Pedestrian Level Wind Study

383 Albert Street & 340 Queen Street

Ottawa, Ontario

REPORT: 18-111-PLW

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind comfort for the proposed mixed-use development located at 383 Albert Street and 340 Queen Street in Ottawa, 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 and safety at key areas within and surrounding the development site. The results and recommendations are summarized in the following paragraphs and detailed in the subsequent report.

A complete summary of the predicted wind conditions is provided in Sections 5.1 and 5.2 of this report, and illustrated in Figures 2A through 5B. Based on the wind tunnel test results, meteorological data analysis, experience with similar developments, and reference to City of Ottawa wind criteria, we conclude that the future wind conditions over all grade-level pedestrian wind-sensitive areas within and surrounding the study site will be suitable for their intended pedestrian uses on a seasonal basis without the need for mitigation. For the Level 9 outdoor amenity terrace on the study building, wind conditions will be calm and suitable for sitting throughout the year.

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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1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by Claridge Homes to undertake a pedestrian level wind study for the proposed mixed-use development located at 383 Albert Street and 340 Queen Street in Ottawa, Ontario. Our mandate within this study, as outlined in GWE proposal #18-031P, dated February 1, 2018, is to investigate pedestrian wind comfort within and surrounding the development site, and to identify any areas where wind conditions may interfere with pedestrian activities so that mitigation measures may be considered, where necessary.

Our work is based on industry standard wind tunnel testing techniques, City of Ottawa wind criteria, architectural drawings prepared by NEUF Architect(e)s dated July 2018, surrounding street layouts, existing and approved future building massing information, and recent site imagery.

2. TERMS OF REFERENCE

The subject site is located at 383 Albert Street and 340 Queen Street in Ottawa, Ontario. The study site is situated on a parcel of land bounded by Queen Street to the north, Lyon Street North to the east, Albert Street to the south, and Bay Street to the west.

The study site is surrounded in the near-field by the urban environs of downtown Ottawa. At greater distances from the study site, the urban exposure gives way to a suburban mix of medium- and low-rise buildings to the northeast rotating clockwise to the southwest. To the southwest the urban exposure gives way to the green space of LeBreton Flats. To the west rotating clockwise to the northeast the urban exposure gives way to the Ottawa River.

The proposed development comprises three building components, referred to as Tower A Condo (26 storeys), Tower B Hotel (9 storeys), and Tower C Rental (26 storeys), which are connected by an 'L'- shaped 2-storey podium. Towers A, B, and C are situated clockwise beginning at the northeast corner of the site, respectively. At grade, the building comprises primarily retail space with access from Albert Street. The condo lobby fronts Queen Street, the rental lobby fronts Albert Street, and the hotel lobby is inset into the southeast corner of the development with access from Albert Street. In the northeast corner of the study building the LRT station can be accessed from both Queen Street and Lyon Street North. Vehicular access to loading space and one level of below-grade parking is available on the west side of the south elevation. The Level 2 mezzanine accommodates various residential and hotel amenities. At Level 3 the podium steps back from the middle of the west elevation, separating most of the hotel and condo units with a roof garden, excluding a wing of hotel rooms along the east elevation. Levels 3 through 8 of Towers A and B generally comprise uniform floorplans of residential and hotel units, respectively, except for the west side of Levels 3 and 4 in Tower A where indoor amenity space resides. At Level 9, Tower B Hotel ends, severing the north connection to Tower A Condo and accommodating a rooftop destination bar with an outdoor amenity terrace on the east side, and the beginnings of Tower C Rental on the west side. Above Level 9, a mechanical penthouse is situated on the roof of the destination bar, and Towers A and C rise with uniform residential floorplates to Level 26, where mechanical penthouses complete each building component.

Grade-level pedestrian areas considered in this study include surrounding sidewalks, laneways, drop-off areas, parking lots, transit stops, and building access points. Wind comfort was also measured over the Level 9 outdoor amenity terrace. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report. Figure 1 illustrates the study site and surrounding context, while photographs 1 through 4 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; and (iii) recommend suitable mitigation measures, where required.

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 Ottawa wind climate and synthesis of wind tunnel data with City of Ottawa wind criteria[1]. The following sections describe the analysis procedures, including a discussion of the pedestrian comfort and safety criteria.

[1] City of Ottawa Terms of Reference – Wind Analysis (Undated)

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 4 following the main text, was constructed at a scale of 1:400. The wind tunnel model includes all existing buildings and approved future developments within a full-scale diameter of approximately 840 m. The general concept and approach to wind tunnel modelling is to provide building and topographic detail in the immediate vicinity of the 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 62 sensor locations on the scale model in GWE's wind tunnel. Of these sensors, sixty (60) were placed at grade and the remaining two (2) sensors were placed over the Level 9 amenity terrace. Wind speed measurements were performed for each of the sensors for 36 wind directions at 10° intervals. Figure 1 illustrates a plan of the site and relevant surrounding context, while sensor locations used to investigate wind conditions are illustrated in Figures 2A through 5B, and in reference images provided throughout the report.

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 A and B provide greater detail of the theory behind wind speed measurements.

Wind tunnel measurements for this project, conducted in GWE'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 and Reports on Engineering Practice No 67.

