GRADIENTWIND
ENGINEERS & SCIENTISTS

PEDESTRIAN LEVEL WIND STUDY

175 John Street North
Hamilton, Ontario

REPORT: GW22-275-WTPLW

December 1st, 2022

PREPARED FOR

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed residential development located at 175 John Street North in Hamilton, 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. Grade-level areas investigated include sidewalks, surface parking, laneways, landscaped areas, transit stops, parks, and building access points. Wind comfort is also evaluated over the Level 3 outdoor amenity terrace. To evaluate the influence of the proposed development on the existing wind conditions surrounding the site, two massing configurations were studied: (i) existing conditions without the proposed development, and (ii) conditions with the proposed development in place. 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 Hamilton wind criteria, architectural drawings provided by SRM Architects Inc. in October 2022, 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 5.2 of this report, and is also illustrated in Figures 2A-4B, as well as Tables A1-A2 and B1-B2 in the appendices. Based on wind tunnel test results, meteorological data analysis, and experience with similar developments in the area, we conclude that conditions over all 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.

Regarding the Level 3 outdoor amenity, if calm conditions comfortable for sitting or more sedentary activities are desired throughout the full space 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 conditions that could be considered unsafe.

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Urban Solutions Planning & Land Development / SRM Architects Inc.
175 JOHN STREET, HAMILTON: PEDESTRIAN LEVEL WIND STUDY

1. INTRODUCTION

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed residential development located at 175 John Street North in Hamilton, Ontario. Two conditions were studied: (i) existing conditions, including all approved, surrounding developments and without the proposed development, and (ii) conditions with the proposed development in place. The study was performed in accordance with industry standard wind tunnel testing techniques, City of Hamilton wind criteria, architectural drawings provided by SRM Architects inc. in October 2022, 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 175 John Street North in Hamilton, Ontario. The study site is situated on a rectangular parcel of land, bounded by Cannon Street East to the south, John Street North to the east, Robert Street to the north, and Hughson Street North to the west.

The study building comprises a 19-storey building with a 2-storey parking podium. One level of below-grade parking and one level of above-grade parking are accessible from the east elevation. The ground floor comprises parking spaces, an amenity area, and a residential lobby fronting John Street North. At Level 3, the building sets back from all elevations to the typical tower floorplate, with indoor and outdoor amenity space provided along the north façade of the tower. Above Level 3, the building comprises exclusively of residential occupancy and rises to full height, where a mechanical penthouse completes the development.

Regarding wind exposures, the near- and far-field surroundings of the development (defined as an area falling within a 200-metre radius of the site, and as the area beyond the near field and within a two-kilometer radius, respectively) are characterized by low-rise suburban exposure in all directions, with Lake Ontario located approximately 1.2 kilometres to the north.

Grade-level areas investigated include sidewalks, surface parking, laneways, landscaped areas, transit stops, parks, and building access points. Wind comfort is also evaluated over the Level 3 balcony terrace amenity area. Figures 1A and 1B illustrate the study site and surrounding context for the existing and
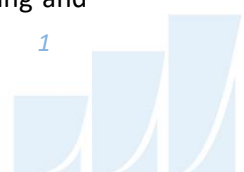
future test scenarios, respectively, and Photographs 1 through 6 depict the wind tunnel model used to conduct the study.

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 Hamilton 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 45 sensor locations on the scale model in Gradient Wind's wind tunnel. Of these 45 sensors, 43 were located at grade and the remaining two sensors were located over the Level 3 amenity balcony terrace. Wind speed measurements were performed for each of the 45 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 Hamilton 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 Terms of Reference: Pedestrian Level Wind Study for Downtown Hamilton, the year is represented by a two-season model, and not according to the traditional calendar method.

The statistical model of the Hamilton 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 Hamilton, 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
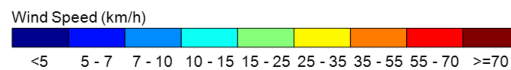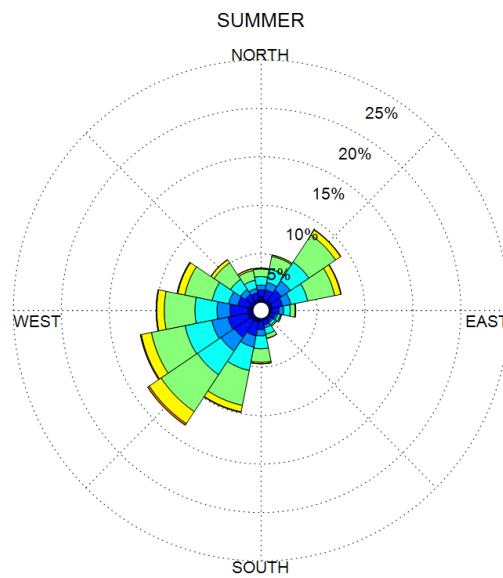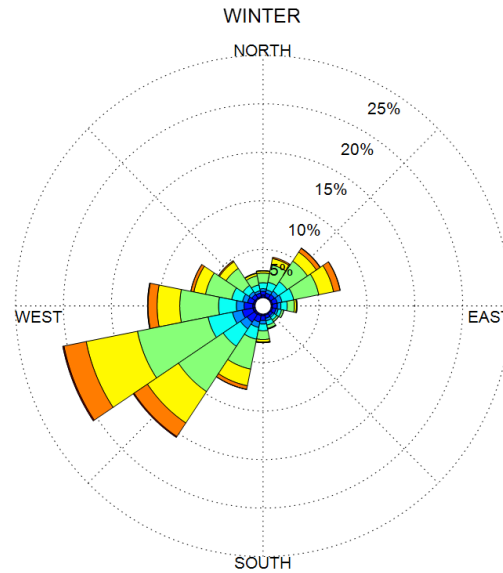
Notes:

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) Walking; and (iv) 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 15 km/h (i.e. 10 km/h – 15 km/h) is acceptable for activities such as standing or leisurely strolling.

