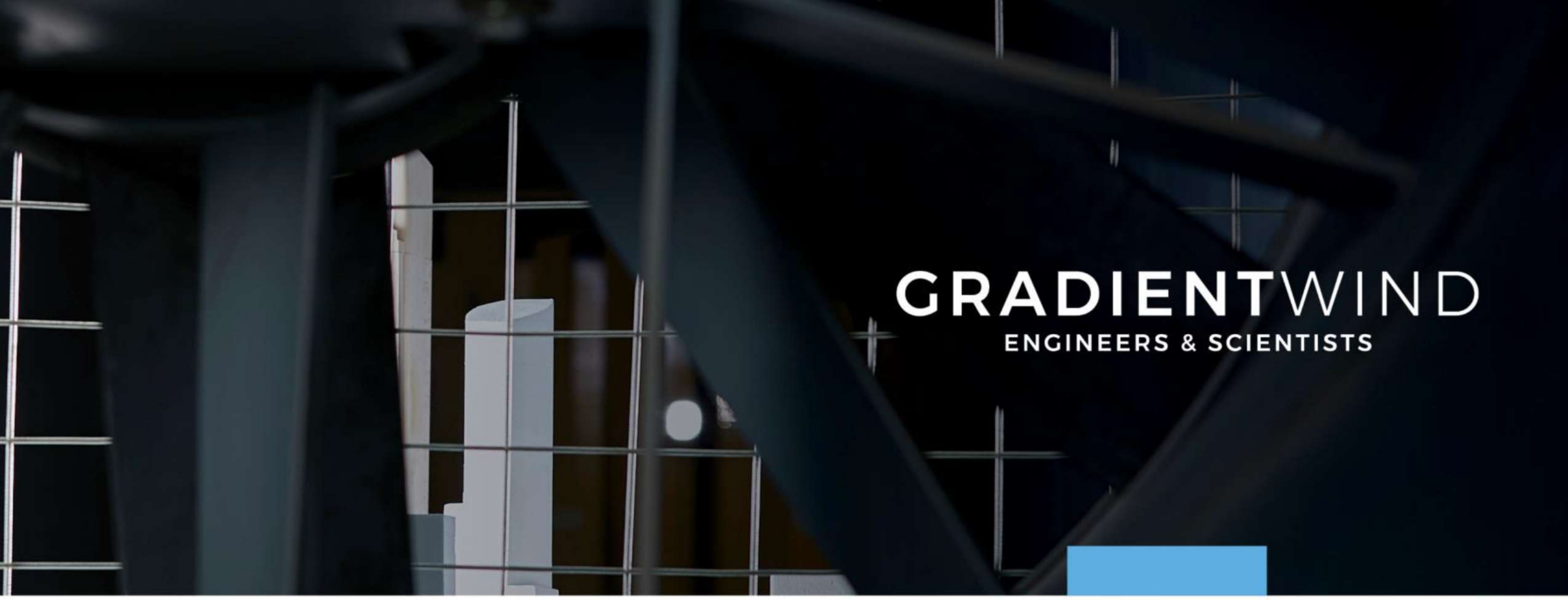
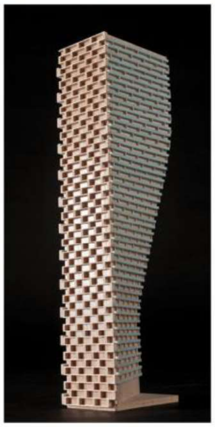


GRADIENTWIND
ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

13 Mountain Street and 19-23 Elm Street
Grimsby, Ontario

Report: 21-077-PLW-2025 R1



May 16, 2025

PREPARED FOR
Woolverton Holdings Corp.
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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study to satisfy Official Plan Amendment (OPA) and Zoning By-Law (ZBLA) application submission requirements for the proposed mixed-use residential development located at 13 Mountain Street and 19-23 Elm Street in Grimsby, Ontario (hereinafter referred to as the "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 wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

The study involves simulation of wind speeds for sixteen (16) 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. A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-4B, and is 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 most surrounding sidewalks, neighbouring surface parking lots, the proposed residential courtyard, and in the vicinity of the proposed building access points, are considered acceptable.

    a. Owing to the mostly suburban environs of the subject site and the limited built-up massing in the vicinity of the proposed development which exposes the proposed development to prevailing winds from the southwest, isolated areas that may occasionally be considered uncomfortable for walking during the winter are predicted to the north, northwest, and southeast of the subject site. The windier conditions are mostly located over roadway surfaces and away from pedestrian accessible areas, and conditions over most of the nearby sidewalks are suitable for walking, or better, throughout the year.

2) If the windier areas within the proposed plaza and the public courtyard will include designated seating or lounging areas, comfort conditions at these areas may be improved by implementing targeted mitigation elements as described in Section 5.1.

3) The foregoing statements and conclusions apply to common weather systems, during which no dangerous wind conditions, as defined in Section 4.4, are expected 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.

Addendum: The PLW study was completed based on architectural drawings prepared by Studio JCI in November 2024. Updated drawings were distributed to the consultant team, dated May 16, 2025, with some changes to the proposed development. Most notably, the height of the proposed development has been reduced from 10 to 8 storeys. At the ground floor, the loading space along the north elevation has been shifted to the east, the building has been slightly extended along the east and northeast elevations and is now closer to the property line. The central residential courtyard has been elevated at Level 2 due to the additional indoor parking at the ground floor. From Levels 2-8, the building has been extended along the northeast elevation, accommodating additional residential units. Additional building setbacks have been incorporated along the east and northeast elevations at Level 4, and from the north and east elevations at Level 8.

The building steps back from the northeast, east, south, and west elevations at Level 4, from all elevations at Level 8, and the mechanical penthouse room has been increased in area.

The noted changes are considered modest from a wind engineering perspective. The wind comfort conditions within and surrounding the subject site and the conclusions and recommendations as detailed in the present study are expected to remain representative of the current site massing.

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1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Woolverton Holdings Corp. to undertake a pedestrian level wind (PLW) study to satisfy Official Plan Amendment (OPA) and Zoning By-Law (ZBLA) application submission requirements for the proposed mixed-use residential development located at 13 Mountain Street and 19-23 Elm Street in Grimsby, Ontario (hereinafter referred to as the "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 wind conditions may interfere with certain pedestrian activities so that mitigation measures may be considered, where required.

The study is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, Niagara Region wind comfort and safety criteria, architectural drawings provided by Studio JCI in November 2024, surrounding street layouts and existing and approved future building massing information obtained from the Town of Grimsby, and recent site imagery.

2. TERMS OF REFERENCE

The subject site is located at 13 Mountain Street and 19-23 Elm Street in Grimsby, situated to the northeast at the intersection of Mountain Street and Elm Street. The proposed development comprises a 10-storey mixed-use residential building with an irregular 'U' shape open to the south. Two existing low-rise buildings to the west (13 and 19 Mountain Street) are to be retained and incorporated.

The ground floor includes a main residential entrance from Mountain Street to a lobby at the northwest corner of the site. A proposed driveway to the north of the site provides access from Mountain Street to a loading area and the underground parking. The northern portion of the ground level is reserved for building services and indoor amenities. To the west, the existing low-rise buildings at 13 and 19 Mountain Street (Woolverton House and Woolverton Hall, respectively), connect to the proposed development, providing additional amenity space. An outdoor plaza is programmed between these two existing buildings. The east and central portions of the ground floor are reserved for residential use, fronting residential and public courtyards that are open to the south, alongside commercial spaces fronting Elm Street.

Levels 2-10 are reserved for residential space. Set backs at Levels 4, 8, and 10 accommodate private terraces. The building is topped by a mechanical penthouse level (MPH).

