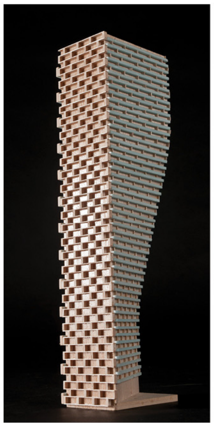
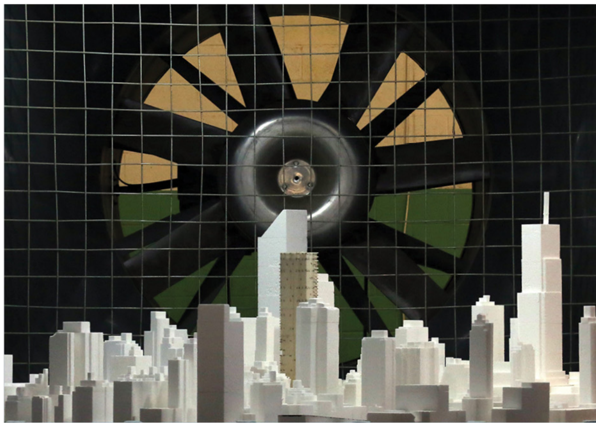
PEDESTRIAN LEVEL WIND STUDY

1050 & 1060 Bank Street
Ottawa, Ontario

Report: 19-188-PLW





November 1, 2019

PREPARED FOR
2641723 Ontario Inc.
648 Cole Avenue
Ottawa, ON K2A 2B7

PREPARED BY
Sacha Ruzzante, MASc., Junior Wind Scientist
Edward Urbanski, M.Eng., Junior Wind Scientist
Justin Ferraro, P.Eng., Principal

127 WALGREEN ROAD, OTTAWA, ON, CANADA K0A 1L0 | 613 836 0934
GRADIENTWIND.COM

EXECUTIVE SUMMARY

This report describes a computer-based pedestrian level wind (PLW) study undertaken to satisfy the requirements for a site plan control application for a proposed development located at 1050 and 1060 Bank Street in Ottawa, Ontario (hereinafter referred to as "subject site"). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where necessary.

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 according to City of Ottawa wind comfort and safety criteria. The results and recommendations derived from these considerations are detailed in the main body of the report and summarized as follows:

1) Wind comfort conditions around the subject site at grade level are predicted to be mostly calm and acceptable for all anticipated uses throughout the year.

2) Wind comfort conditions within the Level 5 amenity terrace are predicted to be calm and suitable for sitting during the summer season, becoming suitable for a mix of sitting and standing during the remaining colder seasons. Of particular importance, sitting conditions are provided for at least 70% of the time during the coldest months of the year with a 1.07-m tall perimeter wind screen. If sitting conditions are desired to extend to the shoulder months summer (i.e., late spring and early autumn), we recommend increasing the perimeter wind screen to at least 1.6 m above the local walking surface.

3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas surrounding the subject site at grade level were found to experience conditions that could be considered uncomfortable or dangerous.

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by 2641723 Ontario Inc. to undertake a computer-based pedestrian level wind (PLW) study to satisfy the requirements for a site plan control application for a proposed development located at 1050 and 1060 Bank Street in Ottawa, Ontario (hereinafter referred to as “subject site”). Our mandate within this study is to investigate pedestrian wind comfort and safety within and surrounding the subject site, and to identify any areas where wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where necessary.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Ottawa wind comfort and safety criteria, architectural drawings provided by KWC Architects Inc. in October 2019, 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 subject site is located at 1050 and 1060 Bank Street in Ottawa, occupying the entire east side of the city block bordered by Aylmer Avenue to the north, Bank Street to the east, Euclid Avenue to the south, and Galt Street to the west. The subject site is also bordered by existing low-rise developments to the west. For ease of description and presentation of wind comfort contours, Aylmer Street is defined as project north.

Axonometric Rendering, Northeast Perspective
(Courtesy of KWC Architects Inc.)

The development comprises a 6-storey building with a wedge-shaped floorplan that runs parallel to the existing roadways on the north, east, and south sides, and parallel to existing developments to the west. The floorplate steps back on all sides at Level 5 to reveal private terraces on the east side, a common amenity terrace within the south end, and a public roof area/walkway on the west side. The floorplate steps back again at Level 6 on the west and south sides. The basement level comprises parking spaces and storage. The ground level comprises a lobby, retail space, and waste and recycling. Level 2 and above comprise residential units. The main residential entrance is located at the east side of the building, while secondary residential entrances are located at the north and west sides. Commercial entrances are located on all sides of the building. A ramp at the northwest corner of the subject site provides access to the basement parking level. Grade-level pedestrian walkways are located on all sides of the proposed development.

The subject site experiences primarily suburban and light urban wind exposures. In the near field, within a radius of 500 meters (m), wind exposures are affected by the Rideau Canal, The Rideau at Lansdowne, and TD Place to the north, and predominantly low-rise residential buildings from the remaining wind directions. At greater distances wind exposures are affected by Dow's Lake and the Ottawa Experimental Farm from the southwest clockwise to west, and the Ottawa River and urban downtown core from the northwest clockwise to north. The remaining compass directions contribute predominantly suburban wind exposures. Figure 1 illustrates the subject site and surrounding context, while Figures 2A-2D illustrate the computational model used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind comfort and safety conditions at key areas within and surrounding the development site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on CFD simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the Ottawa area wind climate, and synthesis of computational data with City of Ottawa wind comfort and safety criteria[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

4.1 Computer-Based Context Modelling

A computer-based PLW study was performed to determine the influence of the wind environment on pedestrian comfort over the proposed development site. Pedestrian comfort predictions, based on the mechanical effects of wind, were determined by combining measured wind speed data from CFD simulations with statistical weather data obtained for Macdonald-Cartier International Airport, Ottawa.

The general concept and approach to CFD modelling is to represent building and topographic details in the immediate vicinity of the study site on the surrounding model, and to create suitable atmospheric wind profiles at the model boundary. The wind profiles are designed to have similar mean and turbulent wind properties consistent with actual site exposures.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative (i.e., windier) wind speed values.

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 820 m.

