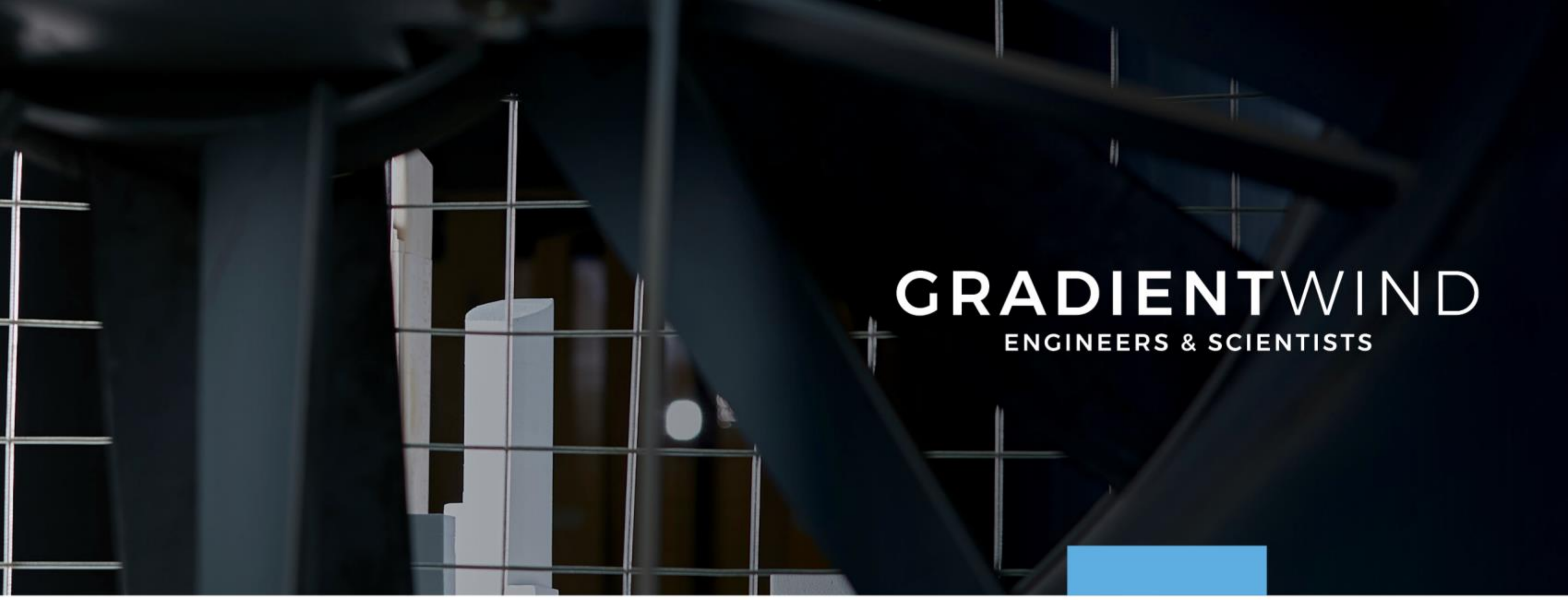
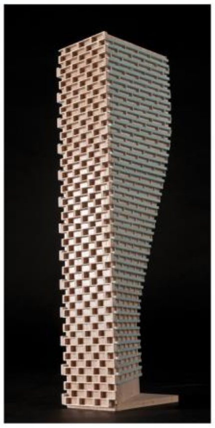
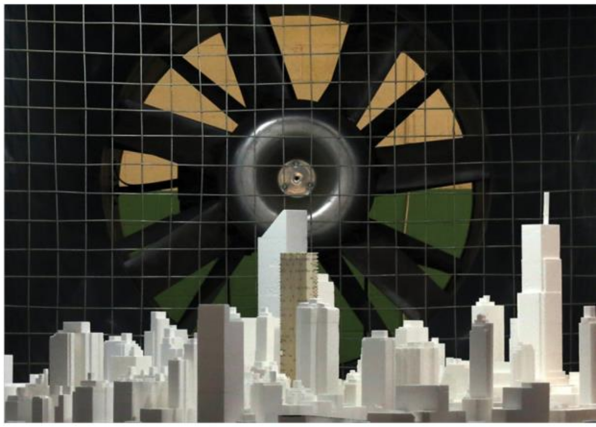


PEDESTRIAN LEVEL WIND STUDY

CF Rideau Centre Registry Project
70 Nicholas Street
Ottawa, Ontario

Report: 21-097-PLW





November 12, 2021

PREPARED FOR
The Cadillac Fairview Corporation Limited
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EXECUTIVE SUMMARY

This report describes the results of a comparative pedestrian level wind (PLW) study undertaken to satisfy the requirements for concurrent Zoning By-law Amendment and Site Plan Control application submissions for a proposed multi-unit residential building located at 70 Nicholas Street in Ottawa, 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 according to City of Ottawa wind comfort and safety criteria. The results and recommendations derived from these considerations are detailed in the main body of the report (Section 5), illustrated in Figures 3A-8B, and 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 the surrounding sidewalks and walkways, transit stops, parking lots, and building access points, are considered acceptable for the intended pedestrian uses throughout the year.

2) Regarding the common amenity terrace at Level 3, wind conditions are predicted to be suitable for mostly sitting during the typical use period, defined as May to October, inclusive. There is an isolated region near the southeast of the terrace that is intended to accommodate a dog run where conditions are predicted to be suitable for sitting at least 76% of the time during the typical use period, and at least 60% of the time during the winter. Since the perimeter of the terrace in this region will include a partially solid barrier rising 1.8 metres (m) above the walking surface, which was modelled as a standard height guard in the simulation model (i.e., 1.07 m), conditions are expected to be suitable for the anticipated uses of the space.

3) Regarding the common amenity terrace at Level 21, wind conditions are predicted to be suitable for a mix of sitting and standing during the typical use period. The simulation model included a solid 1.8-m-tall wind barrier along the full perimeter of the terrace, consistent with the architectural drawings. With the noted barrier, conditions over the terrace are predicted to be suitable for sitting at least 77% of the time during the typical use period. Seating areas over the terrace are intended to be served by landscape structures, which will provide additional shelter. As such, conditions are expected to be suitable for the anticipated uses of the space.

4) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas within and surrounding the subject site were found to experience conditions that could be considered dangerous.

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (Gradient Wind) was retained by The Cadillac Fairview Corporation Limited to undertake a pedestrian level wind (PLW) study to satisfy the requirements for concurrent Zoning By-law Amendment and Site Plan Control application submissions for a proposed multi-unit residential building located at 70 Nicholas Street in Ottawa, 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, City of Ottawa wind comfort and safety criteria, architectural drawings prepared by Zeidler Architecture Inc., in November 2021, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent satellite imagery.

2. TERMS OF REFERENCE

The subject site is located at 70 Nicholas Street in Ottawa on a nominally rectangular parcel of land at the southeast corner of the CF Rideau Centre, adjacent to the Nordstrom department store. This location is currently occupied by an open green space with a designated heritage building (City Registry Office), as well as vehicle ramps to access the parking and loading for the shopping centre. Throughout this report, the Nicholas Street elevation is referred to as the east elevation.

The proposed development comprises a near rectangular 21-storey residential building that is massed as two distinct components and includes two levels of underground parking. It also features retail space, building services, office spaces, and concierge space at grade. The façade of the City Registry Office will be retained and integrated near the lobby area of the proposed development. A drop-off area and ramp to parking is accessible at the southeast corner of the proposed development. Level 2 comprises communal amenity space to the southwest, and locker spaces and building services throughout the remainder of the floorplan; the perimeter of the floor is open to below. At Level 3, indoor amenity spaces are located to the north and west, and residential units are to the southeast. Level 21 includes indoor amenity space along the north elevation and residential units along the south elevation. The building is serviced by a mechanical penthouse at the roof level, while Levels 4 to 20, inclusive, are reserved for residential occupancy. Common amenity terraces are provided at Levels 3 and 21.

The near-field surroundings (defined as an area within 200 metres (m) of the subject site) include a dense mixture of mid to high-rise buildings in all directions, representative of urban exposures. The far-field surroundings (defined as an area beyond the near-field but within a 2-kilometre (km) radius of the subject site) comprise low to high-rise buildings in the southwest, representative of Ottawa's urban core, and low-rise buildings with isolated clusters of taller buildings in the remaining compass directions. The Ottawa River occupies a portion of the northwest quadrant, the Rideau River flows from southeast to northwest approximately 1.5 km to the northeast, and the Rideau Canal flows from southeast to northwest approximately 200 m to the southwest of the subject site.

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

3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind comfort and safety conditions at key areas within and surrounding the development site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the site is based on CFD simulations of wind speeds across the study site within a virtual environment, meteorological analysis of the Ottawa area wind climate, and synthesis of computational data with City of Ottawa wind comfort and safety criteria[1]. The following sections describe the analysis procedures, including a discussion of the noted pedestrian wind criteria.

4.1 Computer-Based Context Modelling

A computer based PLW study was performed to determine the influence of the wind environment on pedestrian comfort over the proposed development site. Pedestrian comfort predictions, based on the mechanical effects of wind, were determined by combining measured wind speed data from CFD simulations with statistical weather data obtained from Ottawa Macdonald-Cartier International Airport. The general concept and approach to CFD modelling is to represent building and topographic details in the immediate vicinity of the study site on the surrounding model, and to create suitable atmospheric wind profiles at the model boundary. The wind profiles are designed to have similar mean and turbulent wind properties consistent with actual site exposures.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the model due to the difficulty of providing accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative (i.e., windier) wind speed values.

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

4.2 Wind Speed Measurements

The PLW analysis was performed by simulating wind flows and gathering velocity data over a CFD model of the site for 16 wind directions and two massing scenarios, as noted in Section 2. The CFD simulation model was centered on the study building, complete with surrounding massing within a radius of approximately 480 m.

