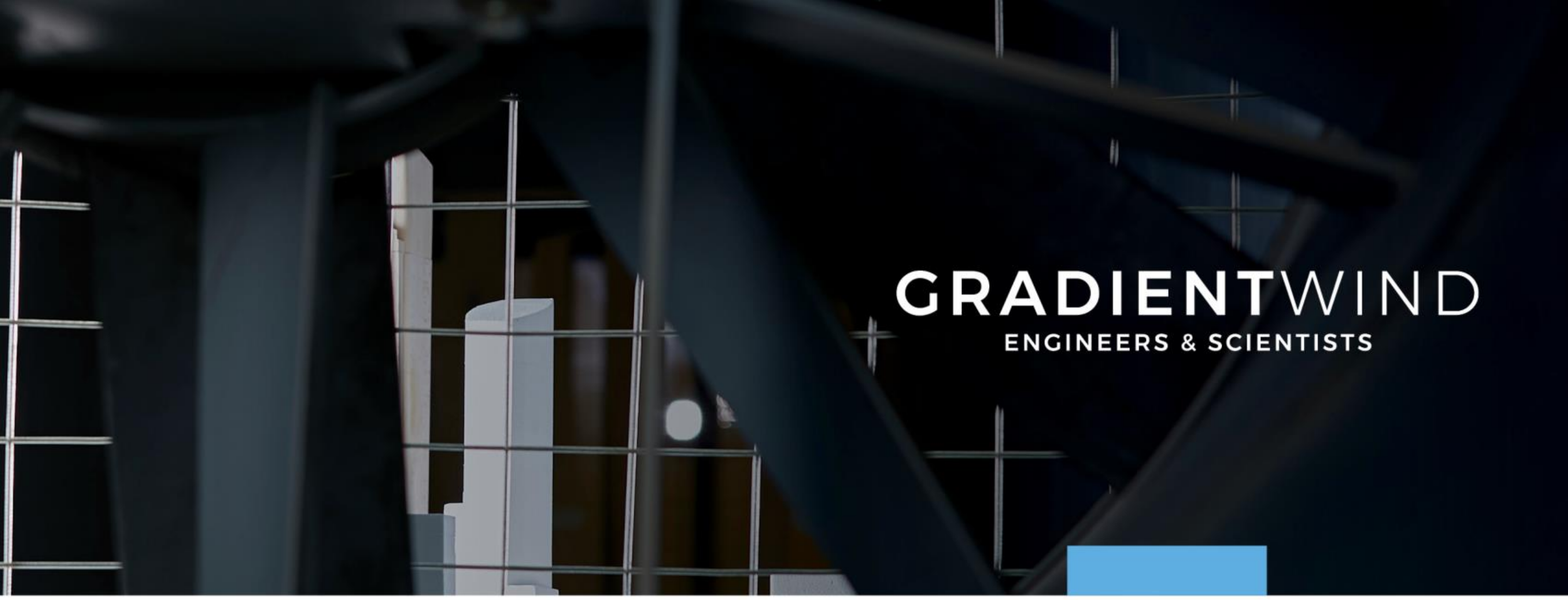
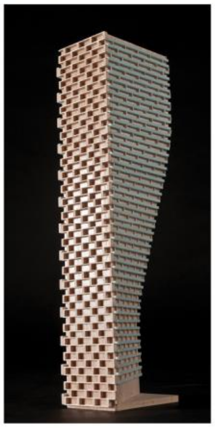


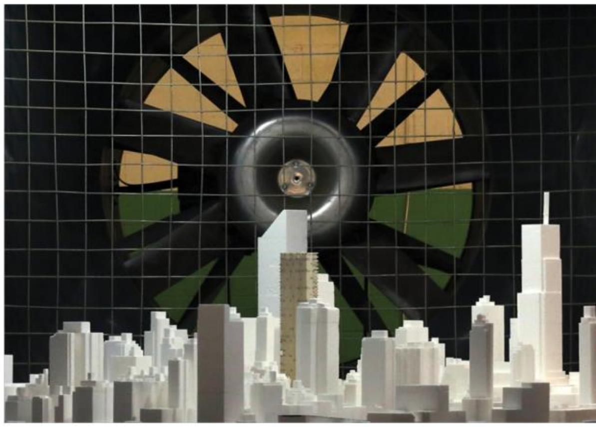
GRADIENTWIND
ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

1166 Gordon Street
Guelph, Ontario

Report: 21-378-PLW





January 14, 2022

PREPARED FOR
GSD Development & Management Inc.
4 Gainsville Avenue
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PREPARED BY
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Steven Hall, M.A.Sc., P.Eng., Senior Wind Engineer

EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study undertaken to satisfy Zoning By-Law Amendment application requirements for the proposed residential development located at 1166 Gordon Street in Guelph, Ontario (hereinafter referred to as “subject site” or “proposed development”). Our mandate within this study is to investigate pedestrian wind comfort and safety 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 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. 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) All grade level areas within and surrounding the subject site are predicted to be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, walkways, laneways, transit stops, in the vicinity of pedestrian building access points, and outdoor amenity spaces are considered acceptable. One exception is as follows:

    a. Conditions over the outdoor amenity spaces along the north and northeast elevations of Apartment Building 1 are predicted to be mostly suitable for sitting during the summer, with small regions being suitable for standing. Depending on the programming of these spaces, the noted conditions may be considered acceptable. If necessary, sitting conditions may be extended over the full amenity spaces with landscaping features such as tall wind barriers, topographical depressions or berms, or dense coniferous plantings.

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, (e.g., 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

Gradient Wind Engineering Inc. (Gradient Wind) was retained by GSD Development & Management Inc. to undertake a pedestrian level wind (PLW) study to satisfy Zoning By-Law Amendment application requirements for the proposed residential development located at 1166 Gordon Street in Guelph, Ontario (hereinafter referred to as “subject site” or “proposed development”). Our mandate within this study is to investigate pedestrian wind comfort and safety 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.

Our work is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, industry standard wind comfort and safety guidelines, architectural drawings prepared by Broadview Architect Inc., in December 2021, surrounding street layouts and existing and approved future building massing information obtained from the City of Guelph, recent satellite imagery, and experience with numerous similar developments.

2. TERMS OF REFERENCE

The subject site is located at 1166 Gordon Street in Guelph, Ontario; bordered by Gordon Street to the southwest, Landsdown Drive to the northeast, existing residential buildings to the northwest, and existing residential buildings and Valley Road to the southeast. Throughout this report, the Gordon Street elevation is referred to as the west elevation.

Rendering, South Perspective
(Courtesy of Broadview Architect Inc.)

The proposed development comprises four three-storey rectangular townhouse blocks along the east of the site, hereinafter referred to as “Block 1, 2, 3, and 4” from north to south, respectively, and two six-storey apartment buildings, each topped with a mechanical penthouse, referred to as “Apartment Building 1 and 2”, at the northwest and southwest of the subject site, respectively.

Above one below-grade parking level shared by Apartment Buildings 1 and 2, which includes an indoor amenity space at the northwest corner, the two apartment buildings share a common ground level. The ground level includes a central residential lobby with the main entrance to the east, indoor amenities to the north and south of the lobby, and residential units and shared support spaces throughout the remainder of the level. At grade, there is a central surface parking lot between the apartment buildings and the townhouses. Access to the central surface parking lot is provided from Landsdown Drive via a laneway between Block 1 and 2 and a laneway between Block 3 and 4. Access to underground parking is provided by a ramp to the south of Apartment Building 2. There are grade-level outdoor amenities along the north, east, and west elevations of the apartment buildings. At Level 2, the apartment buildings step back from the centre and rise with constant rectangular planforms to Level 6. Levels 2 through 6 are reserved for residential occupancy for both apartment buildings.