Regarding wind exposures, the near-field surroundings of the subject site (defined as an area falling within a 200-metre (m) radius of the subject site) are characterized by low-rise residential dwellings in all directions, with low-rise commercial buildings with surface parking lots from the west clockwise to the east. The far-field surroundings (defined as the area beyond the near field and within a two-kilometre (km) radius) include primarily low-rise buildings from the west clockwise to the southeast; Lake Ontario is situated approximately 1.5 km to the north. The Beamer Memorial Conservation Area lies approximately 300 m to the south, where the Niagara Escarpment begins to rise sharply to a height of approximately 100 m above the elevation of the subject site.

Figure 1A illustrates the subject site and surrounding context, representing the proposed future massing scenario, while Figure 1B illustrates the subject site and surrounding context, representing the existing massing scenario. Figures 2A-2H illustrate the computational models used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind conditions at key areas within and surrounding the subject 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 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 Niagara Falls area wind climate, and synthesis of computational data with Niagara Region wind criteria[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

[1] Niagara Region, *Pedestrian Level Wind Study Terms of Reference Guide*, 2022

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 the Niagara Falls International Airport in Niagara County, New York. 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 proposed 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 stronger 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 subject site for 16 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a radius of 480 m. The process was performed for two context massing scenarios, as noted in Section 2.

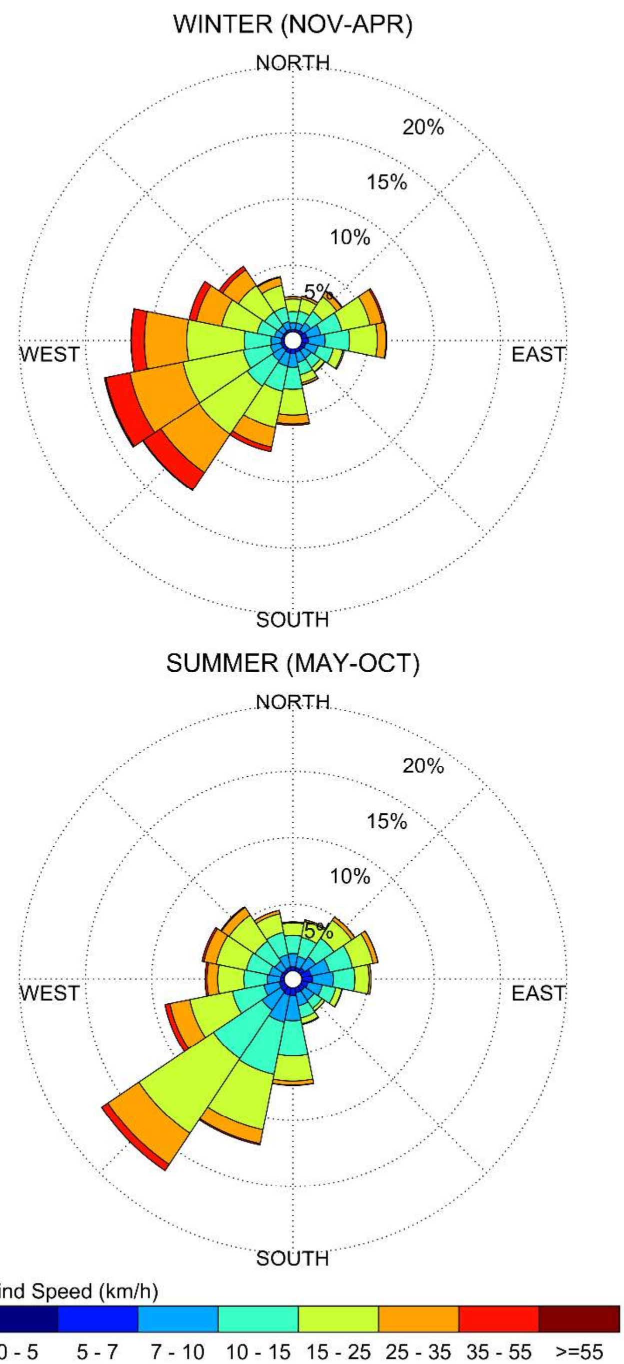
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade were referenced to the wind speed at gradient height to generate 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 Grimsby was developed from approximately 40 years of hourly meteorological wind data recorded at Niagara Falls International Airport. Wind speed and direction data were analyzed during the appropriate hours of pedestrian usage (that is, between 06:00 and 23:00) and divided into two distinct seasons, as stipulated in the wind criteria. Specifically, the summer season is defined as May though October, and the winter season is defined as November through April, inclusive.

The statistical model of the Niagara Falls 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 Grimsby, the most common winds occur for southwesterly 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
NIAGARA FALLS INTERNATIONAL AIRPORT, NIAGARA COUNTY, NEW YORK



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 – Niagara Region

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. Since both mean and gust wind speeds affect pedestrian comfort, their combined effect is defined in the Niagara Region Pedestrian Level Wind Study Terms of Reference Guide. Specifically, the criteria are defined as a Gust Equivalent Mean (GEM) wind speed, which is the greater of the mean wind speed or the gust wind speed divided by 1.85.

The wind speed ranges are based on the Beaufort scale, which describes the effects of forces produced by varying wind speed levels on objects. Four pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort: (1) Sitting; (2) Standing; (3) Walking; and (4) Uncomfortable. Wind conditions suitable for sitting are represented by the colour blue, standing by green, and walking by yellow; uncomfortable conditions are represented by the colour orange, consistent with the Niagara Region Terms of Reference. 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	GEM wind speeds no greater than 10 km/h occurring at least 80% of the time are considered acceptable for sedentary activities, including sitting.
STANDING	≤ 15	GEM wind speeds no greater than 15 km/h occurring at least 80% of the time are considered acceptable for activities such as standing, strolling, or more vigorous activities.
WALKING	≤ 20	GEM wind speeds no greater than 20 km/h occurring at least 80% of the time are considered acceptable for walking or more vigorous activities.
UNCOMFORTABLE	> 20	Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, are considered acceptable for moderate excesses of this criterion.

Regarding wind safety, gust wind speeds greater than 90 km/h, occurring more than 0.1% of the time on an annual basis (based on wind events recorded for 24 hours a day), 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.

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 GEM wind speeds 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 GEM wind speeds 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 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 below. 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
Café / Patio / Bench / Garden	Sitting / Standing
Transit/Bus Stop (Without Shelter)	Standing
Transit/Bus Stop (With Shelter)	Walking
Public Park / Plaza / Amenity Space	Sitting / Standing
Garage / Service Entrance / Parking Lot	Walking

5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-4B which illustrate wind conditions at grade level for the proposed and existing massing scenarios. Conditions are presented as continuous contours of wind comfort and correspond to the various comfort classes noted 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

The subject site is located in a mostly suburban context, with the open exposure of the Niagara Escarpment to the south and Lake Ontario to the north and sparse mid-rise massing in the area, as described in Section 2. When combined with the prevailing southwesterly winds in the area, windier conditions are predicted to the northwest and southeast of the proposed development, particularly during the winter season. Specifically, the grade-level wind comfort conditions within and surrounding the proposed development are predicted to be suitable mostly for walking, or better, throughout the year, with areas of conditions that may be considered occasionally uncomfortable for walking located to the southeast and northwest. The conditions within and surrounding the proposed development are expected following the introduction of the mid-rise development in its surroundings.

The noted conditions are attributed to prevailing winds from the south-southwest clockwise to the west that are predicted to downwash over and along the western and southern façades of the proposed development, and to accelerate around the exposed northwest corner of the proposed development, as well as beneath the building overhang to the north and between the proposed development and the neighbouring property at 11 Mountain Street. During the winter, conditions to the north of the site along the drive aisle serving the proposed development and the access driveway serving 11 Mountain Street are predicted to be suitable for walking for approximately 70% of the time, representing a 10% exceedance of the walking threshold. At the southeast corner of the existing LCBO building, wind conditions are predicted to be suitable for walking for approximately 69% of the time during the winter, representing an exceedance of 11% of the walking threshold. To the northwest of the subject site, conditions during the winter season are predicted to be suitable for walking for approximately 74% of the time, representing a 6% exceedance of the walking criterion.