---

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

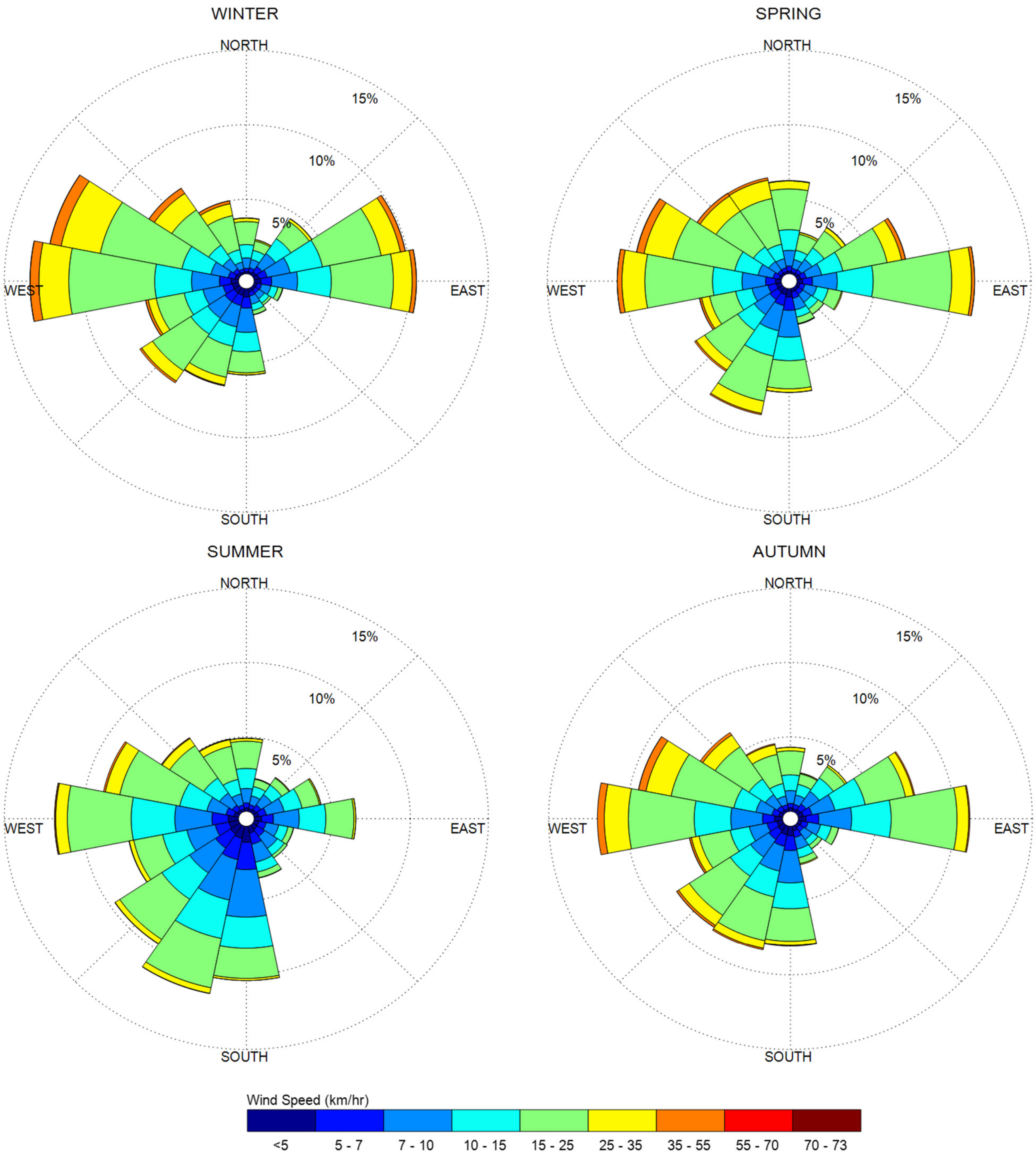
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade, and 1.5 m above the amenity terrace, were referenced to the wind 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 Environment and Climate Change Canada. Wind speed and direction data were analyzed for each month of the year in order to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns. Based on this portion of analysis, the four seasons are represented by grouping data from consecutive months based on similarity of weather patterns, and not according to the traditional calendar method.

The statistical model of the Ottawa area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Ottawa, the most common winds occur for westerly wind directions, followed by those from the east, while the most common wind speeds are below 36 km/h. The directional preference and relative magnitude of wind speed changes somewhat from season to season.

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS DIRECTIONS
MACDONALD-CARTIER INTERNATIONAL AIRPORT, OTTAWA



Notes:

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

4.4 Pedestrian Comfort and Safety Criteria – City of Ottawa

Pedestrian comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 80% non-exceedance mean wind speed ranges, which include (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. More specifically, the comfort classes and associated mean wind speed ranges are summarized as follows:

1) **Sitting:** Mean wind speeds no greater than 10 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 16 km/h.

2) **Standing:** Mean wind speeds no greater than 14 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 22 km/h.

3) **Strolling:** Mean wind speeds no greater than 17 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 27 km/h.

4) **Walking:** Mean wind speeds no greater than 20 km/h occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 32 km/h.

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

The pedestrian safety wind speed criterion is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of 90 km/h is classified as dangerous. The gust speeds, and equivalent mean speeds, are selected based on 'The Beaufort Scale', presented on the following page, which describes the effects of forces produced by varying wind speed levels on objects. Gust speeds are included because pedestrians tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also create problems for pedestrians. The mean gust speed ranges are selected based on 'The Beaufort Scale', which describes the effect of forces produced by varying wind speeds on levels on objects.

THE BEAUFORT SCALE

Number	Description	Wind Speed (Km/h)	Description
2	Light Breeze	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 a mean wind speed of 10 km/h (gust equivalent mean wind speed of 16 km/h) was exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting. Similarly, if mean wind speed of 20 km/h (gust equivalent mean wind speed of 32 km/h) at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As most of these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

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

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

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

5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-6B (following the main text) illustrating the seasonal wind conditions at grade level and within the common amenity terrace at Level 5. The colour contours indicate various comfort classes predicted for certain regions. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by orange, and walking by blue. Uncomfortable conditions are represented by the colour magenta.

5.1 Wind Comfort Conditions – Grade Level

Following the introduction of the subject site, wind conditions around the development are predicted to be calm throughout the year. Wind comfort at grade level is summarized below for each seasonal period.

- Spring Season: Wind conditions are predicted to be suitable for standing on the adjacent sidewalk along Aylmer Avenue, and suitable for sitting on the adjacent pedestrian walkways (Figure 3A).

- Summer Season — Wind conditions are predicted to be suitable for sitting over all areas (Figure 4A).

- Autumn Season — Conditions are similar to those predicted during the spring season, but somewhat calmer as a function of the historical climate data (Figure 5A).

- Winter Season — Conditions are similar to those predicted during the spring season, but moderately windier (Figure 6A).

Wind speeds are predicted to satisfy the sitting and standing comfort classes for all pedestrian areas. While moderate wind channelling is predicted to impact the sidewalk areas along Aylmer Avenue, conditions are predicted to be suitable for standing, or better, throughout the year, which is acceptable. As a general note, conditions are calmer immediately adjacent to the subject building as compared to those at greater distances from the subject building which the above summary is based.

5.2 Wind Comfort Conditions – Level 5 Amenity Terrace

The following discussion is focused on the amenity terrace at Level 5, which is situated at the south end of the building. The terrace is connected to the public roof space that extends the length of the west side of the building. The amenity terrace is predicted to be calm during the summer season, becoming moderately windy during the remaining colder seasons; pedestrian wind comfort is summarized below for each seasonal period. In addition to reporting typical comfort classes within the terrace, Figures 7A-7D represent a refined sitting comfort class, for each seasonal period, to illustrate the percentage of time the terrace will be suitable for sitting, which is a useful metric for design.

- Spring Season: — Conditions are predicted to be suitable for standing over most of the amenity area, while the public walkway is mostly suitable for sitting. As illustrated in Figure 7A, most of the terrace will be suitable for sitting for at least 75% of the time during the spring season.

