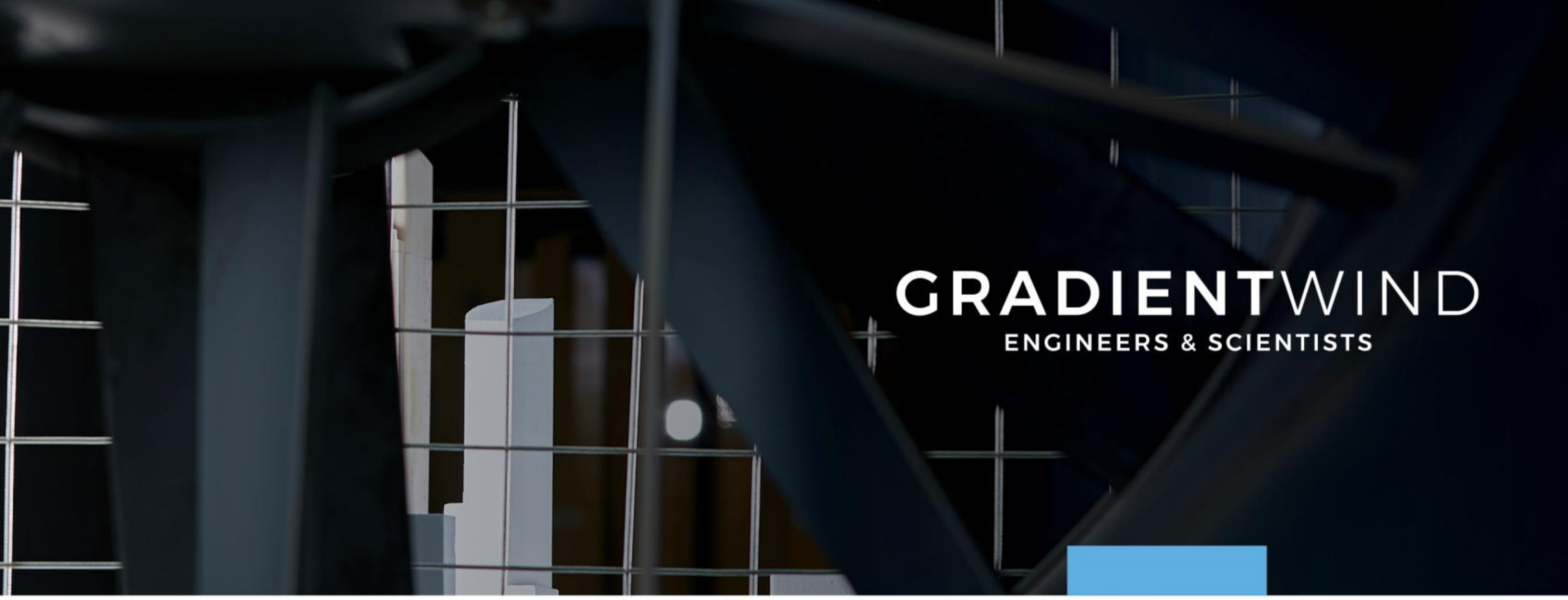
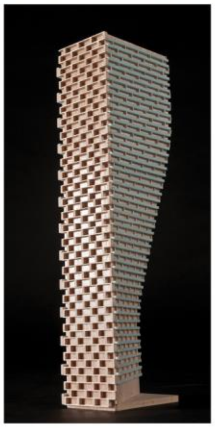
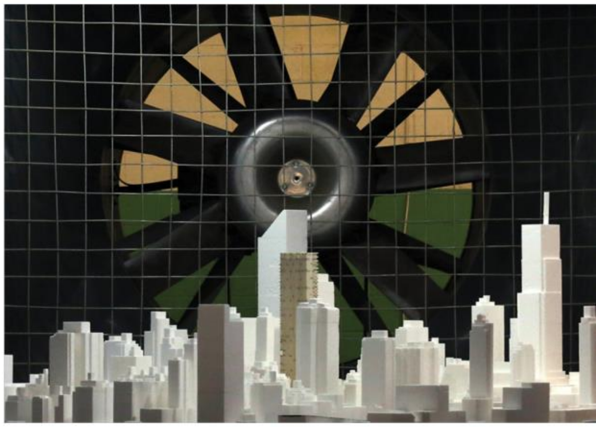


PEDESTRIAN LEVEL WIND STUDY

5234-5278, 5284 Ferry Street &
5928 Clark Avenue
Niagara Falls, Ontario

REPORT: GW23-178-WTPLW





January 17, 2024

PREPARED FOR
NGP Planning Solutions
4999 Victoria Avenue
Niagara Falls, Ontario
L2E 4C9

PREPARED BY
Cristiano Kondo, MESc., Junior Wind Scientist
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EXECUTIVE SUMMARY

This report describes a wind tunnel pedestrian level wind study undertaken to assess wind conditions for a proposed development located at 5234-5278, 5284 Ferry Street & 5928 Clark Avenue in Niagara Falls, Ontario. Two configurations were studied: (i) *existing scenario*, including all approved, surrounding developments and without the proposed development, and (ii) *proposed scenario* with the proposed development 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 at key areas within and surrounding the study site. Grade-level areas investigated include sidewalks, walkways, laneways, parking areas, nearby transit stops, grade-level outdoor amenities, and building access points. Wind comfort is also evaluated over the Level 5 terrace. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report.

Our work is based on industry standard wind tunnel testing and data analysis procedures, architectural drawings provided by Jason Pizzicarola Design - Architects Inc. in December 2023, surrounding street layouts, as well as existing and approved future building massing information obtained from the City of Niagara Falls, and recent site imagery.

A complete summary of the predicted wind conditions is provided in Section 5 of this report and is also illustrated in Figures 2A through 4B, as well as Tables A1-A2 and B1-B3 in the appendices. Based on wind tunnel test results, meteorological data analysis, and experience with similar developments in Niagara Falls, we conclude that the future wind conditions over most grade-level pedestrian wind-sensitive areas within and surrounding the study site will be acceptable for the intended uses on a seasonal basis. Exceptions include several retail entrances, for which mitigation is recommended as detailed in Section 5.2. To ensure wind conditions suitable for sitting or more sedentary activities at pedestrian sensitive locations over the Level 5 terrace, mitigation is recommended as detailed in Section 5.2.

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

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ENGINEERS & SCIENTISTS

TABLE OF CONTENTS

1. INTRODUCTION

This report describes a wind tunnel pedestrian level wind (PLW) study undertaken to assess wind conditions for a proposed development located at 5234-5278, 5284 Ferry Street & 5928 Clark Avenue in Niagara Falls, Ontario. Two configurations were studied: (i) *existing scenario*, including all approved, surrounding developments and without the proposed development, and (ii) *proposed scenario* with the proposed development in place. The study was performed in accordance with industry standard wind tunnel testing techniques, architectural drawings provided by Jason Pizzicarola Design - Architects Inc. in December 2023, surrounding street layouts and existing and approved future building massing information, as well as recent site imagery.

2. TERMS OF REFERENCE

The focus of this wind tunnel pedestrian wind study is the proposed development located at 5234-5278, 5284 Ferry Street & 5928 Clark Avenue in Niagara Falls, Ontario. The study site is located at the southeast corner of the intersection of Ferry Street and Clark Avenue.

The development comprises two 30-storey towers (Towers 1 & 2) situated on the northeast and southwest sides, respectively, of a shared triangular four-storey podium. Towers 1 and 2 are aligned longitudinally with Ferry Street and Clark Avenue, respectively. A service laneway connecting to Clark Avenue bisects the podium, providing access to interior drop-off spaces, hotel lobby entrances, and the ramp to the three above-grade parking levels. The northwest podium portion comprises a commercial space and the northeast portion features the Tower 1 hotel lobby, a commercial space, and a restaurant. A patio is located to the east of the restaurant. The southwest segment features the Tower 2 hotel lobby and a loading area. At Level 2, the segmented podium reconnects, covering the grade-level laneway below, and the floorplate rises uniformly to Level 5, with Levels 2-4 reserved for parking. The podium then sets back to the typical Towers' floorplate at Level 5, featuring a one-storey sky lobby between the towers, with roof-top gardens and terrace areas elsewhere. The hotel towers' floorplates rise to the full height, with tower setbacks at Level 16, and a mechanical penthouse completes each tower.

Regarding wind exposures, the near-field surroundings (defined as an area falling within a 200-metre (m) radius of the subject site) are characterized primarily by low-rise buildings in the west quadrant and surface parking in the north and south quadrants, with isolated mid-rise buildings to the east and northeast. Specifically, the 10-storey hotel (Courtyard by Marriott) to the east, and the 11- and 7-storey hotels (Fairfield by Marriot & Days Inn by Wyndham, respectively) to the north. The far-field surroundings (defined as the area beyond the near field and within a 2-kilometre (km) radius) are characterized primarily by low-rise buildings in all directions, with clusters of high-rise buildings along Fallsview Boulevard to the south. The Niagara River gorge is located approximately 820 metres east of the study site.

Grade-level areas investigated include sidewalks, walkways, laneways, parking areas, nearby transit stops, grade-level outdoor amenities, and building access points. Wind comfort is also evaluated over the Level 5 terrace. Figures 1A and 1B illustrate the *existing* and *proposed* study sites and surrounding context, respectively, and Photographs 1 through 6 depict the wind tunnel model used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to (i) determine pedestrian level wind comfort and safety conditions at key areas within and surrounding the development 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 on the existing wind conditions.

4. METHODOLOGY

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

[1] Niagara Region Pedestrian Level Wind Study Term of Reference Guide, July 2022

4.1 Wind Tunnel Context Modelling

A detailed PLW study is performed to determine the influence of local winds at the pedestrian level for a proposed development. The physical model of the proposed development and relevant surroundings, illustrated in Photographs 1 through 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 metres. The general concept and approach to wind tunnel modelling is to provide building and topographic detail in the immediate vicinity of the study site on the surrounding 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 an accurate seasonal representation of vegetation. The omission of trees and other landscaping elements produces slightly more conservative wind speed values.