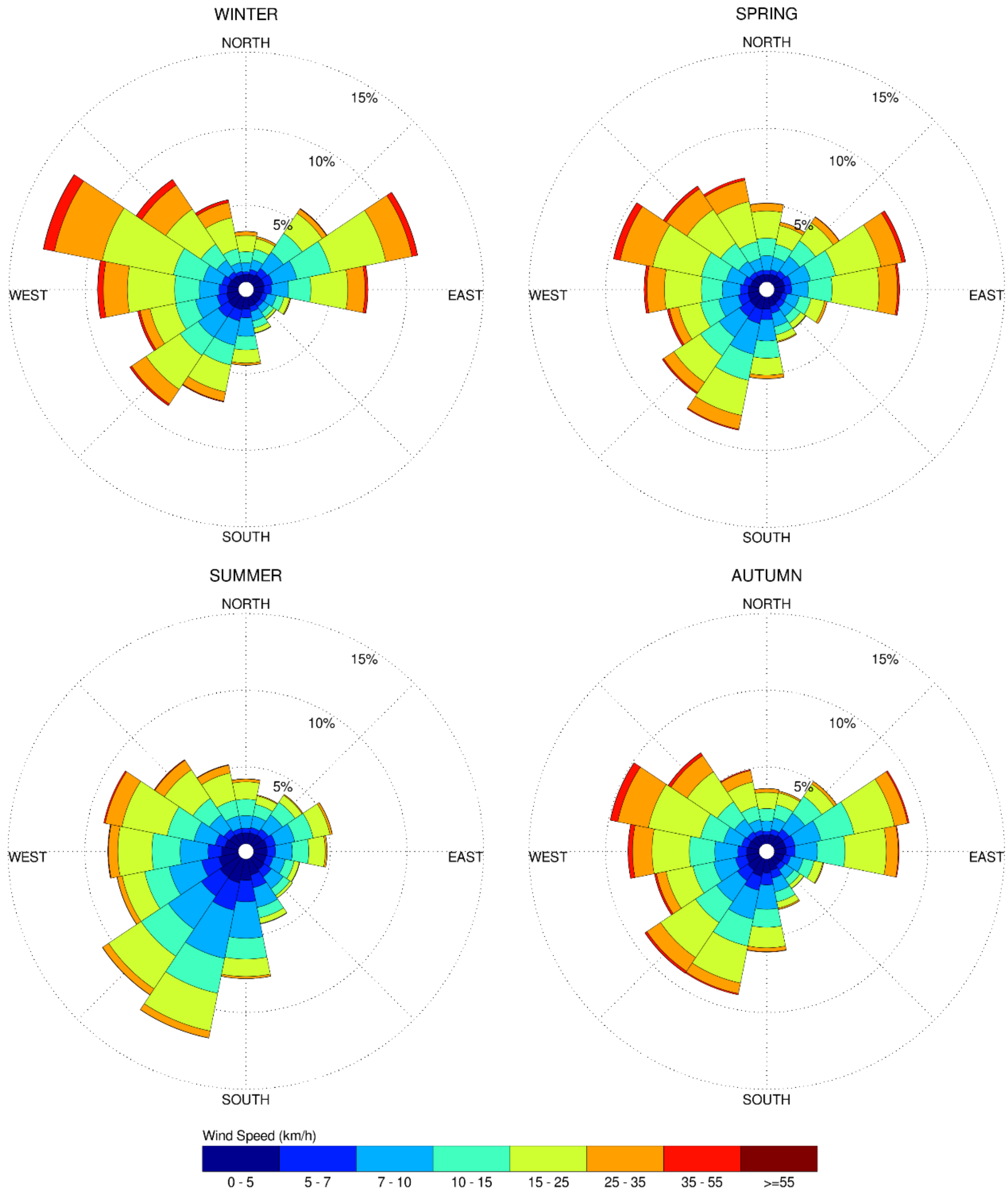
Mean and peak wind speed data obtained over the study site for each wind direction were interpolated to 36 wind directions at 10° intervals, representing the full compass azimuth. Measured wind speeds approximately 1.5 m above local grade and the common amenity terraces were referenced to the wind speed at gradient height to generate mean and peak velocity ratios, which were used to calculate full-scale values. Gradient height represents the theoretical depth of the boundary layer of the earth's atmosphere, above which the mean wind speed remains constant. Further details of the wind flow simulation technique are presented in Appendix A.

4.3 Historical Wind Speed and Direction Data

A statistical model for winds in Ottawa was developed from approximately 40 years of hourly meteorological wind data recorded at Ottawa Macdonald-Cartier International Airport and obtained from Environment and Climate Change Canada. Wind speed and direction data were analyzed for each month of the year to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns.

The statistical model of the Ottawa area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Ottawa, the most common winds occur for westerly wind directions, followed by those from the east, while the most common wind speeds are below 36 km/h. The directional preference and relative magnitude of wind speed changes somewhat from season to season.

SEASONAL DISTRIBUTION OF WIND
OTTAWA MACDONALD-CARTIER INTERNATIONAL AIRPORT



Notes:

1. Radial distances indicate percentage of time of wind events.
2. Wind speeds are mean hourly in km/h, measured at 10 m above the ground.

4.4 Pedestrian Comfort and Safety Criteria – City of Ottawa

Pedestrian comfort and safety criteria are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e., temperature, relative humidity). The comfort criteria assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes are based on 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 32 km/h.

5) **Uncomfortable:** Uncomfortable conditions are characterized by predicted values that fall below the 80% target for walking. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.

The pedestrian safety wind speed criterion is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of 90 km/h is classified as dangerous. The gust speeds, and equivalent mean speeds, are selected based on 'The Beaufort Scale', presented on the following page, which describes the effects of forces produced by varying wind speed levels on objects. Gust speeds are included because pedestrians tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also create problems for pedestrians.

THE BEAUFORT SCALE

Number	Description	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 were exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting. Similarly, if mean wind speed of 20 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established throughout the site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for discrete regions within and surrounding the subject site. This step involves comparing the predicted comfort classes to the desired comfort classes, which are dictated by the location type for each region (i.e., a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their 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	Windiest Desired Comfort Classes
Primary Building Entrance	Standing
Secondary Building Access Point	Walking
Public Sidewalk / Bicycle Path	Walking
Outdoor Amenity Space	Sitting (During Typical Use Period)
Café / Patio / Bench / Garden	Sitting (Typical Use Period)
Transit Stops (Without Shelter)	Standing
Transit Stops (With Shelter)	Walking
Public Park / Plaza	Sitting (Typical Use Period)
Garage / Service Entrance	Walking
Parking Lot	Walking
Vehicular Drop-Off Zone	Walking

5. RESULTS AND DISCUSSION

The following discussion of predicted pedestrian wind conditions for the subject site is accompanied by Figures 3A-6B, which illustrate seasonal wind comfort conditions at grade level for the proposed and existing massing scenarios and Figures 7A-7D which illustrate seasonal wind conditions over the common amenity terraces serving the proposed development. The wind conditions are presented as continuous contours of wind comfort within and surrounding the subject site. The colour contours indicate predicted regions of 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.

Wind conditions over the amenity terraces are also reported for the typical use period, which is defined as May to October, inclusive. Figure 8A illustrates wind comfort conditions during this period, consistent with the comfort classes in Section 4.4, while Figure 8B illustrates contours indicating the percentage of time the noted areas are predicted to be suitable for sitting. Pedestrian conditions are summarized in the following pages for each area of interest.

5.1 Wind Comfort Conditions – Grade Level

Sidewalks and Walkways: Following the introduction of the proposed development, the sidewalks and walkways adjacent to the proposed development, including those along Nicholas Street, Daly Avenue, and Mackenzie King Bridge, are predicted to be suitable for a mix of sitting and standing during the summer and autumn, becoming suitable for a mix of sitting, standing, and strolling during the spring and winter. The noted wind conditions are considered acceptable according to the City of Ottawa wind criteria.

Conditions over the sidewalks with the existing massing are predicted to be suitable for sitting along Nicholas Street and Daly Avenue throughout the year and for standing, or better, along the Mackenzie King Bridge throughout the year. While the introduction of the proposed development results in windier conditions during the colder months in comparison to existing conditions, conditions with the proposed development are considered acceptable.

Transit Stops: Following the introduction of the proposed development, wind conditions in the vicinity of the nearby transit stop along Daly Avenue are predicted to be suitable for sitting during the summer, becoming suitable for standing throughout the remainder of the year. In the vicinity of the nearby transit stops along MacKenzie King Bridge, which include heated shelters, conditions are predicted to be suitable for standing, or better, during the summer and autumn, becoming suitable for strolling, or better, throughout the remainder of the year. The noted conditions are considered acceptable according to the City of Ottawa wind criteria.

Conditions in the vicinity of the transit stop along Daly Avenue with the existing massing are predicted to be suitable for sitting throughout the year, and conditions in the vicinity of the transit stops along MacKenzie King Bridge are predicted to be suitable for standing, or better, throughout the year. While the introduction of the proposed development results in windier conditions in comparison to what exists today, conditions with the proposed development are considered acceptable.

Building Access Points: Owing to the protection of the building façades, conditions in the vicinity of the building access points serving the proposed development, as well as those serving the adjacent existing buildings, are predicted to be suitable for sitting during the summer, becoming suitable for standing, or better, throughout the remainder of the year. The noted conditions are considered acceptable according to the City of Ottawa wind criteria.

5.2 Wind Comfort Conditions – Common Amenity Terraces

Level 3 Amenity Terrace: Wind conditions within the common amenity terrace serving the proposed development at Level 3 are predicted to be suitable for mostly sitting during the typical use period, as illustrated in Figure 8A. There is an isolated region near the southeast of the terrace that is intended to accommodate a dog run where conditions are predicted to be suitable for sitting at least 76% of the time during the typical use period, and at least 60% of the time during the winter. Since the perimeter of the terrace in this region will include a partially solid barrier rising 1.8 m above the walking surface, which was modelled as a standard height guard in the simulation model (i.e., 1.07 m), conditions are expected to be suitable for the anticipated uses of the space.

Level 21 Amenity Terrace: Wind conditions within the common amenity terrace serving the proposed development at Level 21 are predicted to be suitable for a mix of sitting and standing during the typical use period, as illustrated in Figure 8A. The simulation model included a solid 1.8-m-tall wind barrier along the full perimeter of the terrace, consistent with the architectural drawings. With the noted barrier, conditions over the terrace are predicted to be suitable for sitting at least 77% of the time during the typical use period. Seating areas over the terrace are intended to be served by landscape structures, which will provide additional shelter. As such, conditions are expected to be suitable for the anticipated uses of the space.

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 and surrounding the subject site were found 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 (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 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 and illustrated in Figures 3A-8B. Based on computer simulations using the CFD technique, meteorological data analysis of the Ottawa wind climate, City of Ottawa wind comfort and safety criteria, and experience with numerous similar developments, the study concludes the following:

1) 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 the surrounding sidewalks and walkways, transit stops, parking lots, and building access points, are considered acceptable for the intended pedestrian uses throughout the year.

2) Regarding the common amenity terrace at Level 3, wind conditions are predicted to be suitable for mostly sitting during the typical use period, defined as May to October, inclusive. There is an isolated region near the southeast of the terrace that is intended to accommodate a dog run where conditions are predicted to be suitable for sitting at least 76% of the time during the typical use period, and at least 60% of the time during the winter. Since the perimeter of the terrace in this region will include a partially solid barrier rising 1.8 m above the walking surface, which was modelled as a standard height guard in the simulation model (i.e., 1.07 m), conditions are expected to be suitable for the anticipated uses of the space.

3) Regarding the common amenity terrace at Level 21, wind conditions are predicted to be suitable for a mix of sitting and standing during the typical use period. The simulation model included a solid 1.8-m-tall wind barrier along the full perimeter of the terrace, consistent with the architectural drawings. With the noted barrier, conditions over the terrace are predicted to be suitable for sitting at least 77% of the time during the typical use period. Seating areas over the terrace are intended to be served by landscape structures, which will provide additional shelter. As such, conditions are expected to be suitable for the anticipated uses of the space.

4) Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no pedestrian areas within and surrounding the subject site were found to experience conditions that could be considered dangerous.

Sincerely,

Gradient Wind Engineering Inc.