Regarding wind exposures, the near-field surroundings (defined as an area falling within a 200-metre (m) radius of the subject site) include a mid-rise residential building to the south and low-rise residential homes in the remaining compass directions. The far-field surroundings (defined as the area beyond the near field and within a 2-kilometre (km) radius) are characterized by a mix of green space and low-rise massing from the north clockwise to the east-northeast and from the south-southeast clockwise to the west-southwest, and by mostly low-rise residential buildings in the remaining compass directions.

Key areas under consideration include surrounding sidewalks, walkways within and surrounding the subject site, and building access points. 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 comfort and safety 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 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 Guelph area wind climate, and synthesis of computational data with industry standard wind comfort and safety guidelines, including City of Guelph microclimate guidelines[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind guidelines.

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 Region of Waterloo International Airport in Breslau, Ontario. 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 slightly more conservative (i.e., windier) wind speed values.

[1] City of Guelph Pedestrian Level Wind Studies Terms of Reference [May 27, 2019]

4.2 Wind Speed Measurements

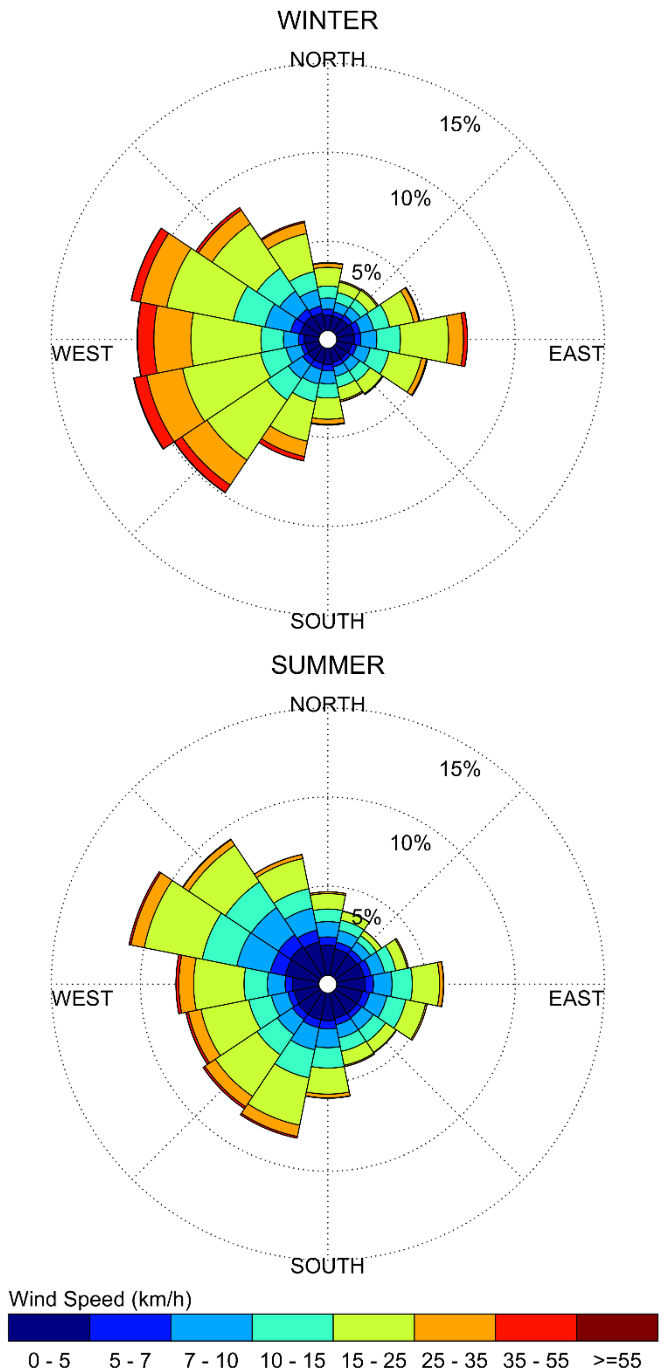
The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the subject site for 12 wind directions. The CFD simulation model was centered on the proposed development, complete with surrounding massing within a diameter of 1.14 km. Mean and peak wind speed 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 Guelph was developed from 44 years (1976-2020) of hourly wind data recorded at Region of Waterloo 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 Guelph area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The seasons considered are Summer (May through October) and Winter (November through April), as defined in the City of Guelph Terms of Reference. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h) between the hours of 06:00-23:00, which correspond to the appropriate hours of pedestrian use. Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction shows the frequency distribution of wind speeds for each wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Guelph, the common winds concerning pedestrian comfort occur from the south-southwest clockwise to north-northwest, as well as those from the east. The directional preference and relative magnitude of the wind speed varies somewhat from season to season, with the summer months displaying the calmest winds relative to the winter.

SEASONAL DISTRIBUTION OF WIND
REGION OF WATERLOO 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 Guidelines

Pedestrian comfort and safety guidelines are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 20% 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 30 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 target.

The pedestrian safety wind speed guideline is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% annual 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 referenced 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	Gust Wind Speed (km/h)	Description
2	Light Breeze	9-17	Wind felt on faces
3	Gentle Breeze	18-29	Leaves and small twigs in constant motion; wind extends light flags
4	Moderate Breeze	30-42	Wind raises dust and loose paper; small branches are moved
5	Fresh Breeze	43-57	Small trees in leaf begin to sway
6	Strong Breeze	58-74	Large branches in motion; Whistling heard in electrical wires; umbrellas used with difficulty
7	Moderate Gale	75-92	Whole trees in motion; inconvenient walking against wind
8	Gale	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 (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 30 km/h) at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As these guidelines 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 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 typical windiest desired comfort classes are summarized on the following page. Depending on the programming of a space, the desired comfort class may differ from this table.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

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

5. RESULTS AND DISCUSSION

The following discussion of the predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-4B, illustrating wind conditions at grade level for the proposed and existing massing scenarios. Conditions are presented as continuous contours of wind comfort within and surrounding the subject site and correspond to the various comfort classes noted in Section 4.4. 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.

Conditions at all areas studied are considered acceptable for the intended pedestrian uses. The details of these conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Sidewalks, Bus Stops, Building Access, and Outdoor Amenity Areas along Gordon Street: Following the introduction of the proposed development, the nearby public sidewalks along Gordon Street are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for strolling, or better, during the winter, with the strolling conditions located near the northwest corner of the subject site. In the vicinity of the nearby transit stops along Gordon Street, conditions are predicted to be suitable for sitting during the summer, becoming suitable for standing during the winter. Conditions in the vicinity of building access points are predicted to be suitable for sitting throughout the year. Conditions over the outdoor amenity areas along Gordon Street are predicted to be suitable for sitting during the summer. The noted conditions are considered acceptable according to the comfort guidelines in Section 4.4.

Conditions over the sidewalks along Gordon Street with the existing massing are predicted to be suitable for mostly sitting during the summer, becoming suitable for a mix of sitting and standing during the winter. In the vicinity of the nearby transit stops, conditions are predicted to be suitable for sitting throughout the year. While the introduction of the proposed development results in slightly windier conditions in comparison to existing conditions, conditions with the proposed development are considered acceptable.

Sidewalks and Building Access along Landsdown Drive: The public sidewalks along Landsdown Drive, near the subject site, are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing during the winter. Conditions in the vicinity of the building access points are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable according to the comfort guidelines in Section 4.4.

Conditions over the sidewalks along Landsdown Drive with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable mostly for standing during the winter. The introduction of the proposed development results in slightly calmer conditions in comparison to existing conditions, which are considered acceptable.