(iii) **Walking** – A wind speed below 20 km/h (i.e. 15 km/h – 20 km/h) is acceptable for walking or more vigorous activities.

(iv) **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
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 through A2 in Appendix A provide a summary of seasonal comfort predictions for each sensor location under the *existing* massing scenario. Similarly, Tables B1 through B2 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.

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, surface parking, laneways, and landscaped areas within and surrounding the proposed development currently experience wind conditions suitable for walking or better during each seasonal period.

2. The transit stops located to the east along John Street North (Sensor 19), and south along Cannon Street East (Sensor 11), currently both experience wind conditions suitable for standing or better throughout the warmer months, with the transit stop to the south intermittently experiencing wind conditions suitable for walking in the winter.

3. McLaren Park to the east (Sensors 20, 21, 23, and 24) is currently comfortable for standing or better during the summer and walking or better during the winter.

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-B2 in Appendix B and illustrated in Figures 3A through 4D, this section summarizes the significant findings of the PLW study with respect to the *proposed scenario*, as follows:

1. Most public sidewalks, driveways, surface parking, and landscaped areas within and surrounding the proposed development will experience wind conditions suitable for walking or better during

each seasonal period, which is acceptable for the intended uses of the spaces. An exception occurs in a strip of landscaping along the west side of the north elevation (Sensors 30 and 31), where wind conditions will marginally exceed the walking criterion intermittently during the winter months. However, considering the marginality and limited basis of the exceedances, and the minimal pedestrian traffic expected in this area, mitigation is not considered necessary.

2. The transit stops located to the east along John Street North (Sensor 19), and south along Cannon Street East (Sensor 11), will both experience wind conditions suitable for standing or better during the warmer months, and walking or better during the winter. It is notable that the conditions at the stop along Connon Street East are pre-existing. If calmer conditions are desired, providing three-walled transit shelters would provide adequate protection during the winter months.

3. McLaren Park to the east (Sensors 20, 21, 23, and 24) will generally be comfortable for sitting during the summer and standing during the winter, which is an improvement from the existing conditions.

4. All primary and secondary building entrances (Including stairwell exits and vehicle access points) will experience wind conditions suitable for standing or better throughout the year, which is appropriate.

5. The Level 3 outdoor amenity balcony terrace (Sensors 44 and 45) will experience wind conditions during the warmer months suitable for sitting or more sedentary activities on the eastern portion of the terrace (Sensor 45), and standing or better on the western portion. It is notable that the exceedance of the sitting criterion during the summer months is marginal, and unless designated seating areas will be provided along the western portion, mitigation is not considered to be a requirement. If calmer conditions are desired, or if the noted west section will contain designated seating, it is recommended to provide 1.6-metre-tall targeted wind barriers, comprising high-solidity windscreens, raised planters with dense coniferous plantings, or a combination thereof, to the immediate northeast. Alternatively, such barriers could be placed along the north perimeter guard of the space or be substituted with targeted overhead canopy or pergola structures instead.

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6. 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.
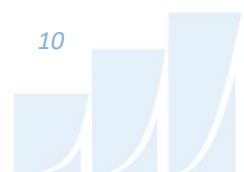
6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the methodology, results, and recommendations related to a pedestrian level wind study for a proposed mixed-use development located at 175 John Street North in Hamilton, 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 5.2 of this report, and is also illustrated in Figures 2A-4B, as well as Tables A1-A2 and B1-B2 in the appendices. Based on wind tunnel test results, meteorological data analysis, and experience with similar developments in the area, we conclude that conditions over all 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.

Regarding the Level 3 outdoor amenity, if calm conditions comfortable for sitting or more sedentary activities are desired throughout the full space 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 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.

