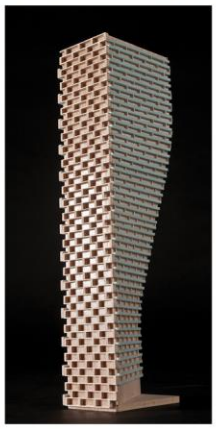
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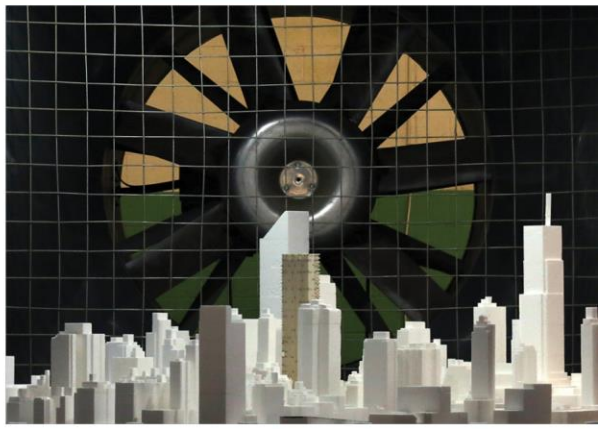
PEDESTRIAN LEVEL WIND STUDY

454-462 Cumberland Avenue
Burlington, Ontario

Report: 23-203-PLW-R1







September 6, 2023

PREPARED FOR

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind (PLW) study to satisfy concurrent Official Plan Amendment (OPA) and Zoning By-Law Amendment (ZBLA) application submission requirements for the proposed seniors residence development located at 454-462 Cumberland Avenue and 3255, 3259, and 3265 New Street in Burlington, 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 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 conditions within and surrounding the subject site according to City of Burlington wind comfort and safety criteria. A complete summary of the predicted wind conditions is provided in Section 5 and illustrated in Figures 3A-5B, and is summarized as follows:

1) All 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, transit stops, the Centennial Bikeway, laneways, walkways, dining patios, and in the vicinity of building access points, are considered acceptable.

2) Wind comfort conditions within the amenity terrace serving the proposed development at Level 7 are predicted to be suitable for sitting over most of the area, with standing conditions along the west perimeter and central to the terrace.

    a. Depending on the programming of the Level 7 amenity terrace, the noted conditions may be considered acceptable. Specifically, if the windier areas along the terrace perimeter will not accommodate seating or more sedentary activities, the noted wind conditions would be considered acceptable.

    b. If required by programming, sitting conditions may be extended around sensitive areas by implementing tall wind screens, typically glazed, and extending 1.8 metres above the walking surface, along the perimeter of the terrace, in place of standard height guards.

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.

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Appendix A – Simulation of the Atmospheric Boundary Layer

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by Traditions Seniors Housing Ltd. to undertake a pedestrian level wind (PLW) study to satisfy concurrent Official Plan Amendment (OPA) and Zoning By-Law Amendment (ZBLA) application submission requirements for the proposed seniors residence located at 454-462 Cumberland Avenue and 3255, 3259, and 3265 New Street in Burlington, 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 is based on industry standard computer simulations using the computational fluid dynamics (CFD) technique and data analysis procedures, City of Burlington wind comfort and safety criteria, architectural drawings provided by McKnight Charron Limited (MCL) Architects in August 2023, surrounding street layouts and existing and approved future building massing information obtained from the City of Burlington, and recent site imagery.

2. TERMS OF REFERENCE

The subject site is located at 454-462 Cumberland Avenue and 3255, 3259, and 3265 New Street in Burlington, situated to the west at the intersection of Cumberland Avenue and New Street on a parcel of land bounded by Cumberland Avenue to the northeast, New Street to the southeast, low-rise buildings to the southwest, and the Centennial Bikeway to the northwest. Throughout this report, Cumberland Avenue is referred to as project east. The subject site is comprised of existing low-rise residential dwellings that will be demolished to construct the proposed development, which comprises a nearly rectangular 7-storey seniors residence, with a height of 19.9 m above grade level.

Above a below-grade parking level, the ground floor of the proposed development includes a dining area and lounge at the northwest corner, a bistro to the north, a reception lobby, offices, and a waste and deliveries area at the northeast corner, residential units to the east, south, and west, and a central multi-purpose space. Dining patios are situated near the northwest corner and to the north, and a dog relieving area is located at the northeast corner of the subject site. Access to the underground parking is provided by a ramp at the southwest corner, via a laneway from New Street. Level 2 includes a central lounge and spa area, and residential units along the perimeter, while Levels 3-6 include dining and servery areas and

a garden room to the north, central lounges and floor specific indoor amenities, and residential units along the west, east, and south elevations. Level 7 includes a central lounge area and comprises residential occupancy throughout the floor. The building steps back from the north elevation at Level 7 to accommodate a green roof, and from the west elevation to accommodate an amenity terrace.

Regarding wind exposures, the near-field surroundings of the development (defined as an area falling within a 200-metre (m) radius of the subject site) are characterized by low-rise residential dwellings from the south clockwise to the northeast and mid-rise buildings to the east and south-southeast. The Centennial Bikeway extends from the southwest to the north-northeast and a soccer field is located to the southeast beyond the mid-rise buildings. The far-field surroundings (defined as the area beyond the near field and within a two-kilometre (km) radius) include low-rise suburban massing in all compass directions with isolated mid- and high-rise buildings from the southwest clockwise to the west-northwest and to the northeast, and the open exposure of Lake Ontario, which is situated approximately 1.2 km to the southeast, from the east-northeast clockwise to the south-southwest.

A site plan for the proposed massing scenario is illustrated in Figure 1A, while the existing scenario is illustrated in Figure 1B. 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 Burlington area wind climate, and synthesis of computational data with City of Burlington wind criteria[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

[1] City of Burlington, *Pedestrian Level Wind Study Guidelines and Terms of Reference,* June 2020

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 John C. Munro Hamilton International Airport in Hamilton, 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 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.

