

GRADIENTWIND

ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

1174 Carp Road
Ottawa, Ontario

Report: 23-299-PLW



March 1, 2024

PREPARED FOR

Le Groupe Maurice
2400 rue des Nations, bureau 137
Saint-Laurent, QC H4R 3G4

PREPARED BY

Omar Rioseco, B.Eng., Junior Wind Scientist
David Huitema, M.Eng., Wind Scientist
Justin Ferraro, P.Eng., Principal

EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy Site Plan Control application submission requirements for the proposed retirement residence development located at 1174 Carp Road in Ottawa, Ontario (hereinafter referred to as “subject site” or “proposed development”). Our mandate within this study is to investigate pedestrian wind conditions within and surrounding the subject site, and to identify areas where conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where 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 (Section 5), illustrated in Figures 3A-7, and summarized as follows:

- 1) Most grade-level areas within and surrounding the subject site are predicted to experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, nearby transit stops, nearby existing surface parking lots, the proposed drive aisle, walkways, drop-off area, loading area, surface parking, and central courtyard, and in the vicinity of building access points, are considered acceptable. A single grade-level area of interest is predicted to experience windier conditions:
 - a. **Parkland West of Subject Site:** Wind conditions within the parkland are predicted to be suitable for mostly sitting during the typical use period (that is, May to October, inclusive), with regions suitable for standing to the north and west.
 - Depending on the programming of the parkland, the noted conditions may be considered acceptable. Specifically, if the noted windier areas will not accommodate designated seating or lounging activities, the noted conditions would be considered acceptable.



- If required by programming, comfort levels at designated seating areas to the northwest within the parkland may be improved by implementing landscaping elements that are targeted around sensitive areas such as tall wind screens and clusters of coniferous trees in dense arrangements, in combination with strategically placed seating with high-back benches or other local wind mitigation.
- 2) The foregoing statements and conclusions apply to common weather systems, during which no dangerous wind conditions, as defined in Section 4.4, are expected anywhere over the subject site. During extreme weather events (for example, thunderstorms, tornadoes, and downbursts), pedestrian safety is the main concern. However, these events are generally short-lived and infrequent and there is often sufficient warning for pedestrians to take appropriate cover.

TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	TERMS OF REFERENCE	1
3.	OBJECTIVES	2
4.	METHODOLOGY	2
4.1	Computer-Based Context Modelling	3
4.2	Wind Speed Measurements.....	3
4.3	Historical Wind Speed and Direction Data	4
4.4	Pedestrian Wind Comfort and Safety Criteria – City of Ottawa.....	6
5.	RESULTS AND DISCUSSION	8
5.1	Wind Comfort Conditions	9
5.2	Wind Safety	11
5.3	Applicability of Results	11
6.	CONCLUSIONS AND RECOMMENDATIONS	12

FIGURES

APPENDICES

Appendix A – Simulation of the Atmospheric Boundary Layer

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Le Groupe Maurice to undertake a pedestrian level wind (PLW) study to satisfy Site Plan Control application submission requirements for the proposed retirement residence located at 1174 Carp Road in Ottawa, Ontario (hereinafter referred to as “subject site” or “proposed development”). Our mandate within this study is to investigate wind conditions within and surrounding the subject site, and to identify areas where conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where 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 prepared by Hobin Architecture in January 2024, 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 subject site is located at 1174 Carp Road in Ottawa, situated to the south at the intersection of Hazeldean Road and Carp Road, on a parcel of land bounded by Hazeldean Road to the northwest, Carp Road to the northeast, low-rise residential dwellings to the southeast, and an empty lot to the southwest. Throughout this report, Carp Road is referred to as project east. The proposed development comprises a 12-storey retirement residence.

Above an underground parking level, the ground floor comprises a near ‘C’-shaped planform with its long axis-oriented along Carp Road and includes various indoor amenities to the north, a retail space at the northeast corner, a main entrance, offices, and a drop-off area to the east, a dining room, commercial and open kitchens, a loading space, and shared building support spaces at the southeast corner, residential units to the southwest, and respite rooms and a respite area at the southwest corner. A courtyard is located central to the subject site within the ‘C’-shaped planform, and a parkland is located to the west. Surface parking is provided to the east and south. A drive aisle extending from Hazeldean Road to Carp Road along the south and west sides of the subject site provides access to the parking ramp near the southwest corner of the proposed development and to the noted drop-off area, loading space, and surface parking. Levels 2-12 are reserved for residential occupancy.



The building steps back from the inner west elevation at Level 2, from the west elevation of the south wing of the building at Level 6, and from the northeast, south, and west elevations at Level 10.

The near-field surroundings, defined as an area within 200-metres (m) of the subject site, include low-rise residential dwellings from the east clockwise to the south-southwest, an empty lot to the southwest, and low-rise commercial buildings with surface parking lots in the remaining directions. The far-field surroundings, defined as an area beyond the near-field but within a 2-kilometre (km) radius of the subject site, are characterized by suburban massing from the north-northeast clockwise to the south-southeast and from the west clockwise to the north-northeast, and by low-rise suburban massing followed by green spaces and fields in the remaining compass.

Site plans for the proposed and existing massing scenarios are illustrated in Figures 1A and 1B, while Figures 2A-2H illustrate the computational models used to conduct the study. The existing massing scenario includes the existing massing and any future developments approved by the City of Ottawa.

3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind 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 subject 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 subject 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 stronger wind speeds.

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 proposed development, complete with surrounding massing within a radius of 500 m. The process was performed for two context massing scenarios, as noted in Section 2.

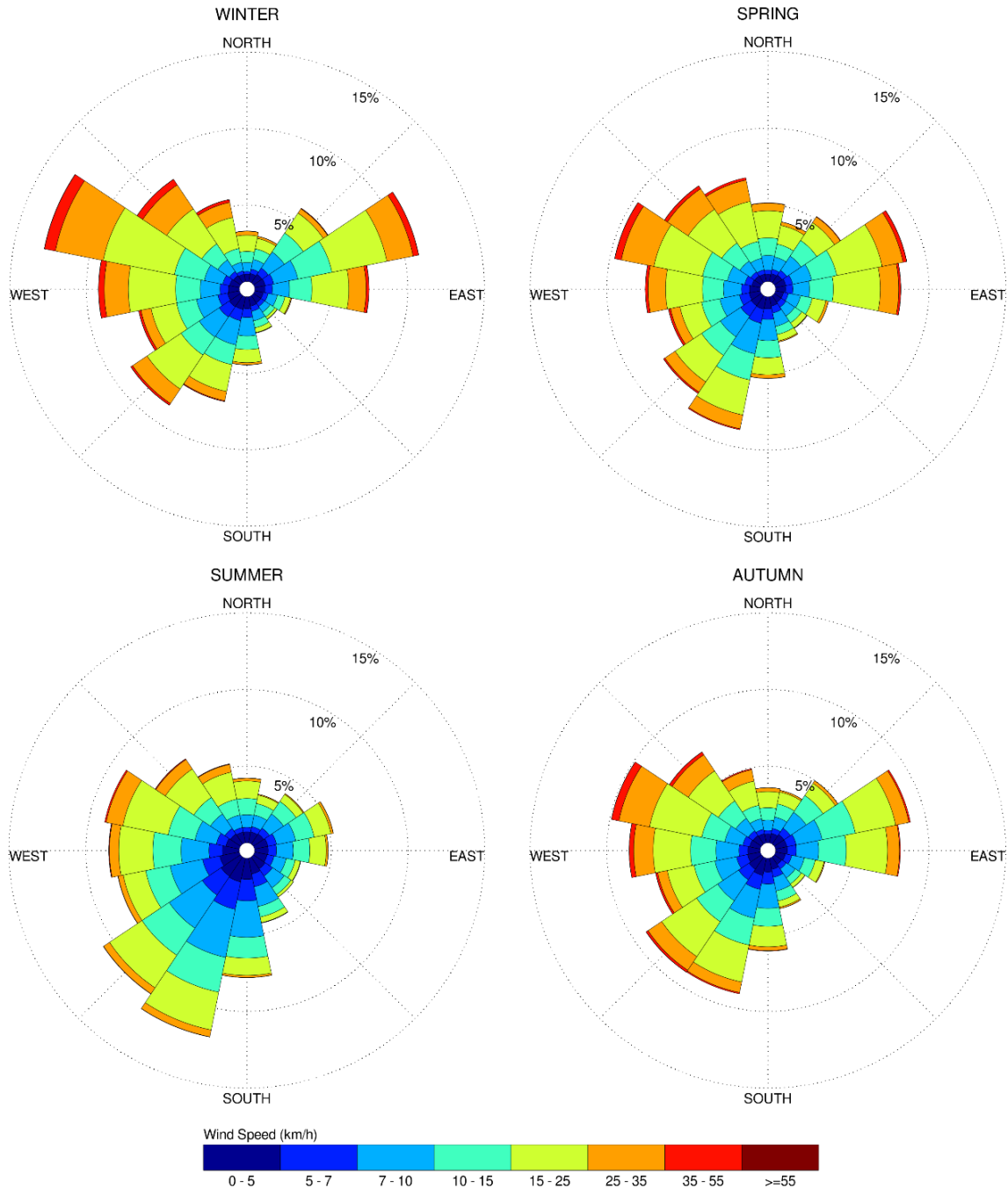
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. 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 wind flow simulation technique are presented in Appendix A.