4.2 Wind Speed Measurements

The PLW study was performed by testing a total of 90 sensor locations on the scale model in Gradient Wind's wind tunnel. Of these 90 sensors, 74 were located at grade and the remaining 16 sensors were located over the Level 5 elevated terrace. Wind speed measurements were performed for each of the 90 sensors for 36 wind directions at 10° intervals. Figures 1A and 1B illustrate the *existing* and *proposed* study sites and surrounding context, respectively, while sensor locations used to investigate wind conditions are illustrated in Figures 2A through 4B.

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

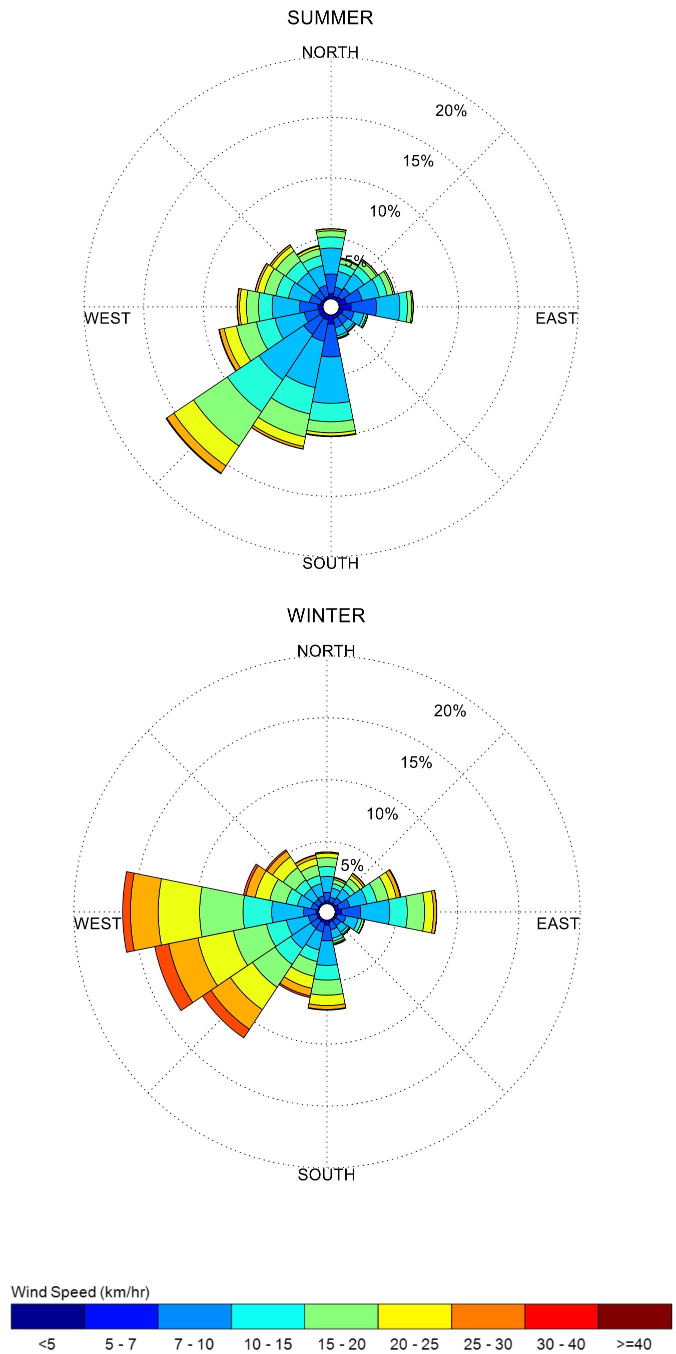
C and D provide greater detail of the theory behind wind speed measurements. Wind tunnel measurements for this project, conducted in Gradient Wind's wind tunnel facility, meet or exceed guidelines found in the National Building Code of Canada 2015 and of 'Wind Tunnel Studies of Buildings and Structures', ASCE Manual 7 Reports on Engineering Practice No 67.

4.3 Meteorological Data Analysis

A statistical model for winds in Niagara Falls was developed from approximately 48-years of hourly meteorological wind data recorded at Niagara Falls International Airport and obtained from Environment and Climate Change Canada. Wind speed and direction data were divided into two distinct seasons, as stipulated in the noted Niagara Region Terms of Reference Guide[1]. More 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 Niagara Falls area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Niagara Falls, the most common winds during the winter concerning pedestrian comfort occur from the west-southwest followed by those from the east. The most common winds during the summer season occur for southwesterly wind directions. The directional preference and relative magnitude of the wind speed varies somewhat from season to season with the summer months displaying the calmest winds relative to the remaining seasonal periods. Also, by convection in microclimate studies, wind direction refers to the wind origin (e.g., a north wind blows from north to south).

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES
NIAGARA FALLS INTERNATIONAL AIRPORT, NIAGARA FALLS, NEW YORK



Notes:

1. Radial distances indicate percentage of time of wind events.

2. Wind speeds are mean hourly in km/h, measured at 10 m above the ground.

4.4 Pedestrian Comfort and Safety Guidelines

Pedestrian comfort and safety guidelines are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e. temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Since both mean and gust wind speeds affect pedestrian comfort, their combined effect is defined in the Niagara Region Terms of Reference[1]. More 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.

Four pedestrian comfort classes and corresponding GEM wind speed ranges are used to assess pedestrian comfort, which include: (i) Sitting; (ii) Standing; (iii) Walking; and (iv) Uncomfortable. More specifically, the comfort classes, wind speed ranges, and limiting criteria are summarized as follows:

(i) **Sitting** – GEM wind speeds below 10 km/h occurring more than 80% of the time would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – GEM wind speeds below 15 km/h (i.e. 10-15 km/h) occurring more than 80% of the time are acceptable for activities such as standing, strolling or more vigorous activities.

(iii) **Walking** – GEM wind speeds below 20 km/h (i.e. 15-20 km/h) occurring more than 80% of the time are acceptable for walking or more vigorous activities.

(iv) **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.

Gust wind speeds greater than 90 km/h, occurring more than 0.1% of the time on an annual basis, 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 a vulnerable member of the population to fall.

Experience and research on people's perception of mechanical wind effects have shown that if the wind speed levels are exceeded 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 or more sedentary activities. Similarly, if GEM wind speeds of 20 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As 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 represented by the sensor (i.e. a sidewalk, building entrance, amenity space, or other). An overview of common pedestrian location types and their desired comfort classes are summarized below.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

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

5. RESULTS AND DISCUSSION

Tables A1 and A2 in Appendix A provide a summary of seasonal comfort predictions for each sensor location under the *existing* massing scenario. Similarly, Tables B1-B3 in Appendix B provide the seasonal comfort predictions for under the *proposed* massing scenario. The tables indicate the 80% non-exceedance GEM wind speeds and corresponding comfort classifications as defined in Section 4.4. In other words, a wind speed threshold of 19.1 for the summer season indicates that 80% of the measured data falls at or below 19.1 km/h during the summer months and conditions are therefore suitable for walking, as the 80% threshold value falls within the exceedance range of 15-20 km/h for walking. 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, walking, etc.).

The most significant findings of the PLW study are summarized in Sections 5.1 and 5.2. To assist with understanding and interpretation, predicted conditions for the proposed development are also illustrated in colour-coded format in Figures 2A through 4B. Conditions suitable for sitting are represented by the colour blue, while standing is represented by green, and walking by yellow. Conditions considered uncomfortable for walking are represented by the colour orange. For locations where the wind safety criterion is exceeded, the sensor is highlighted in red.

5.1 Pedestrian Comfort Suitability – *Existing Scenario*

Based on the analysis of the measured data, consideration of local climate data, and the suitability descriptors provided in Tables A1 and A2 in Appendix A and illustrated in Figures 2A and 2B, this section summarizes the significant findings of the PLW study with respect to the *existing scenario*, as follows:

1. All public sidewalks, walkways, laneways, parking areas, and landscaped spaces within and surrounding the proposed development currently experience wind conditions suitable for walking or better throughout the year.

2. Most principal entrances to the existing hotel and commercial buildings near the site (Sensors 2, 12, 14, & 36) are currently suitable for standing or better throughout the year. Exceptions include the hotel Fairfield by Marriot directly north of the site at 5257 Ferry Street (Sensor 12), which exceeds the standing criterion throughout the year.

3. The existing nearby grade-level outdoor amenities (Sensors 11 & 37) are currently suitable for sitting or more sedentary activities on a seasonal basis.

4. The nearby existing transit stops (Sensors 6 & 15) are currently suitable for standing or better throughout the year.

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

5.2 Pedestrian Comfort Suitability – *Proposed Scenario*

Based on the analysis of the measured data, consideration of local climate data, and the suitability descriptors provided in Tables B1-B3 in Appendix B and illustrated in Figures 3A through 4B, this section summarizes the significant findings of the PLW study with respect to the *proposed scenario*, as follows:

1. Most public sidewalks, walkways, laneways, parking areas, and landscaped spaces within and surrounding the proposed development will experience wind conditions suitable for walking or better throughout the year, which is acceptable for the intended uses of spaces. Exceptions include isolated areas along St. Clark Avenue (Sensors 20 & 25), which exceed the walking criterion during the winter months. It is noteworthy that the exceedance of the walking threshold is marginal (~0.2 km/h, See Appendix B), and wind speeds remain safe, as defined in Section 4.4. Therefore, mitigation is not considered necessary.

2. All hotel lobby and most retail entrances will be comfortable for standing or better throughout the year, which is appropriate. Exceptions include the retail entrances fronting Ferry Street to the northeast and Clair Avenue to the northwest (Sensors 18 & 19 and 48, respectively), which exceed the standing criterion during the winter months. It is recommended to either recess these entrances within the building façade or flank the entrances with vertical wind barriers and overhead canopies.

   All secondary building access points (including stairwell exits and vehicle entrances) throughout the proposed development will be comfortable for walking or better throughout the year, which is appropriate.

3. All principal entrances to the nearby existing hotels and commercial buildings (Sensors 2, 12, 14 & 36) will remain suitable for standing or better throughout the year, which is appropriate for the intended uses of spaces.