Notably, the windier conditions are mostly located over the roadway surfaces and away from pedestrian accessible areas, and conditions over most of the nearby sidewalks are suitable for walking, or better, throughout the year.

Sidewalks along Mountain Street: Conditions over the nearby public sidewalks along Mountain Street under the existing massing are predicted to be suitable for standing, or better, throughout the year. Following the introduction of the proposed development, wind comfort conditions over the nearby sidewalks along Mountain Street are predicted to be suitable for a mix of sitting and standing during the summer, with walking areas to the northwest of the subject site. During the winter, conditions are predicted to be suitable for a mix of standing and walking, with the exception of a portion of the sidewalk to the northwest of the proposed development where conditions may occasionally be considered uncomfortable for walking, as noted above.

Sidewalks along Elm Street: Conditions over the nearby public sidewalks along Elm Street under the existing massing are predicted to be suitable for standing, or better, throughout the year. Following the introduction of the proposed development, wind conditions over the nearby sidewalks along Elm Street are predicted to be suitable for a mix of sitting, standing, and walking during the summer, becoming suitable for walking, or better, during the winter, with the exception of a portion of the sidewalk to the southeast of the subject site, where conditions may occasionally be considered uncomfortable for walking, as noted above.

Driveway to the North of the Subject Site: Under the existing massing, conditions over the existing driveway to the north of the subject site are predicted to be suitable for standing, or better, throughout the year. Following the introduction of the proposed development, wind conditions over the noted area are predicted to be suitable for walking, or better, during the summer, becoming suitable for mostly walking during winter, with isolated areas that may occasionally become uncomfortable for walking, as noted above.

Neighbouring Surface Parking Lots: Under the existing massing, wind conditions over the neighbouring surface parking lots from the north clockwise to the east of the subject site are predicted to be suitable for mostly sitting during the summer and standing during the winter. Following the introduction of the proposed development, wind conditions over the noted neighbouring surface parking lots are predicted to be suitable for standing, or better, during the summer, becoming suitable for a mix of standing and walking during the winter. The noted conditions are considered acceptable.

Public Courtyard : Conditions within the proposed public courtyard are predicted to be suitable for mostly standing throughout the year. During the summer, conditions within the public courtyard are also predicted to be suitable for sitting at least 75% of the time, where the target is 80% to reach the sitting comfort class threshold. If the programming of the public courtyard will not include designated seating or lounging areas, the noted conditions may be considered acceptable. If required by programming, comfort conditions at sensitive-use areas may be improved by implementing landscaping elements such as tall wind screens and coniferous plantings in dense arrangements that are targeted adjacent to designated seating areas, in combination with strategically placed seating with high-back benches, and other local wind mitigation. The extent of the mitigation measures is dependent on the programming of the public courtyard

Proposed Plaza to the West of the Subject Site: Wind comfort conditions within the proposed plaza to the west of the subject site are predicted to be suitable mostly for sitting during the summer, with conditions suitable for standing along the western perimeter of the plaza. Where conditions are suitable for standing during the summer, they are also suitable for sitting at least 70% of the time, where the target is 80% to achieve the sitting criterion. If the programming of the western extent of the plaza will not include designated seating or lounging areas, the noted conditions may be considered acceptable. If required by programming, similar mitigation elements may be implemented as described above for the public courtyard.

Residential Courtyard: Wind conditions within the residential courtyard located at the centre of the subject site are predicted to be suitable for sitting during the summer, becoming suitable mostly for sitting with standing areas to the south during the winter. The noted conditions are considered acceptable.

Building Access Points: Conditions in the vicinity of the primary building access points serving the proposed development are predicted to be suitable for standing, or better, throughout the year, while conditions in the vicinity of the secondary building access points serving the proposed development are predicted to be suitable for walking, or better, 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 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. SUMMARY AND RECOMMENDATIONS

A complete summary of the predicted wind conditions is provided in Section 5 of this report and illustrated in Figures 3A-4B. Based on computer simulations using the CFD technique, meteorological data analysis of the Grimsby wind climate, Niagara Region 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 most surrounding sidewalks, neighbouring surface parking lots, the proposed residential courtyard, and in the vicinity of the proposed building access points, are considered acceptable.

a. Owing to the mostly suburban environs of the subject site and the limited built-up massing in the vicinity of the proposed development which exposes the proposed development to prevailing winds from the southwest, isolated areas that may occasionally be considered uncomfortable for walking during the winter are predicted to the north, northwest, and southeast of the subject site. The windier conditions are mostly located over roadway surfaces and away from pedestrian accessible areas, and conditions over most of the nearby sidewalks are suitable for walking, or better, throughout the year.

2) If the windier areas within the proposed plaza and the public courtyard will include designated seating or lounging areas, comfort conditions at these areas may be improved by implementing targeted mitigation elements as described in Section 5.1.

3) The foregoing statements and conclusions apply to common weather systems, during which no dangerous wind conditions, as defined in Section 4.4, are expected 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.