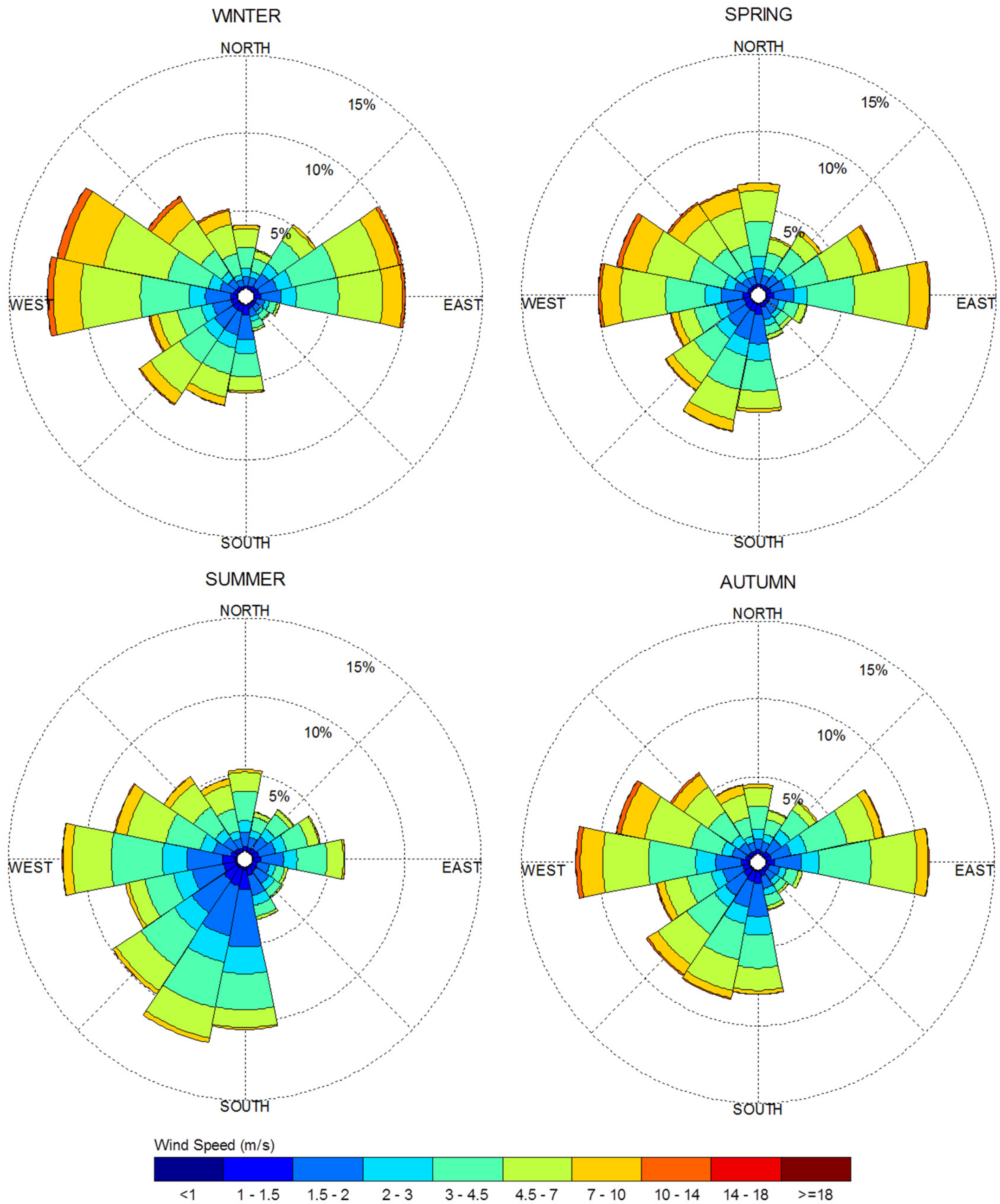
4.3 Meteorological Data Analysis

A statistical model for winds in Ottawa was developed from approximately 40-years of hourly meteorological wind data recorded at Macdonald-Cartier 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. Based on this portion of the analysis, the four seasons are represented by grouping data from consecutive months based on similarity of weather patterns, and not according to the traditional calendar method.

The statistical model of the Ottawa 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 meters per second (m/s). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Ottawa, the most common winds occur for westerly wind directions, followed by those from the east, while the most common wind speeds are below 10 metres per second (m/s).

The directional preference and relative magnitude of wind speed changes somewhat from season to season. By convention in microclimate studies, wind direction refers to the wind origin (e.g., a north wind blows from north to south).

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES
MACDONALD-CARTIER INTERNATIONAL AIRPORT, OTTAWA, ONTARIO



Notes:

1. Radial distances indicate percentage of time of wind events.
2. Wind speeds are mean hourly measured at 10 m above the ground.
3. Apply a factor of 3.6 to convert m/s to km/h (e.g., 10 m/s = 36 km/h).

4.4 Pedestrian Comfort Criteria – City of Ottawa

Pedestrian comfort criteria are based on mechanical wind effects without consideration of other meteorological conditions (i.e., temperature, relative humidity). The City of Ottawa criteria provide an assessment of comfort, assuming pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes and corresponding gust wind speed ranges are used to assess pedestrian comfort, which include: (i) Sitting; (ii) Standing; (iii) Strolling; (iv) Walking; and (v) Uncomfortable. More specifically, the comfort classes, associated wind speed ranges, and limiting criteria are summarized as follows:

(i) **Sitting:** Mean wind speeds less than or equal to 10 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 14 km/h.

(ii) **Standing:** Mean wind speeds less than or equal to 14 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 20 km/h.

(iii) **Strolling:** Mean wind speeds less than or equal to 17 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 25 km/h.

(iv) **Walking:** Mean wind speeds less than or equal to 20 km/h, occurring at least 80% of the time. The gust equivalent mean wind speed is approximately 30 km/h.

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

** **Dangerous:** Gust equivalent mean wind speeds greater than or equal to 90 km/h, occurring more often than 0.1% of the time, are classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall.

Gust speeds are used in the criteria because people tend to be more sensitive to wind gusts than to steady winds for lower wind speed ranges. For strong winds approaching dangerous levels, this effect is less important because the mean wind can also cause problems for pedestrians. The mean gust speed ranges are selected based on 'The Beaufort Scale', which describes the effect of forces produced by varying wind speeds on levels on objects.

THE BEAUFORT SCALE

Number	Description	Wind Speed (km/h)	Description
2	Light Breeze	4-8	Wind felt on faces
3	Gentle Breeze	8-15	Leaves and small twigs in constant motion; Wind extends light flags
4	Moderate Breeze	15-22	Wind raises dust and loose paper; Small branches are moved
5	Fresh Breeze	22-30	Small trees in leaf begin to sway
6	Strong Breeze	30-40	Large branches in motion; Whistling heard in electrical wires; Umbrellas used with difficulty
7	Moderate Gale	40-50	Whole trees in motion; Inconvenient walking against wind
8	Gale	50-60	Breaks twigs off trees; Generally impedes progress

Experience and research on people's perception of mechanical wind effects has shown that if the wind speed levels are exceeded for more than 20% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if mean 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 30 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 across the study site, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type. An overview of common pedestrian location types and their desired comfort classes are summarized on the following page.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired Comfort Classes
Building Entrances	Standing
Public Sidewalks, Bicycle Paths	Strolling / Walking
Outdoor Amenity Spaces	Sitting
Cafés / Patios / Benches / Gardens	Sitting
Transit Shelters	Standing
Public Parks / Plazas	Sitting / Standing / Strolling
Garage / Service Entrances / Parking Lots	Strolling / Walking
Vehicular Drop-Off Zones	Walking

Following the comparison, the location is assigned a descriptor that indicates the suitability of the location for its intended use. The suitability descriptors are summarized as follows:

- **Acceptable**: The predicted wind conditions are suitable for the intended uses of the associated outdoor spaces without the need for mitigation.
- **Acceptable with Mitigation**: The predicted wind conditions are not acceptable for the intended use of a space; however, following the implementation of typical mitigation measures, the wind conditions are expected to satisfy the required comfort guidelines.
- **Mitigation Testing Recommended**: The effectiveness of typical mitigation measures is uncertain, and additional wind tunnel testing is recommended to explore other options and to ensure compliance with the comfort guidelines.
- **Incompatible**: The predicted wind conditions will interfere with the comfortable and/or safe use of a space and cannot be feasibly mitigated to acceptable levels.

5. RESULTS AND DISCUSSION

5.1 Pedestrian Comfort Suitability

Tables 1 through 16, beginning on the following page, provide a summary of seasonal comfort predictions for each sensor location under the future massing scenario, considering the study building and all potential future surrounding developments. The tables indicate the predicted percentages of time that wind speeds will fall into the ranges defined in the wind criteria. A higher numerical value equates to a greater percentage of time that wind speeds will be lower, and therefore more comfortable. Pedestrian comfort is determined by the percentage of time that wind speeds will fall within the stated ranges.

The predicted values within each table are accompanied by a suitability assessment that includes the predicted comfort class (i.e., sitting, standing, strolling, walking, etc.), the location type, the desired comfort class, and a suitability descriptor. The predicted comfort class is defined by the predicted wind speed range percentages, while the location type and the desired comfort class relate to the sensor placement on the wind tunnel model. The suitability descriptor is assigned based on the relationship between the predicted comfort class (for each seasonal period) and the desired comfort class.

Following Tables 1 through 16, the most significant findings of the PLW are summarized. To assist with understanding and interpretation, predicted conditions for the proposed development are also illustrated in colour-coded format in Figures 2A through 5B. Conditions suitable for sitting are represented by the colour green, standing by yellow, strolling by orange, and walking by blue. Measured mean and gust velocity ratios, which constitutes the raw data upon which the results are based, will be made available upon request.