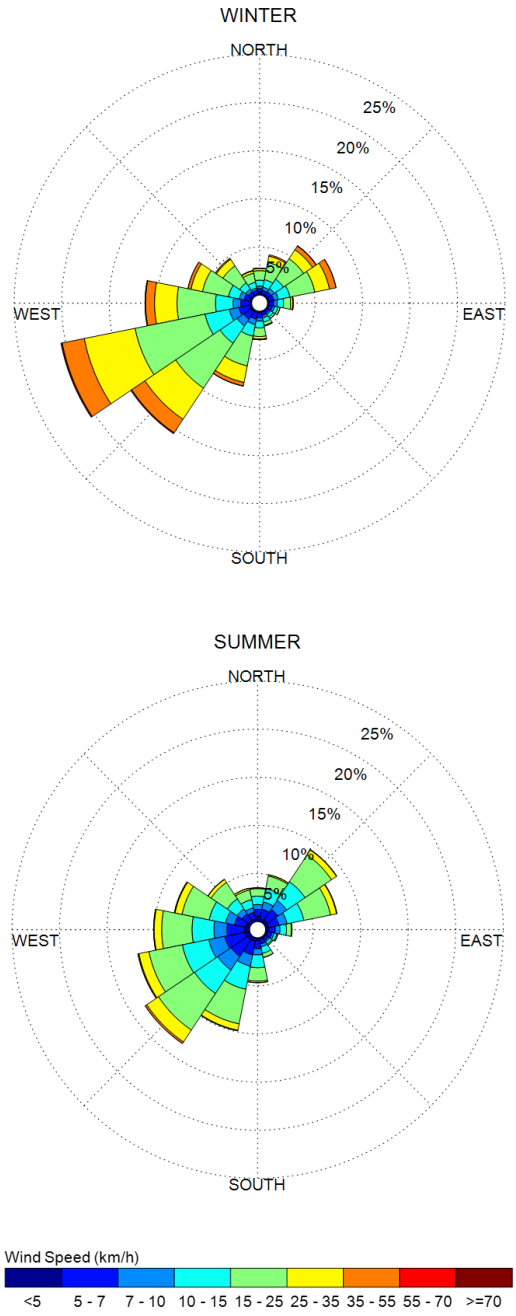
Mean and peak wind speed data obtained over the subject site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade, and the Level 7 common amenity terrace serving the proposed development 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 Hamilton, representative of Burlington, was developed from approximately 50 years of hourly meteorological wind data recorded at John C. Munro Hamilton International Airport and obtained from Environment and Climate Change Canada. 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 through October, while the winter season is defined as November through April, inclusive.

The statistical model of the Burlington area wind climate indicates the directional character of local winds on a seasonal basis and is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in km/h. Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Burlington, the most common winds occur for southwesterly wind directions, followed by those from the northeast, 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
JOHN C. MUNRO HAMILTON INTERNATIONAL AIRPORT, HAMILTON, ONTARIO



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 Burlington

Pedestrian wind criteria are based on the mechanical effects of wind without consideration of other meteorological conditions, such as 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 City of Burlington Pedestrian Level Wind Study Guidelines and Terms of Reference. 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 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. Five pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort: (1) Sitting; (2) Standing; (3) Leisurely Walking; (4) Fast Walking; and (5) Uncomfortable. Specifically, the comfort classes, associated wind speed ranges, and limiting criteria are summarized as follows:

1) **Sitting:** GEM wind speeds no greater than 10 km/h occurring at least 80% of the time would be considered acceptable for sedentary activities, including sitting.

2) **Standing:** GEM wind speeds no greater than 14 km/h occurring at least 80% of the time are acceptable for activities such as standing or more vigorous activities.

3) **Leisurely Walking:** GEM wind speeds no greater than 17 km/h occurring at least 80% of the time are acceptable for leisurely walking, strolling, or more vigorous activities.

4) **Fast Walking:** GEM wind speeds no greater than 20 km/h occurring at least 80% of the time are acceptable for fast walking or more vigorous activities.

5) **Uncomfortable:** Uncomfortable conditions are characterized by predicted values that fall below the 80% target for fast walking.

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.

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 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, fast 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 desired comfort classes, which are dictated by the location type for each region (such as a sidewalk, building entrance, or amenity space). An overview of common pedestrian location types and their typical windiest desired comfort classes are summarized on the following table. 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	Fast Walking
Public Sidewalk / Bicycle Path	Fast Walking
Outdoor Amenity Space	Sitting / Standing
Café / Patio / Bench / Garden	Sitting / Standing
Transit Stop (Without Shelter)	Standing
Transit Stop (With Shelter)	Fast Walking
Public Park / Plaza	Sitting / Standing
Garage / Service Entrance	Fast Walking
Parking Lot	Fast Walking
Vehicular Drop-Off Zone	Fast 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, and by Figures 5A-5B, which illustrate conditions over the Level 7 common amenity terrace serving the proposed development. 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 purple, standing by blue, leisurely walking by green, and fast walking by yellow; uncomfortable conditions are represented by the colour red, consistent with the graphical standards of the City of Burlington Pedestrian Level Wind Study Guidelines and Terms of Reference. The details of these conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Sidewalks along Cumberland Avenue: Following the introduction of the proposed development, wind comfort conditions over the nearby public sidewalks along Cumberland Avenue are predicted to be suitable mostly for sitting during the summer, becoming suitable for standing, or better, during the winter. The noted conditions are considered acceptable.

Conditions over the nearby public sidewalks along Cumberland Avenue with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, during the winter. Notably, conditions following the introduction of the proposed development are mostly similar in comparison to existing conditions, and the wind conditions with the proposed development are nevertheless considered acceptable.

Sidewalks along New Street: Following the introduction of the proposed development, conditions over the public sidewalks along New Street are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for standing, or better, during the winter with an isolated region suitable for leisurely walking. The noted conditions are considered acceptable.

Conditions over the sidewalks along New Street with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, during the winter. While the introduction of the proposed development produces windier conditions in comparison to existing conditions, conditions with the proposed development are nevertheless considered acceptable.

Transit Stops along New Street: Prior to the introduction of the proposed development, wind conditions in the vicinity of the nearby transit stops along New Street are predicted to be suitable for sitting during the summer, becoming suitable for standing during the winter. The noted conditions remain unchanged following the introduction of the proposed development, and the wind conditions with the proposed development are considered acceptable.

Centennial Bikeway North of Subject Site: Following the introduction of the proposed development, conditions over the Centennial Bikeway situated to the north of the subject site are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, during the winter. The noted conditions are considered acceptable.

Conditions over the Centennial Bikeway with the existing massing are predicted to be suitable for sitting during the summer, becoming suitable for standing during the winter. Notably, the introduction of the proposed development is predicted to improve comfort levels over the Centennial Bikeway, in comparison to existing conditions, and conditions with the proposed development are considered acceptable.

Dining Patios and Dog Relieving Area: During the summer, wind conditions over the dining patios near the northwest corner of the subject site and to the north of the bistro are predicted to be suitable for sitting, while conditions over the dog relieving area are predicted to be mostly suitable for standing with conditions suitable for sitting predicted to the west. The noted conditions are considered acceptable.

Proposed Laneway and Walkways Within Subject Site: Conditions over the walkways throughout the subject site are predicted to be suitable for standing, or better, throughout the year. Conditions over the laneway near the southeast corner are predicted to be suitable for a mix of sitting and standing during the summer, becoming suitable for standing, or better, during the winter with a region of conditions suitable for leisurely walking. The noted conditions are considered acceptable.

Building Access Points: Wind conditions in the vicinity of all building access points serving the proposed development are predicted to be suitable for sitting during the summer, and suitable for standing, or better, during the winter season. The noted conditions are considered acceptable.

5.2 Wind Comfort Conditions – Level 7 Common Amenity Terrace

During the summer, wind comfort conditions within the common amenity terrace serving the proposed development at Level 7 are predicted to be suitable for sitting over most of the area, with standing conditions along the west perimeter and central to the terrace, as illustrated in Figure 5A. Where conditions are suitable for standing, they are also suitable for sitting for at least 79% of the time within the standing areas central to the terrace and 75% of the time along the terrace perimeter during the same period, where the target is 80% to achieve the sitting comfort class.

Depending on the programming of the Level 7 amenity terrace, the noted conditions may be considered acceptable. Specifically, if the windier areas along the terrace perimeter will not accommodate seating or more sedentary activities, the noted wind conditions would be considered acceptable. If required by programming, sitting conditions may be extended around sensitive areas by implementing tall wind screens, typically glazed, and extending 1.8 m above the walking surface, in place of standard height guards along the perimeter of the terrace.