LICENSED PROFESSIONAL ENGINEER
S. R. HALL
100197168
Nov 12, 2021
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David Huitema, M.Eng.
Junior Wind Scientist

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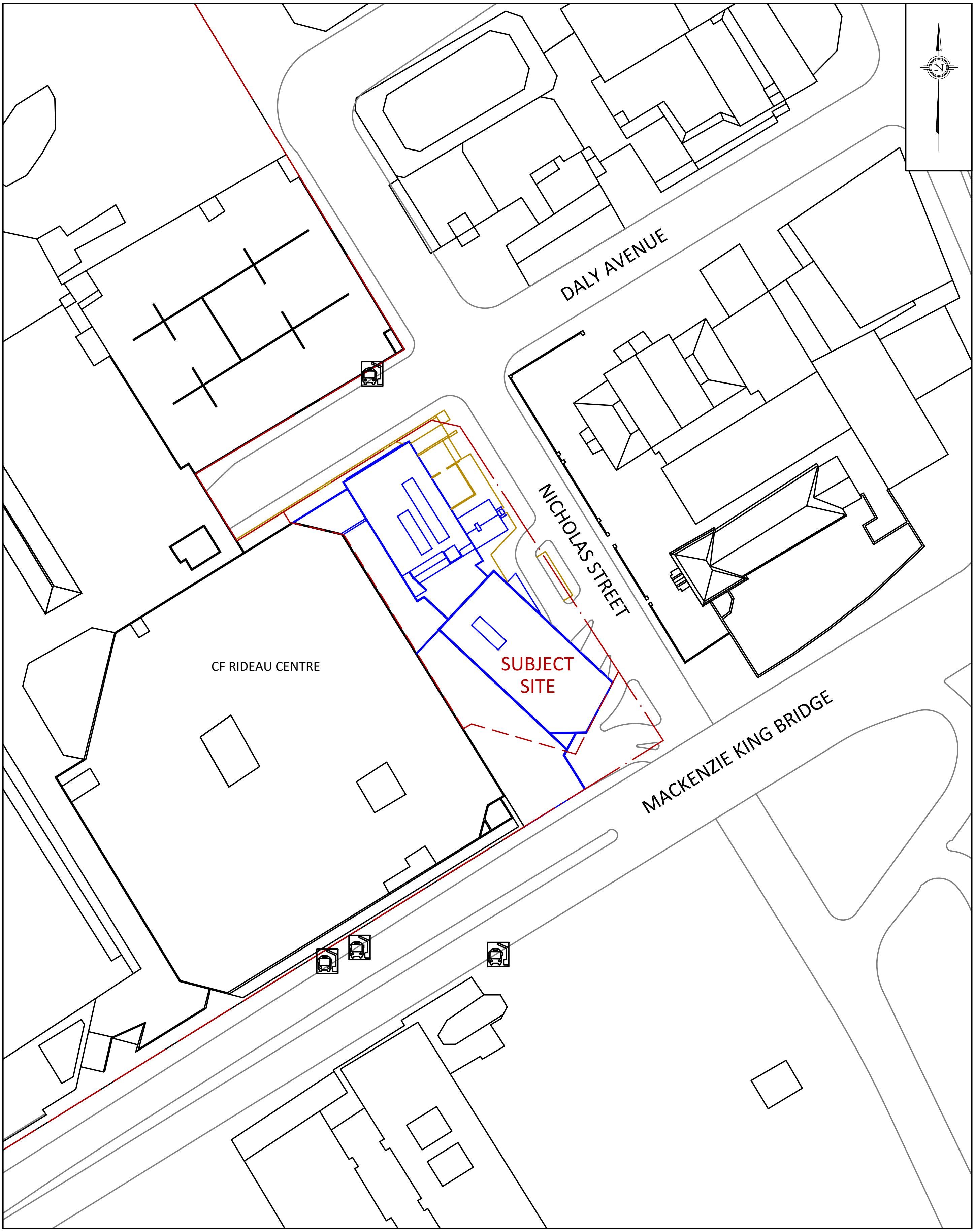

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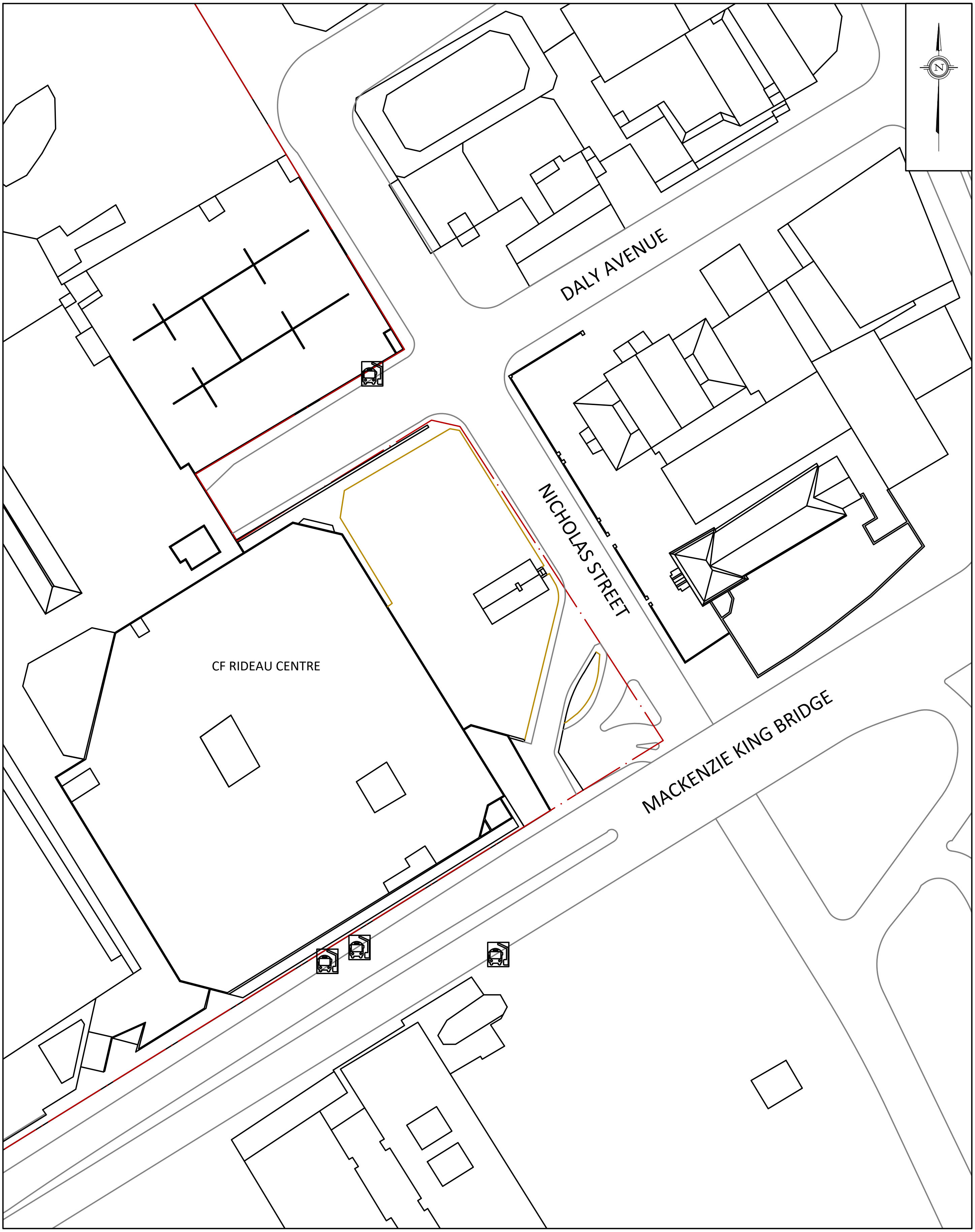
PROJECT	CF RIDEAU CENTRE REGISTRY PROJECT, OTTAWA PEDESTRIAN LEVEL WIND STUDY			DESCRIPTION
SCALE	1:1000	DRAWING NO.	21-097-PLW-1A	FIGURE 1A: PROPOSED SITE PLAN AND SURROUNDING CONTEXT
DATE	NOVEMBER 12, 2021	DRAWN BY	N.M.P.	



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PROJECT: CF RIDEAU CENTRE REGISTRY PROJECT, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 1B: EXISTING SITE PLAN AND SURROUNDING CONTEXT
SCALE: 1:1000	DRAWING NO.: 21-097-PLW-1B	
DATE: NOVEMBER 12, 2021	DRAWN BY: N.M.P.	

