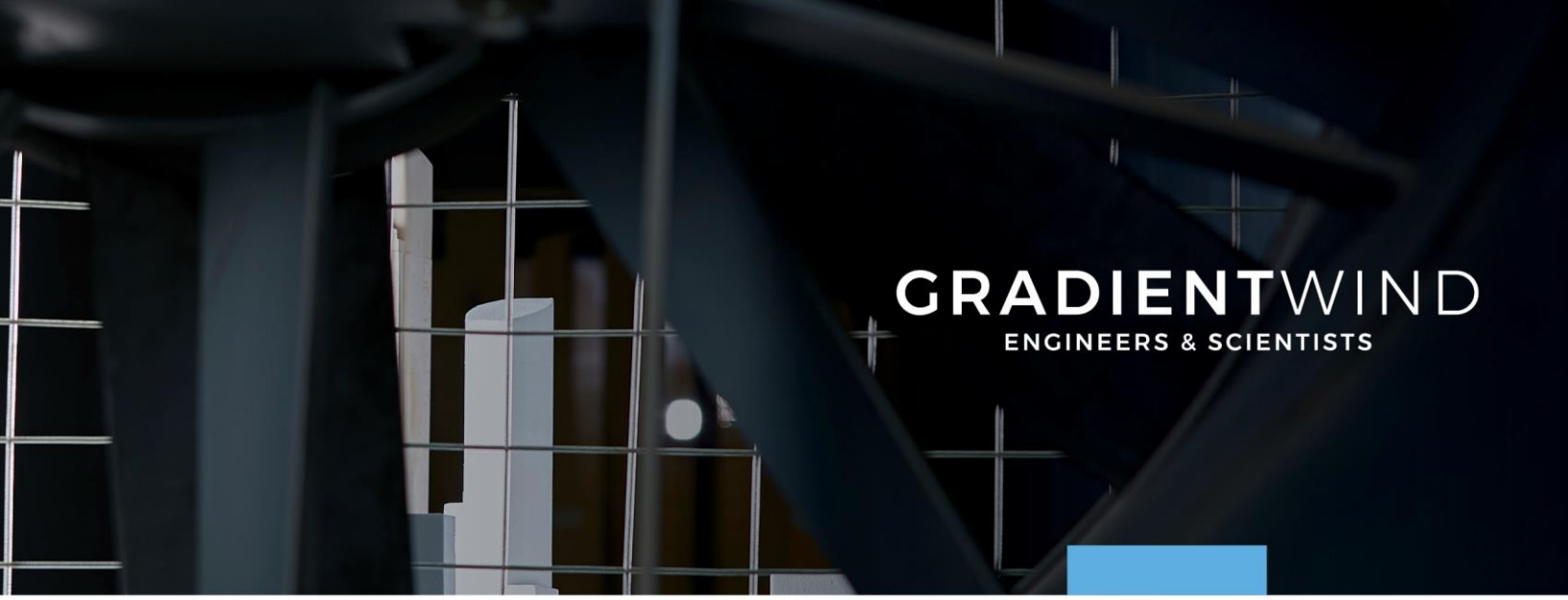
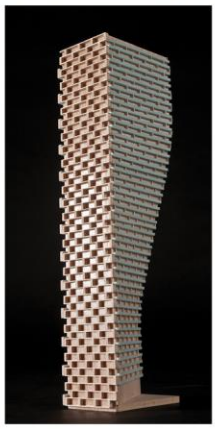


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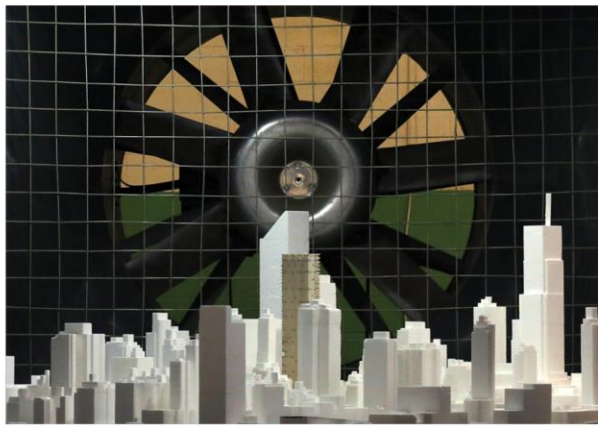
PEDESTRIAN LEVEL WIND STUDY

2362 Fairview Street
Burlington, Ontario

REPORT: GW23-092-WTPLW







April 23, 2024

PREPARED FOR

Lockwood Leasing
1141 South Service Road West
Oakville, Ontario
L6L 6K4

PREPARED BY

Cristiano Kondo, MESc., Junior Wind Scientist
Nick Petersen, P.Eng., Wind Engineer

EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed mixed-use development located at 2362 Fairview Street in Burlington, Ontario. 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. To evaluate the influence of the proposed development on the existing wind conditions surrounding the site, two massing 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. Grade-level areas investigated include sidewalks, walkways, driveways, landscaped spaces, parking areas, and building access points. Wind comfort is also evaluated over the Level 7 and rooftop outdoor amenity terraces. 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, City of Burlington wind criteria, architectural drawings provided by Weston Consulting in March 2024, surrounding street layouts, as well as existing and approved future building massing information 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-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 the area, we conclude that wind conditions, with respect to the *proposed* scenario over most grade level pedestrian-sensitive areas within and surrounding the development site, will be acceptable for the intended pedestrian uses on an annual and seasonal basis. Exceptions include all primary entrances, as well as the internal covered walkway and driveway, for which mitigation is recommended as described in Section 5.2. Additionally, the Level 7 outdoor amenity terraces will be suitable for sitting or more sedentary activities, without the need for mitigation. To ensure the entire rooftop outdoor amenity terrace is similarly suitable for sitting during the warmer months, mitigation is recommended as described 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 wind conditions that could be considered unsafe.

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1. INTRODUCTION

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed mixed-use development located at 2362 Fairview Street in Burlington, Ontario, in support of an OPA/ZBA submission. Two conditions 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, City of Burlington wind criteria, architectural drawings provided by Weston Consulting in March 2024, 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 pedestrian wind study is the proposed development located at 2362 Fairview Street in Burlington, Ontario. The study site is located approximately 300 metres northeast of the intersection of Drury Lane and Fairview Street.

The development comprises an 11-storey building with a "U"-shaped planform open to the south (relative to the project north) and aligned longitudinally with Fairview Street. A proposed driveway runs north-south, perpendicular to Fairview Street, bisecting the ground floor and providing access to loading areas, surface parking, and a ramp to three levels of underground parking. The west portion comprises a community space and a residential lobby to the north fronting the internal driveway, a loading area and an indoor amenity to the east, and residential units elsewhere. The layout of the east portion largely mirrors the west portion, with a commercial space replacing the community space in the north. The upper levels are reserved for residential occupancy. The east and west floorplates bridge at Level 2 to cover the driveway below, and rise to full height, with progressive setbacks from the south at Levels 6, 7, 8, 9 and roof, also accommodating the outdoor amenity terraces at Level 7 and rooftop.

Regarding wind exposures, the near-field (defined as an area falling within a 200-metre radius of the site) and far-field (defined as the area beyond the near field and within a two-kilometer radius) surroundings of the development are characterized by low-rise residential and commercial buildings in all directions. Lake Ontario is approximately 2.3 km to the south.

Grade-level areas investigated include sidewalks, walkways, driveways, landscaped spaces, parking areas, and building access points. Wind comfort is also evaluated over the Level 7 and rooftop outdoor amenity terraces. Figures 1A and 1B illustrate the study site and surrounding context for the existing and future test scenarios, 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 surrounding the site.

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 Burlington area wind climate and synthesis of wind tunnel data with industry-accepted guidelines. The following sections describe the analysis procedures, including a discussion of the pedestrian comfort and safety guidelines.

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 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 85 sensor locations on the scale model in Gradient Wind's wind tunnel. Of these 85 sensors, 68 were located at grade and the remaining 17 sensors were located on the Level 7 and rooftop outdoor amenity terraces. Wind speed measurements were performed for each of the 85 sensors for 36 wind directions at 10° intervals. Figures 1A and 1B illustrate a plan of the site and relevant surrounding context for the existing and future test scenarios, respectively, while sensor locations used to investigate wind conditions are illustrated in Figures 2A through 4B.