5.3 Wind Safety

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

5.4 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-5B. Based on computer simulations using the CFD technique, meteorological data analysis, 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 experience conditions that are considered acceptable for the intended pedestrian uses throughout the year. Specifically, conditions over surrounding sidewalks, transit stops, the Centennial Bikeway, laneways, walkways, dining patios, and in the vicinity of building access points, are considered acceptable.

2) Wind comfort conditions within the amenity terrace serving the proposed development at Level 7 are predicted to be suitable for sitting over most of the area, with standing conditions along the west perimeter and central to the terrace.

a. Depending on the programming of the Level 7 amenity terrace, the noted conditions may be considered acceptable. Specifically, if the windier areas along the terrace perimeter will not accommodate seating or more sedentary activities, the noted wind conditions would be considered acceptable.

b. If required by programming, sitting conditions may be extended around sensitive areas by implementing tall wind screens, typically glazed, and extending 1.8 m above the walking surface, along the perimeter of the terrace, in place of standard height guards.

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,

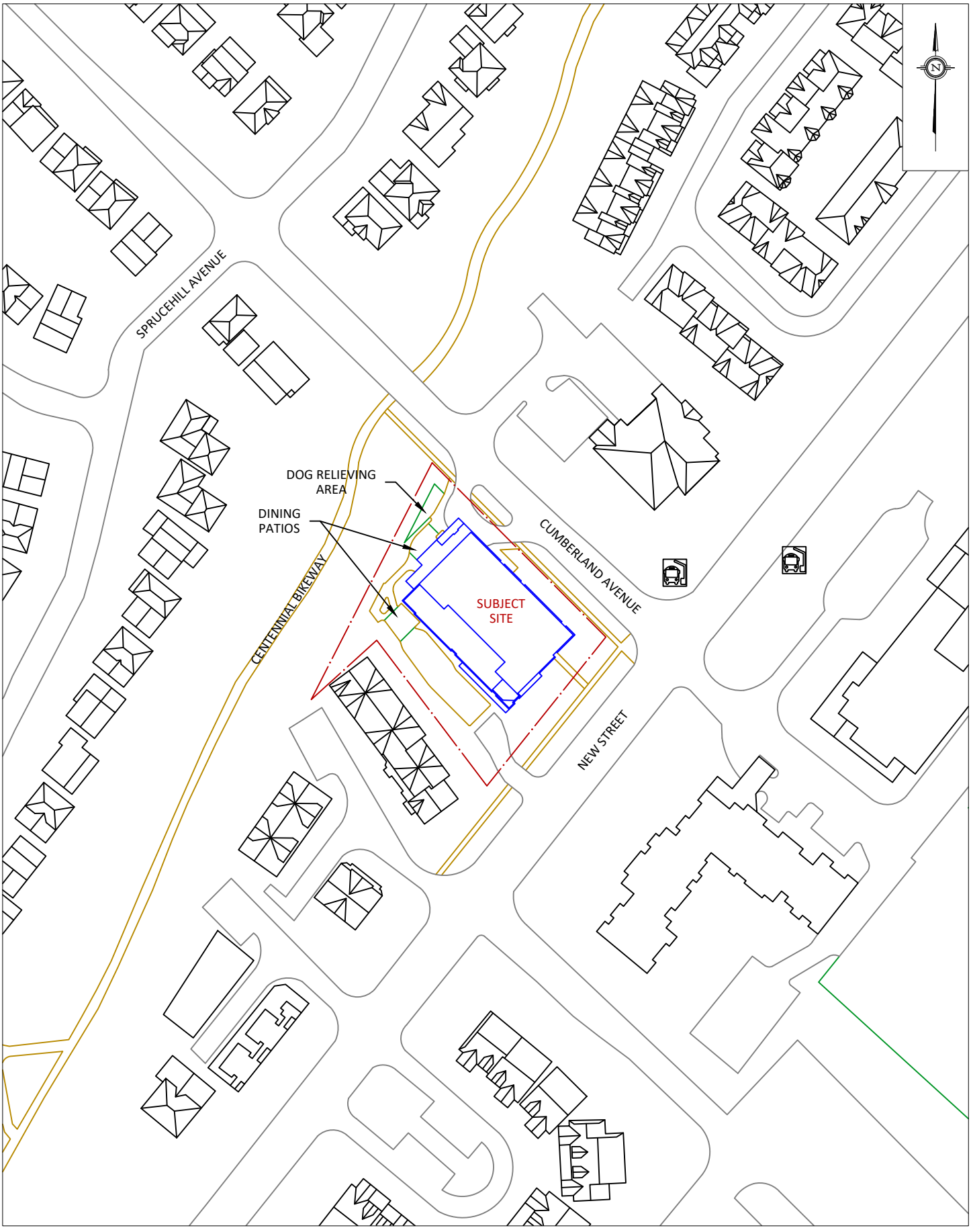
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Sunny Kang, B.A.S.
Project Coordinator



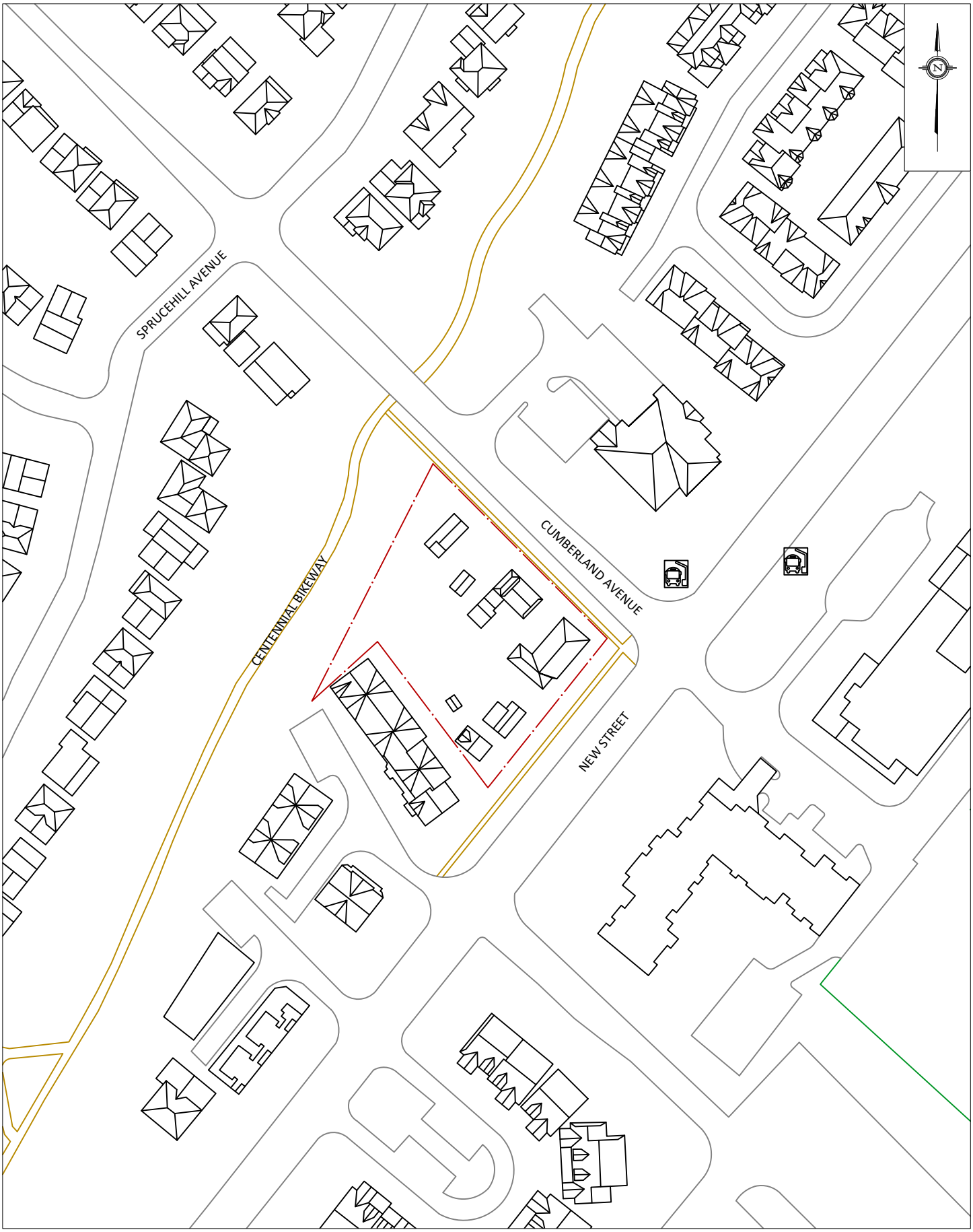
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PROJECT	454-462 CUMBERLAND AVENUE, BURLINGTON PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1500
DRAWING NO.	23-203-PLW-1A
DATE	AUGUST 28, 2023
DRAWN BY	S.K.