- Summer Season: — Conditions are predicted to be suitable for sitting over the entire amenity terrace and the public walkway. As illustrated in Figure 7B, most of the terrace is suitable for sitting for at least 85% of the time during the summer season.

- Autumn Season: Conditions are similar to those predicted during the spring season. As illustrated in Figure 7C, most of the terrace is suitable for sitting for at least 75% of the time during the autumn season.

- Winter Season: Conditions are predicted to be mostly suitable for standing on the amenity terrace. As illustrated in Figure 7D, most of the terrace is suitable for sitting for at least 70% of the time during the winter season.

5.3 Wind Comfort Conditions – Surrounding Area

Wind conditions over surrounding sidewalks beyond the development site, as well as at nearby primary building entrances, will be acceptable for their intended pedestrian uses during each seasonal period upon the introduction of the subject site. Pedestrian wind comfort and safety have been quantified for the specific configuration of existing and foreseeable construction around the study site. Future changes (i.e., construction or demolition) of these surroundings may cause changes to the wind effects in two ways, namely: (i) changes beyond the immediate vicinity of the site would alter the wind profile approaching the site; and (ii) development in proximity to the site would cause changes to local flow patterns. More specifically, development in urban centers generally creates reduction in the mean wind and localized increases in the gustiness of the wind.

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind comfort conditions at grade level and within the Level 5 amenity terrace is provided in Section 5 of this report and illustrated in Figures 3A-7D following the main text. Based on computer simulations using the CFD technique, meteorological data analysis of the Ottawa wind climate, City of Ottawa wind comfort and safety criteria, and experience with similar developments in Ottawa, we conclude the following:

1) Wind comfort conditions around the subject site at grade level are predicted to be mostly calm and acceptable for all anticipated uses throughout the year.

2) Wind comfort conditions within the Level 5 amenity terrace are predicted to be calm and suitable for sitting during the summer season, becoming suitable for a mix of sitting and standing during the remaining colder seasons. Of particular importance, sitting conditions are provided for at least

70% of the time during the coldest months of the year with a 1.07-m tall perimeter wind screen. If sitting conditions are desired to extend to the shoulder months summer (i.e., late spring and early autumn), we recommend increasing the perimeter wind screen to at least 1.6 m above the local walking surface.

3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas surrounding the subject site at grade level were found to experience conditions that could be considered uncomfortable or dangerous.

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

Sincerely,

Gradient Wind Engineering Inc.

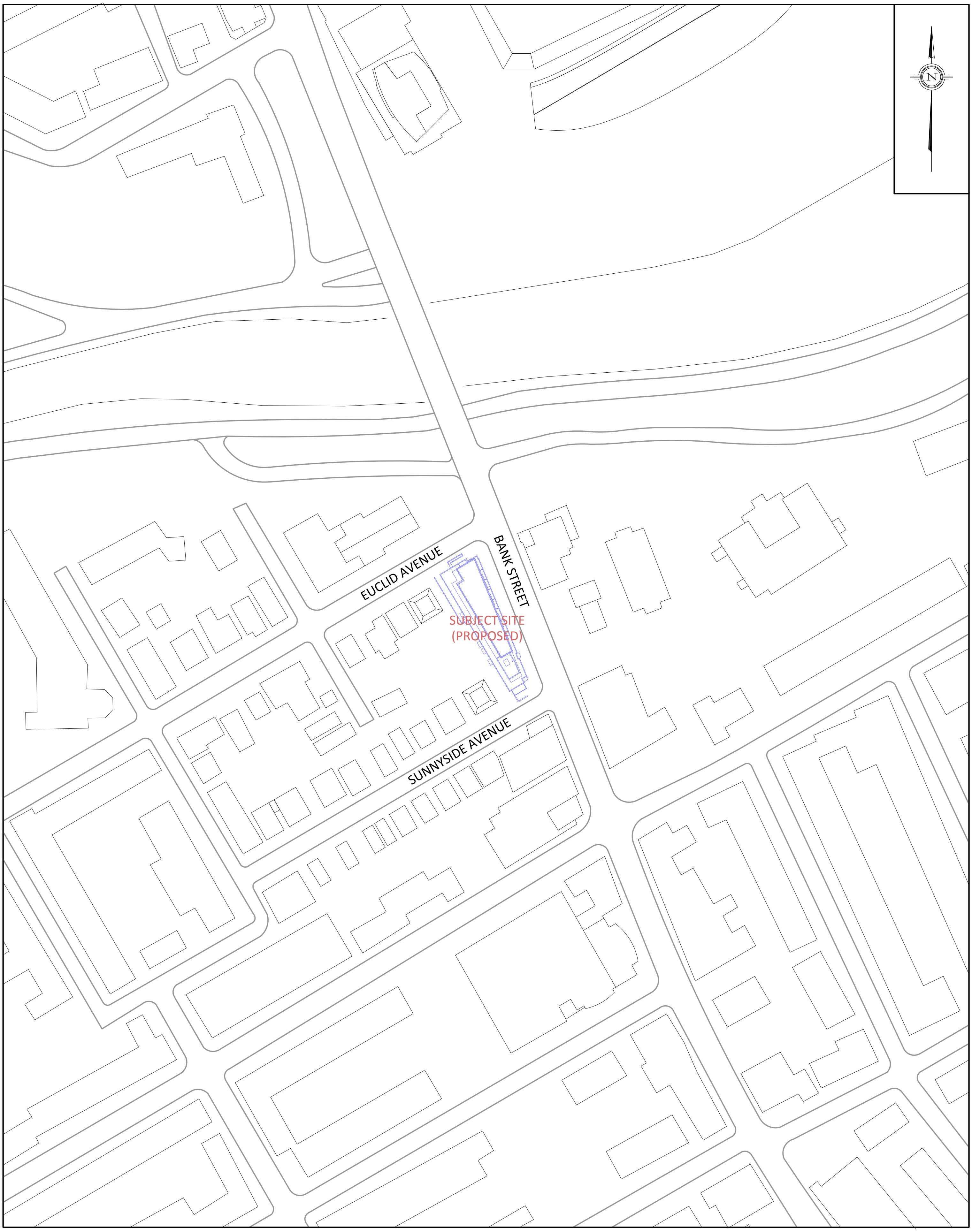
Sacha Ruzzante, MASc.
Junior Wind Scientist

LICENSED PROFESSIONAL ENGINEER
J. D. FERRARO
100158495
Dec. 10, 2019
PROVINCE OF ONTARIO

Justin Ferraro, P.Eng.
Principal

Edward Urbanski, M.Eng.
Junior Wind Scientist

Gradient Wind File #19-188



GRADIENTWIND
ENGINEERS & SCIENTISTS

127 WALGREEN ROAD , OTTAWA, ON
613 836 0934 • GRADIENTWIND.COM

PROJECT	1050 & 1060 BANK STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:2500 (APPROX.)	DRAWING NO.	GW19-188-PLW-1
DATE	NOVEMBER 1, 2019	DRAWN BY	C.E.