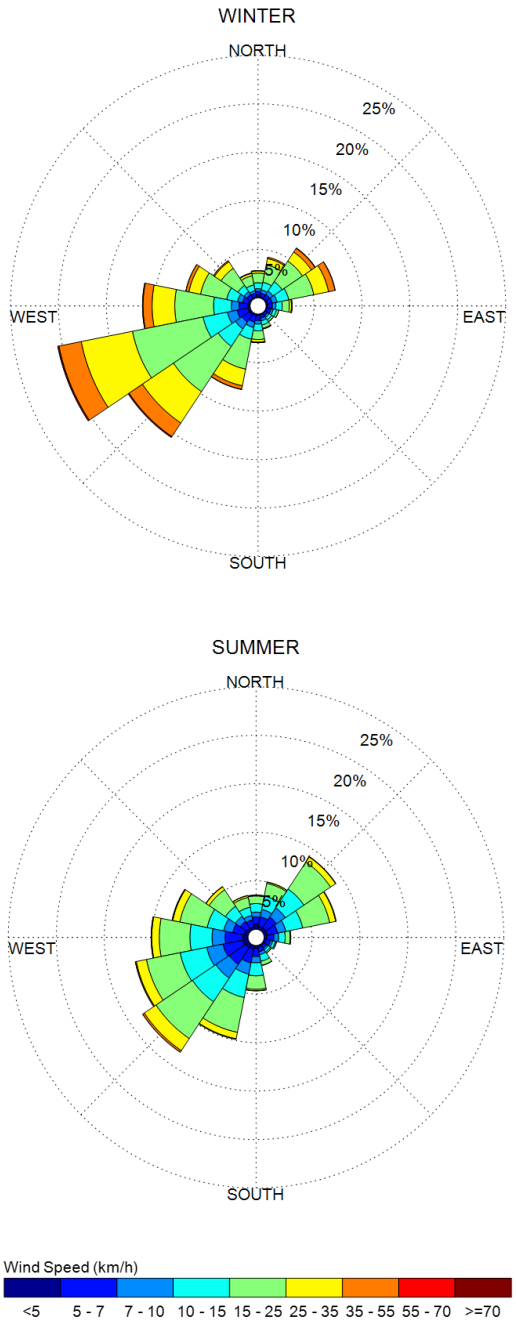
Mean and peak wind speed values for each location and wind direction were calculated from real-time pressure measurements, recorded at a sample rate of 500 samples per second, and taken over a 60-second time period. This period at model-scale corresponds approximately to one hour in full-scale, which 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 Burlington was developed from approximately 40-years of hourly meteorological wind data recorded at John C. Munro Hamilton International Airport, and obtained from the local branch of Atmospheric Environment Services of Environment Canada. Wind speed and direction data were analyzed for each month of the year in order to determine the statistically prominent wind directions and corresponding speeds, and to characterize similarities between monthly weather patterns. Following the Pedestrian Level Wind Study Guidelines and Terms of Reference for Burlington, the year is represented by a two-season model, and not according to the traditional calendar method.

The statistical model of the Burlington 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 km/h. Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Burlington, the most common winds concerning pedestrian comfort occur from the southwest, followed by those from the northeast. The directional preference and relative magnitude of the wind speed varies somewhat from season to season, with the summer months displaying calmer winds relative to the winter.

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES
JOHN C. MUNRO HAMILTON INTERNATIONAL AIRPORT, HAMILTON, ONTARIO



Notes:

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

4.4 Pedestrian 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. Four pedestrian comfort classes are based on 80% non-exceedance Guest Equivalent Mean (GEM) wind speed ranges, which include (i) Sitting; (ii) Standing; (iii) Strolling, (iv) Walking; and (v) Uncomfortable. More specifically, the comfort classes and associated GEM wind speed ranges are summarized as follows:

(i) **Sitting** – A wind speed below 10 km/h (i.e. 0 – 10 km/h) would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – A wind speed below 14 km/h (i.e. 10 km/h – 14 km/h) is acceptable for activities such as standing.

(iii) **Leisurely Walking (Strolling)** – A wind speed below 17 km/h (i.e. 14 km/h – 17 km/h) is acceptable for activities such as strolling.

(iv) **Fast Walking (Walking)**– A wind speed below 20 km/h (i.e. 17 km/h – 20 km/h) is acceptable for walking or more vigorous activities.

(v) **Uncomfortable** – A wind speed over 20 km/h is classified as uncomfortable from a pedestrian comfort standpoint. Brisk walking and exercise, such as jogging, would be acceptable for moderate excesses of this criterion.

The pedestrian safety wind speed guideline is based on the approximate threshold that would cause a vulnerable member of the population to fall. A 0.1% exceedance gust wind speed of greater than 90 km/h is classified as dangerous.

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 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 / Strolling
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens	Sitting / Standing / Strolling
Plazas	Strolling
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-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 17-20 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, strolling, 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, strolling by yellow, and walking by orange. Conditions considered uncomfortable for walking are represented by the colour magenta.

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-A2 in Appendix A and illustrated in Figures 2A through 2B, this section summarizes the significant findings of the PLW study with respect to the *existing scenario*, as follows:

1. All public sidewalks, walkways, driveways, landscaped spaces, and parking areas within and surrounding the proposed development currently experience wind conditions suitable for strolling or better throughout the year.
2. The existing backyard areas along the south side of the site (Sensors 15-18) are currently suitable for standing during the summer months and strolling or better during the winter months.
3. The nearby retail entrances directly east and west of the study site (Sensors 10 & 25, respectively), are currently suitable for standing or better on a seasonal basis.
4. 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 be suitable for walking or better throughout the year, which is acceptable for the intended uses of spaces. Exceptions include an isolated sidewalk portion along Fairview Street (Sensor 9), and portions of the covered walkway and driveway internal to the site (Sensors 53-55 & 58), which exceed the walking criterion during the winter months as salient winds are channelled through the breezeway.

   For the offsite sidewalk and the internal driveway portions (Sensors 9 & 58, respectively), the exceedance of the walking criterion is marginal (< 0.9km/h), restricted to the colder months, and wind speeds remain safe. Additionally, pedestrian use of the central driveway area is limited (Sensors 55 & 58). Therefore, the noted wind conditions are considered acceptable. For the walkways flanking the driveway (Sensors 53 & 54), it is recommended to stagger windscreens and/or dense planters along the walkway to buffer the channelled winds. The exact composition and configuration of these and other mitigations in the following paragraphs can be coordinated with the design team as the landscape plans develop.

2. All existing backyard areas along the south of the site (Sensors 15-18) will generally be suitable for standing or better during the summer months and walking or better during the winter months. It is notable that the significant plantings and high-solidity fencing surrounding each yard will result in significantly calmer conditions in practice. The noted conditions are considered acceptable for the intended uses of spaces.

3. Most primary residential lobby, commercial, and community space entrances will exceed the annual standing criterion (Sensors 53, 54, 56, & 57) as they are located in the windy breezeway. It is recommended to recess these entrances within the façade or provide flanking vertical wind barriers. Alternatively, consider relocating these entrances to areas with calmer wind speeds: the lobby entrances to the south elevations (Sensors 64 & 65), the commercial entrance to the west end of the north elevation (Sensor 50), and the community space entrance to the east end of the north elevation (Sensor 48/49).

   All secondary building access points (including vehicular entrances, building exits, and loading areas) will generally be suitable for strolling or better on a seasonal basis, which is acceptable.

4. The private grade-level townhome patios and entrances along the east, south, and west elevations will generally be suitable for standing or better throughout the year, which is appropriate.
5. The nearby existing retail entrances directly east and west of the study site (Sensors 10 & 25, respectively), will generally remain suitable for standing or better on a seasonal basis, which is acceptable.
6. The Level 7 outdoor amenity terraces (Sensors 69 & 70) will be suitable for sitting or more sedentary activities during the summer months, without the need for mitigation.
7. The rooftop outdoor amenity (Sensors 71-85) will generally be suitable for sitting during the summer months, with a few isolated areas experiencing intermittent standing wind conditions (Sensors 73, 80, 82, & 84). If sitting conditions are desired in these areas, then it is recommended to provide targeted upwind barriers and/or overhead pergolas/trellis structures. Barriers may take the form of high-solidity wind screens, dense coniferous plantings in planters, or a combination thereof, and should rise at least 1.6 metres at the time of installation.
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 could be 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 2362 Fairview Street in Burlington, 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-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 the area, we conclude that wind conditions, with respect to the *proposed* scenario over most grade level pedestrian-sensitive areas within and surrounding the development site, will be acceptable for the intended pedestrian uses on an annual and seasonal basis. Exceptions include all primary entrances, as well as the internal covered walkway and driveway, for which mitigation is recommended as described in Section 5.2.

Additionally, the Level 7 outdoor amenity terraces will be suitable for sitting or more sedentary activities, without the need for mitigation. To ensure the entire rooftop outdoor amenity terrace is similarly suitable for sitting during the warmer months, mitigation is recommended as described 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 wind conditions that could be considered unsafe.

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

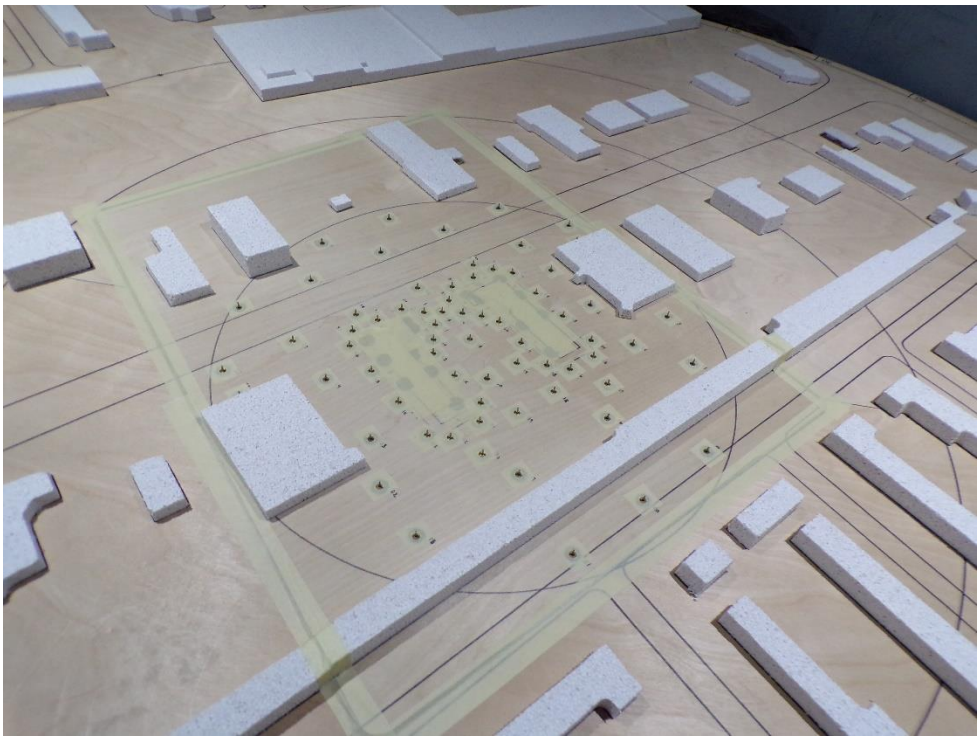
Sincerely,

Gradient Wind Engineering Inc.