Logan McFadden, B.Eng.,
Junior Wind Scientist

Nick Petersen, P.Eng.,
Wind Engineer

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PHOTOGRAPH 1: CLOSE-UP VIEW OF EXISTING CONTEXT MODEL LOOKING NORTHWEST
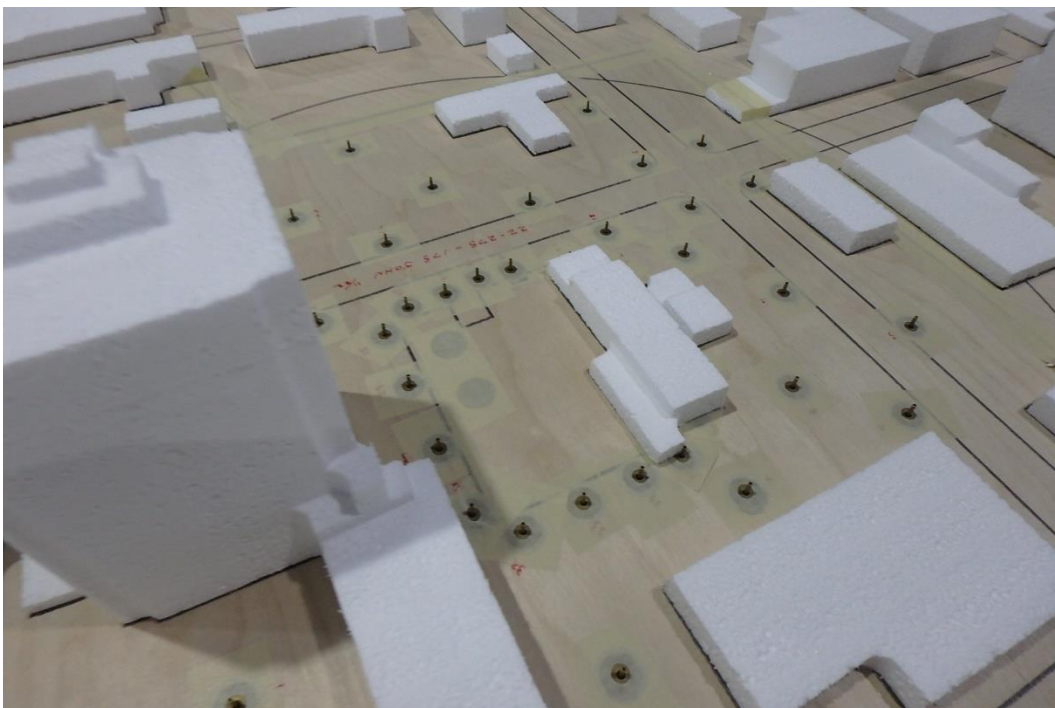
PHOTOGRAPH 2: CLOSE-UP VIEW OF EXISTING CONTEXT MODEL LOOKING SOUTHEAST
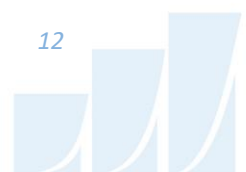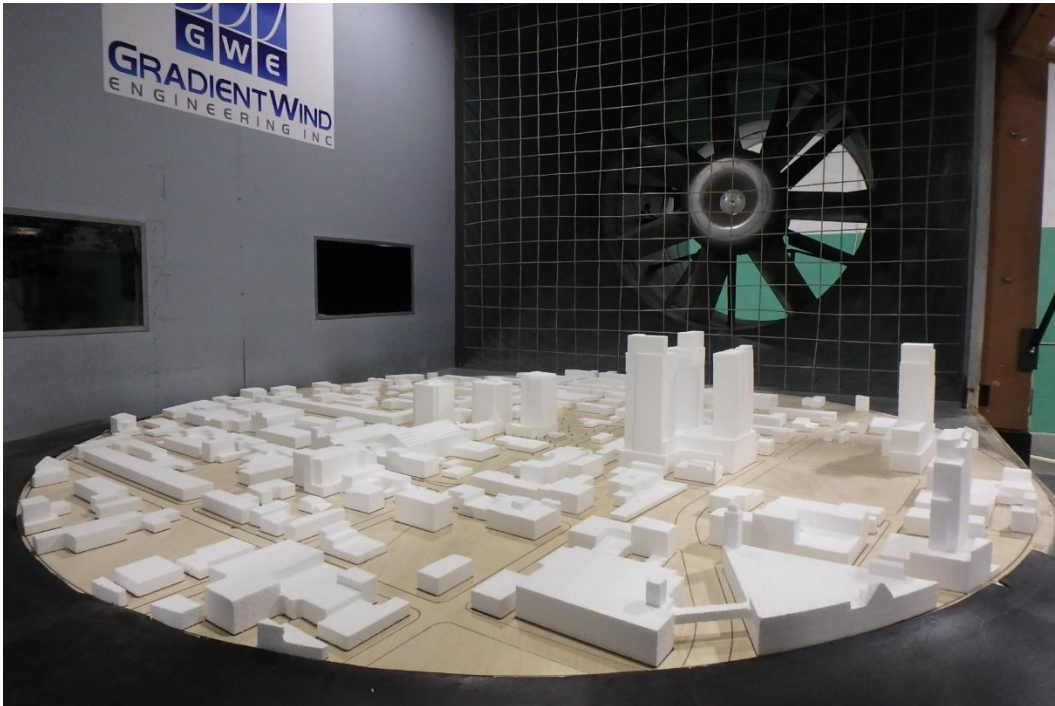
PHOTOGRAPH 3: STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING DOWNWIND

