Pedestrian Level Wind Study

1705 Carling Avenue

Ottawa, Ontario

REPORT: GWE18-056-CFDPLW

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EXECUTIVE SUMMARY

This report describes a computer-based pedestrian level wind study for a proposed mixed-use development with residential care facility and apartment dwelling occupancies, located at 1705 Carling Avenue 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 following paragraphs and detailed 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, and reference to City of Ottawa pedestrian wind speed criteria, we conclude that all grade level areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal basis. More specifically, surrounding sidewalks, walkways, building access points, nearby transit stops, the landscaped courtyard, and the newly created park to the northwest of the site will experience appropriate wind conditions throughout the year.

The rooftop terrace at the north side of the building will be comfortable for sitting during the summer months without the need for mitigation. For the rooftop terraces at the west side of the building, it is recommended that 1.8 m tall high-solidity wind barriers be installed along the perimeter of the terraces to ensure conditions will be suitable for sitting or more sedentary activities during the typical use period.

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

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1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by The Founders Residences Ottawa LP to undertake a computer-based pedestrian level wind (PLW) study for 1705 Carling Avenue in Ottawa, Ontario. Our mandate within this study, as outlined in GWE proposal #18-061P, dated March 6, 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 CFD simulation and data analysis procedures, architectural drawings provided by Roderick Lahey Architect Inc. in April 2018, 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 a proposed mixed-use development with residential care facility and apartment dwelling occupancies, located at 1705 Carling Avenue in Ottawa, Ontario. The study site is located in the middle of a parcel of land bounded by Carlin Avenue to the south, Cole Avenue to the east, Tillbury Avenue to the north, and Highland Avenue to the west. In the near-field, the site is surrounded by suburban low-rise residential developments along the north side of Carling Avenue and low-rise commercial developments on the south side. Farther away from the study site, the area composition is characterized by a mixture of parks and low-rise suburban buildings from the southeast clockwise to the south, and predominantly low-rise suburban exposure in all other directions. The Queensway lies approximately 400 metres to the south of the study site and runs from southwest-northeast. An open exposure created by the Central Experimental Farm lies approximately 2.5 kilometres to the east of the site, and the Ottawa River is approximately 1.5 kilometres to the northwest.

The proposed development features a nine-storey building and will reach a maximum height of 32.1 metres, measured from grade to the top of the mechanical penthouse. The building planform is T-shaped with the top of the ‘T’ oriented along Carling Avenue. A landscaped courtyard is located at the northwest inset of the building, and a future park will be located to the northwest of the site. A ramp at the northeast inset of the building provides access to underground parking, and is accessed from Carling Avenue along the east side of the building. The main building access points are at the centre of the south elevation from Carling Avenue and at the northeast inset by a vehicle drop-off area. The ground floor contains shared building amenity spaces including a dining hall and recreational space. Level 2 and above comprises residential units. The building planform remains constant until Level 7, where the floorplate sets back from the southwest corner of the west wing to create an outdoor amenity space. The floorplate also sets back at Level 8 on the northwest corner of the west wing and the north side of the north wing to create outdoor amenity spaces.

Key areas under consideration for pedestrian wind comfort include surrounding sidewalks, walkways, building access points, nearby transit stops, the landscaped courtyard, the newly created park to the northwest of the site, and the various rooftop outdoor amenity areas. Figure 1A illustrates the study site and surrounding context, while Figure 1B illustrates elevated outdoor amenity areas. Figures 2A and 2B illustrate the computational model used to conduct the study.

3. OBJECTIVES

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

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on Computational Fluid Dynamics (CFD) simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the 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

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

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.

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 for 12 wind directions over a CFD simulation model centered on the study building, and encompassing surrounding massing within a diameter of approximately 822 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.

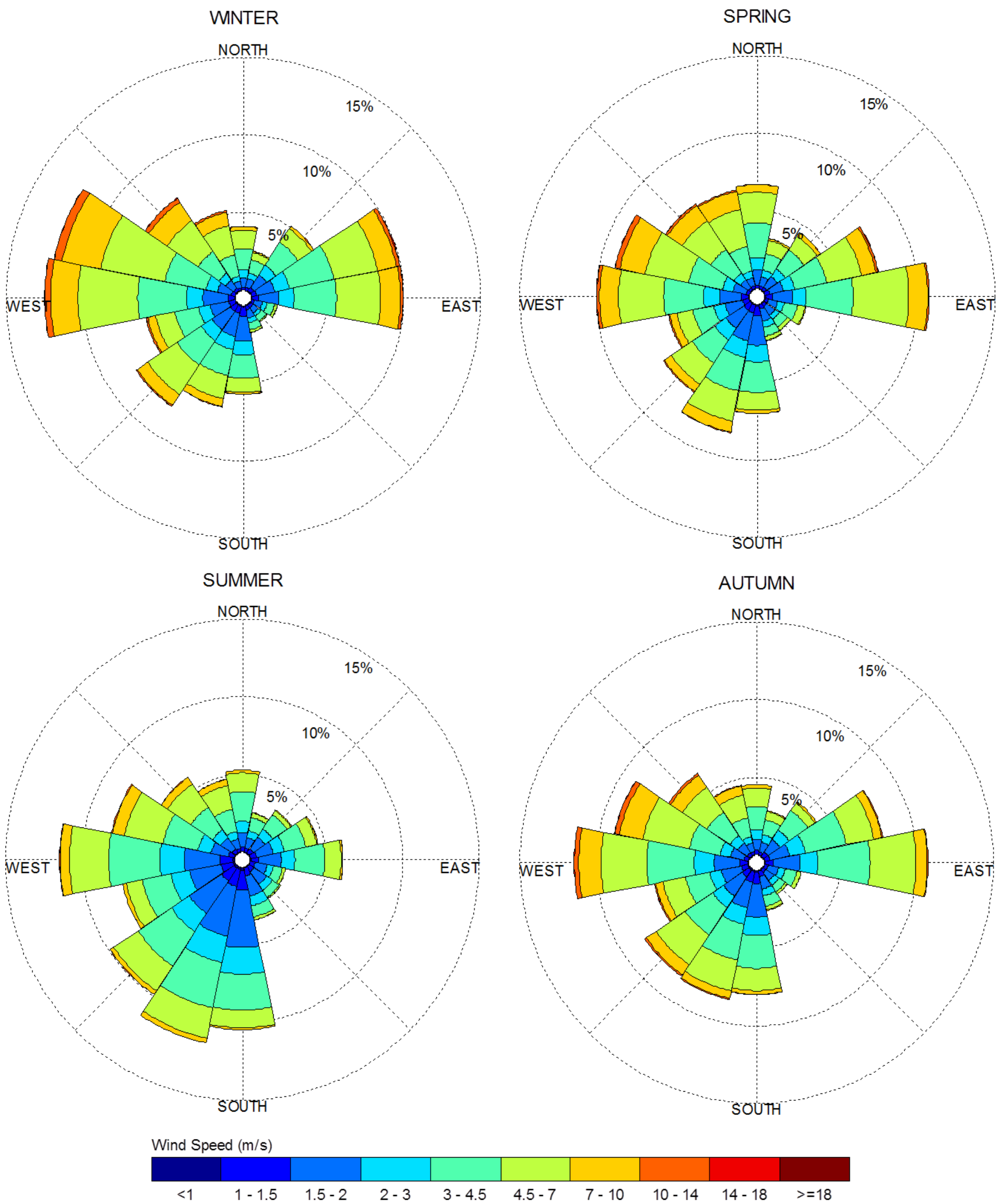
4.3 Meteorological Data Analysis

A statistical model for winds in 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 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 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 10 metres per second (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. Wind speeds represent mean hourly wind speeds measured at 10 m above the ground.

