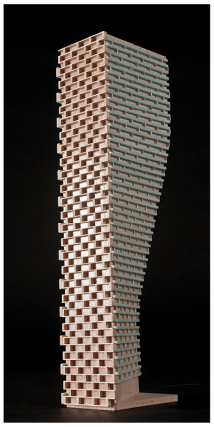
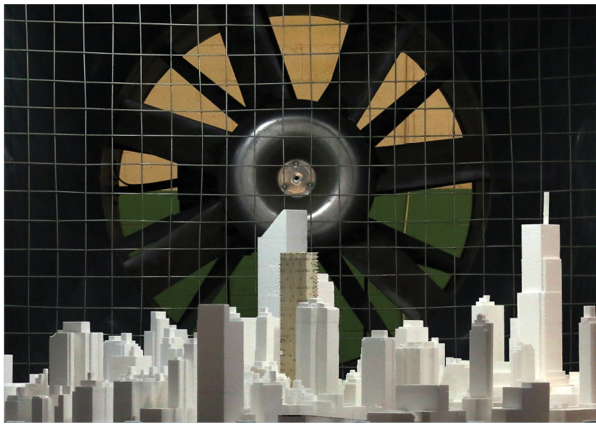
GRADIENTWIND
ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

2032-2050 Robie Street
Halifax, Nova Scotia

Report: 20-100-WTPLW





June 8, 2020

PREPARED FOR
Westwood Construction
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EXECUTIVE SUMMARY

This report describes a comparative pedestrian level wind (PLW) study undertaken to assess wind conditions for a proposed 21-storey residential development located at 2032-2050 Robie Street in Halifax, Nova Scotia (hereinafter referred to as "subject site" or "proposed development"). Two configurations were studied: (i) existing conditions, including all approved, surrounding developments and without the subject site; and (ii) future conditions with the subject site in place. The study involves wind tunnel measurements of pedestrian wind speeds using a physical scale model, combined with meteorological data integration, to assess pedestrian comfort and safety at key areas within and surrounding the subject site. Grade-level areas investigated include sidewalks, private yards, parking areas, landscaped spaces, parks, transit stops, and building access points. Wind conditions are also evaluated over the Level 3 outdoor amenity terrace serving the subject site. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report.

A complete summary of the predicted future and existing wind conditions is provided in Section 5.2 of this report, illustrated in Figures 2A-3B, and presented numerically in Tables A1 and A2 and B1-B3 in the appendices. Based on wind tunnel test results, meteorological data analysis of the Halifax wind climate, and City of Halifax wind comfort and safety criteria, architectural drawings provided by Architecture49 Inc. in April 2020, surrounding street layouts, as well as existing and approved future building massing information obtained from the City of Halifax, and recent site imagery, we conclude that the future wind conditions over all grade-level pedestrian wind-sensitive areas within and surrounding the subject site will be acceptable for the intended uses on a seasonal basis. Additionally, the Level 3 outdoor amenity terrace is predicted to be suitable and acceptable for sitting or more sedentary activities during the summer season, without the need for mitigation.

A comparison of the existing versus future wind comfort conditions surrounding the subject site indicates that the proposed development will have a generally neutral influence on grade-level wind conditions, with a few minor exceptions. Halifax Common and the sidewalk areas to the east of the subject site are predicted to be somewhat calmer upon the introduction of the proposed development, while portions of the landscaped spaces, sidewalk areas, and parking spaces to the north of the subject site are predicted to be somewhat windier; conditions nevertheless remain acceptable for the intended uses.

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

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.

TABLE OF CONTENTS

1. INTRODUCTION

This report describes a comparative pedestrian level wind (PLW) study undertaken to assess wind conditions for a proposed residential development located at 2032-2050 Robie Street in Halifax, Nova Scotia (hereinafter referred to as "subject site" or "proposed development"). Two configurations were studied: (i) existing conditions, including all approved, surrounding developments and without the subject site; and (ii) future conditions with the subject site in place. The study was performed in accordance with industry standard wind tunnel testing techniques, City of Halifax wind comfort and safety criteria, architectural drawings provided by Architecture49 Inc in April 2020, surrounding street layouts and existing and approved future building massing information, as well as recent site imagery.

2. TERMS OF REFERENCE

The subject site is located at 2032-2050 Robie Street in Halifax, Nova Scotia; situated to the north of Robie Street and Quinpool Road. The proposed development comprises a 21-storey residential building, plus mechanical penthouse, rising from the north side of a 2-storey podium. Above two levels of below-grade parking, accessed from Robie Street via a ramp at the north side of the development, a residential lobby is situated at the north side of the building fronting Robie Street. At Level 2 the building steps out from all elevations cantilevering over grade. At Level 3 the podium steps back from the south elevation to the base of the building accommodating a large rooftop amenity space. The remaining building floorplans comprise residential occupancy. At Level 20 the floorplate steps back from the east and west sides creating additional private terrace spaces, and above Level 21 the building steps back from all elevations to the mechanical penthouse, reaching a maximum height of approximately 85 metres (m), or 278 feet.

Regarding wind exposures, the near- and far-field surroundings of the subject site mostly comprise low-rise residential dwellings interspersed with mid-rise buildings to the north. This continues clockwise to east, with the Atlantic Ocean bordering the northeast/east perimeter. Low- to mid-rise residential buildings and low-rise commercial buildings are situated to the east. A mixture of several building types continues clockwise to south, defining downtown Halifax. The south comprises low-rise residential buildings continuing clockwise for all remaining directions, with a cluster of low- and mid-rise buildings immediately west. An additional cluster of mid-rise buildings also exists in the far-field density to the southwest, approximately 1 kilometer (km) from the subject site. The Atlantic Ocean also borders the south/southwest far-field.

Grade-level areas investigated include sidewalks, private yards, parking areas, landscaped spaces, parks, transit stops, and building access points. Wind conditions are also evaluated over the Level 3 outdoor amenity terrace serving the subject site. Figure 1 illustrates the subject site and surrounding context, while Photographs 1-6 depict the wind tunnel models used to conduct the comparative PLW study.

3. OBJECTIVES

The principal objectives of this study are to (i) determine 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; (iii) recommend suitable mitigation measures, where required; and (iv) evaluate the influence of the proposed development and of surrounding approved future developments, on the existing wind conditions.

4. METHODOLOGY

The approach followed to quantify pedestrian wind conditions over the subject site is based on wind tunnel measurements of wind speeds at select locations on a reduced-scale physical model, meteorological analysis of the Halifax area wind climate, synthesis of wind tunnel data with City of Halifax wind comfort and safety criteria[1], as well as industry-accepted guidelines. The following sections describe the analysis procedures, including a discussion of the noted wind comfort and safety criteria.

4.1 Wind Tunnel Context Modelling

A detailed comparative PLW study is performed to determine the influence of local winds at the pedestrian level for the proposed development. The physical model of the subject site and relevant surroundings, illustrated in Photographs 1-6 following the main text, was constructed at a scale of 1:400. The wind tunnel model includes all existing buildings and approved future developments within a full-scale diameter of approximately 840 m. The general concept and approach to wind tunnel modelling is to provide building and topographic detail in the immediate vicinity of the subject site on the surrounding

[1] City of Halifax. "Halifax Regional Centre Land Use By-law (Package A)", November 30, 2019. PDF file.

model, and to rely on a length of wind tunnel upwind of the model to develop wind properties consistent with known turbulent intensity profiles that represent the surrounding terrain.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the wind tunnel 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.

4.2 Wind Speed Measurements

The PLW study was performed by testing a total of 47 sensor locations on the scale model of the subject site in Gradient Wind's physical wind tunnel. Of these 47 sensors, 44 were located at grade and the remaining three sensors were located on the Level 3 amenity terrace. Wind speed measurements were performed for each of the 47 sensors for 36 wind directions at 10° intervals. Figure 1 illustrates a plan of the subject site and relevant surrounding context, while sensor locations used to investigate wind conditions are illustrated in Figures 2A-3B (following the main text).

Mean and peak wind speed values for each location and wind direction were calculated from real-time pressure measurements, recorded at a sample rate of 500 samples per second, and taken over a 60-second time period. This period at model-scale corresponds approximately to one hour in full-scale, which matches the time frame of full-scale meteorological observations. Measured mean and gust wind speeds at grade were referenced to the wind speed measured near the ceiling of the wind tunnel to generate mean and peak wind speed ratios. Ceiling height in the wind tunnel represents the depth of the boundary layer of wind flowing over the earth's surface, referred to as the gradient height. Within this boundary layer, mean wind speed increases up to the gradient height and remains constant thereafter.

Appendices C and D provide greater detail of the theory behind wind speed measurements. Wind tunnel measurements for this project meet or exceed guidelines found in the National Building Code of Canada 2015 and of 'Wind Tunnel Studies of Buildings and Structures', ASCE Manual and Reports on Engineering Practice No 67.