Building Access, Outdoor Amenity Spaces, and Surface Parking Central to Subject Site: The central surface parking lot in between the townhouses and apartment buildings are predicted to be suitable mostly for sitting during the summer, becoming suitable for a mix of sitting, standing, and strolling during the winter, with the strolling conditions located towards the north of the parking lot. Conditions in the vicinity of the building access points fronting the central parking lot are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing during the winter. Conditions over the outdoor amenity areas along the east elevation of the apartment buildings are predicted to be suitable for sitting during the summer. The noted conditions are considered acceptable according to the comfort guidelines in Section 4.4.

Walkway and Building Access Along South Elevation of Subject Site: Conditions over the walkway along the south elevation of the subject site are predicted to be suitable for sitting during the summer, becoming suitable for a mix of sitting and standing during the winter. In the vicinity of the building access points, conditions are predicted to be suitable for sitting throughout the year. The noted conditions are considered acceptable according to the comfort guidelines in Section 4.4.

Outdoor Amenity Area Along North Elevation: Conditions over the outdoor amenity spaces along the north and northeast elevations of Apartment Building 1 are predicted to be mostly suitable for sitting during the summer, with small regions near the northeast and northwest corners of Apartment Building 1 being suitable for standing. Depending on the programming of these spaces, the noted conditions may be considered acceptable. If necessary, sitting conditions may be extended over the full amenity spaces with landscaping features such as tall wind barriers, topographical depressions or berms, or dense coniferous plantings.

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 were found 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 (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 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.

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 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 Guelph wind climate, industry standard wind comfort and safety guidelines, and experience with numerous similar developments, the study concludes the following:

1) All grade level areas within and surrounding the subject site are predicted to be acceptable for the intended pedestrian uses throughout the year. Specifically, wind conditions over surrounding sidewalks, walkways, laneways, transit stops, in the vicinity of pedestrian building access points, and outdoor amenity spaces are considered acceptable. One exception is as follows:

    a. Conditions over the outdoor amenity spaces along the north and northeast elevations of Apartment Building 1 are predicted to be mostly suitable for sitting during the summer, with small regions being suitable for standing. Depending on the programming of these spaces, the noted conditions may be considered acceptable. If necessary, sitting conditions may be extended over the full amenity spaces with landscaping features such as tall wind barriers, topographical depressions or berms, or dense coniferous plantings.

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, (e.g., 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
S. R. HALL
100197168
Feb. 4, 2022
PROVINCE OF ONTARIO

Edward Urbanski, M.Eng.
Wind Scientist

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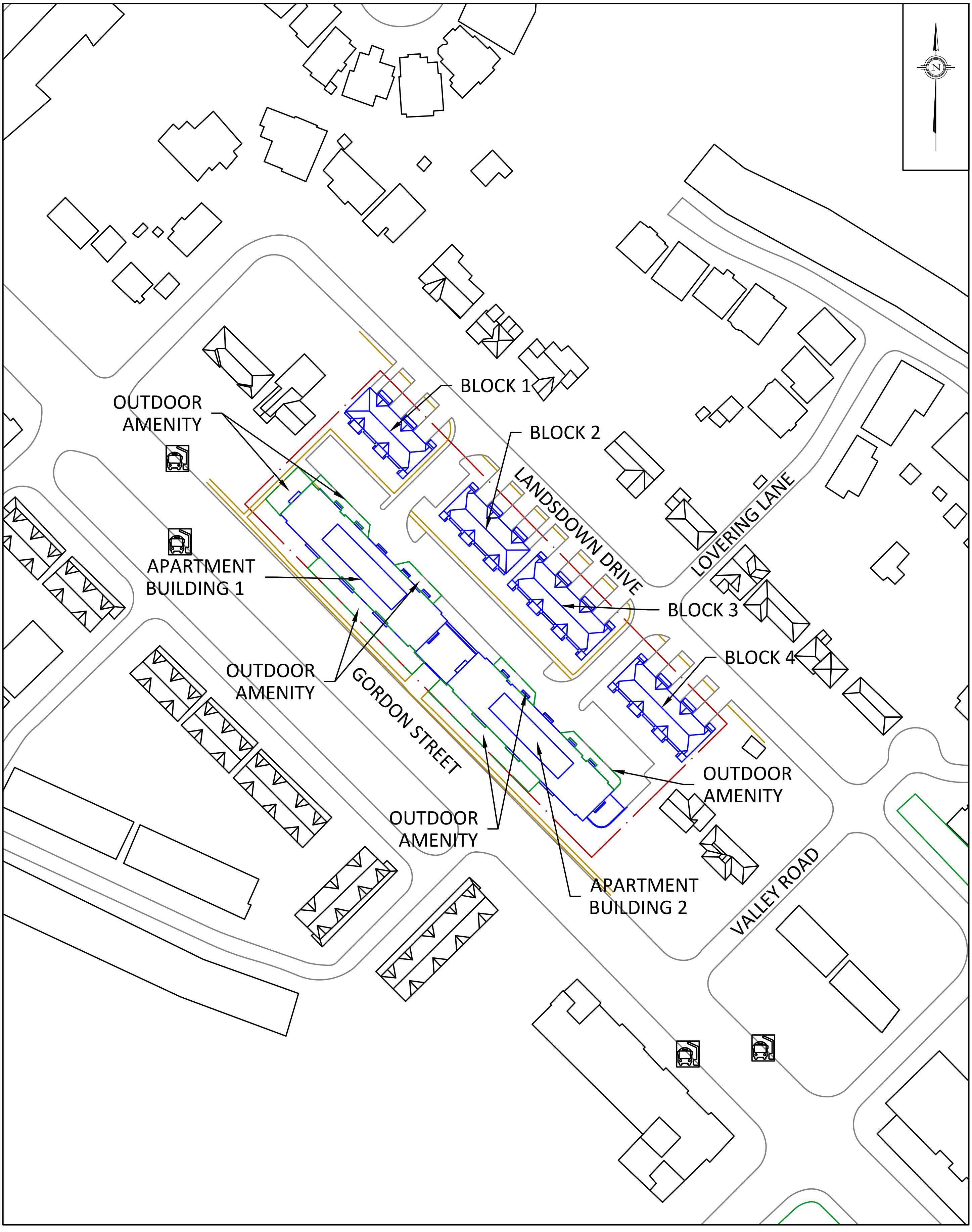