4.4 Pedestrian Comfort Guidelines

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

(i) **Sitting:** Mean wind speeds less than or equal to 10 kilometers 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 criteria 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 criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established across the study site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type. An overview of common pedestrian location types and their desired comfort classes are summarized on the following page.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

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

5. RESULTS AND DISCUSSION

The foregoing discussion of predicted pedestrian wind conditions for the study site is accompanied by Figures 3A through 6B (following the main text) illustrating the seasonal wind conditions at grade level and on the roof patio. The colour contours indicate predicted regions of the various comfort classes. Wind conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing are represented by yellow, strolling by salmon and conditions suitable for walking are represented by blue. The colour magenta indicates wind conditions considered uncomfortable for walking.

Carling Avenue Sidewalk including Building Entrance (Tags A & B): The sidewalk along the south side of the building (Tag A) will mostly be comfortable for sitting during the summer season, becoming suitable for standing, or better, during the remaining seasons. Towards the southeast and southwest corners of the building, conditions will be somewhat windier and suitable for standing for all seasons except winter, where conditions on the southwest corner will become suitable for strolling. At the senior's condominium/residential care facility entrance along the south elevation (Tag B), conditions will be calmer and comfortable for sitting throughout the year. The noted conditions are acceptable for the intended pedestrian uses of the spaces.

Entrance Driveway Sidewalk and Drop-Off Area Including Entrances (Tags C & D): The sidewalk along the east side of the building (Tag C) will be comfortable for sitting during the summer season, becoming suitable for standing, or better, during the remaining seasons. At the residential care facility entrance (Tag D), conditions will be calmer and comfortable for sitting throughout the year. The noted conditions are acceptable for the intended pedestrian uses of the spaces.

North Parking Lot, Loading Dock and Underground Parking Access (Tag E): The parking lot to the north of the building will be comfortable for standing, or better, during the spring, summer, and autumn seasons, becoming suitable for strolling during the winter. Closer to the building, including at the loading area and underground parking entrance, conditions will be calmer and comfortable for sitting throughout the year. The noted conditions are acceptable for the intended pedestrian uses of the spaces.

Landscaped Courtyard and Walkway (Tags F & G): The walkway within the northwest inset of the building (Tag F) will be comfortable for standing, or better, throughout the year, which is acceptable. The landscaped courtyard in the center of the walkway (Tag G) will be comfortable for sitting during the typical use period, defined as late spring through to early autumn, becoming suitable for standing, or better, during the remaining seasons.

Future Park (Tag H): The future park to the northwest of the development will be suitable for sitting during the typical use period, becoming suitable for standing, or better, during the remaining seasons, which is acceptable.

Rooftop Terraces (Tags I-K): For the rooftop terraces at the west side of the building (Tags I & J), wind conditions were measured to be comfortable for sitting or standing during the summer months. To ensure that conditions on these terrace spaces are suitable for sitting or more sedentary activities during the typical use period, defined as late spring through early autumn, we recommend introducing 1.8 m tall solid wind barriers in place of the standard terrace guards along the perimeter of the terraces. The wind barriers may take the form of high-solidity architectural wind screens and/or dense coniferous plantings. For the north rooftop terrace (Tag K), conditions will be comfortable for sitting or more sedentary activities throughout the summer months, without the need for mitigation. If seating conditions extending into the spring and autumn are desired, it is recommended to introduce 1.8 m tall wind guards around the terrace perimeter.

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 and bus stops, will be comfortable for their intended pedestrian uses during each seasonal period upon the introduction of the proposed development at 1705 Carling Avenue.

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. SUMMARY AND RECOMMENDATIONS

This document summarizes the results of a pedestrian level wind study undertaken to assess wind for the proposed mixed-use development with residential care facility and apartment dwelling occupancies, located at 1705 Carling Avenue in Ottawa, Ontario. This work is based on industry standard CFD simulation and data analysis procedures, architectural drawings provided by Roderick Lahey Architect Inc. in April 2018, surrounding street layouts, existing and approved future building massing information obtained from the City of Ottawa, and recent site imagery.

Based on CFD test results, interpretation, and 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 basis. More specifically, surrounding sidewalks, walkways, building access points, nearby transit stops, the landscaped courtyard, and the newly created park to the northwest of the site will experience acceptable wind conditions throughout the year.

The rooftop terrace at the north side of the building will be comfortable for sitting during the summer months without the need for mitigation. For the rooftop terraces at the west side of the building, it is recommended that 1.8 m tall high-solidity wind barriers be installed along the perimeter of the terraces to ensure conditions will be suitable for sitting or more sedentary activities during the typical use period.

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

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

Sincerely,

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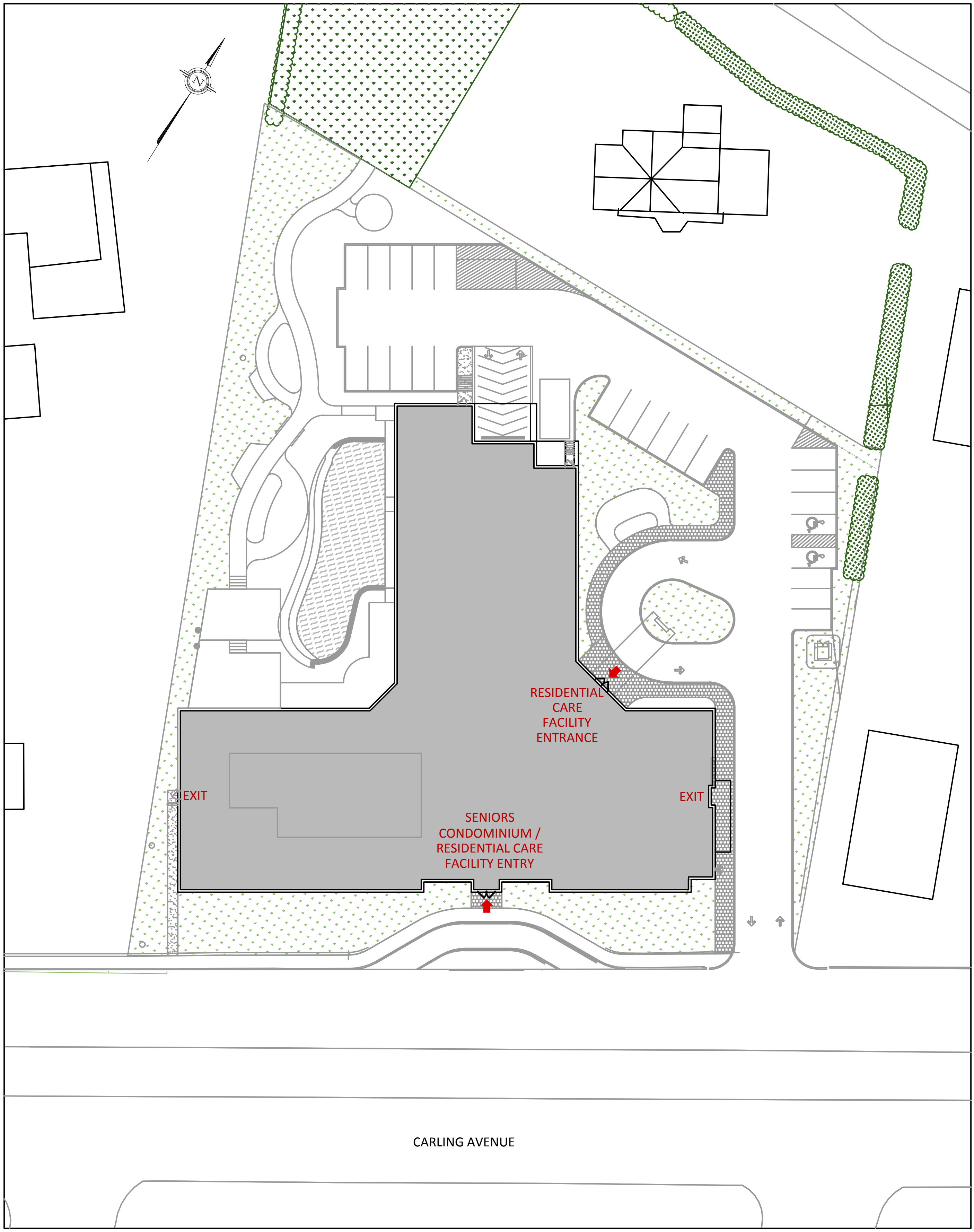