4.3 Historical Wind Speed and Direction Data

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 prominent 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 prominence 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 Wind Comfort and Safety Criteria – City of Ottawa

Pedestrian wind comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (that is, temperature and relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes based on 20% non-exceedance mean wind speed ranges are used to assess pedestrian comfort: (1) Sitting; (2) Standing; (3) Strolling; (4) Walking; and (5) Uncomfortable. The gust speeds, and equivalent mean speeds, are selected based on the Beaufort scale, which describes the effects of forces produced by varying wind speed levels on objects. Wind conditions suitable for sitting are represented by the colour blue, standing by green, strolling by yellow, and walking by orange; uncomfortable conditions are represented by the colour magenta. Specifically, the comfort classes, associated wind speed ranges, and limiting criteria are summarized as follows:

PEDESTRIAN WIND COMFORT CLASS DEFINITIONS

Wind Comfort Class	GEM Speed (km/h)	Description
SITTING	≤ 10	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.
STANDING	≤ 14	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.
STROLLING	≤ 17	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.
WALKING	≤ 20	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.
UNCOMFORTABLE	> 20	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.



Regarding wind safety, 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. 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. Notably, 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.

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 (equivalent gust wind speed of approximately 16 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 (equivalent gust wind speed of approximately 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 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 subject 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 target comfort classes, which are dictated by the location type for each region (that is, a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their typical windiest target comfort classes are summarized on the following page. Depending on the programming of a space, the desired comfort class may differ from this table.

TARGET PEDESTRIAN WIND COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Target Comfort Classes
Primary Building Entrance	Standing
Secondary Building Access Point	Walking
Public Sidewalk / Bicycle Path	Walking
Outdoor Amenity Space	Sitting / Standing
Café / Patio / Bench / Garden	Sitting / Standing
Transit Stop (Without Shelter)	Standing
Transit Stop (With Shelter)	Walking
Public Park / Plaza	Sitting / Standing
Garage / Service Entrance	Walking
Parking Lot	Walking
Vehicular Drop-Off Zone	Walking

5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-6B, illustrating wind conditions at grade level for the proposed and existing massing scenarios. Conditions are presented as continuous contours of wind comfort throughout the subject site and correspond to the comfort classes presented in Section 4.4.

Wind comfort conditions are also reported for the typical use period, which is defined as May to October, inclusive. Figure 7 illustrates comfort conditions at grade level, consistent with the comfort classes in Section 4.4. The details of these conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions

Sidewalks and Transit Stop along Hazeldean Road: Following the introduction of the proposed development, wind comfort conditions over the nearby public sidewalks along Hazeldean Road are predicted to be suitable for standing, or better, during the summer, becoming suitable for a mix of standing and strolling during the autumn, winter, and spring. Conditions in the vicinity of the nearby transit stop along Hazeldean Road, which is served by a typical shelter, are predicted to be suitable for standing during the spring, summer, and autumn, becoming suitable for strolling during the winter. The noted conditions are considered acceptable.

Wind conditions over the sidewalks along Hazeldean Road with the existing massing are predicted to be suitable for standing, or better, during the summer and autumn, becoming suitable for a mix of standing and strolling during the winter and spring. With the existing massing, conditions in the vicinity of the noted nearby transit stop along Hazeldean Road are predicted to be suitable for standing during the summer and autumn, becoming suitable for a mix of standing and strolling during the spring, and suitable for strolling during the winter. While the introduction of the proposed development produces slightly windier conditions over Hazeldean Road, wind comfort conditions with the proposed development are nevertheless considered acceptable.

Sidewalks along Carp Road: Following the introduction of the proposed development, conditions over the nearby public sidewalks along Carp Road are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for standing, or better, during the autumn, with an isolated region suitable for strolling near the intersection of Hazeldean Road and Carp Road, and suitable for strolling, or better, during the winter and spring, with an isolated region suitable for walking near the noted intersection during the winter. The noted conditions are considered acceptable.

Wind conditions over the sidewalks along Carp Road with the existing massing are predicted to be suitable for a mix of sitting and standing during summer, becoming suitable for standing during the autumn, and suitable for a mix of standing and strolling during the winter and spring. While the introduction of the proposed development produces slightly windier conditions in comparison to existing conditions, wind comfort conditions with the proposed development are nevertheless considered acceptable.



Neighbouring Existing Surface Parking Lots: Following the introduction of the proposed development, conditions over the neighbouring existing surface parking lots located from the northwest clockwise to the east of the subject site are predicted to be suitable for standing, or better, during the summer and autumn, becoming suitable for strolling, or better, during the spring and winter. The noted conditions are considered acceptable.

With the existing massing, conditions over the noted neighbouring surface parking lots are predicted to be suitable for standing, or better, during the summer and autumn, with an isolated region suitable for strolling within the northwest surface parking lot during the autumn, becoming suitable for strolling, or better, during the winter and spring. Notably, the introduction of the proposed development is predicted to improve comfort levels over some of the noted areas in comparison to existing conditions, and wind conditions with the proposed development are nevertheless considered acceptable.

Courtyard and Parkland: During the typical use period, wind conditions within the courtyard situated central to the subject site are predicted to be suitable for sitting, as illustrated in Figure 7. The noted conditions are considered acceptable.

During the typical use period, wind conditions within the parkland situated to the west of the subject site are predicted to be suitable for mostly sitting, with regions suitable for standing to the north and west, as illustrated in Figure 7.

Depending on the programming of the parkland, the noted conditions may be considered acceptable. Specifically, if the noted windier areas suitable for standing will not accommodate designated seating or lounging activities, the noted conditions would be considered acceptable.

If required by programming, comfort levels at designated seating areas to the northwest within the parkland may be improved by implementing landscaping elements that are targeted around sensitive areas such as tall wind screens and clusters of coniferous trees in dense arrangements, in combination with strategically placed seating with high-back benches or other local wind mitigation.



Drive Aisle, Walkways, Drop-off Area, Loading Area, and Surface Parking Within Subject Site: Wind conditions over the drive aisle, surface parking, the loading area, and the proposed walkways within the subject site are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, throughout the remainder of the year. Conditions over the drop-off area to the east of the proposed development are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

Building Access Points: Wind conditions in the vicinity of the building access points along the south elevation of the north wing are predicted to be suitable for sitting during the spring, summer, and autumn, becoming suitable for a mix of sitting and standing during the winter. Conditions in the vicinity of the remaining building access points serving the proposed development are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable.

5.2 Wind Safety

Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas within or surrounding the subject site are expected to experience conditions that could be considered dangerous, as defined in Section 4.4.

5.3 Applicability of Results

Pedestrian wind comfort and safety have been quantified for the specific configuration of existing and foreseeable construction around the subject site. Future changes (that is, 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 subject site would alter the wind profile approaching the subject site; and (ii) development in proximity to the subject site would cause changes to local flow patterns.



6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-7. 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 numerous similar developments, the study concludes the following:

- 1) Most grade-level areas within and surrounding the subject site are predicted to experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, nearby transit stops, nearby existing surface parking lots, the proposed drive aisle, walkways, drop-off area, loading area, surface parking, and central courtyard, and in the vicinity of building access points, are considered acceptable. A single grade-level area of interest is predicted to experience windier conditions:
 - a. **Parkland West of Subject Site:** Wind conditions within the parkland are predicted to be suitable for mostly sitting during the typical use period (that is, May to October, inclusive), with regions suitable for standing to the north and west.
 - Depending on the programming of the parkland, the noted conditions may be considered acceptable. Specifically, if the noted windier areas will not accommodate designated seating or lounging activities, the noted conditions would be considered acceptable.
 - If required by programming, comfort levels at designated seating areas to the northwest within the parkland may be improved by implementing landscaping elements that are targeted around sensitive areas such as tall wind screens and clusters of coniferous trees in dense arrangements, in combination with strategically placed seating with high-back benches or other local wind mitigation.



- 2) The foregoing statements and conclusions apply to common weather systems, during which no dangerous wind conditions, as defined in Section 4.4, are expected anywhere over the subject site. During extreme weather events (for example, thunderstorms, tornadoes, and downbursts), pedestrian safety is the main concern. However, these events are generally short-lived and infrequent and there is often sufficient warning for pedestrians to take appropriate cover.