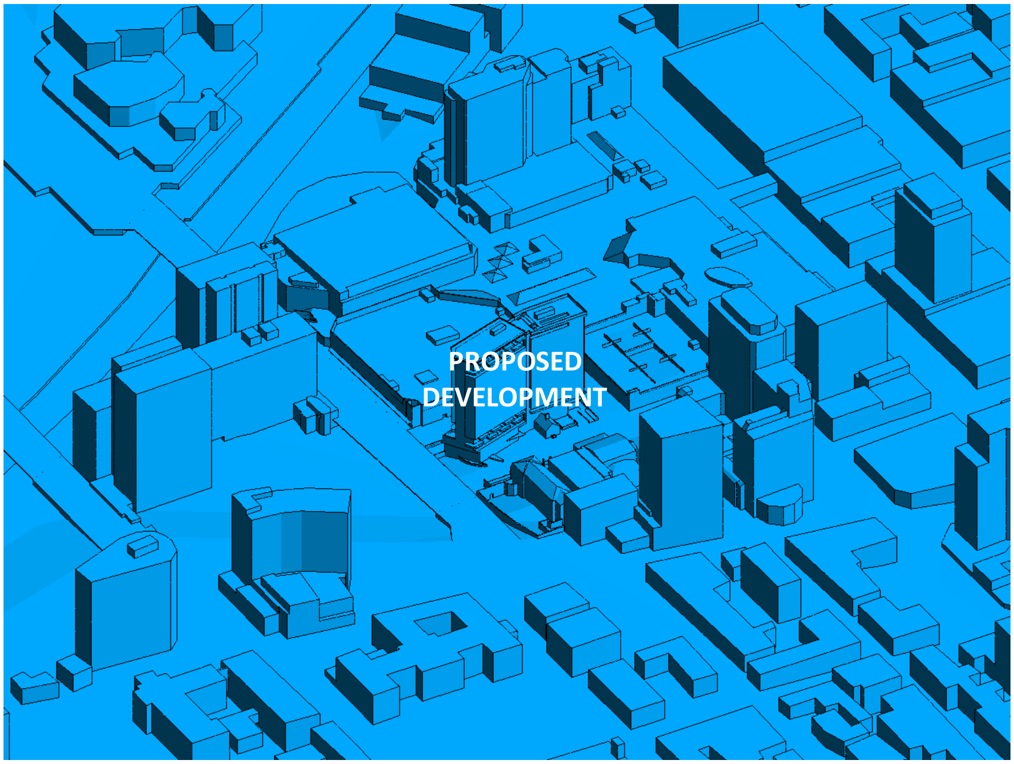


FIGURE 2A: COMPUTATIONAL MODEL, PROPOSED MASSING, EAST PERSPECTIVE

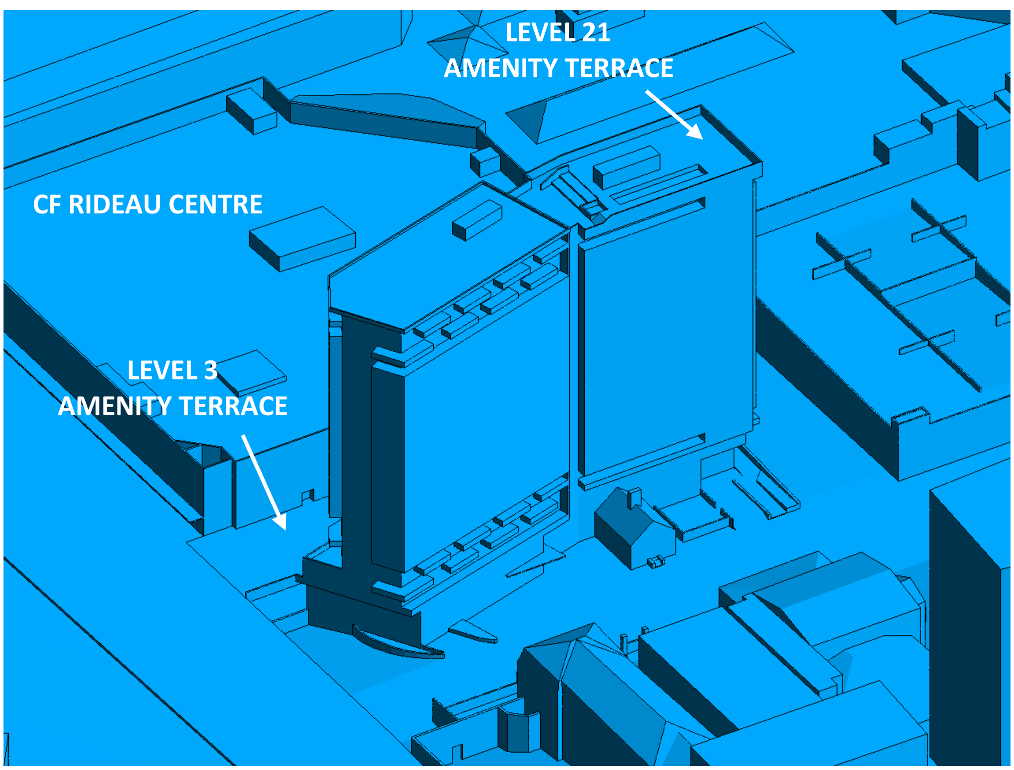


FIGURE 2B: CLOSE UP OF FIGURE 2A

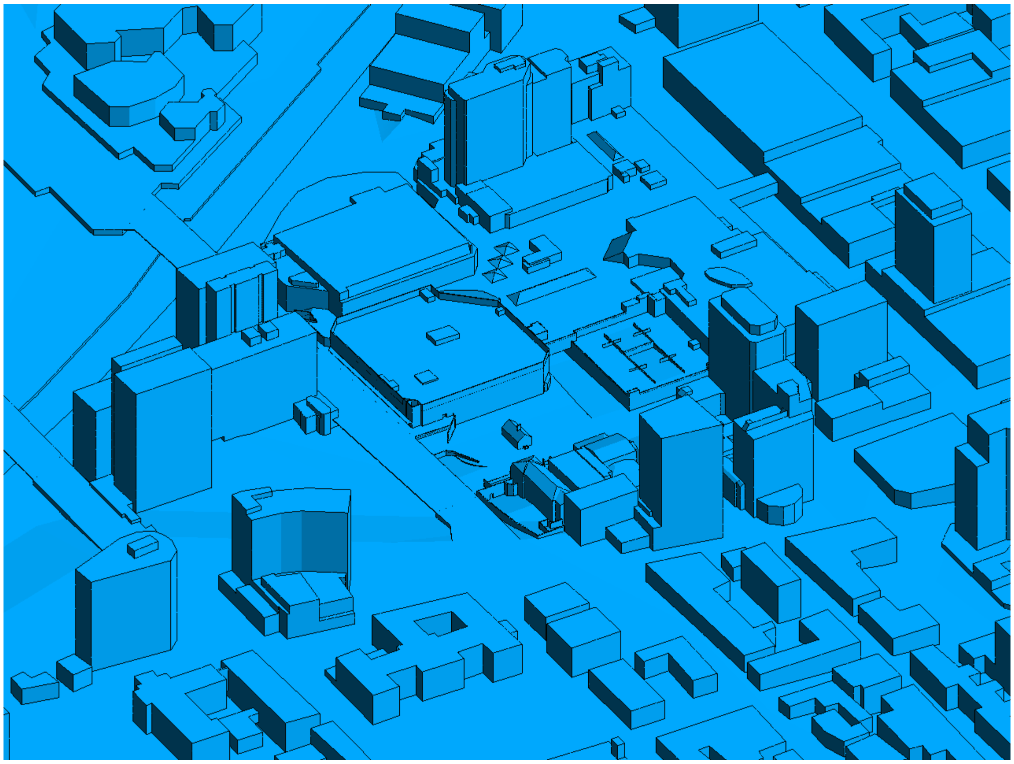


FIGURE 2C: COMPUTATIONAL MODEL, EXISTING MASSING, EAST PERSPECTIVE

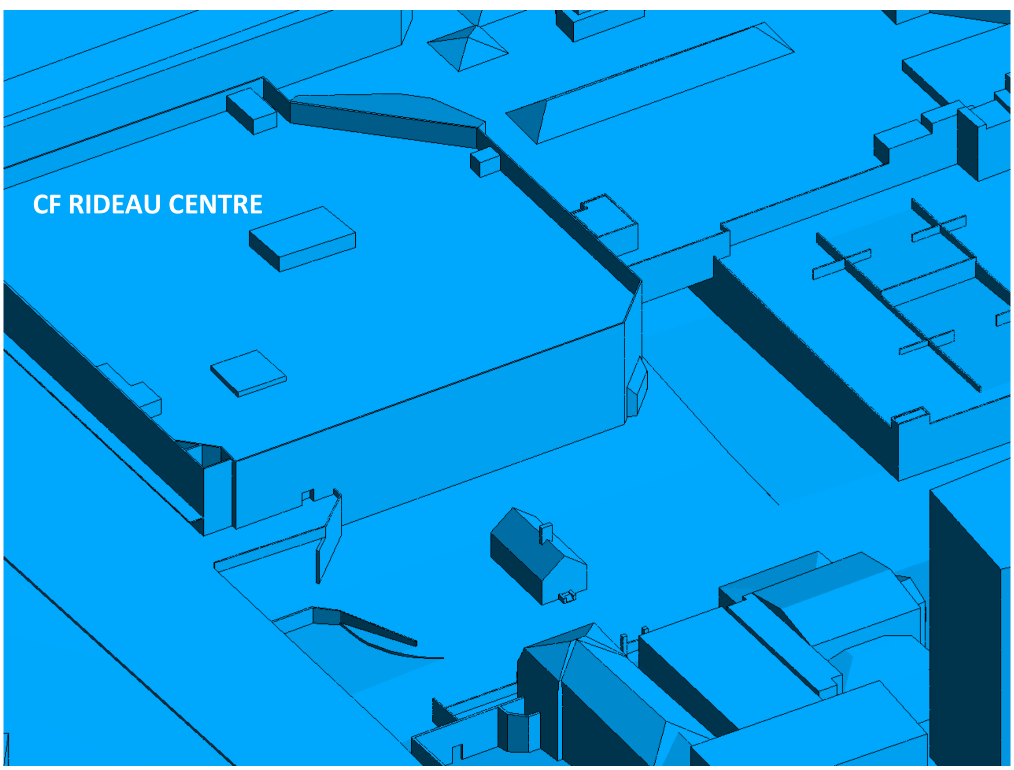


FIGURE 2D: CLOSE UP OF FIGURE 2C

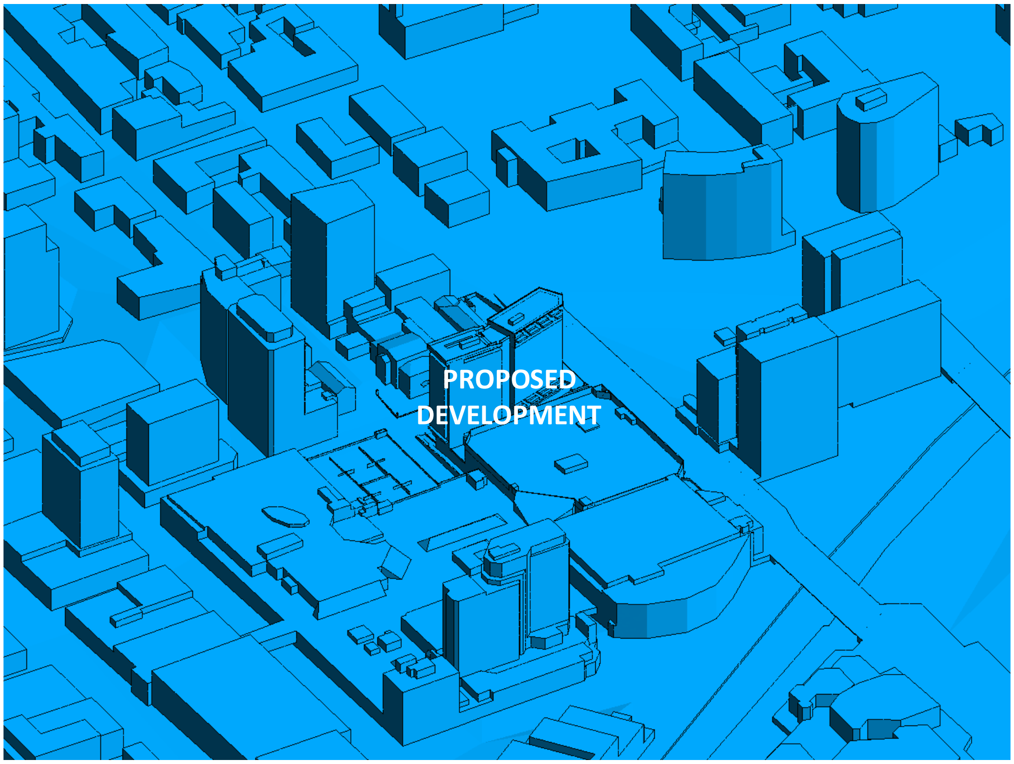


FIGURE 2E: COMPUTATIONAL MODEL, PROPOSED MASSING, WEST PERSPECTIVE

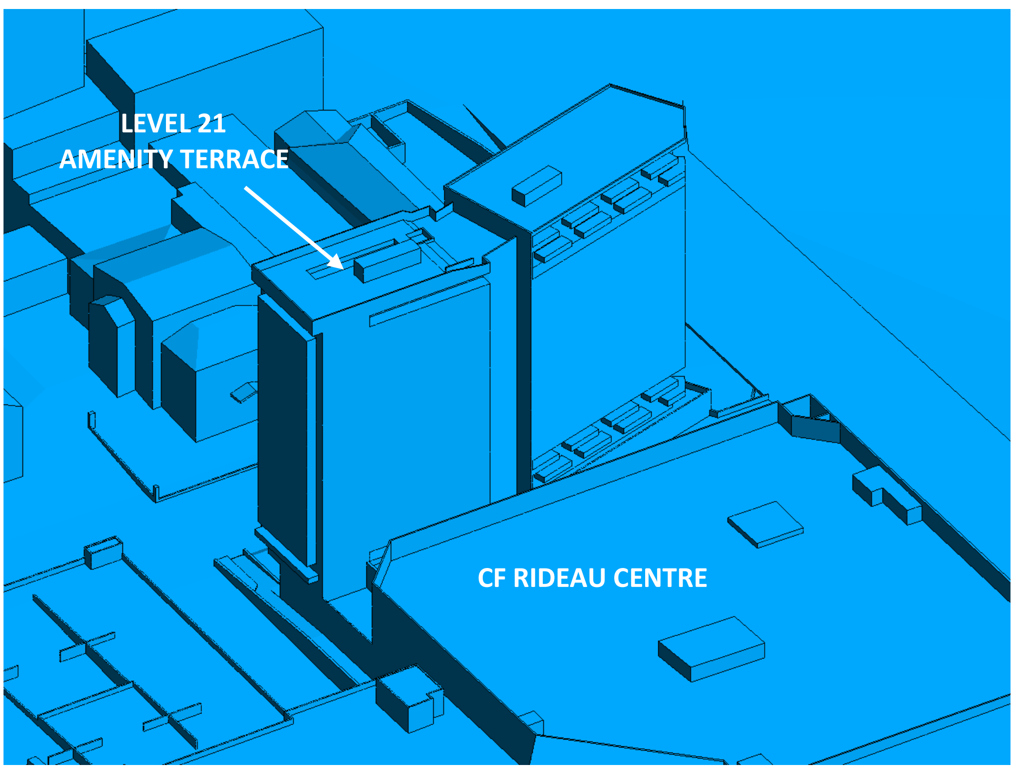


FIGURE 2F: CLOSE UP OF FIGURE 2E