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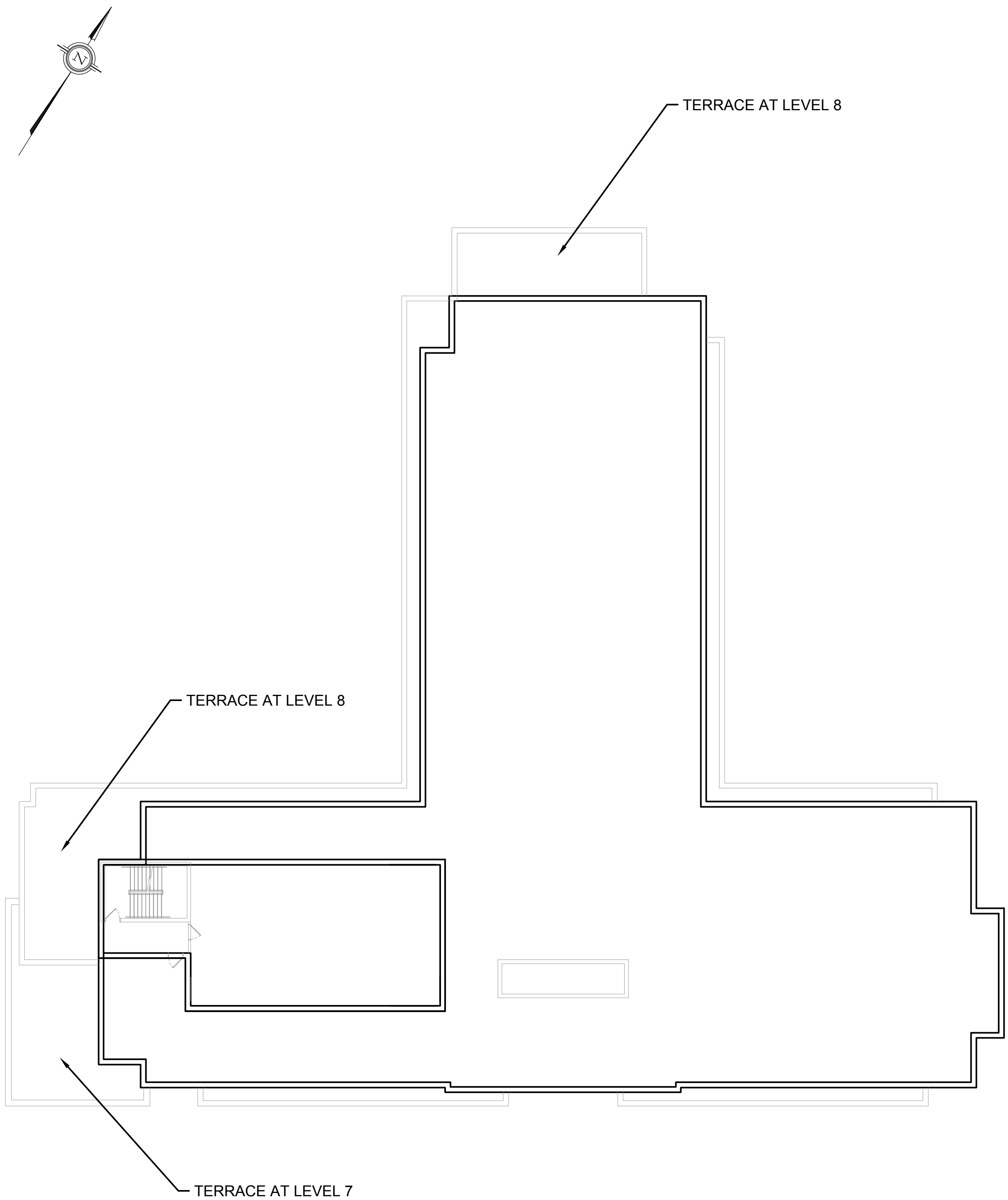
PROJECT: 1705 CARLING AVENUE, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 1A: SITE PLAN AND SURROUNDING CONTEXT
SCALE: 1:600 (APPROX.)	DRAWING NO. GWE18-056-PLW-1A	
DATE: APRIL 19, 2018	DRAWN BY: K.A.	



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PROJECT 1705 CARLING AVENUE, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION FIGURE 1B: ROOF PLAN
SCALE 1:400 (APPROX.)	DRAWING NO. GWE18-056-PLW-1B	
DATE APRIL 19, 2018	DRAWN BY K.A.	