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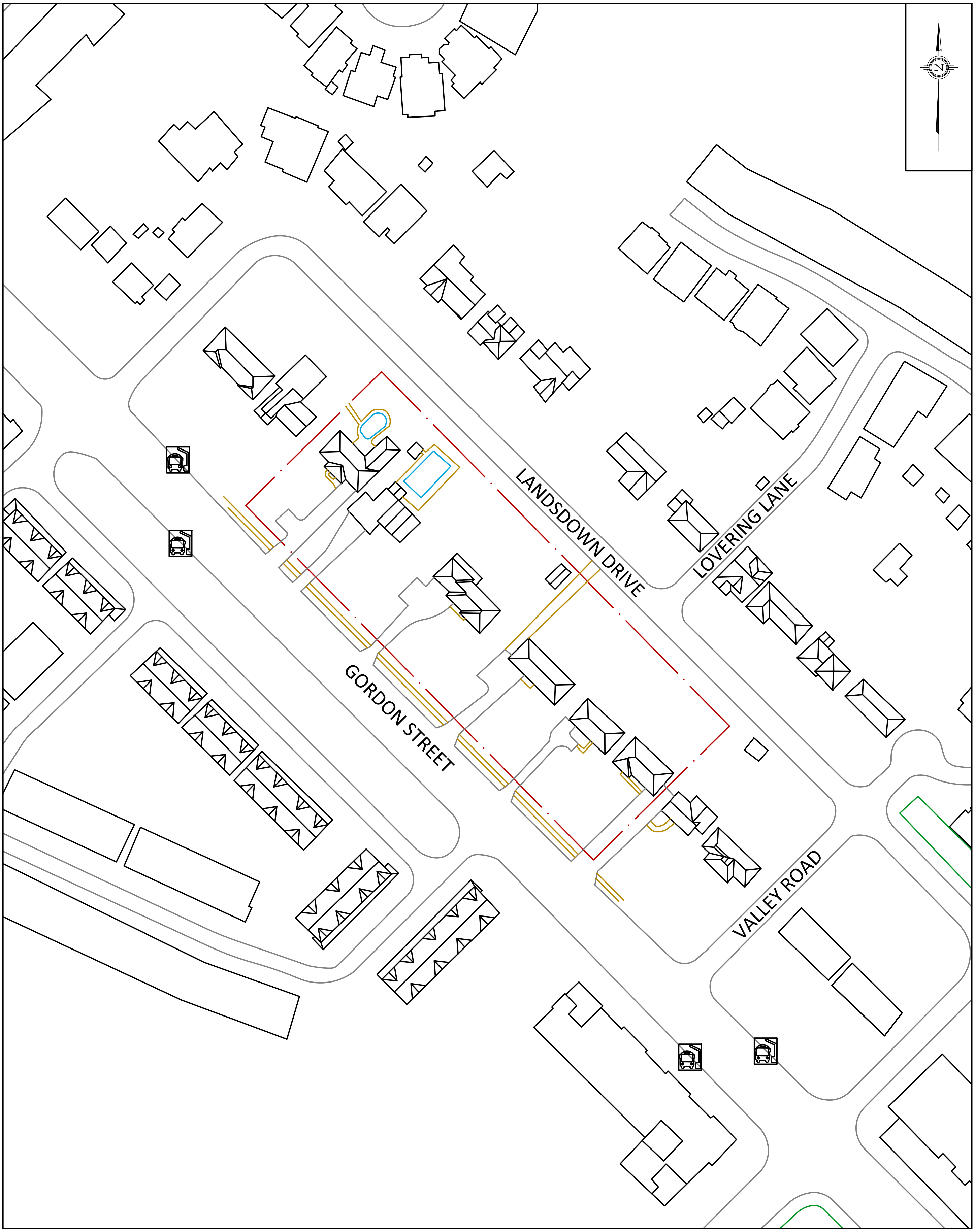
PROJECT		DESCRIPTION
1166 GORDON STREET, GUELPH PEDESTRIAN LEVEL WIND STUDY		FIGURE 1A: PROPOSED SITE PLAN AND SURROUNDING CONTEXT
SCALE 1:1000	DRAWING NO. 21-378-PLW-1A	
DATE JANUARY 14, 2022	DRAWN BY N.M.P.	



GRADIENTWIND ENGINEERS & SCIENTISTS 127 WALGREEN ROAD, OTTAWA, ON 613 836 0934 • GRADIENTWIND.COM	PROJECT: 1166 GORDON STREET, GUELPH PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 1B: PROPOSED SITE PLAN AND SURROUNDING CONTEXT
	SCALE: 1:1000	DRAWING NO.: 21-378-PLW-1B	
	DATE: JANUARY 14, 2022	DRAWN BY: N.M.P.	