Sincerely,

Gradient Wind Engineering Inc.



David Huitema, M.Eng.
Wind Scientist

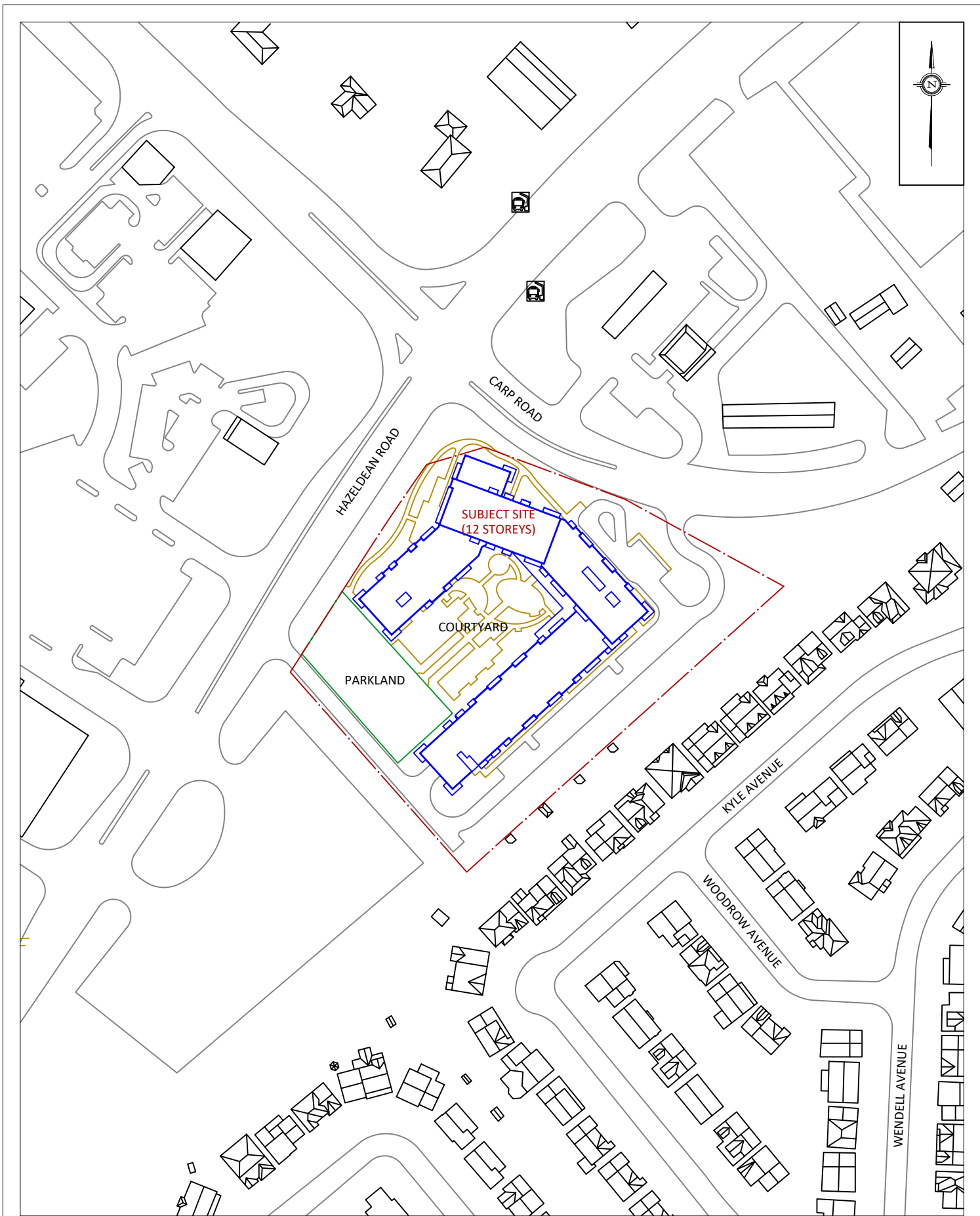


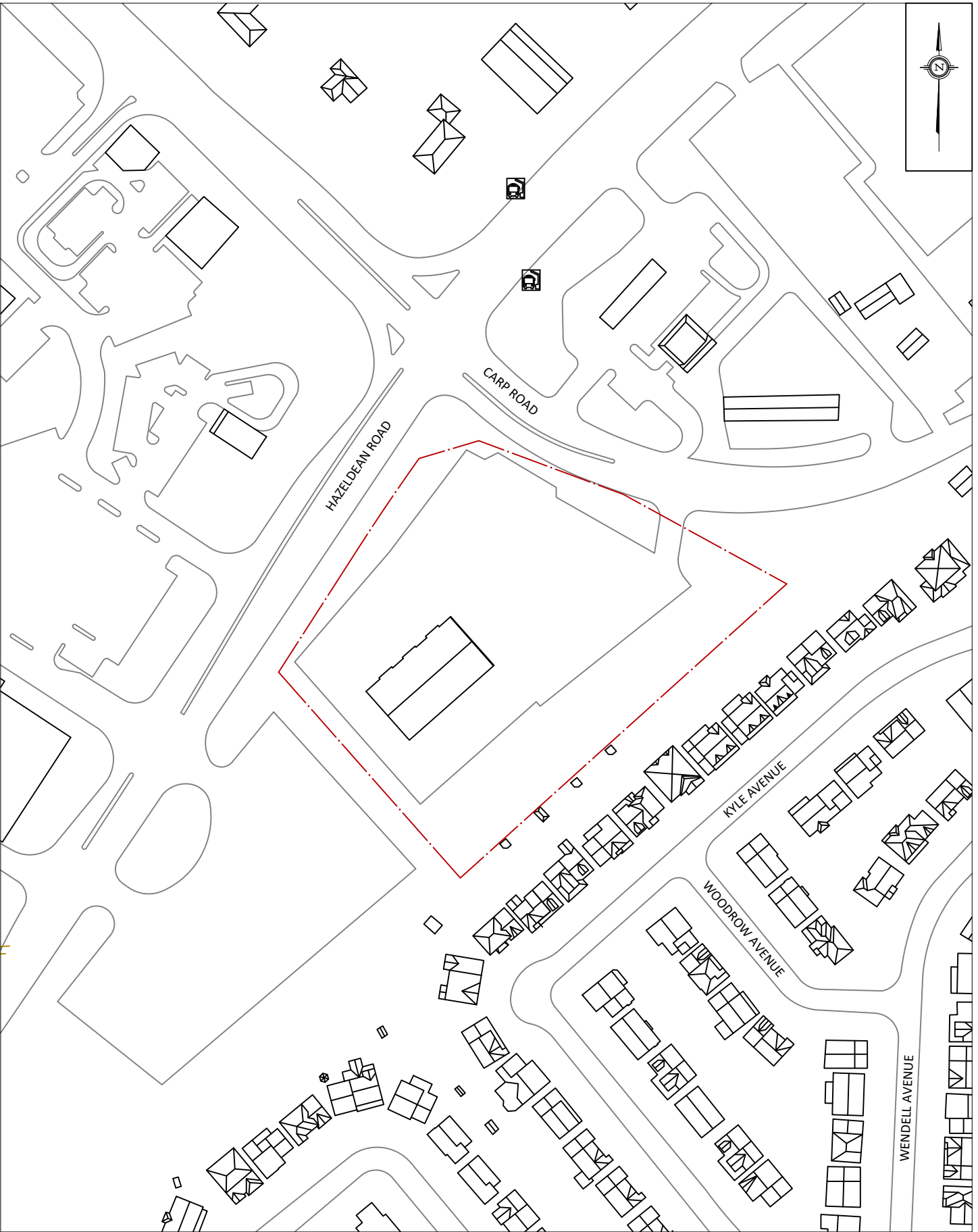
Omar Rioseco, B.Eng.
Junior Wind Scientist



Justin Ferraro, P.Eng.
Principal







PROJECT	1174 CARP ROAD, OTTAWA PEDESTRIAN LEVEL WIND STUDY	
SCALE	1:2000	DRAWING NO. 23-299-PLW-1B
DATE	MARCH 1, 2024	DRAWN BY S.K.