DESCRIPTION

FIGURE 1:
SITE PLAN AND SURROUNDING CONTEXT

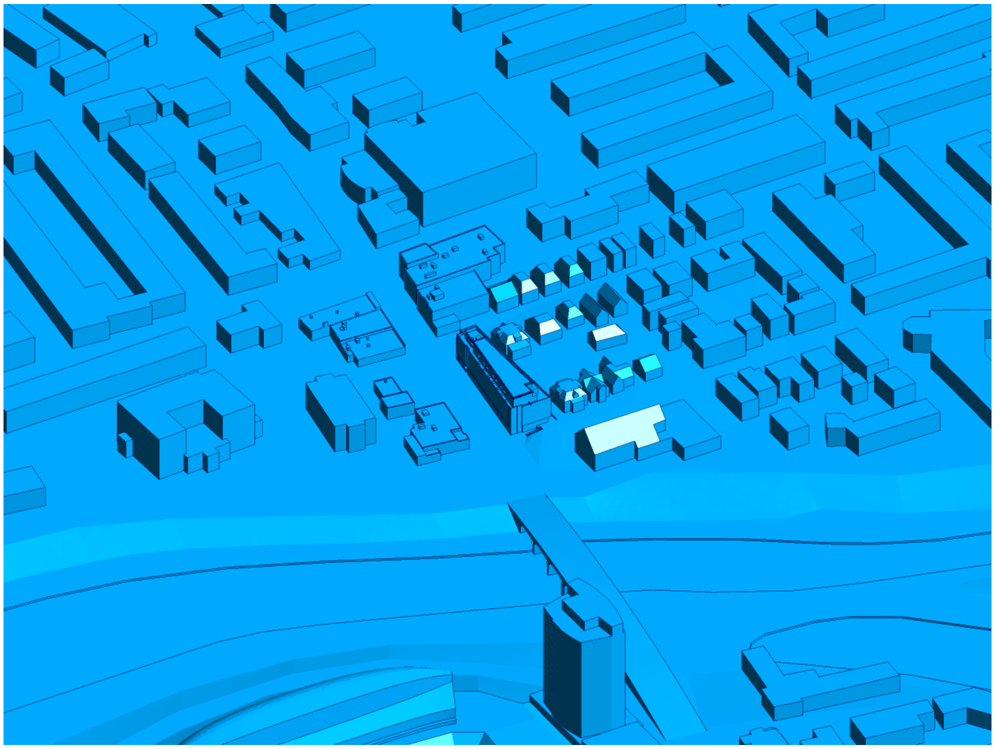


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

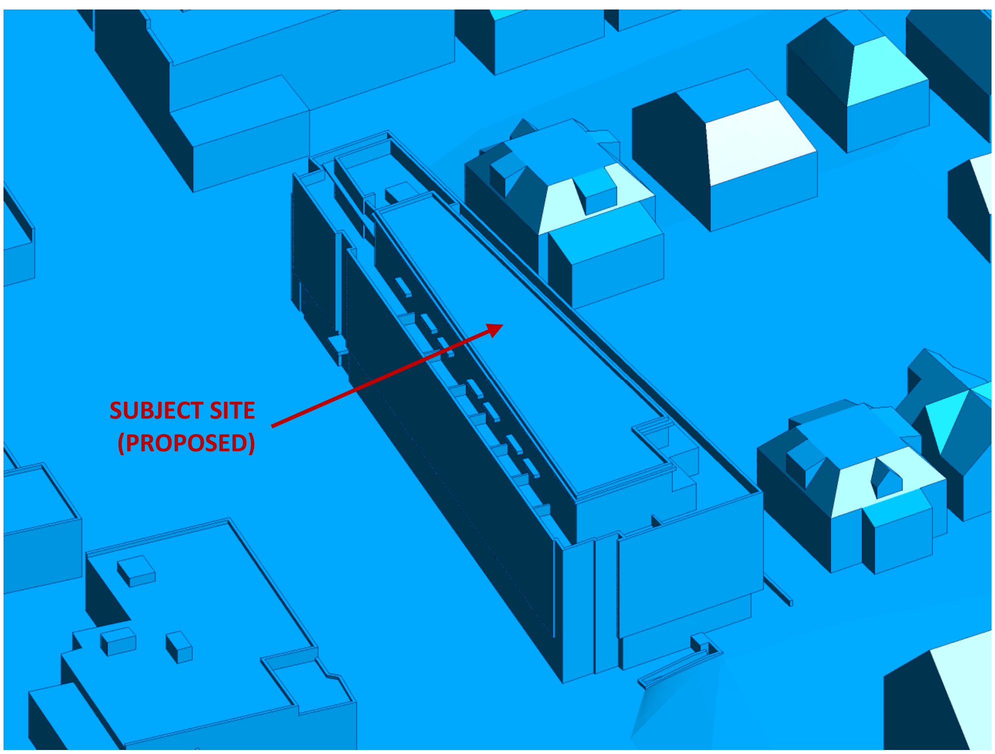


FIGURE 2B: CLOSE UP OF FIGURE 2A

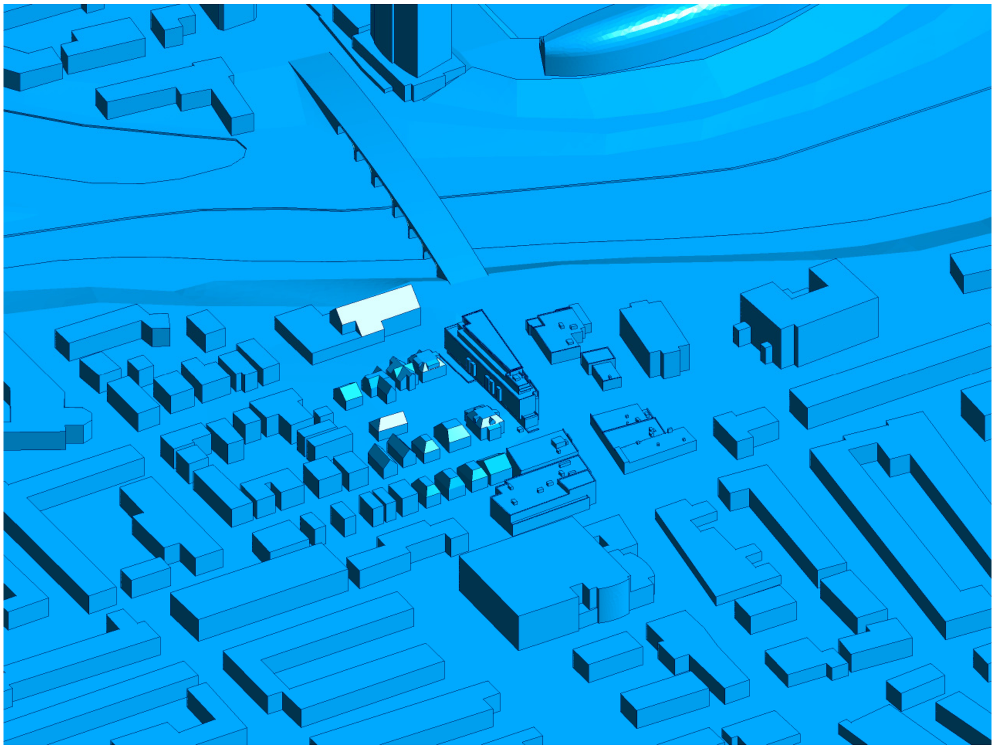


FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

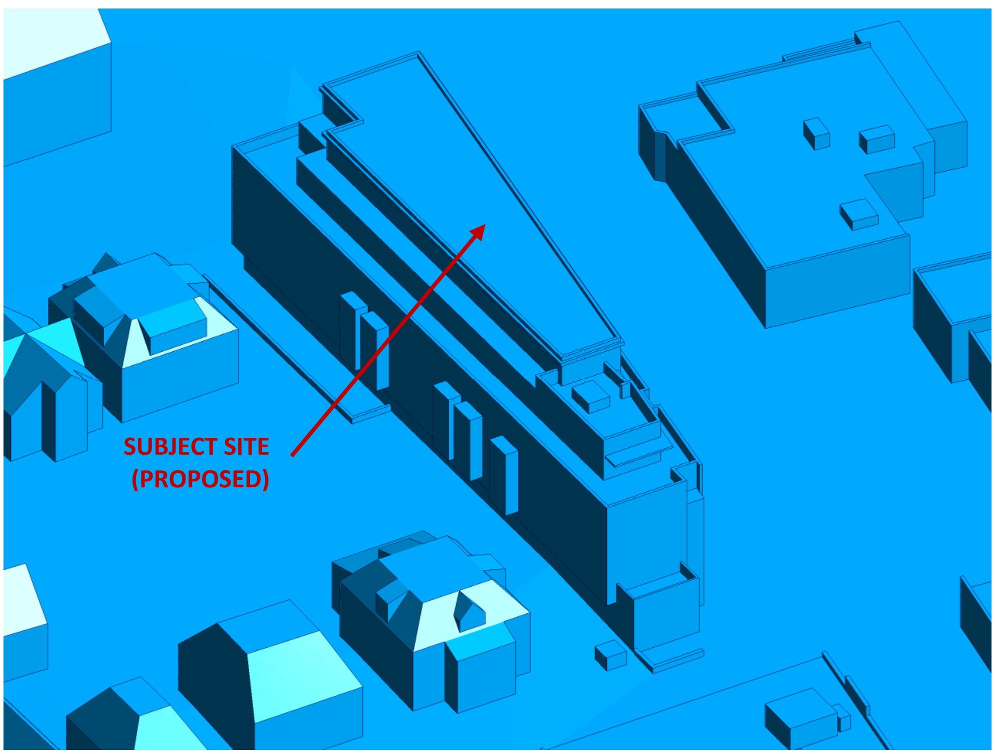


FIGURE 2D: CLOSE UP OF FIGURE 2C

FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

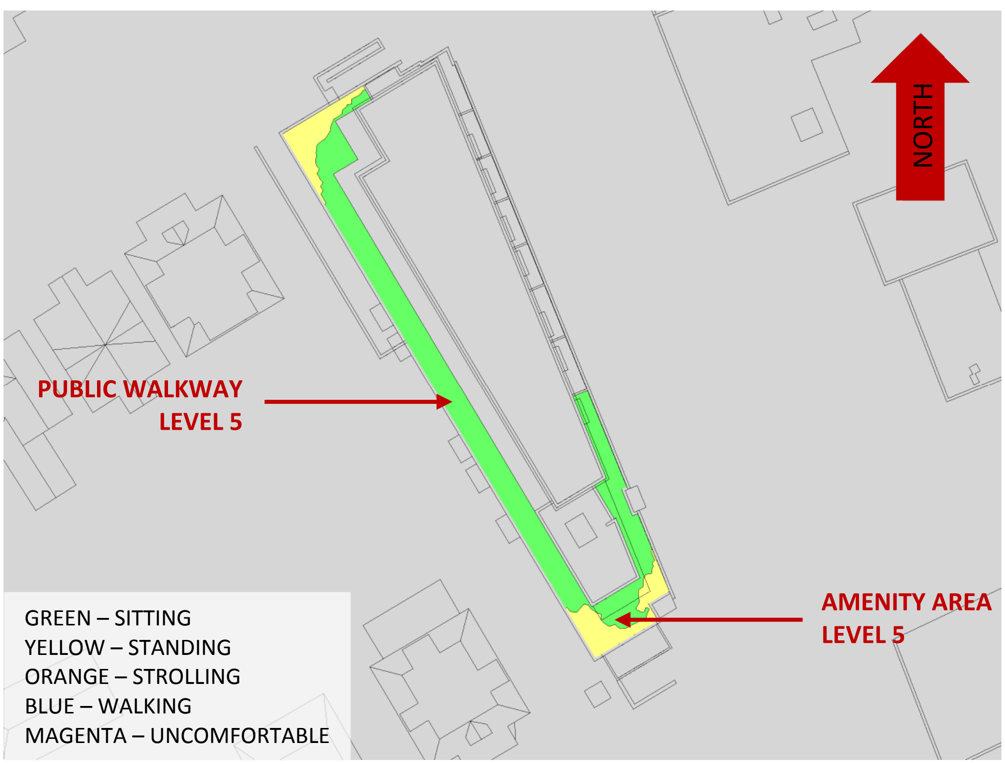


FIGURE 3B: SPRING – WIND CONDITIONS WITHIN COMMON AMENITY TERRACE