TABLE 1: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #1	Spring	80	90	94	97	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	87	94	97	98	Sitting			
	Autumn	82	91	95	97	Sitting			
	Winter	78	88	93	96	Standing			
Sensor #2	Spring	75	84	88	92	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	83	90	93	95	Sitting			
	Autumn	78	86	90	93	Standing			
	Winter	73	81	86	90	Standing			
Sensor #3	Spring	79	88	92	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	87	93	95	97	Sitting			
	Autumn	82	89	93	95	Sitting			
	Winter	77	86	90	93	Standing			
Sensor #4	Spring	77	87	91	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	84	92	95	97	Sitting			
	Autumn	79	88	92	95	Standing			
	Winter	75	85	90	93	Standing			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

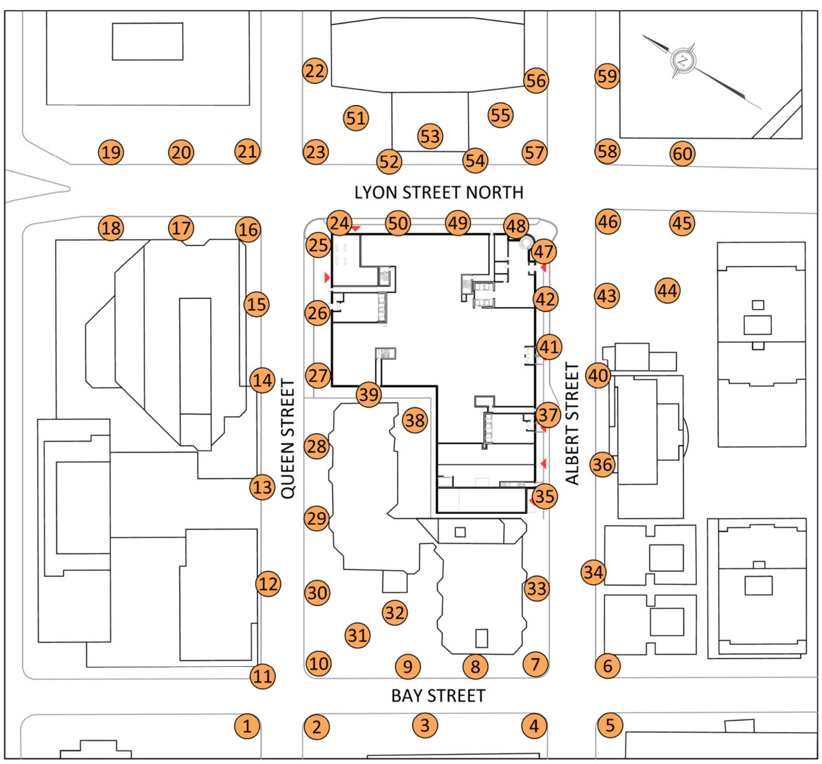


TABLE 2: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #5	Spring	89	96	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	94	98	99	100	Sitting			
	Autumn	90	96	98	99	Sitting			
	Winter	87	95	97	99	Sitting			
Sensor #6	Spring	85	93	96	98	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	91	96	98	99	Sitting			
	Autumn	86	93	96	98	Sitting			
	Winter	82	91	94	97	Sitting			
Sensor #7	Spring	82	91	94	97	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	88	95	97	98	Sitting			
	Autumn	83	92	95	97	Sitting			
	Winter	79	88	93	95	Standing			
Sensor #8	Spring	77	87	91	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	85	92	95	97	Sitting			
	Autumn	80	88	92	95	Sitting			
	Winter	75	85	89	92	Standing			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

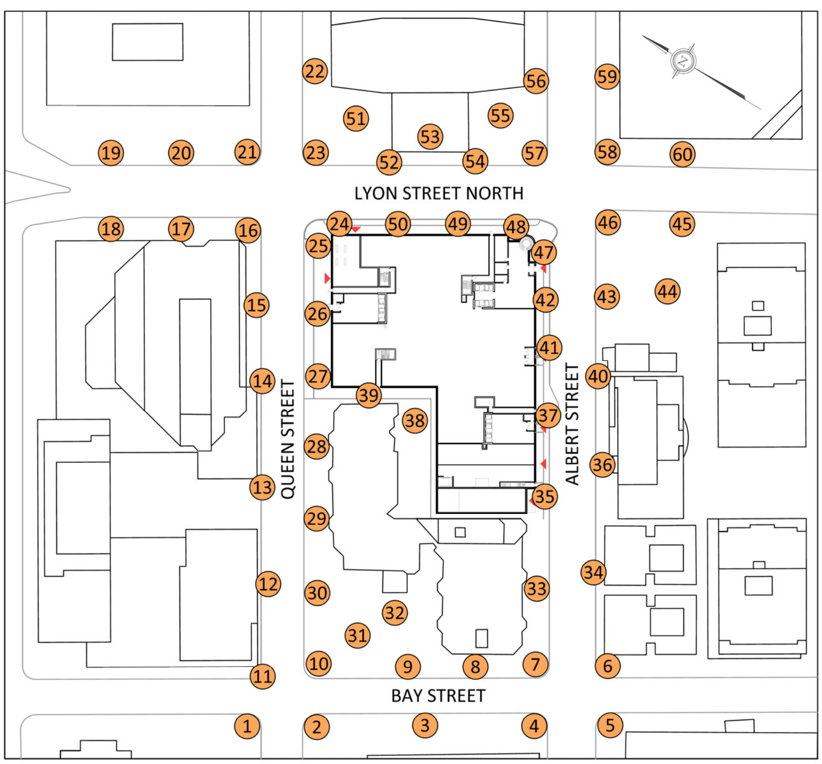


TABLE 3: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		**≤ 10**	**≤ 14**	**≤ 17**	**≤ 20**				
Guideline (% of Time)		**≥80%**	**≥80%**	**≥80%**	**≥80%**				
Sensor #9	**Spring**	76	86	91	95	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	83	92	95	97	Sitting			
	Autumn	78	88	92	95	Standing			
	Winter	73	84	89	93	Standing			
Sensor #10	**Spring**	78	87	91	94	Standing	Transit Stop/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	85	92	95	97	Sitting			
	Autumn	80	88	92	94	Sitting			
	Winter	74	84	88	92	Standing			
Sensor #11	**Spring**	78	87	91	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	84	91	94	96	Sitting			
	Autumn	79	87	91	94	Standing			
	Winter	74	83	88	91	Standing			
Sensor #12	**Spring**	88	96	99	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	93	98	99	100	Sitting			
	Autumn	89	96	99	99	Sitting			
	Winter	87	95	98	99	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

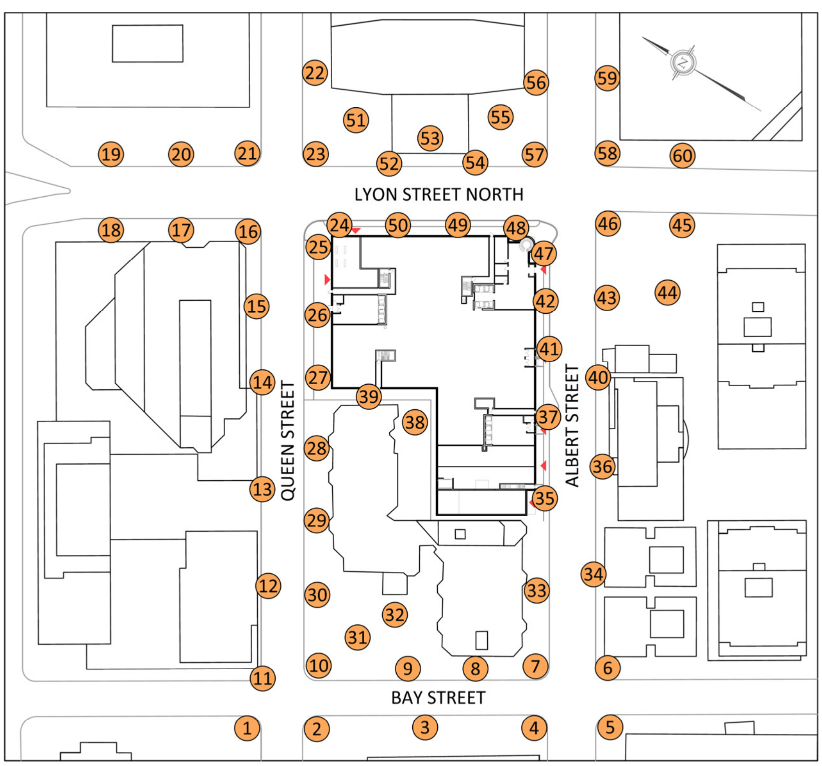


TABLE 4: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #13	**Spring**	80	90	95	97	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	87	95	97	99	Sitting			
	Autumn	82	92	95	98	Sitting			
	Winter	78	89	94	97	Standing			
Sensor #14	**Spring**	81	92	96	98	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	89	96	98	99	Sitting			
	Autumn	83	93	97	98	Sitting			
	Winter	80	91	96	98	Sitting			
Sensor #15	**Spring**	85	95	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	93	98	99	100	Sitting			
	Autumn	88	96	98	99	Sitting			
	Winter	85	95	98	99	Sitting			
Sensor #16	**Spring**	78	90	95	97	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	87	95	97	99	Sitting			
	Autumn	81	92	95	97	Sitting			
	Winter	77	89	94	96	Standing			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

