

**PEDESTRIAN LEVEL
WIND STUDY**

2829 DUMAURIER AVENUE
OTTAWA, ONTARIO

Report: 20-150-PLW



January 22, 2021

PREPARED FOR

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study to satisfy Zoning By-law Amendment (ZBA) and Site Plan Control Application (SPA) requirements for a proposed mixed-use development located at 2829 Dumaaurier Avenue 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, as required.

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 wind comfort and safety within and surrounding the subject 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, illustrated in Figures 3A-5D, and summarized as follows:

- 1) All areas at grade will be suitable for their intended uses throughout the year. This includes all building access points, nearby sidewalks, walkways, surface parking areas, and landscaped areas.
- 2) Wind conditions over the north amenity terrace at Level 7, atop the podium, are predicted to be suitable for a mix of sitting and standing during the summer season, becoming suitable for a mix of standing and strolling during the spring and autumn seasons. During the winter season, conditions are predicted to be suitable for a mix of standing, strolling, and walking.
 - a. The noted wind comfort predictions correspond to an extensive mitigation strategy that has been developed by the design team, including the landscape architect. With the noted mitigation strategy, the areas predicted to be suitable for standing during the summer season are also predicted to be suitable for sitting at least 65% of the time, as illustrated in Figure 5B. Since a reasonable level of mitigation has been considered in the landscape plan on account of the suburban exposures for the prominent wind directions, the noted conditions are considered satisfactory for the intended uses of the areas.



- 3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level or on the elevated amenity terraces were found to experience conditions that could be considered dangerous, as defined in Section 4.4.
- 4) Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associated hardware



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1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Brigil to undertake a pedestrian level wind (PLW) study to satisfy Zoning By-law Amendment (ZBA) and Site Plan Control Application (SPA) submission requirements for a proposed mixed-use development located at 2829 Dumaaurier Avenue 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, as required.

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 of the subject site provided by RLA Inc. in December 2020, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery.

2. TERMS OF REFERENCE

The focus of this PLW study is a proposed 30-storey mixed-use development located at 2829 Dumaaurier Avenue in Ottawa, Ontario. The subject site is situated on a parcel of land bounded by Dumaaurier Avenue to the east and existing developments to the north, west, and south.

The proposed building comprises a 30-storey tower which rises from the south leg of a six-storey L-shaped podium. The building steps back from all elevations at Level 7, which provides for outdoor amenity space on the roof of the podium at the north end of the tower. The tower sets back from all elevations at Level 29, and again from the north elevation at the MPH Floor.



*Architectural Rendering, Southeast Perspective
(Courtesy of RLA Inc.)*



The ground floor includes lobby, commercial, indoor amenity, and building support services space. The primary residential entrance will be located near the centre of the east elevation. Commercial entrances will be located along the east and south sides of the building. A laneway to the south of the building provides access to at-grade parking along the west side of the property and to the underground parking entrance at the northwest corner of the building.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) include low-rise buildings, parkland, and a 14-storey residential building to the southwest. The far-field surroundings (defined as an area beyond the near-field but within a 2-kilometre (km) radius of the subject site) include primarily low-rise residential buildings in all directions, as well as mid-rise buildings along Redmond Road to the north, and near the intersection of Baseline Road and Greenbank road to the southeast. The Ottawa River lies approximately 1.4 km to the northwest.

Key areas under consideration include surrounding sidewalks, walkways, building access points, and the Level 7 amenity terrace. 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 criteria¹. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

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

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 Ottawa 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 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.

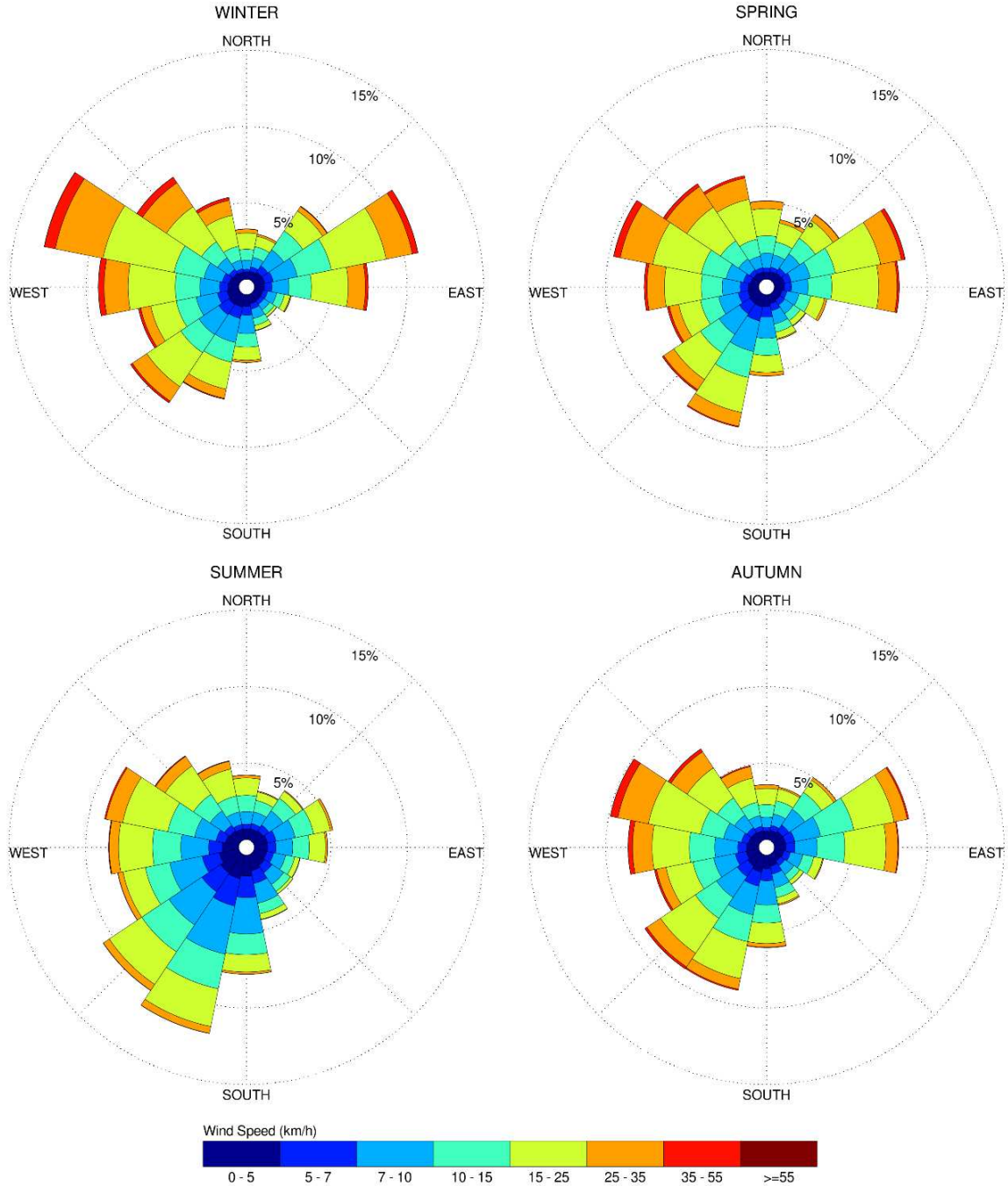
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds on a continuous measurement plane 1.5 m above local grade and above the elevated amenity terraces were 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. Further details of the CFD wind flow simulation technique are presented in Appendix A.

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 Ottawa 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 to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns.