DESCRIPTION

FIGURE 1A:
PROPOSED SITE PLAN AND SURROUNDING CONTEXT



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SCALE	1:1500
DRAWING NO.	23-203-PLW-1B
DATE	AUGUST 28, 2023
DRAWN BY	S.K.

DESCRIPTION

FIGURE 1B:
EXISTING SITE PLAN AND SURROUNDING CONTEXT

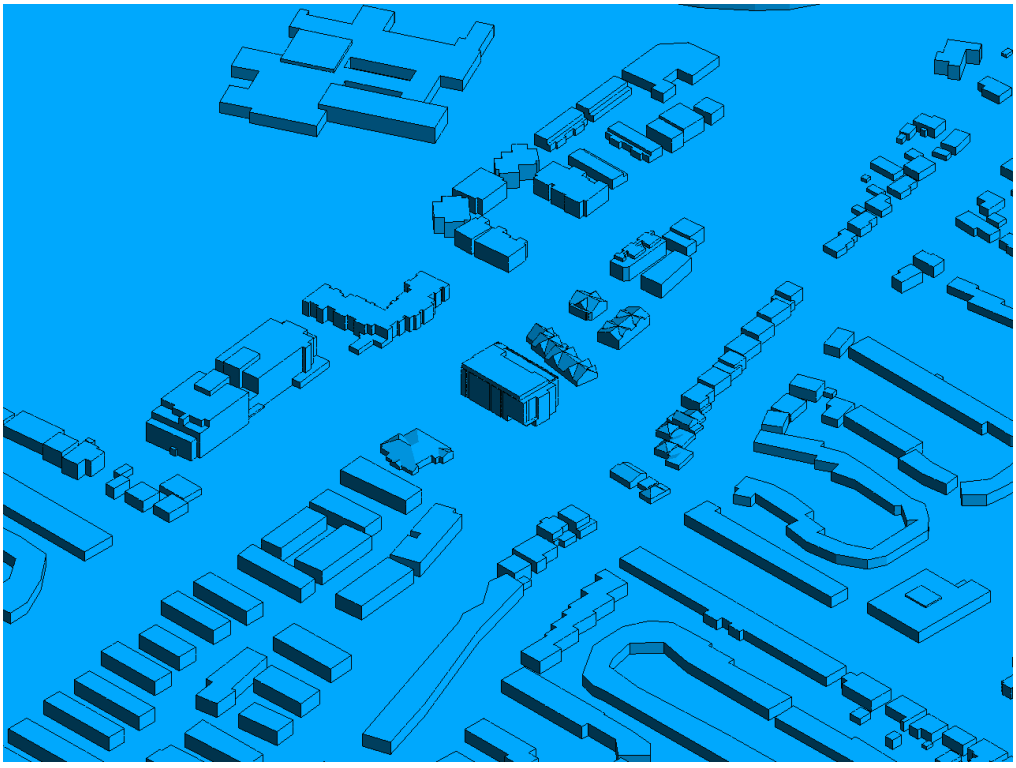


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, NORTH PERSPECTIVE

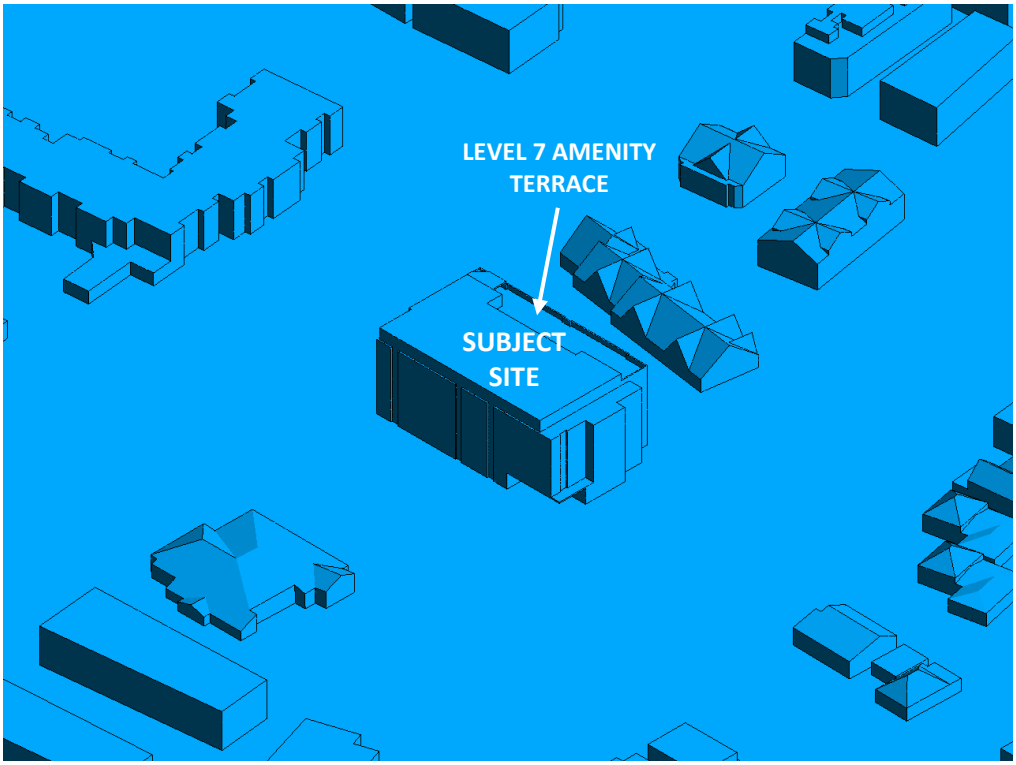


FIGURE 2B: CLOSE-UP VIEW OF FIGURE 2A