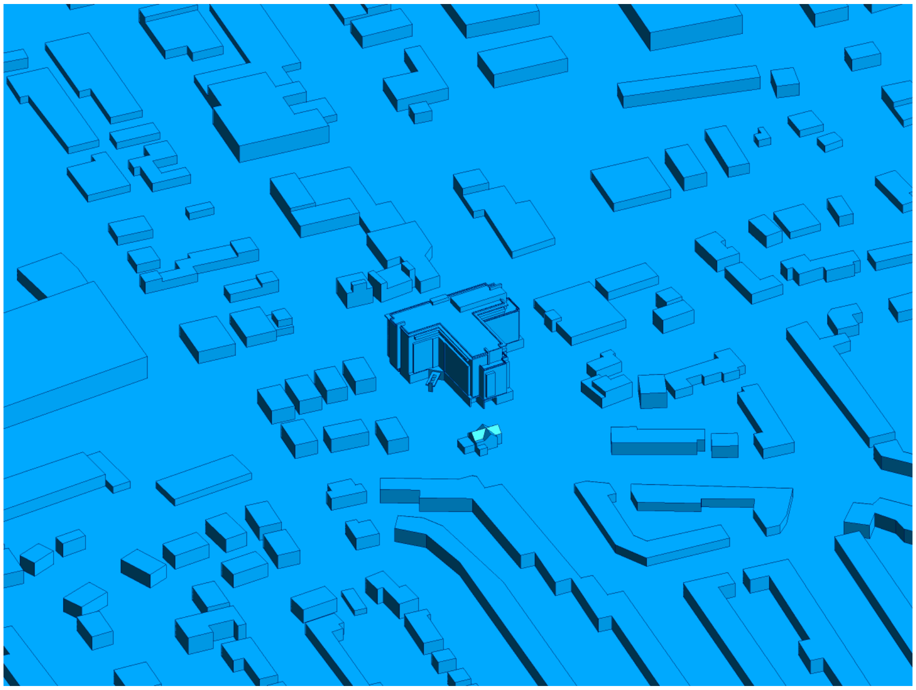


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

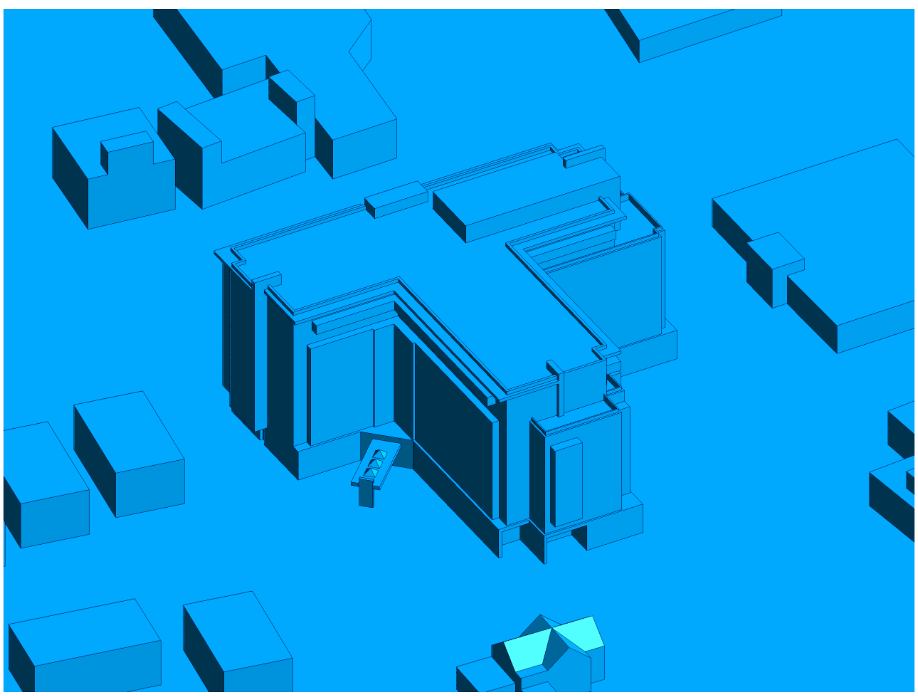


FIGURE 2B: STUDY BUILDING, NORTH PERSPECTIVE

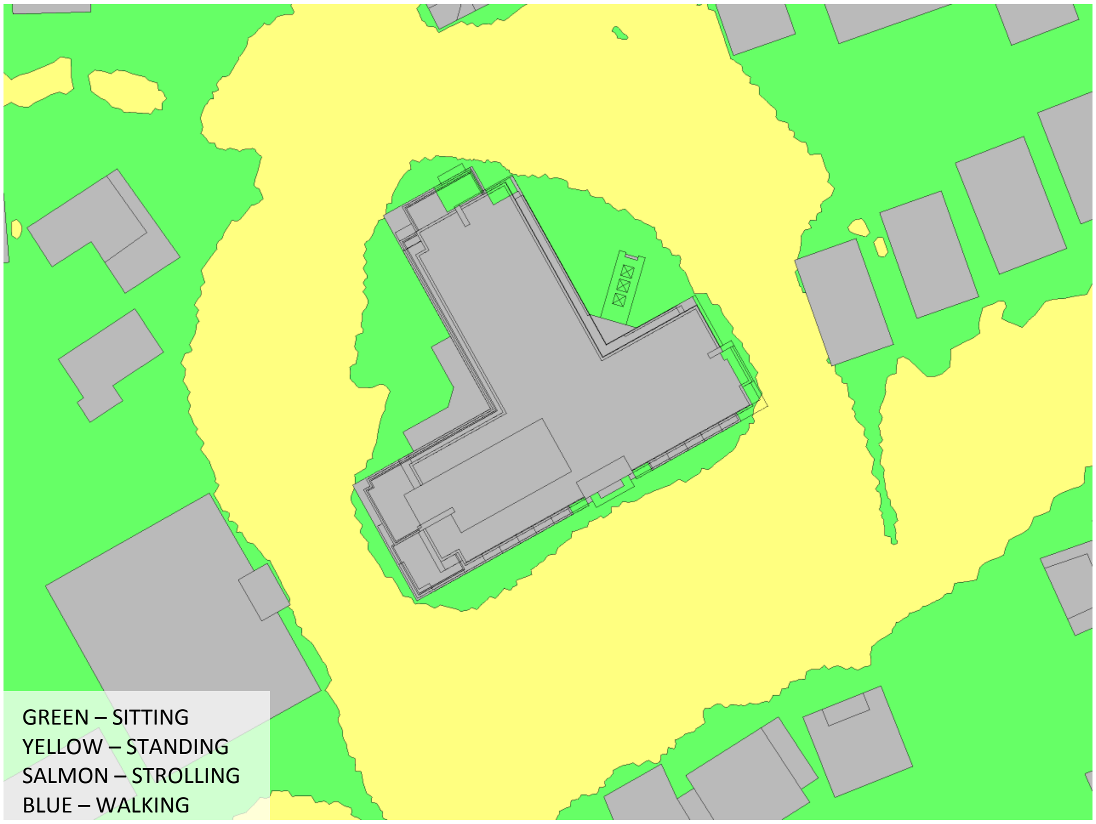
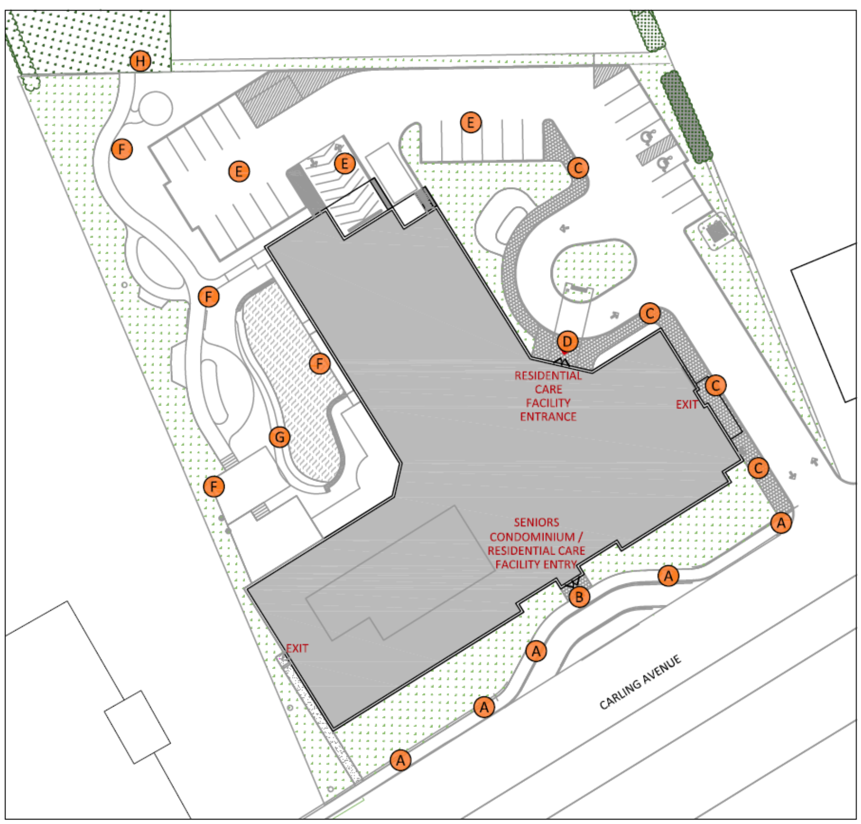
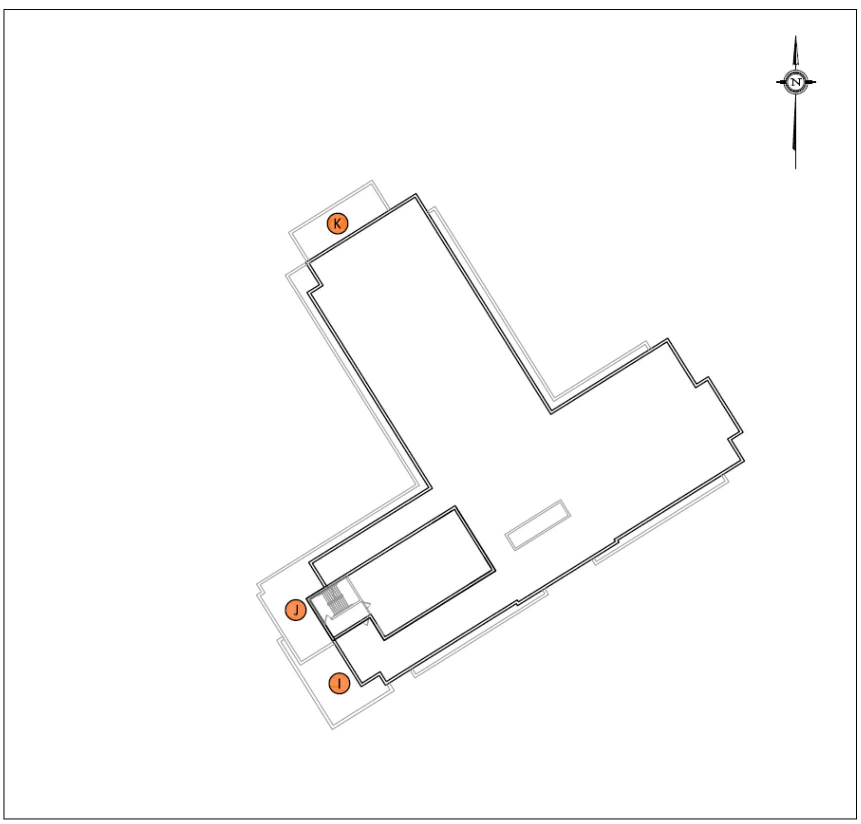