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 WIND OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT



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 criteria 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 equivalent gust 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 equivalent gust 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 equivalent gust 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 equivalent gust 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 BEAUFORT SCALE

Number	Description	Wind Speed (km/h)		Description
		Mean	Gust	
2	Light Breeze	6-11	9-17	Wind felt on faces
3	Gentle Breeze	12-19	18-29	Leaves and small twigs in constant motion; wind extends light flags
4	Moderate Breeze	20-28	30-42	Wind raises dust and loose paper; small branches are moved
5	Fresh Breeze	29-38	43-57	Small trees in leaf begin to sway
6	Strong Breeze	39-49	58-74	Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty
7	Moderate Gale	50-61	75-92	Whole trees in motion; inconvenient walking against wind
8	Gale	62-74	93-111	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 a mean wind speed of 10 km/h were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting. Similarly, if mean wind speed of 20 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As 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 throughout the site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for discrete regions within and surrounding the subject site. This step involves comparing the predicted comfort classes to the desired comfort classes, which are dictated by the location type for each region (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	Standing / Strolling / Walking
Primary Public Sidewalk	Strolling / Walking
Secondary Public Sidewalk / Bicycle Path	Walking
Outdoor Amenity Space	Sitting / Standing / Strolling
Café / Patio / Bench / Garden	Sitting
Transit Stop	Sitting / Standing
Public Park / Plaza	Standing / Strolling
Garage / Service Entrance	Walking
Parking Lot	Strolling / Walking
Vehicular Drop-Off Zone	Standing / Strolling / Walking

5. RESULTS AND DISCUSSION

The following discussion of predicted pedestrian wind conditions is accompanied by Figures 3A-3D and Figures 4A-4D (following the main text), illustrating seasonal wind comfort conditions at grade level and within the elevated amenity terrace at Level 7, respectively. Wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site. The colour contours indicate various comfort classes predicted for certain regions, which correspond to the City of Ottawa wind comfort criteria in Section 4.4.

Conditions comfortable for sitting or more sedentary activities are represented by the colour green, standing by yellow, strolling by orange, and walking by blue. Uncomfortable wind conditions are represented by the colour magenta. In addition to the wind comfort results, Figures 5A-5D illustrate the percentage of time during each season that wind conditions will be suitable for sitting on the amenity terrace at Level 7. Wind conditions are summarized on the following pages for each area of interest.

5.1 Wind Comfort – Grade Level

Dumaurier Avenue: Conditions along Dumaurier Avenue are predicted to be suitable for a mix of sitting and standing during the summer season and suitable for strolling, or better, during the spring and autumn seasons. During the winter season, the sidewalks are predicted to be suitable for walking or better.

Conditions are generally windiest near the northeast and southeast corners of the building, which are affected by downwash and acceleration of horizontal winds. Conditions are generally calm along the east edge of the property, excluding the noted corners. These conditions are acceptable according to the wind comfort criteria in Section 4.4.

Surface Parking: Conditions within the surface parking area to the west of the proposed building are predicted to be suitable for standing during the summer season and suitable for strolling, or better, during the remaining colder seasons. These conditions are acceptable according to the wind comfort criteria in Section 4.4.

Driveway, South of Proposed Building: The driveway at the south of the subject site is predicted to be suitable for a mix of sitting, standing, and strolling during the summer season. During the spring and autumn seasons, conditions are predicted to be suitable for walking, or better. During the winter season, uncomfortable conditions may develop along the driveway. However, the walkway, which is located on the north side of the driveway and adjacent to the south façade of the proposed building, is predicted to be suitable for walking, or better, during the coldest months of the year. These conditions are acceptable according to the wind comfort criteria in Section 4.4.

Primary Building Entrances: Wind conditions in the immediate vicinity of all primary building entrances serving the proposed development are predicted to be suitable for standing, or better, throughout the year. These conditions are considered acceptable according to the wind comfort criteria in Section 4.4.

5.2 Wind Comfort – Level 7 Amenity Terrace

The north podium roof, which is planned to serve amenity functions, includes 1.8-m-tall solid wind screens along the west, north, and east perimeters of the roof, stepping down to 1.1 m along the south perimeter. The amenity area also includes three groups of 1.1-m-tall solid high-back benches in equal pairs, with their long dimensions oriented north-south (perpendicular to the north perimeter of the roof). The landscape plan also includes 1.2-m-tall planters spaced between each set of benches. The noted planters include a coniferous tree per planter, rising to a total height of at least 3.2 m at the time of planting. Additionally, 1.2-m-tall planters are planned along the south end of the podium roof with their long dimensions oriented north-south.

With the noted mitigation measures, conditions over the north podium roof are predicted to be suitable for a mix of sitting and standing during the summer season, as illustrated in Figure 4B. During the spring and autumn seasons, conditions are predicted to be suitable for a mix of standing and strolling, as illustrated in Figures 4A and 4C, respectively. During the winter season, conditions are predicted to be suitable for a mix of standing, strolling, and walking, as illustrated in Figure 4D.

During the summer season, the areas predicted to be suitable for standing are also predicted to be suitable for sitting at least 65% of the time, as illustrated in Figure 5B. Since a reasonable level of mitigation has been considered in the landscape plan on account of the suburban exposures for the prominent wind directions, the noted conditions are considered satisfactory for the intended uses of the areas.

5.3 Wind Safety

Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level or on the elevated amenity terraces were found to experience conditions that could be considered dangerous, as defined in Section 4.4.

5.4 Applicability of Results

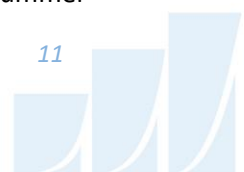
Wind conditions over surrounding sidewalks beyond the subject site, as well as at nearby primary building entrances, will be acceptable for their intended pedestrian uses during each seasonal period upon the introduction of the subject site. Pedestrian wind comfort and safety have been quantified for 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. In general, development in urban centers generally creates reduction in the mean wind speeds and localized increases in the gustiness of the wind.

Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associated hardware.

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind comfort and safety conditions is provided in Section 5 and illustrated in Figures 3A-5D (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, the study concludes the following:

- 1) All areas at grade will be suitable for their intended uses throughout the year. This includes all building access points, nearby sidewalks, walkways, surface parking areas, and landscaped areas.
- 2) Wind conditions over the north amenity terrace at Level 7, atop the podium, are predicted to be suitable for a mix of sitting and standing during the summer season, becoming suitable for a mix of standing and strolling during the spring and autumn seasons. During the winter season, conditions are predicted to be suitable for a mix of standing, strolling, and walking.
 - a. The noted wind comfort predictions correspond to an extensive mitigation strategy that has been developed by the design team, including the landscape architect. With the noted mitigation strategy, the areas predicted to be suitable for standing during the summer



season are also predicted to be suitable for sitting at least 65% of the time, as illustrated in Figure 5B. Since a reasonable level of mitigation has been considered in the landscape plan on account of the suburban exposures for the prominent wind directions, the noted conditions are considered satisfactory for the intended uses of the areas.

- 3) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas surrounding the subject site at grade level or on the elevated amenity terraces were found to experience conditions that could be considered dangerous, as defined in Section 4.4.
- 4) Regarding primary and secondary building access points, wind conditions predicted in this study are only applicable to pedestrian comfort and safety. As such, the results should not be construed to indicate wind loading on doors and associated hardware.