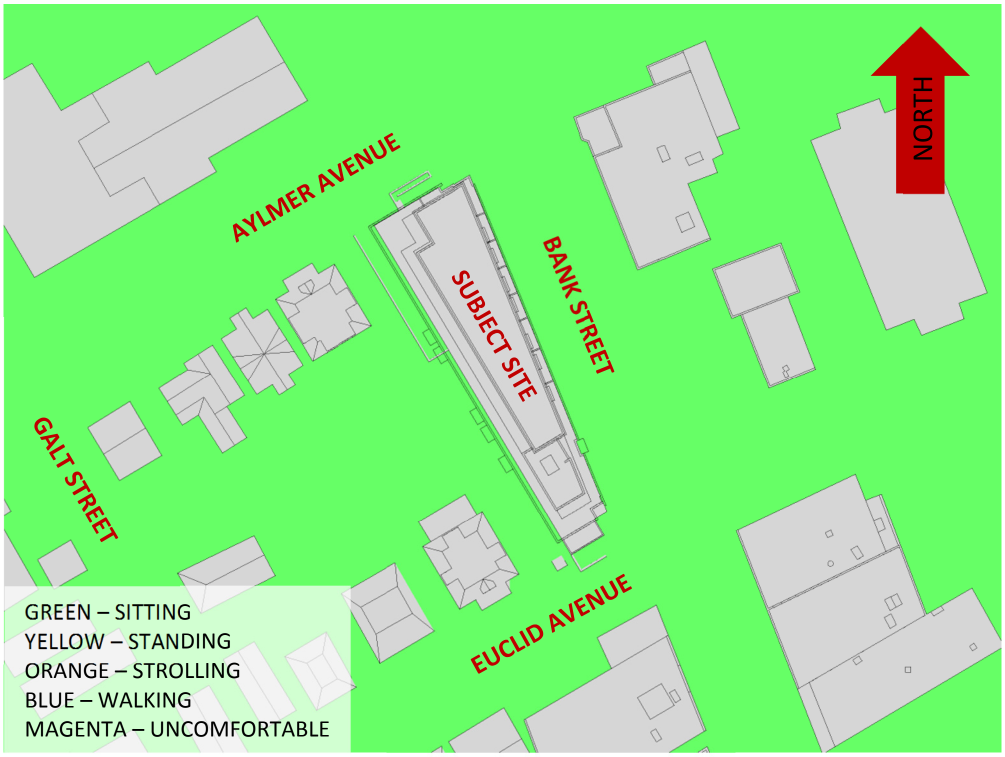


FIGURE 4A: SUMMER – WIND CONDITIONS AT GRADE LEVEL

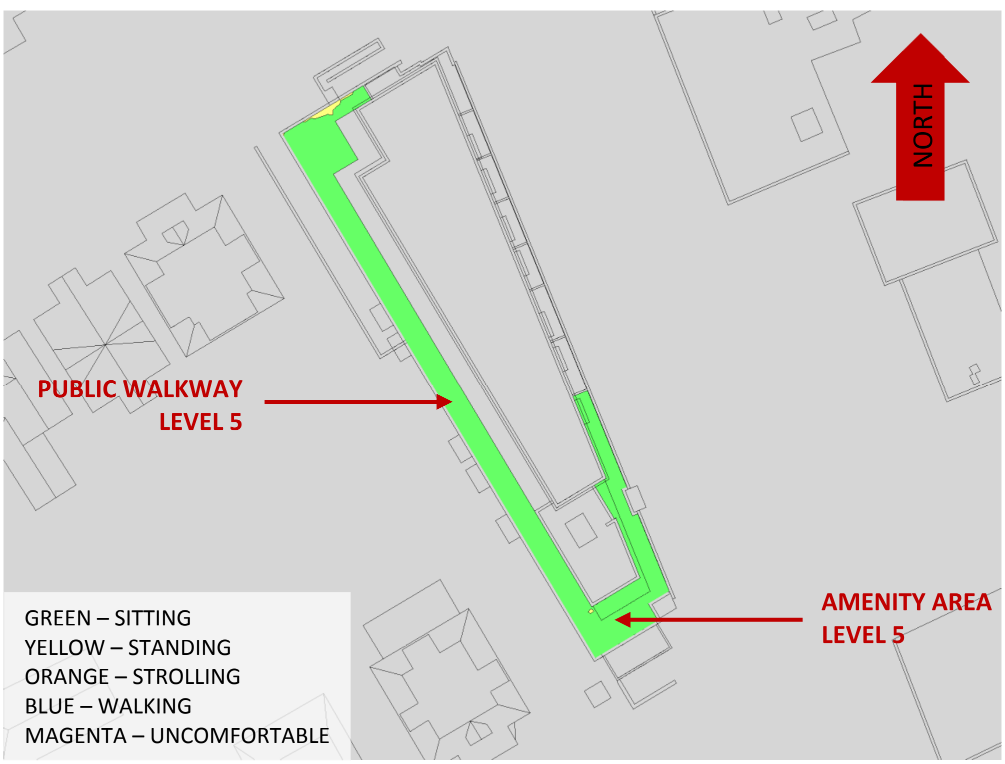


FIGURE 4B: SUMMER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACE

FIGURE 5A: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

FIGURE 5B: AUTUMN – WIND CONDITIONS WITHIN COMMON AMENITY TERRACE

FIGURE 6A: WINTER – WIND CONDITIONS AT GRADE LEVEL

FIGURE 6B: WINTER – WIND CONDITIONS WITHIN COMMON AMENITY TERRACE

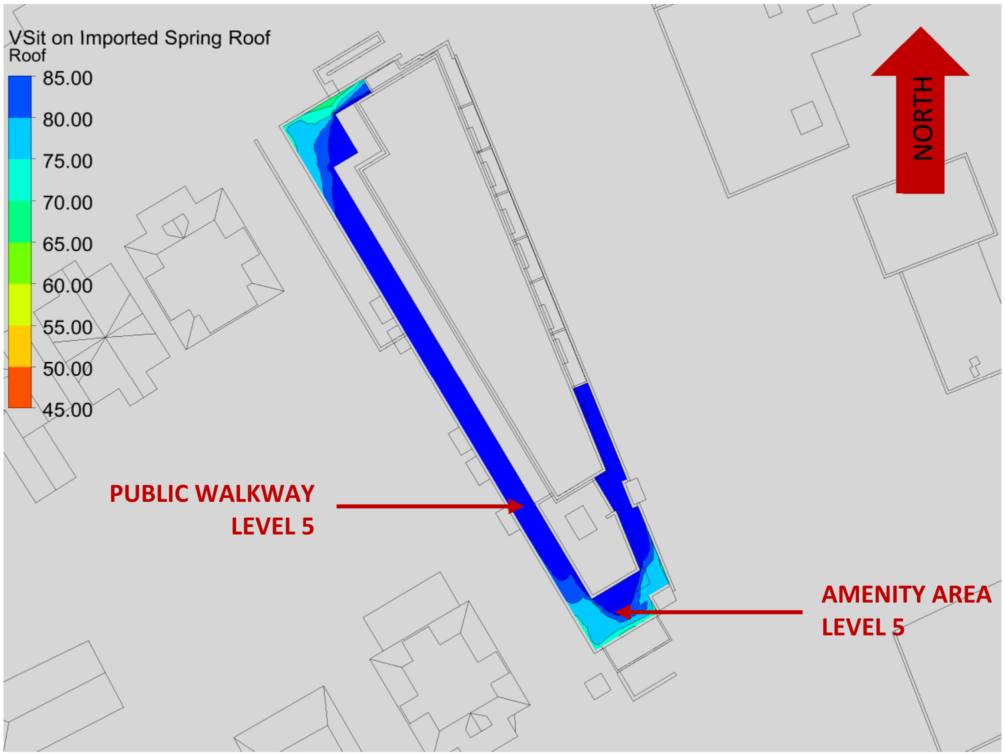