DESCRIPTION	FIGURE 1B: EXISTING SITE PLAN AND SURROUNDING CONTEXT
-------------	--

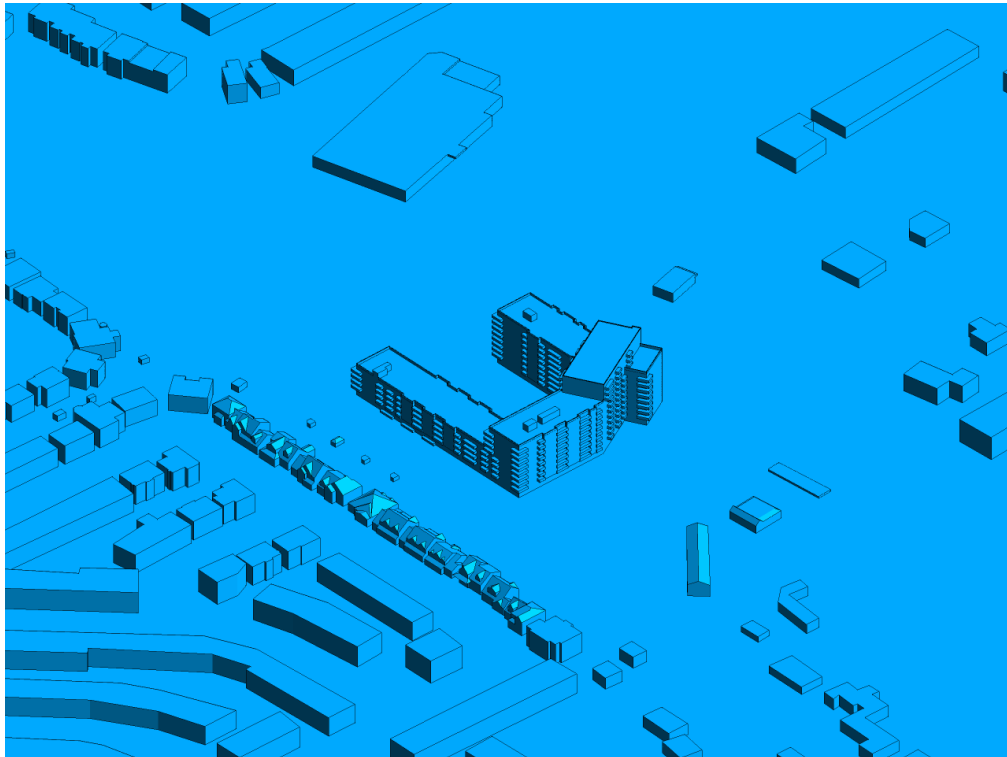


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, EAST PERSPECTIVE

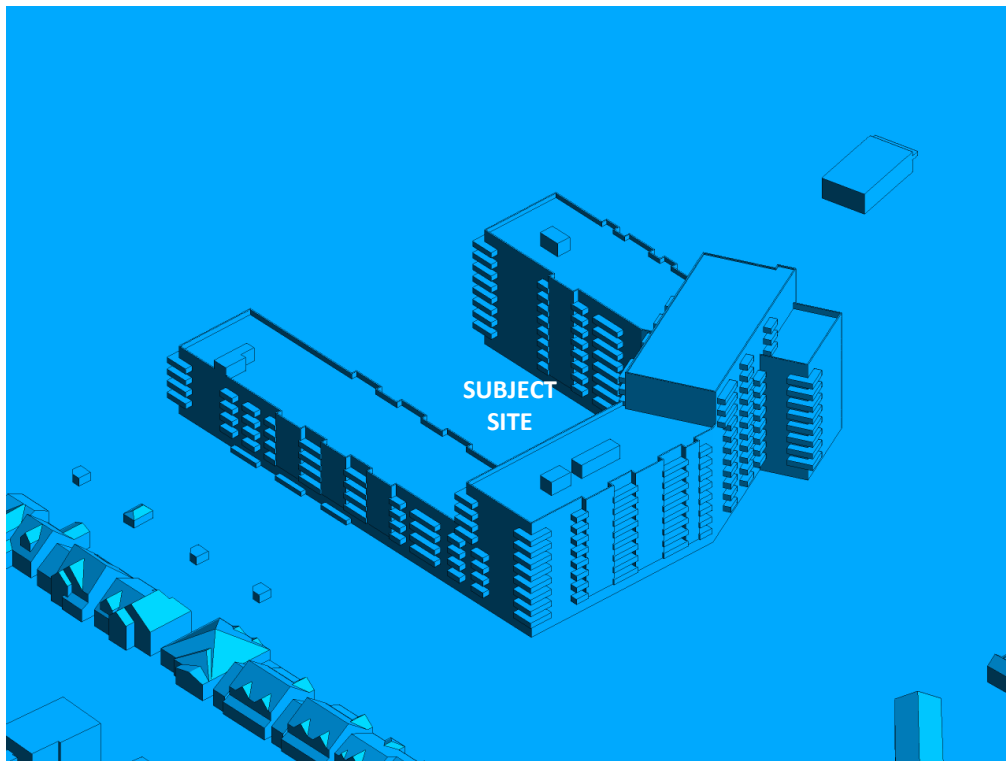


FIGURE 2B: CLOSE UP OF FIGURE 2A



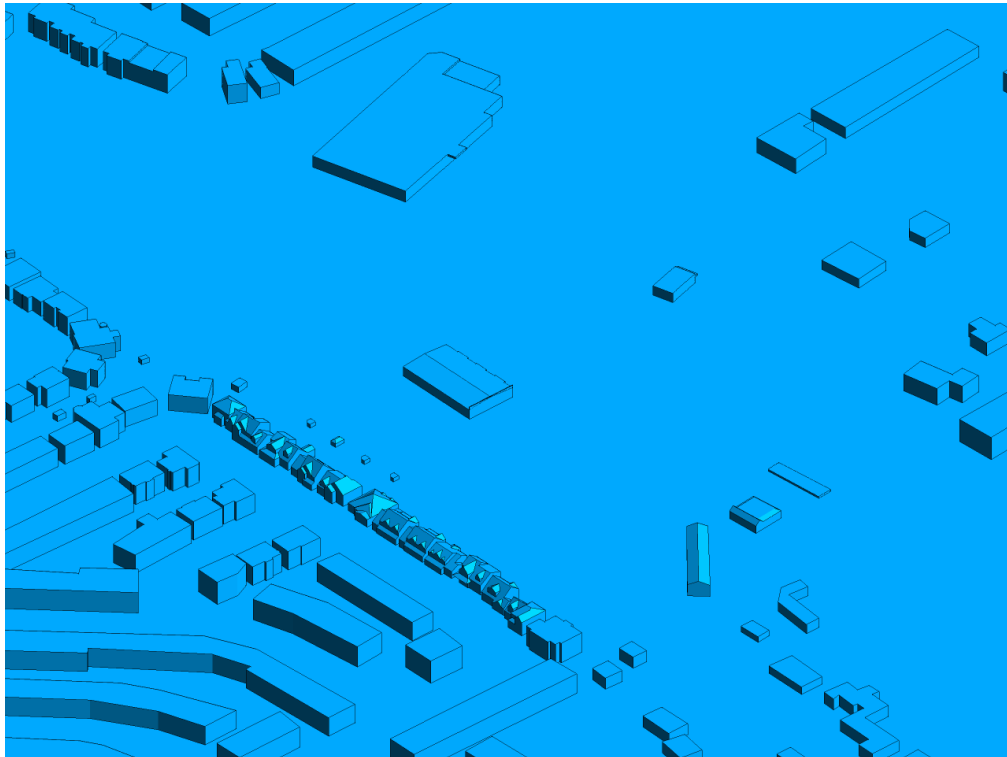


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, EAST PERSPECTIVE

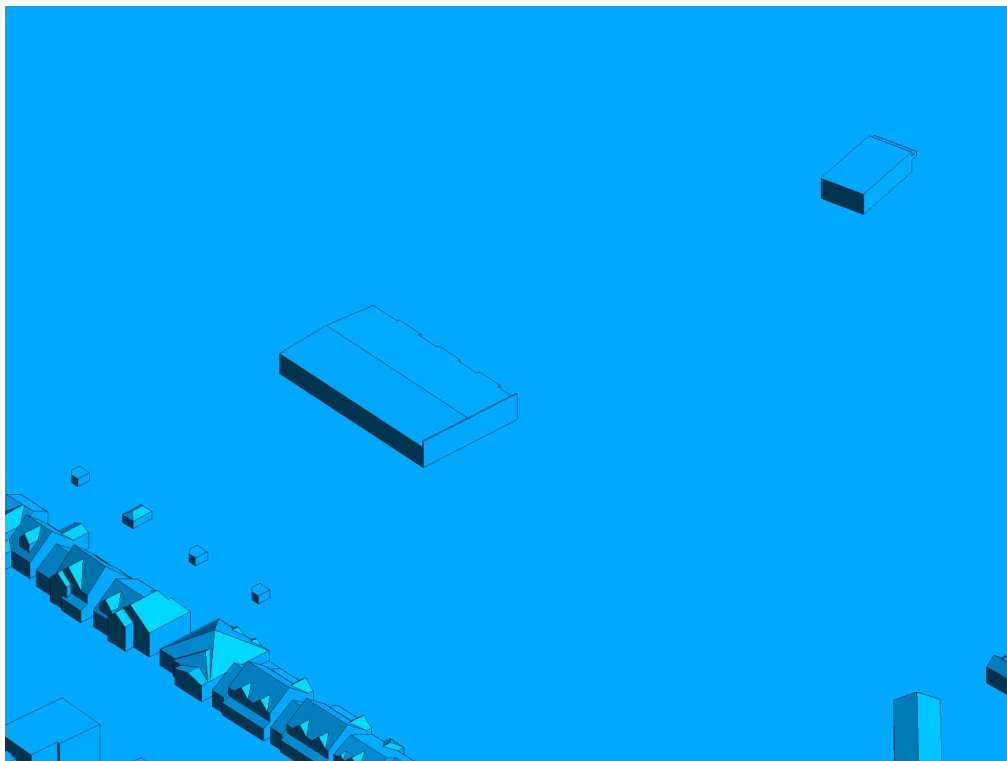


FIGURE 2D: CLOSE UP OF FIGURE 2C