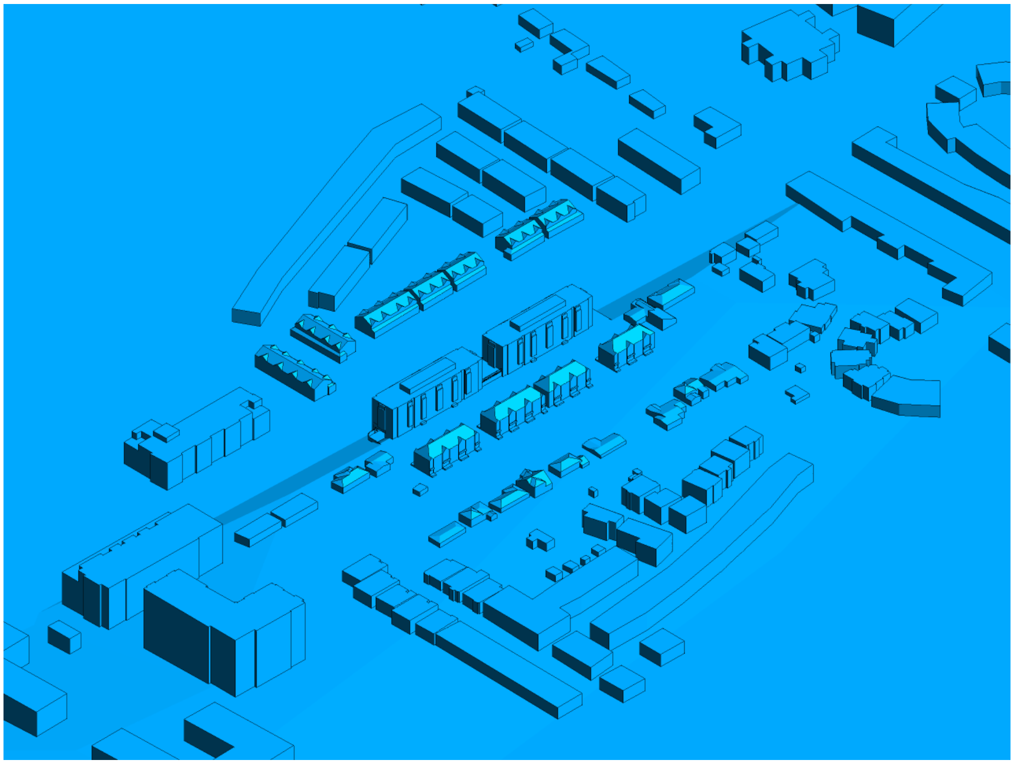


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, EAST PERSPECTIVE

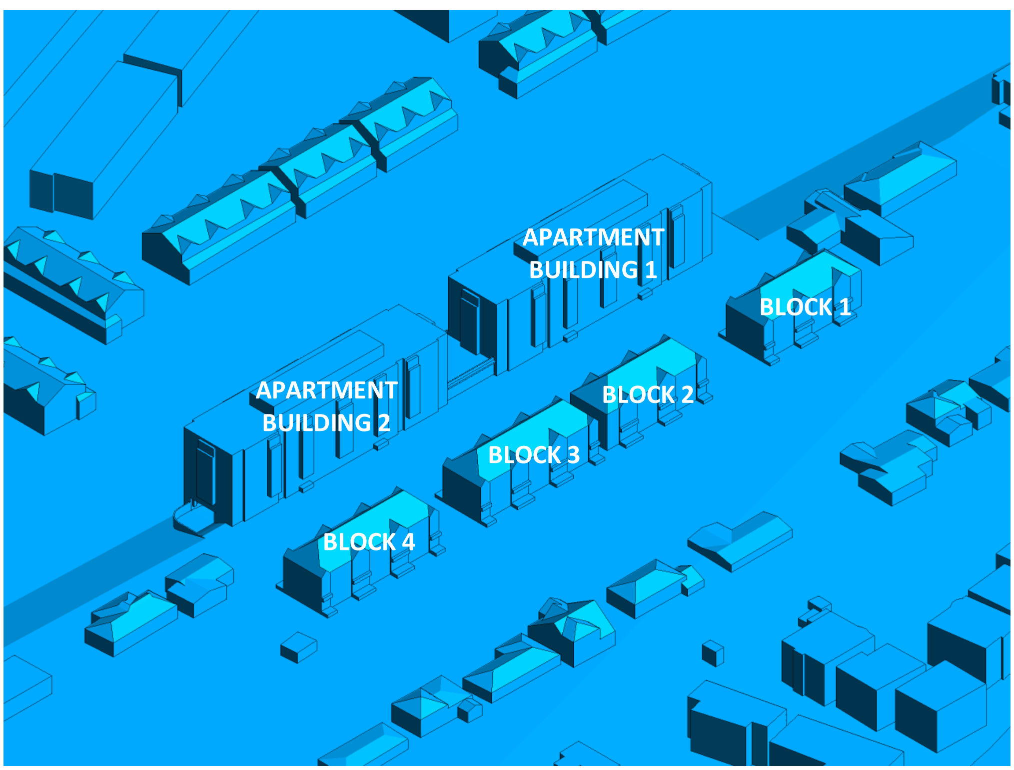


FIGURE 2B: CLOSE-UP VIEW OF FIGURE 2A

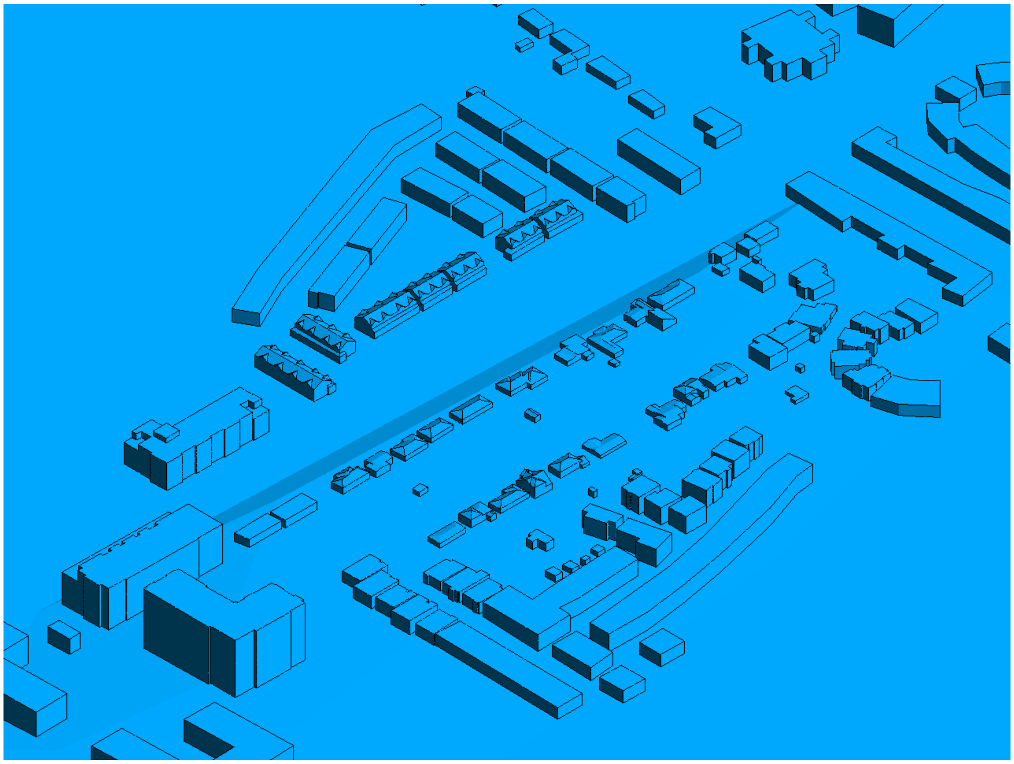


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, EAST PERSPECTIVE

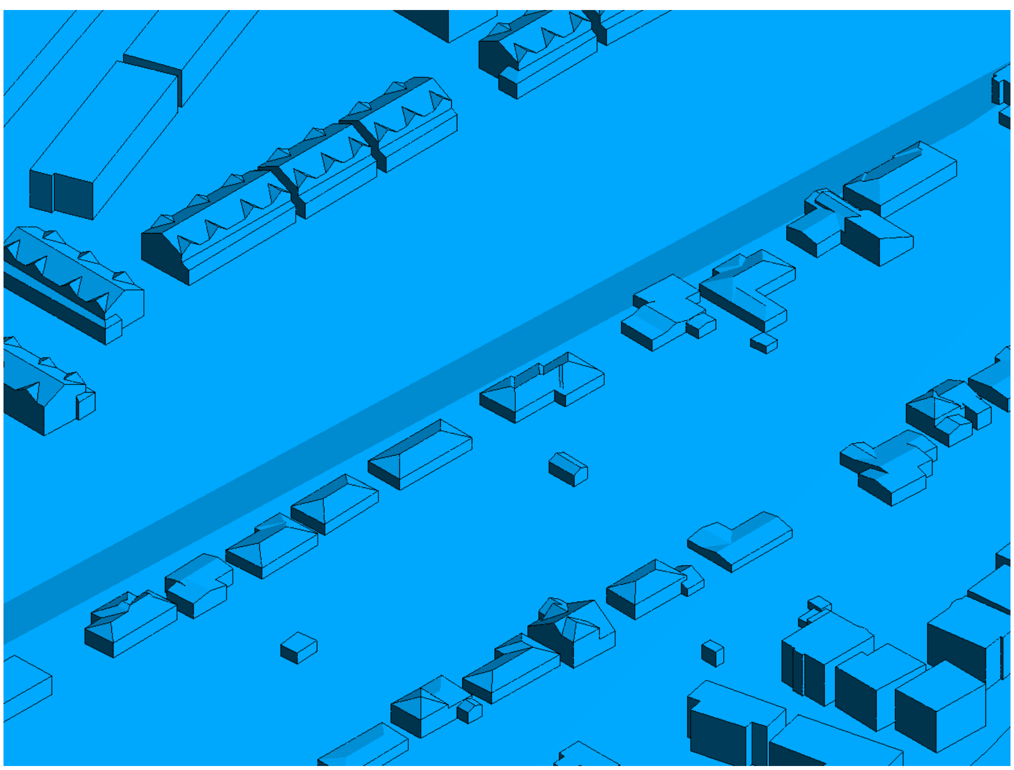


FIGURE 2D: CLOSE-UP VIEW OF FIGURE 2C

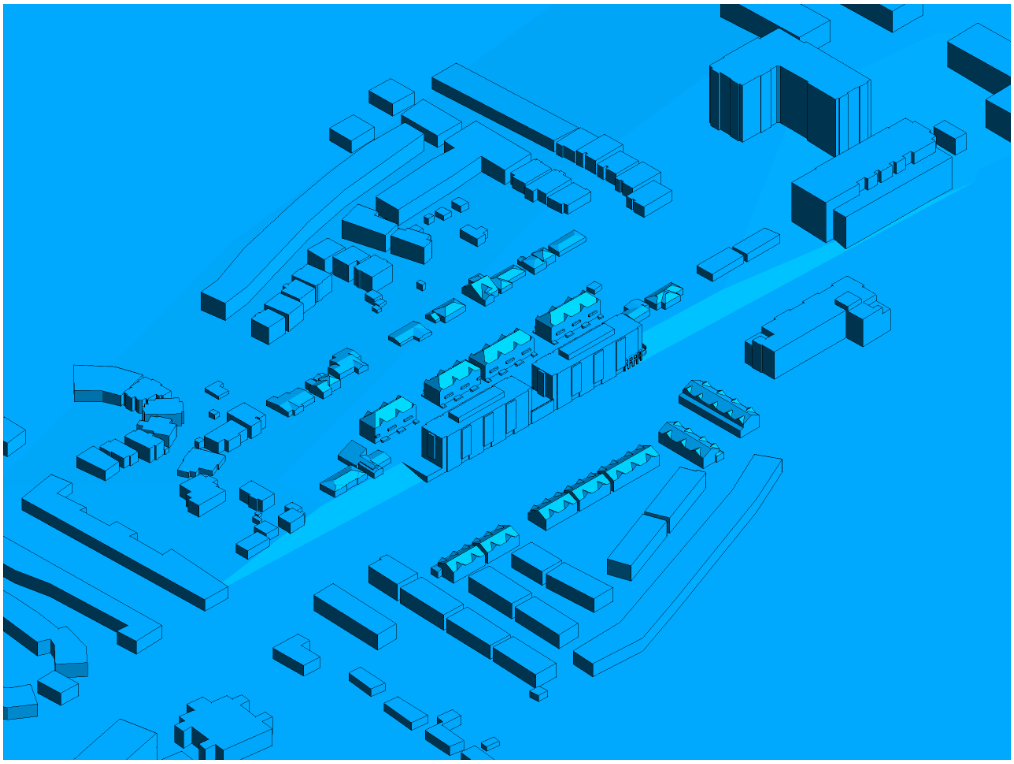


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, WEST PERSPECTIVE