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

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

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

ROBERT STREET

HUGHSON STREET NORTH

JOHN STREET NORTH

CANNON STREET EAST

N
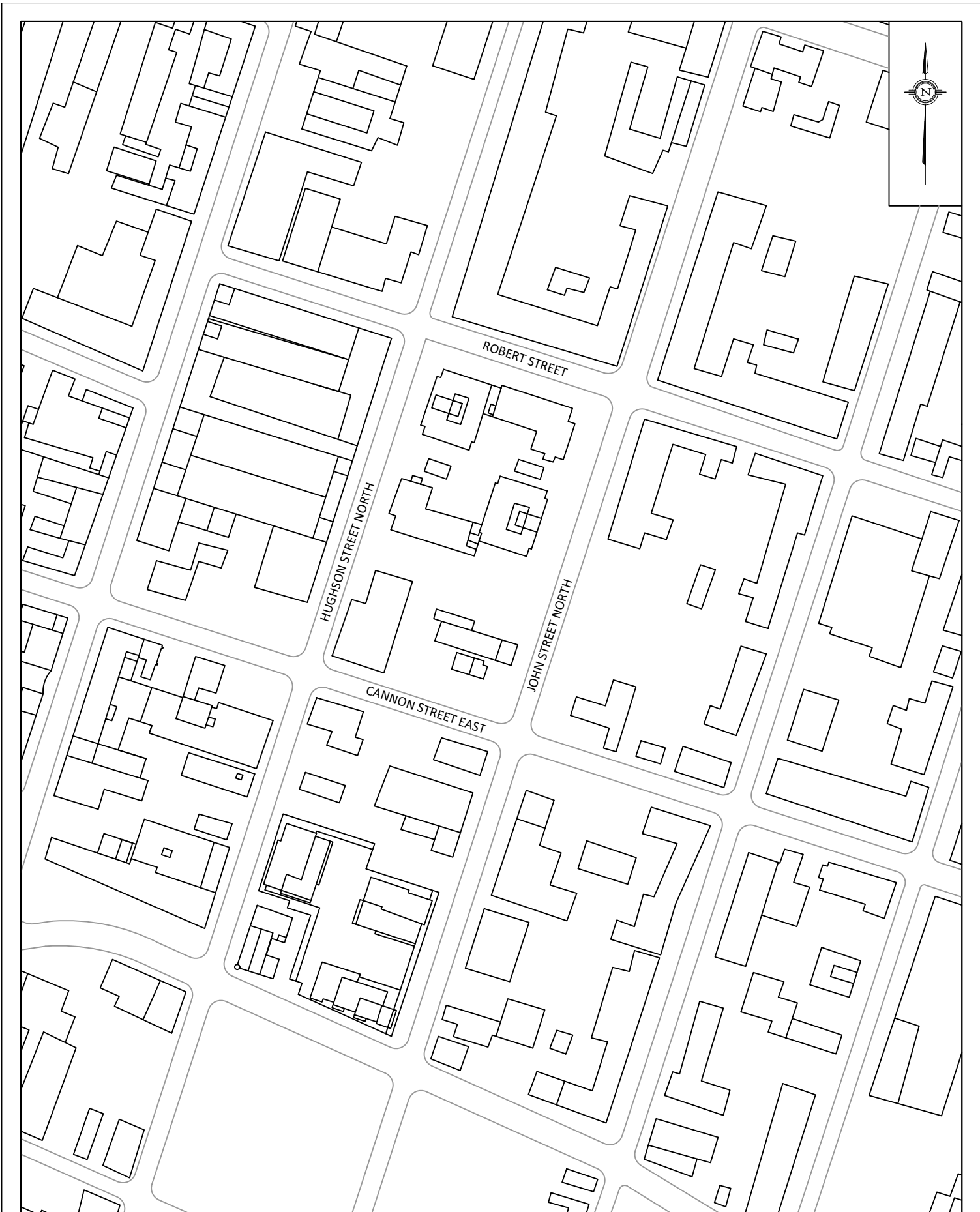
PROJECT
175 JOHN STREET N, HAMILTON
PEDESTRIAN LEVEL WIND STUDY

SCALE
1:2500 (APPROX.)

DRAWING NO.
GW22-275-PLW-1A

DATE
DECEMBER 1, 2022

DRAWN BY
C.E.

DESCRIPTION

FIGURE 1A:
EXISTING SITE PLAN
AND SURROUNDING CONTEXT

ROBERT STREET

HUGHSON STREET NORTH

JOHN STREET NORTH

CANNON STREET EAST

N

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| SCALE | 1:2500 (APPROX.) |
| DATE | DECEMBER 1, 2022 |

| DRAWING NO. | GW22-275-PLW-1B |
| DRAWN BY | C.E. |

DESCRIPTION

FIGURE 1B:
PROPOSED SITE PLAN
AND SURROUNDING CONTEXT

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

JOHN STREET NORTH

CANNON STREET EAST

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
1:850 (APPROX.)

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GW22-275-PLW-2A

DATE
DECEMBER 1, 2022

DRAWN BY
C.E.

DESCRIPTION
FIGURE 2A: SUMMER
EXISTING GROUND FLOOR PLAN
PEDESTRIAN COMFORT PREDICTIONS

JOHN STREET NORTH

CANNON STREET EAST

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	175 JOHN STREET N, HAMILTON PEDESTRIAN LEVEL WIND STUDY	DESCRIPTION
SCALE 1:850 (APPROX.)	DRAWING NO. GW22-275-PLW-2B	FIGURE 2B: WINTER EXISTING GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS
DATE DECEMBER 1, 2022	DRAWN BY C.E.	

FIGURE 3A: SUMMER PROPOSED GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS

Labels visible in drawing: JOHN STREET NORTH, CANNON STREET EAST, PARKING RAMP, LOADING, LOBBY, AMENITY

Legend:

PREDICTED COMFORT CLASSES
- (#) SITTING (blue)
- (#) STANDING (green)
- (#) WALKING (yellow)
- (#) UNCOMFORTABLE (orange)

WIND SAFETY CRITERION
- (#) ACCEPTABLE (black)
- (#) EXCEEDED (red)

NOTES:
1. SCALE IS APPROXIMATE.
2. (#) PEDESTRIAN LEVEL WIND SENSOR LOCATION.

PARKING RAMP

JOHN STREET NORTH

CANNON STREET EAST

LOADING

LOBBY

AMENITY

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	1:850 (APPROX.)
DRAWING NO.	GW22-275-PLW-3B
DATE	DECEMBER 1, 2022
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DESCRIPTION