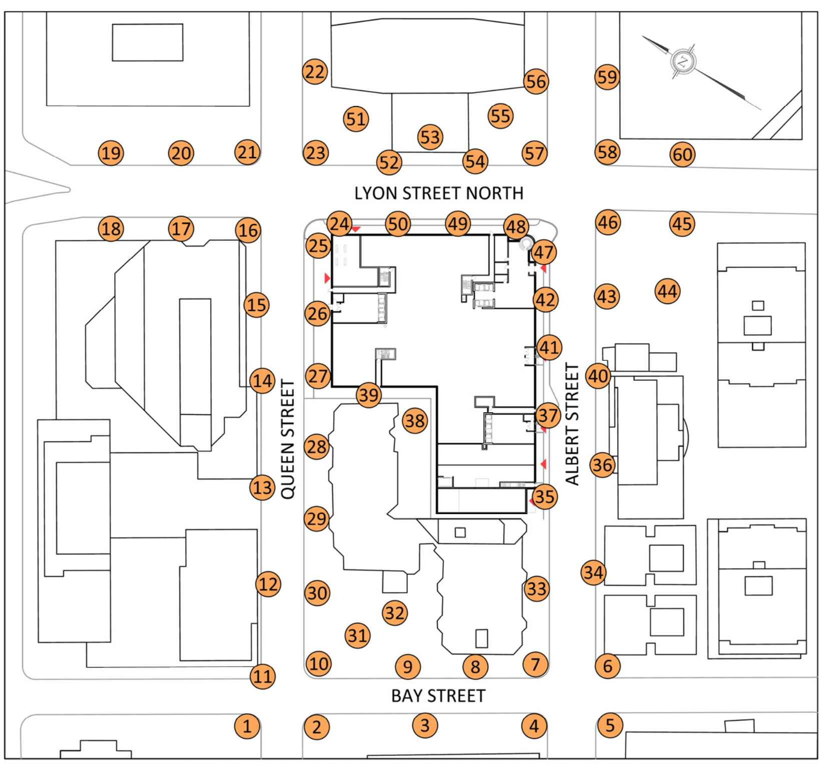


TABLE 5: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #17	**Spring**	75	87	92	95	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	86	93	96	98	Sitting			
	Autumn	80	90	93	96	Sitting			
	Winter	74	86	91	94	Standing			
Sensor #18	**Spring**	79	89	93	96	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	88	94	96	98	Sitting			
	Autumn	83	91	94	96	Sitting			
	Winter	77	87	91	94	Standing			
Sensor #19	**Spring**	71	85	91	95	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	83	92	96	98	Sitting			
	Autumn	76	88	93	96	Standing			
	Winter	71	85	91	95	Standing			
Sensor #20	**Spring**	71	84	90	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	82	91	95	97	Sitting			
	Autumn	75	87	92	95	Standing			
	Winter	70	83	89	93	Standing			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

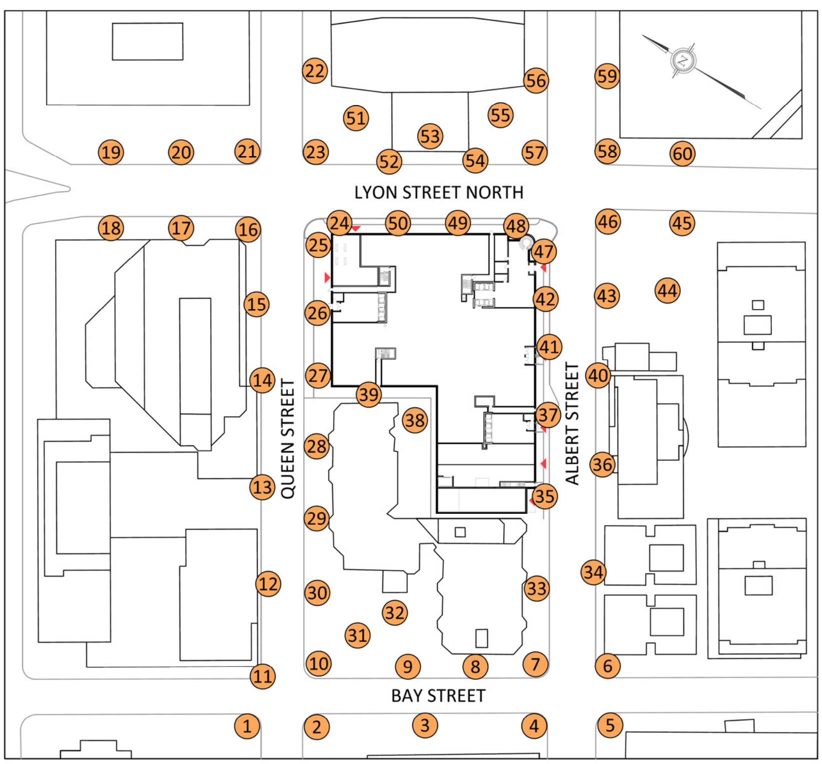


TABLE 6: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #21	Spring	67	81	88	92	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	79	89	93	96	Standing			
	Autumn	71	83	89	92	Standing			
	Winter	65	78	85	89	Strolling			
Sensor #22	Spring	60	76	84	90	Strolling	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	72	85	90	94	Standing			
	Autumn	64	79	85	90	Strolling			
	Winter	58	74	81	87	Strolling			
Sensor #23	Spring	70	84	90	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	82	91	95	97	Sitting			
	Autumn	74	86	91	94	Standing			
	Winter	67	81	88	92	Standing			
Sensor #24	Spring	88	95	97	98	Sitting	LRT Entrance/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	93	97	98	99	Sitting			
	Autumn	89	95	97	98	Sitting			
	Winter	85	93	95	97	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

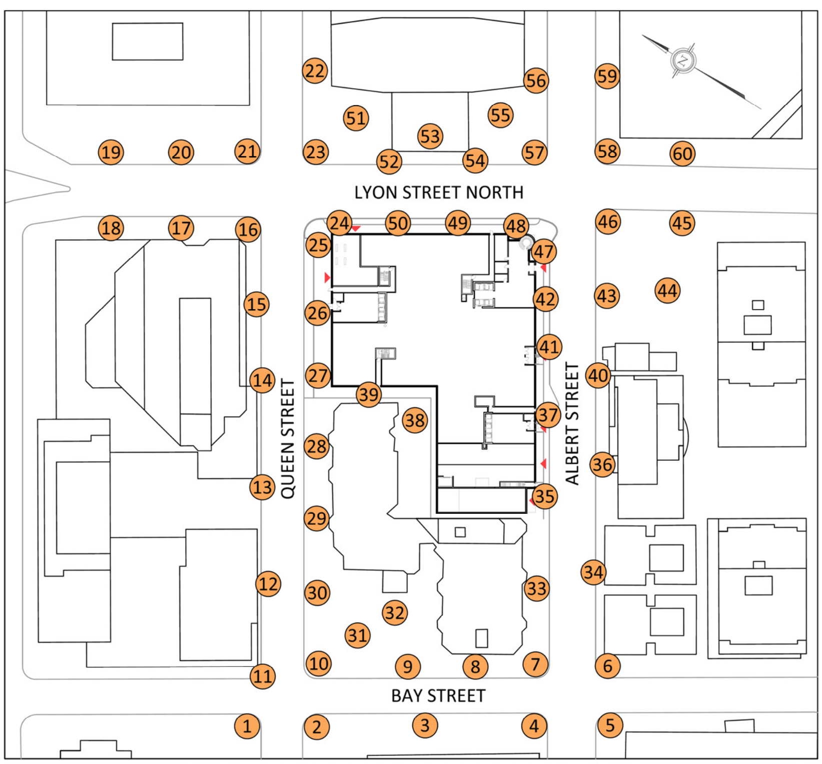


TABLE 7: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #25	Spring	84	95	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	93	98	99	100	Sitting			
	Autumn	88	96	99	99	Sitting			
	Winter	84	94	98	99	Sitting			
Sensor #26	Spring	85	95	98	99	Sitting	Lobby Entrance/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	92	98	99	100	Sitting			
	Autumn	88	96	98	99	Sitting			
	Winter	85	94	98	99	Sitting			
Sensor #27	Spring	84	95	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	91	98	99	100	Sitting			
	Autumn	86	95	98	99	Sitting			
	Winter	83	94	98	99	Sitting			
Sensor #28	Spring	81	92	96	98	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	88	96	98	99	Sitting			
	Autumn	83	93	96	98	Sitting			
	Winter	80	91	95	98	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