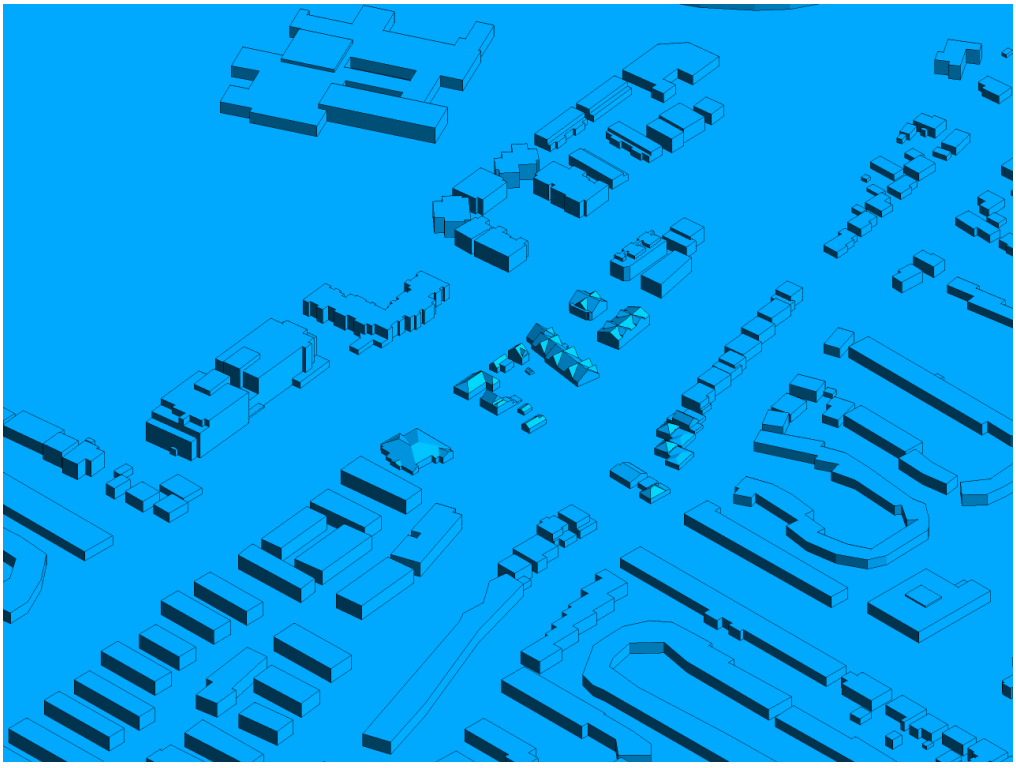


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, NORTH PERSPECTIVE

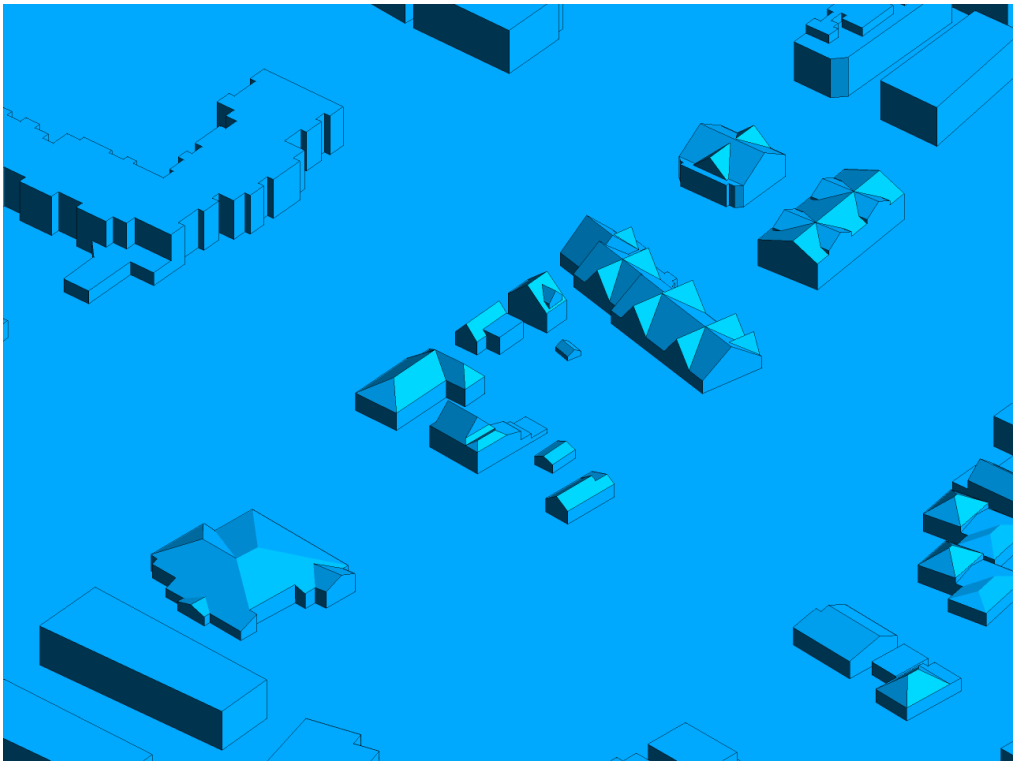


FIGURE 2D: CLOSE-UP VIEW OF FIGURE 2C

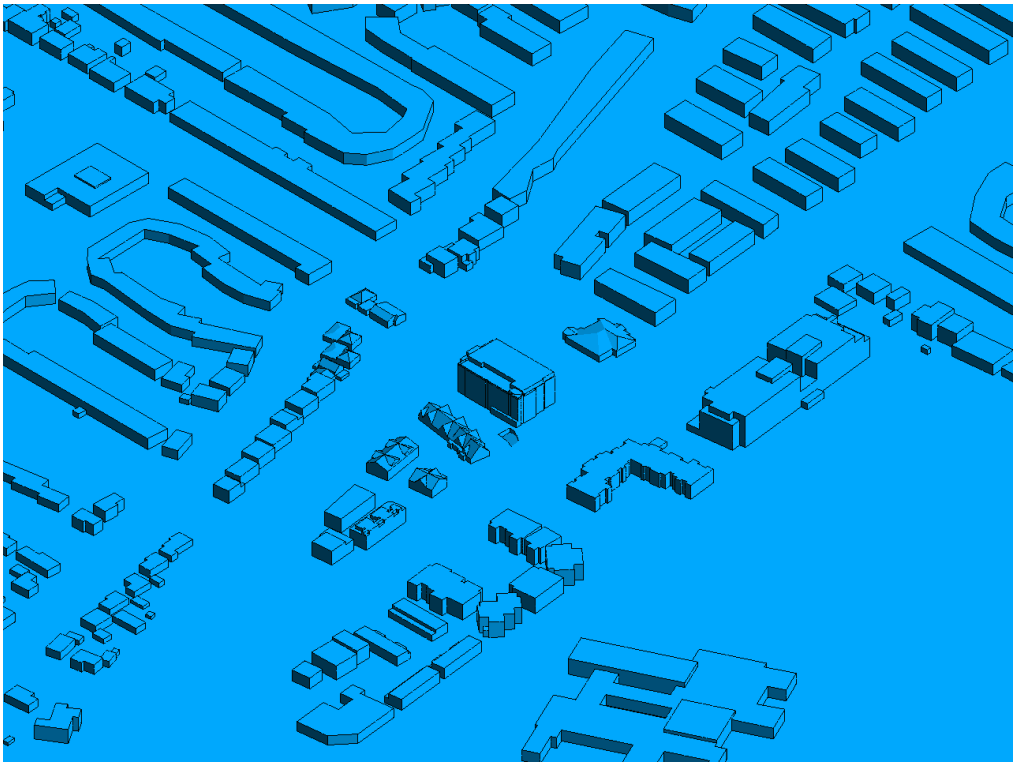


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, SOUTH PERSPECTIVE

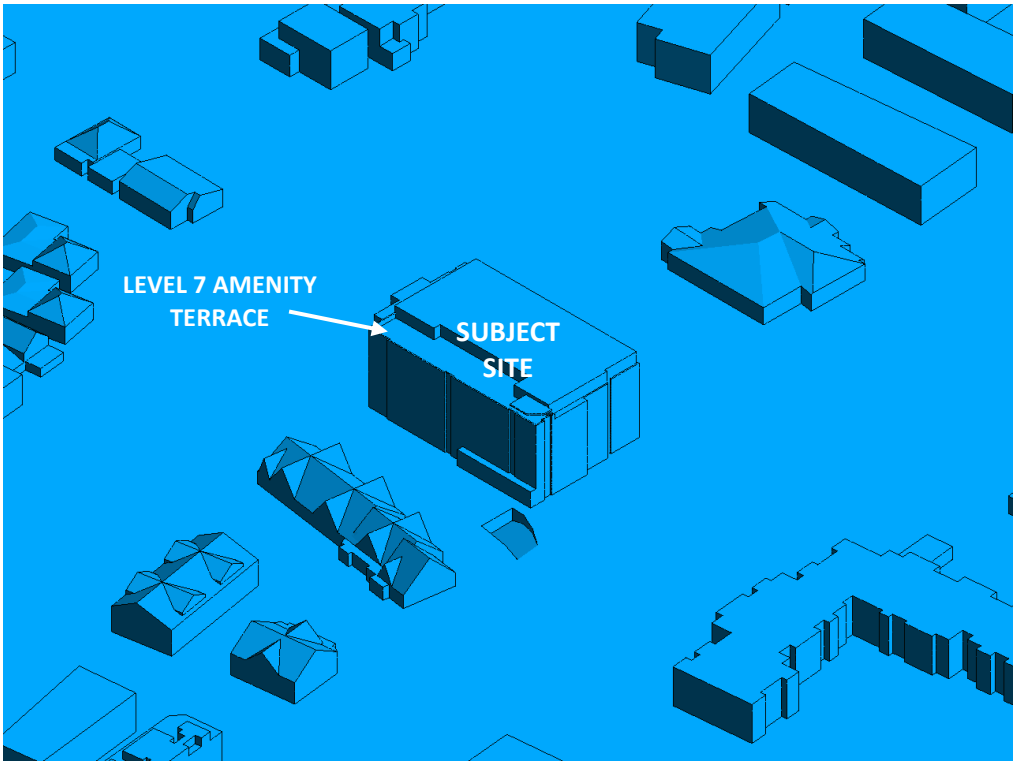


FIGURE 2F: CLOSE-UP VIEW OF FIGURE 2E

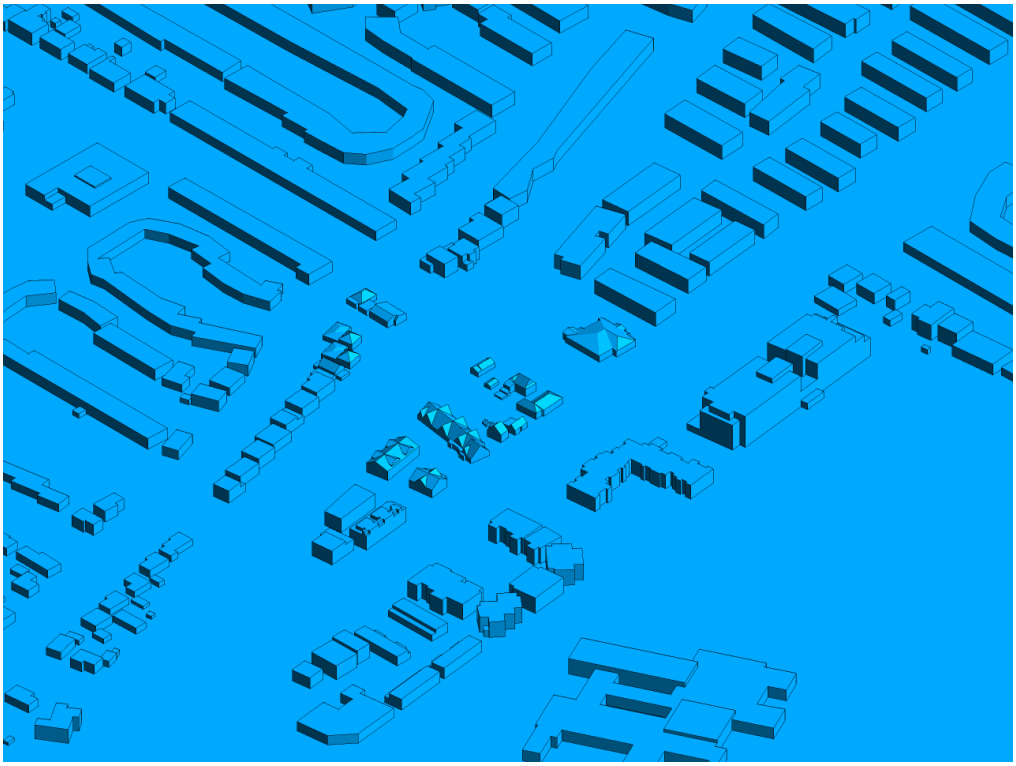