Cristiano Kondo, MESc.,
Junior Wind Scientist

Nick Petersen, P.Eng.,
Wind Engineer

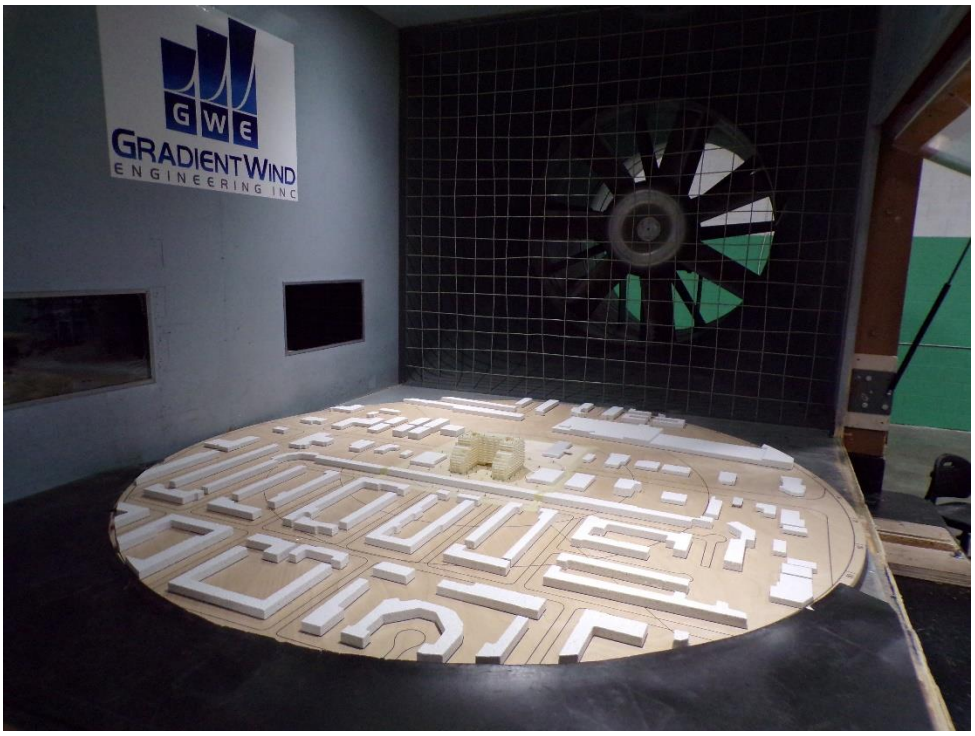
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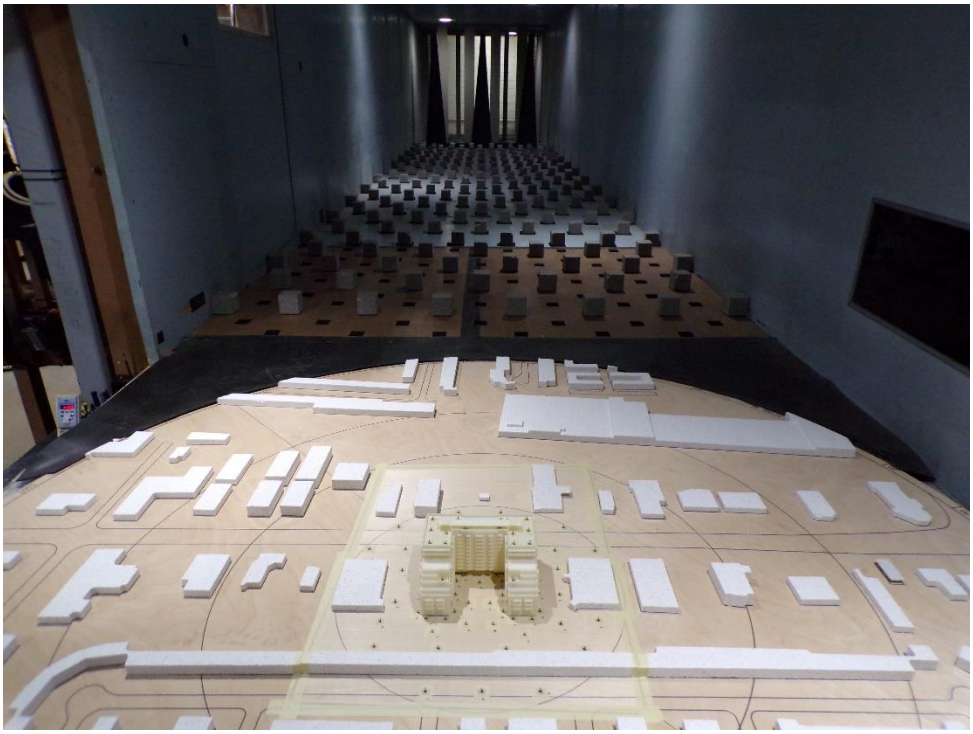
PHOTOGRAPH 1: CLOSE-UP VIEW OF EXISTING CONTEXT MODEL LOOKING NORTH