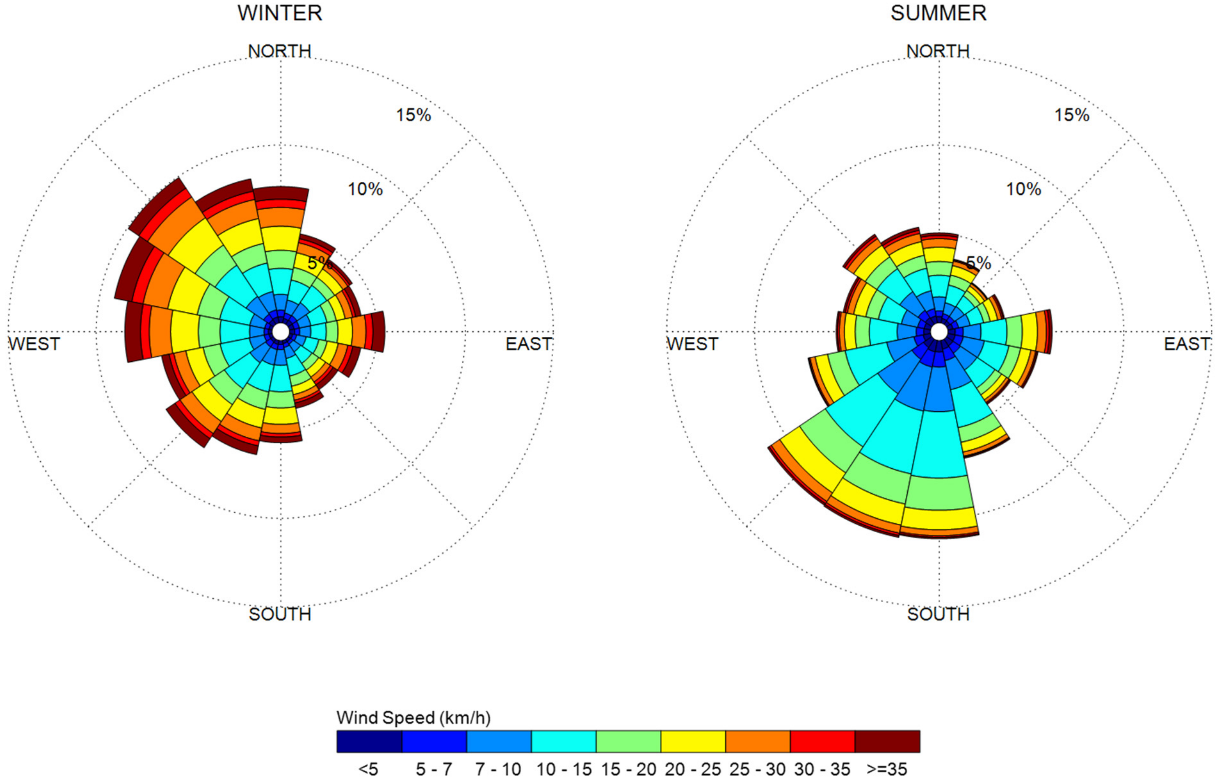
4.3 Meteorological Data Analysis – CFB Shearwater Airport

A statistical model for winds in Halifax was developed from 38-years (1982-2019) of hourly meteorological wind data recorded at CFB Shearwater 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. Per the Halifax Regional Centre Land Use By-Law, the summer season is defined as May-October, while the winter season is defined as November-April.

The statistical model of CFB Shearwater Airport, which indicates the directional character of local winds during the summer and winter seasons, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometres 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 Halifax, the most common winds concerning pedestrian wind comfort occur from the southwest clockwise to north, as well as those from the east. Southerly winds are common during the summer season, while westerly and northerly winds are common during the winter season.

The directional preference and relative magnitude of wind speed varies somewhat from season to season, with the summer months displaying the calmest winds relative to the winter season.

DISTRIBUTION OF WIND
CFB SHEARWATER AIRPORT, SHEARWATER, NOVA SCOTIA



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 Halifax

Pedestrian comfort and safety criteria are based on the Halifax Regional Centre Land Use By-law, and on mechanical wind effects without consideration of other meteorological conditions (i.e., temperature and relative humidity). The criteria provide an assessment of comfort, assuming pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes and corresponding gust wind speed ranges are used to assess comfort levels, which include: (i) sitting, (ii) standing, (iii) strolling, (iv) walking, and (v) uncomfortable.

The comfort classes, associated wind speed ranges and limiting criteria are summarized as follows:

(i) **Sitting** – Wind speeds below 10 km/h (i.e., 0 – 10 km/h) that occur more than 80% of the time would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – Wind speeds below 14 km/h (i.e., 0 – 14 km/h) that occur more than 80% of the time are acceptable for activities such as standing, strolling or more vigorous activities.

(iii) **Strolling** – Wind speeds below 17 km/h (i.e., 0 – 17 km/h) that occur more than 80% of the time are acceptable for activities such as standing, strolling or more vigorous activities.

(iv) **Walking** – Wind speeds below 20 km/h (i.e., 0 – 20 km/h) occurring more than 80% of the time are acceptable for walking or more vigorous activities.

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

Regarding safety, wind speeds greater than 90 km/h, occurring more than 0.1% of the time, 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 wind speeds associated with the noted comfort and safety categories are referred to as Gust Equivalent Mean (GEM) wind speeds. The GEM wind speed is defined as the maximum of the mean wind speed and the gust wind speed divided by 1.85. For the noted safety criterion, the gust wind speed is considered. The gust 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.

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
9	Strong Gale	112-132	Slight structural damage occurs, e.g. roofing shingles may become loose
10	Storm	133-153	Trees uprooted; considerable structural damage occurs

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 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 or more sedentary activities. Similarly, if 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 most of 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 at tested locations, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type. An overview of common pedestrian location types and their desired comfort classes is summarized on the following page.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired Comfort Classes
Primary Building Entrance	Standing
Secondary Building Access Point	Standing / Walking
Primary Public Sidewalks / Walkways	Strolling / Walking
Secondary Public Sidewalks / Walkways	Walking
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens / Plazas	Sitting / Standing / Strolling
Transit Stops	Sitting / Standing
Public Parks	Sitting / Standing / Strolling
Garage / Service Entrances	Walking
Vehicular Drop-Off Zones	Standing / Strolling
Laneways / Loading Zones	Strolling / Walking

5. RESULTS AND DISCUSSION

5.1 Pedestrian Comfort Suitability – Future Conditions

Tables A1 and A2 in Appendix A provide a summary of wind comfort and safety predictions for each sensor location under the future massing scenario considering the proposed development and all existing and approved surrounding developments. The tables indicate the 80% non-exceedance gust wind speeds and corresponding comfort classifications, as defined in Section 4.4. In other words, a GEM wind speed threshold of 12.1 for the summer season indicates that 80% of the measured data falls at or below 12.1 km/h during the summer season and conditions are therefore suitable for standing, as the 80% threshold value falls within the range of 10-14 km/h for standing.

The tables include the predicted threshold values for each sensor location during each season, accompanied by the corresponding predicted comfort class (i.e., sitting, standing, strolling, walking, etc.)

The most significant findings of the PLW study are summarized in Section 5.2 below. To assist with understanding and interpretation, predicted conditions for the proposed development are also illustrated in colour-coded format in Figures 2A and 3A. Conditions suitable for sitting are represented by the colour green, standing by yellow, strolling by orange, and walking by blue. Conditions considered uncomfortable for walking are represented by the colour magenta. Measured mean and gust velocity ratios, which constitutes the raw data upon which the results are based, will be made available upon request.

5.2 Summary of Findings – Future Conditions

Based on the analysis of the measured data, consideration of local climate data, City of Halifax wind comfort and safety criteria, and the suitability descriptors provided in Tables A1 & A2 in Appendix A, this section summarizes the most significant findings of the PLW study with respect to future conditions, as follows:

1. All surrounding public sidewalk areas along Robie Street and Quinpool Road will experience wind conditions suitable for strolling or better during the summer season, and for walking or better during the winter season, which are acceptable for the intended uses of the spaces.
2. All private yards and parking areas along the west side of the proposed development will be suitable for standing or better during the summer season, and for strolling or better during the winter season, which are considered appropriate.
3. Pedestrian comfort in the immediate vicinity of the transit stops along Robie Street, represented by sensors 9, 17, and 26, is predicted to be suitable for standing or better throughout the year, which is acceptable.
4. The western end of Halifax Common, a public park situated to the immediate east of Robie Street and represented by sensors 5-15, will generally be served by wind conditions comfortable for standing or better during the summer season, becoming suitable for strolling or better during the winter months. The noted conditions are considered acceptable.
5. The landscaped area to the immediate north of the subject site, represented by sensor 39, is predicted to be suitable for strolling during the summer season. During the winter season, conditions are expected to marginally exceed the walking criterion on a limited basis on account of prominent winds from the west-northwest and northwest, followed by those from the east, as well as from the south-southwest and southwest.

a. The existing conditions test indicates that the windy conditions during the winter season are pre-existing and only mildly exacerbated with the introduction of the proposed development. Given the limited basis and marginality of the exceedance, as well as the relative importance of the space to pedestrians during the colder months of the year, mitigation is not recommended.

6. The Level 3 outdoor amenity terrace, represented by sensors 45-47, will be comfortable for sitting or more sedentary activities during the summer season, without the need for mitigation. During the winter season, conditions are predicted to be suitable for standing. The noted conditions are considered acceptable.

7. Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas over the subject site were found to experience wind conditions that are considered dangerous.

5.3 Pedestrian Comfort Suitability – Existing vs Future Conditions

To evaluate the influence of the proposed development on existing wind conditions at and near the subject site, an additional PLW test was performed for the existing site massing (i.e., without the proposed development present). A comparison of wind comfort results for the existing and future massing configurations is provided in Figures 2A-3B and Tables B1-B3 in Appendix B, which provide a summary of the comparative wind comfort predictions based on annually-averaged wind statistics. Photographs of the two massing scenarios follow the main text.

Pedestrian wind comfort resulting from the construction of the proposed development and future surrounding developments may be described as being *unchanged*, *improved*, or *reduced* as compared to the existing conditions. These designations are not strictly determined by the predicted percentage values, rather by the change to the predicted comfort class, as defined in Section 4.4.

A review of Tables B1-B3 indicates that wind speeds at most grade-level areas will remain unchanged upon the introduction of the proposed development, with improvements predicted within Halifax Common and along sidewalk areas to the east of the subject site (sensors 5-7, 9, and 13). Although wind speeds marginally increase along portions of the landscaped spaces, sidewalk areas, and parking spaces to the north of the subject site (sensors 18, 19, 39, and 40), conditions nevertheless remain acceptable for the intended uses.