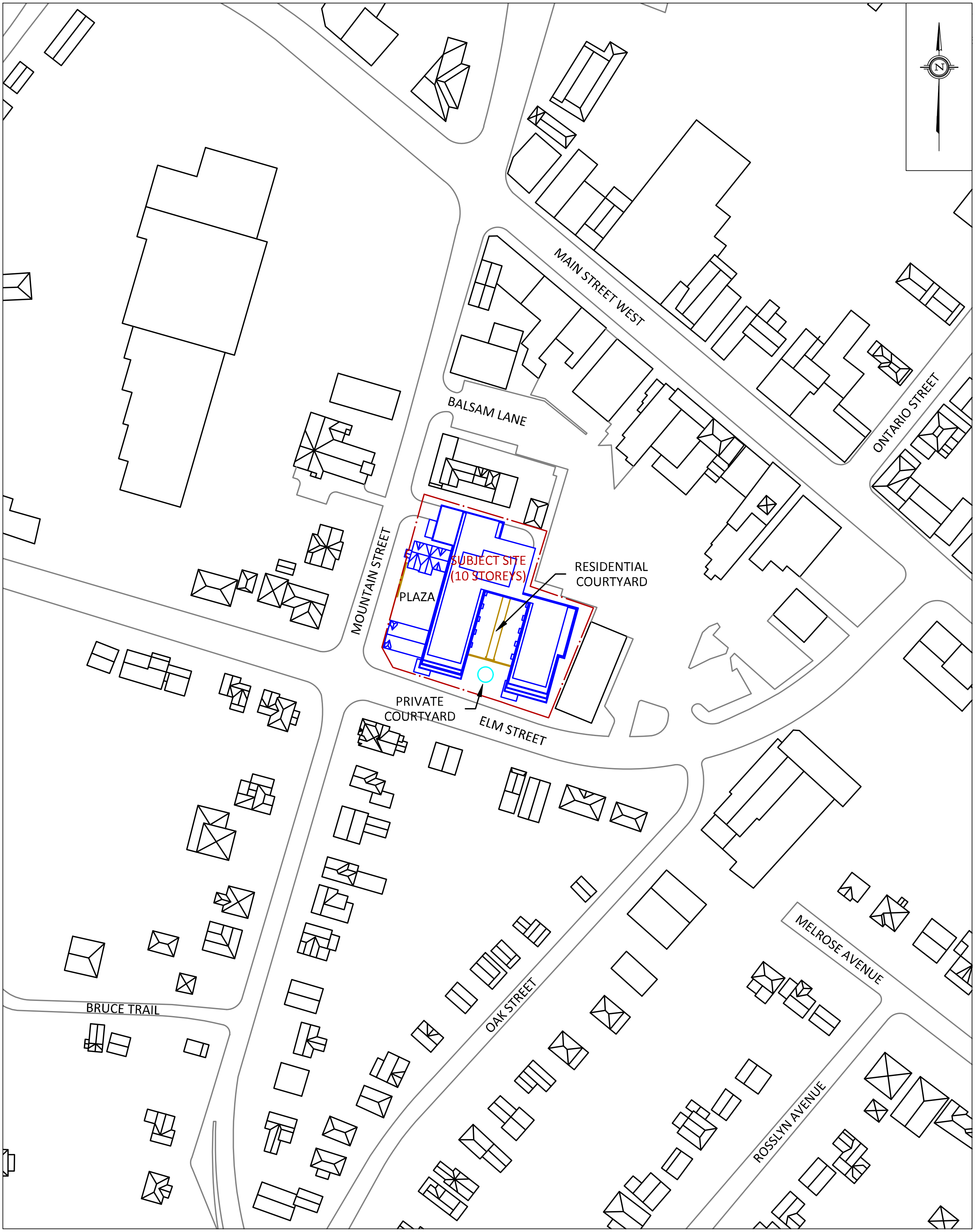
Sincerely,

Gradient Wind Engineering Inc.

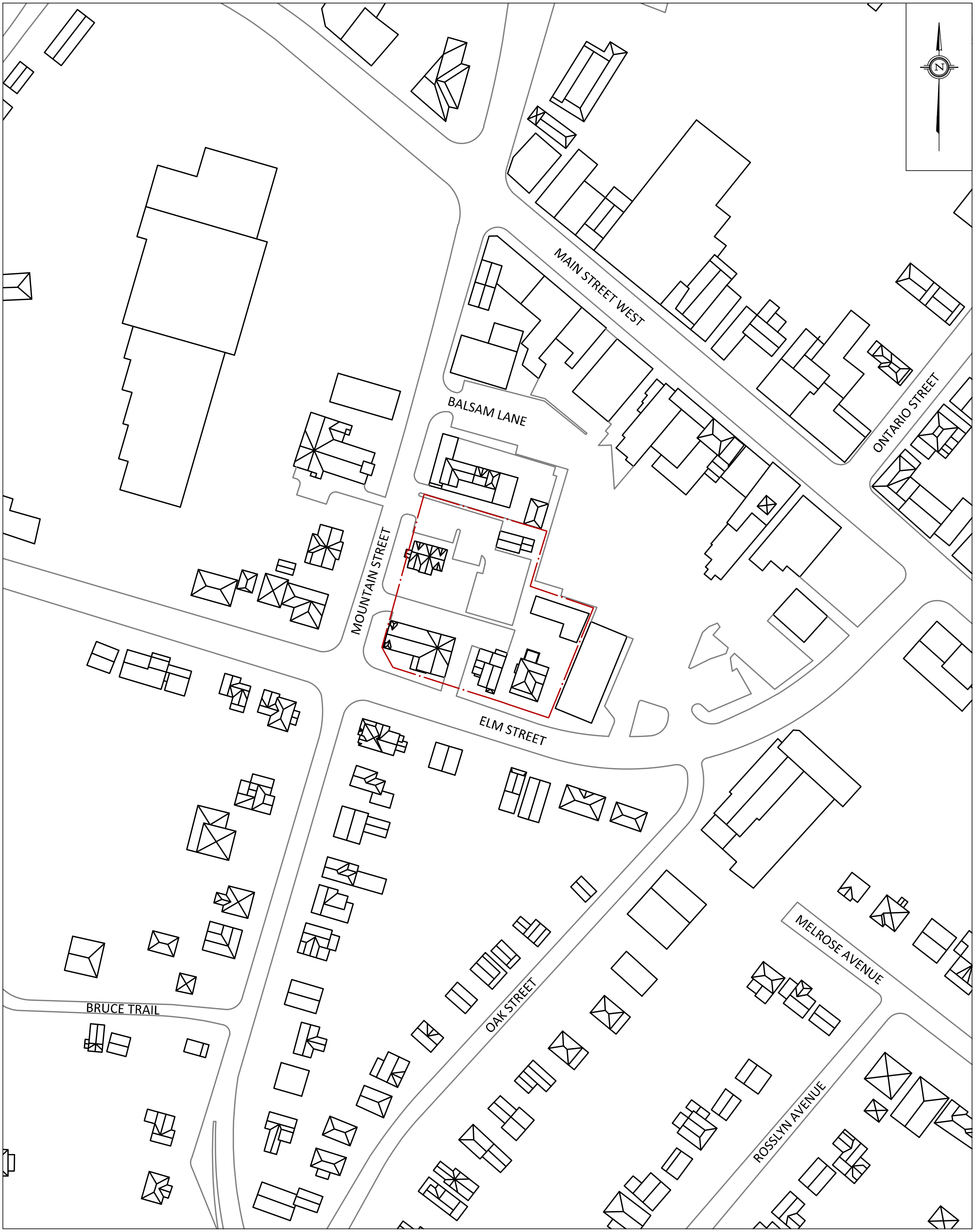
LICENSED PROFESSIONAL ENGINEER
D. T. HUITEMA
100561777
May 20, 2025
PROVINCE OF ONTARIO

Omar Rioseco, B.Eng.
Junior Wind Scientist

David Huitema, M.Eng., P.Eng.
CFD Lead Engineer



GRADIENTWIND ENGINEERS & SCIENTISTS 127 WALGREEN ROAD, OTTAWA, ON 613 836 0934 • GRADIENTWIND.COM	PROJECT 13 MOUNTAIN STREET AND 19 ELM STREET, GRIMSBY PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION FIGURE 1A: PROPOSED SITE PLAN AND SURROUNDING CONTEXT
	SCALE 1:2000	DRAWING NO. 21-077-PLW-2025-1A	
	DATE DECEMBER 3, 2024	DRAWN BY S.K.	



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127 WALGREEN ROAD, OTTAWA, ON
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PROJECT		DESCRIPTION
13 MOUNTAIN STREET AND 19 ELM STREET, GRIMSBY PEDESTRIAN LEVEL WIND STUDY		FIGURE 1B: EXISTING SITE PLAN AND SURROUNDING CONTEXT
SCALE 1:2000	DRAWING NO. 21-077-PLW-2025-1B	
DATE DECEMBER 3, 2024	DRAWN BY S.K.	