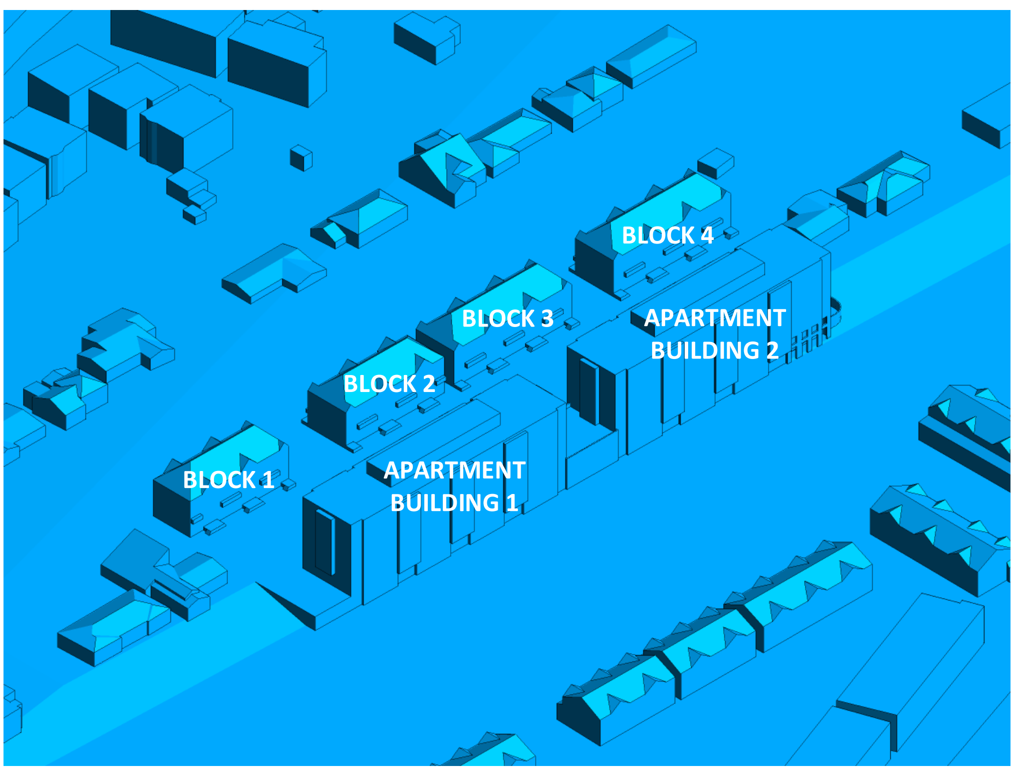


FIGURE 2F: CLOSE-UP VIEW OF FIGURE 2E

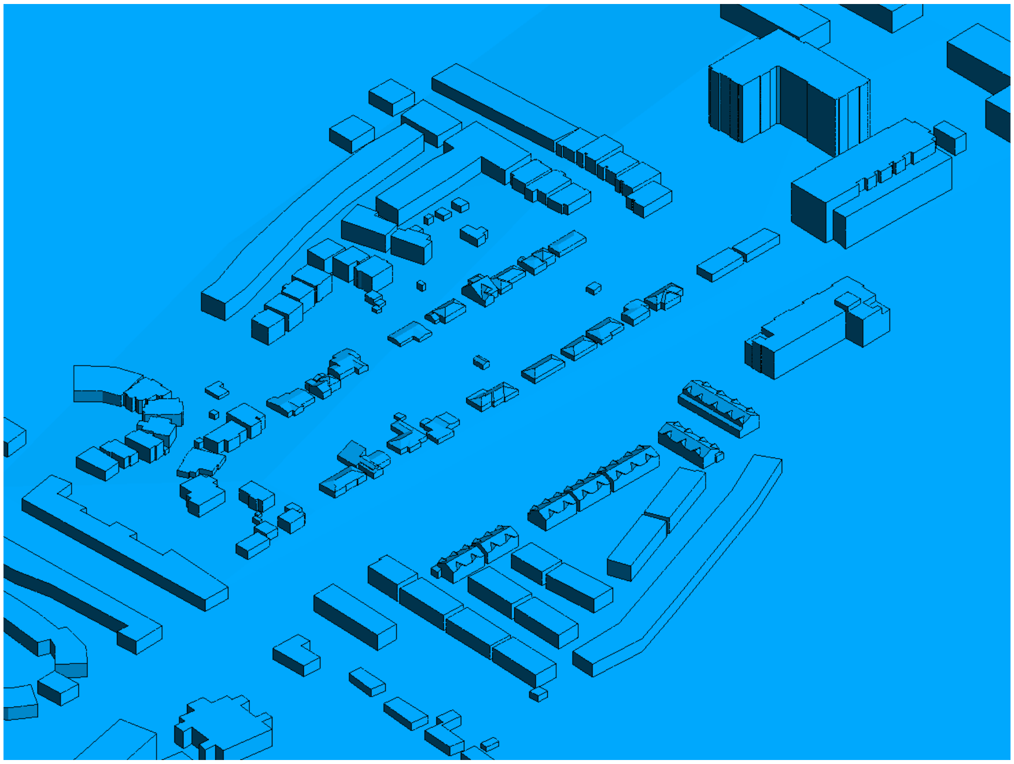


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, WEST PERSPECTIVE

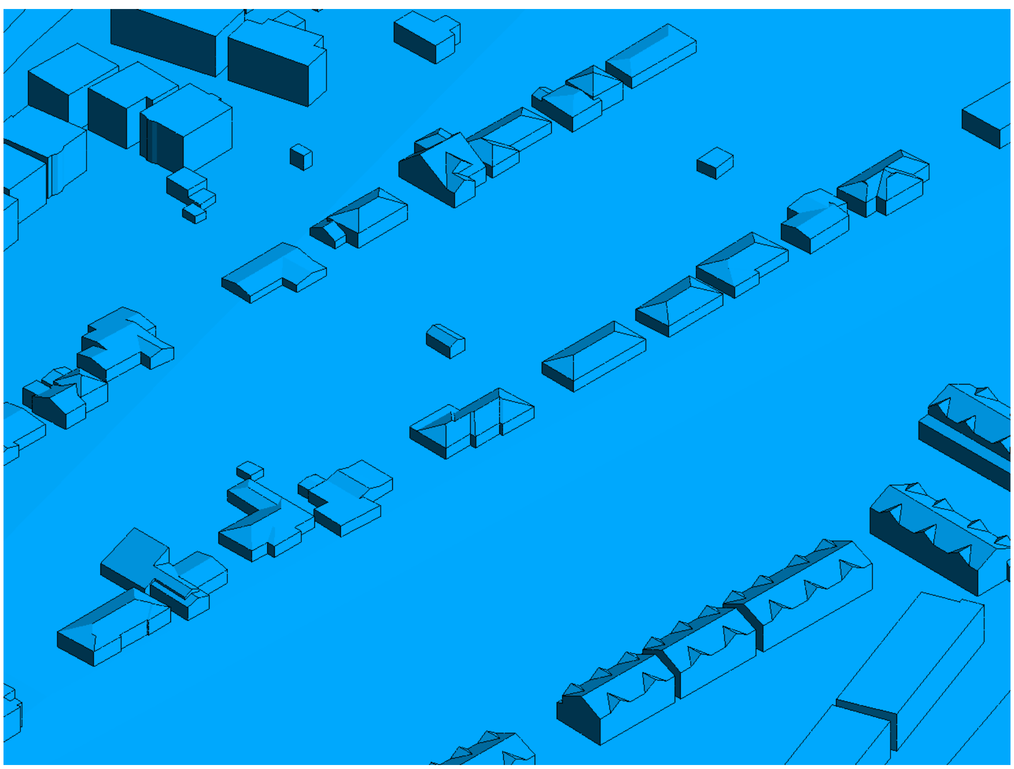


FIGURE 2H: CLOSE-UP VIEW OF FIGURE 2G

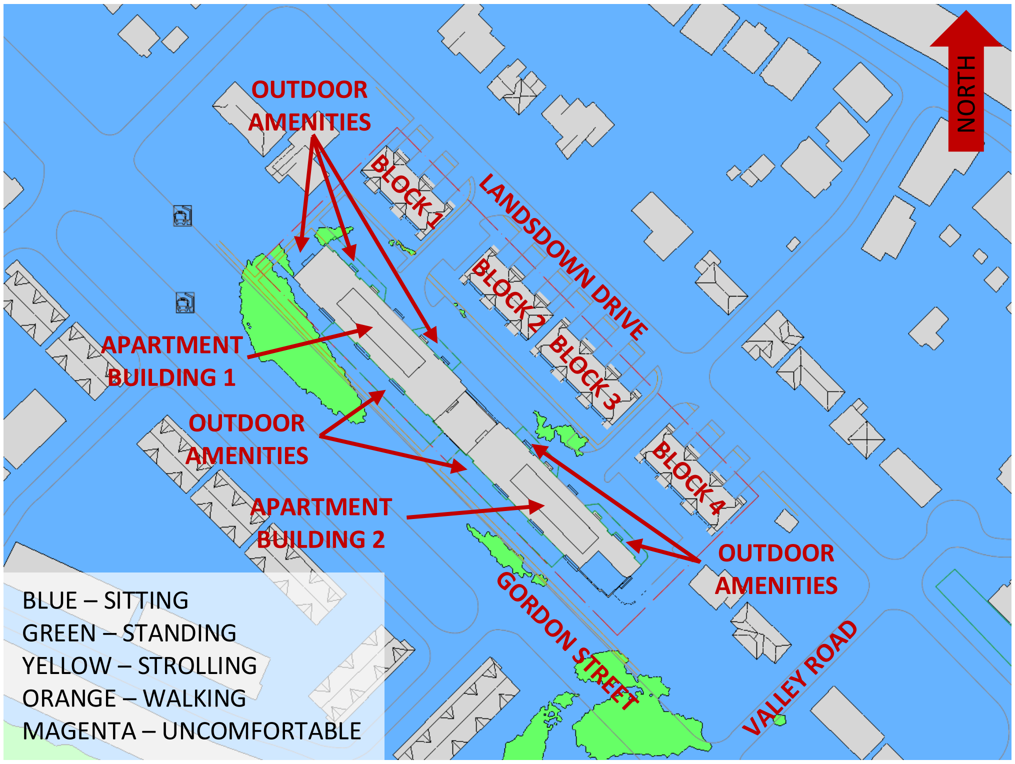


FIGURE 3A: SUMMER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

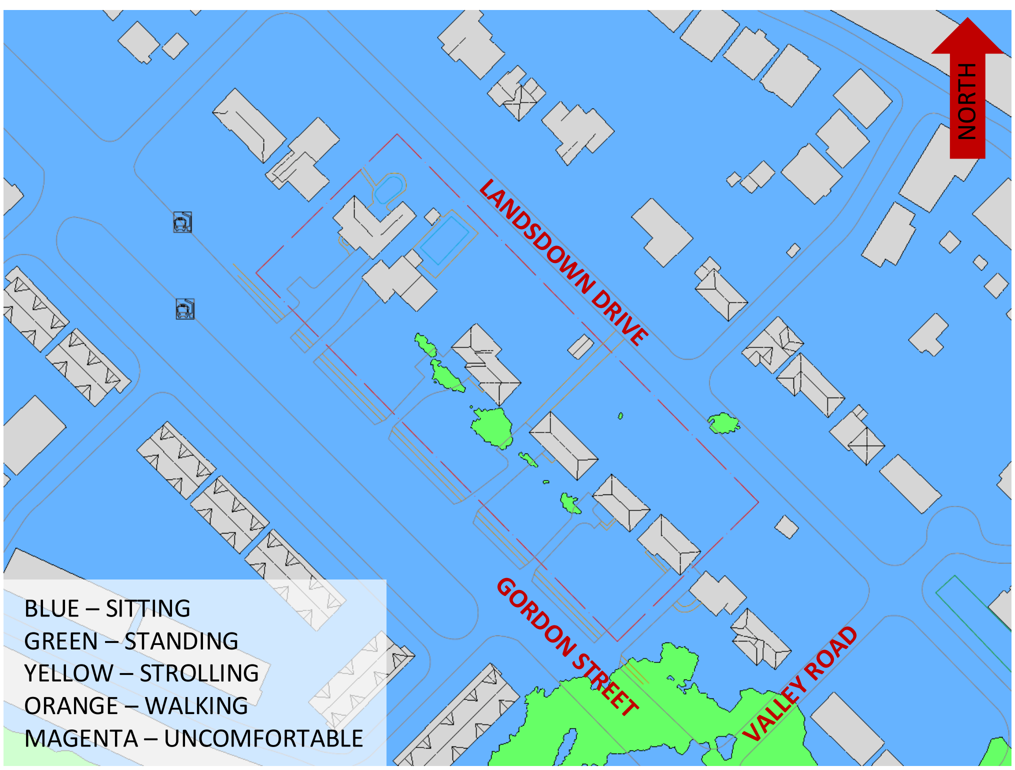