6. CONCLUSIONS AND RECOMMENDATIONS

A complete summary of the predicted future and existing wind conditions is provided in Section 5.2 of this report, illustrated in Figures 2A-3B, and presented numerically in Tables A1 and A2 and B1-B3 in the appendices. Based on wind tunnel test results, meteorological data analysis of the Halifax wind climate, and City of Halifax wind comfort and safety criteria, we conclude that the future wind conditions over all grade-level pedestrian wind-sensitive areas within and surrounding the subject site will be acceptable for the intended uses on a seasonal basis. Additionally, the Level 3 outdoor amenity terrace is predicted to be suitable and acceptable for sitting or more sedentary activities during the summer season, without the need for mitigation.

A comparison of the existing versus future wind comfort conditions surrounding the subject site indicates that the proposed development will have a generally neutral influence on grade-level wind conditions, with a few minor exceptions. Halifax Common and the sidewalk areas to the east of the subject site are predicted to be somewhat calmer upon the introduction of the proposed development, while portions of the landscaped spaces, sidewalk areas, and parking spaces to the north of the subject site are predicted to be somewhat windier; conditions nevertheless remain acceptable for the intended uses.

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

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.

This concludes our PLW study and report. Please advise the undersigned of any questions or comments.

Sincerely,

Gradient Wind Engineering Inc.