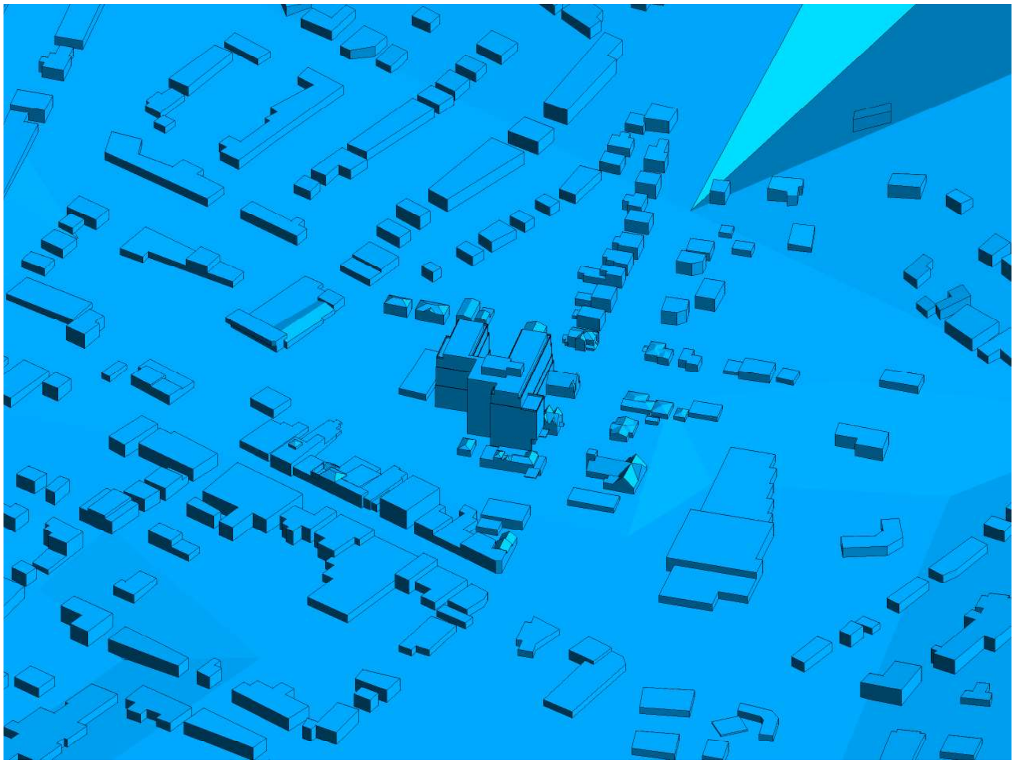

FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTH PERSPECTIVE

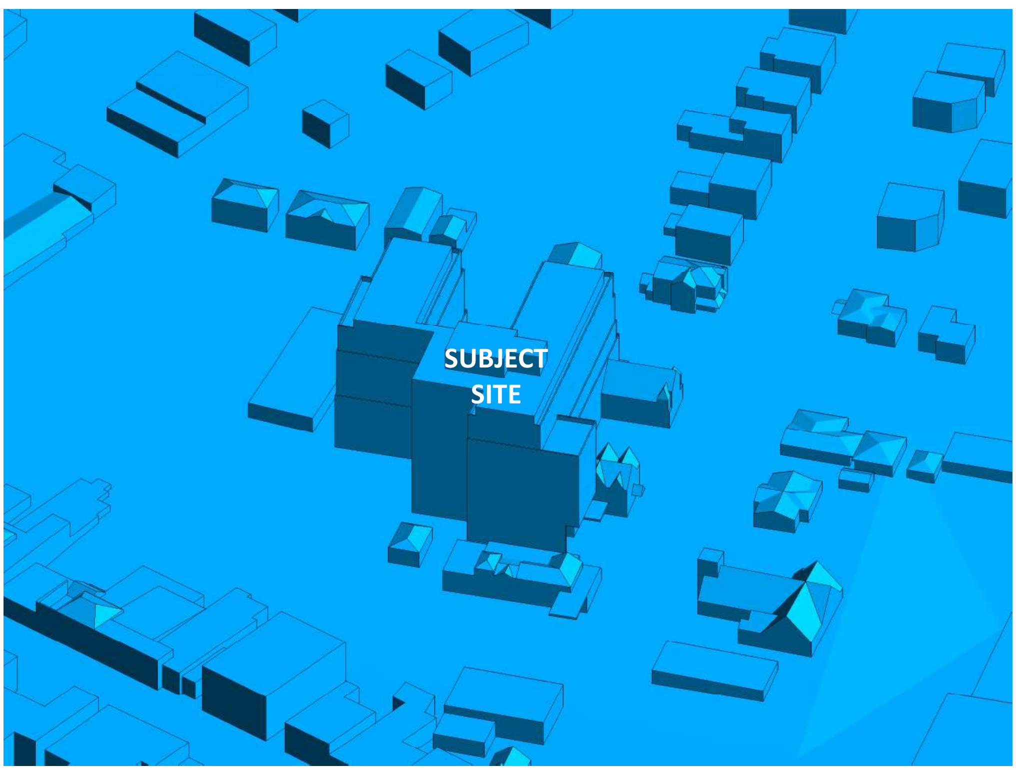

FIGURE 2B: CLOSE-UP VIEW OF FIGURE 2A

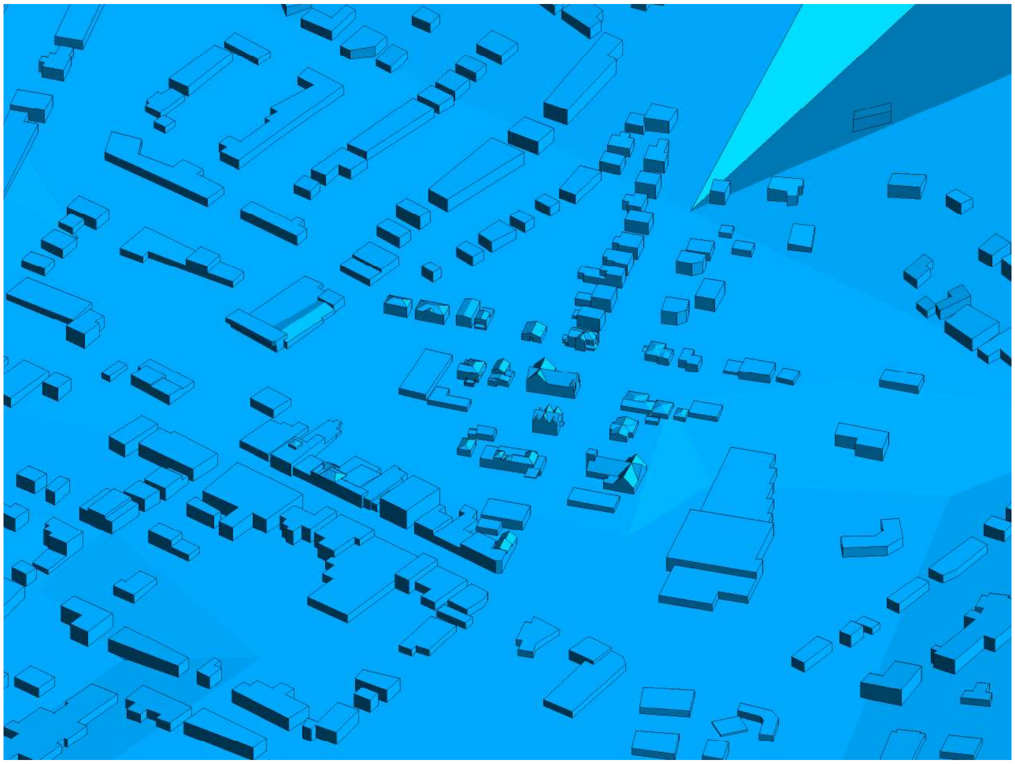

FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, NORTH PERSPECTIVE

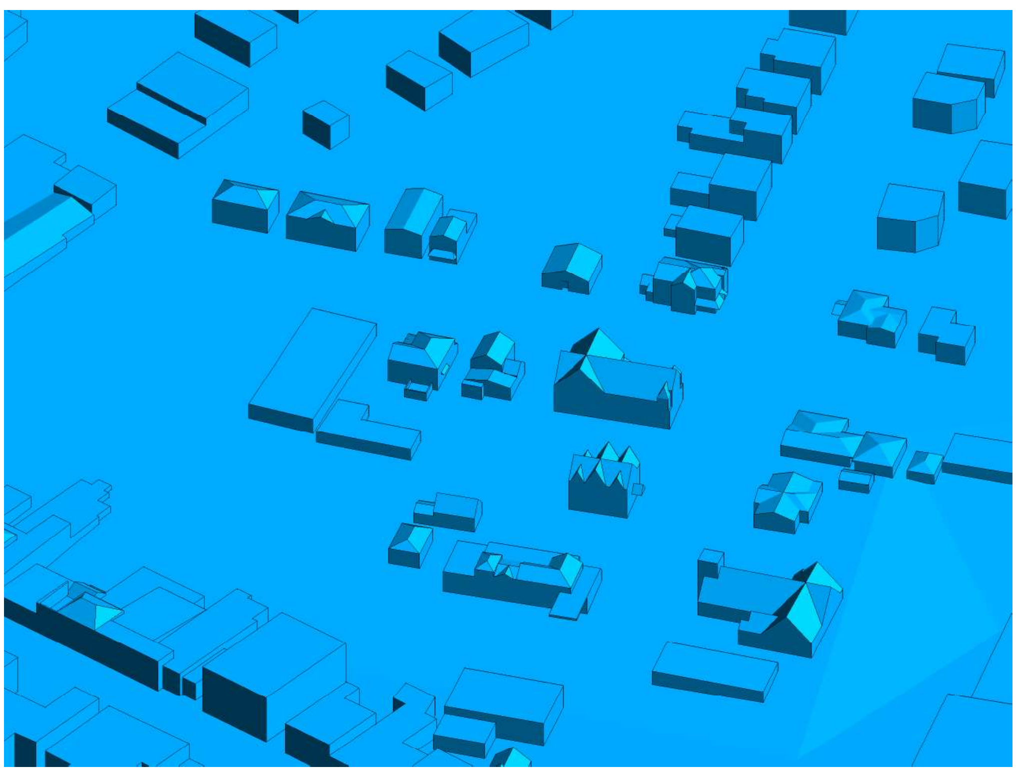

FIGURE 2D: CLOSE-UP VIEW OF FIGURE 2C

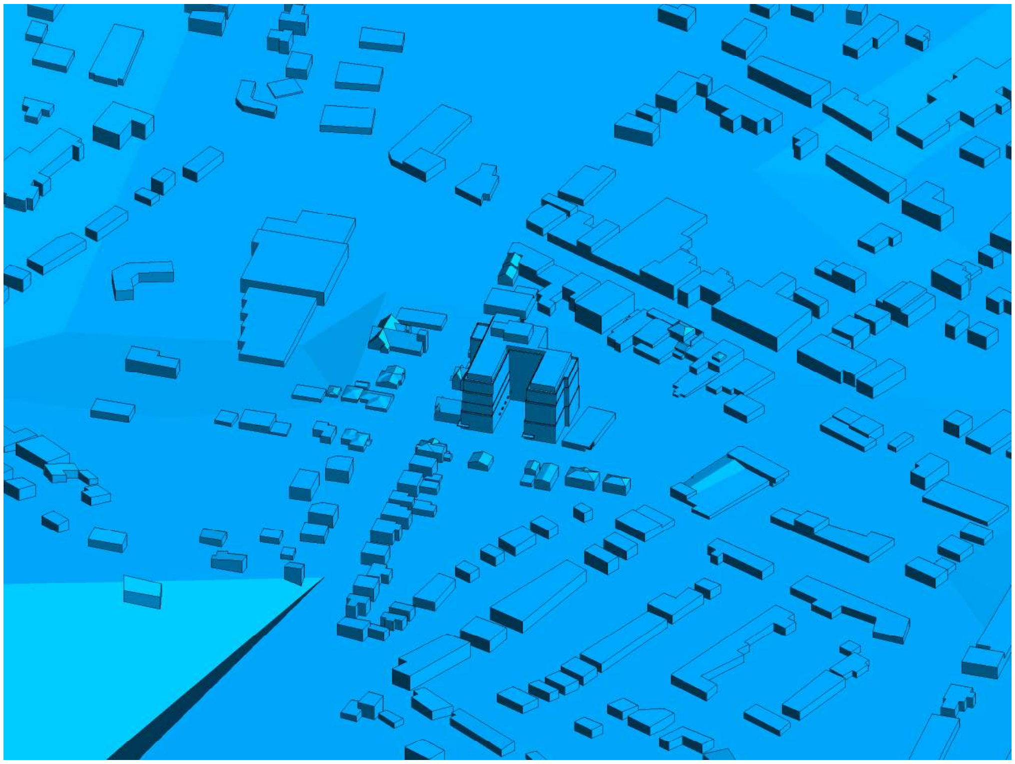

FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTH PERSPECTIVE

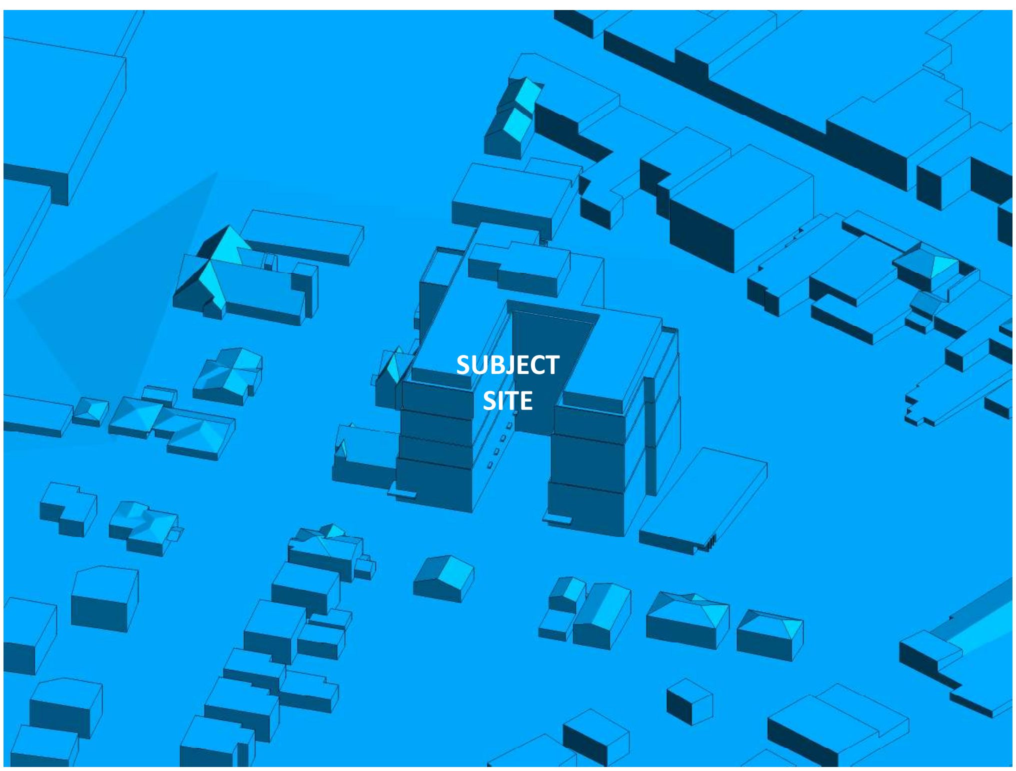

FIGURE 2F: CLOSE-UP VIEW OF FIGURE 2E