FIGURE 3B: SUMMER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING

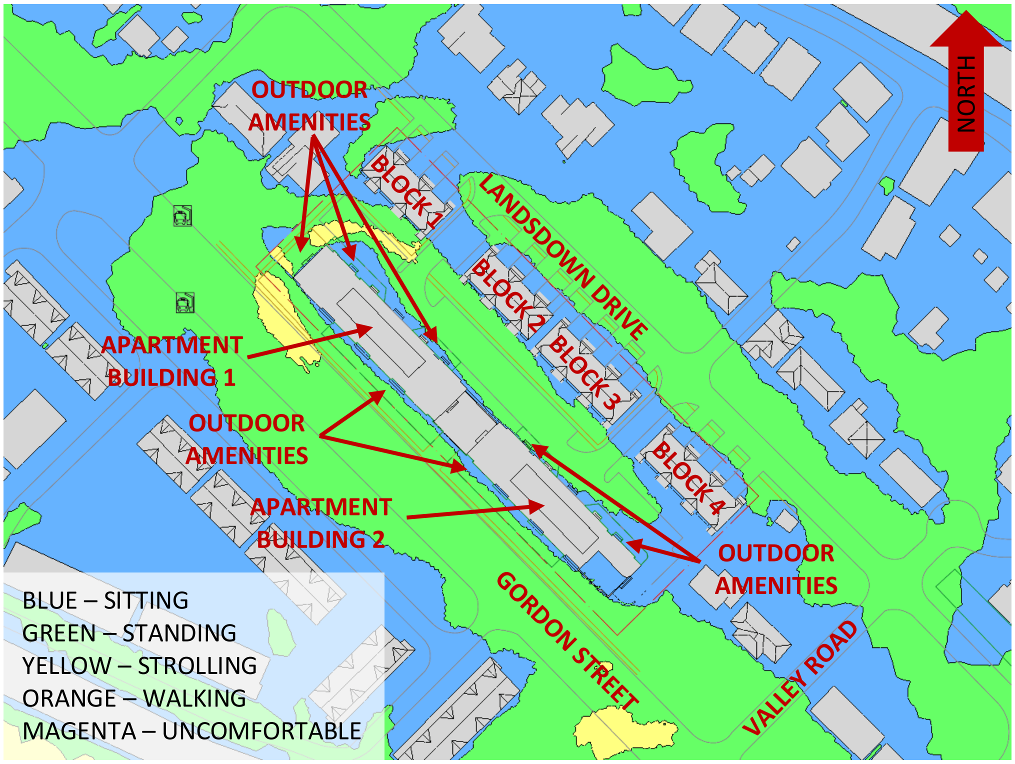


FIGURE 4A: WINTER – WIND COMFORT, GRADE LEVEL – PROPOSED MASSING

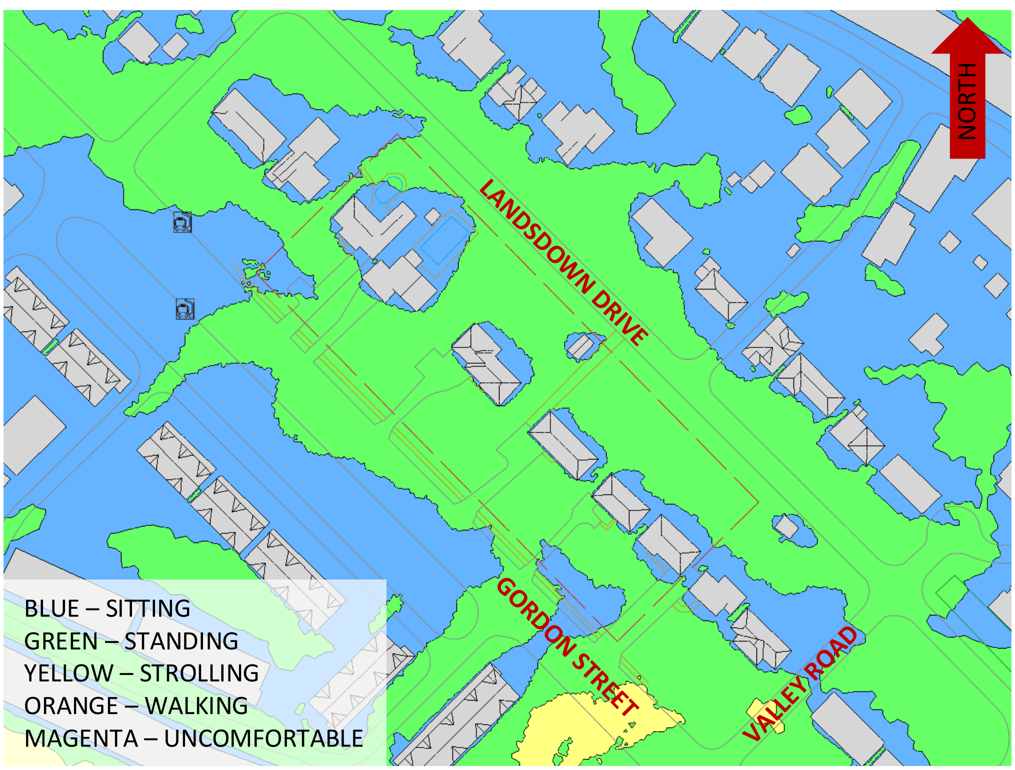
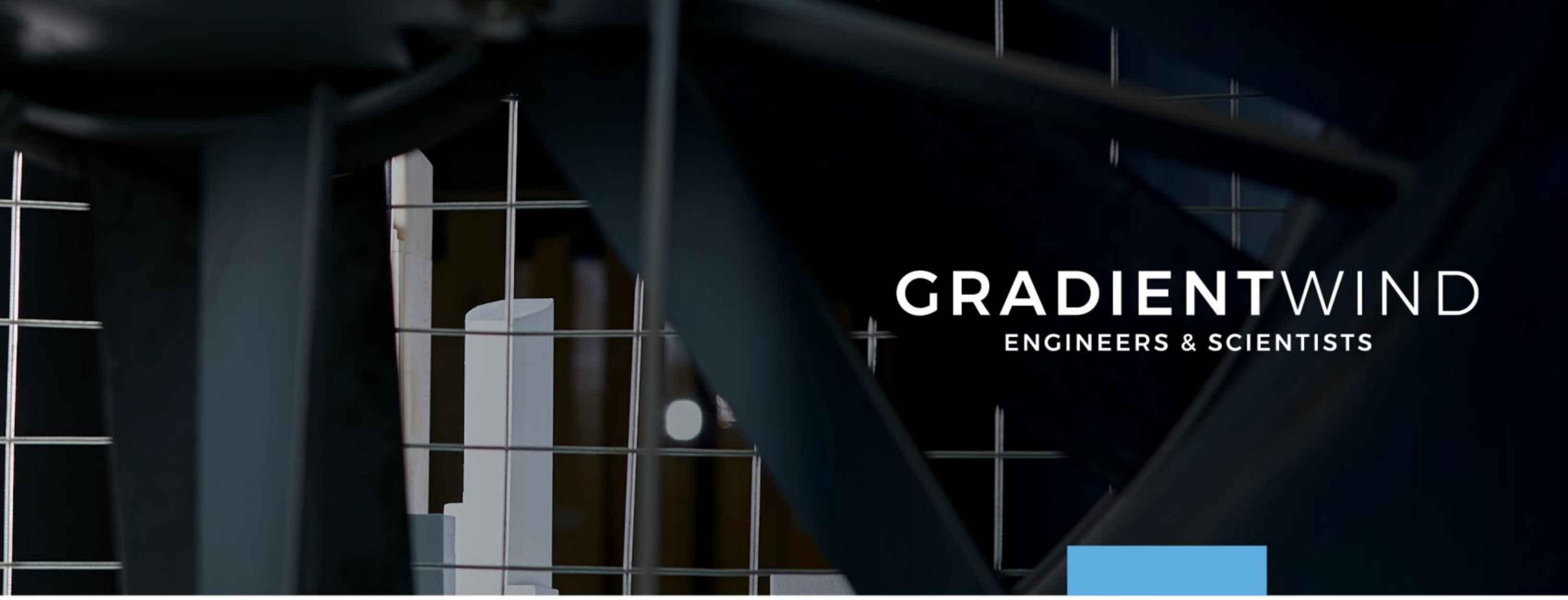


FIGURE 4B: WINTER – WIND COMFORT, GRADE LEVEL – EXISTING MASSING



APPENDIX A

SIMULATION OF THE ATMOSPHERIC BOUNDARY LAYER

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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 60% mean wind speed for Guelph 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 (Degrees True)	Alpha Value (α)
0	0.22
59	0.20
93	0.22
130	0.23
180	0.21
208	0.21
230	0.23
251	0.23
272	0.23
291	0.24
308	0.24
328	0.23

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).

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

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

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.

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