FIGURE 3A: SPRING – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



1705 CARLING AVENUE – GRADE REFERENCE MARKER LOCATIONS

FIGURE 3B: SPRING – OUTDOOR AMENITY AREA WIND CONDITIONS



1705 CARLING AVENUE – PATIO REFERENCE MARKER LOCATIONS

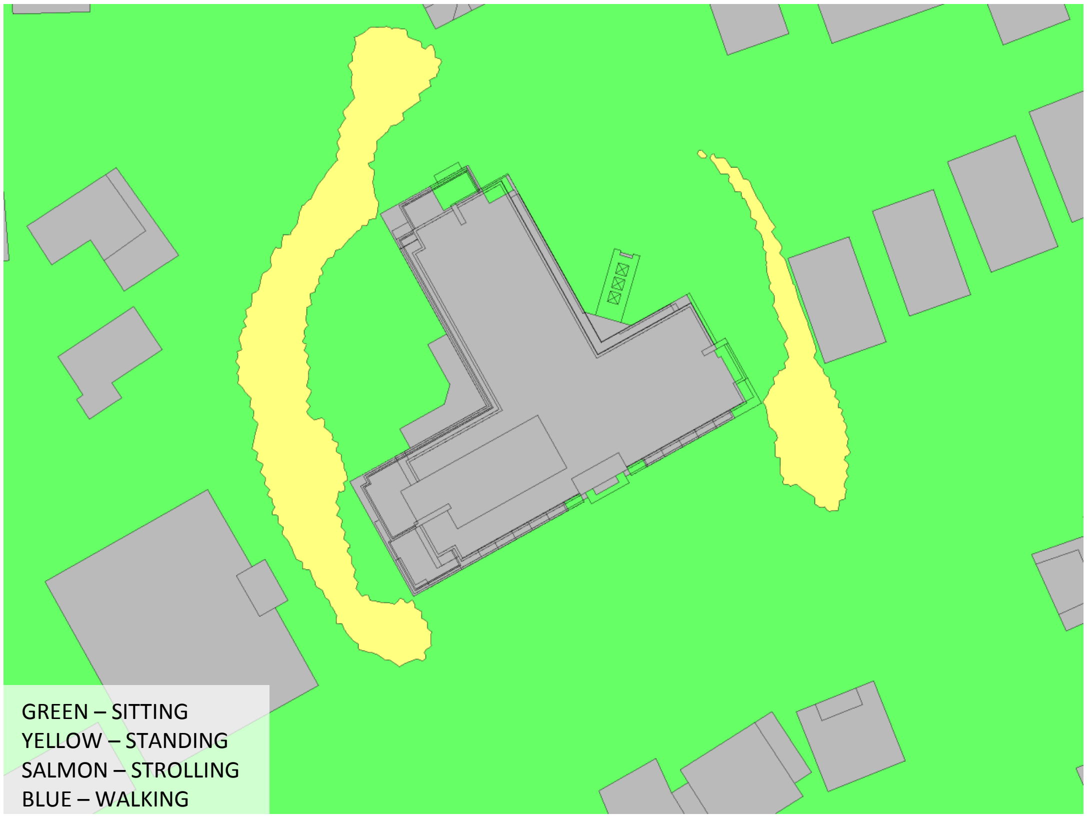
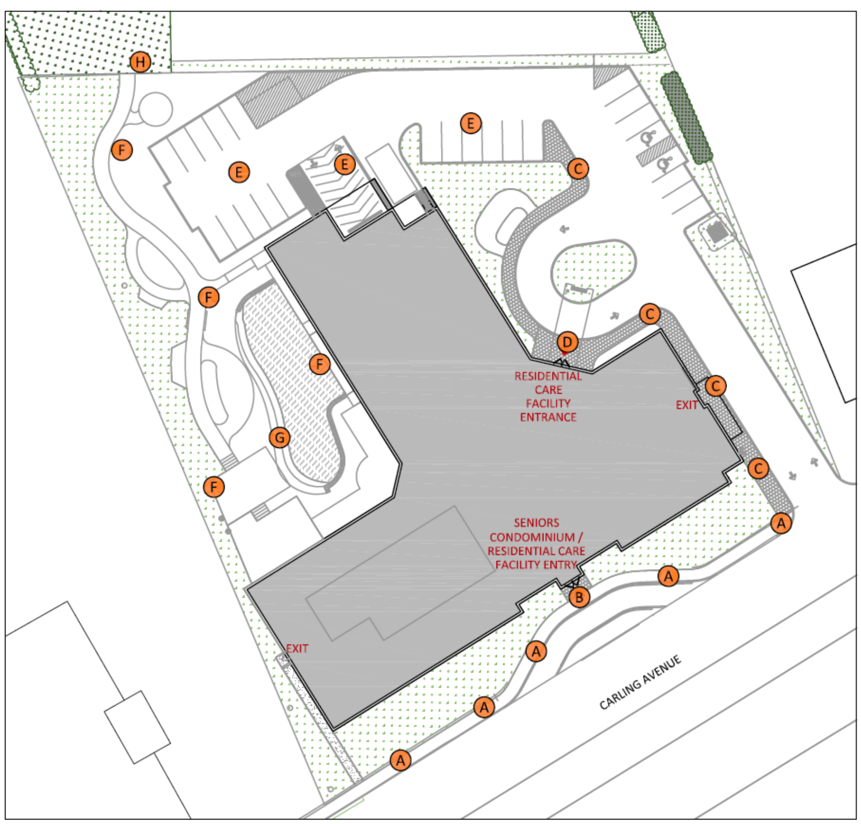
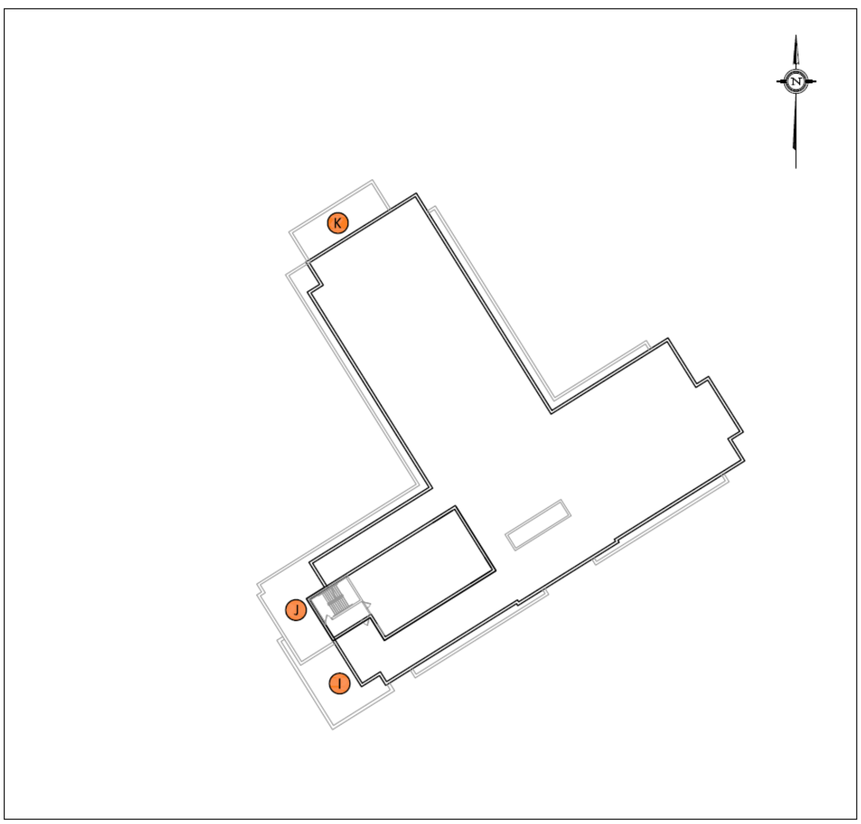


