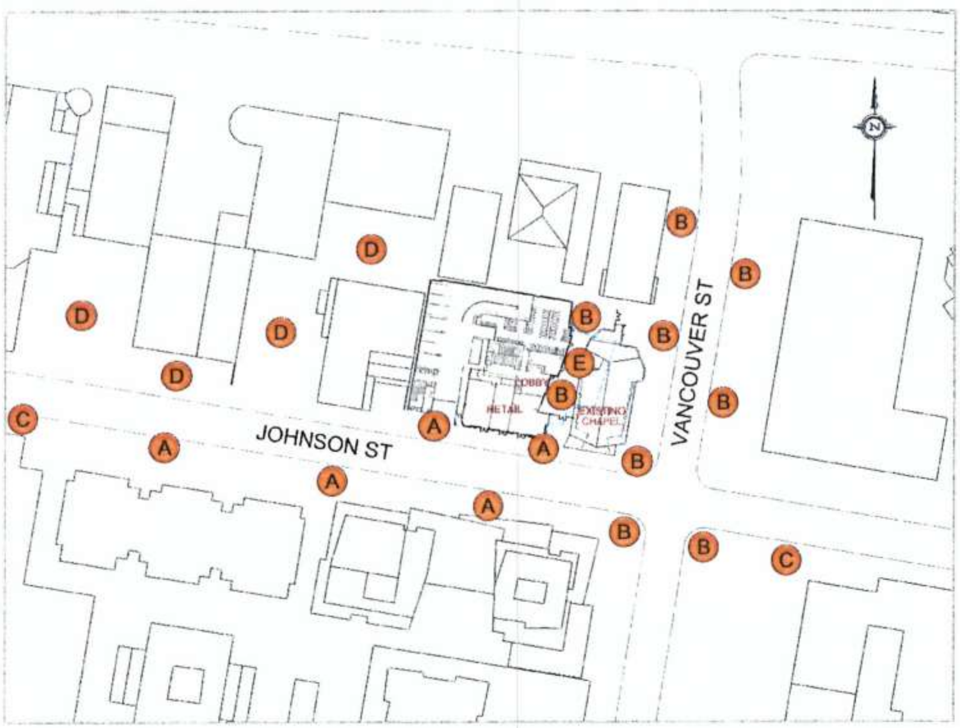


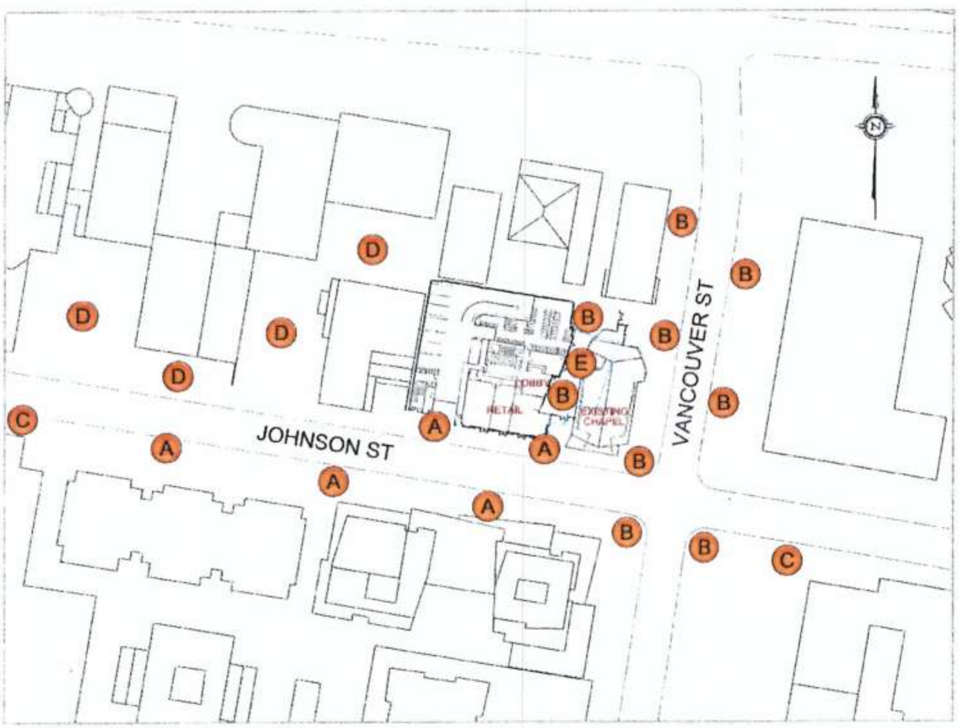
FIGURE 2B: STUDY SITE, LOOKING EAST

FIGURE 3: SPRING – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



1400 VANCOUVER STREET - REFERENCE LOCATIONS

FIGURE 4: SUMMER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



1400 VANCOUVER STREET - REFERENCE LOCATIONS

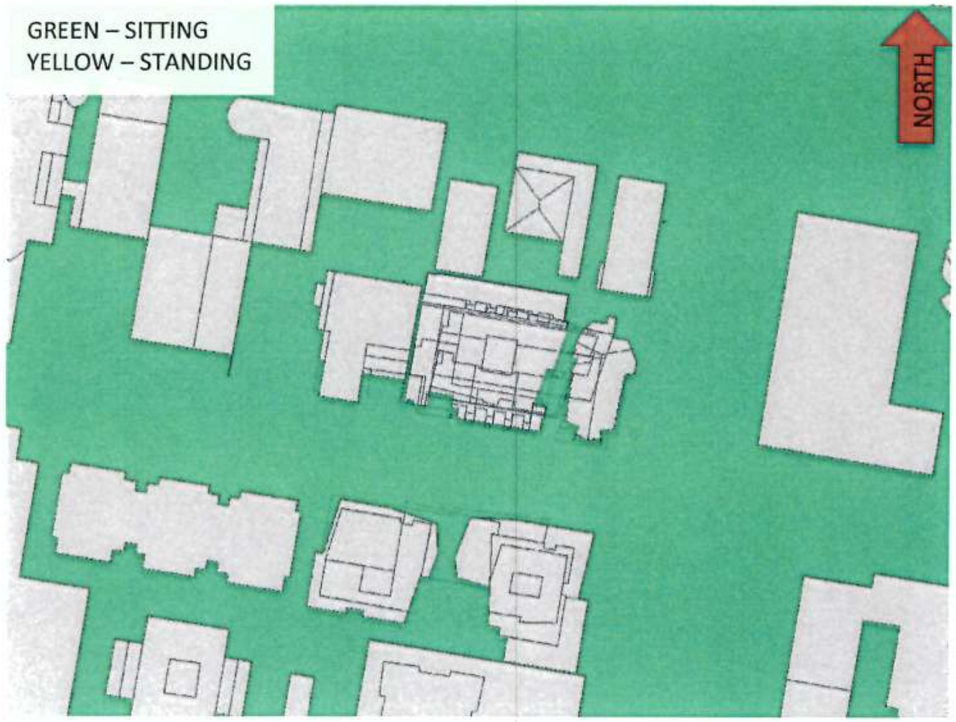
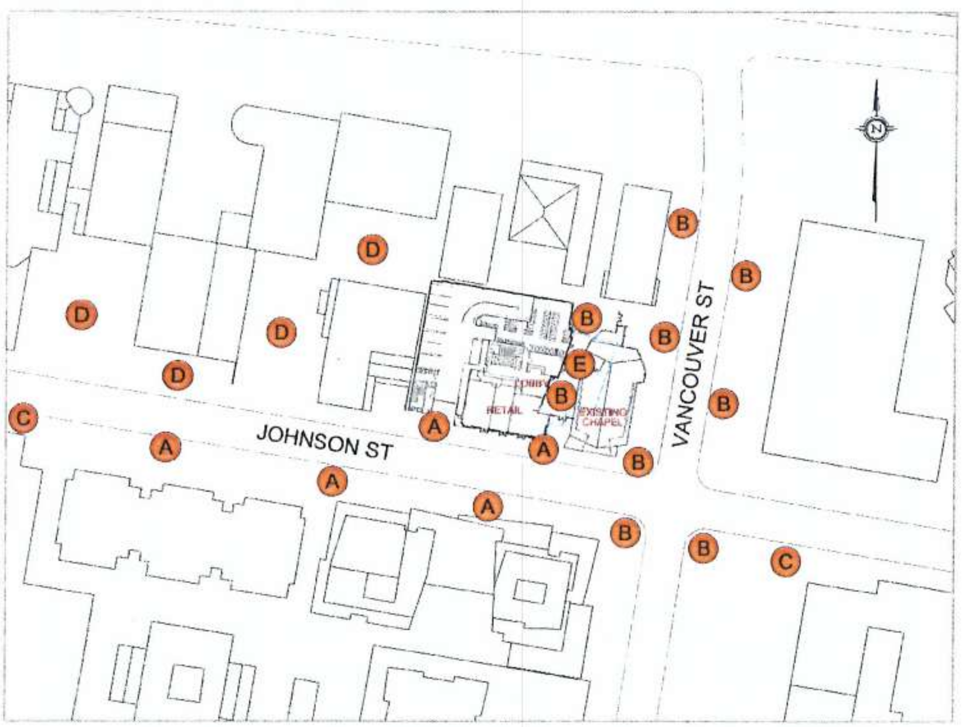
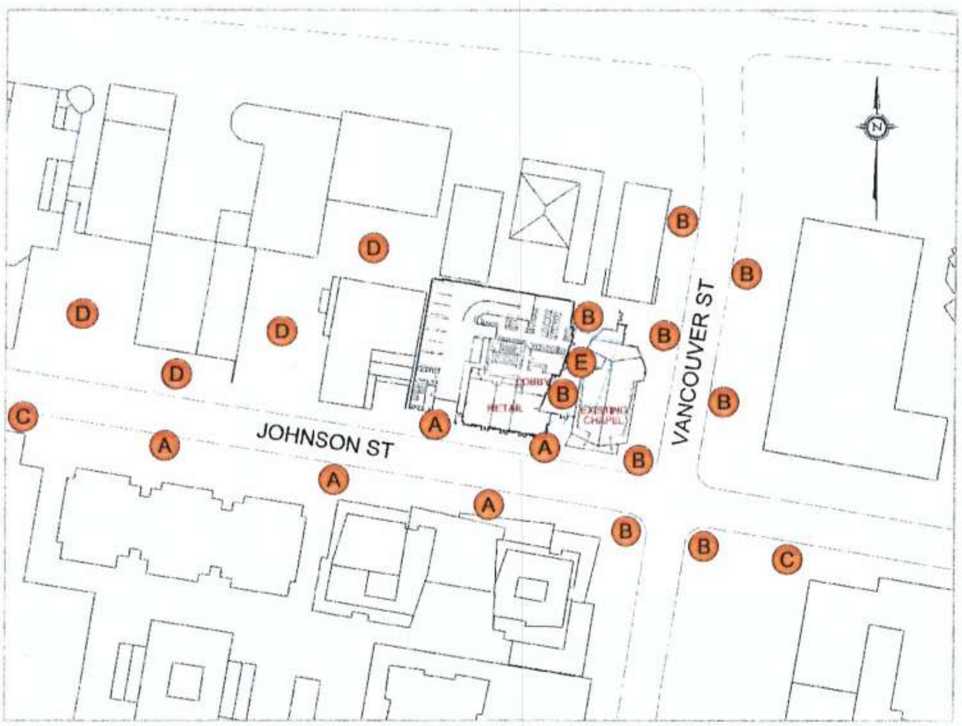