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, SOUTH PERSPECTIVE

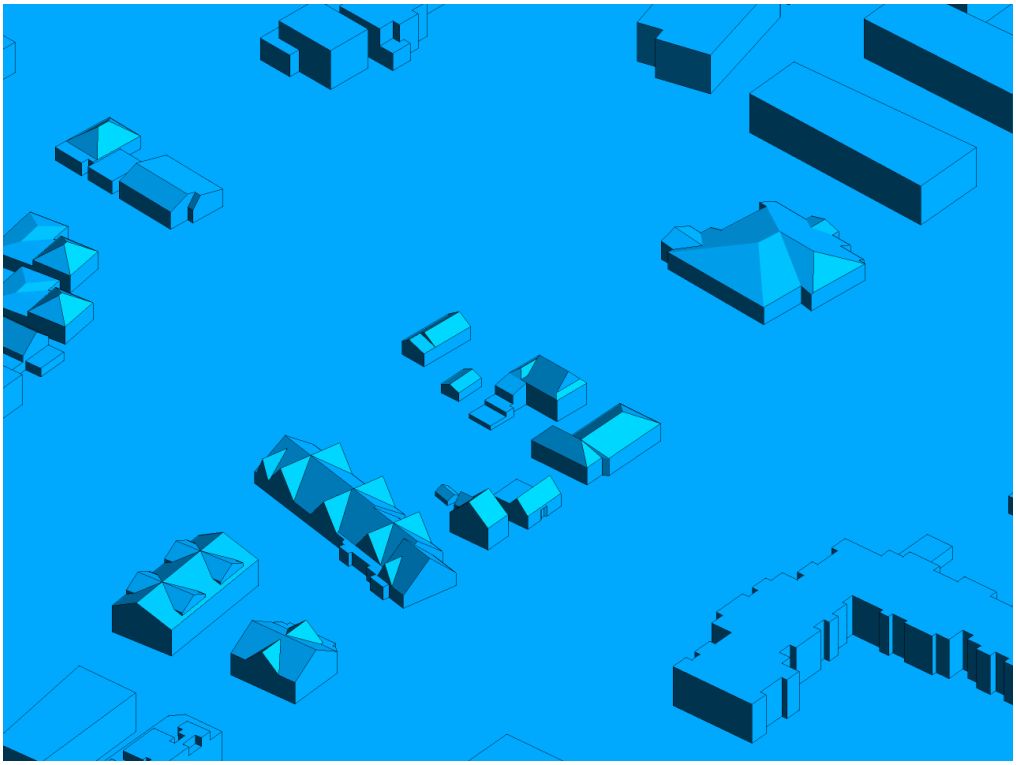


FIGURE 2H: CLOSE-UP VIEW OF FIGURE 2G

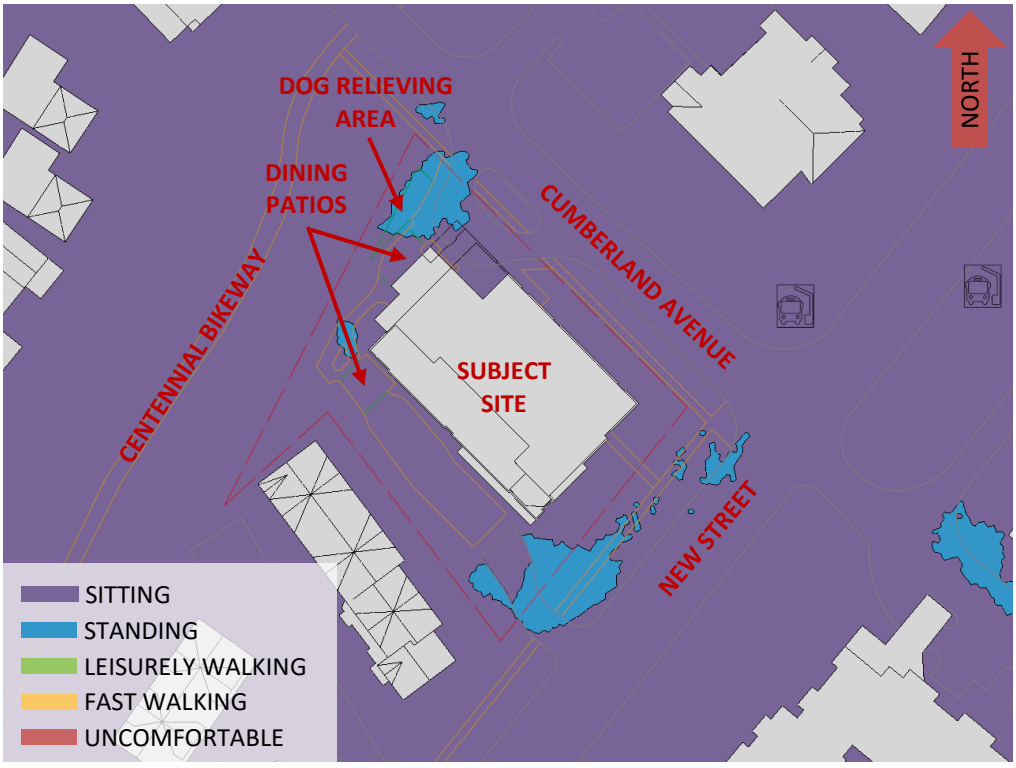


FIGURE 3A: SUMMER – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL



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

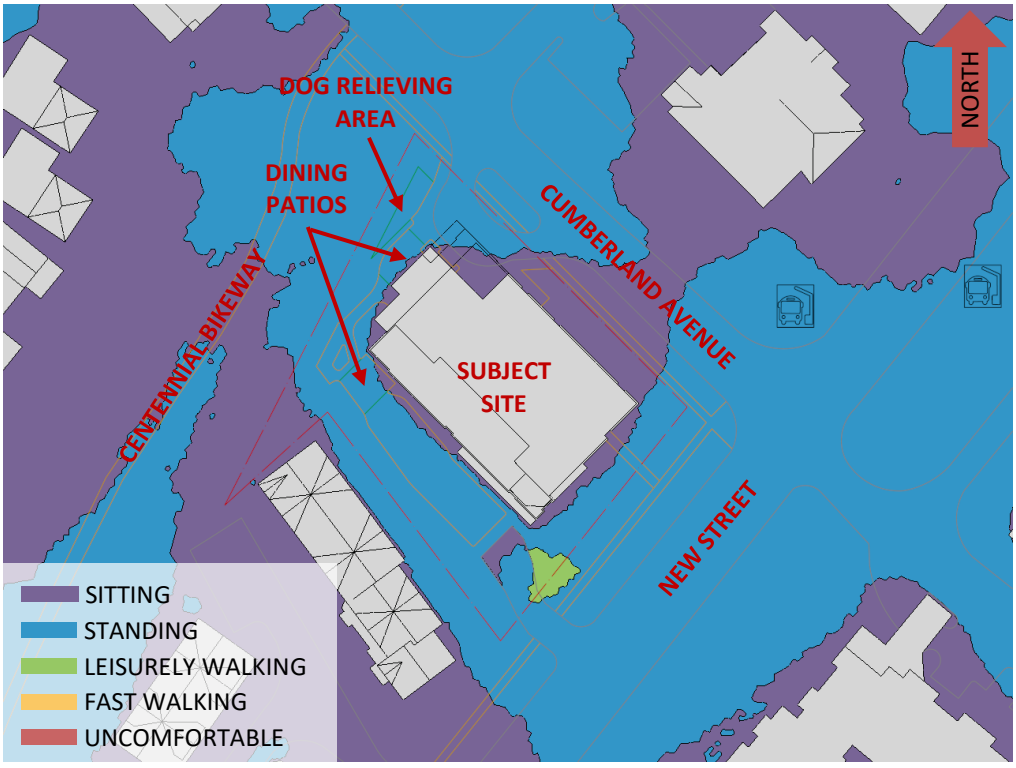


FIGURE 4A: WINTER – PROPOSED MASSING – WIND COMFORT, GRADE LEVEL

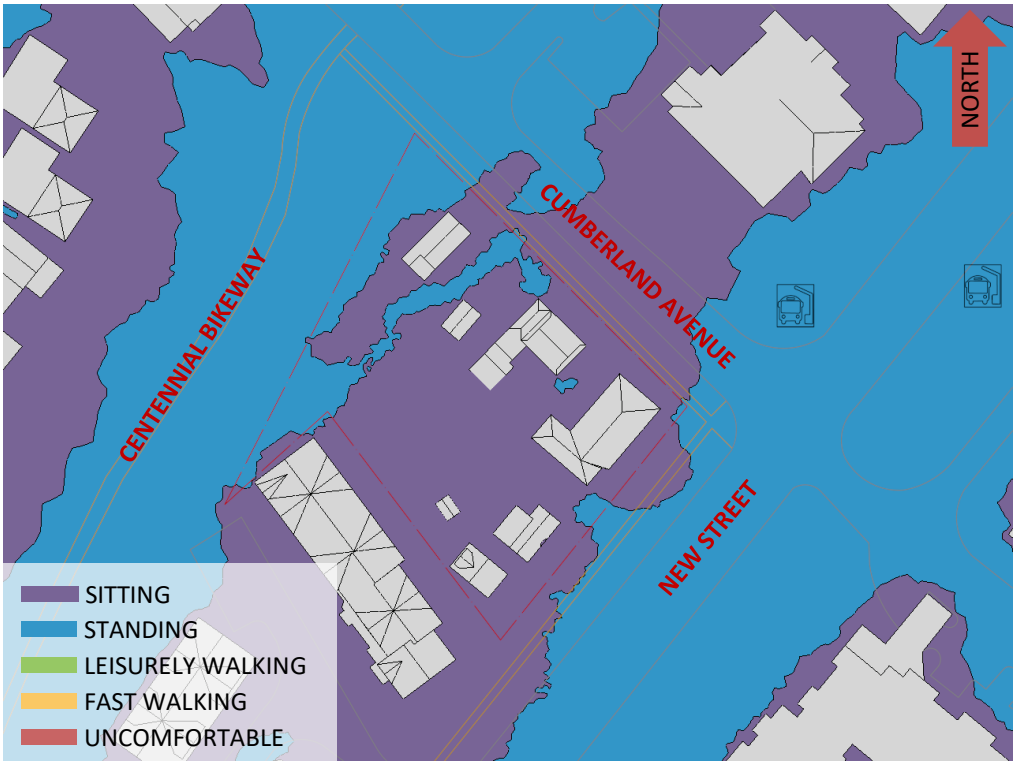