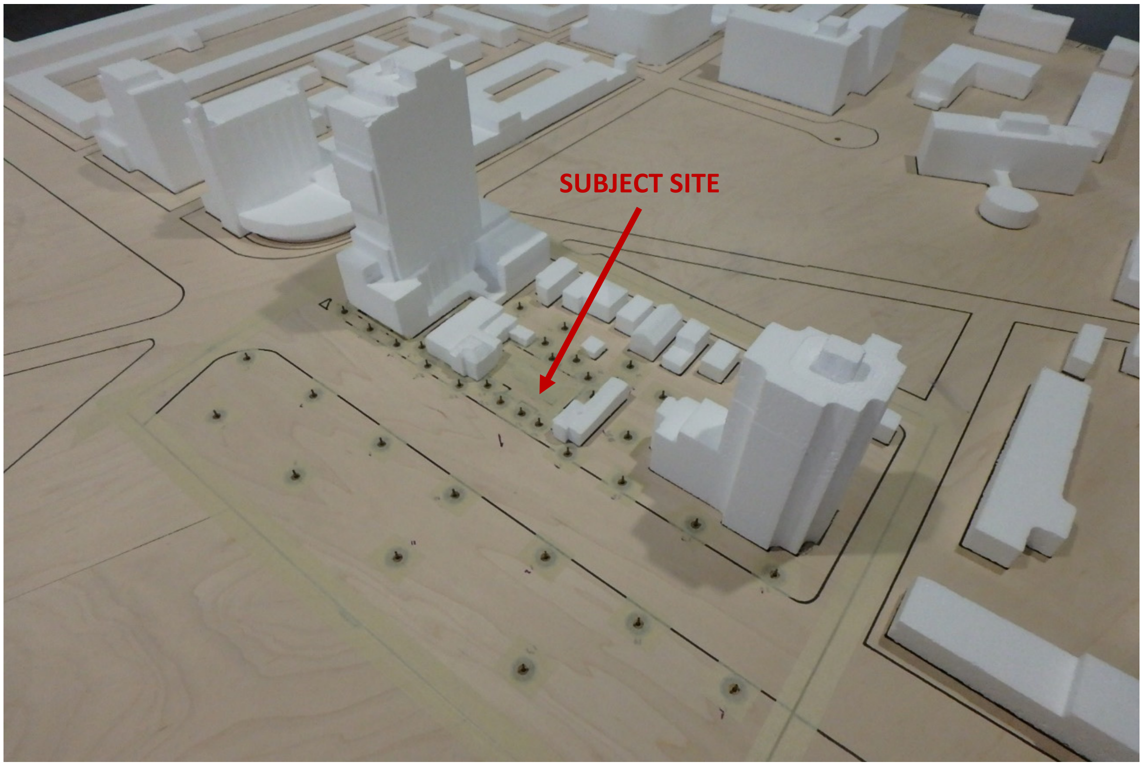
Original Signed

Original Signed

Nick Petersen, B.Eng., EIT
Junior Wind Scientist

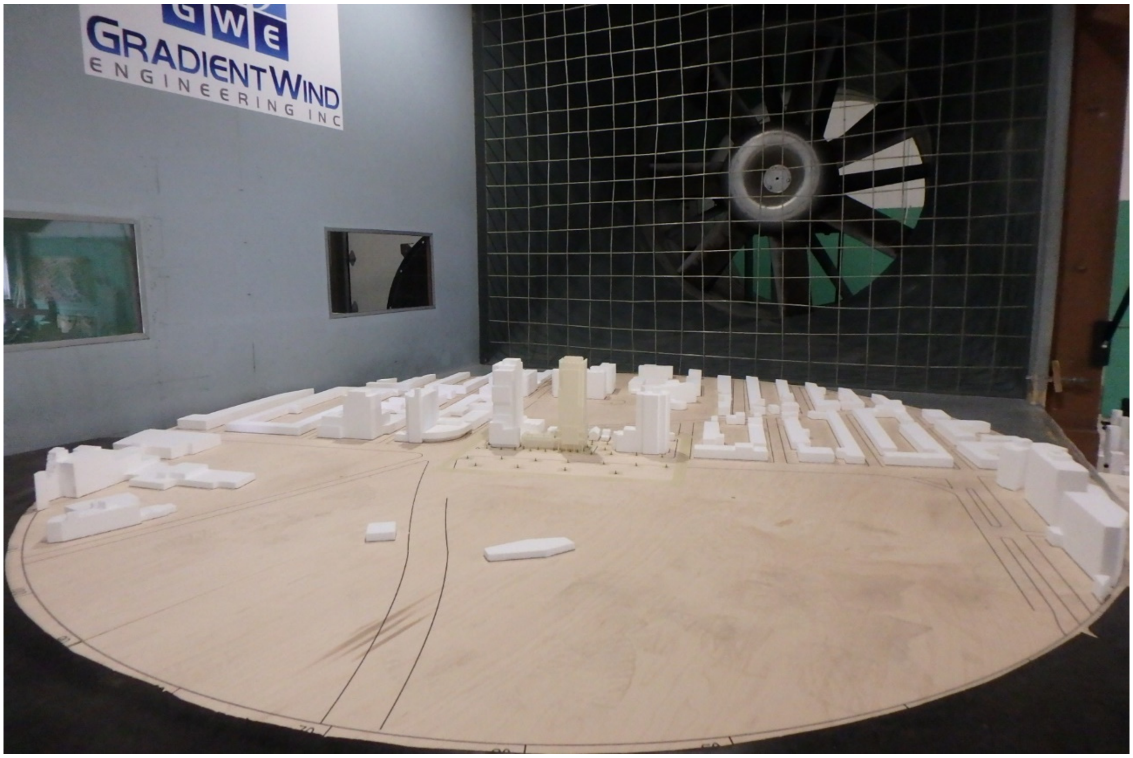
Justin Ferraro, P.Eng.
Principal

Gradient Wind File 20-100-WTPLW



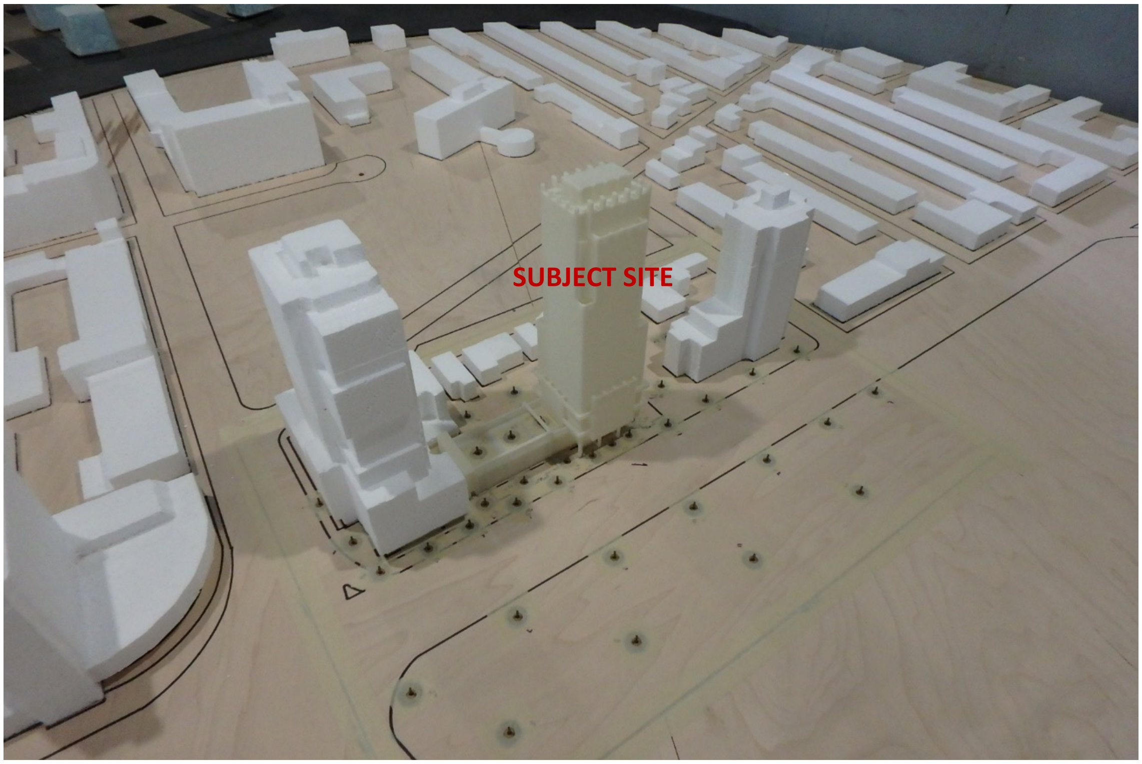
PHOTOGRAPH 1: CLOSE-UP VIEW OF CONTEXT MODEL, LOOKING SOUTHWEST – EXISTING

PHOTOGRAPH 2: CLOSE-UP VIEW OF CONTEXT MODEL, LOOKING NORTHEAST – EXISTING

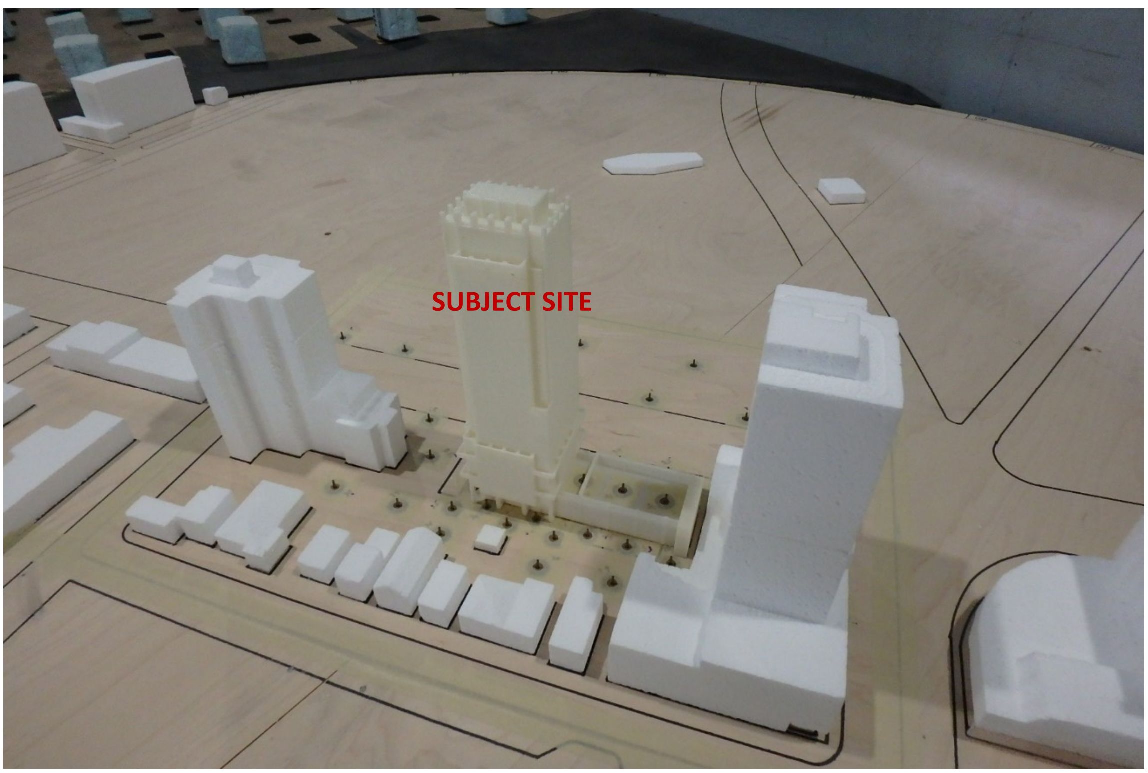


PHOTOGRAPH 3: WIND TUNNEL STUDY MODEL, LOOKING DOWNWIND – FUTURE

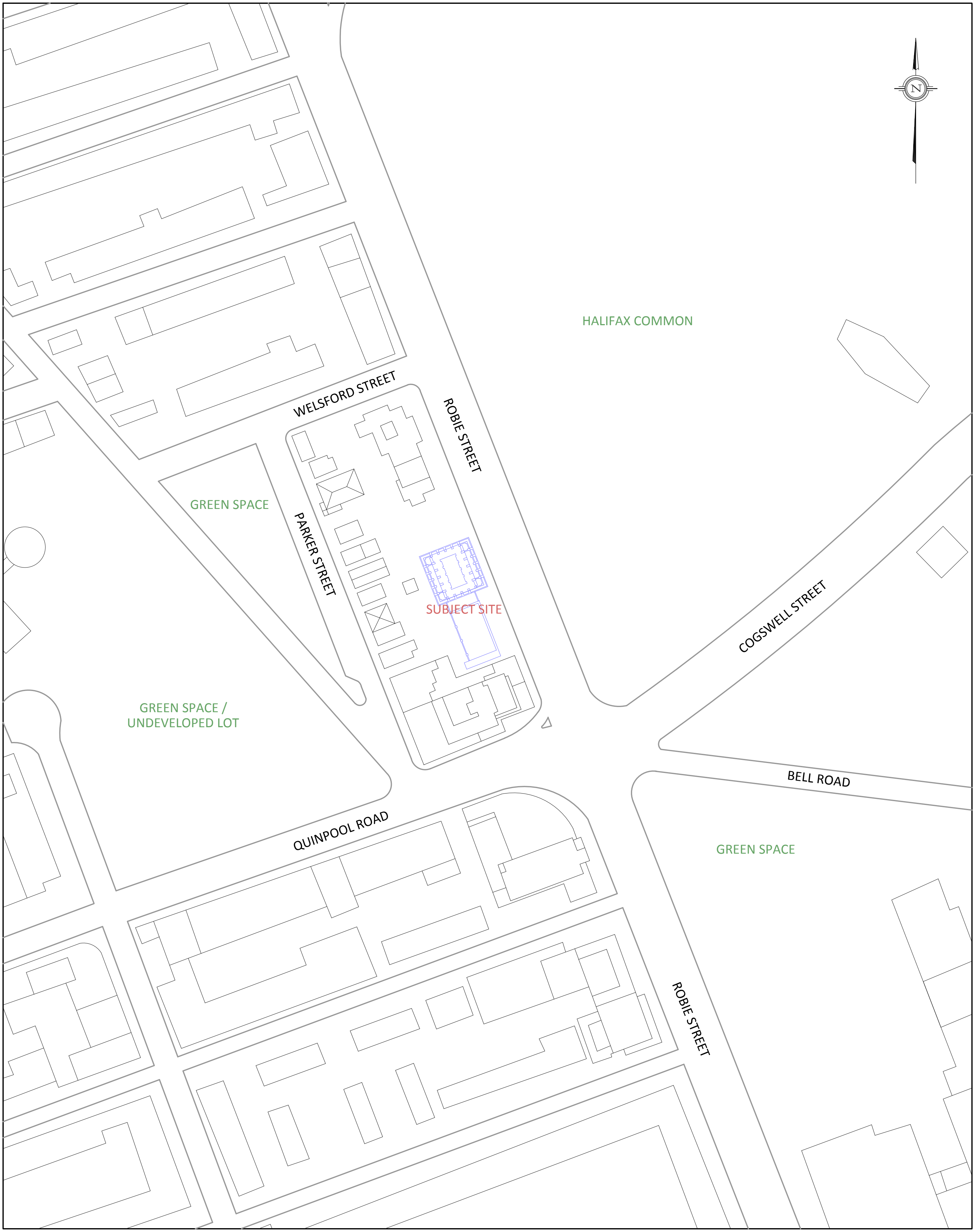
PHOTOGRAPH 4: WIND TUNNEL STUDY MODEL, LOOKING UPWIND – FUTURE



PHOTOGRAPH 5: CLOSE-UP VIEW OF STUDY MODEL, LOOKING NORTHWEST – FUTURE



PHOTOGRAPH 6: CLOSE-UP VIEW OF STUDY MODEL, LOOKING NORTHEAST – FUTURE



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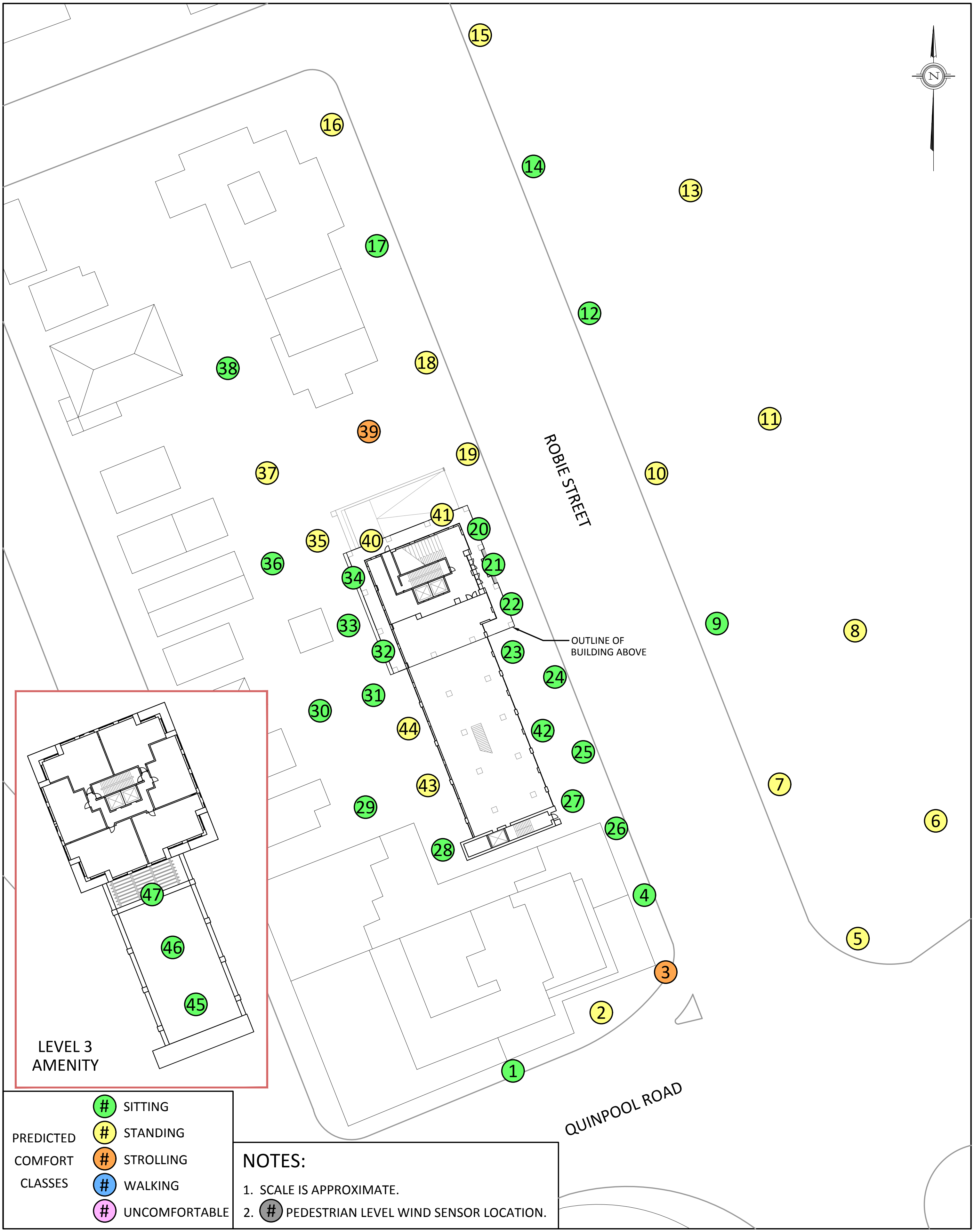
PROJECT		DESCRIPTION
2032-2050 ROBIE STREET, HALIFAX PEDESTRIAN LEVEL WIND STUDY		FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
SCALE 1:2500 (APPROX.)	DRAWING NO. 20-100-PLW-1	
DATE JUNE 8, 2020	DRAWN BY N.P.	