FIGURE 5: AUTUMN – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



1400 VANCOUVER STREET - REFERENCE LOCATIONS

FIGURE 6: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



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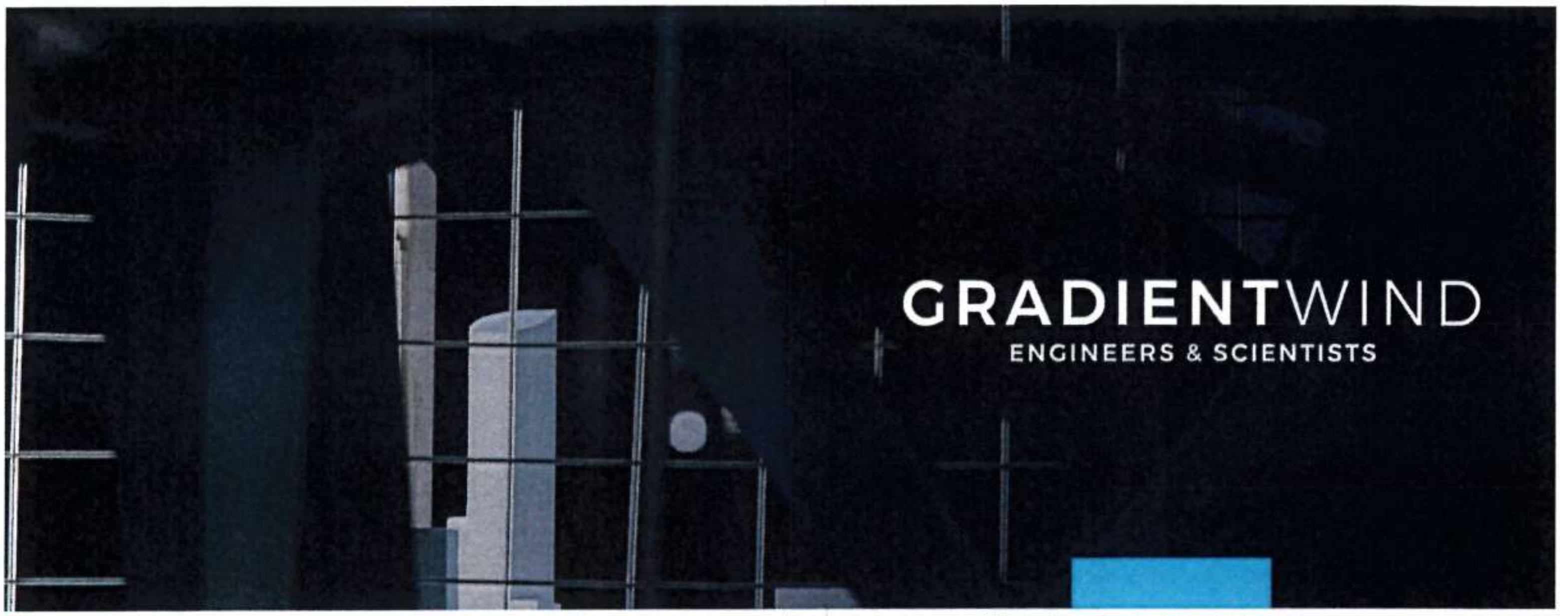

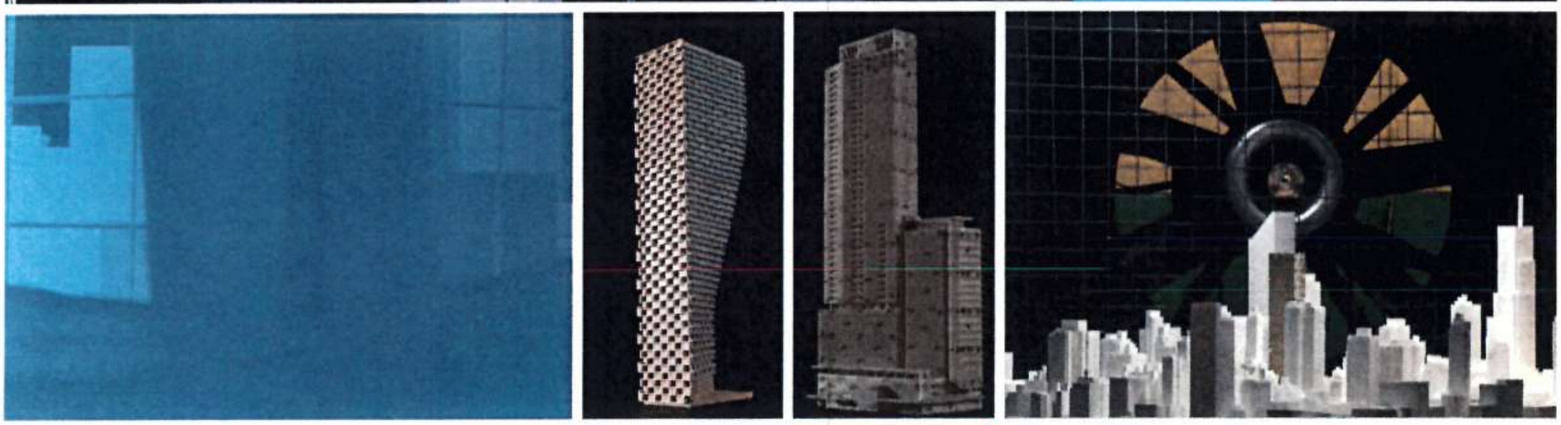

APPENDIX A

WIND TUNNEL SIMULATION OF THE NATURAL WIND

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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 metres (m) to 600 m.