4. The proposed patio to the northeast (Sensors 72-74) will be suitable for sitting during the summer months and standing or better during the winter months, which is acceptable for the intended use of space.

5. The existing nearby grade-level outdoor amenities (Sensors 11 & 37) will remain suitable for sitting or more sedentary activities on a seasonal basis, which is appropriate.

6. The nearby existing transit stops (Sensors 6 & 15) will remain suitable for standing throughout the year, which is appropriate.

7. Considering the Level 5 terrace (Sensors 75-90), the entrances to the sky lobby (Sensors 80, 82, & 89) will generally be suitable for standing or better throughout the year, which is acceptable. The remaining terrace area will experience a mix of walking, standing, and sitting wind conditions during the summer months. To ensure wind conditions are suitable for sitting or more sedentary activities at pedestrian-sensitive locations, it is recommended to raise the terrace perimeter guard to at least 2.0 metres above the walking surface. Additionally, any designated seating areas are recommended to be equipped with targeted upwind barriers and/or overhead pergola structures. Such barriers should measure at least 1.6-metres-tall, be situated to the northwest/southwest, and may comprise high-solidity windscreens, raised planters with coniferous plantings, or a combination thereof. The exact configuration can be coordinated with the design team as the landscaping plans develop.

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

6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the methodology, results, and recommendations related to a pedestrian level wind study for a proposed development located at 5234-5278, 5284 Ferry St & 5928 Clark Avenue in

Niagara Falls, Ontario. The study was performed in accordance with industry standard wind tunnel testing and data analysis procedures.

A complete summary of the predicted wind conditions is provided in Section 5 of this report and is also illustrated in Figures 2A through 4B, as well as Tables A1-A2 and B1-B3 in the appendices. Based on wind tunnel test results, meteorological data analysis, and experience with similar developments in Niagara Falls, we conclude that the future wind conditions over most grade-level pedestrian wind-sensitive areas within and surrounding the study site will be acceptable for the intended uses on a seasonal basis. Exceptions include several retail entrances, for which mitigation is recommended as detailed in Section 5.2. To ensure wind conditions are suitable for sitting or more sedentary activities at pedestrian-sensitive locations over the Level 5 terrace, mitigation is recommended as detailed in Section 5.2.

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

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

Sincerely,

Gradient Wind Engineering Inc.

Cristiano Kondo, MESc.,
Junior Wind Scientist

Nick Petersen, P.Eng.,
Wind Engineer

GW23-178-WTPLW

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

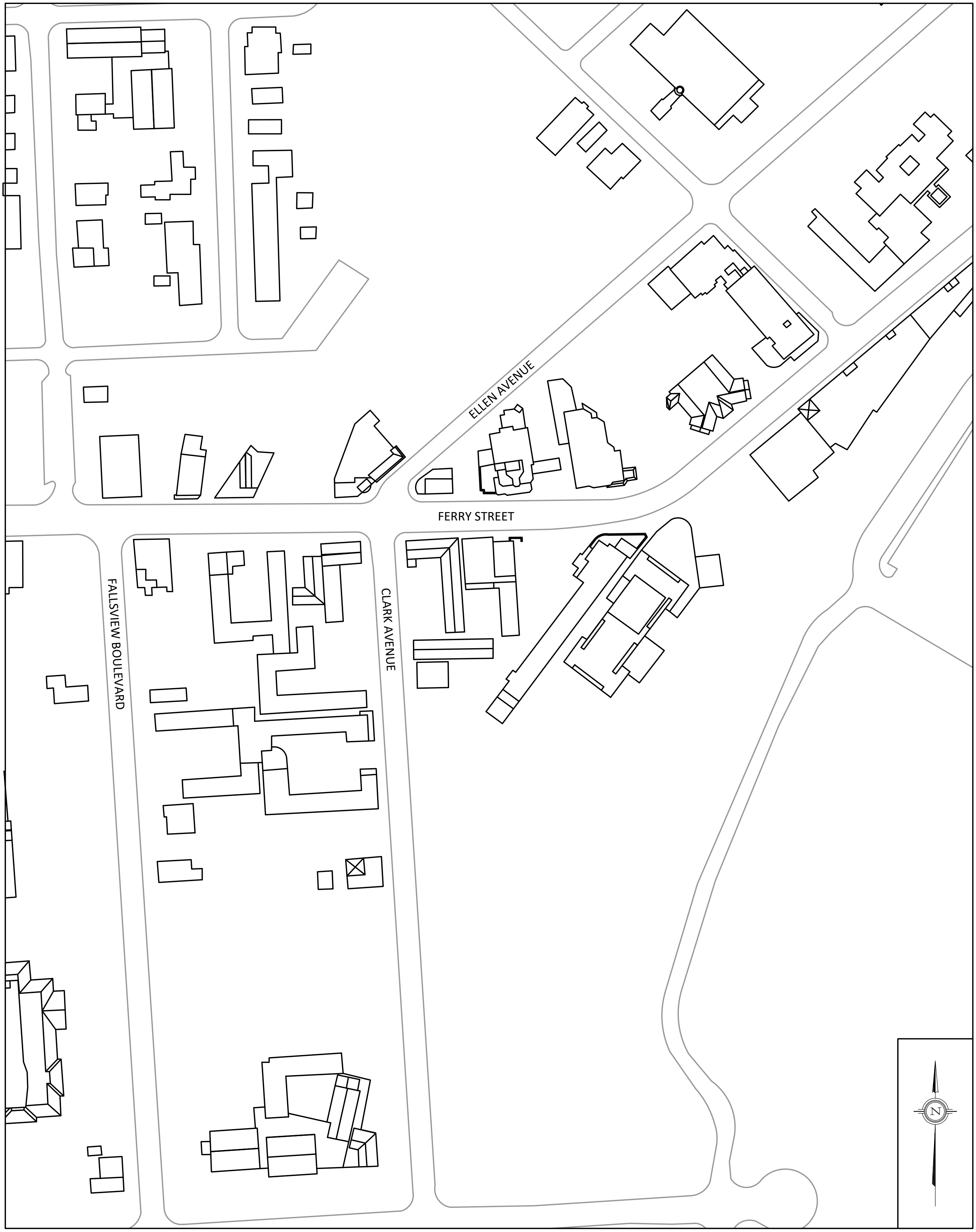
PHOTOGRAPH 2: CLOSE-UP VIEW OF EXISTING CONTEXT MODEL LOOKING SOUTHEAST

PHOTOGRAPH 3: PROPOSED STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING DOWNWIND

PHOTOGRAPH 4: PROPOSED STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING UPWIND

PHOTOGRAPH 5: CLOSE-UP VIEW OF PROPOSED STUDY MODEL LOOKING SOUTHEAST

PHOTOGRAPH 6: CLOSE-UP VIEW OF PROPOSED STUDY MODEL LOOKING NORTHWEST



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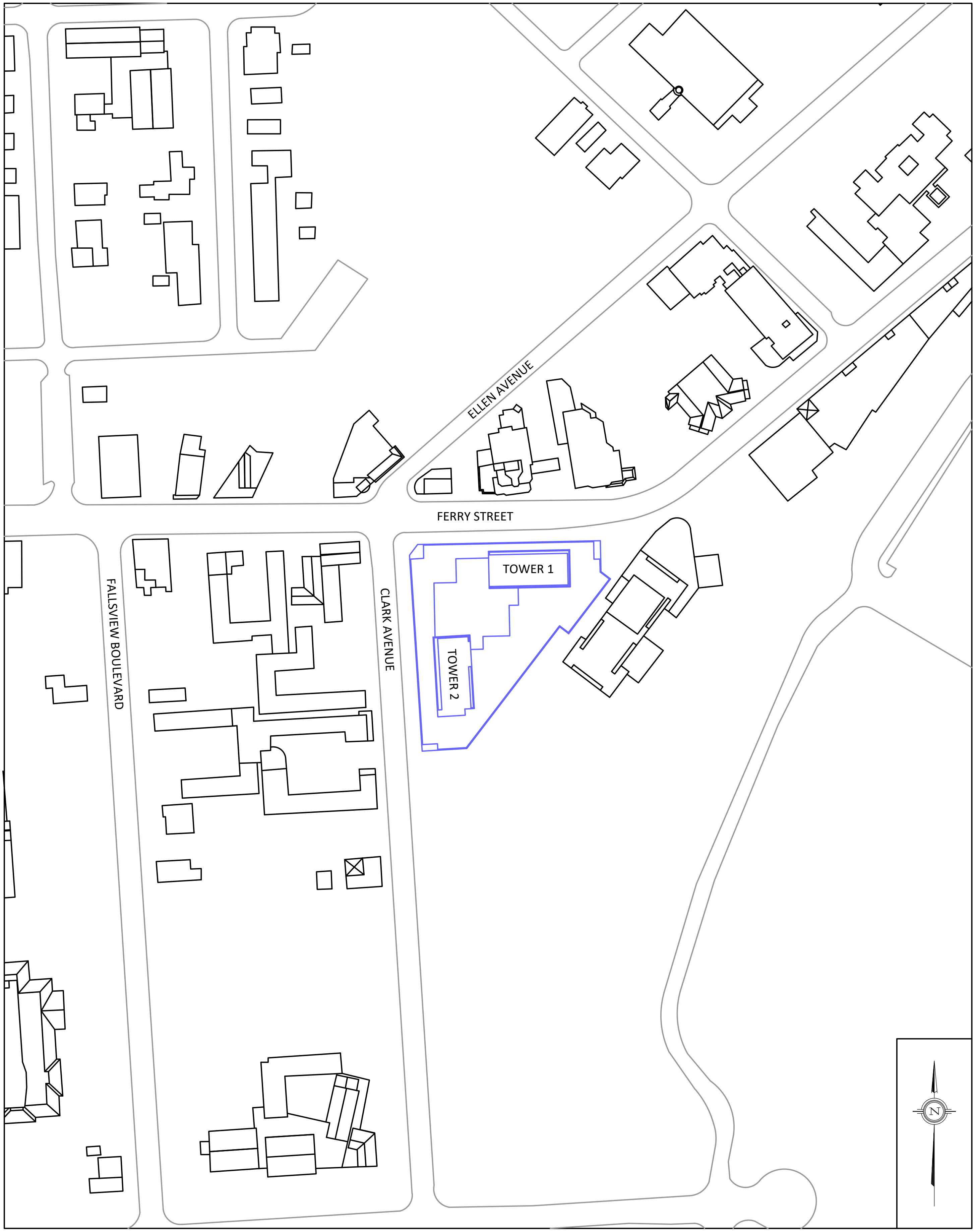
PROJECT 5234-5278 + 5284 FERRY ST. & 5928 CLARKE AVE., NIAGARA FALLS PEDESTRIAN LEVEL WIND STUDY	
SCALE 1:2500 (APPROX.)	DRAWING NO. GW23-178-PLW-1A
DATE JANUARY 17, 2024	DRAWN BY K.A.