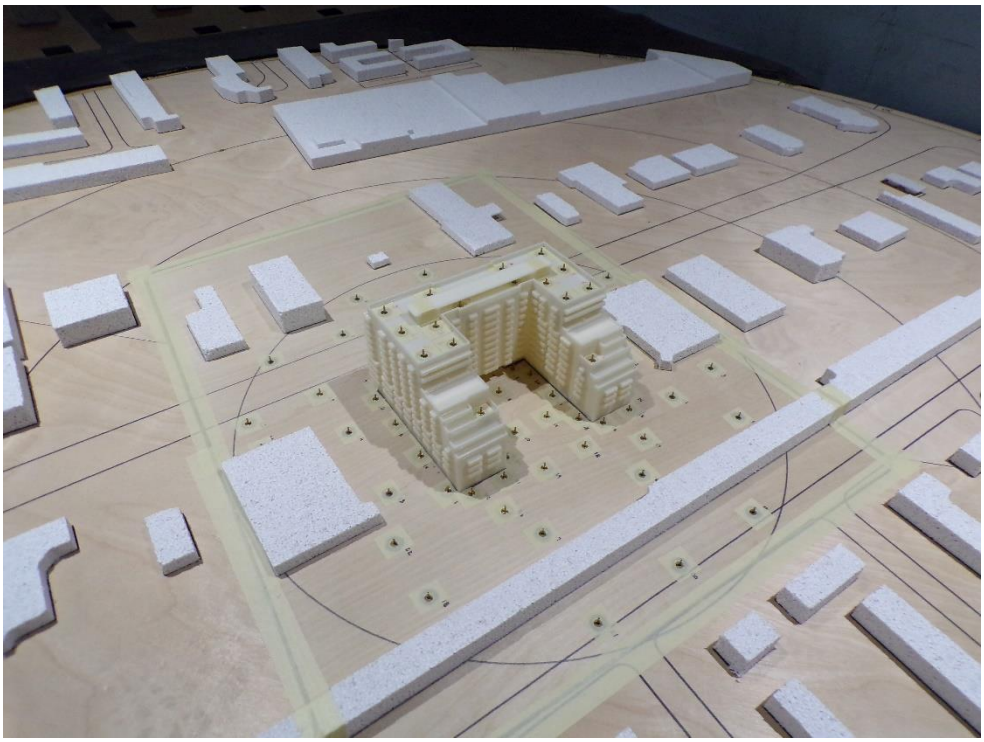
PHOTOGRAPH 2: CLOSE-UP VIEW OF EXISTING CONTEXT MODEL LOOKING SOUTH



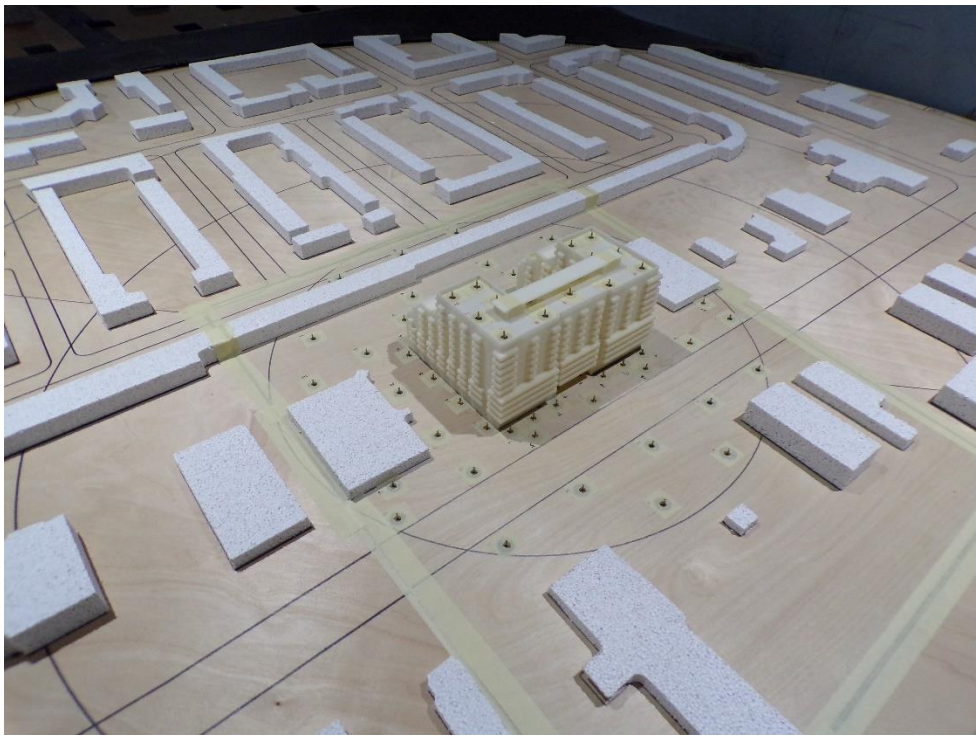
PHOTOGRAPH 3: PROPOSED STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING DOWNWIND



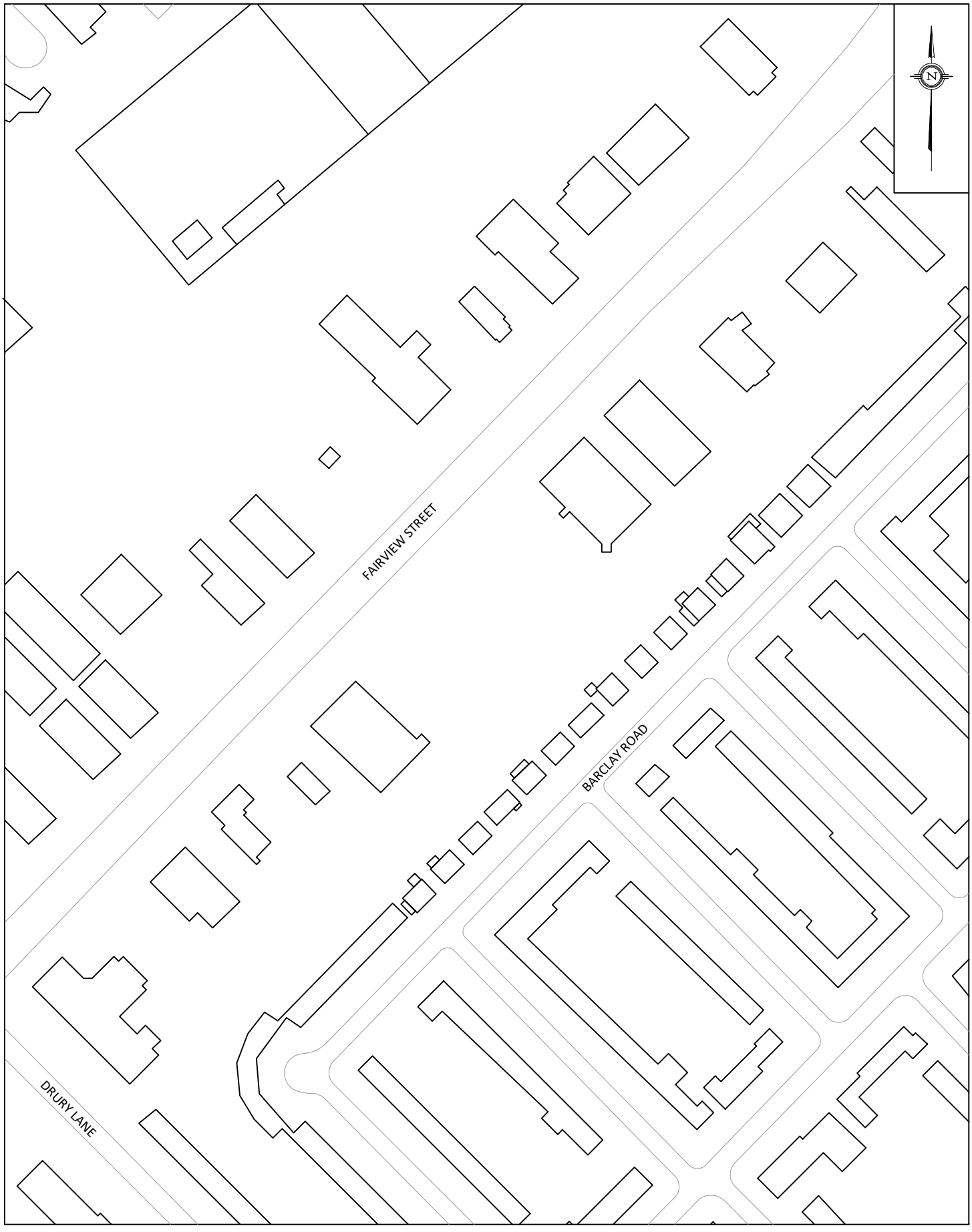
PHOTOGRAPH 4: PROPOSED STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING UPWIND



PHOTOGRAPH 5: CLOSE-UP VIEW OF STUDY MODEL LOOKING NORTH



PHOTOGRAPH 6: CLOSE-UP VIEW OF STUDY MODEL LOOKING SOUTH



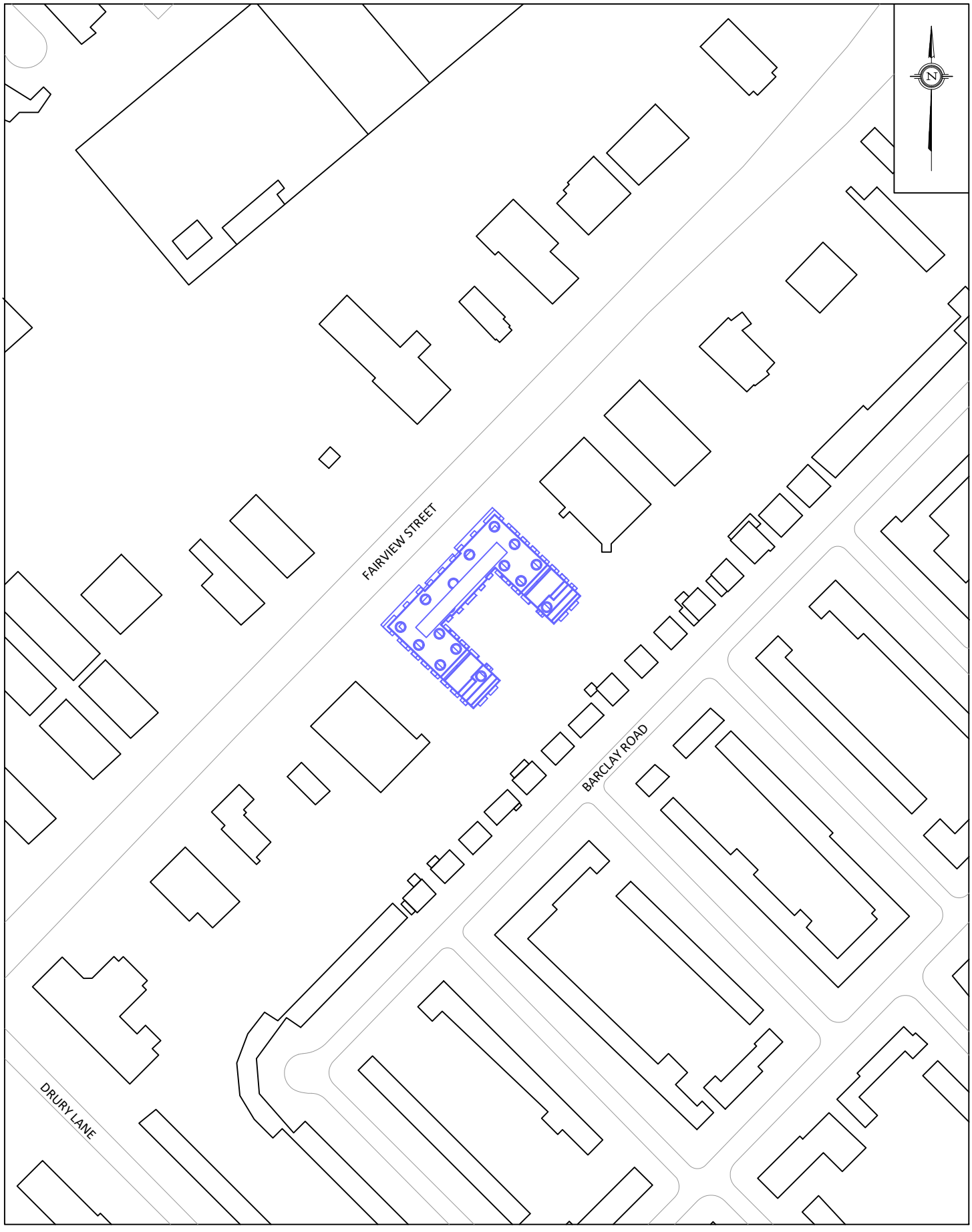
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SCALE	1:2500 (APPROX.)
DRAWING NO.	GW23-092-PLW-2024-1A
DATE	APRIL 23, 2024
DRAWN BY	K.A.