FIGURE 7A: SPRING – PERCENTAGE OF TIME SUITABLE FOR SITTING – LEVEL 5 TERRACE

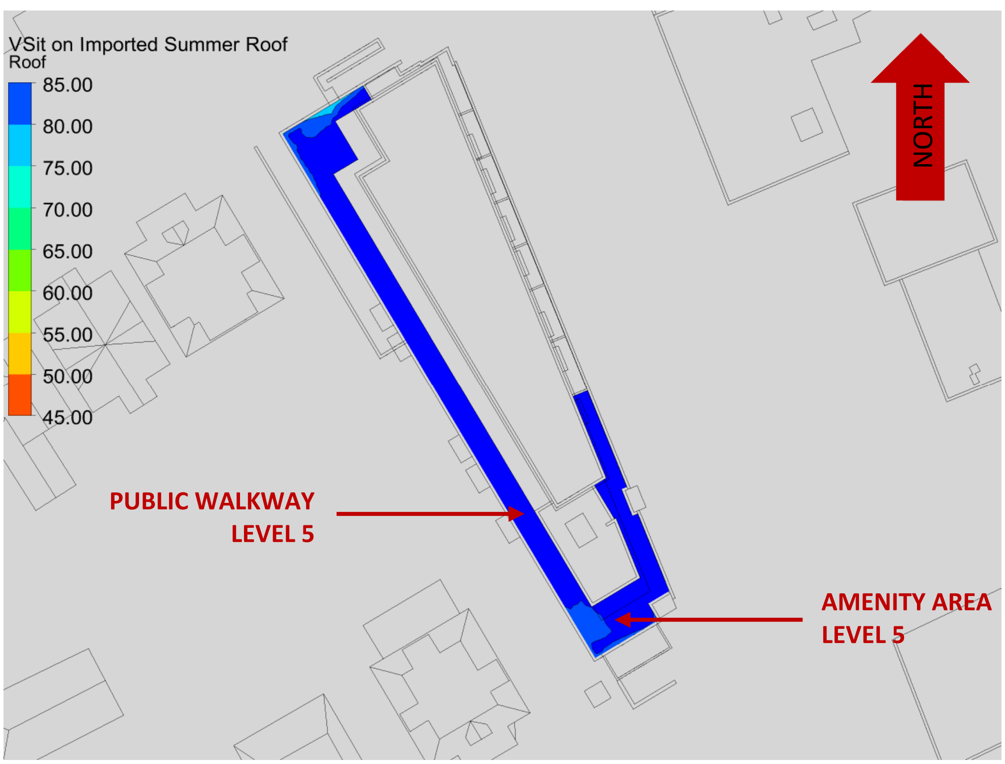


FIGURE 7B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING – LEVEL 5 TERRACE

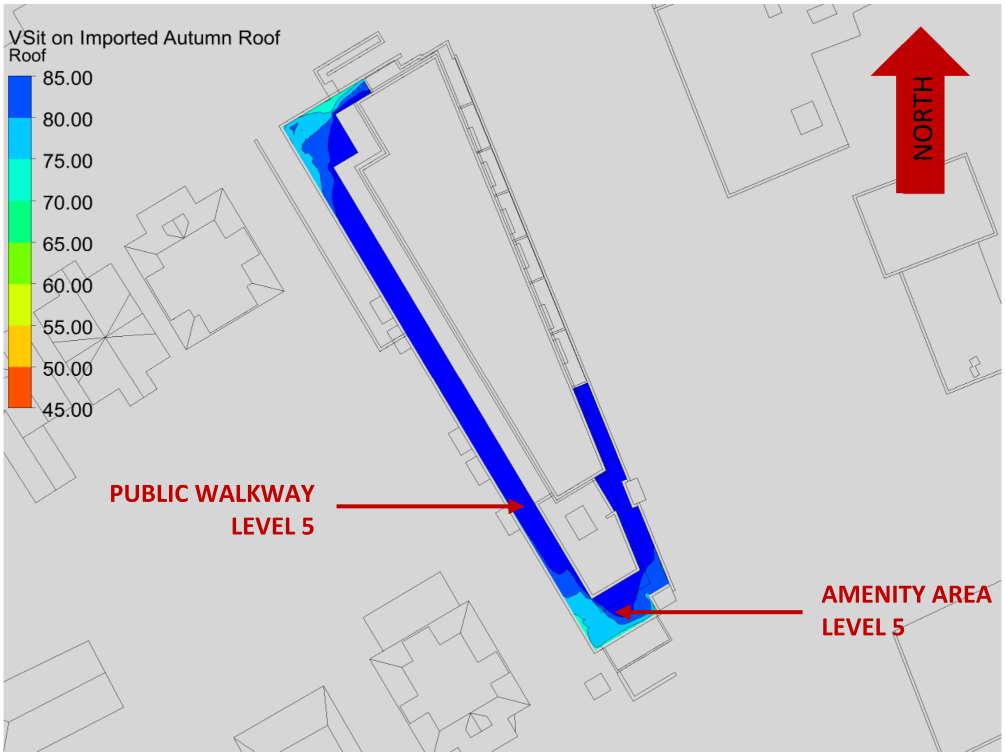


FIGURE 7C: AUTUMN – PERCENTAGE OF TIME SUITABLE FOR SITTING – LEVEL 5 TERRACE

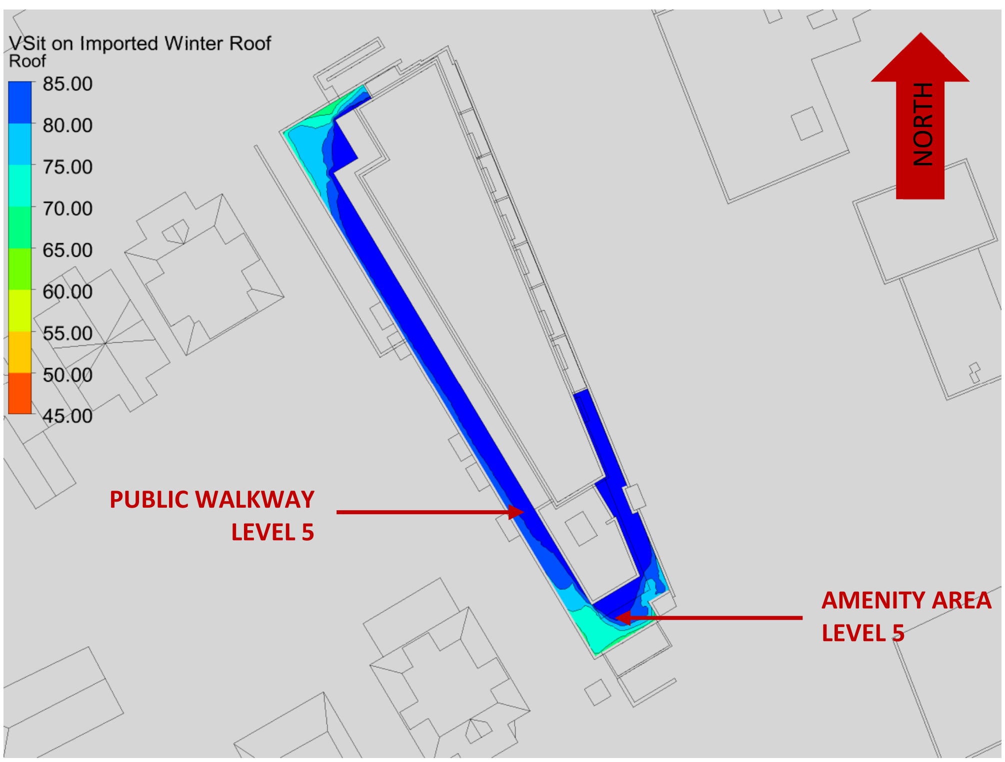


FIGURE 7D: WINTER – PERCENTAGE OF TIME SUITABLE FOR SITTING – LEVEL 5 TERRACE

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

127 WALGREEN ROAD, OTTAWA, ON, CANADA K0A 1L0 | 613 836 0934
GRADIENTWIND.COM

SIMULATION OF THE NATURAL WIND

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

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

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

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

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

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

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 centre of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel center-line axis.