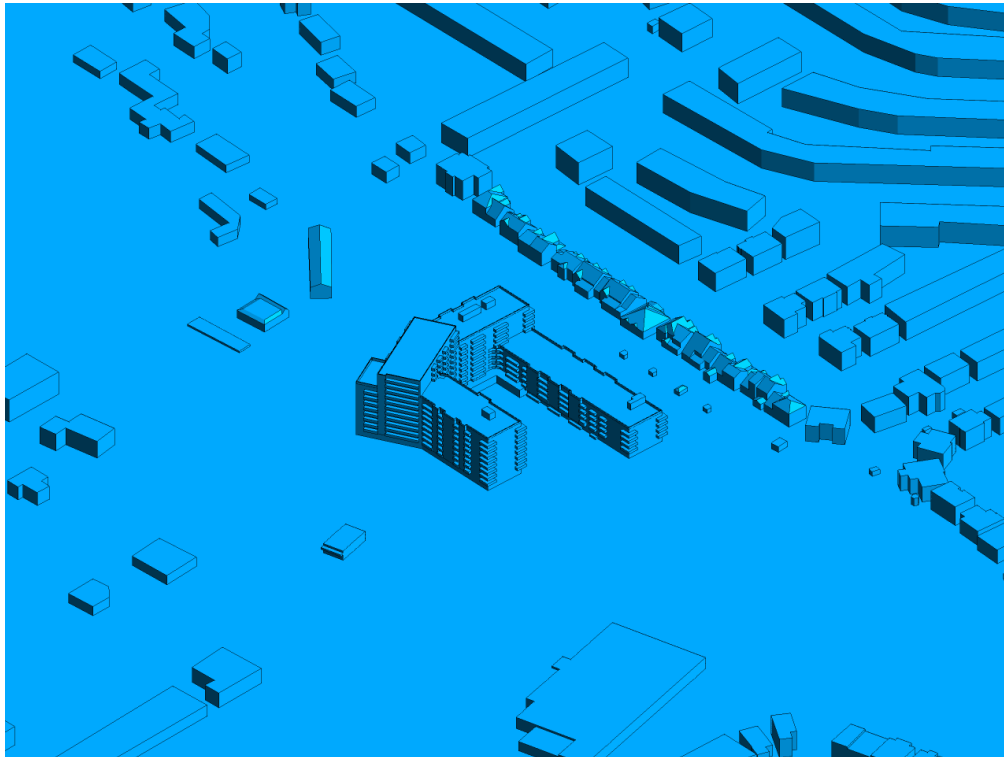


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, WEST PERSPECTIVE

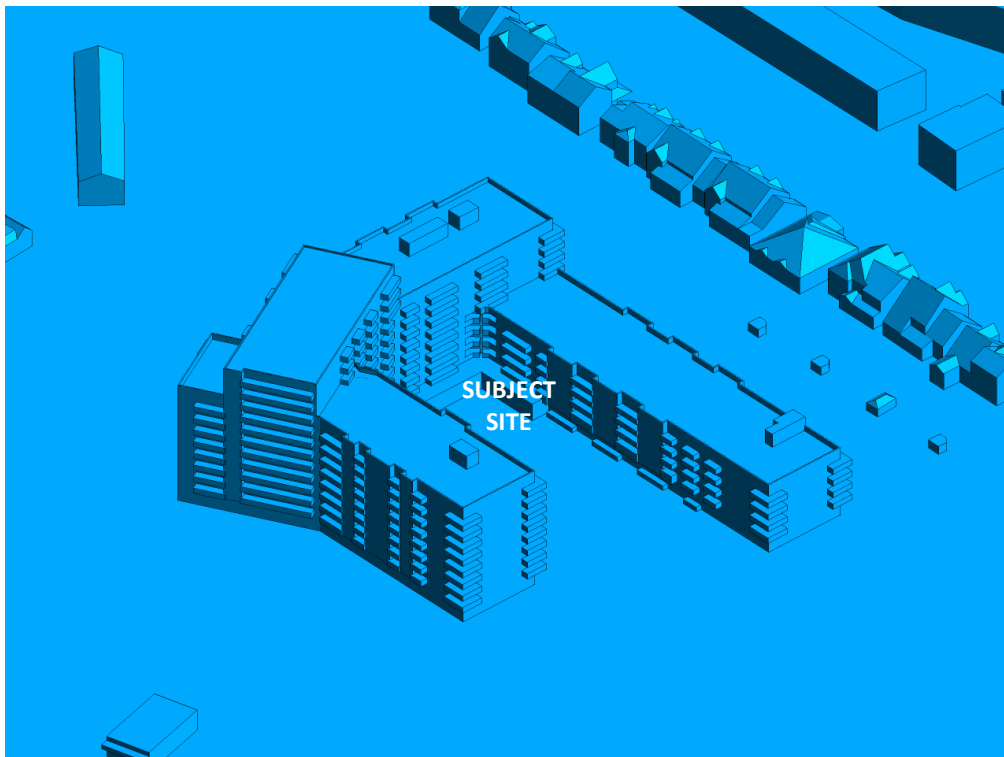


FIGURE 2F: CLOSE UP OF FIGURE 2E



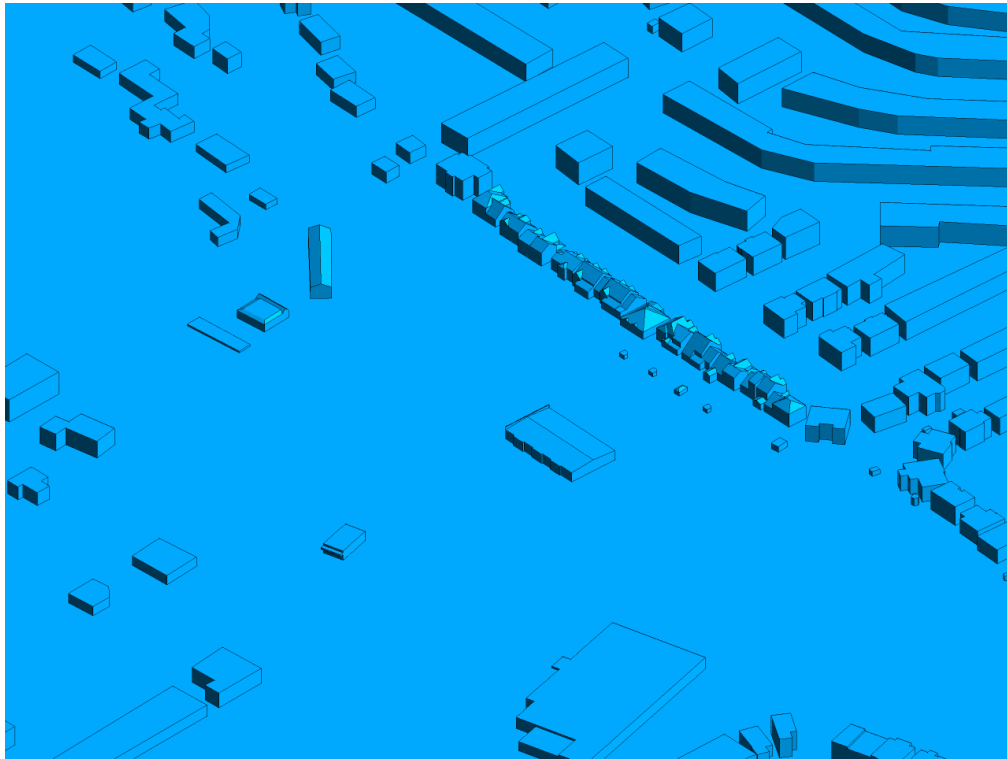


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, WEST PERSPECTIVE

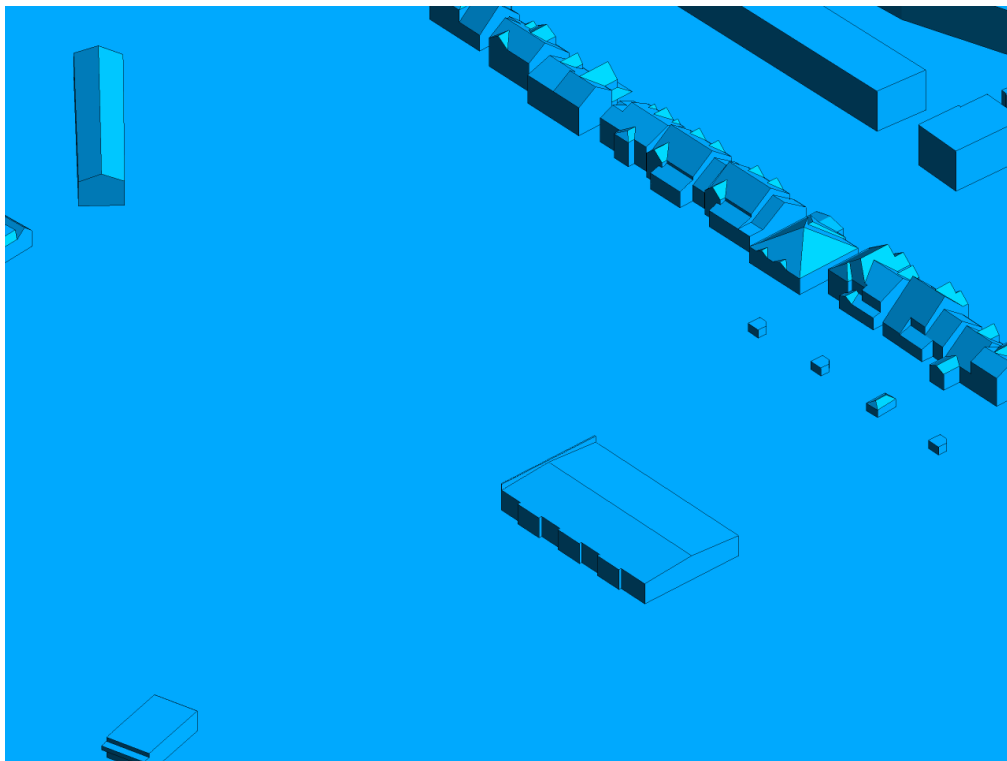


FIGURE 2H: CLOSE UP OF FIGURE 2G



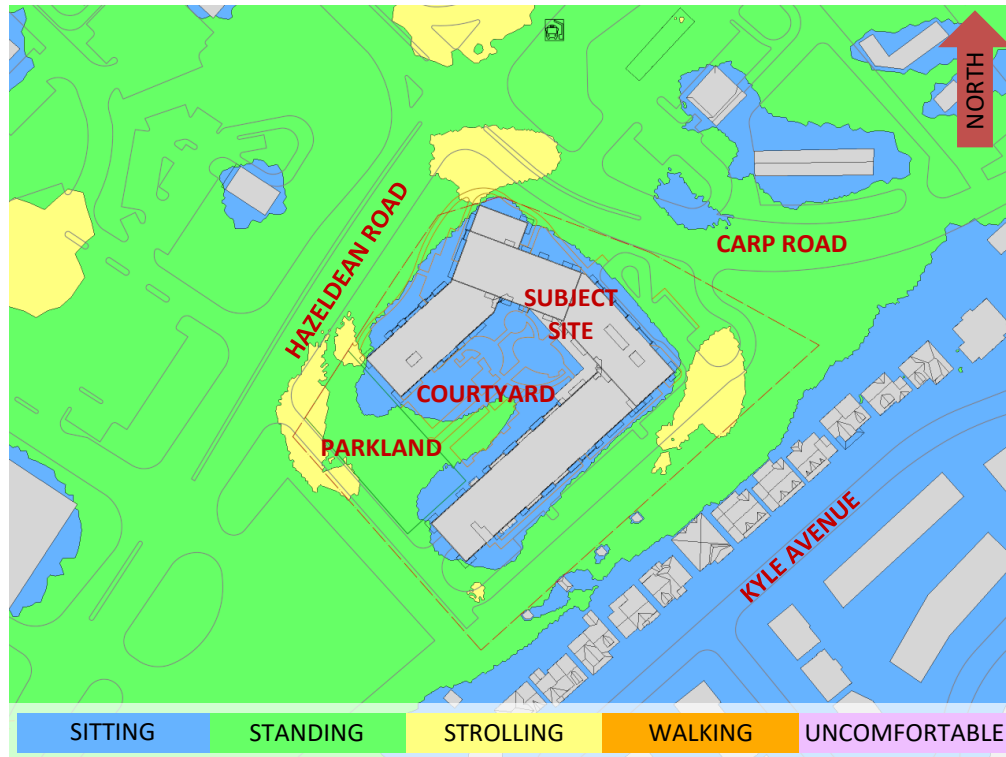


FIGURE 3A: SPRING – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