DESCRIPTION

FIGURE 1A:
EXISTING SCENARIO
AND SURROUNDING CONTEXT



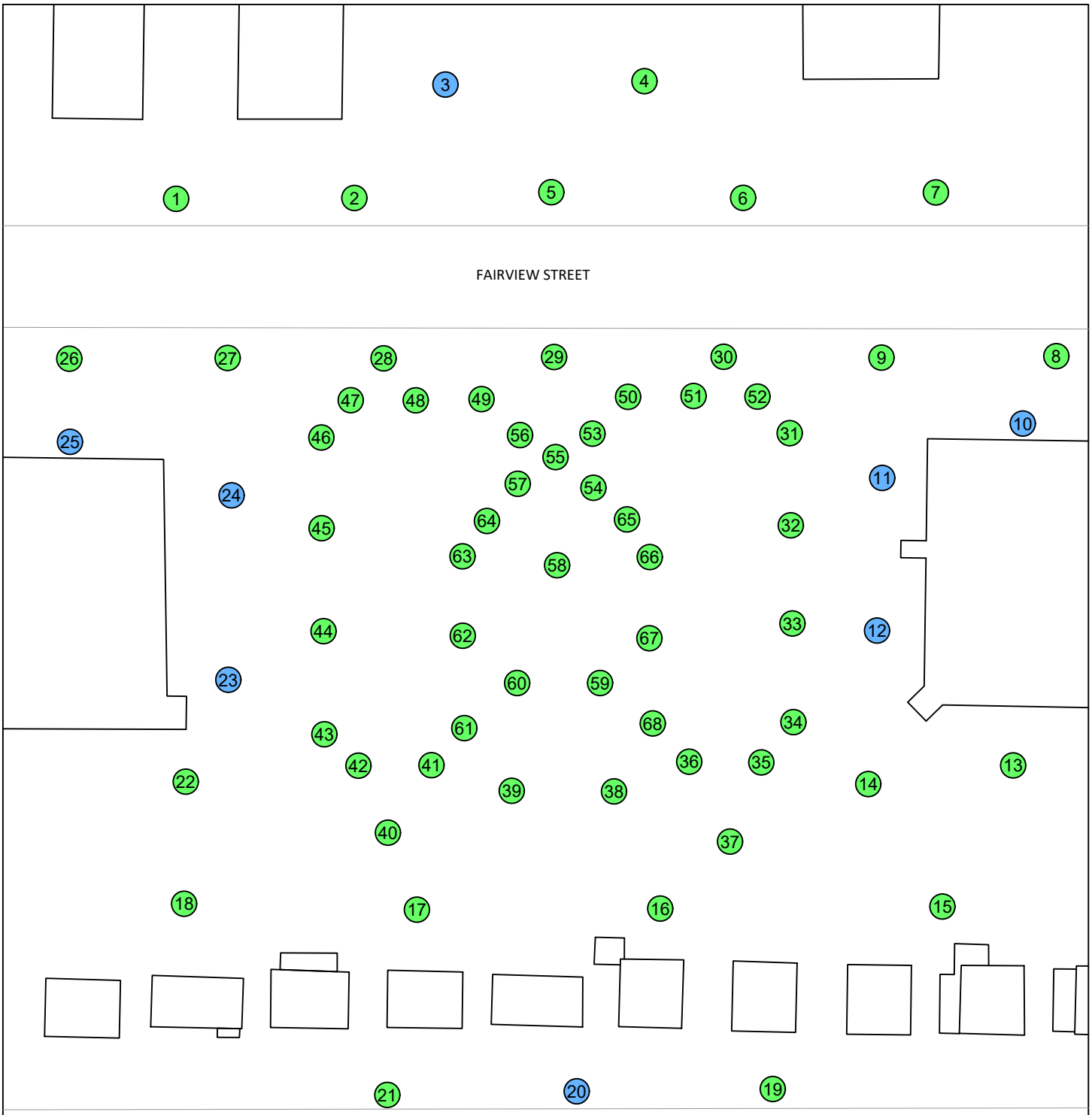
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DATE	APRIL 23, 2024
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DESCRIPTION

FIGURE 1B:
FUTURE SCENARIO
AND SURROUNDING CONTEXT

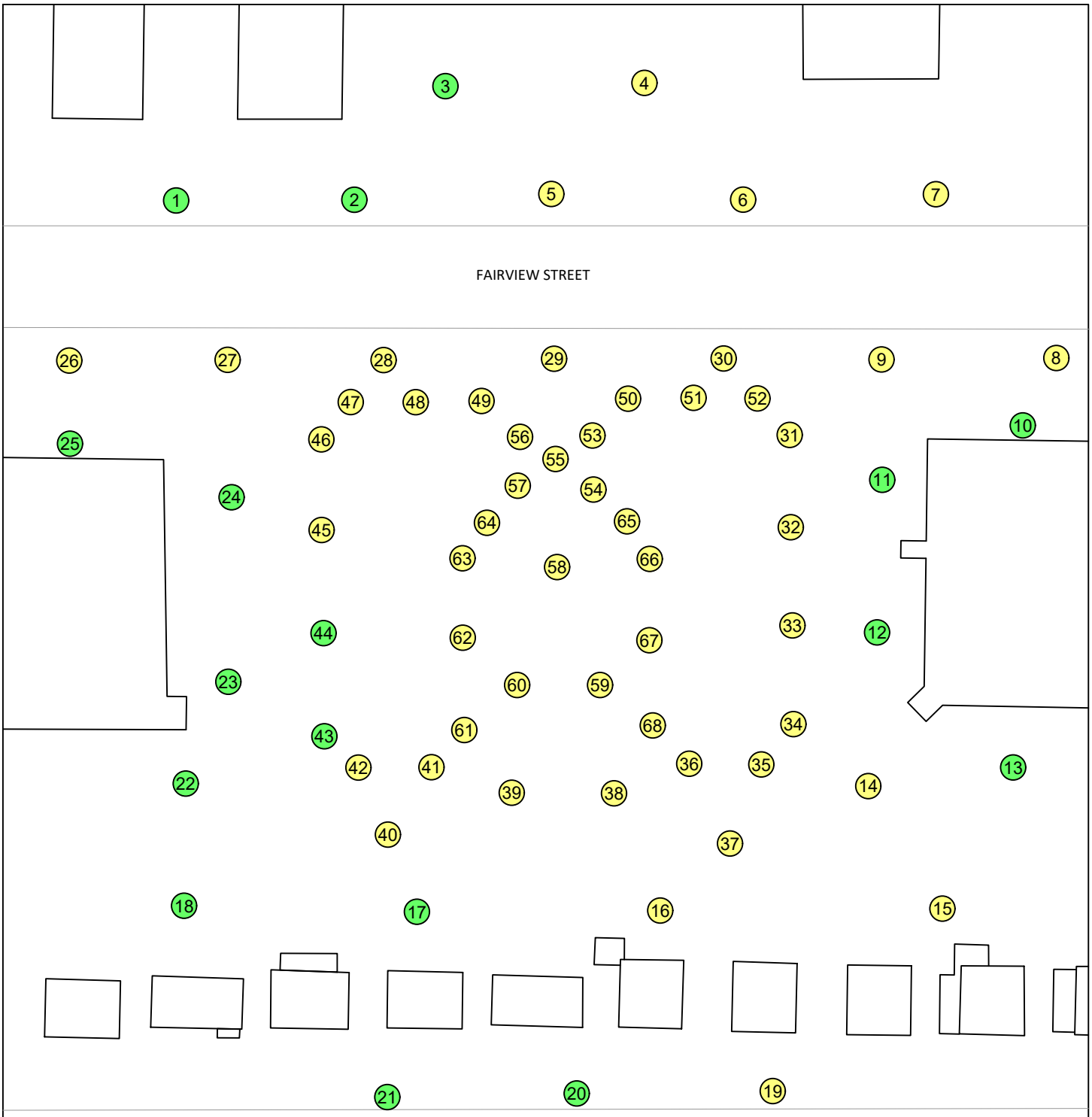


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DATE	APRIL 23, 2024
DRAWN BY	K.A.