Sincerely,

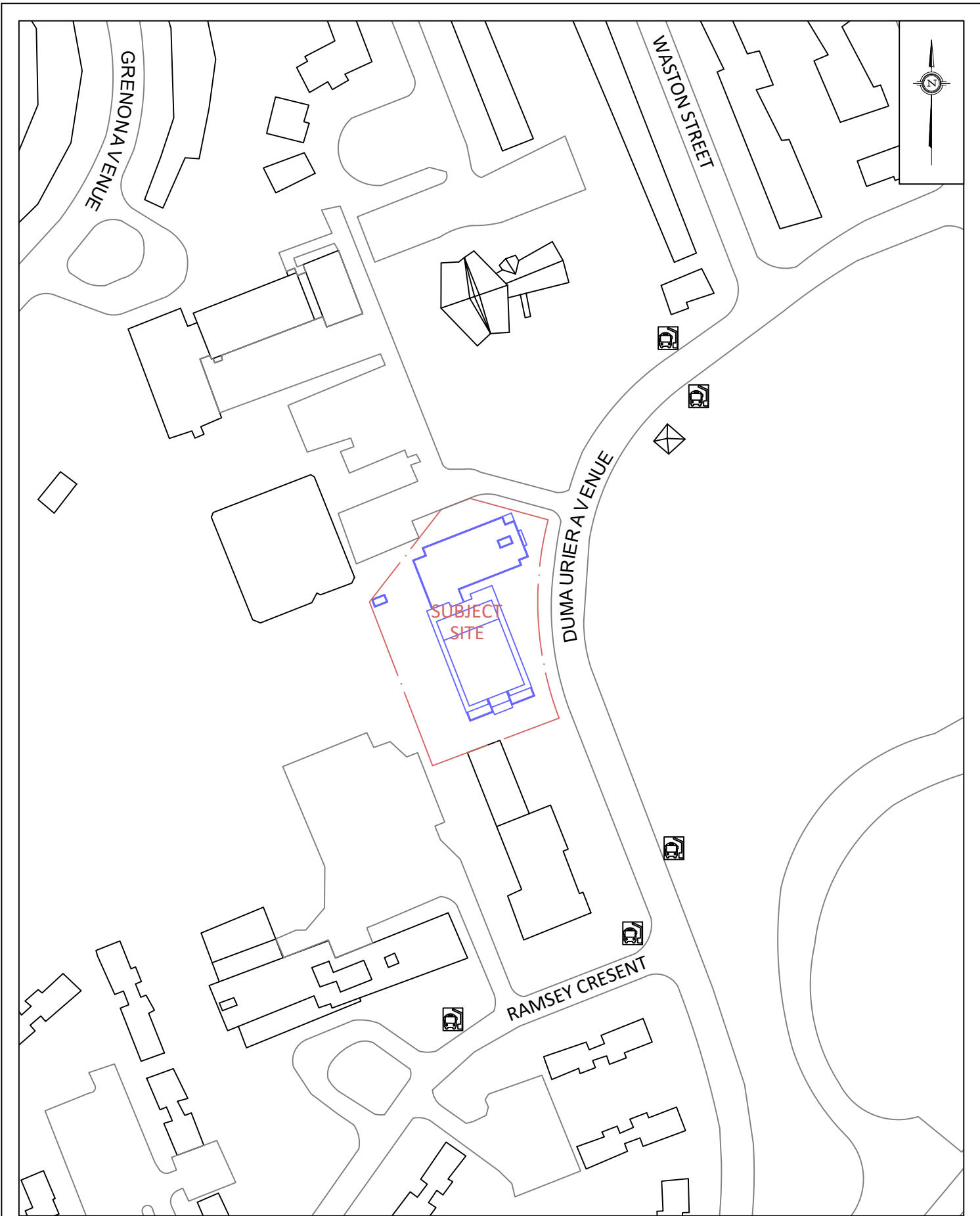
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PROJECT	2829 DUMAURIER AVENUE, OTTAWA PEDESTRIAN LEVEL WIND STUDY	
SCALE	1:1750	DRAWING NO. 20-150-PLW-1
DATE	JANUARY 15, 2021	DRAWN BY N.M.P.