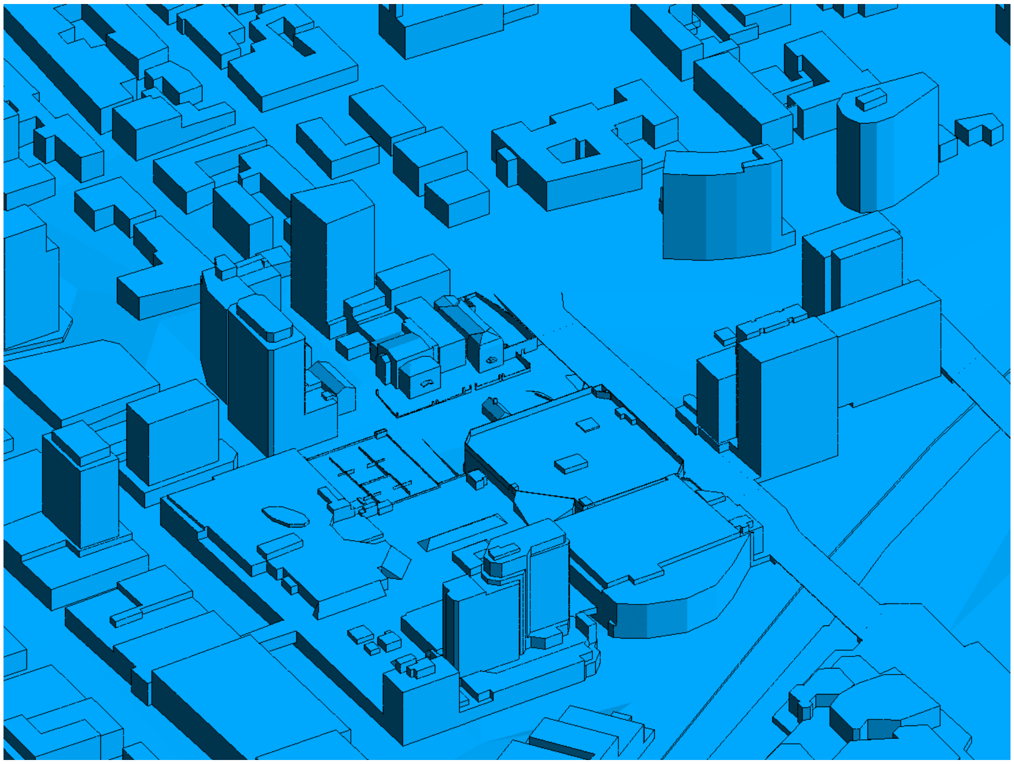


FIGURE 2G: COMPUTATIONAL MODEL, EXISTING MASSING, WEST PERSPECTIVE

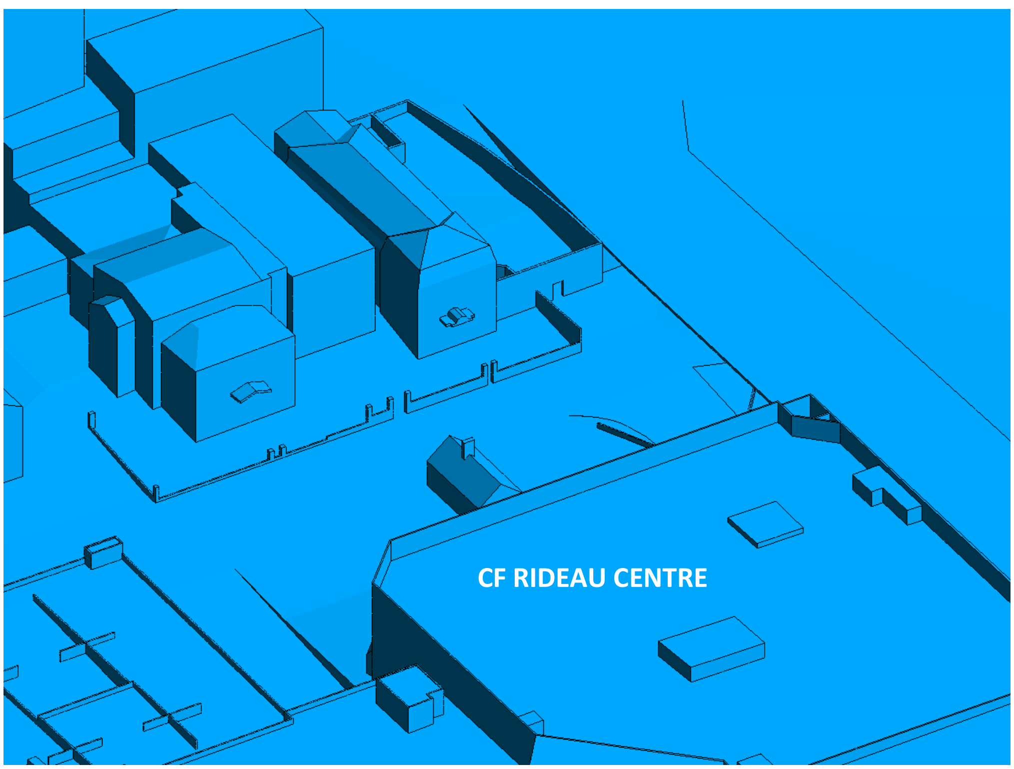


FIGURE 2H: CLOSE UP OF FIGURE 2G

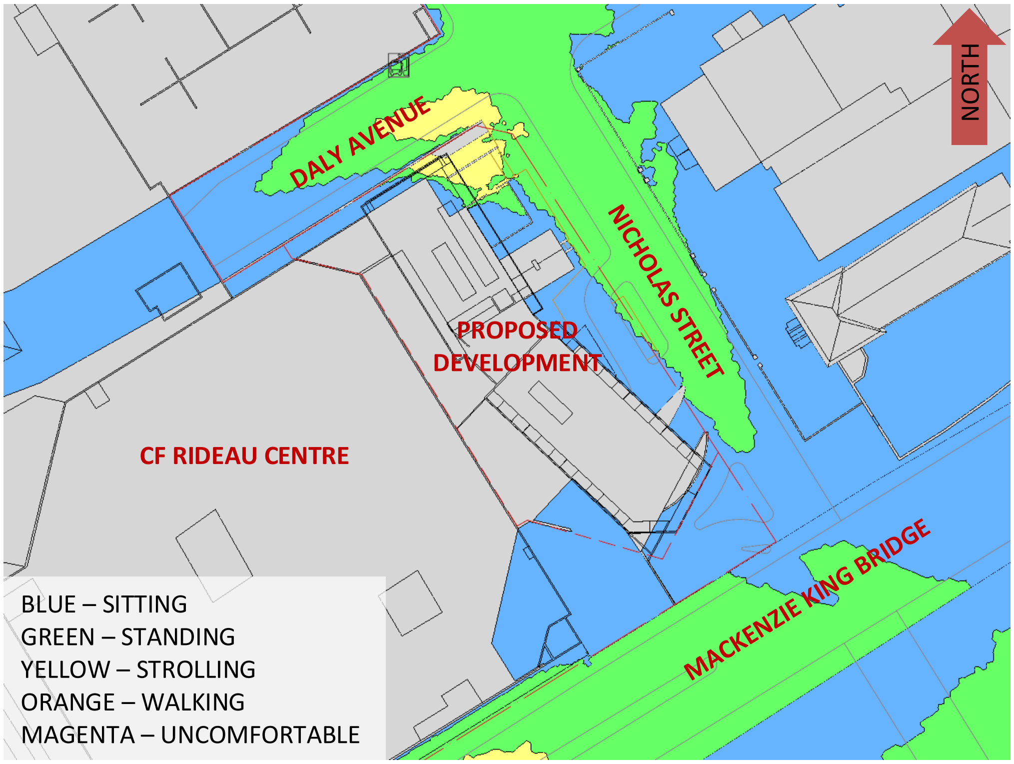


FIGURE 3A: SPRING – PROPOSED MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

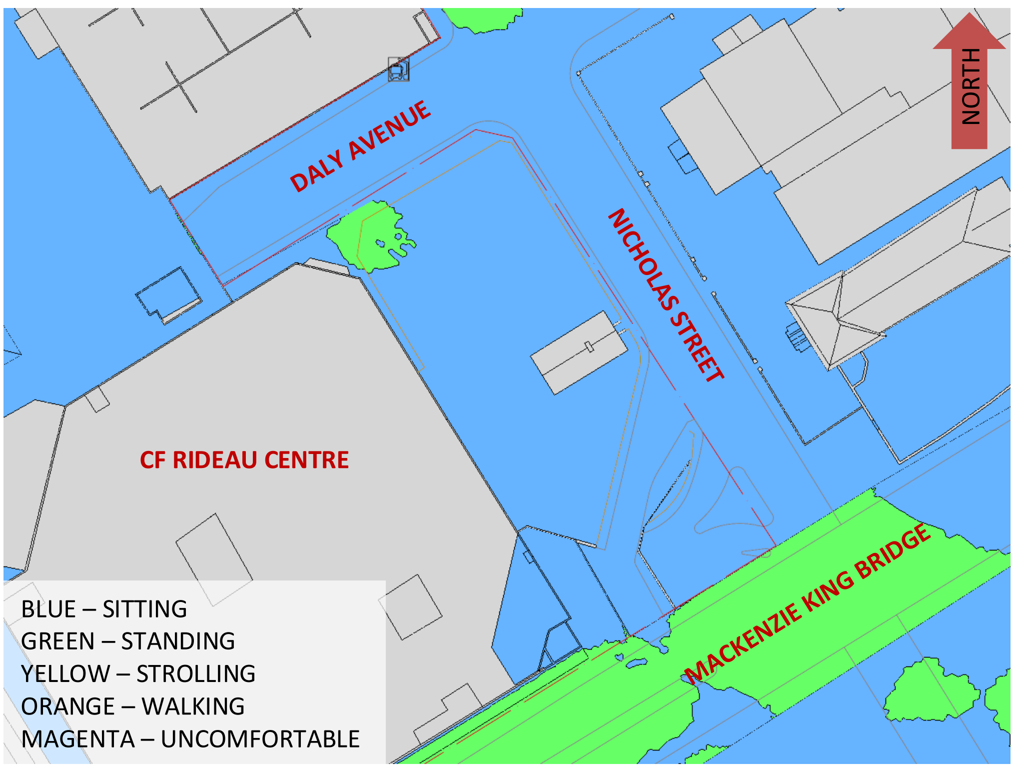


FIGURE 3B: SPRING – EXISTING MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

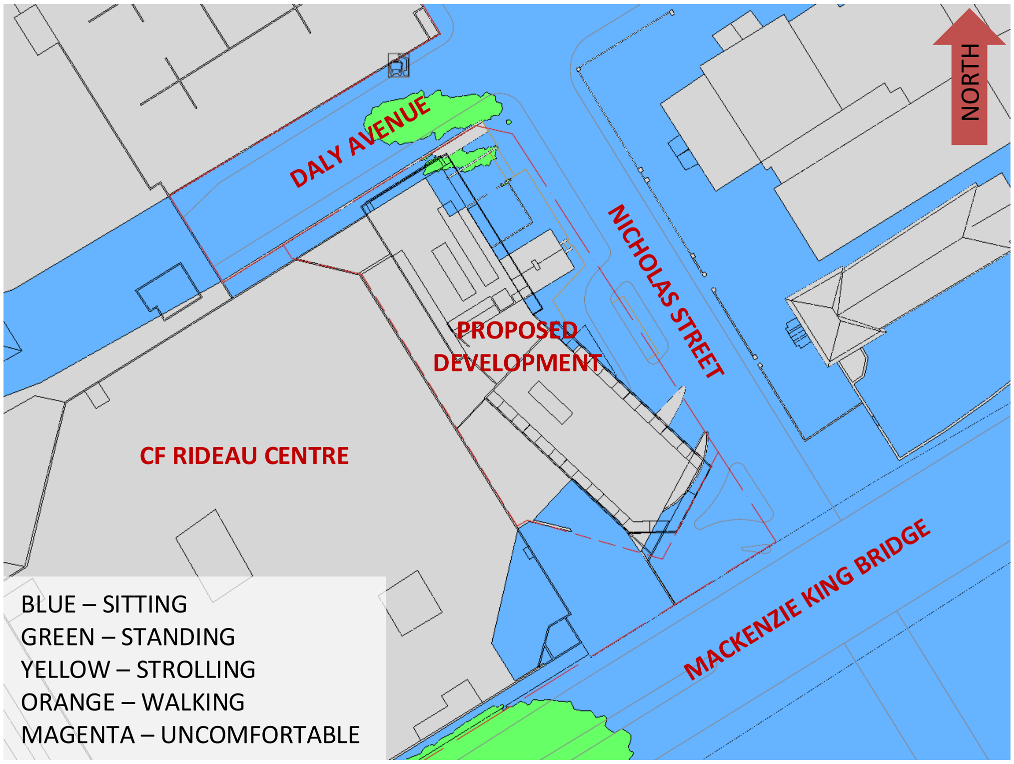


FIGURE 4A: SUMMER – PROPOSED MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