DESCRIPTION

FIGURE 2A: SUMMER
EXISTING GRADE LEVEL PLW SENSOR LAYOUT
PEDESTRIAN COMFORT PREDICTIONS

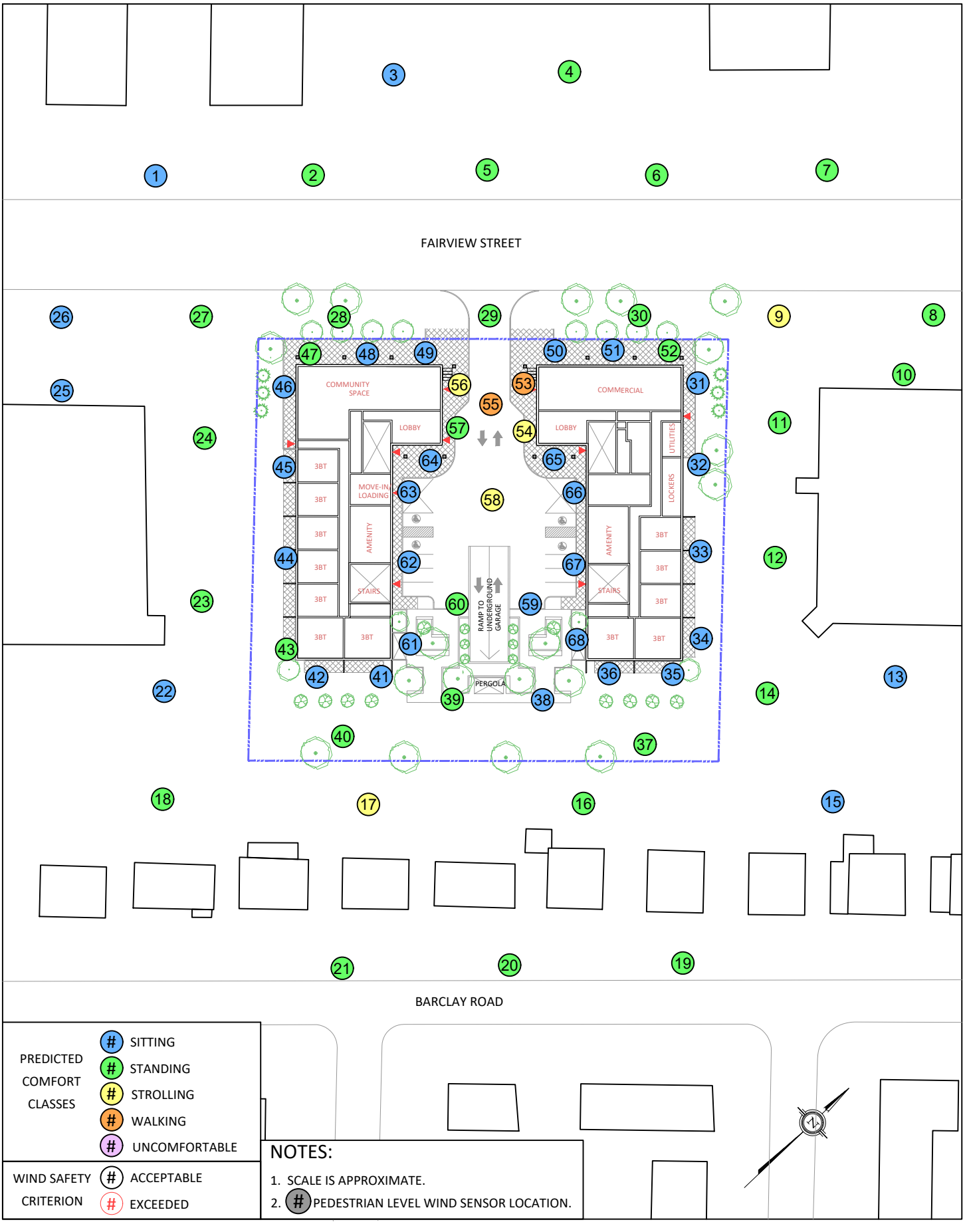


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SCALE	1:1000 (APPROX.)
DRAWING NO.	GW23-092-PLW-2024-2B
DATE	APRIL 23, 2024
DRAWN BY	K.A.

DESCRIPTION

FIGURE 2B: WINTER
EXISTING GRADE LEVEL PLW SENSOR LAYOUT
PEDESTRIAN COMFORT PREDICTIONS



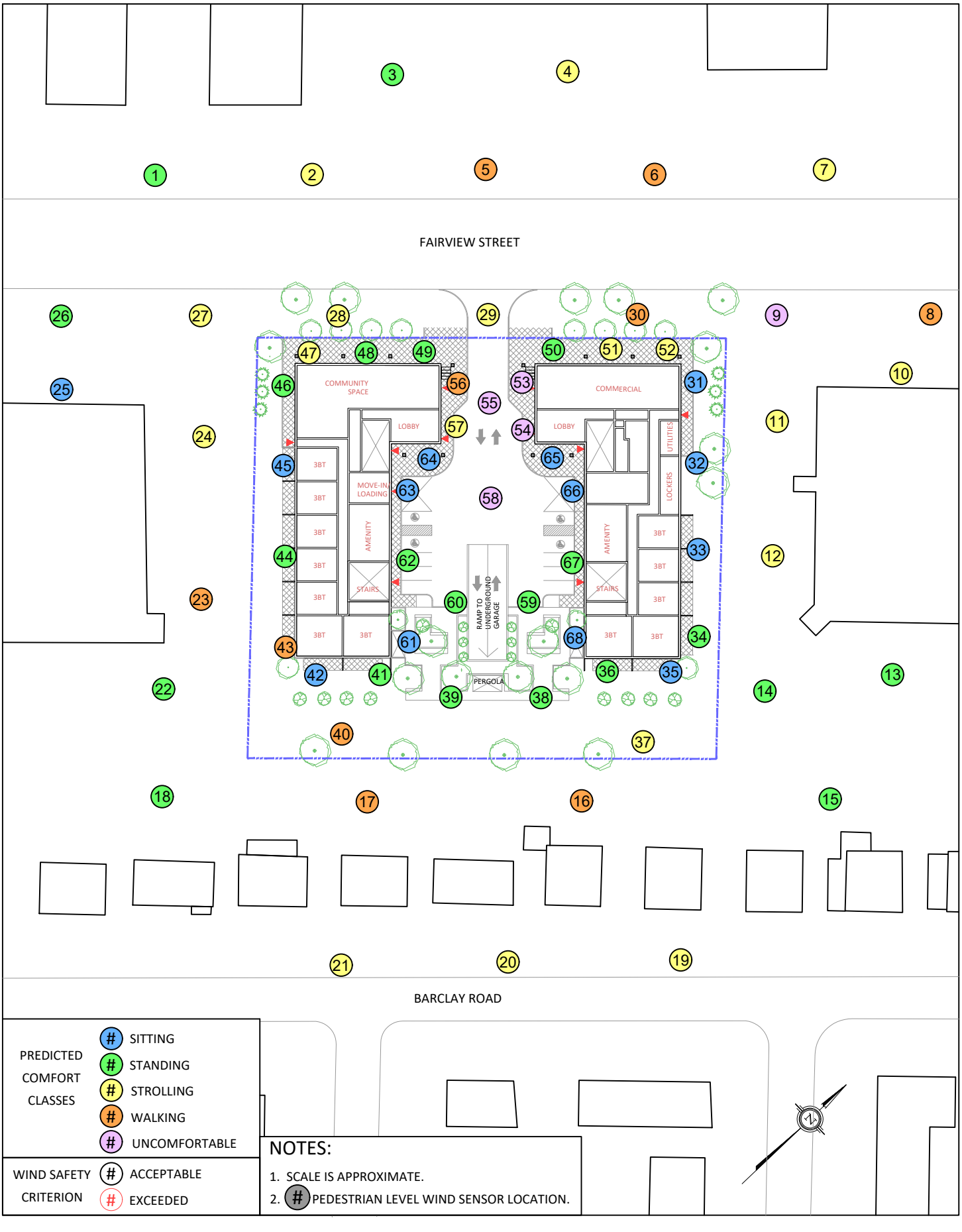
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PROJECT	2362 FAIRVIEW STREET, BURLINGTON PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1000 (APPROX.)
DRAWING NO.	GW23-092-PLW-2024-3A
DATE	APRIL 23, 2024
DRAWN BY	K.A.

DESCRIPTION

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



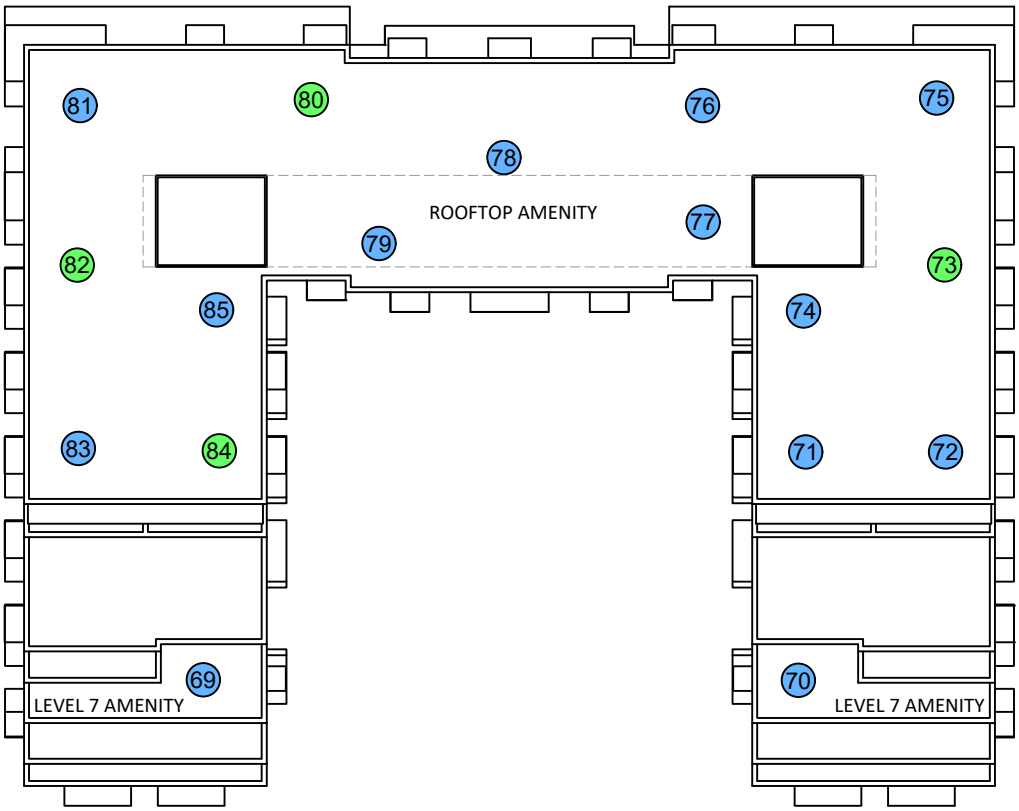
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PROJECT	2362 FAIRVIEW STREET, BURLINGTON PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1000 (APPROX.)
DRAWING NO.	GW23-092-PLW-2024-3B
DATE	APRIL 23, 2024
DRAWN BY	K.A.