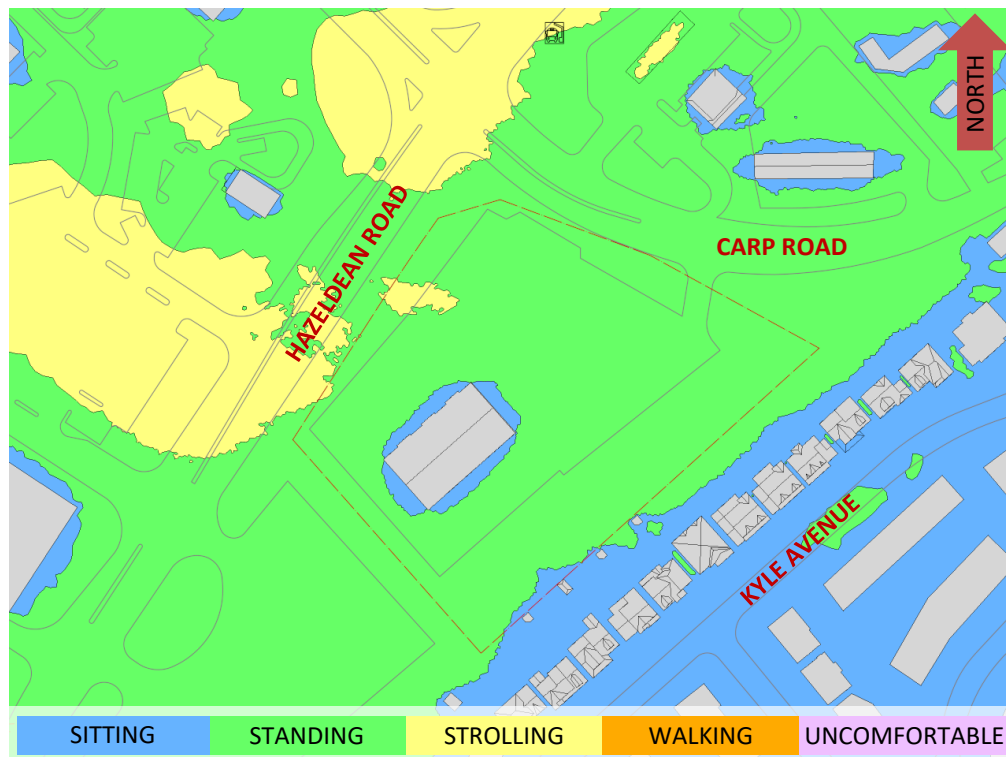


FIGURE 3B: SPRING – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



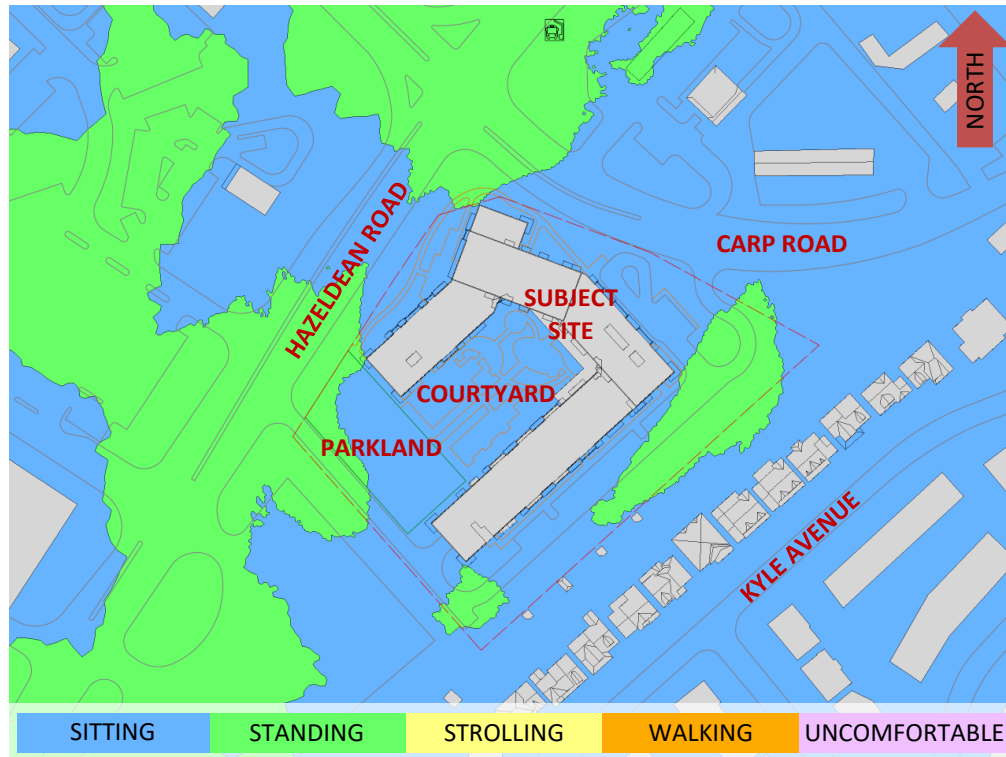


FIGURE 4A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

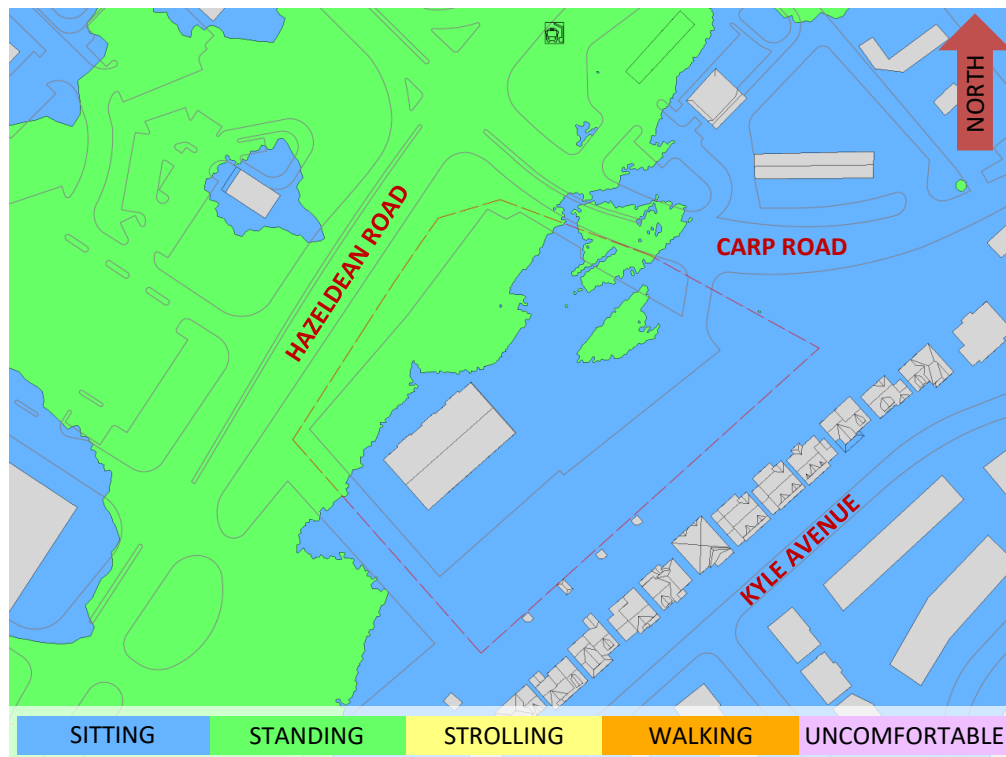


FIGURE 4B: SUMMER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



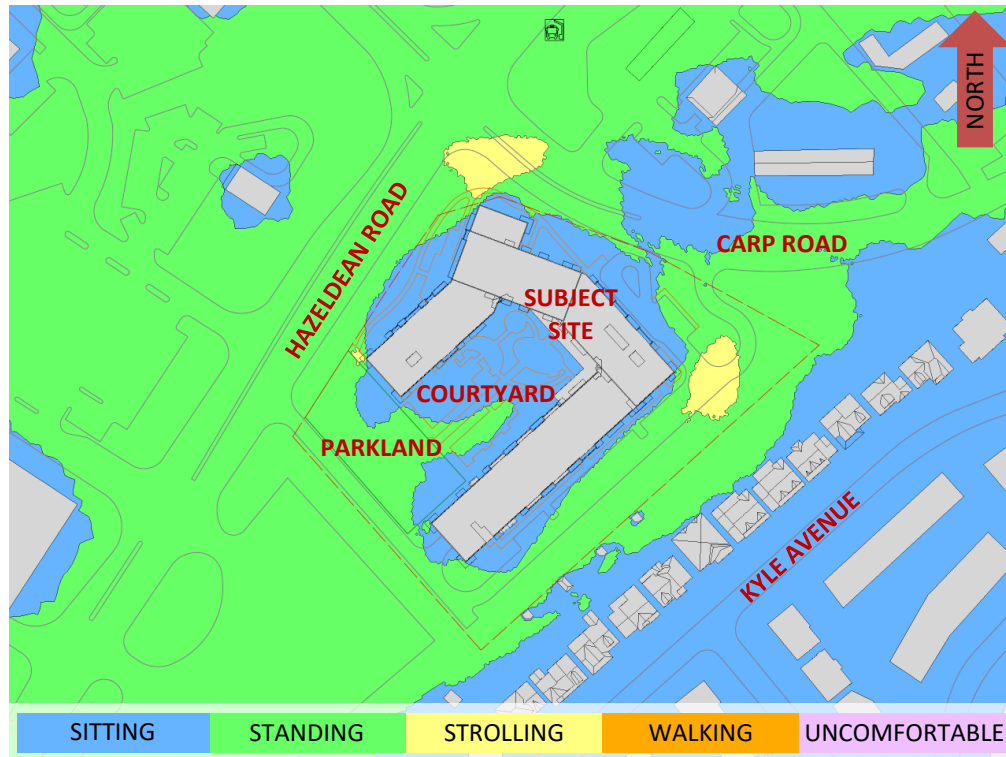


FIGURE 5A: AUTUMN – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