NOTES:

1. SCALE IS APPROXIMATE.
2. # PEDESTRIAN LEVEL WIND SENSOR LOCATION.

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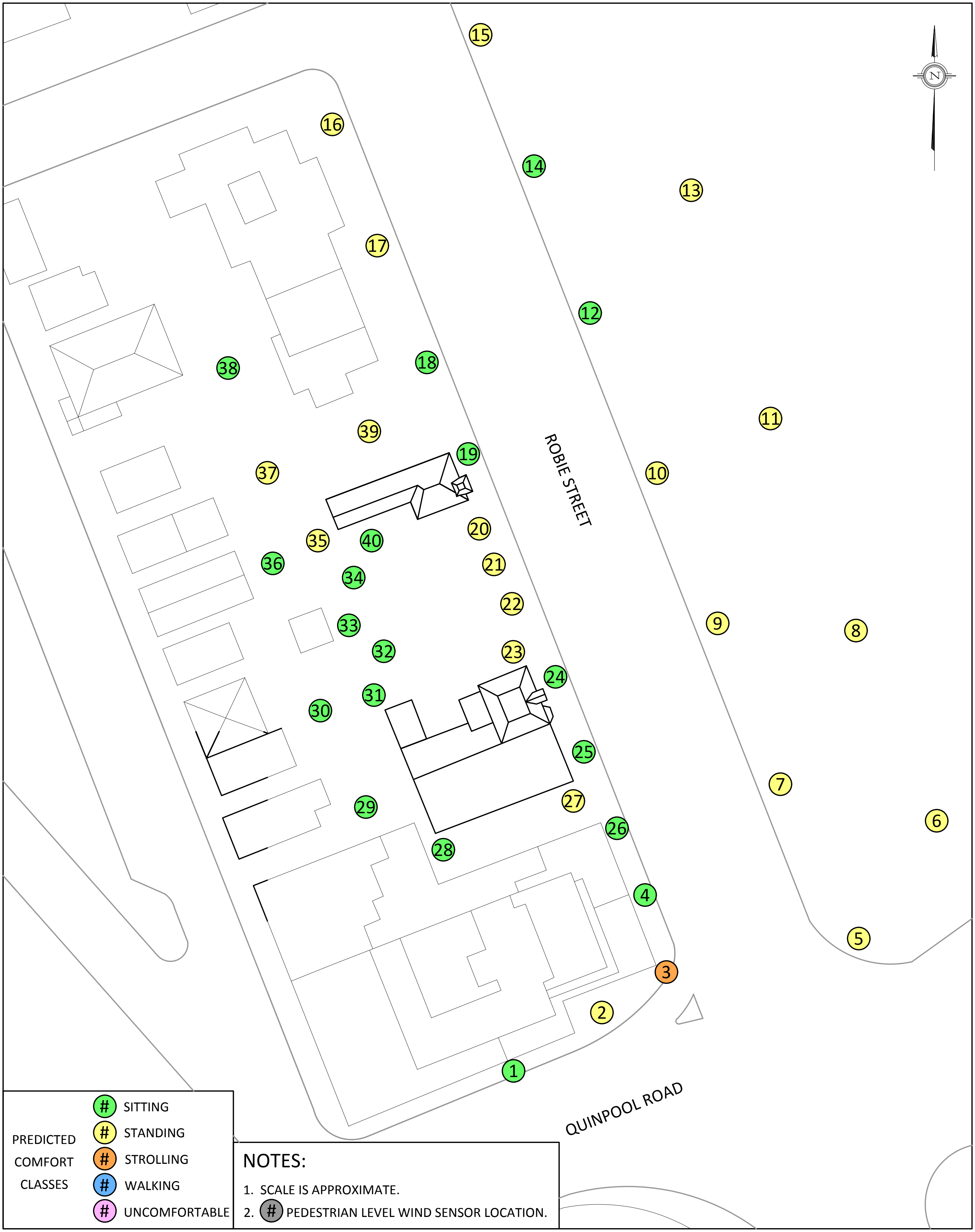
PROJECT	2032-2050 ROBIE STREET, HALIFAX PEDESTRIAN LEVEL WIND STUDY	
SCALE 1:900 (APPROX.)	DRAWING NO. 20-100-PLW-2A	
DATE JUNE 8, 2020	DRAWN BY N.P.	

DESCRIPTION

FIGURE 2A: SUMMER
GROUND FLOOR PLAN
FUTURE PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

- SITTING
- STANDING
- STROLLING
- WALKING
- UNCOMFORTABLE

NOTES:

1. SCALE IS APPROXIMATE.
2. # PEDESTRIAN LEVEL WIND SENSOR LOCATION.

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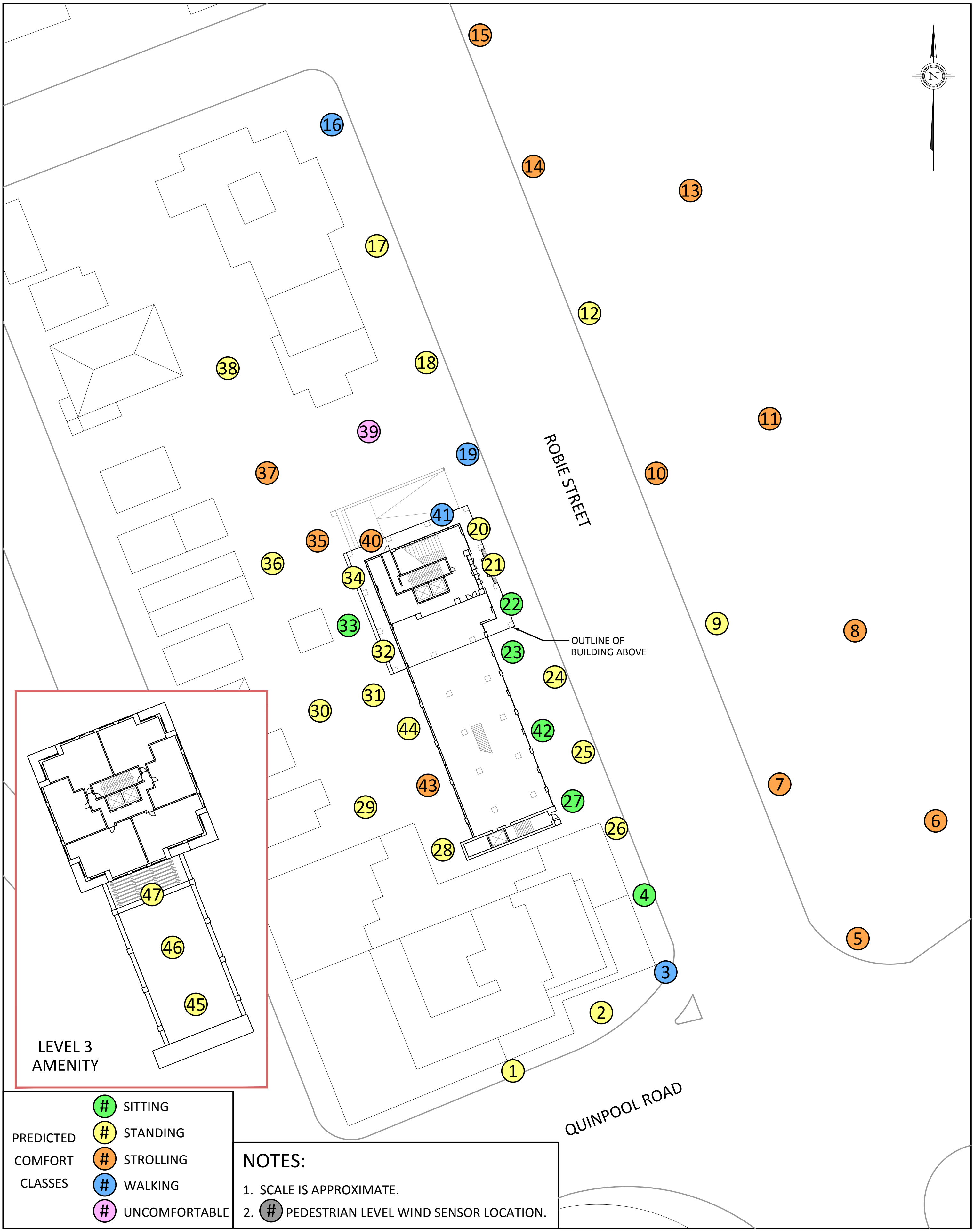
PROJECT	2032-2050 ROBIE STREET, HALIFAX PEDESTRIAN LEVEL WIND STUDY
SCALE	1:900 (APPROX.)
DRAWING NO.	20-100-PLW-2B
DATE	JUNE 8, 2020
DRAWN BY	N.P.
DESCRIPTION	FIGURE 2B: SUMMER GROUND FLOOR PLAN EXISTING PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

- # SITTING
- # STANDING
- # STROLLING
- # WALKING
- # UNCOMFORTABLE

NOTES:

1. SCALE IS APPROXIMATE.
2. # PEDESTRIAN LEVEL WIND SENSOR LOCATION.

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SCALE	1:900 (APPROX.)	DRAWING NO.	20-100-PLW-3A
DATE	JUNE 8, 2020	DRAWN BY	N.P.