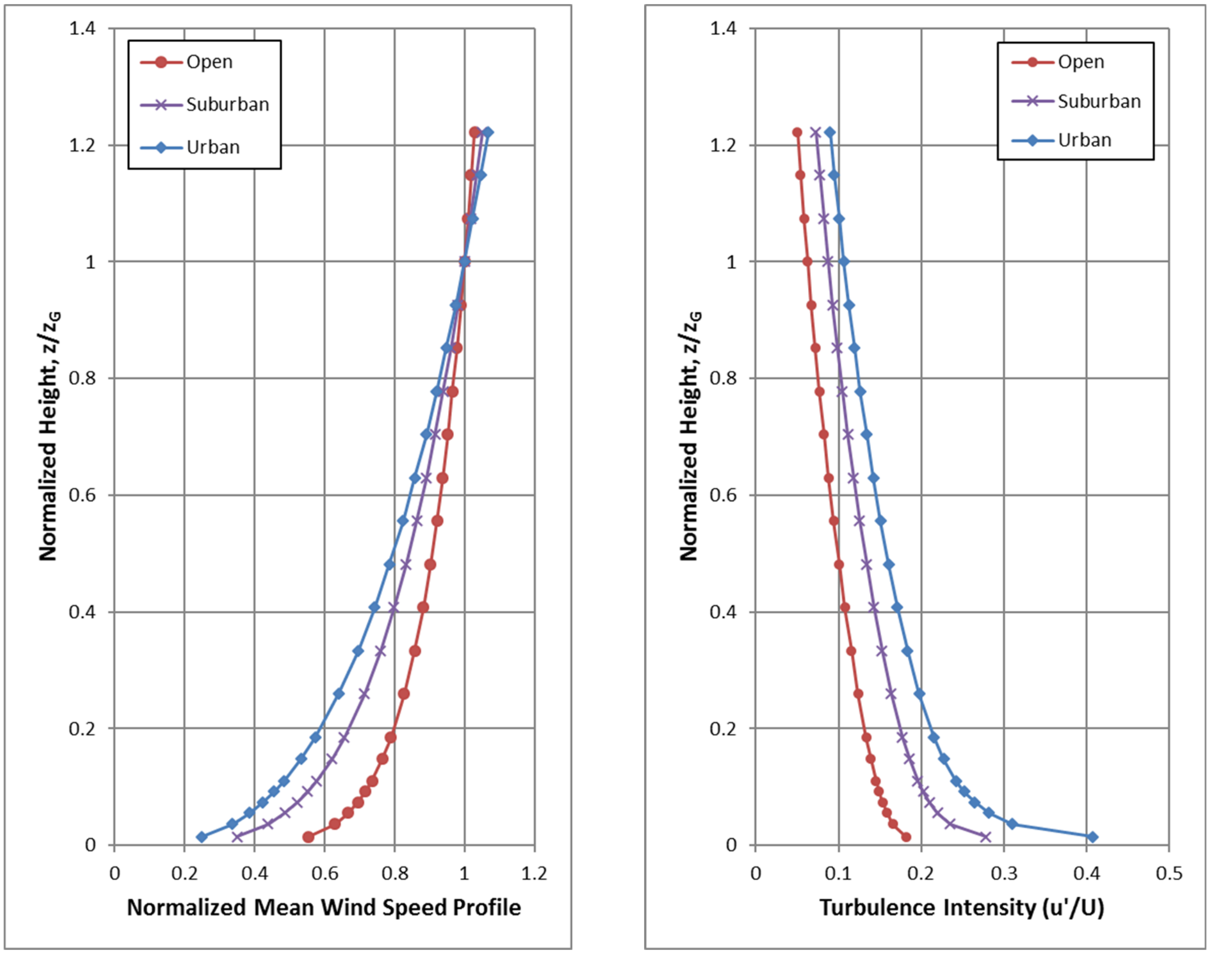


FIGURE A1 (LEFT): MEAN WIND SPEED PROFILES;
FIGURE A2 (RIGHT): TURBULENCE INTENSITY PROFILES

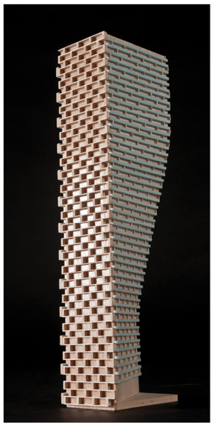
REFERENCES

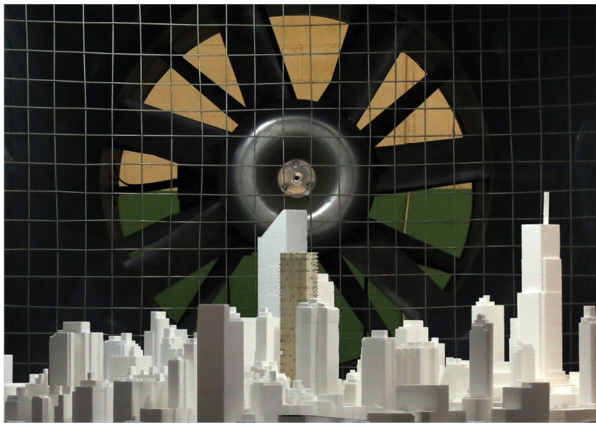
1. Teunissen, H.W., 'Characteristics of The Mean Wind And Turbulence In The Planetary Boundary Layer', Institute For Aerospace Studies, University Of Toronto, UTIAS # 32, Oct. 1970

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





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

127 WALGREEN ROAD, OTTAWA, ON, CANADA K0A 1L0 | 613 836 0934
GRADIENTWIND.COM

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:

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

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

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

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

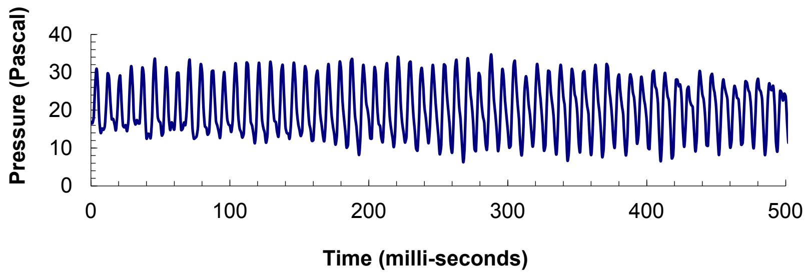


FIGURE B1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

REFERENCES

1. Davenport, A.G., '*The Dependence of Wind Loading on Meteorological Parameters*', Proc. of Int. Res. Seminar, Wind Effects on Buildings & Structures, NRC, Ottawa, 1967, University of Toronto Press.

2. Wu, S., Bose, N., 'An *Extended Power Law Model for the Calibration of Hot-wire/Hot-film Constant Temperature Probes*', Int. J. of Heat Mass Transfer, Vol.17, No.3, pp.437-442, Pergamon Press.