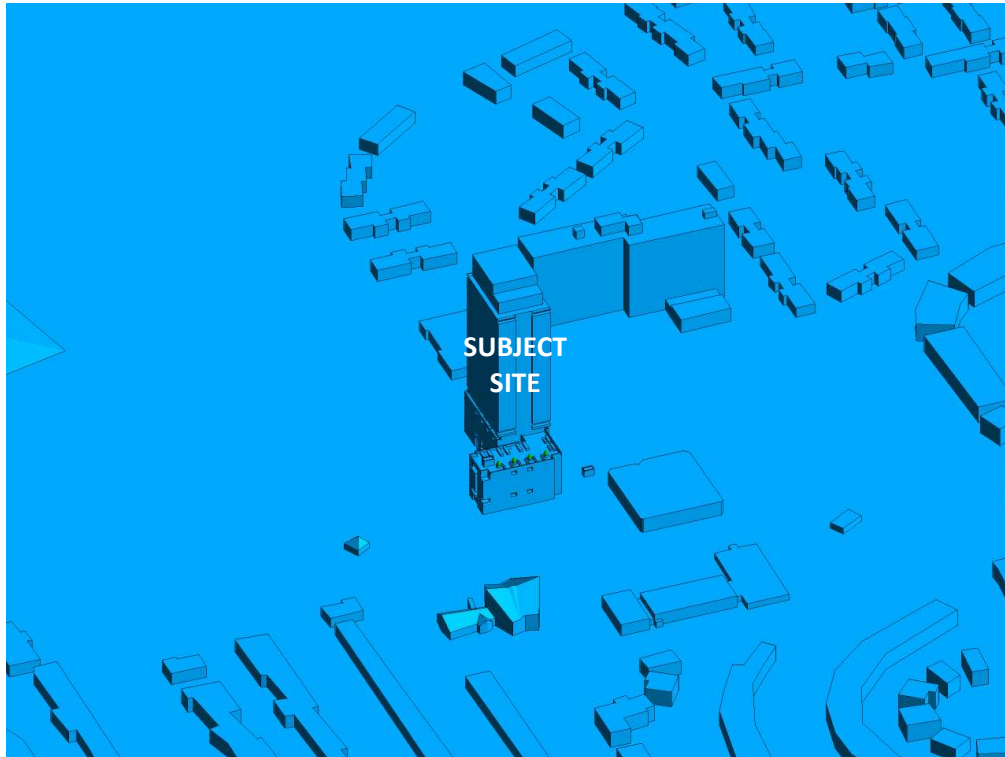


FIGURE 2A: COMPUTATIONAL MODEL, NORTH PERSPECTIVE

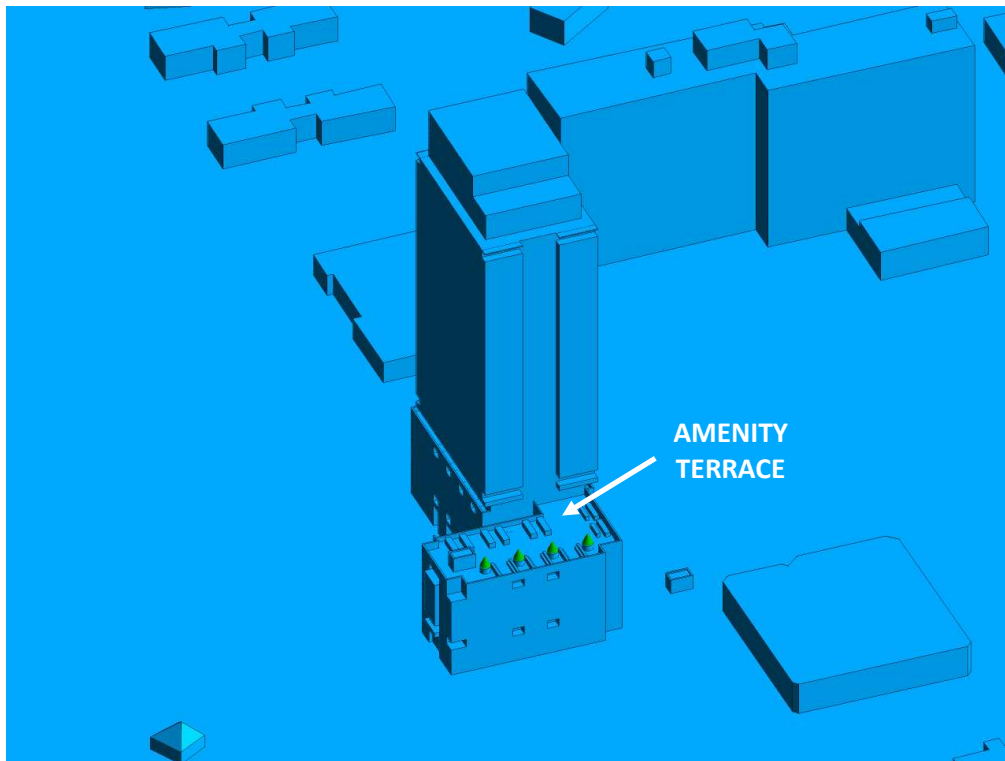


FIGURE 2B: CLOSE UP OF FIGURE 2A



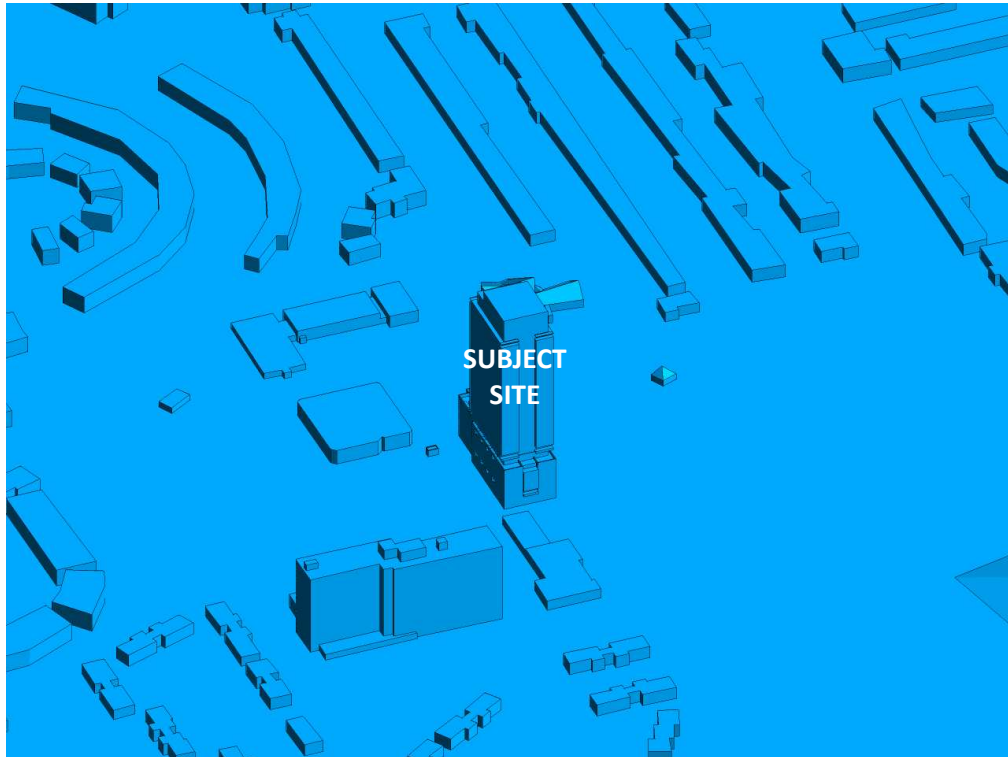


FIGURE 2C: COMPUTATIONAL MODEL, SOUTH PERSPECTIVE

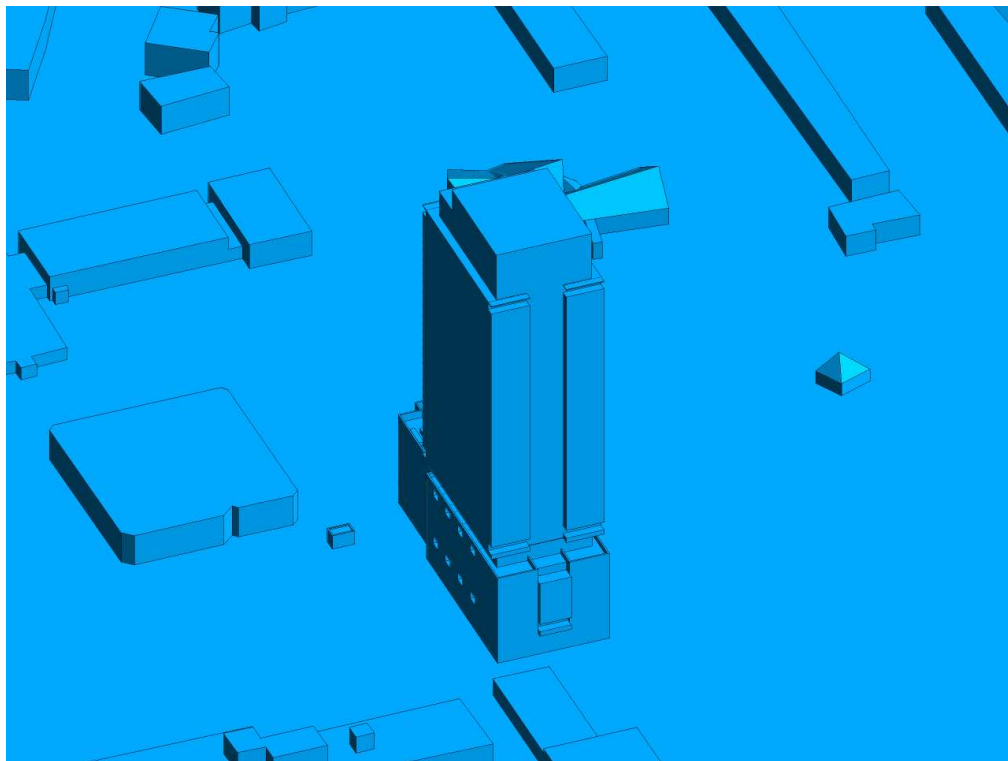


FIGURE 2D: CLOSE UP OF FIGURE 2C



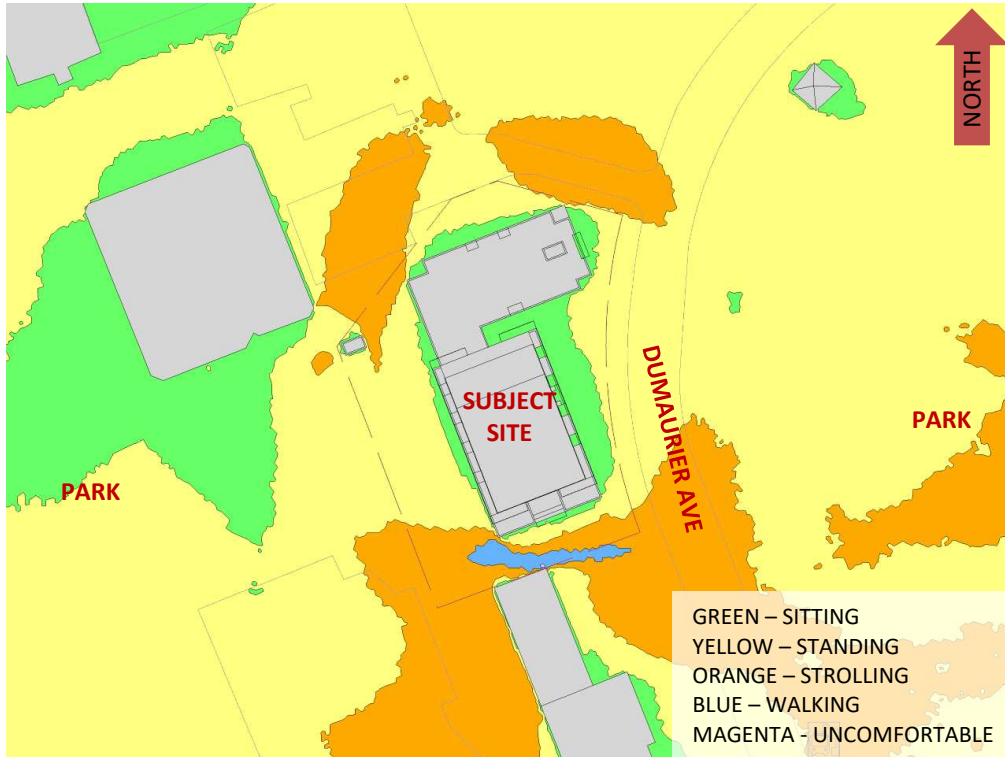


FIGURE 3A: SPRING – WIND CONDITIONS AT GRADE LEVEL

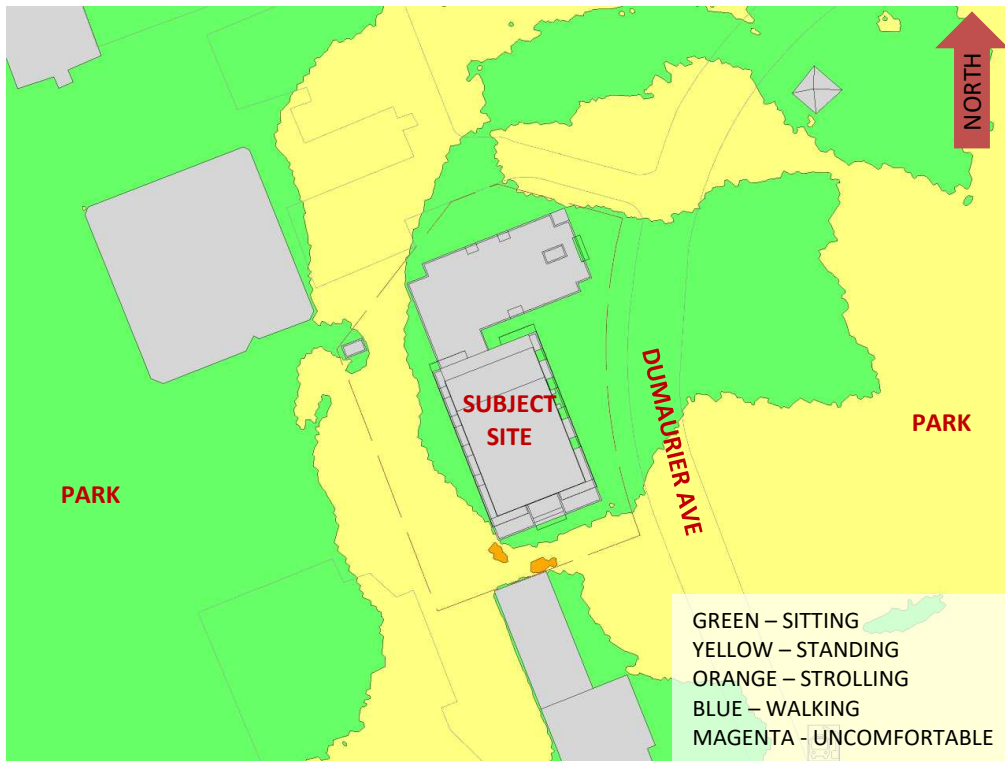


FIGURE 3B: SUMMER – WIND CONDITIONS AT GRADE LEVEL

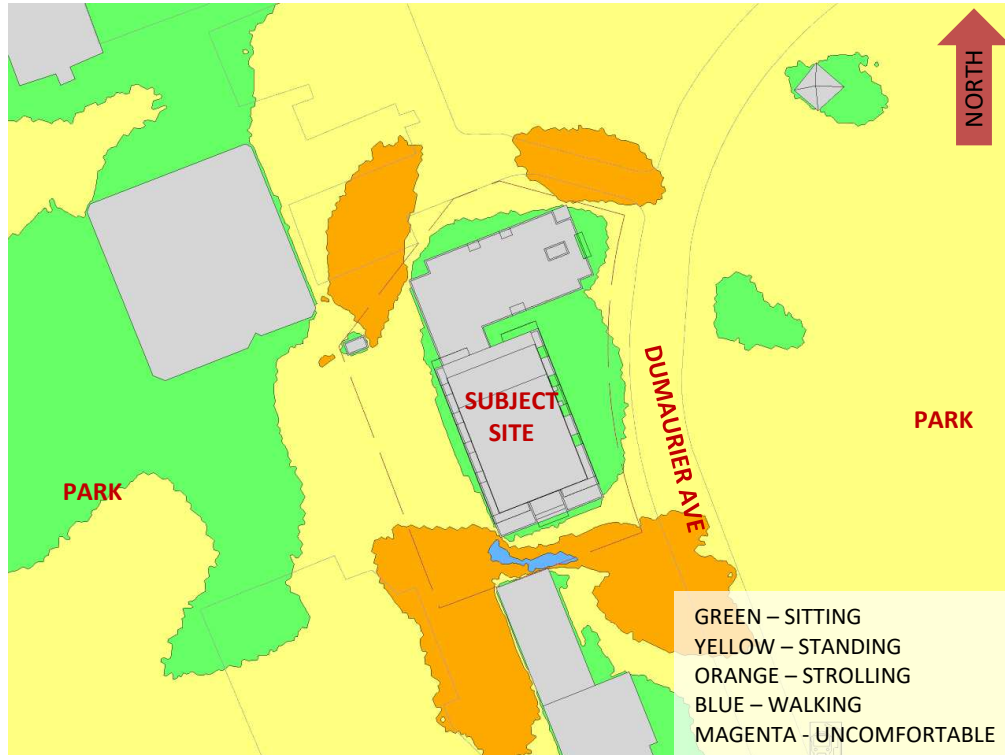


FIGURE 3C: AUTUMN – WIND CONDITIONS AT GRADE LEVEL

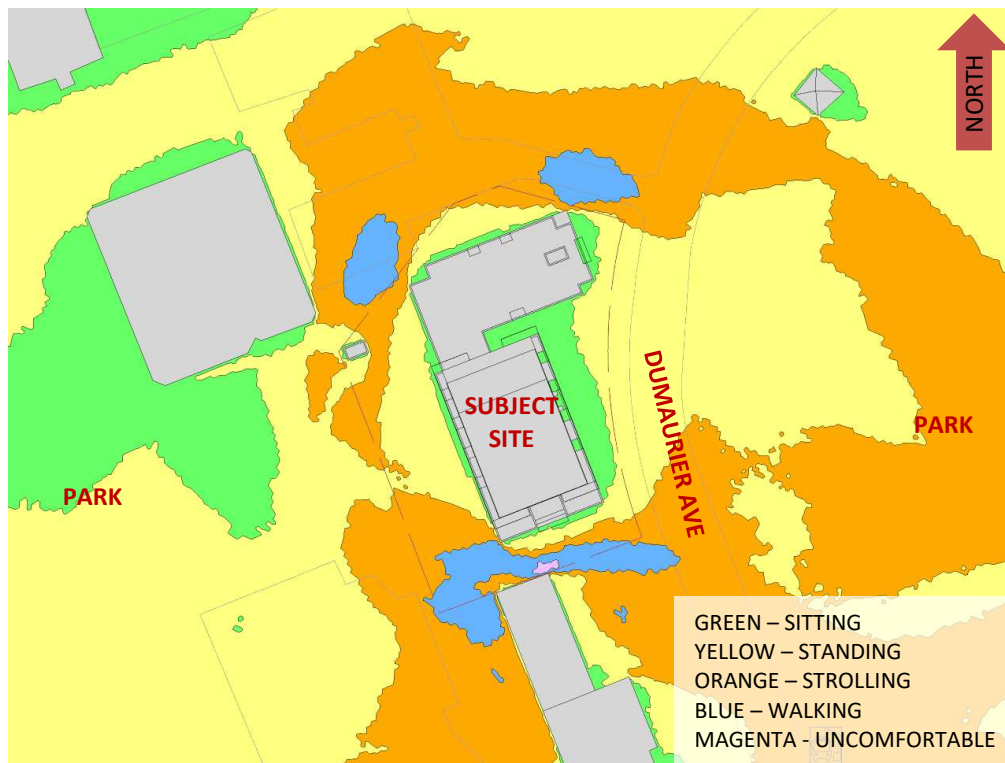


FIGURE 3D: WINTER – WIND CONDITIONS AT GRADE LEVEL

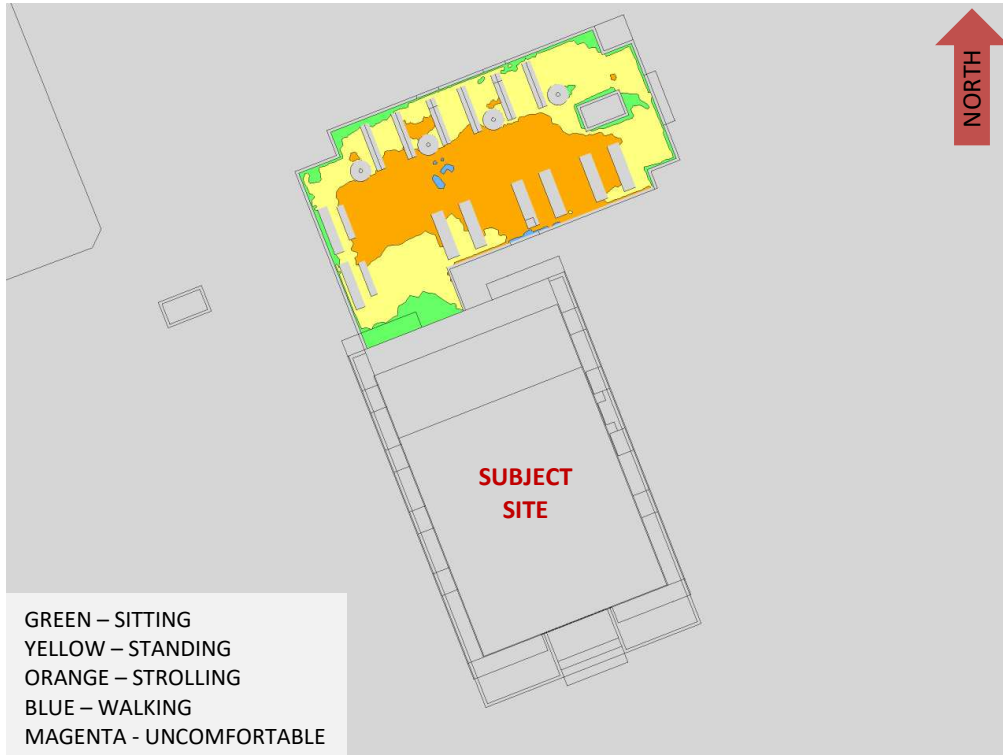


FIGURE 4A: SPRING – WIND COMFORT CONDITIONS, L7 AMENITY TERRACE

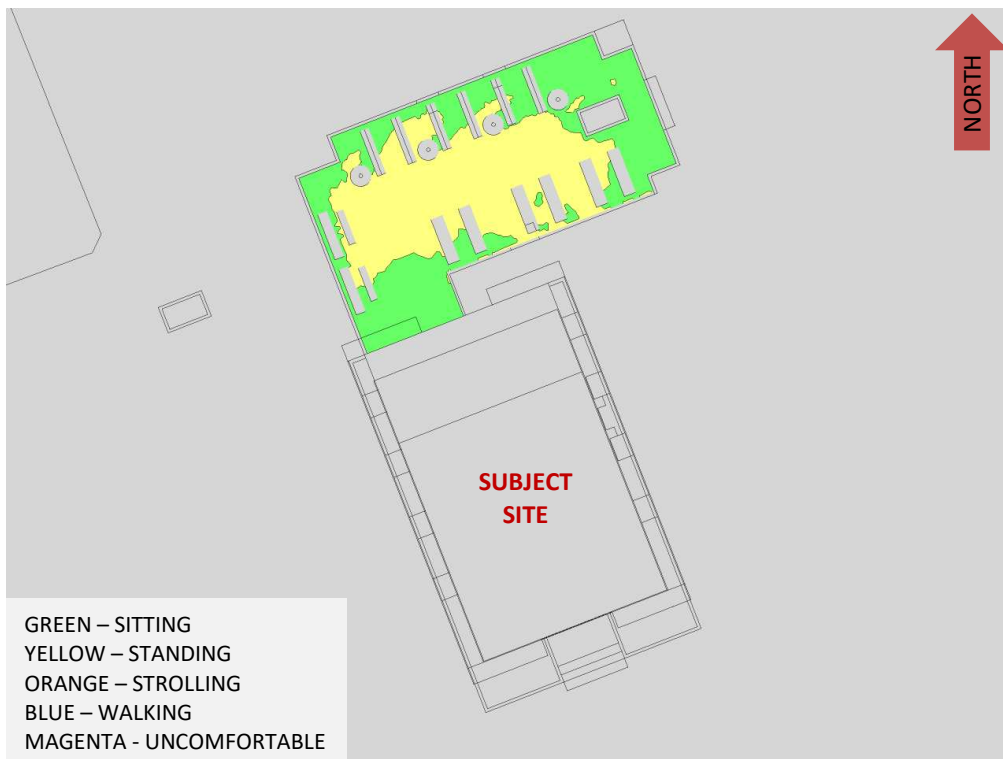


FIGURE 4B: SUMMER – WIND COMFORT CONDITIONS, L7 AMENITY TERRACE

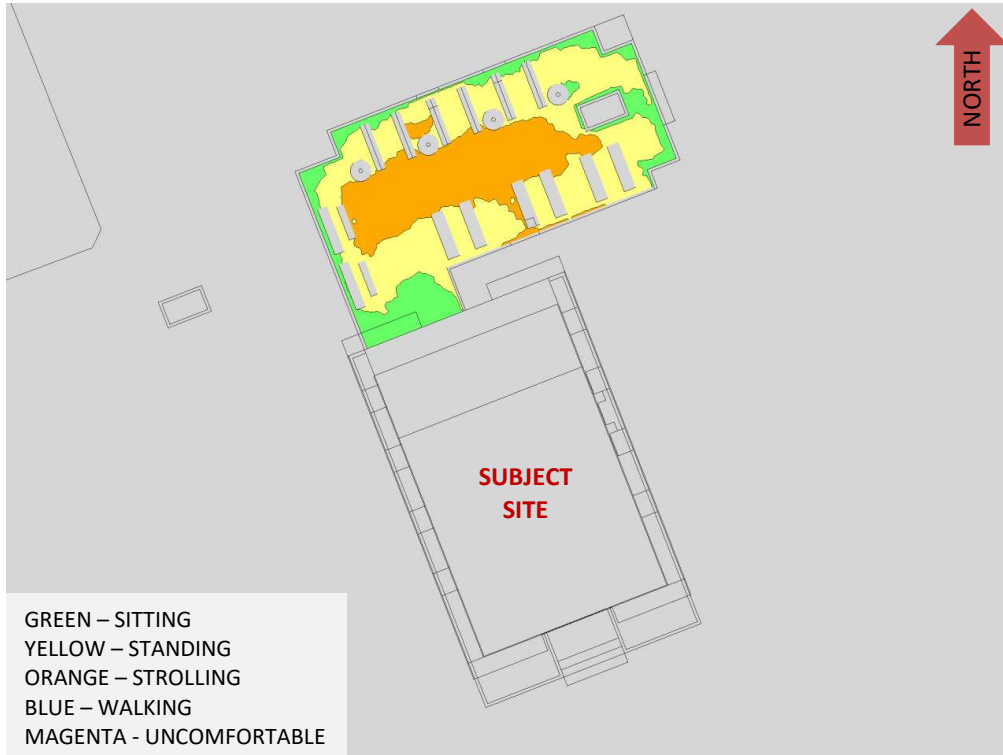


FIGURE 4C: AUTUMN – WIND COMFORT CONDITIONS, L7 AMENITY TERRACE

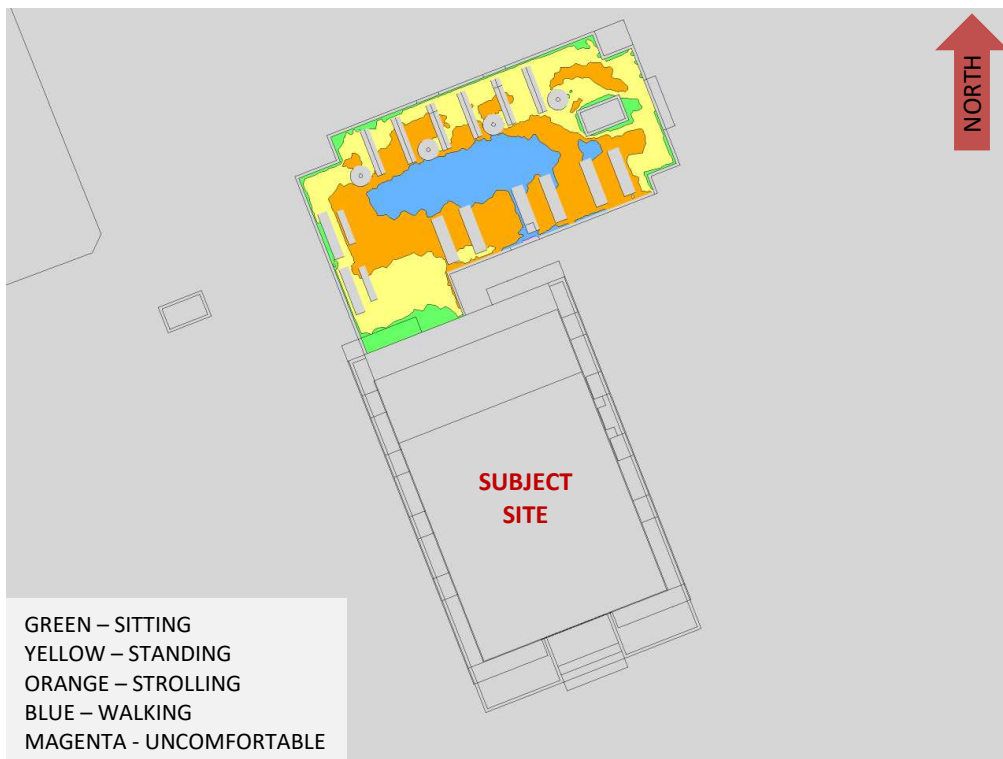