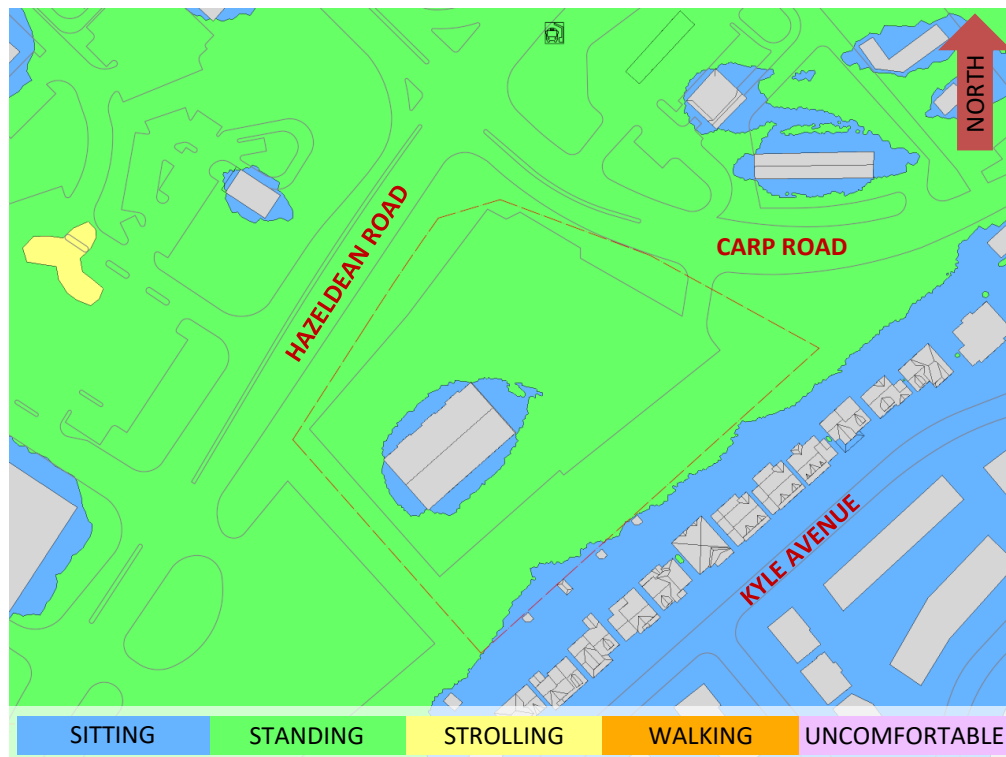


FIGURE 5B: AUTUMN – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



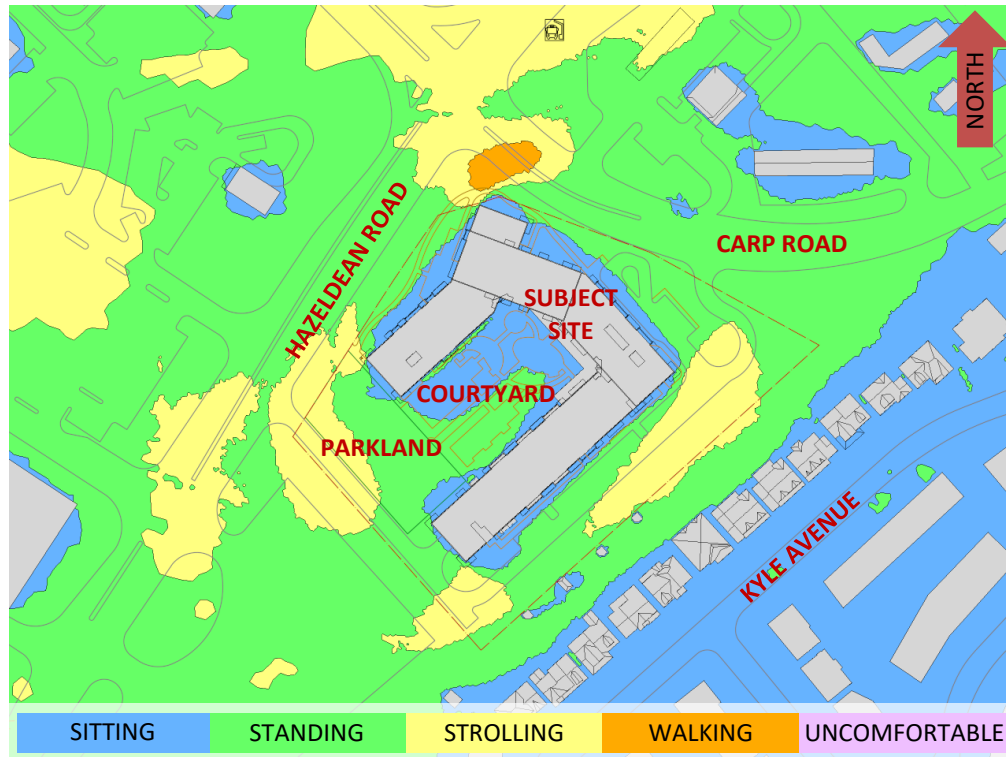


FIGURE 6A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

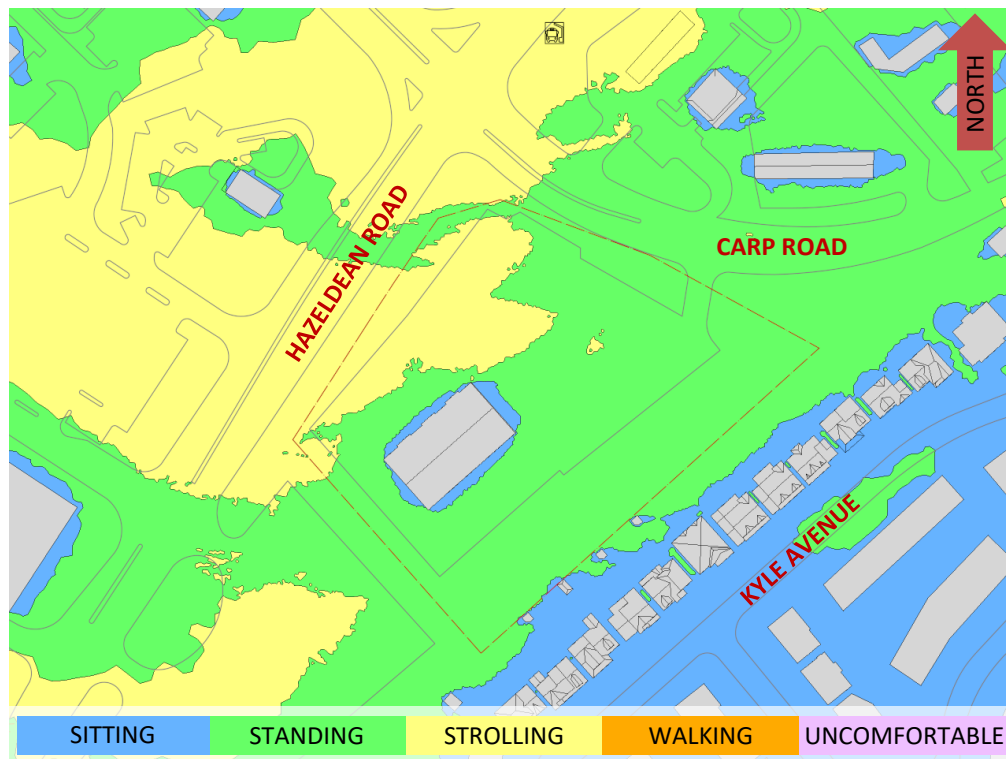


FIGURE 6B: WINTER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



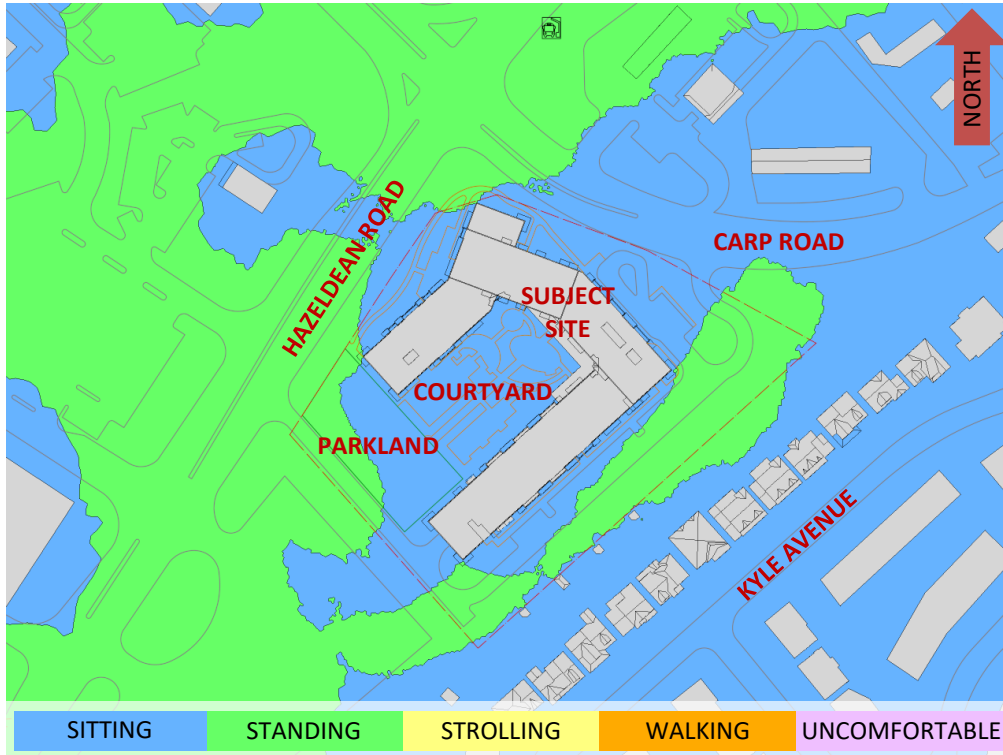
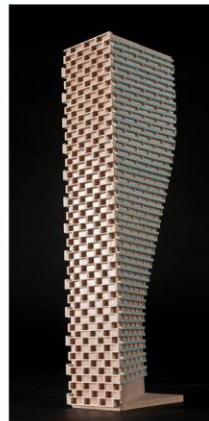


FIGURE 7: TYPICAL USE PERIOD – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

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, 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 (that is, 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 (Degrees True)	Alpha Value (α)
0	0.20
49	0.22
74	0.22
103	0.23
167	0.20
197	0.19
217	0.19
237	0.19
262	0.19
282	0.19
301	0.20
324	0.20

TABLE 2: DEFINITION OF UPSTREAM EXPOSURE (ALPHA VALUE)

Upstream Exposure Type	Alpha Value (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.