DESCRIPTION

FIGURE 3A: WINTER
GROUND FLOOR PLAN
FUTURE PEDESTRIAN COMFORT PREDICTIONS

PREDICTED COMFORT CLASSES

- # SITTING
- # STANDING
- # STROLLING
- # WALKING
- # UNCOMFORTABLE

NOTES:

1. SCALE IS APPROXIMATE.
2. # PEDESTRIAN LEVEL WIND SENSOR LOCATION.

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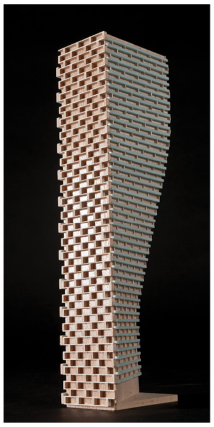
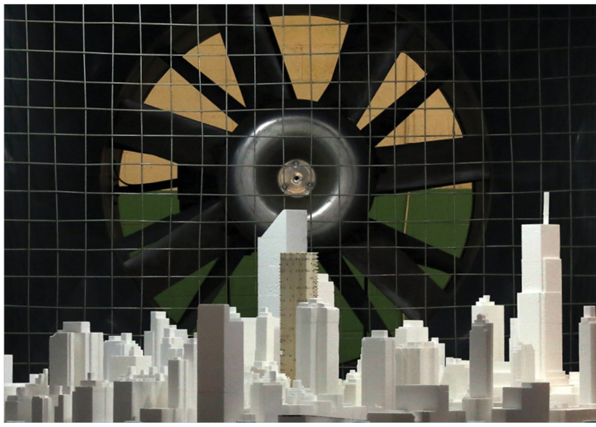
PROJECT		DESCRIPTION
2032-2050 ROBIE STREET, HALIFAX PEDESTRIAN LEVEL WIND STUDY		FIGURE 3B: WINTER GROUND FLOOR PLAN EXISTING PEDESTRIAN COMFORT PREDICTIONS
SCALE: 1:900 (APPROX.)	DRAWING NO.: 20-100-PLW-3B	
DATE: JUNE 8, 2020	DRAWN BY: N.P.	





APPENDIX A

PEDESTRIAN COMFORT SUITABILITY, TABLES A1 & A2
(FUTURE CONDITIONS)

Guidelines	
Pedestrian Comfort	**20% Exceedance Wind Speed** 0-10 km/h = Sitting; 10-14 km/h = Standing; 14-17 km/h = Strolling; 17-20 km/h = Walking; >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

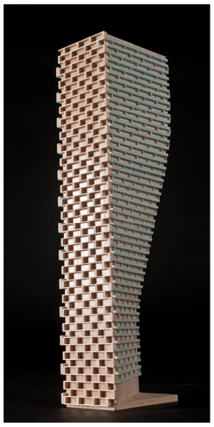
TABLE A1: SUMMARY OF PEDESTRIAN COMFORT AND SAFETY (FUTURE CONDITIONS)

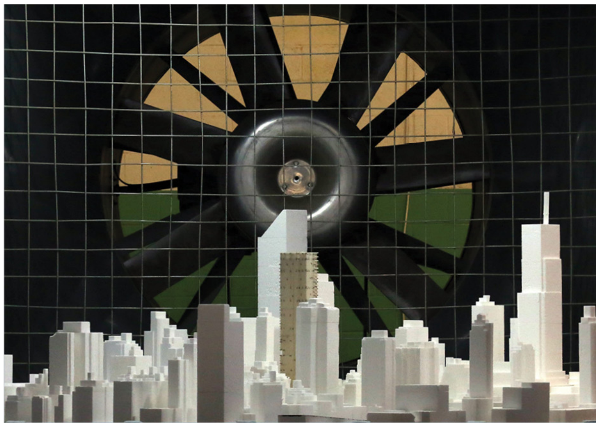
Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind peed	Safety Class
1	9.4	Sitting	12.8	Standing	52.7	Safe
2	10.6	Standing	12.8	Standing	58.3	Safe
3	14.2	Strolling	18.2	Walking	65.2	Safe
4	6.7	Sitting	9.9	Sitting	41.1	Safe
5	11.9	Standing	16.4	Strolling	54.4	Safe
6	11.7	Standing	15.8	Strolling	56.1	Safe
7	11.2	Standing	15.1	Strolling	54.8	Safe
8	10.8	Standing	15.3	Strolling	53.5	Safe
9	9.7	Sitting	14.0	Standing	52.5	Safe
10	10.1	Standing	15.6	Strolling	57.9	Safe
11	10.7	Standing	15.8	Strolling	52.6	Safe
12	9.1	Sitting	13.3	Standing	48.1	Safe
13	10.0	Standing	15.3	Strolling	50.6	Safe
14	9.3	Sitting	14.4	Strolling	53.1	Safe
15	10.8	Standing	15.7	Strolling	56.0	Safe
16	12.1	Standing	19.2	Walking	66.6	Safe
17	8.7	Sitting	12.7	Standing	53.9	Safe
18	10.3	Standing	13.7	Standing	57.1	Safe
19	13.6	Standing	19.6	Walking	65.3	Safe
20	7.4	Sitting	11.1	Standing	49.4	Safe
21	7.0	Sitting	10.0	Standing	42.9	Safe
22	6.3	Sitting	9.1	Sitting	41.2	Safe
23	6.3	Sitting	9.1	Sitting	35.0	Safe
24	7.2	Sitting	10.7	Standing	42.1	Safe
25	8.3	Sitting	12.1	Standing	44.3	Safe
26	7.9	Sitting	12.4	Standing	55.4	Safe
27	6.6	Sitting	9.1	Sitting	35.5	Safe
28	9.9	Sitting	12.2	Standing	52.8	Safe
29	8.5	Sitting	11.4	Standing	42.4	Safe
30	9.7	Sitting	12.7	Standing	52.2	Safe
31	7.3	Sitting	10.7	Standing	42.3	Safe
32	7.3	Sitting	10.1	Standing	42.4	Safe
33	7.0	Sitting	9.5	Sitting	36.1	Safe
34	9.2	Sitting	11.1	Standing	54.3	Safe
35	11.8	Standing	15.7	Strolling	58.8	Safe

Guidelines	
Pedestrian Comfort	**20% Exceedance Wind Speed** 0-10 km/h = Sitting; 10-14 km/h = Standing; 14-17 km/h = Strolling; 17-20 km/h = Walking; >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

TABLE A2: SUMMARY OF PEDESTRIAN COMFORT AND SAFETY (FUTURE CONDITIONS)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
36	8.9	Sitting	12.0	Standing	46.8	Safe
37	11.4	Standing	15.3	Strolling	65.8	Safe
38	8.7	Sitting	12.3	Standing	47.2	Safe
39	16.2	Strolling	21.8	Uncomfortable	70.8	Safe
40	10.8	Standing	14.7	Strolling	60.1	Safe
41	10.6	Standing	17.4	Walking	71.2	Safe
42	6.4	Sitting	9.1	Sitting	34.6	Safe
43	12.2	Standing	14.5	Strolling	64.3	Safe
44	10.1	Standing	13.2	Standing	50.7	Safe
45	8.4	Sitting	11.2	Standing	43.0	Safe
46	9.5	Sitting	13.0	Standing	51.7	Safe
47	7.4	Sitting	10.1	Standing	39.3	Safe





APPENDIX B

PEDESTRIAN COMFORT SUITABILITY, TABLES B1-B3
(EXISTING VS FUTURE CONDITIONS)

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Guidelines	
Pedestrian Comfort	**20% Exceedance Wind Speed** 0-10 km/h = Sitting; 10-14 km/h = Standing; 14-17 km/h = Strolling; 17-20 km/h = Walking; >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% Exceedance Wind Speed** 0-90 km/h = Safe

TABLE B1: COMPARATIVE SUMMARY OF PEDESTRIAN COMFORT

Sensor	Massing Scenario	Summer Pedestrian Comfort			Winter Pedestrian Comfort		
		Wind Speed (km/h) 80% data ≤	Predicted Comfort Class	Future Comfort Class Compared to Existing	Wind Speed (km/h) 80% data ≤	Predicted Comfort Class	Future Comfort Class Compared to Existing
1	Existing	9.8	Sitting	-	13.2	Standing	-
	Future	9.4	Sitting	Unchanged	12.8	Standing	Unchanged
2	Existing	10.2	Standing	-	12.1	Standing	-
	Future	10.6	Standing	Unchanged	12.8	Standing	Unchanged
3	Existing	14.6	Strolling	-	18.8	Walking	-
	Future	14.2	Strolling	Unchanged	18.2	Walking	Unchanged
4	Existing	6.6	Sitting	-	9.4	Sitting	-
	Future	6.7	Sitting	Unchanged	9.9	Sitting	Unchanged
5	Existing	12.5	Standing	-	17.4	Walking	-
	Future	11.9	Standing	Unchanged	16.4	Strolling	Improved
6	Existing	12.3	Standing	-	17.3	Walking	-
	Future	11.7	Standing	Unchanged	15.8	Strolling	Improved
7	Existing	12.8	Standing	-	17.8	Walking	-
	Future	11.2	Standing	Unchanged	15.1	Strolling	Improved
8	Existing	11.3	Standing	-	16.1	Strolling	-
	Future	10.8	Standing	Unchanged	15.3	Strolling	Unchanged
9	Existing	10.9	Standing	-	15.4	Strolling	-
	Future	9.7	Sitting	Improved	14.0	Standing	Improved
10	Existing	10.0	Standing	-	14.0	Standing	-
	Future	10.1	Standing	Unchanged	15.6	Strolling	Reduced
11	Existing	11.7	Standing	-	16.6	Strolling	-
	Future	10.7	Standing	Unchanged	15.8	Strolling	Unchanged
12	Existing	8.8	Sitting	-	12.8	Standing	-
	Future	9.1	Sitting	Unchanged	13.3	Standing	Unchanged
13	Existing	12.1	Standing	-	17.5	Walking	-
	Future	10.0	Standing	Unchanged	15.3	Strolling	Improved
14	Existing	9.7	Sitting	-	14.6	Strolling	-
	Future	9.3	Sitting	Unchanged	14.4	Strolling	Unchanged
15	Existing	10.4	Standing	-	14.8	Strolling	-
	Future	10.8	Standing	Unchanged	15.7	Strolling	Unchanged