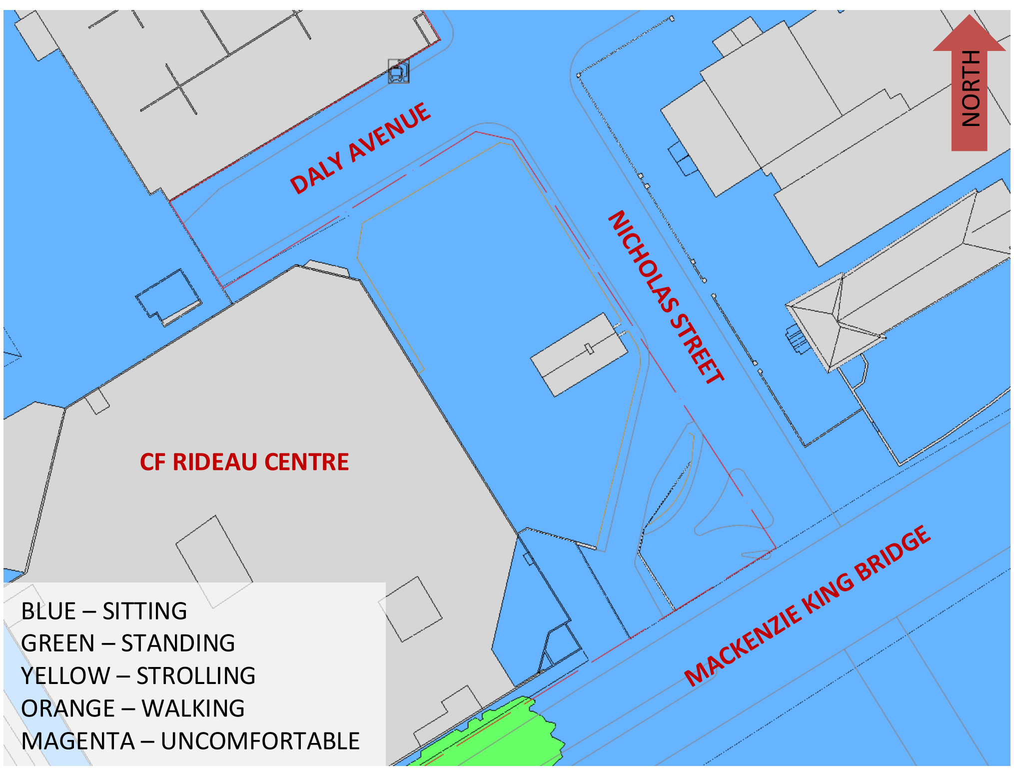


FIGURE 4B: SUMMER – EXISTING MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

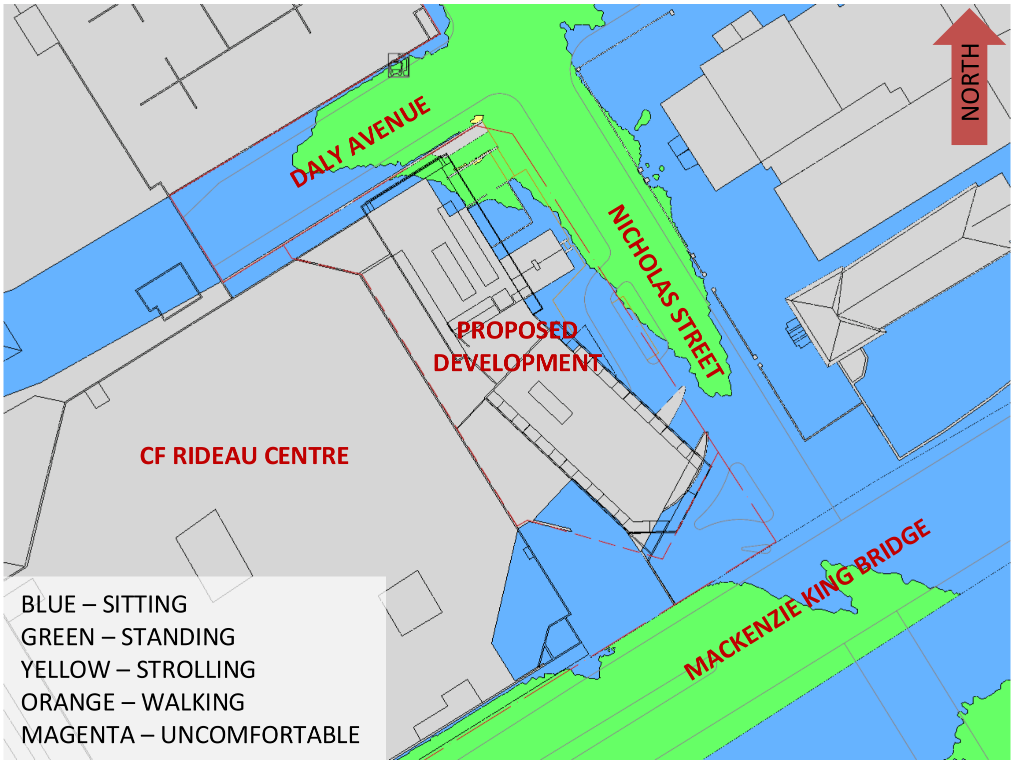


FIGURE 5A: AUTUMN – PROPOSED MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

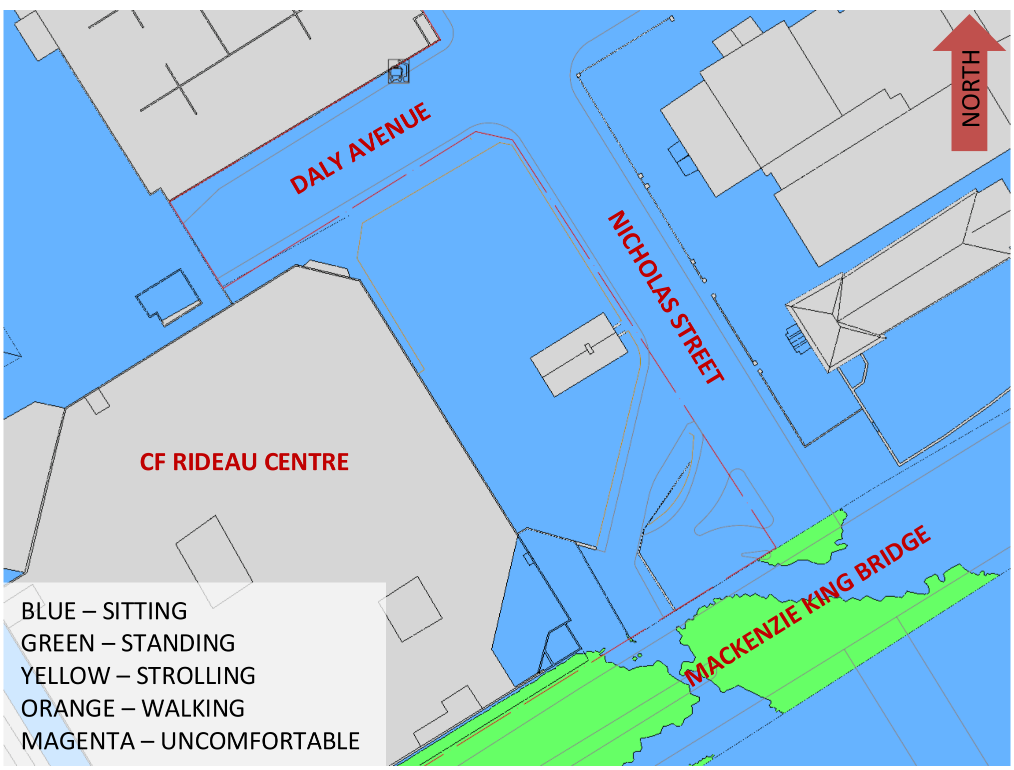


FIGURE 5B: AUTUMN – EXISTING MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

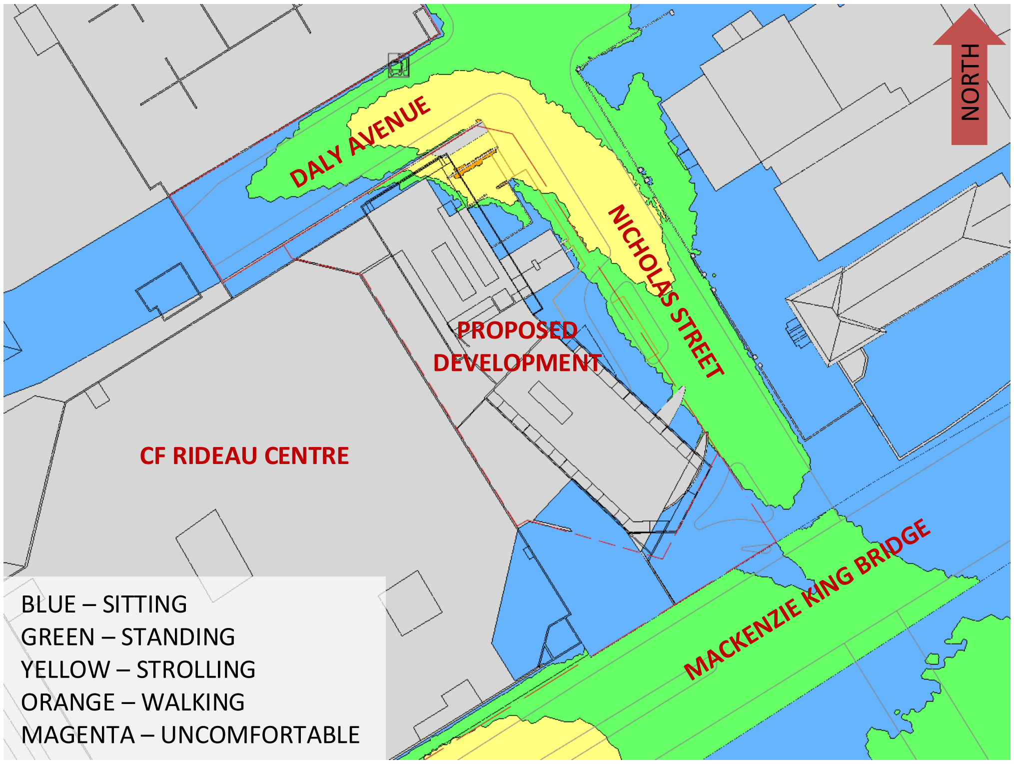


FIGURE 6A: WINTER – PROPOSED MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