FIGURE 4A: SUMMER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



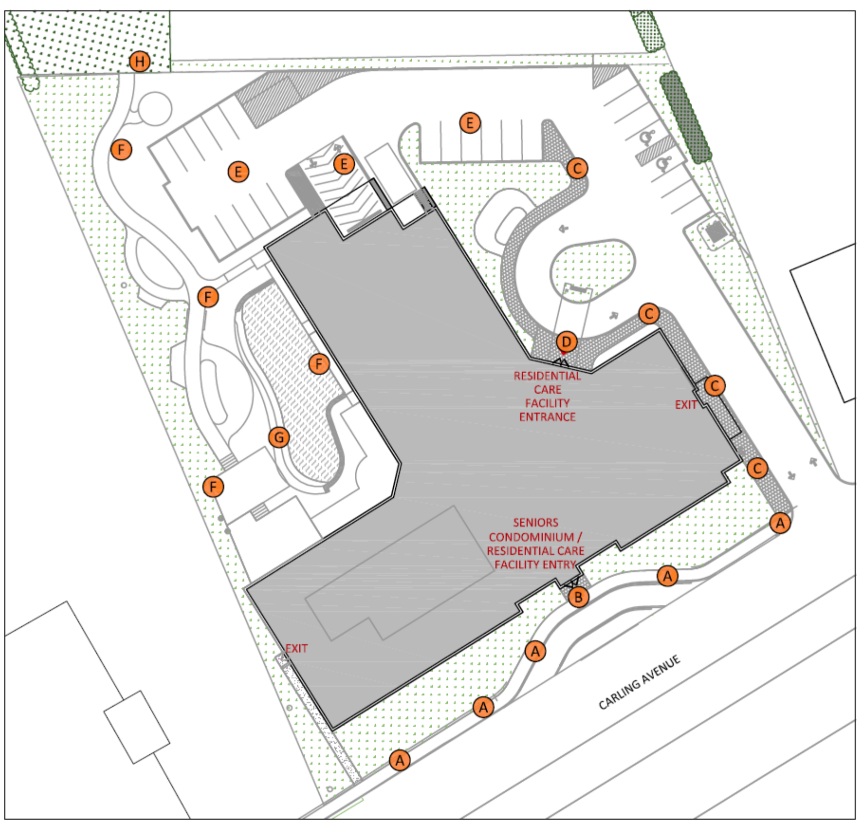
1705 CARLING AVENUE – GRADE REFERENCE MARKER LOCATIONS

FIGURE 4B: SUMMER – OUTDOOR AMENITY AREA WIND CONDITIONS



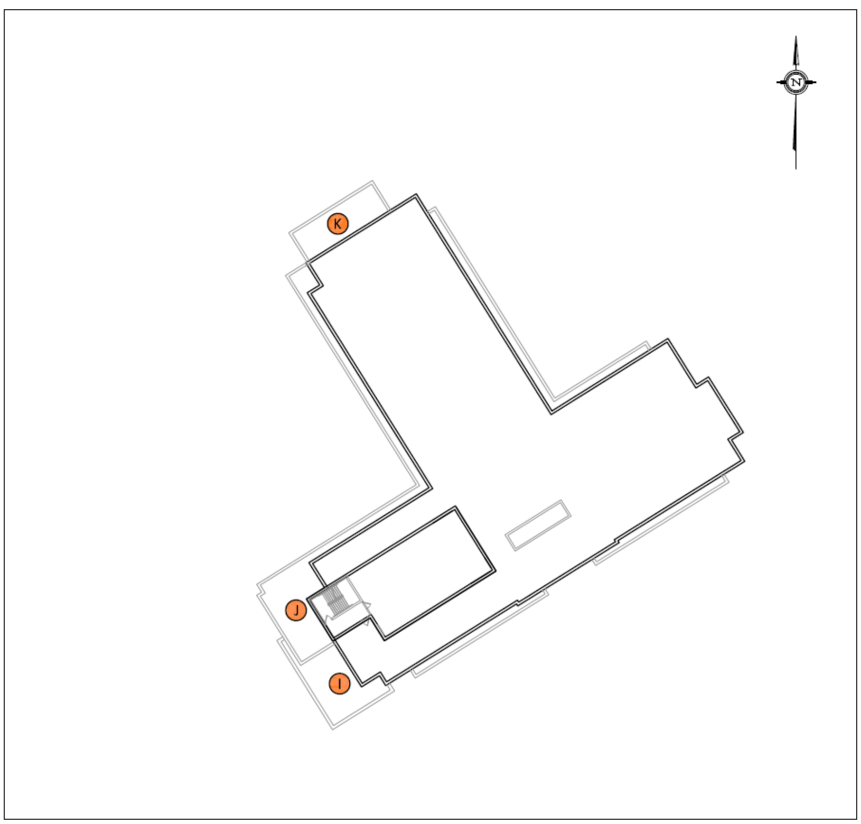
1705 CARLING AVENUE – PATIO REFERENCE MARKER LOCATIONS