Guidelines	
Pedestrian Comfort	**20% Exceedance Wind Speed** 0-10 km/h = Sitting; 10-14 km/h = Standing; 14-17 km/h = Strolling; 17-20 km/h = Walking; >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% Exceedance Wind Speed** 0-90 km/h = Safe

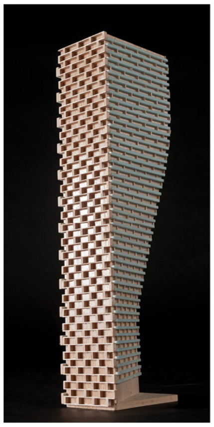
TABLE B2: COMPARATIVE SUMMARY OF PEDESTRIAN COMFORT

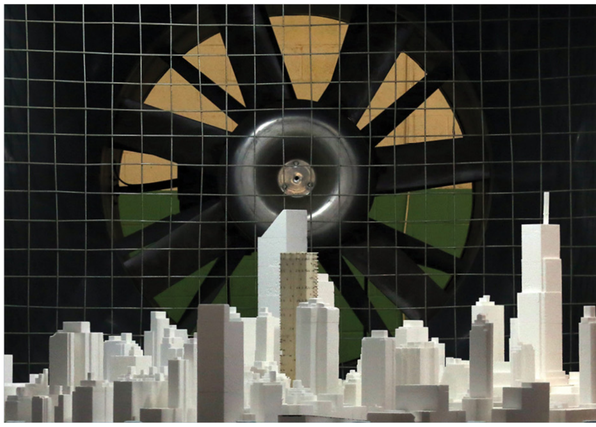
Sensor	Massing Scenario	Summer Pedestrian Comfort			Winter Pedestrian Comfort		
		Wind Speed (km/h) 80% data ≤	Predicted Comfort Class	Future Comfort Class Compared to Existing	Wind Speed (km/h) 80% data ≤	Predicted Comfort Class	Future Comfort Class Compared to Existing
16	Existing	11.6	Standing	-	18.4	Walking	-
	Future	12.1	Standing	Unchanged	19.2	Walking	Unchanged
17	Existing	10.0	Standing	-	14.0	Standing	-
	Future	8.7	Sitting	Improved	12.7	Standing	Unchanged
18	Existing	9.2	Sitting	-	13.3	Standing	-
	Future	10.3	Standing	Reduced	13.7	Standing	Unchanged
19	Existing	9.2	Sitting	-	13.3	Standing	-
	Future	13.6	Standing	Reduced	19.6	Walking	Reduced
20	Existing	11.0	Standing	-	15.2	Strolling	-
	Future	7.4	Sitting	Improved	11.1	Standing	Improved
21	Existing	12.6	Standing	-	16.8	Strolling	-
	Future	7.0	Sitting	Improved	10.0	Standing	Improved
22	Existing	11.0	Standing	-	15.0	Strolling	-
	Future	6.3	Sitting	Improved	9.1	Sitting	Improved
23	Existing	12.7	Standing	-	17.9	Walking	-
	Future	6.3	Sitting	Improved	9.1	Sitting	Improved
24	Existing	8.0	Sitting	-	10.7	Standing	-
	Future	7.2	Sitting	Unchanged	10.7	Standing	Unchanged
25	Existing	8.5	Sitting	-	11.9	Standing	-
	Future	8.3	Sitting	Unchanged	12.1	Standing	Unchanged
26	Existing	8.7	Sitting	-	14.3	Strolling	-
	Future	7.9	Sitting	Unchanged	12.4	Standing	Improved
27	Existing	12.3	Standing	-	20.5	Uncomfortable	-
	Future	6.6	Sitting	Improved	9.1	Sitting	Improved
28	Existing	7.3	Sitting	-	10.3	Standing	-
	Future	9.9	Sitting	Unchanged	12.2	Standing	Unchanged
29	Existing	8.3	Sitting	-	11.3	Standing	-
	Future	8.5	Sitting	Unchanged	11.4	Standing	Unchanged
30	Existing	7.2	Sitting	-	10.0	Sitting	-
	Future	9.7	Sitting	Unchanged	12.7	Standing	Reduced

Guidelines	
Pedestrian Comfort	**20% Exceedance Wind Speed** 0-10 km/h = Sitting; 10-14 km/h = Standing; 14-17 km/h = Strolling; 17-20 km/h = Walking; >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% Exceedance Wind Speed** 0-90 km/h = Safe

TABLE B3: COMPARATIVE SUMMARY OF PEDESTRIAN COMFORT

Sensor	Massing Scenario	Summer Pedestrian Comfort			Winter Pedestrian Comfort		
		Wind Speed (km/h) 80% data ≤	Predicted Comfort Class	Future Comfort Class Compared to Existing	Wind Speed (km/h) 80% data ≤	Predicted Comfort Class	Future Comfort Class Compared to Existing
31	Existing	9.3	Sitting	-	13.7	Standing	-
	Future	7.3	Sitting	Unchanged	10.7	Standing	Unchanged
32	Existing	8.7	Sitting	-	11.8	Standing	-
	Future	7.3	Sitting	Unchanged	10.1	Standing	Unchanged
33	Existing	8.4	Sitting	-	11.5	Standing	-
	Future	7.0	Sitting	Unchanged	9.5	Sitting	Improved
34	Existing	9.2	Sitting	-	12.6	Standing	-
	Future	9.2	Sitting	Unchanged	11.1	Standing	Unchanged
35	Existing	10.1	Standing	-	14.0	Standing	-
	Future	11.8	Standing	Unchanged	15.7	Strolling	Reduced
36	Existing	7.5	Sitting	-	10.3	Standing	-
	Future	8.9	Sitting	Unchanged	12.0	Standing	Unchanged
37	Existing	11.0	Standing	-	15.0	Strolling	-
	Future	11.4	Standing	Unchanged	15.3	Strolling	Unchanged
38	Existing	9.8	Sitting	-	13.5	Standing	-
	Future	8.7	Sitting	Unchanged	12.3	Standing	Unchanged
39	Existing	13.3	Standing	-	18.1	Walking	-
	Future	16.2	Strolling	Reduced	21.8	Uncomfortable	Reduced
40	Existing	7.3	Sitting	-	10.0	Standing	-
	Future	10.8	Standing	Reduced	14.7	Strolling	Reduced





APPENDIX C

WIND TUNNEL SIMULATION OF THE NATURAL WIND

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WIND TUNNEL SIMULATION OF THE NATURAL WIND

Wind flowing over the surface of the earth develops a boundary layer due to the drag produced by surface features such as vegetation and man-made structures. Within this boundary layer, the mean wind speed varies from zero at the surface to the gradient wind speed at the top of the layer. The height of the top of the boundary layer is referred to as the gradient height, above which the velocity remains more-or-less constant for a given synoptic weather system. The mean wind speed is taken to be the average value over one hour. Superimposed on the mean wind speed are fluctuating (or turbulent) components in the longitudinal (i.e. along wind), vertical and lateral directions. Although turbulence varies according to the roughness of the surface, the turbulence level generally increases from nearly zero (smooth flow) at gradient height to maximum values near the ground. While for a calm ocean the maximum could be 20%, the maximum for a very rough surface such as the center of a city could be 100%, or equal to the local mean wind speed. The height of the boundary layer varies in time and over different terrain roughness within the range of 400 metres (m) to 600 m.

Simulating real wind behaviour in a wind tunnel requires simulating the variation of mean wind speed with height, simulating the turbulence intensity, and matching the typical length scales of turbulence. It is the ratio between wind tunnel turbulence length scales and turbulence scales in the atmosphere that determines the geometric scales that models can assume in a wind tunnel. Hence, when a 1:200 scale model is quoted, this implies that the turbulence scales in the wind tunnel and the atmosphere have the same ratios. Some flexibility in this requirement has been shown to produce reasonable wind tunnel predictions compared to full scale. In model scale the mean and turbulence characteristics of the wind are obtained with the use of spires at one end of the tunnel and roughness elements along the floor of the tunnel. The fan is located at the model end and wind is pulled over the spires, roughness elements and model. It has been found that, to a good approximation, the mean wind profile can be represented by a power law relation, shown below, giving height above ground versus wind speed.

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

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.