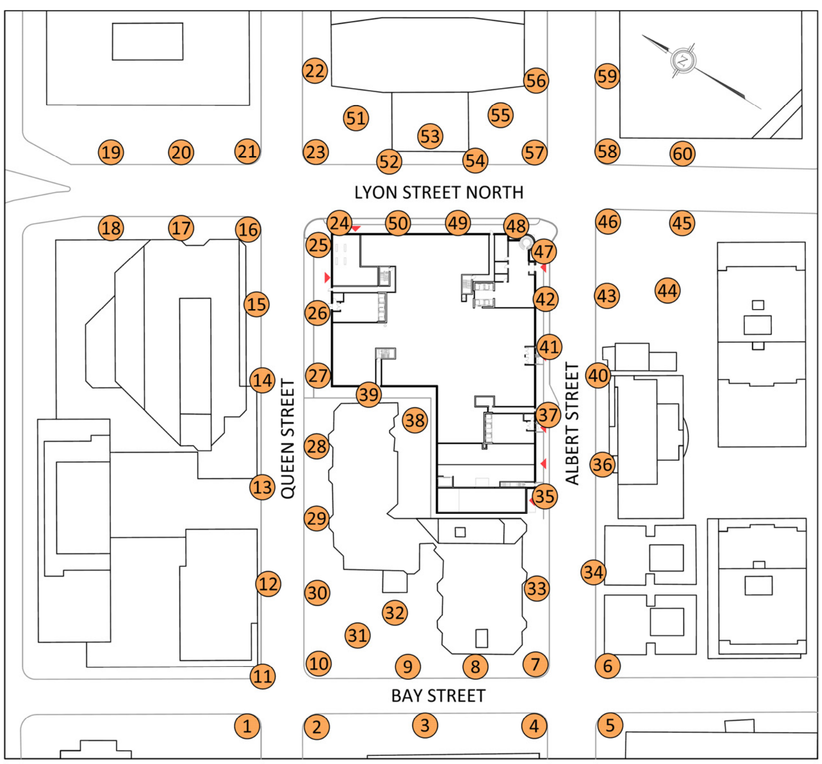


TABLE 8: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #29	**Spring**	74	86	91	95	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	82	91	95	97	Sitting			
	Autumn	76	87	92	95	Standing			
	Winter	72	84	90	93	Standing			
Sensor #30	**Spring**	75	86	90	93	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	82	90	94	96	Sitting			
	Autumn	77	86	90	93	Standing			
	Winter	72	83	87	91	Standing			
Sensor #31	**Spring**	84	94	97	99	Sitting	Drop-off	Walking	Acceptable
	Summer	91	97	99	99	Sitting			
	Autumn	86	94	97	99	Sitting			
	Winter	83	93	96	98	Sitting			
Sensor #32	**Spring**	87	94	97	98	Sitting	Drop-off	Walking	Acceptable
	Summer	92	97	99	99	Sitting			
	Autumn	88	95	97	98	Sitting			
	Winter	84	92	96	98	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

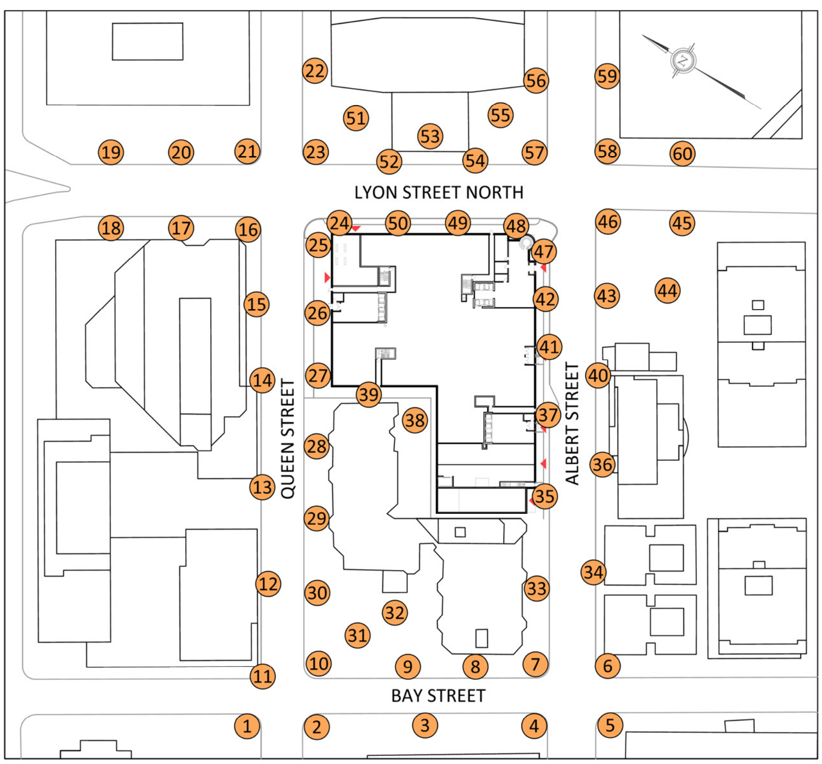


TABLE 9: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #33	Spring	92	98	99	100	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	95	99	100	100	Sitting			
	Autumn	92	98	99	100	Sitting			
	Winter	90	97	99	100	Sitting			
Sensor #34	Spring	88	95	97	98	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	92	97	98	99	Sitting			
	Autumn	88	94	97	98	Sitting			
	Winter	84	92	95	97	Sitting			
Sensor #35	Spring	90	97	99	100	Sitting	Vehicular Entrance/ Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	94	99	100	100	Sitting			
	Autumn	90	97	99	100	Sitting			
	Winter	88	97	99	100	Sitting			
Sensor #36	Spring	93	98	100	100	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	96	99	100	100	Sitting			
	Autumn	93	98	99	100	Sitting			
	Winter	91	98	99	100	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