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



1705 CARLING AVENUE – GRADE REFERENCE MARKER LOCATIONS

FIGURE 5B: AUTUMN – OUTDOOR AMENITY AREA WIND CONDITIONS



1705 CARLING AVENUE – PATIO REFERENCE MARKER LOCATIONS

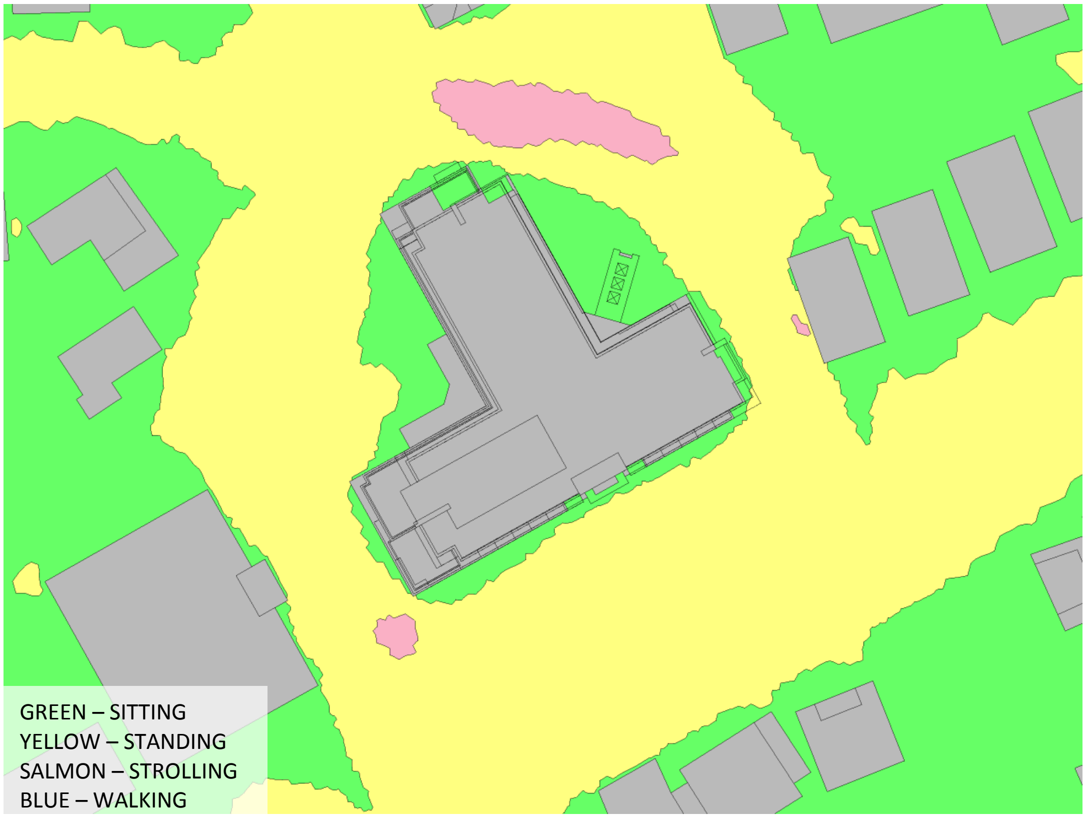
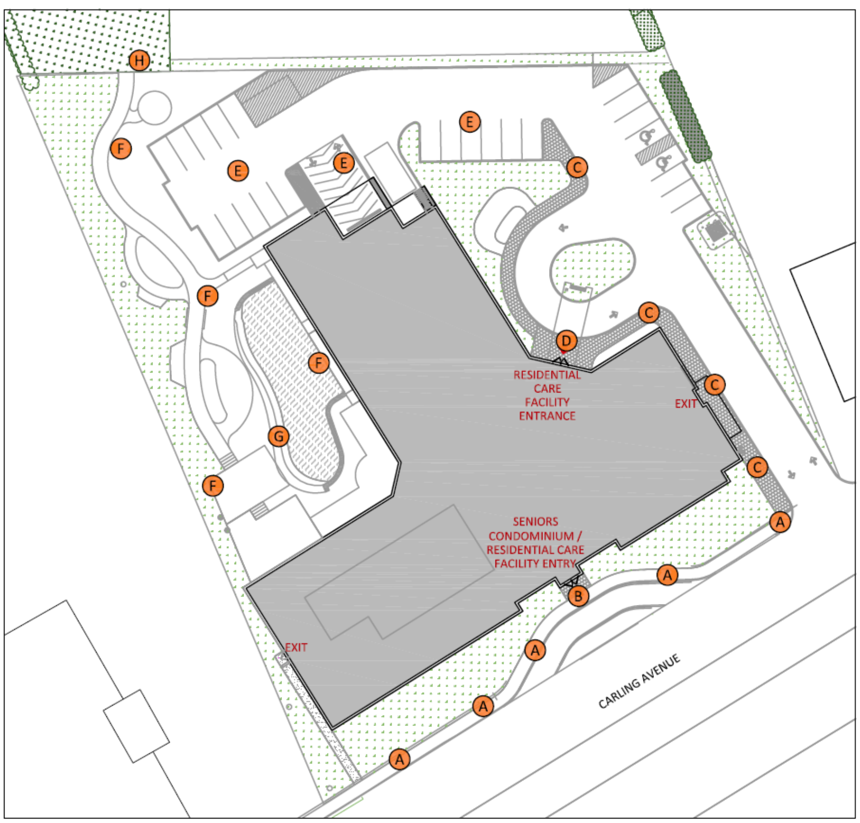
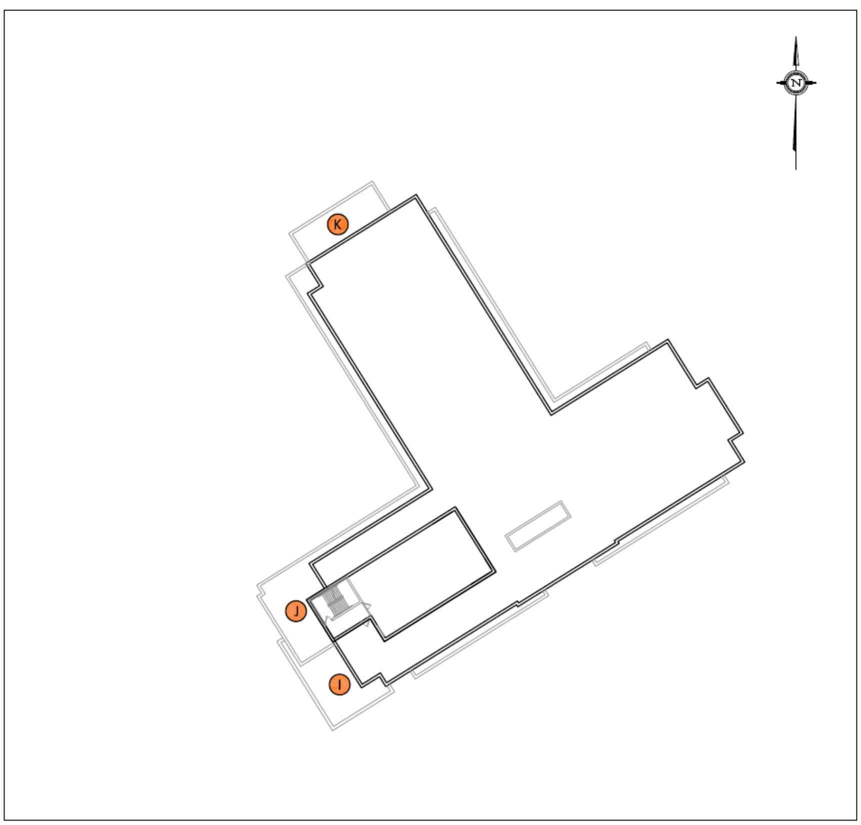