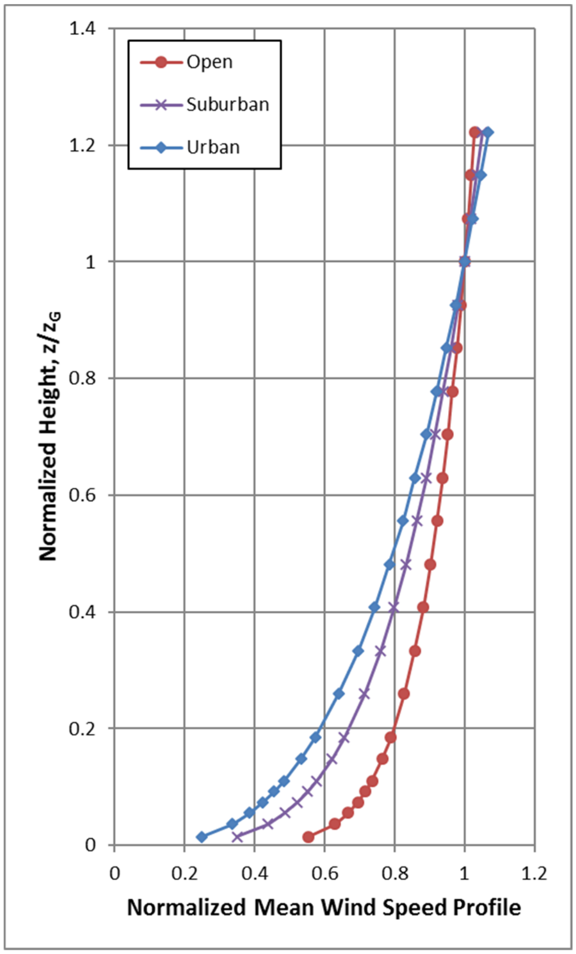
Figure C1 on the following page plots three velocity profiles for open country, and suburban and urban exposures. The exponent α varies according to the type of upwind terrain; α ranges from 0.14 for open country to 0.33 for an urban exposure. Figure C2 illustrates the theoretical variation of turbulence for open country, suburban and urban exposures.

The integral length scale of turbulence can be thought of as an average size of gust in the atmosphere. Although it varies with height and ground roughness, it has been found to generally be in the range of 100 m to 200 m in the upper half of the boundary layer. Thus, for a 1:300 scale, the model value should be between 1/3 and 2/3 of a metre. Integral length scales are derived from power spectra, which describe the energy content of wind as a function of frequency. There are several ways of determining integral length scales of turbulence. One way is by comparison of a measured power spectrum in model scale to a non-dimensional theoretical spectrum such as the Davenport spectrum of longitudinal turbulence. Using the Davenport spectrum, which agrees well with full-scale spectra, one can estimate the integral scale by plotting the theoretical spectrum with varying L until it matches as closely as possible the measured spectrum:

$$f \times S(f) = \frac{\frac{4(Lf)^2}{U_{10}^{\,2}}}{\left[1 + \frac{4(Lf)^2}{U_{10}^{\,2}}\right]^{\frac{4}{3}}}$$

Where, f is frequency, S(f) is the spectrum value at frequency f, U10 is the wind speed 10 m above ground level, and L is the characteristic length of turbulence.

Once the wind simulation is correct, the model, constructed to a suitable scale, is installed at the centre of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel centre-line axis.



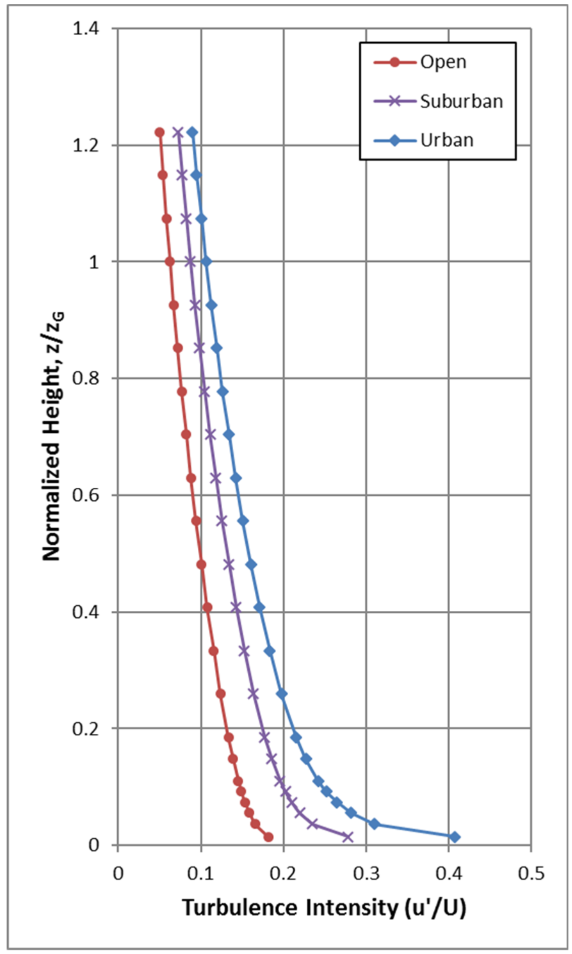


FIGURE C1 (LEFT): MEAN WIND SPEED PROFILES
FIGURE C2 (RIGHT): TURBULENCE INTENSITY PROFILES

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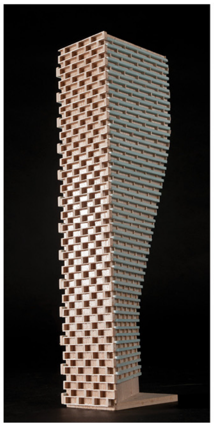

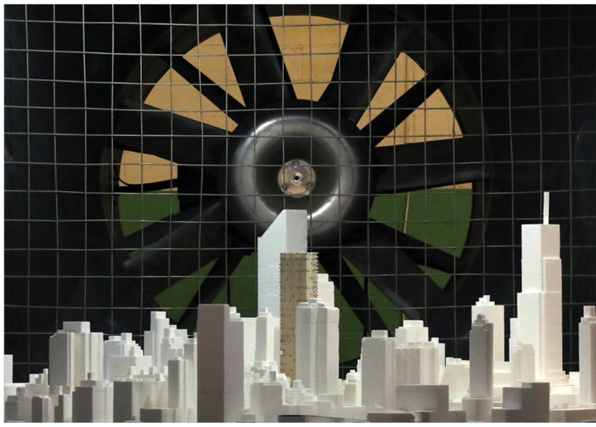

APPENDIX D

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

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PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

Pedestrian level wind studies are performed in a wind tunnel on a physical model of the study buildings at a suitable scale. Instantaneous wind speed measurements are recorded at a model height corresponding to 1.5 metres (m) full scale using either a hot wire anemometer or a pressure-based transducer. Measurements are performed at any number of locations on the model and usually for 36 wind directions. For each wind direction, the roughness of the upwind terrain is matched in the wind tunnel to generate the correct mean and turbulent wind profiles approaching the model.

The hot wire anemometer is an instrument consisting of a thin metallic wire conducting an electric current. It is an omni-directional device equally sensitive to wind approaching from any direction in the horizontal plane. By compensating for the cooling effect of wind flowing over the wire, the associated electronics produce an analog voltage signal that can be calibrated against velocity of the air stream. For all measurements, the wire is oriented vertically so as to be sensitive to wind approaching from all directions in a horizontal plane.

The pressure sensor is a small cylindrical device that measures instantaneous pressure differences over a small area. The sensor is connected via tubing to a transducer that translates the pressure to a voltage signal that is recorded by computer. With appropriately designed tubing, the sensor is sensitive to a suitable range of fluctuating velocities.

For a given wind direction and location on the model, a time history of the wind speed is recorded for a period of time equal to one hour in full-scale. The analog signal produced by the hot wire or pressure sensor is digitized at a rate of 400 samples per second. A sample recording for several seconds is illustrated in Figure D1. This data is analyzed to extract the mean, root-mean-square (rms) and the peak of the signal. The peak value, or gust wind speed, is formed by averaging a number of peaks obtained from sub-intervals of the sampling period. The mean and gust speeds are then normalized by the wind tunnel gradient wind speed, which is the speed at the top of the model boundary layer, to obtain mean and gust ratios. At each location, the measurements are repeated for 36 wind directions to produce normalized polar plots, which will be provided upon request.

In order to determine the duration of various wind speeds at full scale for a given measurement location the gust ratios are combined with a statistical (mathematical) model of the wind climate for the project site. This mathematical model is based on hourly wind data obtained from one or more meteorological stations (usually airports) close to the project location. The probability model used to represent the data is the Weibull distribution expressed as:

$$P\left(> U_g\right) = A_\theta \bullet \exp\left[\left(-\frac{U_g}{C\theta}\right)^{K\theta}\right]$$

Where,

P (> U_g) is the probability, fraction of time, that the gradient wind speed ***U_g*** is exceeded; ***θ*** is the wind direction measured clockwise from true north, ***A***, ***C***, ***K*** are the Weibull coefficients, (Units: A - dimensionless, C - wind speed units [km/h] for instance, K - dimensionless). ***A_θ*** is the fraction of time wind blows from a 10° sector centered on ***θ***.

Analysis of the hourly wind data recorded for a length of time, on the order of 10 to 30 years, yields the ***A_θ, C_θ*** and ***K_θ*** values. The probability of exceeding a chosen wind speed level, say 20 km/h, at sensor *N* is given by the following expression:

$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

$$P_N(>20) \quad = \quad \Sigma_\theta P\{>20/(U_N/U_g)\}$$

Where, ***U_N/U_g*** is the gust velocity ratios, where the summation is taken over all 36 wind directions at 10° intervals.

If there are significant seasonal variations in the weather data, as determined by inspection of the C_θ and K_θ values, then the analysis is performed separately for two or more times corresponding to the groupings of seasonal wind data. Wind speed levels of interest for predicting pedestrian comfort are based on the comfort guidelines chosen to represent various pedestrian activity levels as discussed in the main text.

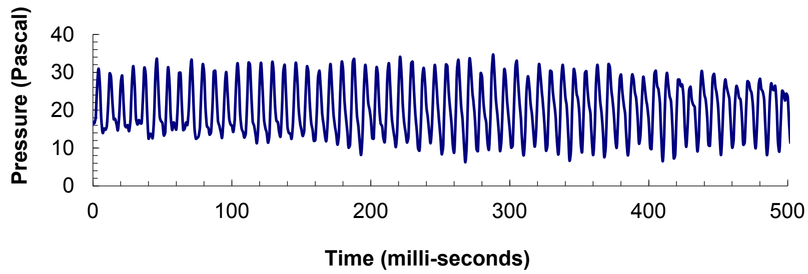

FIGURE D1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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