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

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

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

Figure B1 on the following page plots three velocity profiles for open country, and suburban and urban exposures.

The exponent α varies according to the type of upwind terrain; α ranges from 0.14 for open country to 0.33 for an urban exposure. Figure B2 illustrates the theoretical variation of turbulence for open country, suburban and urban exposures.

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

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

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

Once the wind simulation is correct, the model, constructed to a suitable scale, is installed at the 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.

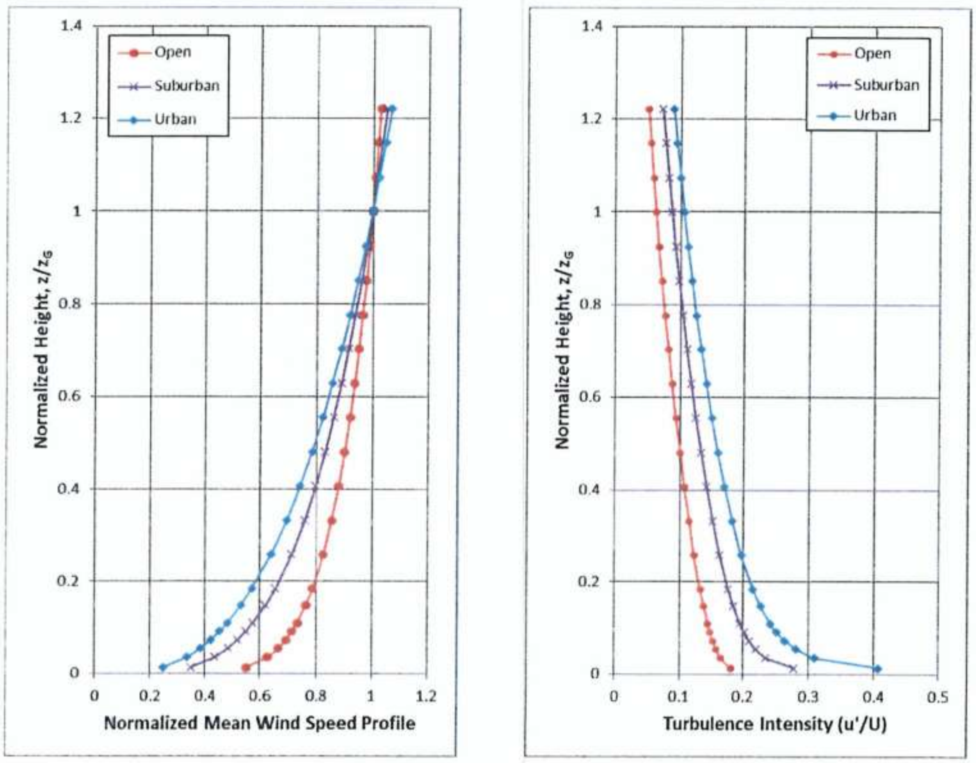

FIGURE A1 (LEFT): MEAN WIND SPEED PROFILES;
FIGURE A2 (RIGHT): TURBULENCE INTENSITY PROFILES