DESCRIPTION

FIGURE 1A:
EXISTING SCENARIO
AND SURROUNDING CONTEXT



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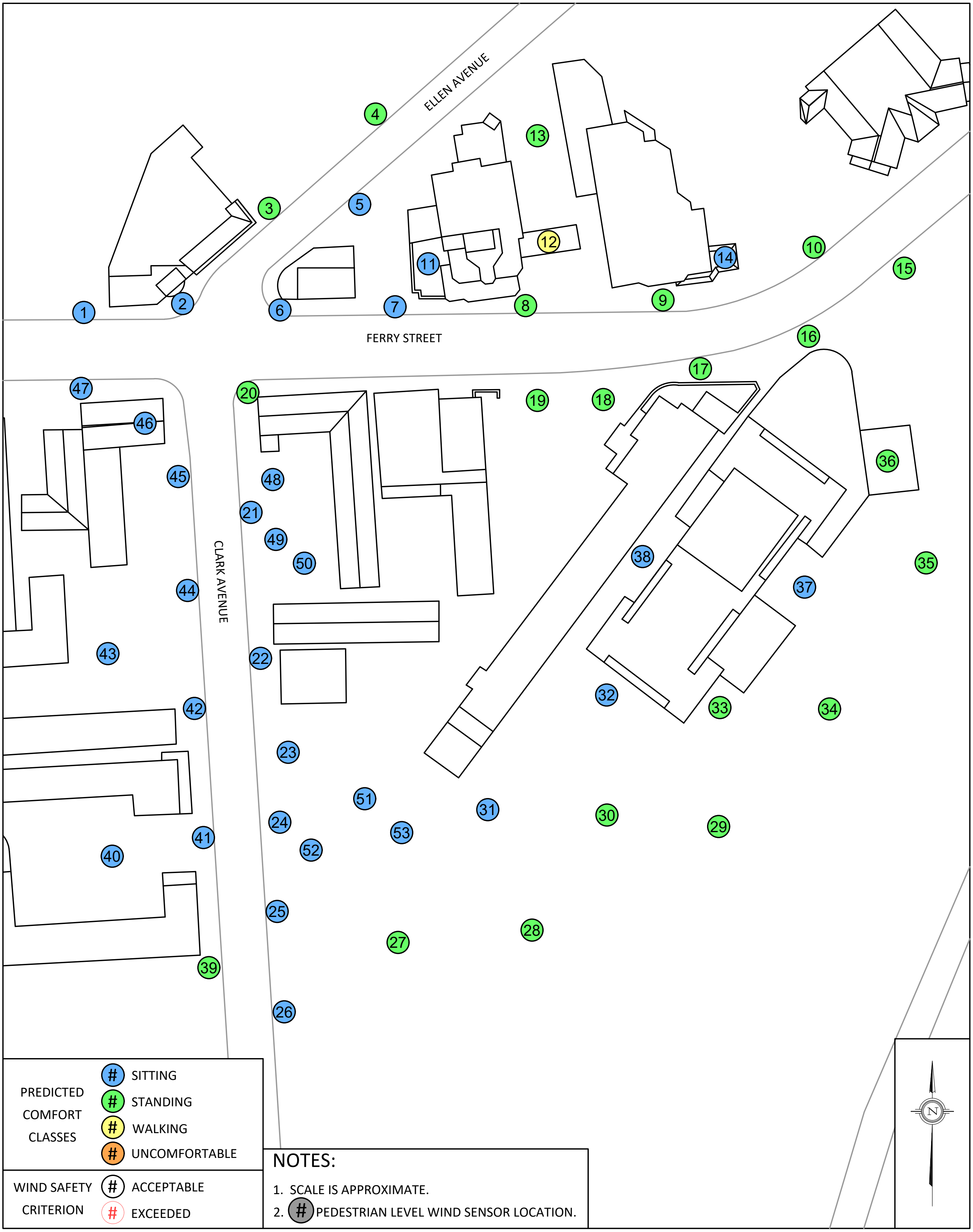
PROJECT	5234-5278 + 5284 FERRY ST. & 5928 CLARKE AVE., NIAGARA FALLS PEDESTRIAN LEVEL WIND STUDY
SCALE	1:2500 (APPROX.)
DRAWING NO.	GW23-178-PLW-1B
DATE	JANUARY 17, 2024
DRAWN BY	K.A.

DESCRIPTION

FIGURE 1B:
FUTURE SCENARIO
AND SURROUNDING CONTEXT



PREDICTED COMFORT CLASSES	#	SITTING
	#	STANDING
	#	WALKING
	#	UNCOMFORTABLE
WIND SAFETY CRITERION	#	ACCEPTABLE
	#	EXCEEDED

NOTES:

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

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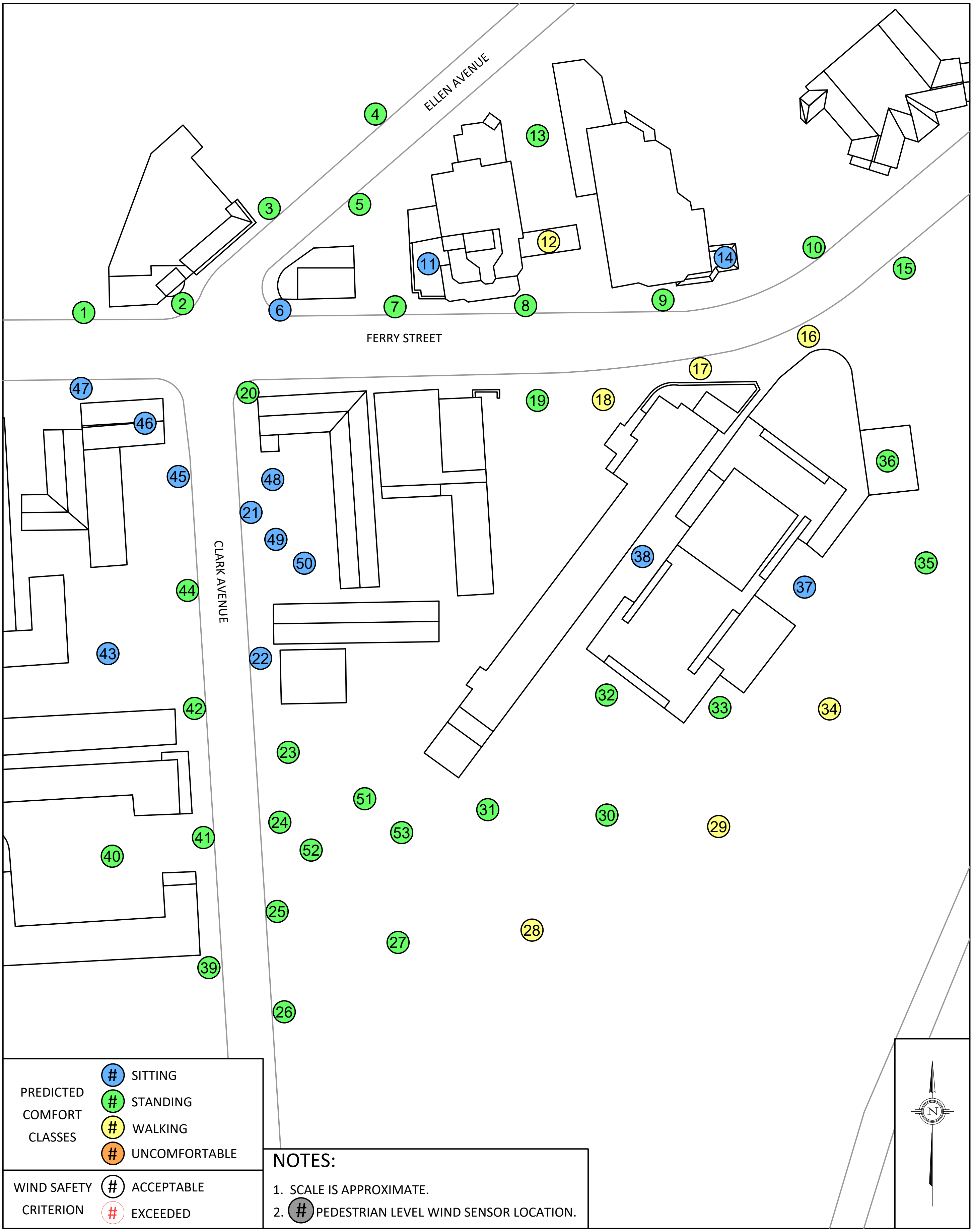
PROJECT 5234-5278 + 5284 FERRY ST. & 5928 CLARKE AVE., NIAGARA FALLS PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION FIGURE 2A: SUMMER EXISTING GRADE LEVEL PLW SENSOR LAYOUT PEDESTRIAN COMFORT PREDICTIONS
SCALE 1:1200 (APPROX.)	DRAWING NO. GW23-178-PLW-2A	
DATE JANUARY 17, 2024	DRAWN BY K.A.	