FIGURE 6A: WINTER – GRADE-LEVEL PEDESTRIAN WIND CONDITIONS



1705 CARLING AVENUE – GRADE REFERENCE MARKER LOCATIONS

FIGURE 6B: WINTER – OUTDOOR AMENITY AREA WIND CONDITIONS



1705 CARLING AVENUE – PATIO REFERENCE MARKER LOCATIONS

APPENDIX A

SIMULATION OF THE NATURAL WIND

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

WIND TUNNEL SIMULATION OF THE NATURAL WIND

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

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

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

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 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***, ***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.

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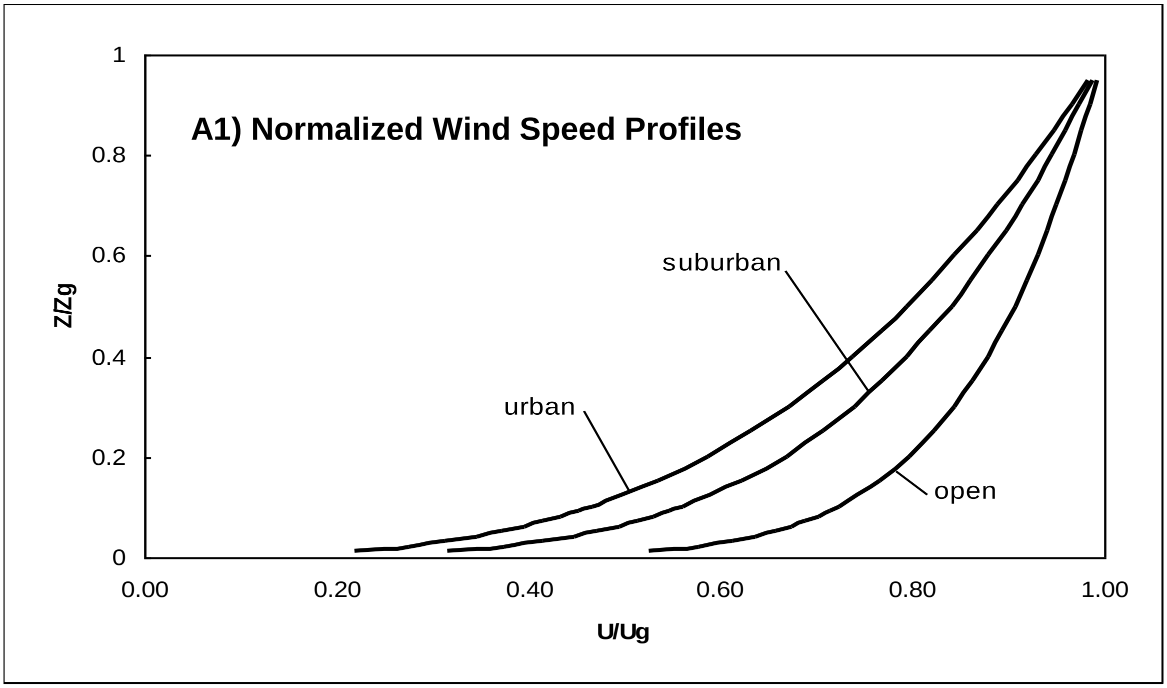


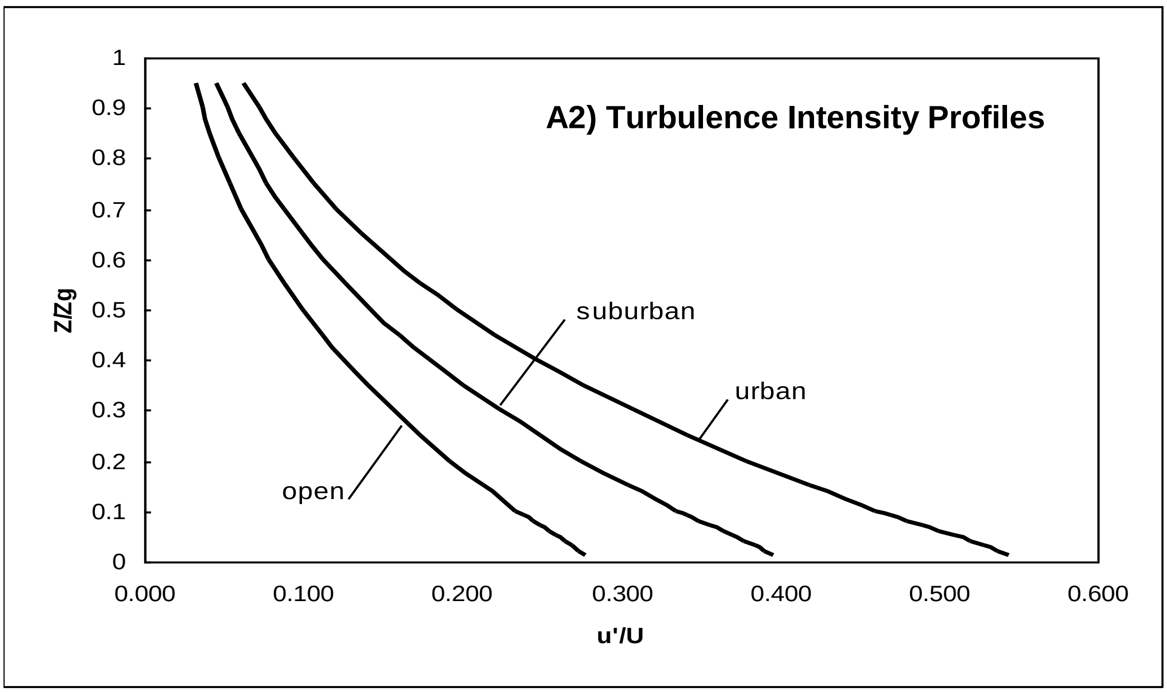


Figure A1 (Top): Mean Wind Speed Profiles

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:

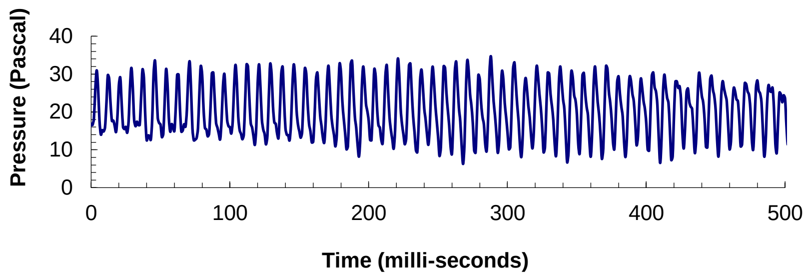
$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

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

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

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

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



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