FIGURE 3B: WINTER
PROPOSED GROUND FLOOR PLAN
PEDESTRIAN COMFORT PREDICTIONS

BALCONY TERRACE

44 45

AMENITY

AMENITY

AMENITY

1 BED + DEN

1 BED

BALCONY

BALCONY

2 BED

1 BED

2 BED
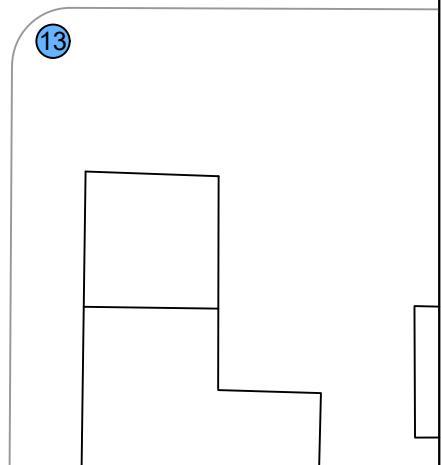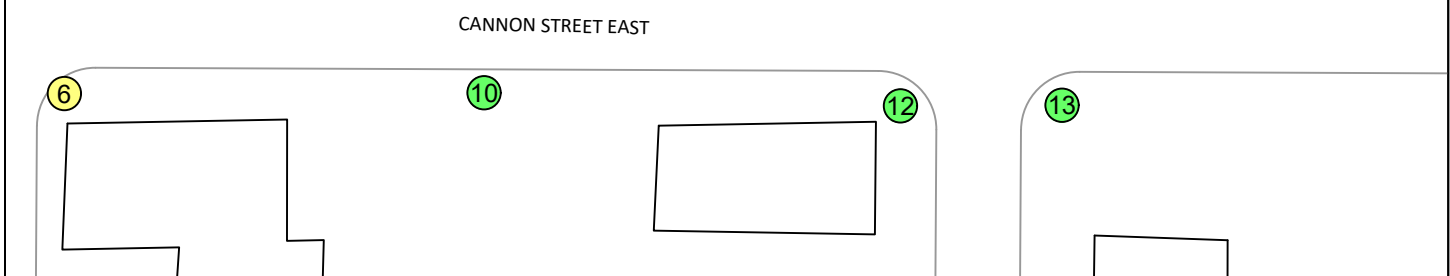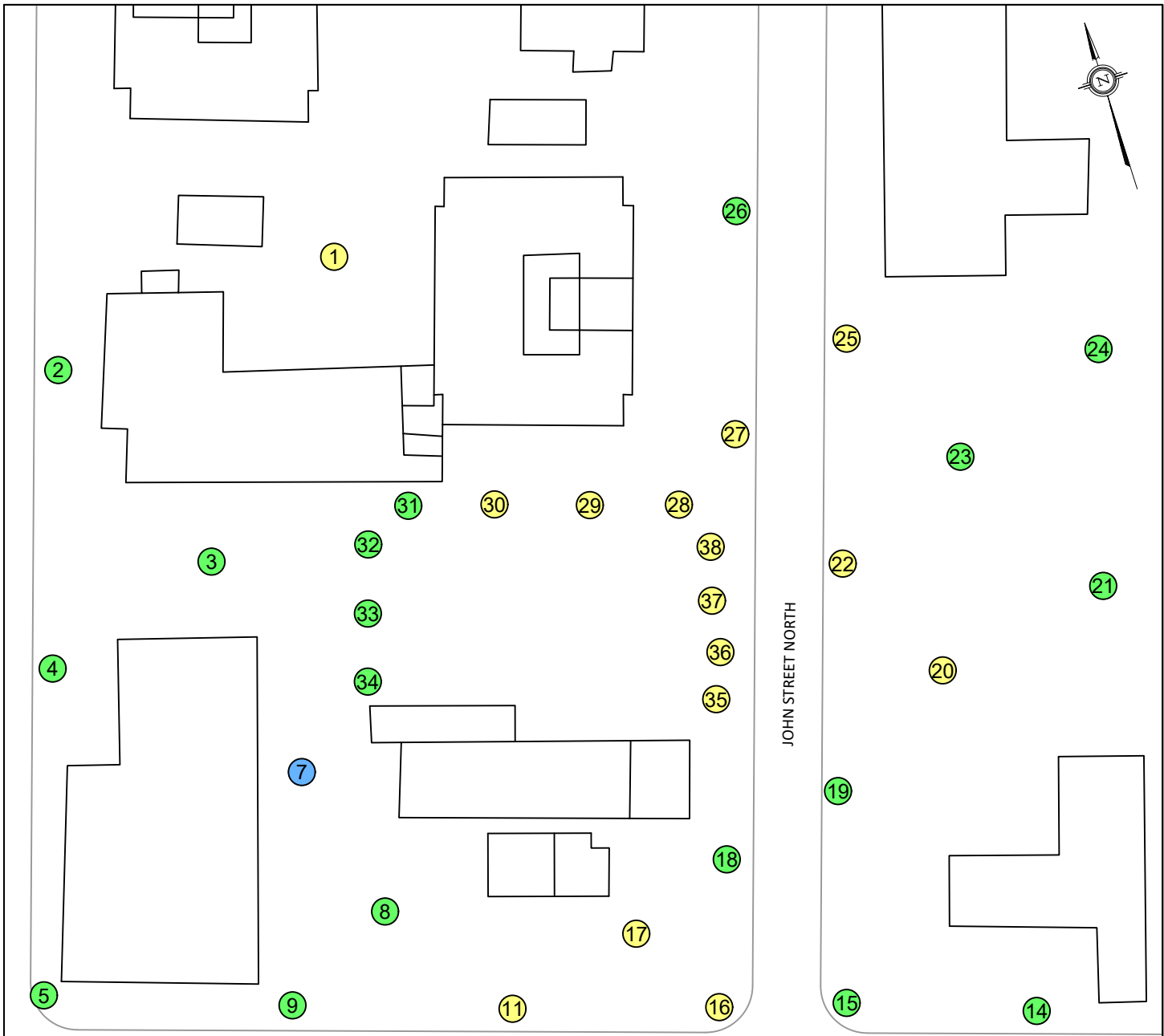
PREDICTED COMFORT CLASSES

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

WIND SAFETY CRITERION

- # ACCEPTABLE
- # EXCEEDED

NOTES:

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

PROJECT	175 JOHN STREET N, HAMILTON PEDESTRIAN LEVEL WIND STUDY	DESCRIPTION
SCALE 1:300 (APPROX.)	DRAWING NO. GW22-275-PLW-4A	FIGURE 4A: SUMMER LEVEL 3 AMENITY PLAN PEDESTRIAN COMFORT PREDICTIONS
DATE DECEMBER 1, 2022	DRAWN BY C.E.	