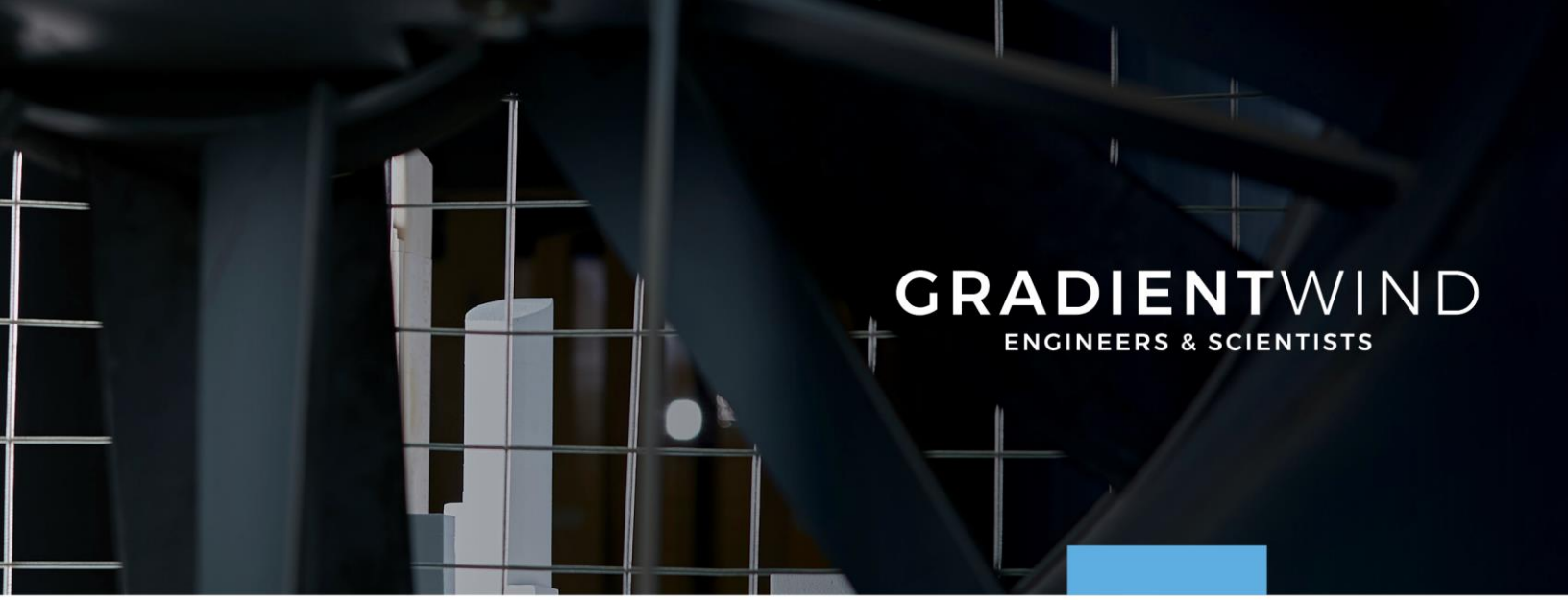
FIGURE 4B: WINTER – EXISTING MASSING – WIND COMFORT, GRADE LEVEL



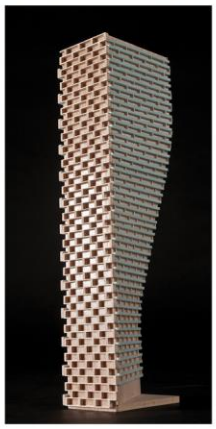
FIGURE 5A: SUMMER – WIND COMFORT, LEVEL 7 AMENITY TERRACE



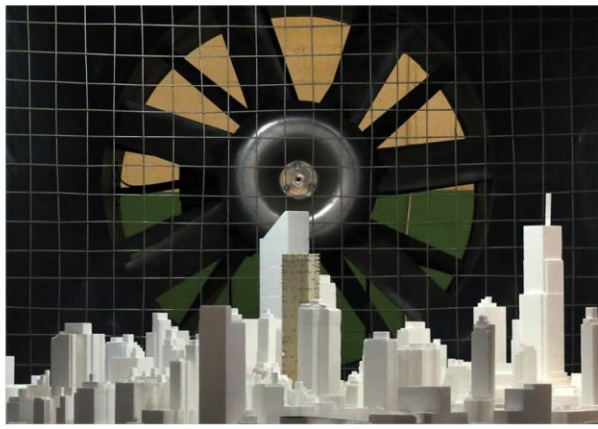
FIGURE 5B: WINTER – WIND COMFORT, LEVEL 7 AMENITY TERRACE











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 50% mean wind speed for Burlington 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	0.24
22.5	0.24
45	0.25
67.5	0.22
90	0.20
112.5	0.19
135	0.19
157.5	0.19
180	0.19
202.5	0.22
225	0.24
247.5	0.25
270	0.25
292.5	0.24
315	0.24
337.5	0.25

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].

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

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

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.

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.