NOTES:

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

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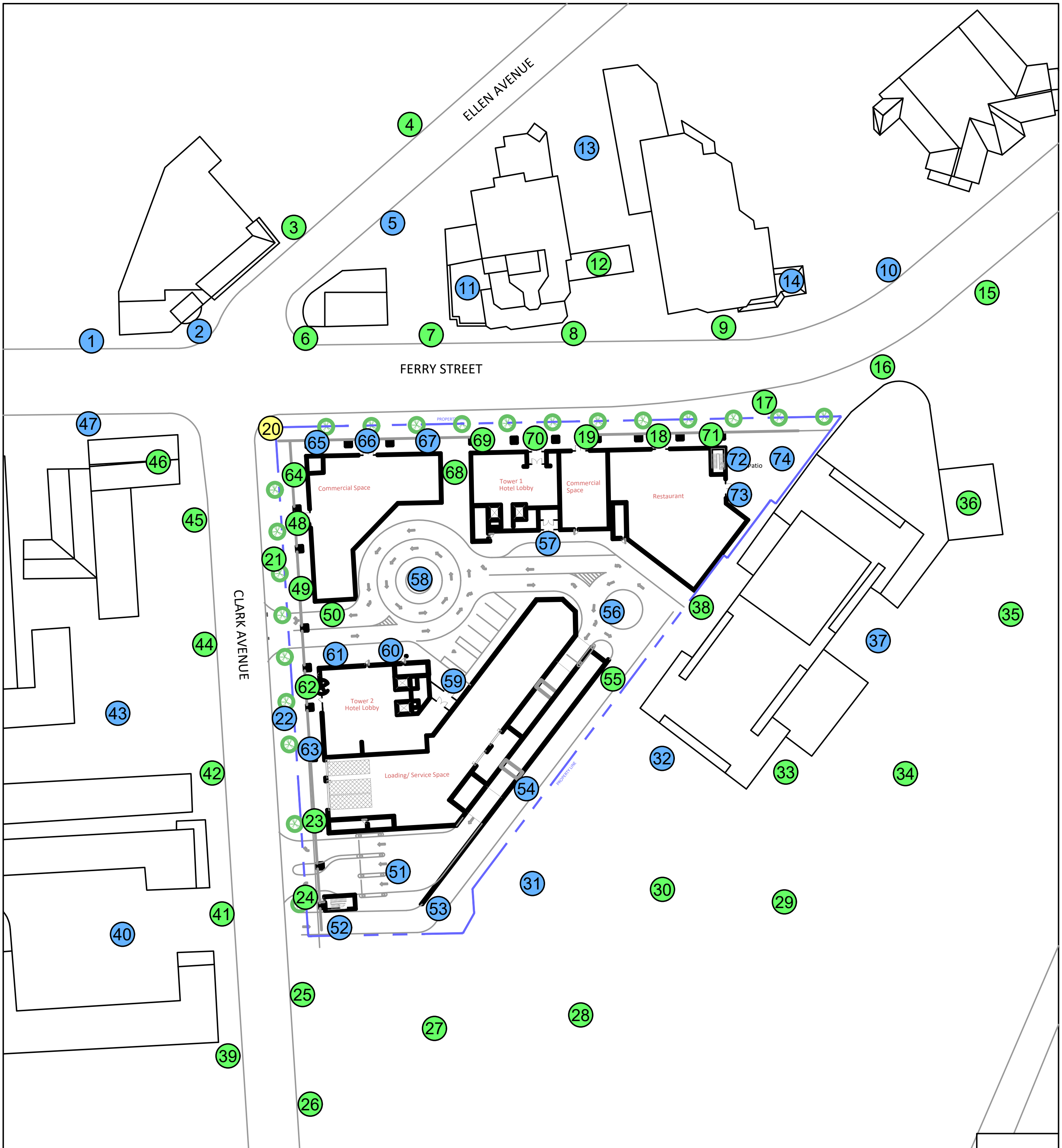
PROJECT 5234-5278 + 5284 FERRY ST. & 5928 CLARKE AVE., NIAGARA FALLS PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION FIGURE 2B: WINTER EXISTING GRADE LEVEL PLW SENSOR LAYOUT PEDESTRIAN COMFORT PREDICTIONS
SCALE 1:1200 (APPROX.)	DRAWING NO. GW23-178-PLW-2B	
DATE JANUARY 17, 2024	DRAWN BY K.A.	



PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING
#	UNCOMFORTABLE

WIND SAFETY CRITERION	
#	ACCEPTABLE
#	EXCEEDED

NOTES:

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

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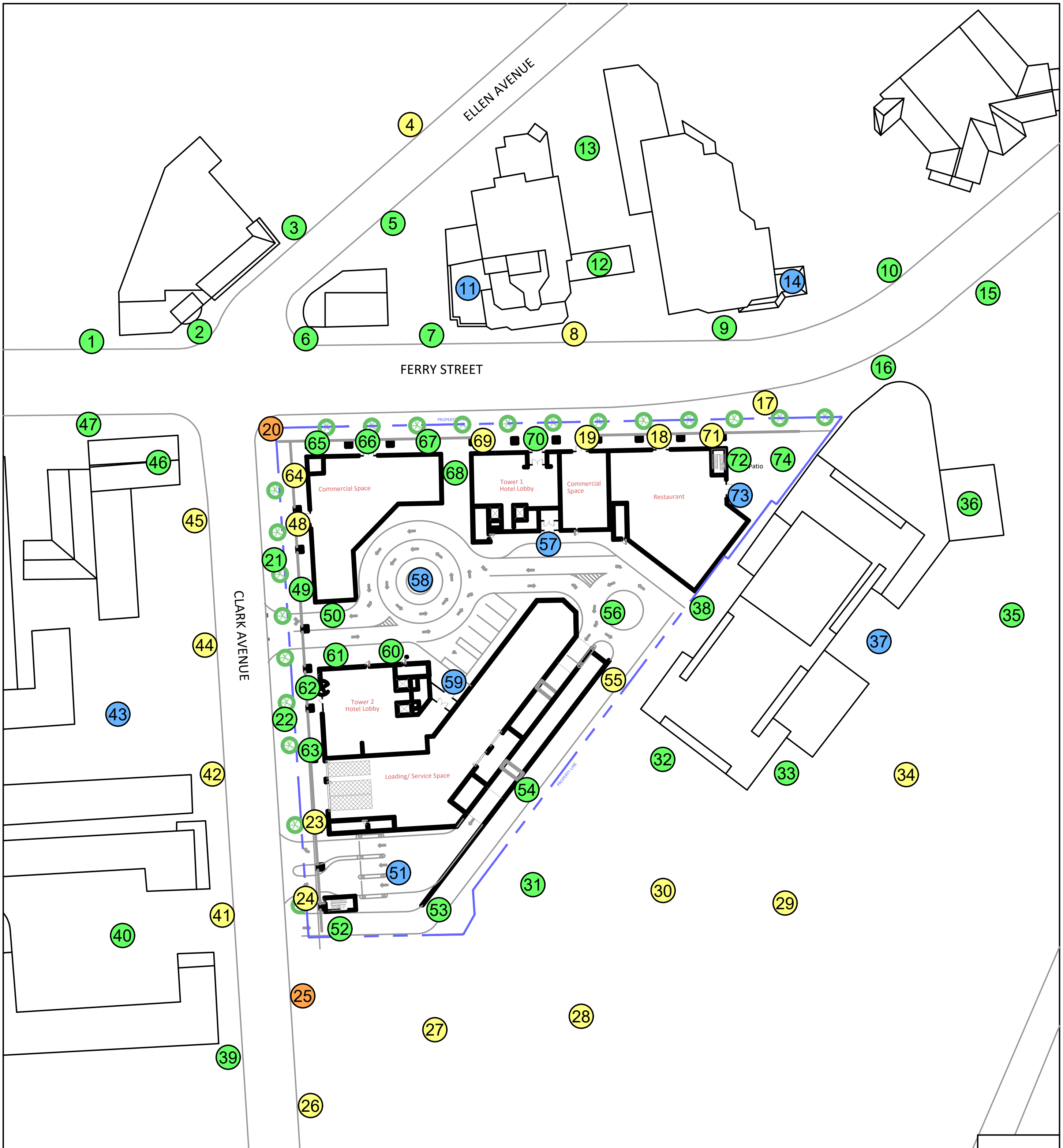
SCALE: 1:1200 (APPROX.)

DRAWING NO.: GW23-178-PLW-3A

DATE: JANUARY 17, 2024

DRAWN BY: K.A.

DESCRIPTION: FIGURE 3A: SUMMER FUTURE GRADE LEVEL PLW SENSOR LAYOUT PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING
#	UNCOMFORTABLE

WIND SAFETY CRITERION	
#	ACCEPTABLE
#	EXCEEDED

NOTES:

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

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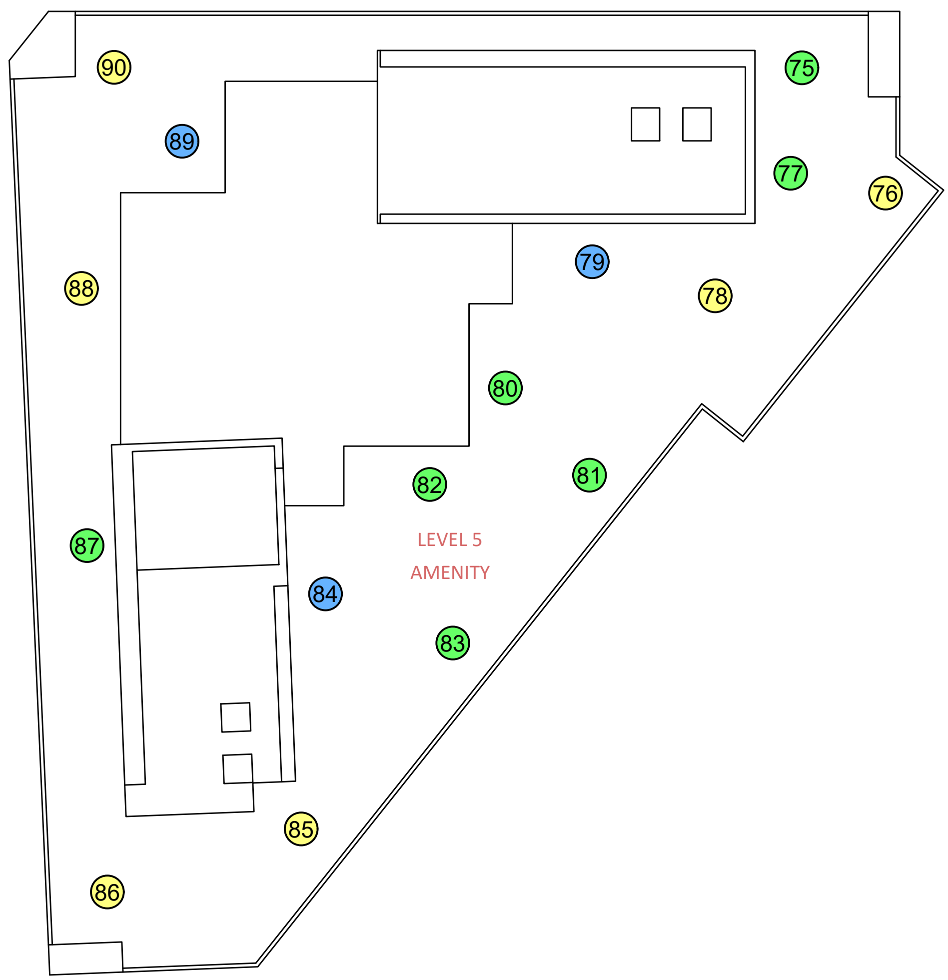
SCALE	1:1200 (APPROX.)	DRAWING NO.	GW23-178-PLW-3B
DATE	JANUARY 17, 2024	DRAWN BY	K.A.

DESCRIPTION

FIGURE 3B: WINTER
FUTURE GRADE LEVEL PLW SENSOR LAYOUT
PEDESTRIAN COMFORT PREDICTIONS

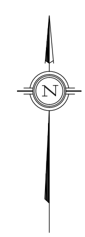


PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING
#	UNCOMFORTABLE

WIND SAFETY CRITERION	
#	ACCEPTABLE
#	EXCEEDED

NOTES:

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



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PROJECT: 5234-5278 + 5284 FERRY ST. & 5928 CLARKE AVE., NIAGARA FALLS PEDESTRIAN LEVEL WIND STUDY

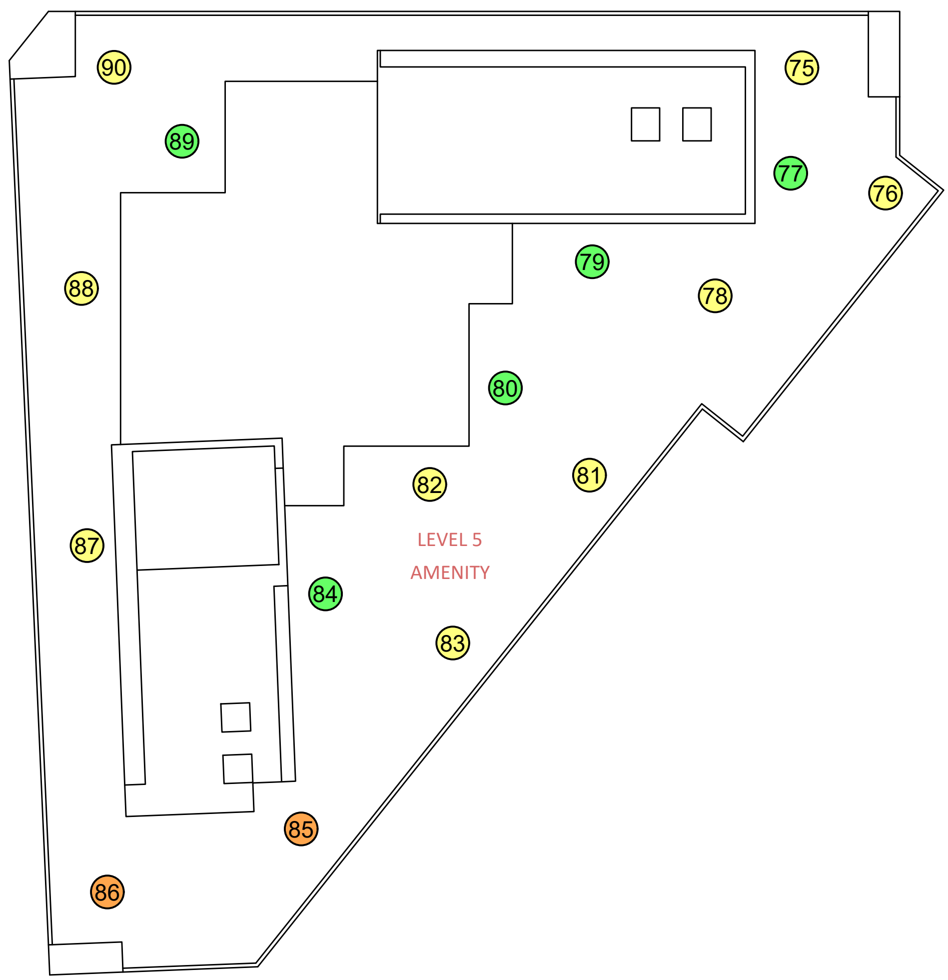
SCALE: 1:800 (APPROX.)

DRAWING NO.: GW23-178-PLW-4A

DATE: JANUARY 17, 2024

DRAWN BY: K.A.

DESCRIPTION: FIGURE 4A: SUMMER FUTURE TERRACE PLW SENSOR LAYOUT PEDESTRIAN COMFORT PREDICTIONS

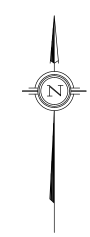


PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING
#	UNCOMFORTABLE

WIND SAFETY CRITERION	
#	ACCEPTABLE
#	EXCEEDED

NOTES:

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



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PROJECT: 5234-5278 + 5284 FERRY ST. & 5928 CLARKE AVE., NIAGARA FALLS
PEDESTRIAN LEVEL WIND STUDY

SCALE: 1:800 (APPROX.)

DRAWING NO.: GW23-178-PLW-4B

DATE: JANUARY 17, 2024

DRAWN BY: K.A.

DESCRIPTION:
FIGURE 4B: WINTER
FUTURE TERRACE PLW SENSOR LAYOUT
PEDESTRIAN COMFORT PREDICTIONS

APPENDIX A

PEDESTRIAN COMFORT SUITABILITY, TABLES A1-A2
(EXISTING SCENARIO)

Guidelines	
Pedestrian Comfort	**20% exceedance wind speed** 0-10 km/h = Sitting, 10-15 km/h = Standing, 15-20 km/h = Walking, >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

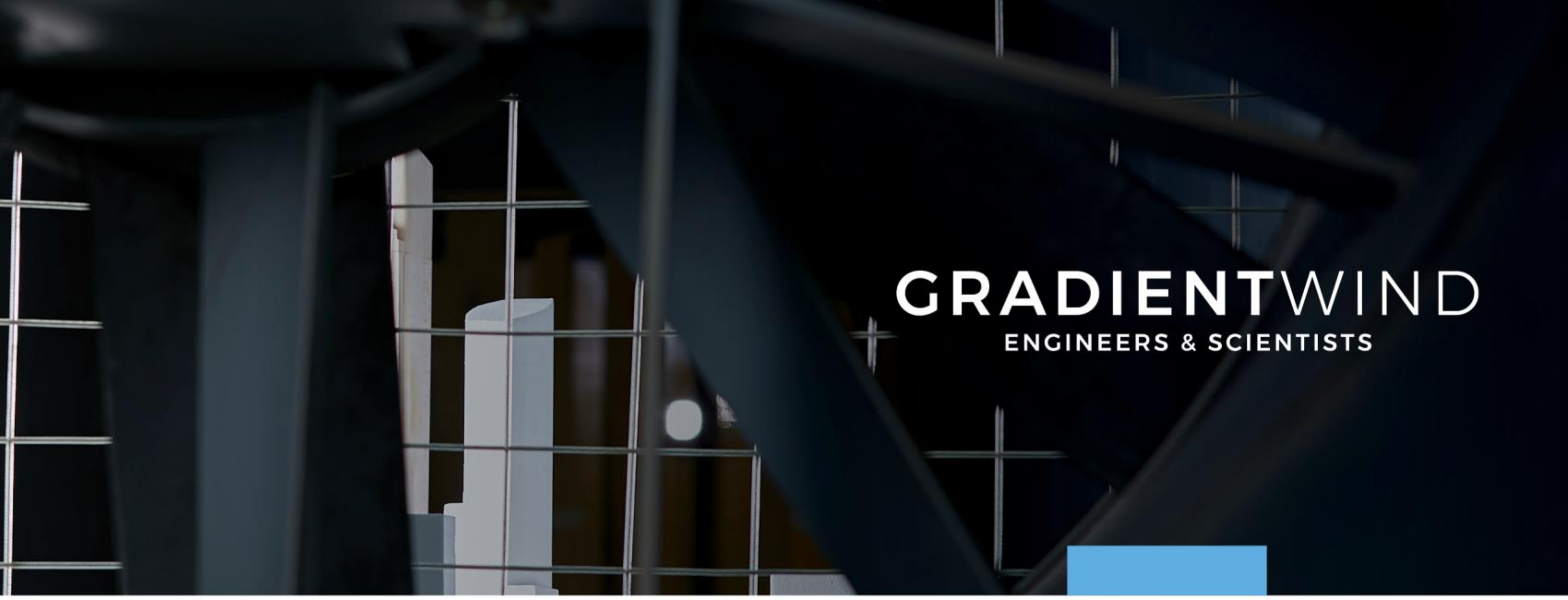
TABLE A1: SUMMARY OF PEDESTRIAN COMFORT (EXISTING SCENARIO)