N

BALCONY TERRACE

44   45

AMENITY

AMENITY

AMENITY

1 BED + DEN

1 BED

BALCONY

BALCONY

2 BED

1 BED

2 BED
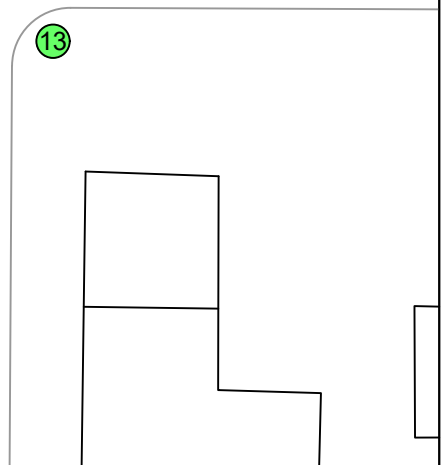
PREDICTED COMFORT CLASSES

- (#) SITTING
- (#) STANDING
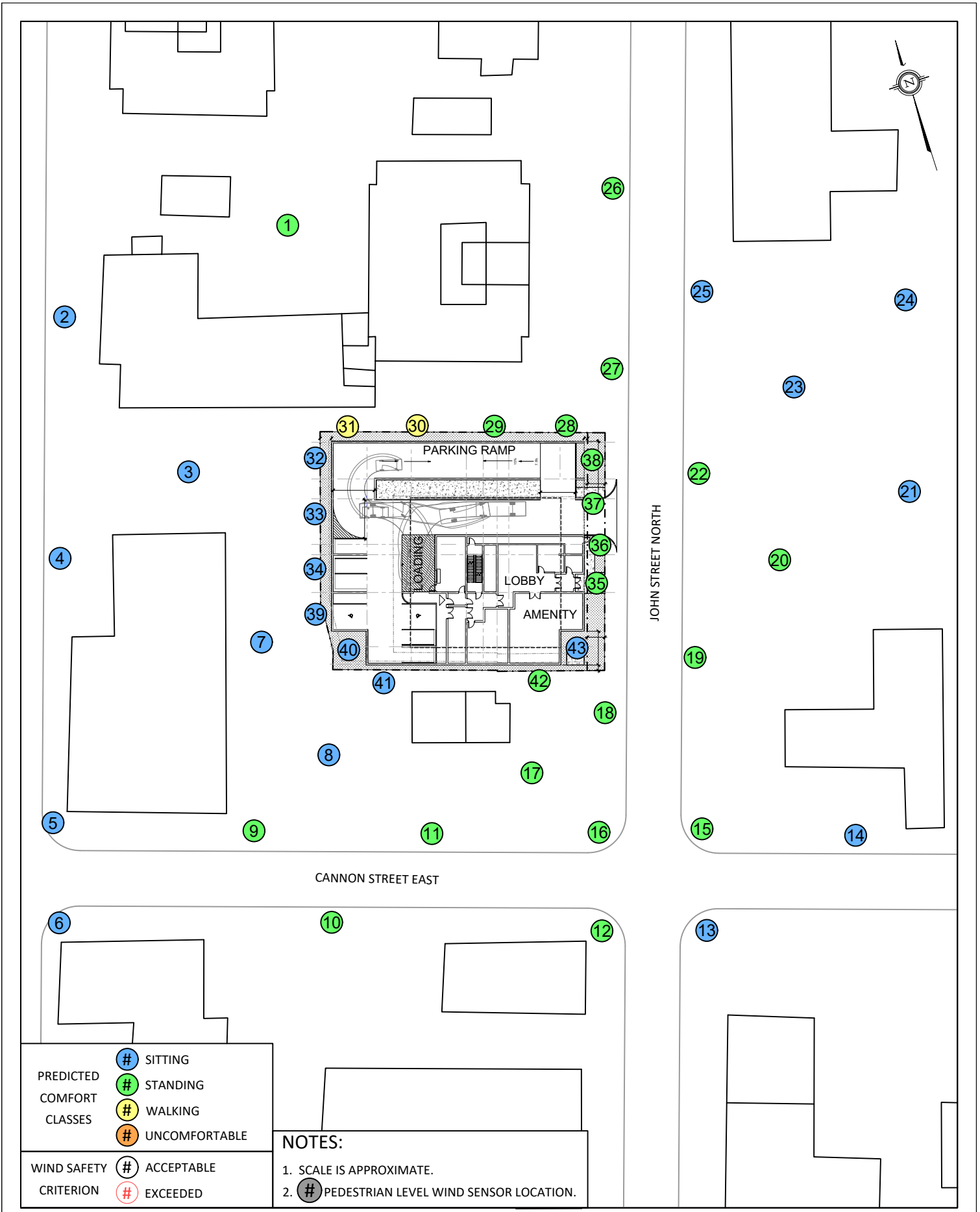- (#) WALKING
- (#) UNCOMFORTABLE

WIND SAFETY CRITERION

- (#) ACCEPTABLE
- (#) EXCEEDED

NOTES:

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

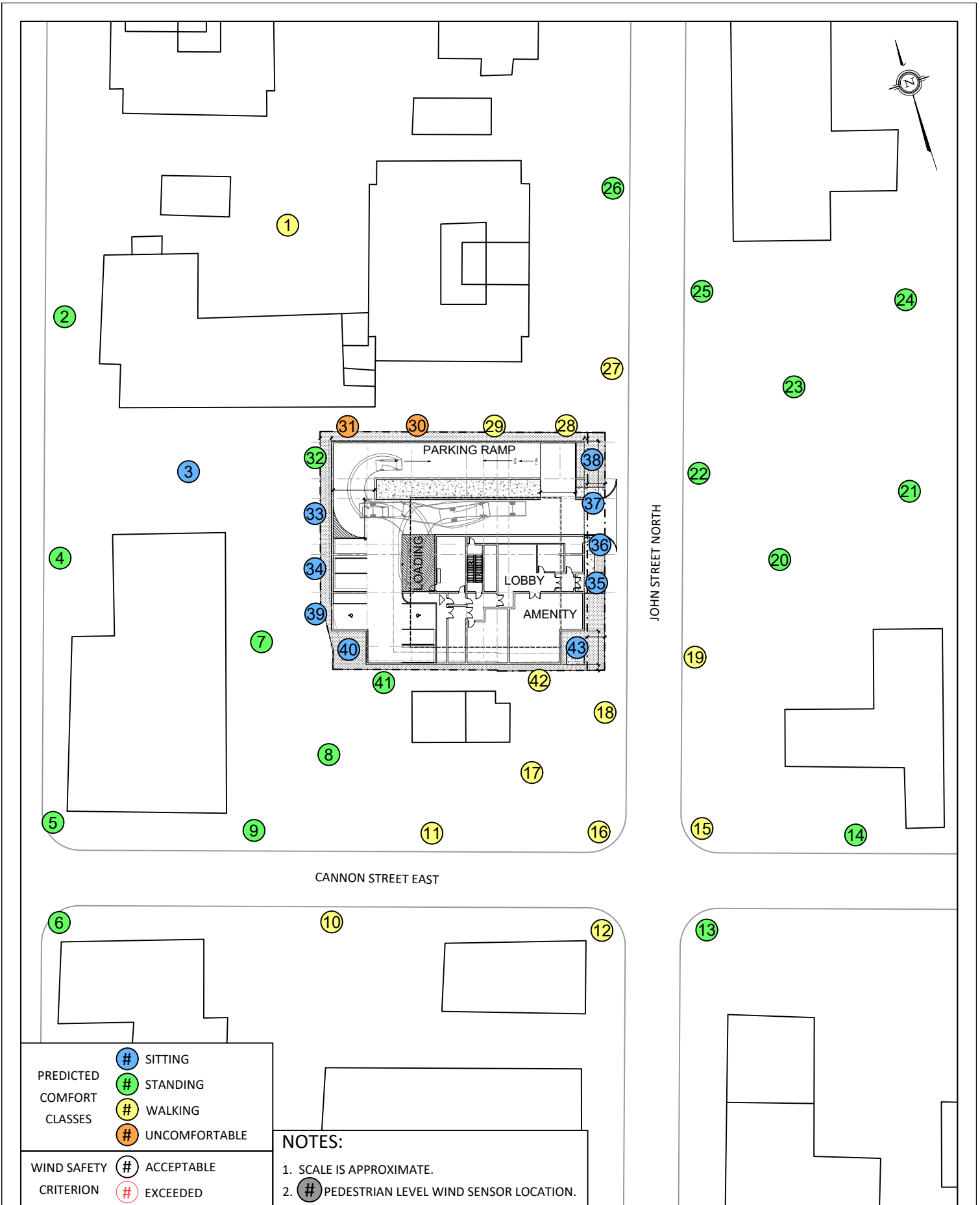| PROJECT	175 JOHN STREET N, HAMILTON PEDESTRIAN LEVEL WIND STUDY	DESCRIPTION
SCALE 1:300 (APPROX.)	DRAWING NO. GW22-275-PLW-4B	FIGURE 4B: WINTER LEVEL 3 AMENITY PLAN PEDESTRIAN COMFORT PREDICTIONS
DATE DECEMBER 1, 2022	DRAWN BY C.E.	