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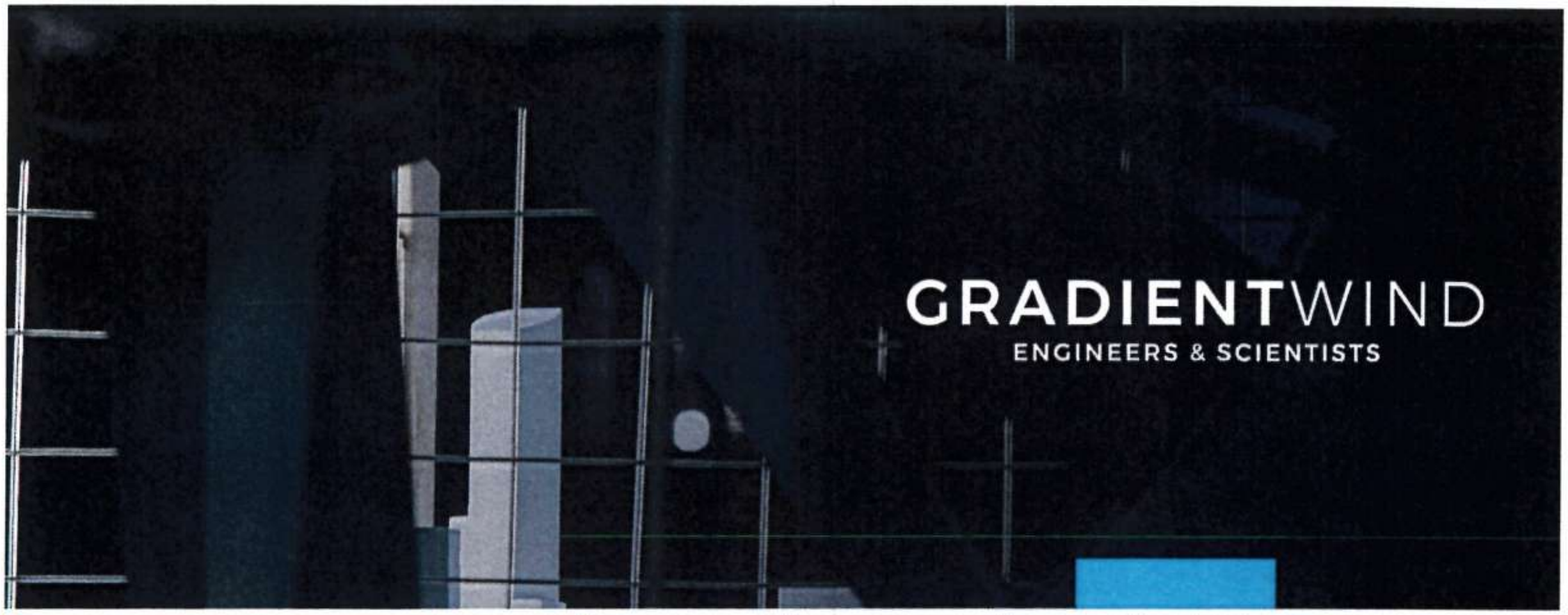

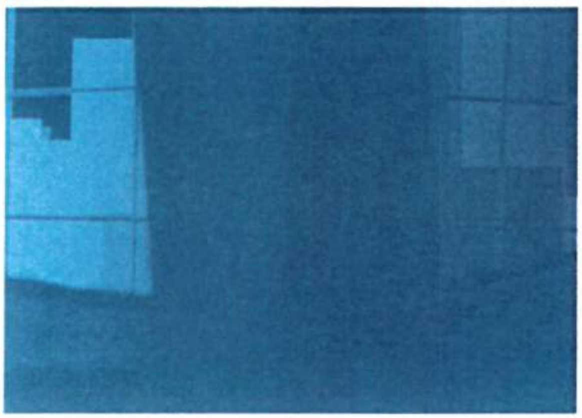

APPENDIX B

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

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

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PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

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

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

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

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

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

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

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

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

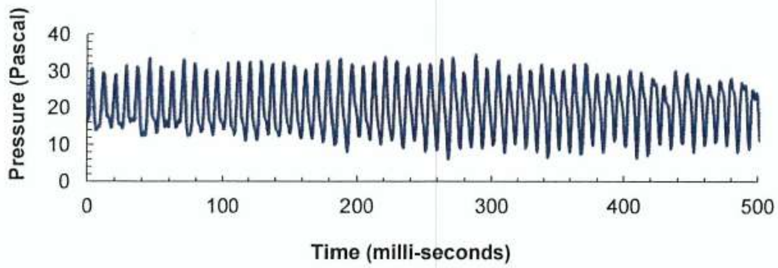

FIGURE B1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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