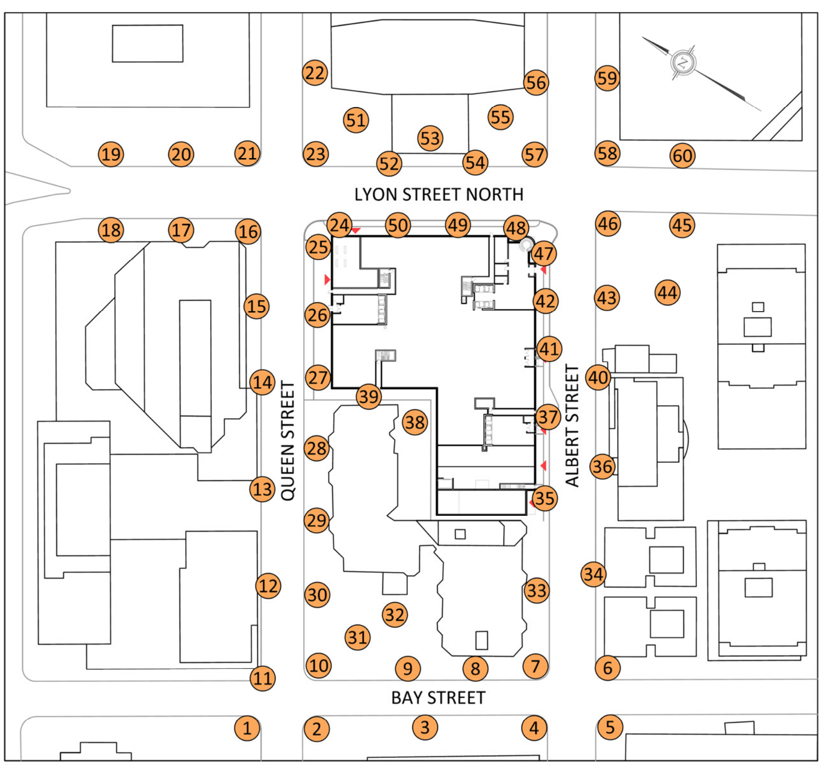


TABLE 10: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #37	**Spring**	91	98	99	100	Sitting	Lobby Entrance/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	97	99	100	100	Sitting			
	Autumn	93	99	100	100	Sitting			
	Winter	90	98	99	100	Sitting			
Sensor #38	**Spring**	93	98	100	100	Sitting	Neighboring Outdoor Amenity	Sitting	Acceptable
	Summer	96	99	100	100	Sitting			
	Autumn	93	98	99	100	Sitting			
	Winter	91	98	99	100	Sitting			
Sensor #39	**Spring**	91	98	99	100	Sitting	Laneway	Strolling/ Walking	Acceptable
	Summer	95	99	100	100	Sitting			
	Autumn	92	98	99	100	Sitting			
	Winter	90	97	99	100	Sitting			
Sensor #40	**Spring**	95	99	100	100	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	98	100	100	100	Sitting			
	Autumn	96	99	100	100	Sitting			
	Winter	94	99	100	100	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

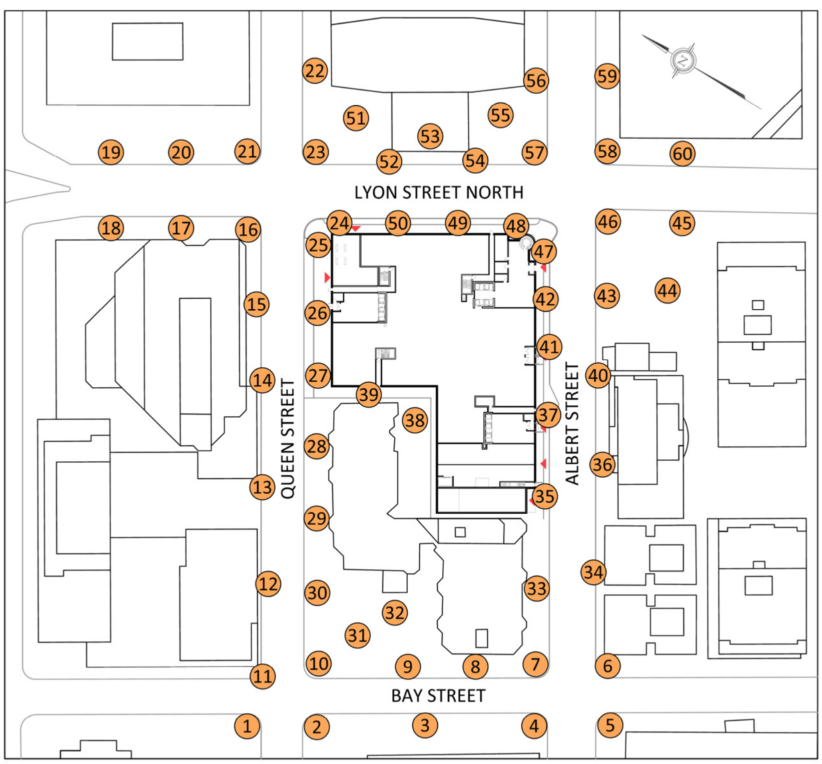


TABLE 11: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #41	Spring	90	97	99	100	Sitting	Retail Entrance/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	94	99	100	100	Sitting			
	Autumn	90	97	99	100	Sitting			
	Winter	89	97	99	100	Sitting			
Sensor #42	Spring	91	98	100	100	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	96	99	100	100	Sitting			
	Autumn	93	98	99	100	Sitting			
	Winter	91	98	99	100	Sitting			
Sensor #43	Spring	87	96	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	93	98	99	100	Sitting			
	Autumn	90	97	99	99	Sitting			
	Winter	87	96	98	99	Sitting			
Sensor #44	Spring	89	97	99	100	Sitting	Parking Lot	Strolling/ Walking	Acceptable
	Summer	95	99	99	100	Sitting			
	Autumn	92	97	99	100	Sitting			
	Winter	89	96	99	99	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

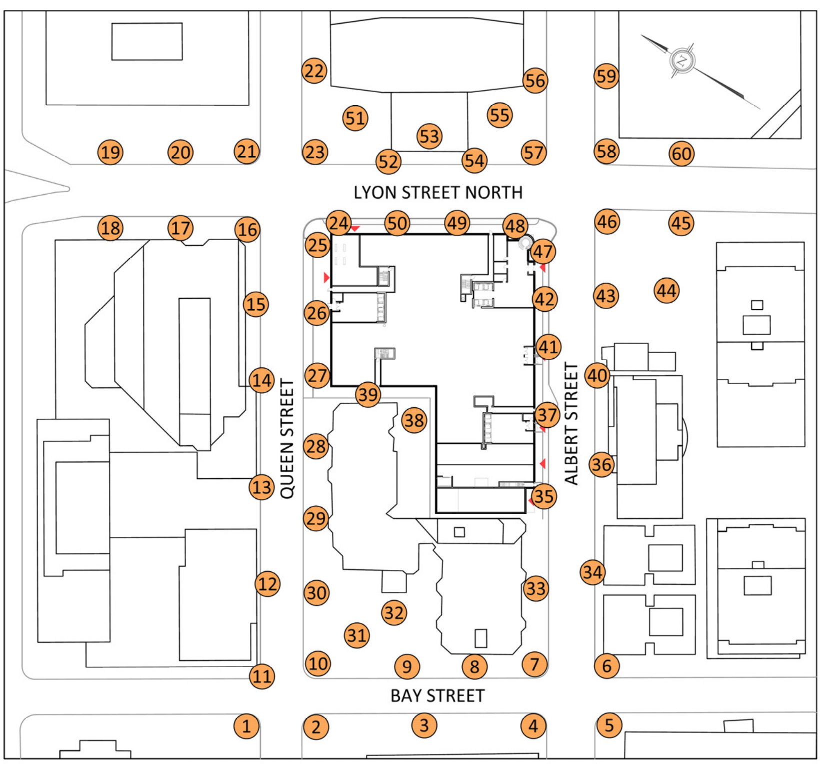


TABLE 12: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #45	**Spring**	85	95	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	93	98	99	100	Sitting			
	Autumn	87	96	98	99	Sitting			
	Winter	84	94	97	99	Sitting			
Sensor #46	**Spring**	78	89	93	96	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	88	94	97	98	Sitting			
	Autumn	82	92	95	97	Sitting			
	Winter	78	89	93	96	Standing			
Sensor #47	**Spring**	88	96	98	99	Sitting	Lobby Entrance/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	94	98	99	100	Sitting			
	Autumn	91	97	99	99	Sitting			
	Winter	89	97	99	99	Sitting			
Sensor #48	**Spring**	89	96	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	94	98	99	100	Sitting			
	Autumn	91	96	98	99	Sitting			
	Winter	87	95	97	99	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