DESCRIPTION

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



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

NOTES:

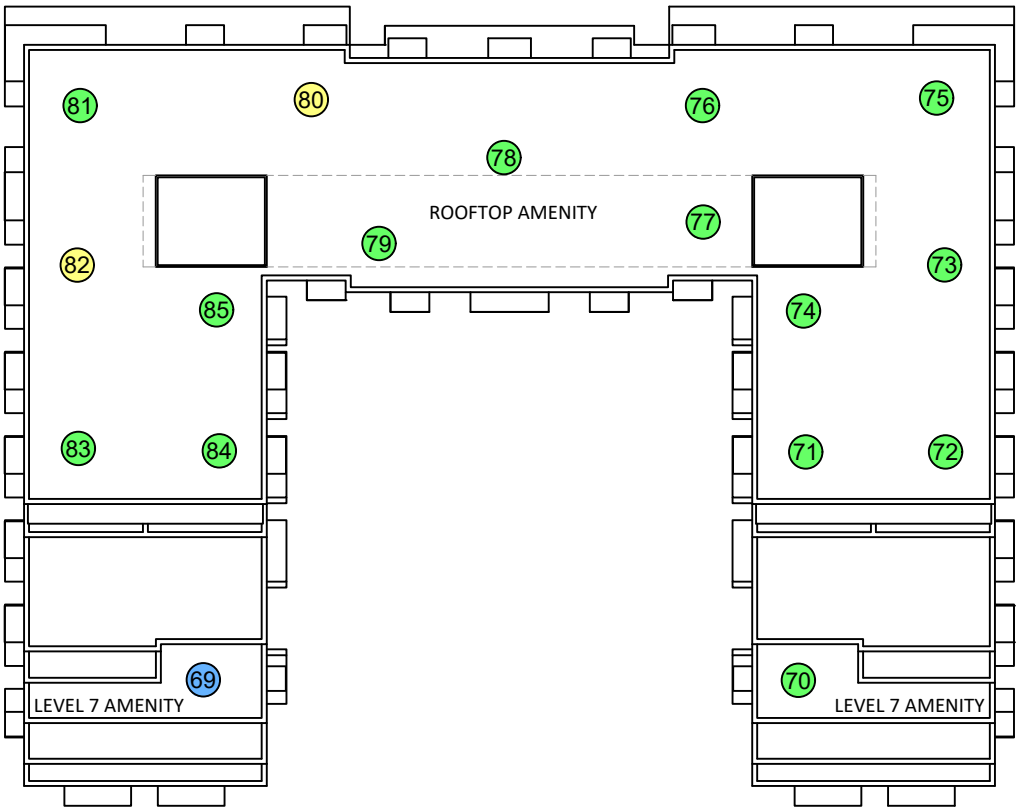
1. SCALE IS APPROXIMATE.
2. # PEDESTRIAN LEVEL WIND SENSOR LOCATION.

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PROJECT	2362 FAIRVIEW STREET, BURLINGTON PEDESTRIAN LEVEL WIND STUDY
SCALE	1:600 (APPROX.)
DRAWING NO.	GW23-092-PLW-2024-4A
DATE	APRIL 23, 2024
DRAWN BY	K.A.

DESCRIPTION

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



PREDICTED COMFORT CLASSES

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

WIND SAFETY CRITERION

- # ACCEPTABLE
- # EXCEEDED

NOTES:

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

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PROJECT	2362 FAIRVIEW STREET, BURLINGTON PEDESTRIAN LEVEL WIND STUDY
SCALE	1:600 (APPROX.)
DRAWING NO.	GW23-092-PLW-2024-4B
DATE	APRIL 23, 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)