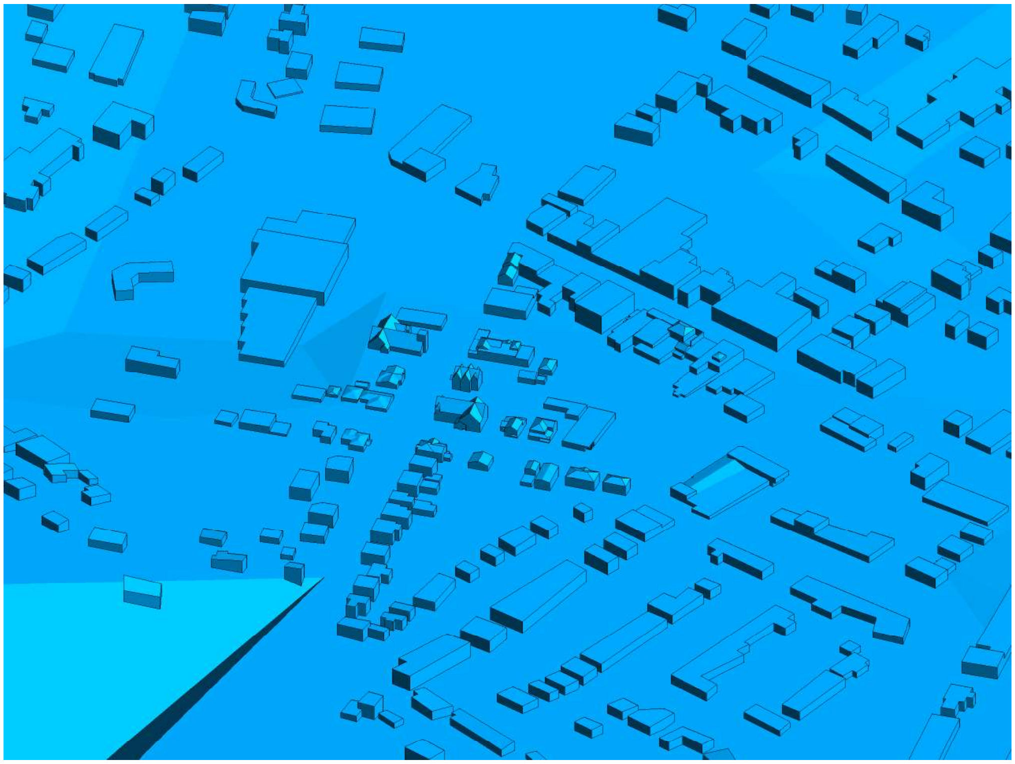

FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, SOUTH PERSPECTIVE

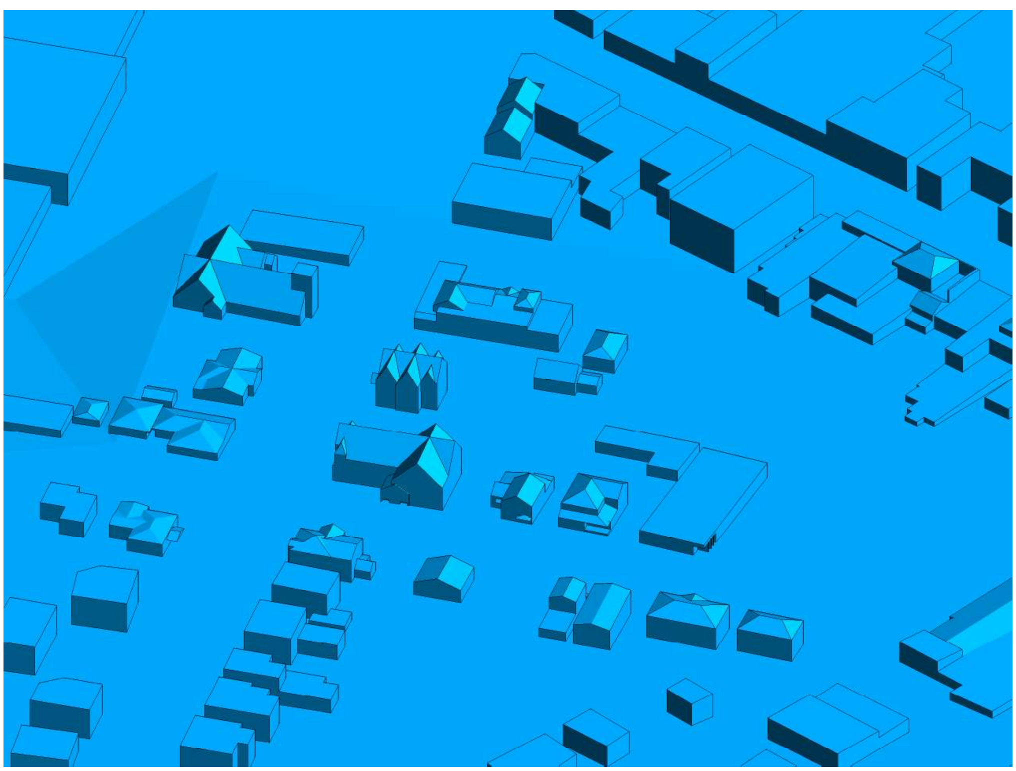

FIGURE 2H: CLOSE-UP VIEW OF FIGURE 2G

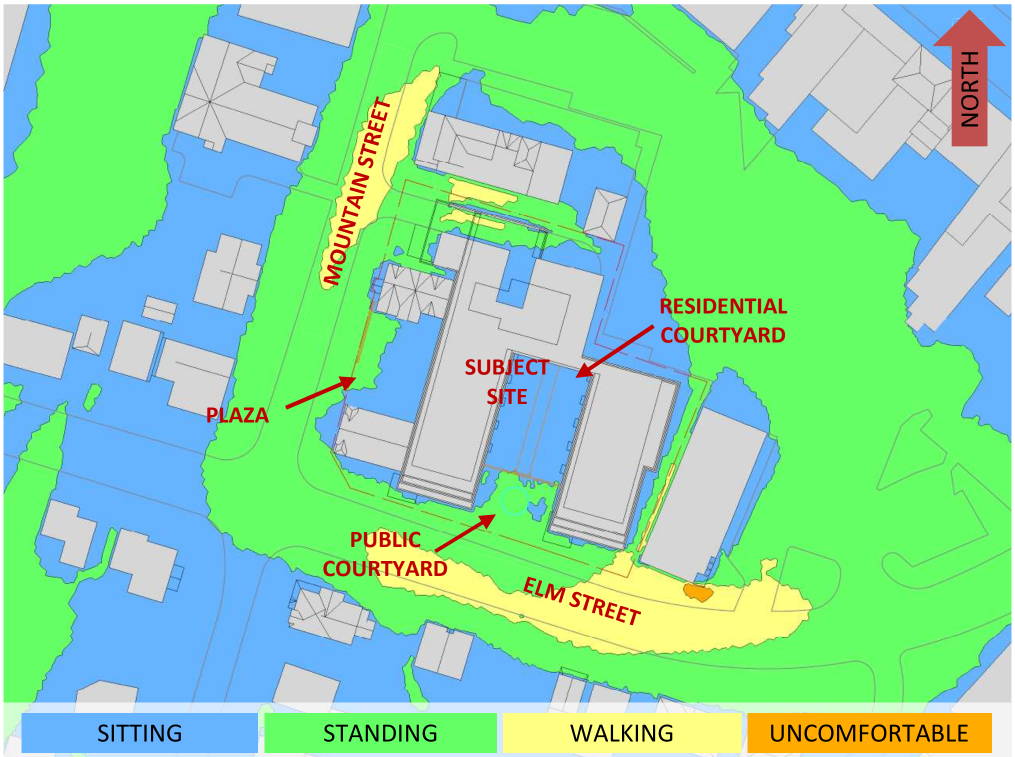

FIGURE 3A: SUMMER – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

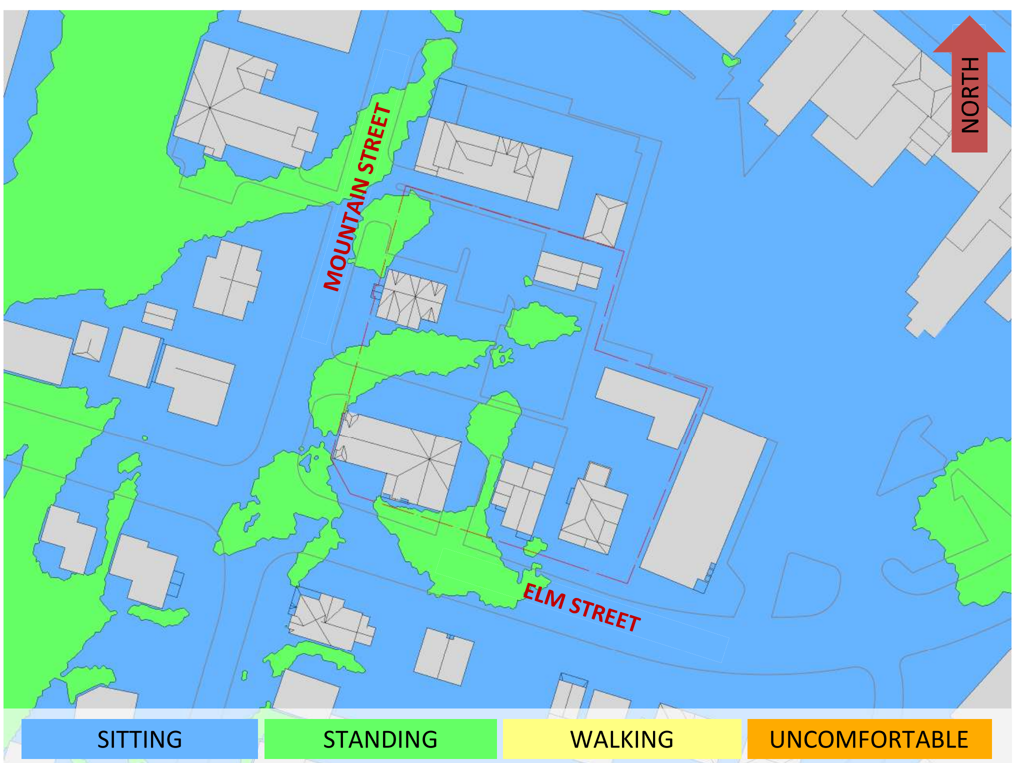

FIGURE 3B: SUMMER – EXISTING MASSING – WIND COMFORT, GRADE LEVEL

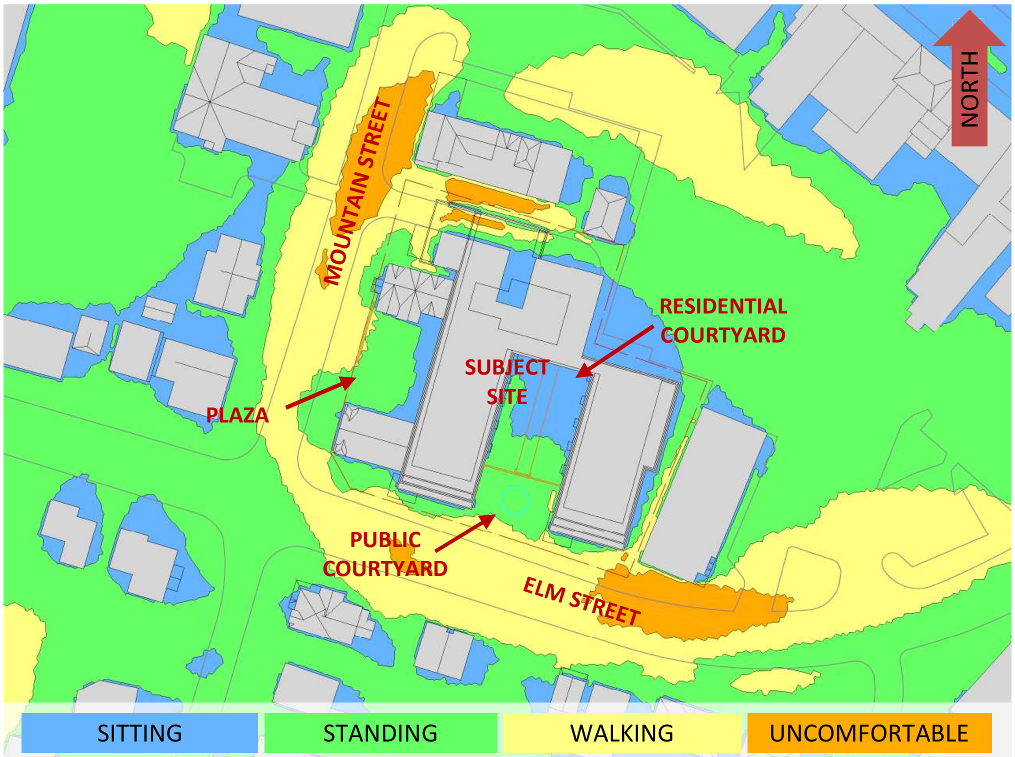

FIGURE 4A: WINTER – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

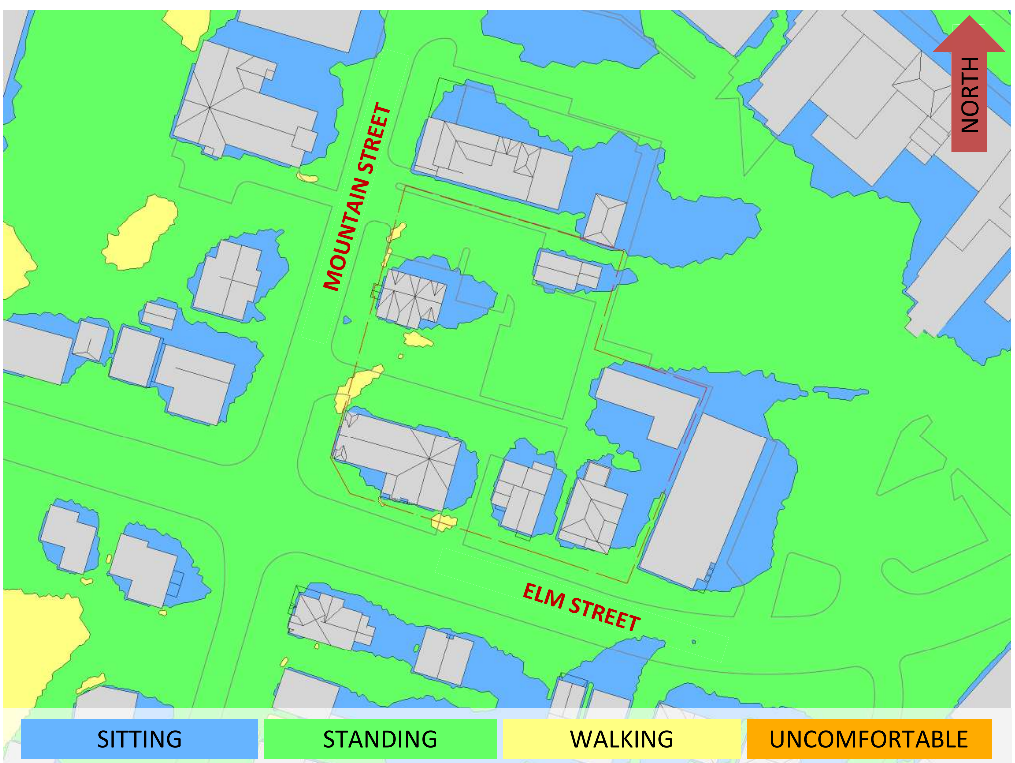

FIGURE 4B: WINTER – EXISTING MASSING – WIND COMFORT, GRADE LEVEL

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].

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

where, $\boldsymbol{U}$ = mean wind speed, $\boldsymbol{U_g}$ = gradient wind speed, $\boldsymbol{Z}$ = height above ground, $\boldsymbol{Z_g}$ = depth of the boundary layer (gradient height), and α is the power law exponent.

For the model, U_g is set to 6.5 metres per second (m/s), which approximately corresponds to the 35% mean wind speed for Grimsby 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 is 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	0.19
22.5	0.19
45	0.19
67.5	0.19
90	0.21
112.5	0.23
135	0.22
157.5	0.21
180	0.20
202.5	0.20
225	0.20
247.5	0.20
270	0.22
292.5	0.23
315	0.21
337.5	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].

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

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

where, $\boldsymbol{I}$ = turbulence intensity, $\boldsymbol{L_t}$ = turbulence length scale, $\boldsymbol{Z}$ = 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

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