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APPENDIX A

**PEDESTRIAN COMFORT SUITABILITY, TABLES A1-A2
(EXISTING CONDITIONS)**

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 CONDITIONS)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
1	14.5	Standing	18.5	Walking	69.2	Safe
2	10.8	Standing	14.3	Standing	51.4	Safe
3	9.6	Sitting	12.3	Standing	49.2	Safe
4	8.9	Sitting	11.7	Standing	42.1	Safe
5	9.9	Sitting	13.4	Standing	46.4	Safe
6	11.3	Standing	15.8	Walking	52.1	Safe
7	6.9	Sitting	9.1	Sitting	36.0	Safe
8	7.9	Sitting	10.6	Standing	42.9	Safe
9	10.9	Standing	15.0	Standing	52.4	Safe
10	10.2	Standing	14.0	Standing	52.2	Safe
11	11.1	Standing	15.7	Walking	60.0	Safe
12	9.6	Sitting	13.9	Standing	58.0	Safe
13	8.5	Sitting	12.2	Standing	53.6	Safe
14	8.7	Sitting	12.1	Standing	50.0	Safe
15	9.0	Sitting	13.2	Standing	57.1	Safe
16	10.8	Standing	15.6	Walking	60.8	Safe
17	11.2	Standing	16.1	Walking	62.0	Safe
18	10.1	Standing	13.9	Standing	51.7	Safe
19	9.4	Sitting	12.6	Standing	47.9	Safe
20	11.9	Standing	16.4	Walking	54.6	Safe
21	8.8	Sitting	12.3	Standing	49.5	Safe
22	12.3	Standing	16.9	Walking	59.4	Safe
23	10.1	Standing	14.2	Standing	56.6	Safe
24	10.6	Standing	14.4	Standing	54.8	Safe
25	11.4	Standing	15.6	Walking	63.2	Safe
26	11.0	Standing	14.5	Standing	49.7	Safe
27	13.7	Standing	18.7	Walking	65.1	Safe
28	14.1	Standing	18.8	Walking	65.2	Safe
29	13.6	Standing	18.1	Walking	72.2	Safe
30	11.5	Standing	15.9	Walking	61.9	Safe
31	9.7	Sitting	13.4	Standing	51.0	Safe
32	10.4	Standing	13.9	Standing	55.7	Safe
33	9.8	Sitting	12.9	Standing	57.9	Safe
34	10.0	Sitting	13.2	Standing	62.0	Safe
35	10.8	Standing	15.1	Walking	52.7	Safe
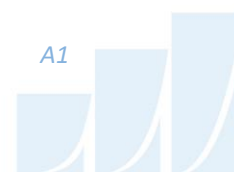
A1

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A2

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 CONDITONS)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
36	12.1	Standing	16.6	Walking	55.8	Safe
37	14.2	Standing	19.6	Walking	63.7	Safe
38	14.3	Standing	19.6	Walking	64.8	Safe

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APPENDIX B

PEDESTRIAN COMFORT SUITABILITY, TABLES B1-B2
(PROPOSED SCENARIO)

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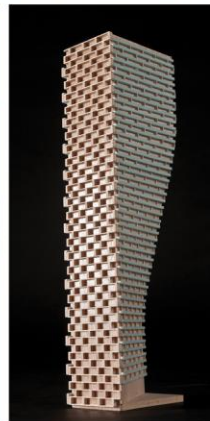ENGINEERS & SCIENTISTS