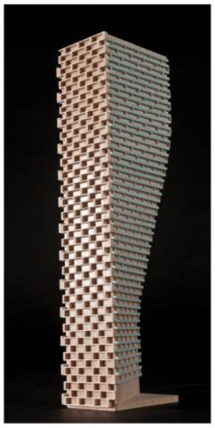
Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
1	9.3	Sitting	11.7	Standing	38.7	Safe
2	8.3	Sitting	10.3	Standing	39.3	Safe
3	10.8	Standing	12.8	Standing	49.1	Safe
4	11.5	Standing	13.9	Standing	54.8	Safe
5	10.0	Sitting	12.0	Standing	44.2	Safe
6	7.1	Sitting	8.9	Sitting	32.6	Safe
7	9.4	Sitting	12.5	Standing	41.1	Safe
8	10.6	Standing	13.4	Standing	48.0	Safe
9	11.0	Standing	14.3	Standing	49.4	Safe
10	12.4	Standing	14.7	Standing	55.9	Safe
11	6.6	Sitting	8.5	Sitting	32.6	Safe
12	16.8	Walking	19.5	Walking	75.5	Safe
13	11.1	Standing	13.9	Standing	51.6	Safe
14	6.2	Sitting	7.5	Sitting	35.4	Safe
15	10.5	Standing	13.9	Standing	46.6	Safe
16	11.2	Standing	15.2	Walking	49.8	Safe
17	12.0	Standing	15.5	Walking	48.4	Safe
18	12.1	Standing	15.2	Walking	51.9	Safe
19	10.1	Standing	13.2	Standing	45.3	Safe
20	10.2	Standing	12.3	Standing	46.7	Safe
21	8.1	Sitting	10.0	Sitting	37.2	Safe
22	7.7	Sitting	9.8	Sitting	36.7	Safe
23	7.7	Sitting	10.3	Standing	36.8	Safe
24	8.8	Sitting	11.0	Standing	38.5	Safe
25	9.8	Sitting	11.8	Standing	41.0	Safe
26	9.7	Sitting	12.3	Standing	40.8	Safe
27	10.8	Standing	13.5	Standing	44.3	Safe
28	12.3	Standing	15.6	Walking	49.7	Safe
29	13.1	Standing	16.4	Walking	55.3	Safe
30	11.0	Standing	14.0	Standing	49.5	Safe
31	9.5	Sitting	12.4	Standing	42.8	Safe
32	8.4	Sitting	10.8	Standing	42.3	Safe
33	11.0	Standing	12.4	Standing	67.9	Safe
34	14.4	Standing	18.1	Walking	67.5	Safe
35	12.1	Standing	14.1	Standing	54.5	Safe

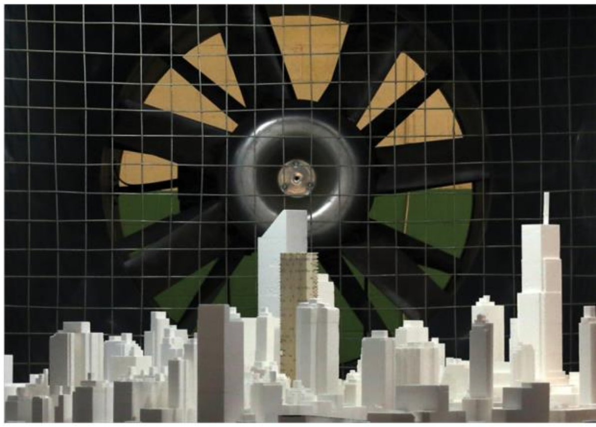
Guidelines	
Pedestrian Comfort	**20% exceedance wind speed** 0-10 km/h = Sitting, 10-15 km/h = Standing, 15-20 km/h = Walking, >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

TABLE A2: SUMMARY OF PEDESTRIAN COMFORT (EXISTING SCENARIO)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
36	10.5	Standing	12.1	Standing	50.0	Safe
37	7.1	Sitting	8.6	Sitting	32.1	Safe
38	8.8	Sitting	9.8	Sitting	46.3	Safe
39	11.5	Standing	13.8	Standing	49.1	Safe
40	8.7	Sitting	11.4	Standing	34.5	Safe
41	8.2	Sitting	10.1	Standing	36.7	Safe
42	9.0	Sitting	11.5	Standing	37.5	Safe
43	6.0	Sitting	7.5	Sitting	28.2	Safe
44	8.7	Sitting	10.3	Standing	38.0	Safe
45	8.2	Sitting	9.5	Sitting	40.7	Safe
46	8.2	Sitting	9.9	Sitting	40.1	Safe
47	6.9	Sitting	9.1	Sitting	33.0	Safe
48	7.0	Sitting	8.8	Sitting	33.5	Safe
49	7.6	Sitting	9.4	Sitting	35.3	Safe
50	6.6	Sitting	8.6	Sitting	30.0	Safe
51	9.6	Sitting	12.2	Standing	38.7	Safe
52	9.2	Sitting	11.6	Standing	38.9	Safe
53	9.6	Sitting	12.3	Standing	40.5	Safe







APPENDIX B

PEDESTRIAN COMFORT SUITABILITY, TABLES B1-B3
(PROPOSED SCENARIO)

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Guidelines	
Pedestrian Comfort	**20% exceedance wind speed** 0-10 km/h = Sitting, 10-15 km/h = Standing, 15-20 km/h = Walking, >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

TABLE B1: SUMMARY OF PEDESTRIAN COMFORT (PROPOSED SCENARIO)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
1	8.8	Sitting	10.7	Standing	35.6	Safe
2	9.8	Sitting	12.3	Standing	40.5	Safe
3	11.6	Standing	13.5	Standing	51.3	Safe
4	13.2	Standing	16.0	Walking	57.3	Safe
5	9.9	Sitting	11.9	Standing	45.6	Safe
6	10.1	Standing	12.5	Standing	43.0	Safe
7	11.7	Standing	14.0	Standing	52.6	Safe
8	11.6	Standing	15.7	Walking	55.5	Safe
9	10.9	Standing	14.7	Standing	54.7	Safe
10	10.0	Sitting	13.5	Standing	46.3	Safe
11	7.6	Sitting	10.0	Sitting	38.6	Safe
12	10.8	Standing	13.7	Standing	52.4	Safe
13	9.8	Sitting	13.2	Standing	50.5	Safe
14	6.1	Sitting	7.6	Sitting	31.6	Safe
15	10.9	Standing	14.5	Standing	49.2	Safe
16	10.6	Standing	14.8	Standing	51.0	Safe
17	12.9	Standing	17.6	Walking	57.2	Safe
18	11.5	Standing	15.2	Walking	47.9	Safe
19	11.7	Standing	16.0	Walking	48.1	Safe
20	17.2	Walking	20.2	Uncomfortable	64.8	Safe
21	11.6	Standing	13.6	Standing	49.8	Safe
22	9.9	Sitting	12.0	Standing	41.8	Safe
23	10.4	Standing	16.0	Walking	56.6	Safe
24	11.3	Standing	16.8	Walking	58.2	Safe
25	13.5	Standing	20.2	Uncomfortable	65.4	Safe
26	11.8	Standing	16.5	Walking	55.7	Safe
27	12.5	Standing	18.0	Walking	59.3	Safe
28	13.4	Standing	18.2	Walking	62.0	Safe
29	13.3	Standing	16.5	Walking	55.2	Safe
30	12.1	Standing	15.4	Walking	51.7	Safe
31	9.4	Sitting	11.6	Standing	44.9	Safe
32	8.6	Sitting	10.9	Standing	44.4	Safe
33	11.0	Standing	13.1	Standing	55.9	Safe
34	14.4	Standing	16.7	Walking	64.5	Safe
35	12.4	Standing	14.4	Standing	48.5	Safe

Guidelines	
Pedestrian Comfort	**20% exceedance wind speed** 0-10 km/h = Sitting, 10-15 km/h = Standing, 15-20 km/h = Walking, >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

TABLE B2: SUMMARY OF PEDESTRIAN COMFORT (PROPOSED SCENARIO)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
36	10.1	Standing	12.3	Standing	48.9	Safe
37	7.1	Sitting	8.5	Sitting	30.4	Safe
38	10.6	Standing	11.9	Standing	42.4	Safe
39	10.7	Standing	13.7	Standing	45.4	Safe
40	8.5	Sitting	11.1	Standing	32.4	Safe
41	11.6	Standing	16.0	Walking	49.6	Safe
42	13.1	Standing	16.5	Walking	50.5	Safe
43	7.3	Sitting	9.0	Sitting	36.9	Safe
44	13.0	Standing	15.9	Walking	53.4	Safe
45	13.4	Standing	15.8	Walking	53.0	Safe
46	11.0	Standing	12.5	Standing	44.7	Safe
47	8.4	Sitting	10.5	Standing	41.8	Safe
48	12.8	Standing	15.4	Walking	59.5	Safe
49	10.6	Standing	12.8	Standing	48.6	Safe
50	10.7	Standing	14.5	Standing	53.4	Safe
51	6.1	Sitting	9.0	Sitting	37.2	Safe
52	8.2	Sitting	11.5	Standing	47.3	Safe
53	9.3	Sitting	11.4	Standing	44.0	Safe
54	8.1	Sitting	11.2	Standing	42.3	Safe
55	14.3	Standing	18.4	Walking	61.6	Safe
56	10.0	Sitting	14.4	Standing	47.9	Safe
57	6.3	Sitting	8.5	Sitting	29.3	Safe
58	8.3	Sitting	10.0	Sitting	43.9	Safe
59	4.4	Sitting	5.5	Sitting	18.1	Safe
60	7.2	Sitting	10.3	Standing	40.1	Safe
61	7.9	Sitting	12.0	Standing	46.9	Safe
62	10.9	Standing	13.9	Standing	49.7	Safe
63	9.6	Sitting	12.5	Standing	44.1	Safe
64	13.7	Standing	15.5	Walking	63.4	Safe
65	9.9	Sitting	12.7	Standing	52.7	Safe
66	10.0	Sitting	11.8	Standing	45.3	Safe
67	9.2	Sitting	11.8	Standing	39.7	Safe
68	11.8	Standing	13.2	Standing	47.7	Safe
69	11.9	Standing	16.1	Walking	51.1	Safe
70	10.2	Standing	14.4	Standing	47.2	Safe