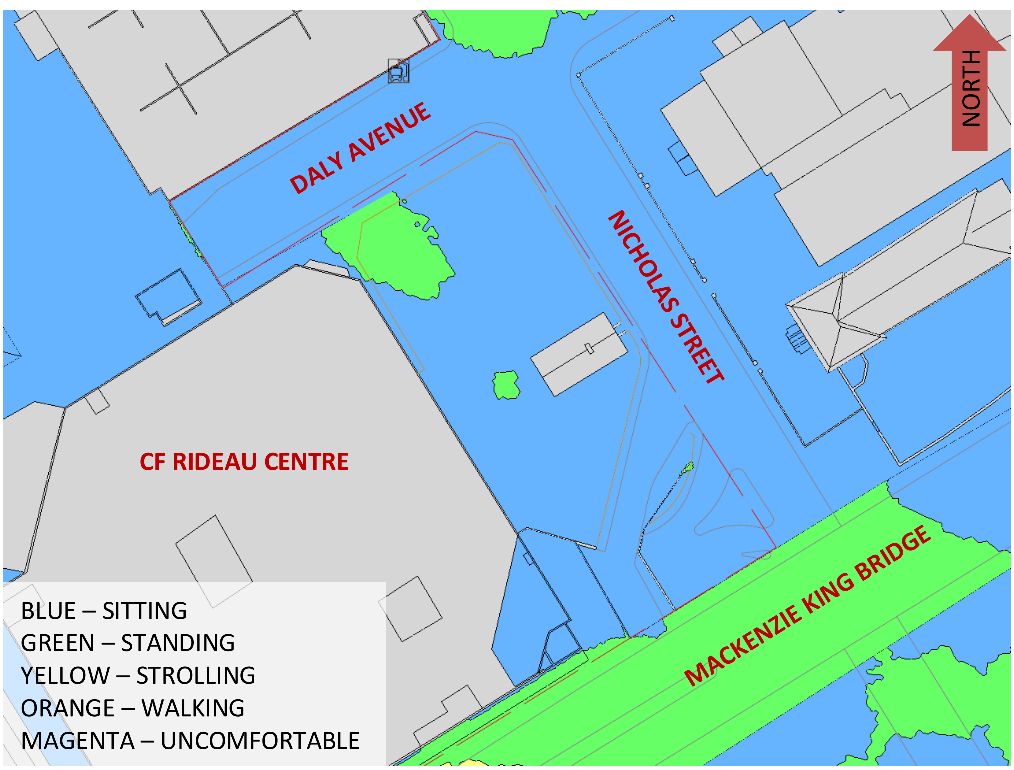


FIGURE 6B: WINTER – EXISTING MASSING– WIND COMFORT CONDITIONS, GRADE LEVEL

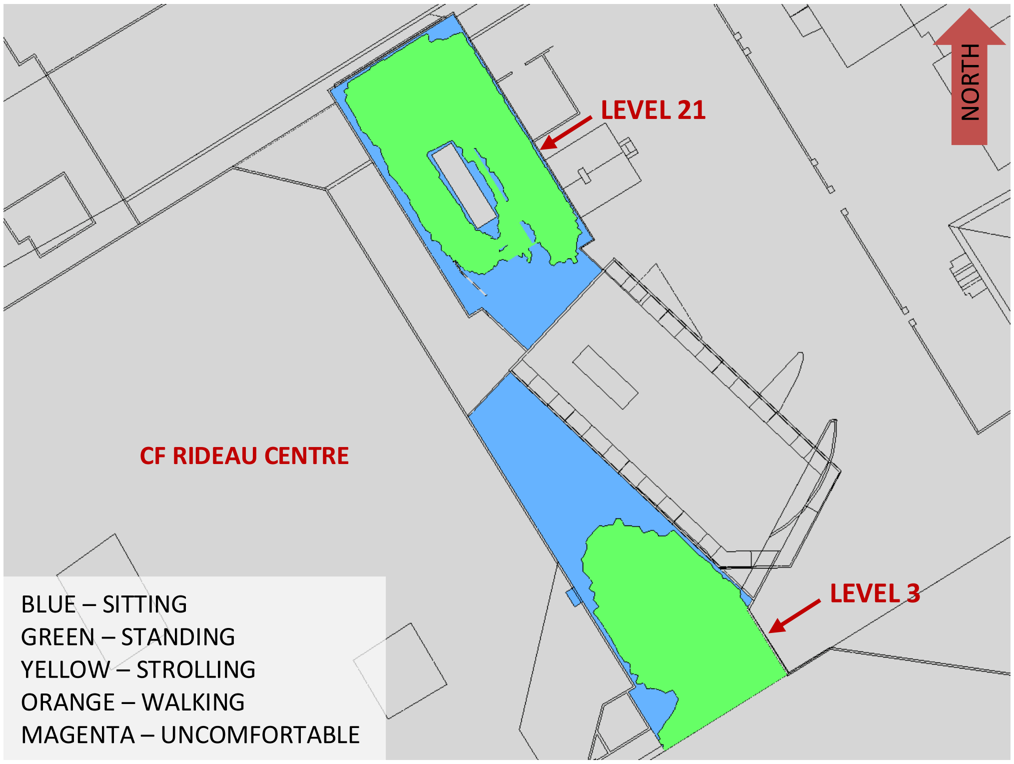


FIGURE 7A: SPRING – WIND COMFORT, AMENITY TERRACES

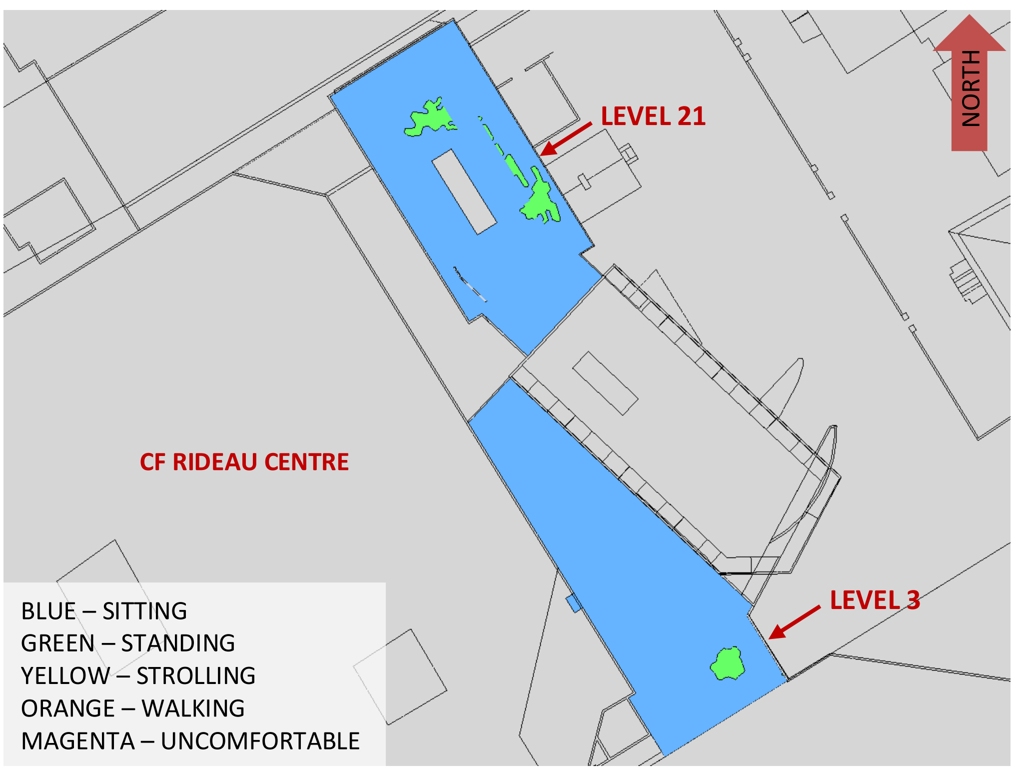


FIGURE 7B: SUMMER – WIND COMFORT, AMENITY TERRACES

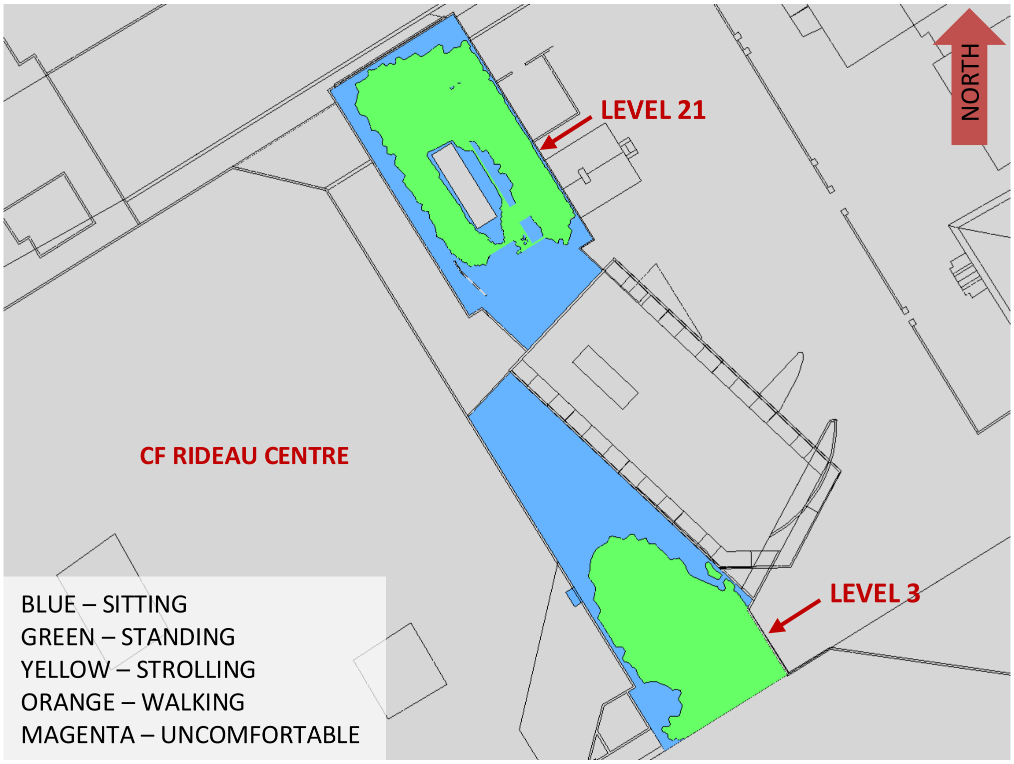


FIGURE 7C: AUTUMN – WIND COMFORT, AMENITY TERRACES

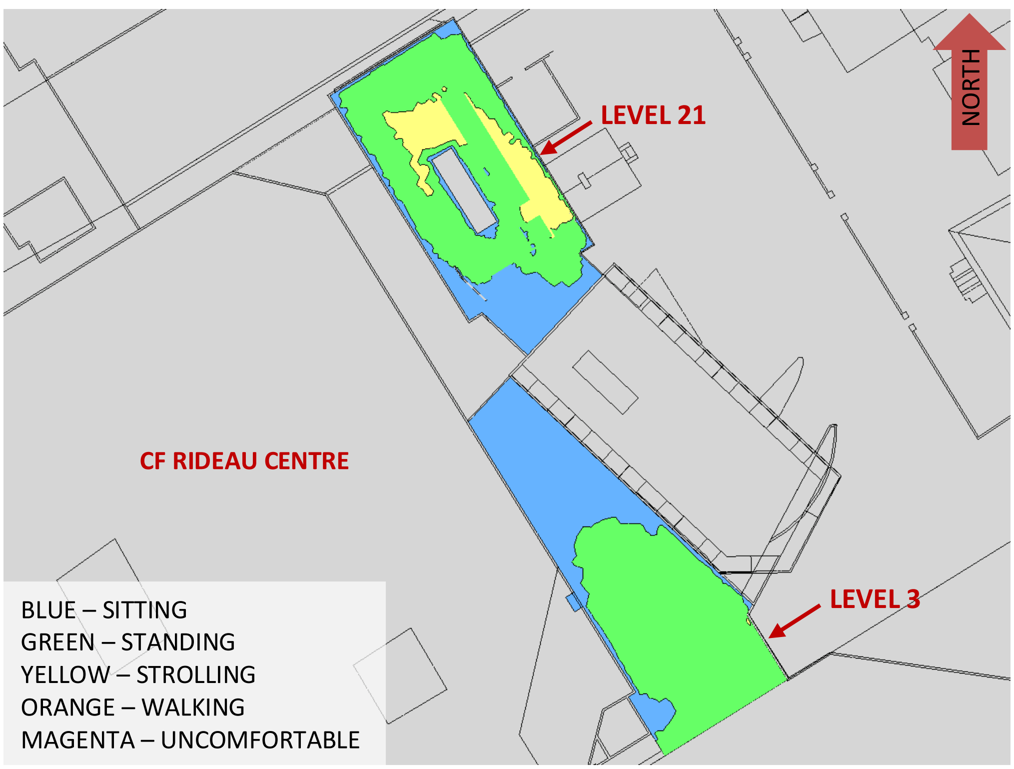


FIGURE 7D: WINTER – WIND COMFORT, AMENITY TERRACES

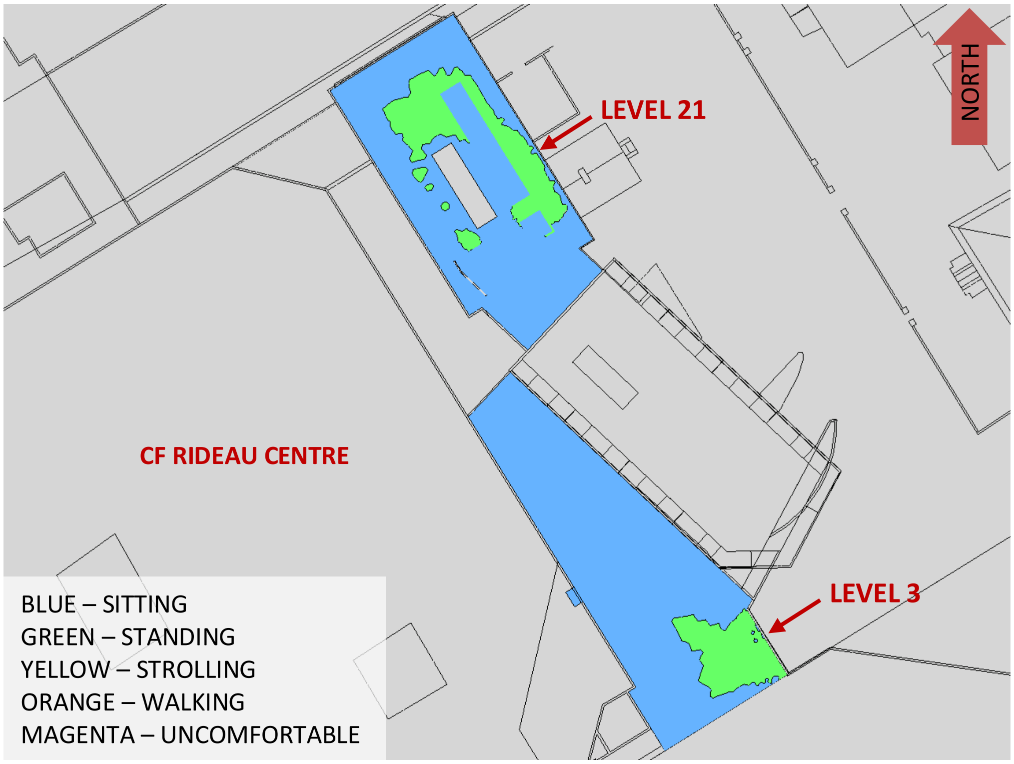


FIGURE 8A: TYPICAL USE PERIOD – WIND COMFORT, AMENITY TERRACES

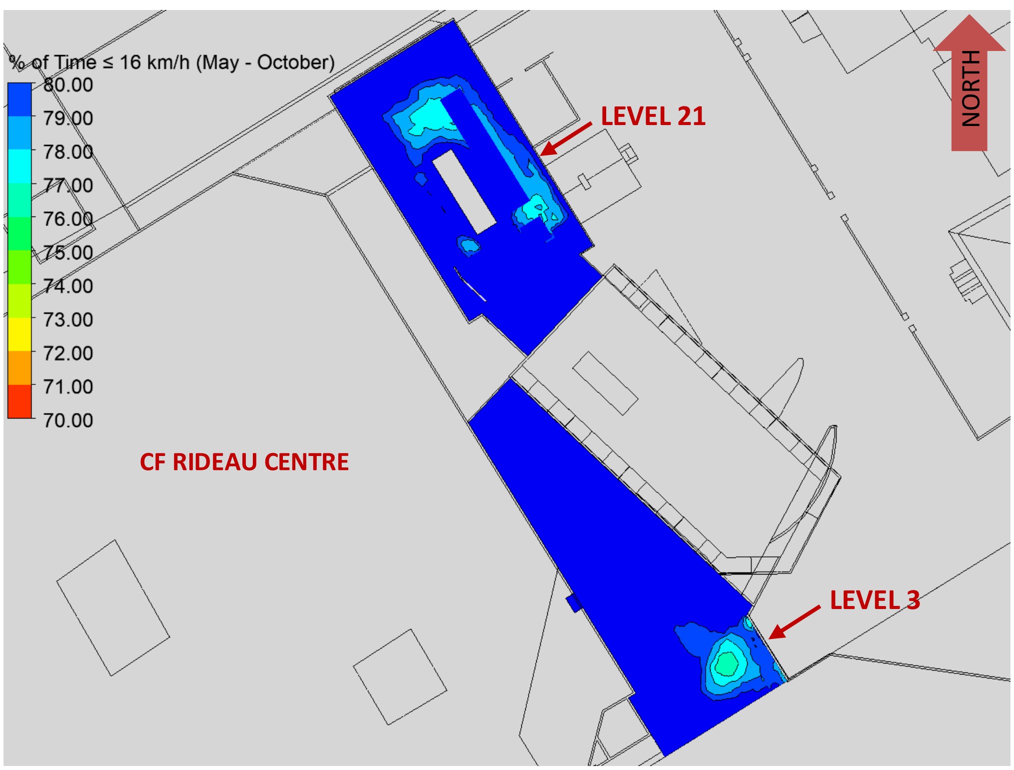
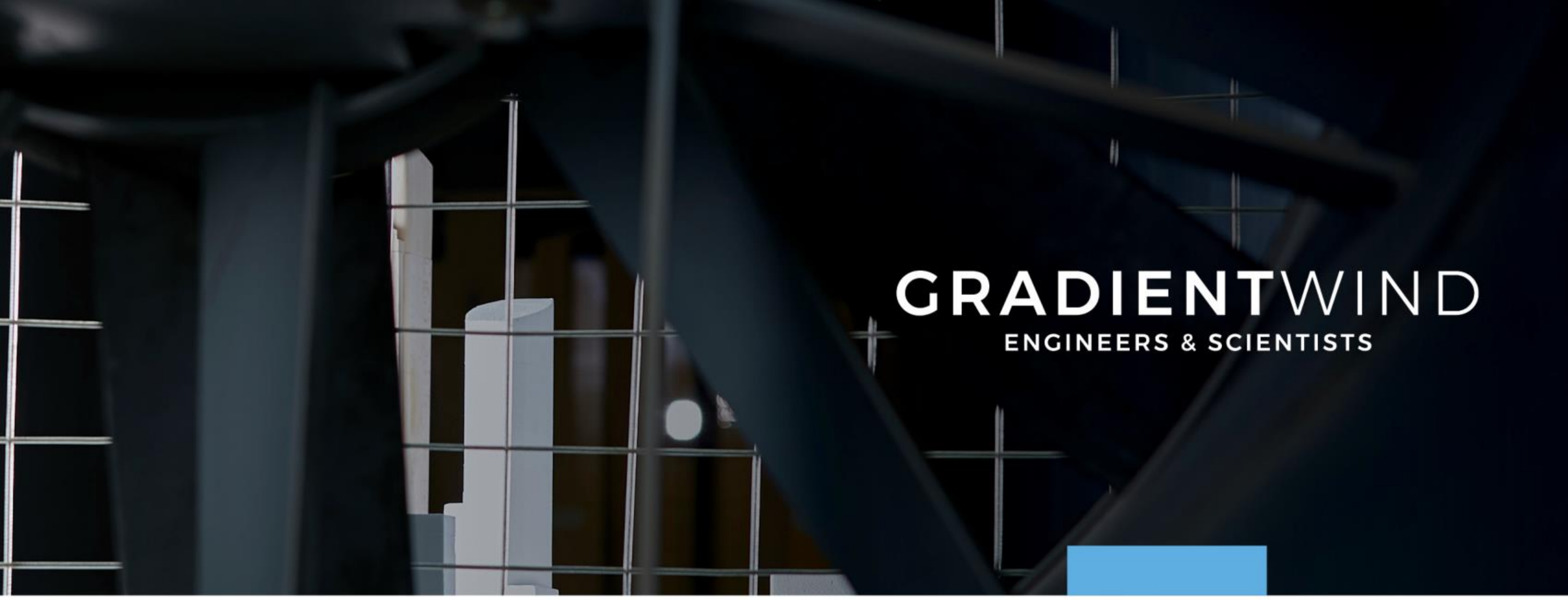
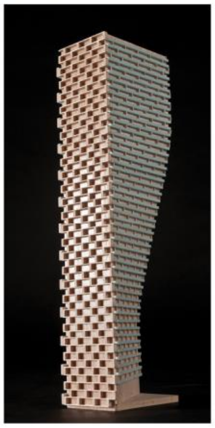
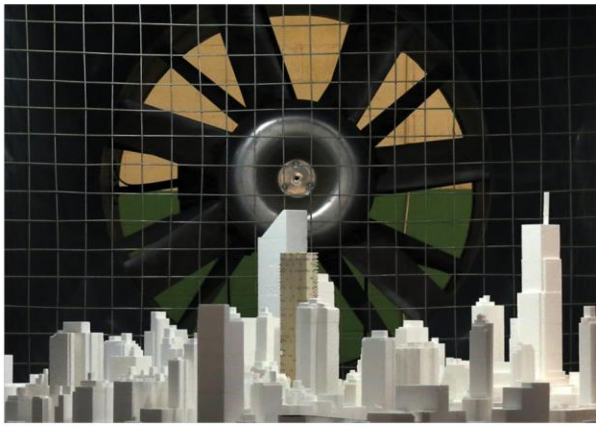


FIGURE 8B: TYPICAL USE PERIOD – % OF TIME SUITABLE FOR SITTING, AMENITY TERRACES







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 Ottawa based on historical climate data and statistical analyses. When the results are normalized by this velocity, they are relatively insensitive to the selection of gradient wind speed.

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

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

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

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

Wind Direction (Degrees True)	Alpha Value (α)
0	0.22
22.5	0.23
45	0.25
67.5	0.25
90	0.25
112.5	0.24
135	0.23
157.5	0.25
180	0.27
202.5	0.29
225	0.31
247.5	0.29
270	0.22
292.5	0.23
315	0.21
337.5	0.21

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).

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

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

where, ***I*** = turbulence intensity, $\boldsymbol{L_t}$ = 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

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[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 Engieering Symposium, IWES 2003*, Taiwan, 2003.