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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 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	10.9	Standing	13.9	Standing	49.9	Safe
2	11.3	Standing	13.8	Standing	48.1	Safe
3	8.5	Sitting	10.8	Standing	39.8	Safe
4	11.1	Standing	14.3	Strolling	47.5	Safe
5	11.6	Standing	14.7	Strolling	48.5	Safe
6	12.9	Standing	16.9	Strolling	53.2	Safe
7	12.1	Standing	15.3	Strolling	51.8	Safe
8	12.0	Standing	16.2	Strolling	55.3	Safe
9	12.4	Standing	16.3	Strolling	51.5	Safe
10	9.0	Sitting	13.1	Standing	53.4	Safe
11	9.1	Sitting	12.1	Standing	39.6	Safe
12	7.7	Sitting	10.8	Standing	38.7	Safe
13	10.2	Standing	13.1	Standing	49.0	Safe
14	12.4	Standing	17.0	Strolling	53.3	Safe
15	10.7	Standing	14.4	Strolling	49.1	Safe
16	10.8	Standing	14.5	Strolling	50.1	Safe
17	10.2	Standing	13.4	Standing	46.7	Safe
18	10.3	Standing	13.7	Standing	47.6	Safe
19	10.3	Standing	14.2	Strolling	48.3	Safe
20	10.0	Sitting	13.4	Standing	45.4	Safe
21	10.4	Standing	13.8	Standing	46.7	Safe
22	10.2	Standing	12.9	Standing	46.9	Safe
23	8.0	Sitting	10.5	Standing	37.9	Safe
24	9.3	Sitting	12.1	Standing	43.7	Safe
25	7.8	Sitting	10.5	Standing	38.4	Safe
26	11.2	Standing	14.5	Strolling	50.6	Safe
27	12.5	Standing	16.7	Strolling	52.6	Safe
28	11.8	Standing	15.3	Strolling	49.9	Safe
29	12.3	Standing	16.3	Strolling	50.8	Safe
30	12.3	Standing	16.6	Strolling	53.0	Safe
31	12.1	Standing	16.2	Strolling	49.7	Safe
32	11.1	Standing	15.0	Strolling	51.3	Safe
33	10.8	Standing	14.7	Strolling	48.5	Safe
34	11.9	Standing	16.2	Strolling	50.7	Safe
35	11.8	Standing	15.7	Strolling	49.6	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 (EXISTING SCENARIO)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
36	11.8	Standing	15.6	Strolling	49.6	Safe
37	12.1	Standing	16.2	Strolling	52.9	Safe
38	12.1	Standing	16.2	Strolling	51.3	Safe
39	11.9	Standing	15.9	Strolling	50.7	Safe
40	11.7	Standing	15.4	Strolling	50.4	Safe
41	11.6	Standing	15.4	Strolling	48.3	Safe
42	11.4	Standing	14.9	Strolling	46.9	Safe
43	10.9	Standing	14.0	Standing	45.6	Safe
44	10.1	Standing	13.2	Standing	44.9	Safe
45	11.1	Standing	14.7	Strolling	48.3	Safe
46	11.5	Standing	15.5	Strolling	50.8	Safe
47	11.5	Standing	15.1	Strolling	50.0	Safe
48	12.0	Standing	15.6	Strolling	50.2	Safe
49	12.5	Standing	16.6	Strolling	50.7	Safe
50	11.5	Standing	15.2	Strolling	49.4	Safe
51	12.3	Standing	16.4	Strolling	51.4	Safe
52	11.6	Standing	15.4	Strolling	49.2	Safe
53	12.1	Standing	15.9	Strolling	50.5	Safe
54	12.1	Standing	16.1	Strolling	50.9	Safe
55	11.8	Standing	15.3	Strolling	49.3	Safe
56	12.0	Standing	15.8	Strolling	49.4	Safe
57	12.0	Standing	15.9	Strolling	49.6	Safe
58	12.0	Standing	15.6	Strolling	49.7	Safe
59	11.2	Standing	15.1	Strolling	49.7	Safe
60	11.0	Standing	14.7	Strolling	47.0	Safe
61	11.0	Standing	14.5	Strolling	47.3	Safe
62	11.9	Standing	15.8	Strolling	49.4	Safe
63	11.9	Standing	15.5	Strolling	50.0	Safe
64	11.6	Standing	15.4	Strolling	49.5	Safe
65	12.0	Standing	15.8	Strolling	50.7	Safe
66	11.5	Standing	15.1	Strolling	49.9	Safe
67	11.4	Standing	14.9	Strolling	48.0	Safe
68	11.4	Standing	15.2	Strolling	49.9	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, 10-14 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: 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	9.6	Sitting	12.2	Standing	44.0	Safe
2	12.5	Standing	15.5	Strolling	55.7	Safe
3	9.2	Sitting	11.7	Standing	51.6	Safe
4	11.8	Standing	15.4	Strolling	59.6	Safe
5	13.6	Standing	17.2	Walking	68.7	Safe
6	13.9	Standing	18.9	Walking	65.9	Safe
7	11.8	Standing	16.2	Strolling	54.7	Safe
8	11.6	Standing	17.3	Walking	65.7	Safe
9	14.6	Strolling	20.9	Uncomfortable	69.4	Safe
10	10.5	Standing	16.4	Strolling	68.4	Safe
11	12.3	Standing	16.0	Strolling	64.6	Safe
12	10.9	Standing	14.1	Strolling	52.9	Safe
13	8.9	Sitting	11.6	Standing	44.5	Safe
14	10.7	Standing	13.4	Standing	46.4	Safe
15	9.6	Sitting	12.0	Standing	41.2	Safe
16	13.6	Standing	18.3	Walking	64.1	Safe
17	14.2	Strolling	19.9	Walking	68.3	Safe
18	10.3	Standing	13.7	Standing	47.5	Safe
19	11.0	Standing	14.4	Strolling	53.6	Safe
20	11.4	Standing	15.7	Strolling	56.4	Safe
21	11.7	Standing	16.4	Strolling	56.9	Safe
22	8.1	Sitting	10.2	Standing	54.4	Safe
23	13.1	Standing	18.2	Walking	64.6	Safe
24	12.6	Standing	16.2	Strolling	60.8	Safe
25	6.8	Sitting	9.0	Sitting	40.3	Safe
26	9.1	Sitting	11.5	Standing	41.2	Safe
27	11.7	Standing	14.6	Strolling	50.8	Safe
28	12.3	Standing	16.0	Strolling	74.5	Safe
29	10.7	Standing	14.3	Strolling	53.3	Safe
30	13.7	Standing	19.2	Walking	70.0	Safe
31	7.9	Sitting	9.7	Sitting	55.0	Safe
32	6.5	Sitting	8.2	Sitting	33.8	Safe
33	7.0	Sitting	9.2	Sitting	36.8	Safe
34	8.5	Sitting	11.5	Standing	46.4	Safe
35	7.8	Sitting	9.8	Sitting	43.4	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 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	8.0	Sitting	10.3	Standing	42.3	Safe
37	12.3	Standing	15.2	Strolling	57.6	Safe
38	10.0	Sitting	12.6	Standing	49.5	Safe
39	10.1	Standing	13.0	Standing	46.6	Safe
40	12.8	Standing	17.1	Walking	70.3	Safe
41	8.3	Sitting	10.6	Standing	54.8	Safe
42	7.5	Sitting	9.2	Sitting	54.6	Safe
43	12.8	Standing	19.4	Walking	75.7	Safe
44	8.4	Sitting	12.3	Standing	53.8	Safe
45	6.9	Sitting	9.3	Sitting	37.5	Safe
46	8.3	Sitting	10.4	Standing	44.3	Safe
47	11.6	Standing	15.4	Strolling	66.2	Safe
48	8.2	Sitting	11.0	Standing	42.7	Safe
49	8.9	Sitting	12.8	Standing	52.6	Safe
50	7.4	Sitting	10.2	Standing	42.9	Safe
51	9.3	Sitting	14.2	Strolling	58.1	Safe
52	11.1	Standing	16.1	Strolling	60.7	Safe
53	17.3	Walking	23.8	Uncomfortable	73.9	Safe
54	16.9	Strolling	24.4	Uncomfortable	79.9	Safe
55	19.4	Walking	26.2	Uncomfortable	79.0	Safe
56	15.1	Strolling	19.8	Walking	81.0	Safe
57	12.1	Standing	15.0	Strolling	63.5	Safe
58	14.7	Strolling	20.2	Uncomfortable	68.2	Safe
59	10.0	Sitting	13.6	Standing	58.8	Safe
60	10.4	Standing	13.4	Standing	50.4	Safe
61	6.8	Sitting	8.7	Sitting	36.2	Safe
62	8.8	Sitting	10.8	Standing	49.9	Safe
63	6.3	Sitting	8.1	Sitting	33.8	Safe
64	6.3	Sitting	8.0	Sitting	38.4	Safe
65	6.0	Sitting	7.5	Sitting	29.3	Safe
66	6.2	Sitting	8.0	Sitting	31.0	Safe
67	9.2	Sitting	11.5	Standing	54.7	Safe
68	7.0	Sitting	9.1	Sitting	34.9	Safe
69	7.0	Sitting	8.8	Sitting	34.4	Safe
70	7.7	Sitting	10.6	Standing	42.2	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 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	9.9	Sitting	13.3	Standing	53.0	Safe
72	9.3	Sitting	12.7	Standing	48.9	Safe
73	10.1	Standing	12.8	Standing	51.0	Safe
74	8.6	Sitting	10.8	Standing	53.7	Safe
75	7.8	Sitting	10.2	Standing	43.6	Safe
76	9.5	Sitting	12.5	Standing	55.6	Safe
77	8.4	Sitting	11.4	Standing	58.9	Safe
78	9.1	Sitting	12.8	Standing	57.4	Safe
79	9.9	Sitting	13.8	Standing	62.1	Safe
80	10.9	Standing	16.7	Strolling	80.3	Safe
81	7.8	Sitting	10.7	Standing	51.6	Safe
82	11.3	Standing	15.9	Strolling	77.0	Safe
83	8.7	Sitting	11.3	Standing	44.5	Safe
84	10.3	Standing	13.6	Standing	56.8	Safe
85	8.0	Sitting	10.4	Standing	41.1	Safe



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; 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:

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

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 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.

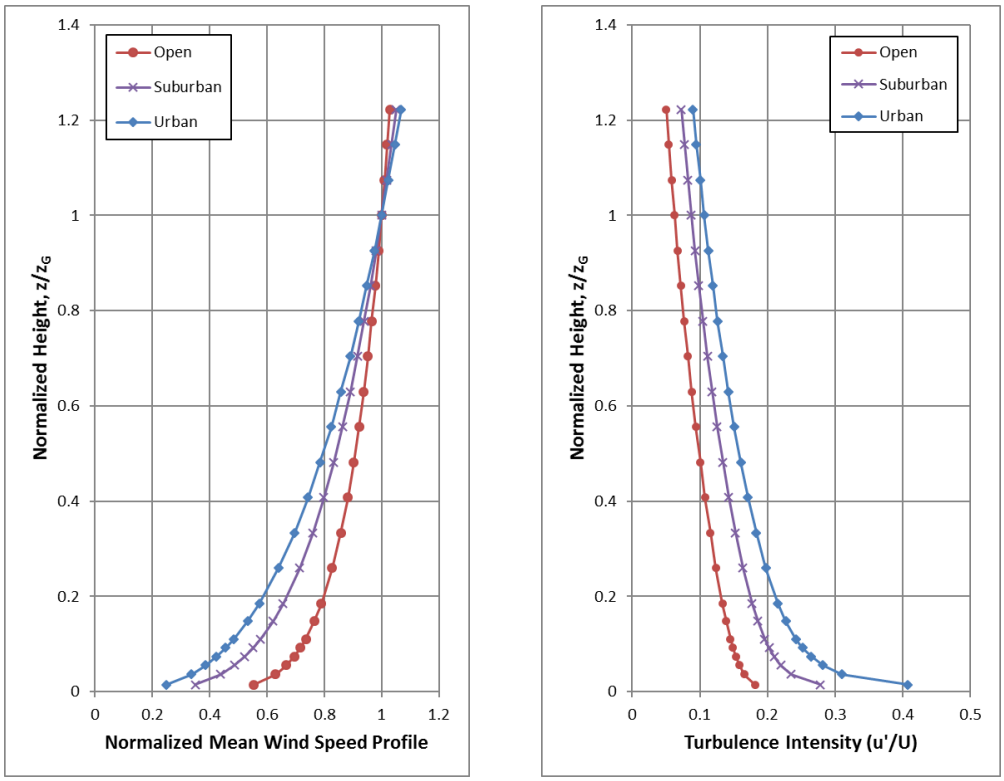


FIGURE C1 (LEFT): MEAN WIND SPEED PROFILES;
FIGURE C2 (RIGHT): TURBULENCE INTENSITY PROFILES

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2. Flay, R.G., Stevenson, D.C., 'Integral Length Scales in an Atmospheric Boundary Layer Near The Ground', 9th Australian Fluid Mechanics Conference, Auckland, Dec. 1966

3. ESDU, 'Characteristics of Atmospheric Turbulence Near the Ground', 74030

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

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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 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) = Σ_θ 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.

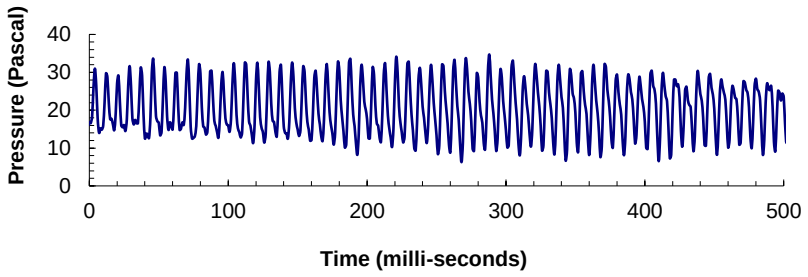


FIGURE D1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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