Guidelines	
Pedestrian Comfort	**20% exceedance wind speed** 0-10 km/h = Sitting, 10-15 km/h = Standing, 15-20 km/h = Walking, >20 km/h = Uncomfortable
Pedestrian Safety	**0.1% exceedance wind speed** 0-90 km/h = Safe

TABLE B3: SUMMARY OF PEDESTRIAN COMFORT (PROPOSED SCENARIO)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
71	11.6	Standing	15.1	Walking	49.2	Safe
72	8.1	Sitting	10.4	Standing	38.6	Safe
73	7.3	Sitting	9.4	Sitting	37.6	Safe
74	9.6	Sitting	12.1	Standing	47.8	Safe
75	13.9	Standing	17.7	Walking	67.2	Safe
76	15.1	Walking	18.7	Walking	61.7	Safe
77	12.3	Standing	14.7	Standing	55.2	Safe
78	15.1	Walking	18.7	Walking	59.7	Safe
79	8.7	Sitting	11.1	Standing	40.8	Safe
80	11.1	Standing	13.2	Standing	50.5	Safe
81	12.8	Standing	16.7	Walking	57.3	Safe
82	13.5	Standing	17.3	Walking	56.4	Safe
83	14.9	Standing	18.2	Walking	68.7	Safe
84	9.3	Sitting	11.2	Standing	44.6	Safe
85	17.6	Walking	22.1	Uncomfortable	82.2	Safe
86	16.1	Walking	23.3	Uncomfortable	70.2	Safe
87	13.3	Standing	15.5	Walking	55.9	Safe
88	15.6	Walking	18.8	Walking	72.2	Safe
89	9.1	Sitting	11.1	Standing	38.3	Safe
90	16.6	Walking	19.1	Walking	63.5	Safe

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APPENDIX C

WIND TUNNEL SIMULATION OF THE NATURAL WIND

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; U = mean wind speed, U_g = gradient wind speed, Z = height above ground, Z_g = depth of the boundary layer (gradient height) and α is the power law exponent.

Figure B1 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:

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

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 center of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel center-line axis.

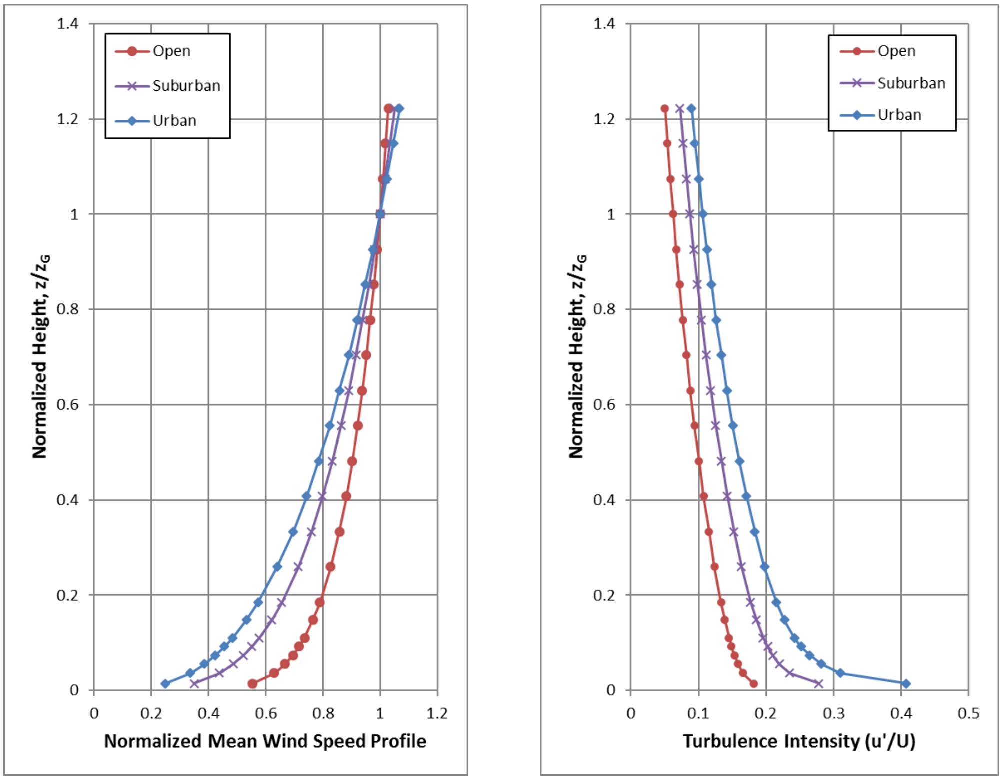

FIGURE C1 (LEFT): MEAN WIND SPEED PROFILES;
FIGURE C2 (RIGHT): TURBULENCE INTENSITY PROFILES

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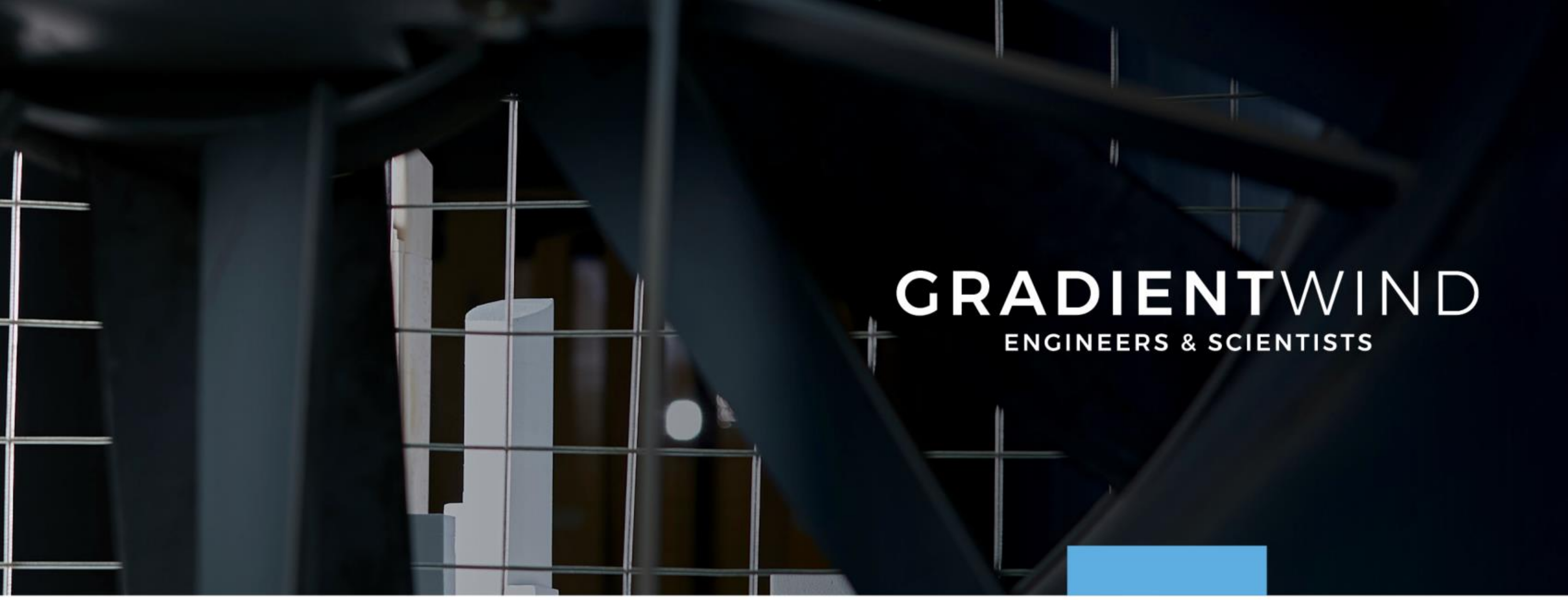
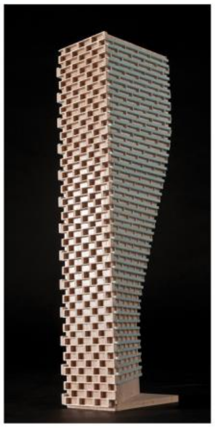
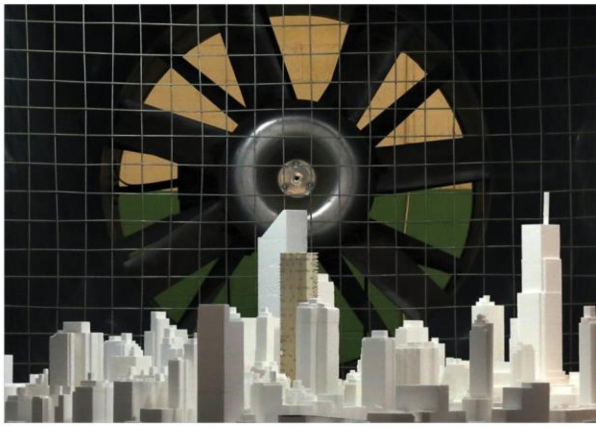
4. Bradley, E.F., Coppin, P.A., Katen, P.C., ‘*Turbulent Wind Structure Above Very Rugged Terrain*’, 9th Australian Fluid Mechanics Conference, Auckland, Dec. 1966







APPENDIX D

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

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 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:

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

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

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.

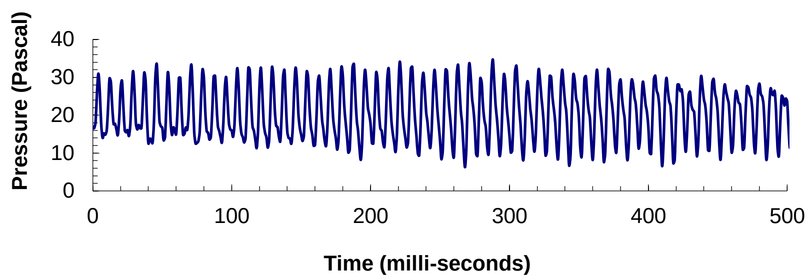


FIGURE D1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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