FIGURE 4D: WINTER – WIND COMFORT CONDITIONS, L7 AMENITY TERRACE

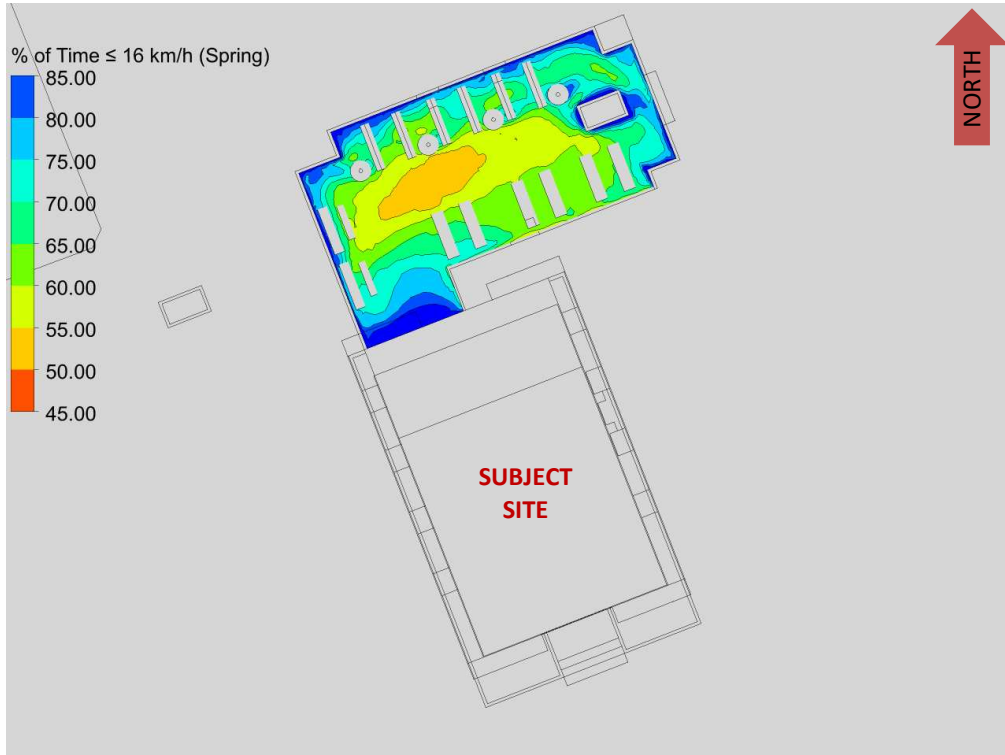


FIGURE 5A: SPRING – PERCENTAGE OF TIME SUITABLE FOR SITTING, L7 AMENITY TERRACE

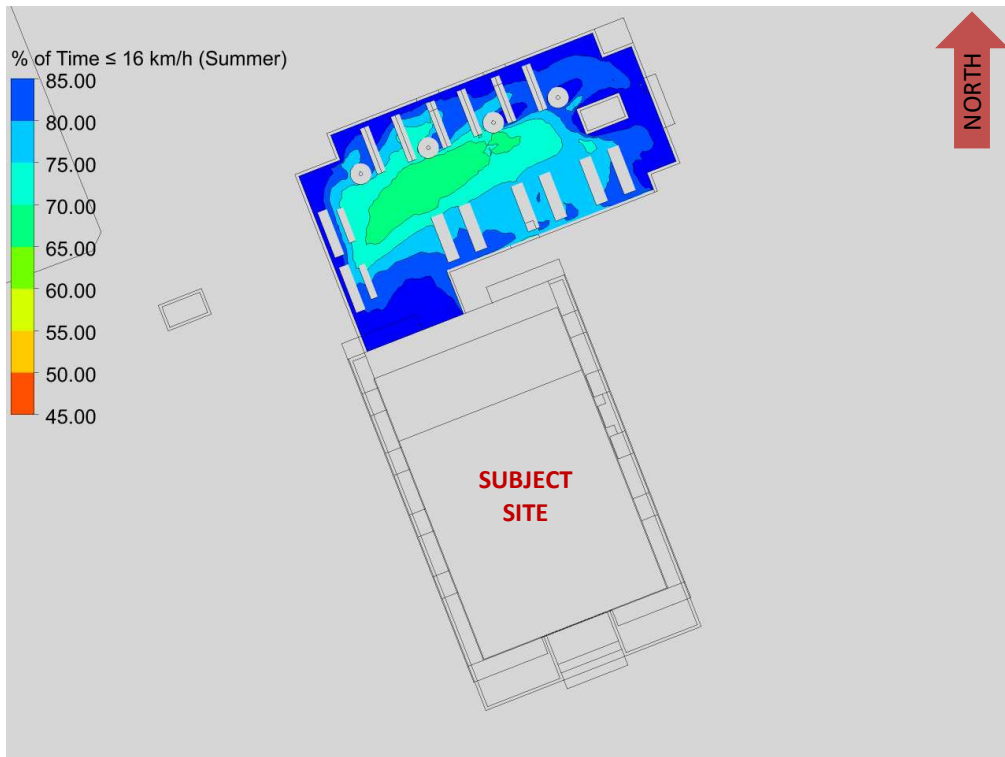


FIGURE 5B: SUMMER – PERCENTAGE OF TIME SUITABLE FOR SITTING, L7 AMENITY TERRACE

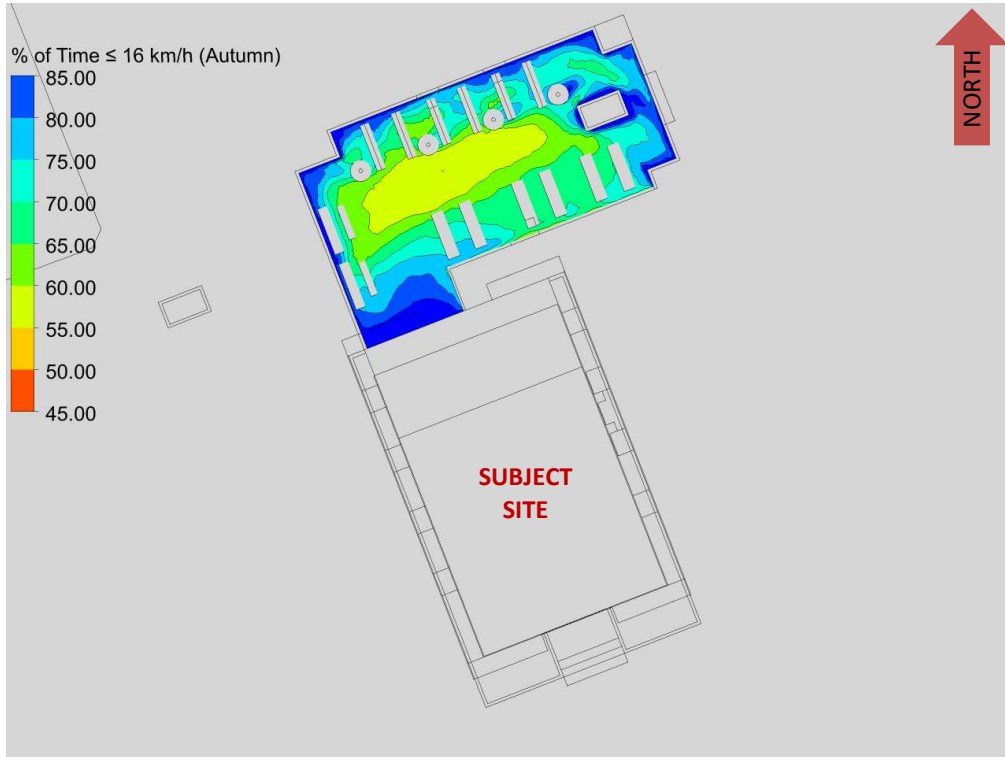


FIGURE 5C: AUTUMN – PERCENTAGE OF TIME SUITABLE FOR SITTING, L7 AMENITY TERRACE

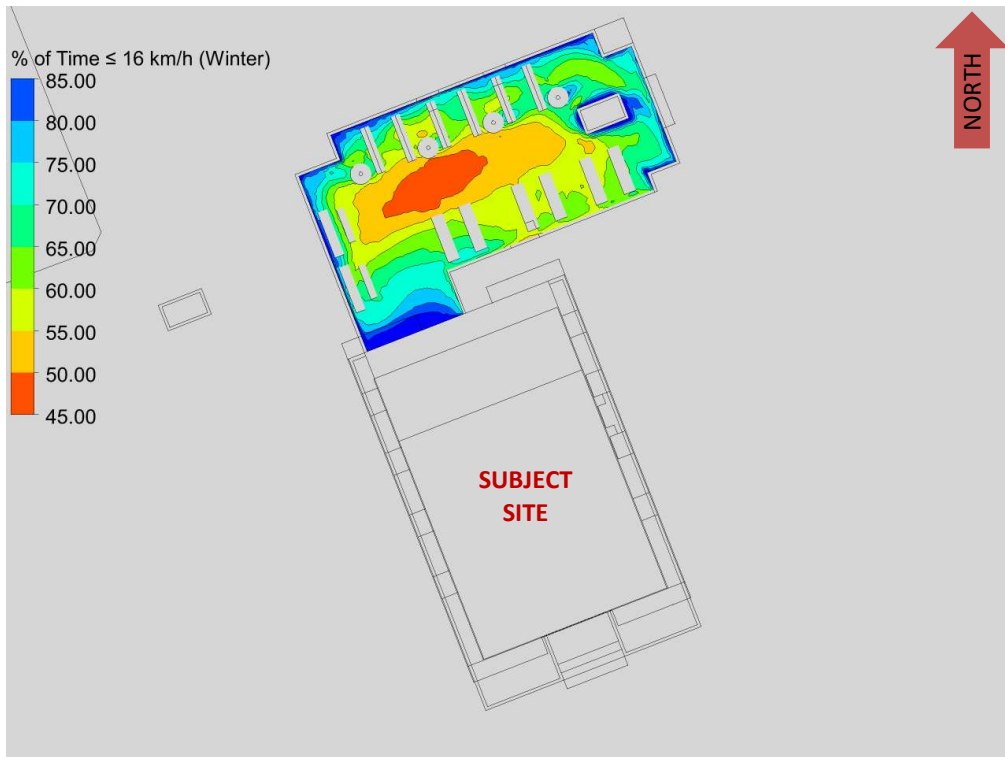


FIGURE 5D: WINTER – PERCENTAGE OF TIME SUITABLE FOR SITTING, L7 AMENITY TERRACE

GRADIENTWIND

ENGINEERS & SCIENTISTS



APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

The atmospheric boundary layer (ABL) is defined by the velocity and turbulence profiles according to industry standard practices. The mean wind profile can be represented, to a good approximation, by a power law relation, Equation (1), giving height above ground versus wind speed [1], [2].

$$U = U_g \left(\frac{Z}{Z_g} \right)^\alpha \quad \text{Equation (1)}$$

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.