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 CONDITIONS)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
1	13.9	Standing	17.3	Walking	67.1	Safe
2	9.8	Sitting	12.7	Standing	47.7	Safe
3	7.7	Sitting	9.9	Sitting	38.1	Safe
4	8.9	Sitting	11.8	Standing	42.3	Safe
5	8.5	Sitting	11.4	Standing	42.3	Safe
6	9.6	Sitting	13.2	Standing	46.6	Safe
7	8.7	Sitting	11.7	Standing	42.2	Safe
8	8.8	Sitting	11.7	Standing	46.9	Safe
9	10.1	Standing	13.3	Standing	54.3	Safe
10	11.4	Standing	15.3	Walking	57.0	Safe
11	13.7	Standing	18.8	Walking	71.0	Safe
12	11.8	Standing	16.6	Walking	60.0	Safe
13	10.0	Sitting	14.3	Standing	56.5	Safe
14	8.9	Sitting	13.4	Standing	54.3	Safe
15	11.3	Standing	16.0	Walking	58.6	Safe
16	13.8	Standing	19.1	Walking	63.6	Safe
17	14.7	Standing	20.0	Walking	68.8	Safe
18	14.6	Standing	19.9	Walking	68.0	Safe
19	12.8	Standing	18.2	Walking	68.1	Safe
20	10.3	Standing	13.6	Standing	53.6	Safe
21	7.5	Sitting	10.3	Standing	45.2	Safe
22	11.1	Standing	14.9	Standing	58.0	Safe
23	8.0	Sitting	11.0	Standing	47.4	Safe
24	8.0	Sitting	10.4	Standing	42.4	Safe
25	9.3	Sitting	12.1	Standing	46.9	Safe
26	10.4	Standing	13.5	Standing	47.2	Safe
27	11.5	Standing	16.0	Walking	59.1	Safe
28	11.2	Standing	16.4	Walking	63.1	Safe
29	14.5	Standing	19.8	Walking	67.7	Safe
30	15.8	Walking	21.6	Uncomfortable	73.2	Safe
31	16.1	Walking	22.2	Uncomfortable	76.1	Safe
32	7.9	Sitting	11.1	Standing	44.1	Safe
33	7.0	Sitting	9.5	Sitting	39.5	Safe
34	7.1	Sitting	9.1	Sitting	35.4	Safe
35	6.9	Sitting	8.8	Sitting	40.0	Safe

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B1

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 CONDITONS)

Sensor	Pedestrian Comfort				Pedestrian Safety	
	Summer		Winter		Annual	
	Wind Speed	Comfort Class	Wind Speed	Comfort Class	Wind Speed	Safety Class
36	6.7	Sitting	8.5	Sitting	34.3	Safe
37	6.4	Sitting	8.5	Sitting	31.3	Safe
38	8.1	Sitting	9.9	Sitting	46.3	Safe
39	7.5	Sitting	9.6	Sitting	39.4	Safe
40	7.4	Sitting	9.6	Sitting	37.0	Safe
41	9.7	Sitting	13.4	Standing	53.4	Safe
42	11.6	Standing	16.8	Walking	64.6	Safe
43	7.3	Sitting	9.1	Sitting	62.1	Safe
44	11.4	Standing	14.9	Standing	61.7	Safe
45	8.0	Sitting	10.9	Standing	43.0	Safe

B2

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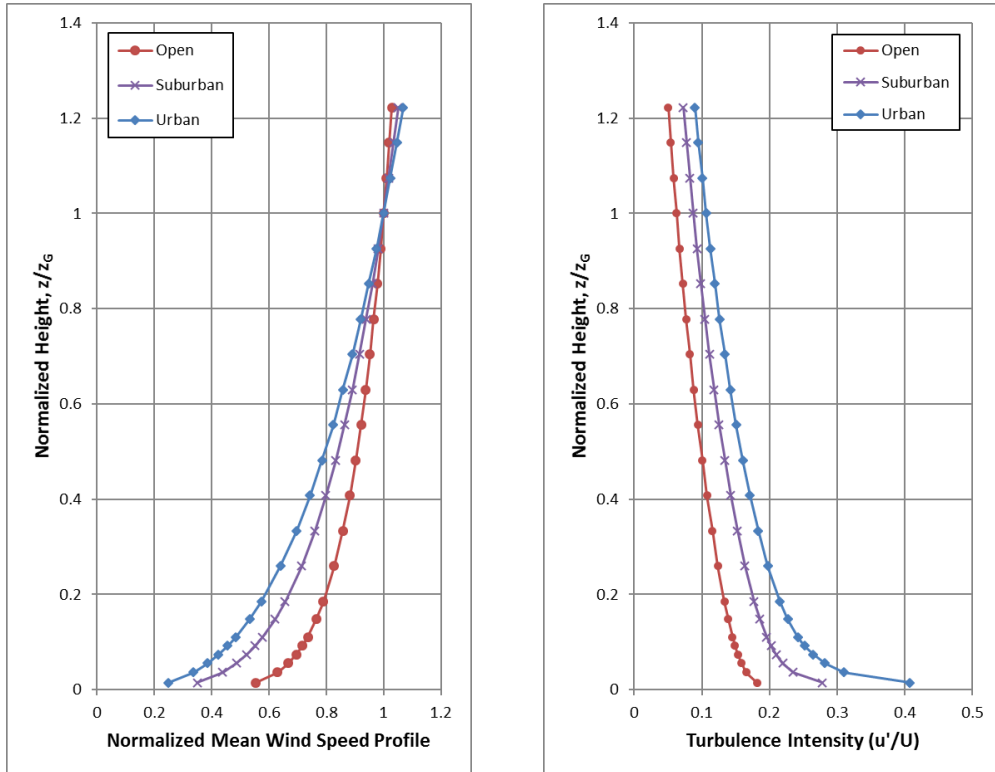
The exponent α varies according to the type of upwind terrain; α ranges from 0.14 for open country to 0.33 for an urban exposure. Figure C2 illustrates the theoretical variation of turbulence for open country, suburban and urban exposures.

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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C3

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C4

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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.

D1

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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:

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

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

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

D2

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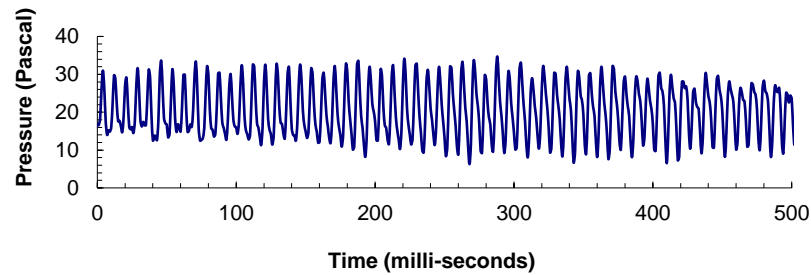
FIGURE D1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR

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D3

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