For the model, U_g is set to 6.5 metres per second (m/s), which approximately corresponds to the 60% mean wind speed for Ottawa based on historical climate data and statistical analyses. When the results are normalized by this velocity, they are relatively insensitive to the selection of gradient wind speed.

Z_g is set to 540 m. The selection of gradient height is relatively unimportant, so long as it exceeds the building heights surrounding the subject site. The value has been selected to correspond to our physical wind tunnel reference value.

α is determined based on the upstream exposure of the far-field surroundings (i.e., the area that it not captured within the simulation model).

Table 1 presents the values of α used in this study, while Table 2 presents several reference values of α . When the upstream exposure of the far-field surroundings is a mixture of multiple types of terrain, the α values are a weighted average with terrain that is closer to the subject site given greater weight.

TABLE 1: UPSTREAM EXPOSURE (ALPHA VALUE) VS TRUE WIND DIRECTION

Wind Direction (° True)	Alpha (α) Value
0	0.22
49	0.24
74	0.23
103	0.24
167	0.23
197	0.23
217	0.22
237	0.22
262	0.24
282	0.22
301	0.21
324	0.22

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

Upstream Exposure Type	α
Open Water	0.14-0.15
Open Field	0.16-0.19
Light Suburban	0.21-0.24
Heavy Suburban	0.24-0.27
Light Urban	0.28-0.30
Heavy Urban	0.31-0.33

The turbulence model in the computational fluid dynamics (CFD) simulations is a two-equation shear-stress transport (SST) model, and thus the ABL turbulence profile requires that two parameters be defined at the inlet of the domain. The turbulence profile is defined following the recommendations of the Architectural Institute of Japan for flat terrain [3].

$$I(Z) = \begin{cases} 0.1 \left(\frac{Z}{Z_g} \right)^{-\alpha-0.05}, & Z > 10 \text{ m} \\ 0.1 \left(\frac{10}{Z_g} \right)^{-\alpha-0.05}, & Z \leq 10 \text{ m} \end{cases} \quad \text{Equation (2)}$$

$$L_t(Z) = \begin{cases} 100 \text{ m} \sqrt{\frac{Z}{30}}, & Z > 30 \text{ m} \\ 100 \text{ m}, & Z \leq 30 \text{ m} \end{cases} \quad \text{Equation (3)}$$

where, I = turbulence intensity, L_t = turbulence length scale, Z = height above ground, and α is the power law exponent used for the velocity profile in Equation (1).

Boundary conditions on all other domain boundaries are defined as follows: the ground is a no-slip surface; the side walls of the domain have a symmetry boundary condition; the top of the domain has a specified shear, which maintains a constant wind speed at gradient height; and the outlet has a static pressure boundary condition.

REFERENCES

- [1] P. Arya, "Chapter 10: Near-neutral Boundary Layers," in *Introduction to Micrometeorology*, San Diego, California, Academic Press, 2001.
- [2] S. A. Hsu, E. A. Meindl and D. B. Gilhousen, "Determining the Power-Law Wind Profile Exponent under Near-neutral Stability Conditions at Sea," vol. 33, no. 6, 1994.
- [3] Y. Tamura, H. Kawai, Y. Uematsu, K. Kondo and T. Okhuma, "Revision of AIJ Recommendations for Wind Loads on Buildings," in *The International Wind Engineering Symposium, IWES 2003*, Taiwan, 2003.