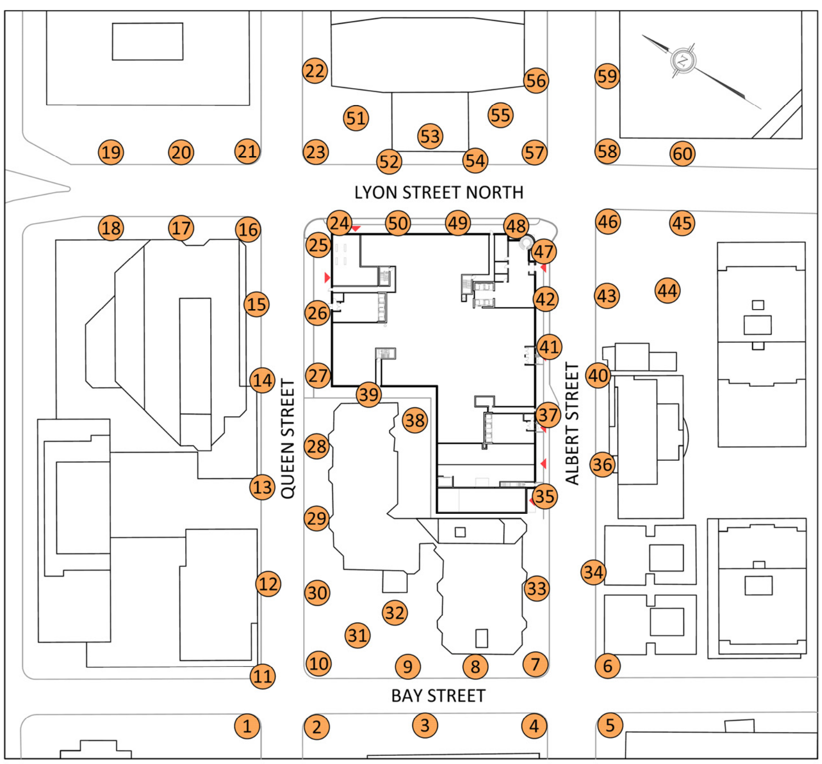


TABLE 13: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #49	**Spring**	86	95	97	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	93	97	99	99	Sitting			
	Autumn	88	95	98	99	Sitting			
	Winter	84	93	96	98	Sitting			
Sensor #50	**Spring**	87	94	97	99	Sitting	Transit Stop/ Public Sidewalk	Standing/ Strolling/ Walking	Acceptable
	Summer	93	97	99	99	Sitting			
	Autumn	89	95	98	99	Sitting			
	Winter	85	93	96	98	Sitting			
Sensor #51	**Spring**	80	90	94	96	Sitting	Drop-off	Walking	Acceptable
	Summer	87	94	97	98	Sitting			
	Autumn	82	90	94	96	Sitting			
	Winter	77	87	92	95	Standing			
Sensor #52	**Spring**	76	86	90	93	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	84	91	94	96	Sitting			
	Autumn	79	87	91	94	Standing			
	Winter	73	83	88	91	Standing			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

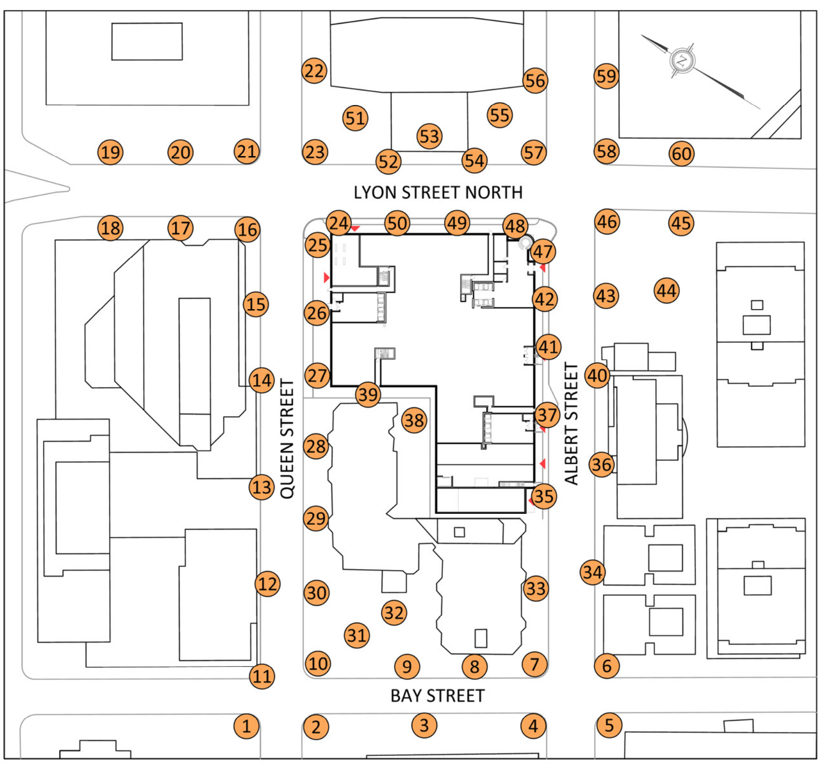


TABLE 14: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #53	Spring	80	88	92	95	Sitting	Drop-off	Walking	Acceptable
	Summer	86	92	95	97	Sitting			
	Autumn	81	89	92	94	Sitting			
	Winter	76	85	89	92	Standing			
Sensor #54	Spring	89	97	99	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	94	98	99	100	Sitting			
	Autumn	90	97	98	99	Sitting			
	Winter	87	95	98	99	Sitting			
Sensor #55	Spring	85	94	97	98	Sitting	Drop-off	Walking	Acceptable
	Summer	91	97	98	99	Sitting			
	Autumn	86	94	97	98	Sitting			
	Winter	82	92	95	97	Sitting			
Sensor #56	Spring	66	81	88	92	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	76	87	92	95	Standing			
	Autumn	68	82	88	92	Standing			
	Winter	63	78	85	89	Strolling			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

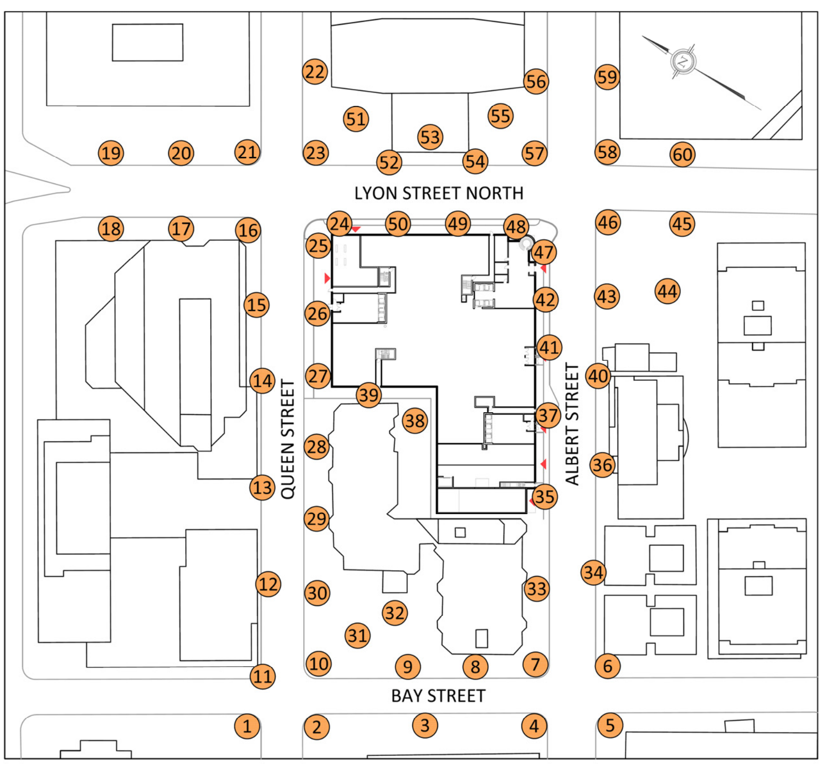


TABLE 15: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #57	Spring	83	94	97	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	90	97	99	99	Sitting			
	Autumn	85	95	98	99	Sitting			
	Winter	83	94	97	99	Sitting			
Sensor #58	Spring	71	84	90	94	Standing	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	82	91	95	97	Sitting			
	Autumn	76	87	92	95	Standing			
	Winter	70	83	89	93	Standing			
Sensor #59	Spring	84	95	98	99	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	91	98	99	100	Sitting			
	Autumn	86	95	98	99	Sitting			
	Winter	83	94	97	99	Sitting			
Sensor #60	Spring	86	93	96	98	Sitting	Public Sidewalk	Strolling/ Walking	Acceptable
	Summer	91	96	98	99	Sitting			
	Autumn	87	94	96	98	Sitting			
	Winter	83	91	95	97	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS

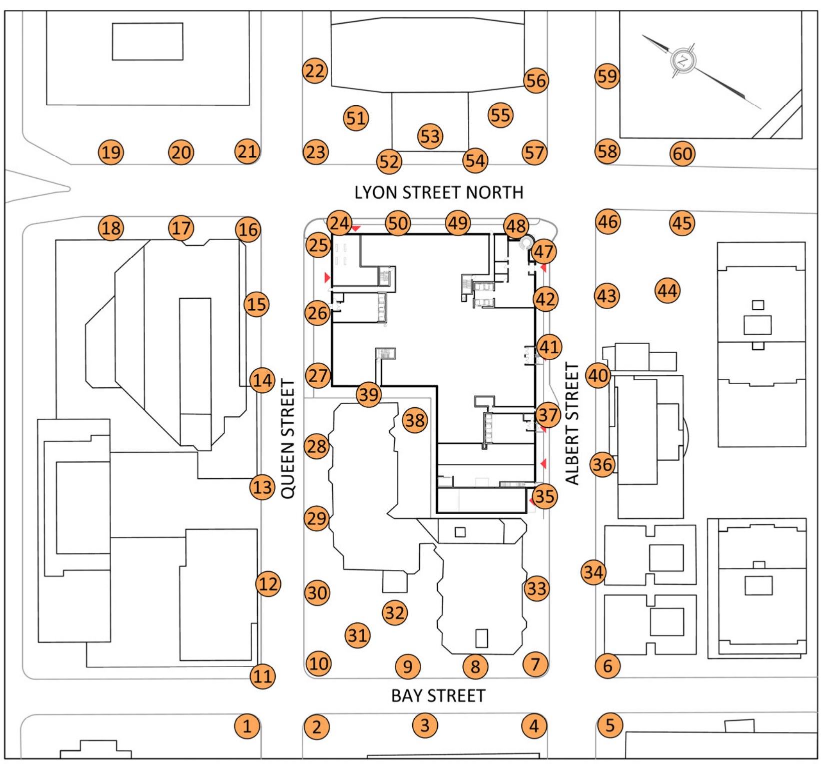
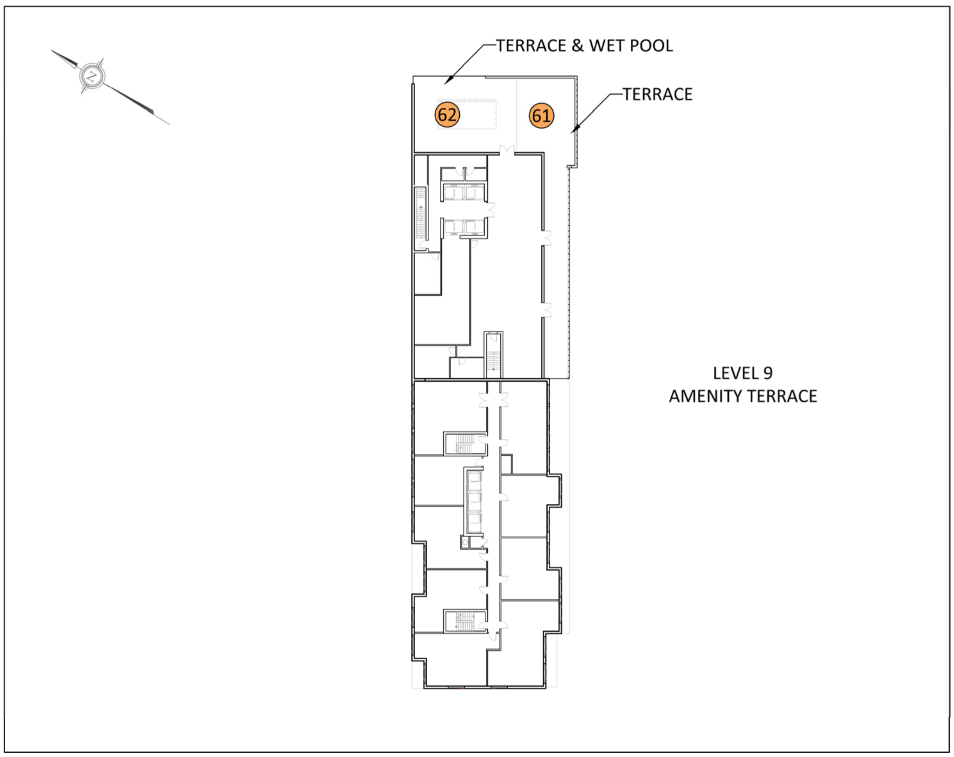


TABLE 16: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 10	≤ 14	≤ 17	≤ 20				
Guideline (% of Time)		≥80%	≥80%	≥80%	≥80%				
Sensor #61	Spring	90	97	99	100	Sitting	Level 9 Amenity Terrace	Sitting	Acceptable
	Summer	94	98	99	100	Sitting			
	Autumn	91	97	99	100	Sitting			
	Winter	89	97	99	100	Sitting			
Sensor #62	Spring	94	99	100	100	Sitting	Level 9 Amenity Terrace	Sitting	Acceptable
	Summer	97	100	100	100	Sitting			
	Autumn	95	99	100	100	Sitting			
	Winter	93	99	100	100	Sitting			

383 ALBERT STREET & 340 QUEEN STREET: PLW SENSOR LOCATIONS



5.2 Summary of Findings

Based on the analysis of the measured data, consideration of local climate data, and the suitability descriptors provided in Tables 1 through 16 in Section 5.1, this section summarizes the most significant findings of the PLW study, as follows:

1. All surrounding public sidewalks along Queen Street, Bay Street, Lyon Street North, and Albert Street will experience wind conditions suitable for strolling or better, with most locations being suitable for standing or better, throughout the year, which is acceptable.
2. All primary, secondary, and vehicular building access points will be comfortable for sitting on a seasonal basis.
3. All laneways and parking lots within and surrounding the development site will be calm and suitable for sitting during each seasonal period, which is considered appropriate.
4. All transit stops and vehicular drop-off zones surrounding the development site will experience wind conditions comfortable for standing or better throughout the year, which is appropriate.
5. The neighbouring outdoor amenity area west of the study building (represented by sensor 38) will be suitable for sitting or more sedentary activities throughout the year, which is acceptable.
6. The Level 9 outdoor amenity terrace serving the proposed development (represented by sensors 61 and 62) will be calm and comfortable for sitting or more sedentary activities throughout each seasonal period, without the need for mitigation.
7. 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 the proposed mixed-use development located at 383 Albert Street & 340 Queen Street in Ottawa, Ontario. The study was performed in accordance with the scope of work described in GWE proposal #18-031P, dated February 1, 2018. The work is based on industry standard wind tunnel testing and data analysis procedures, City of Ottawa wind criteria, architectural drawings prepared by NEUF Architect(e)s dated July 2018, surrounding street layouts, existing and approved future building massing information obtained from the City of Ottawa, and recent site imagery.

A complete summary of the predicted wind conditions is provided in Sections 5.1 and 5.2 of this report and illustrated in Figures 2A through 5B. Based on the foregoing study, we conclude that the future wind conditions over all grade-level pedestrian wind-sensitive areas within and surrounding the study site will be suitable for their intended pedestrian uses on a seasonal basis without the need for mitigation. For the Level 9 outdoor amenity terrace on the study building, wind conditions will be calm and suitable for sitting or more sedentary activities throughout the year.

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.

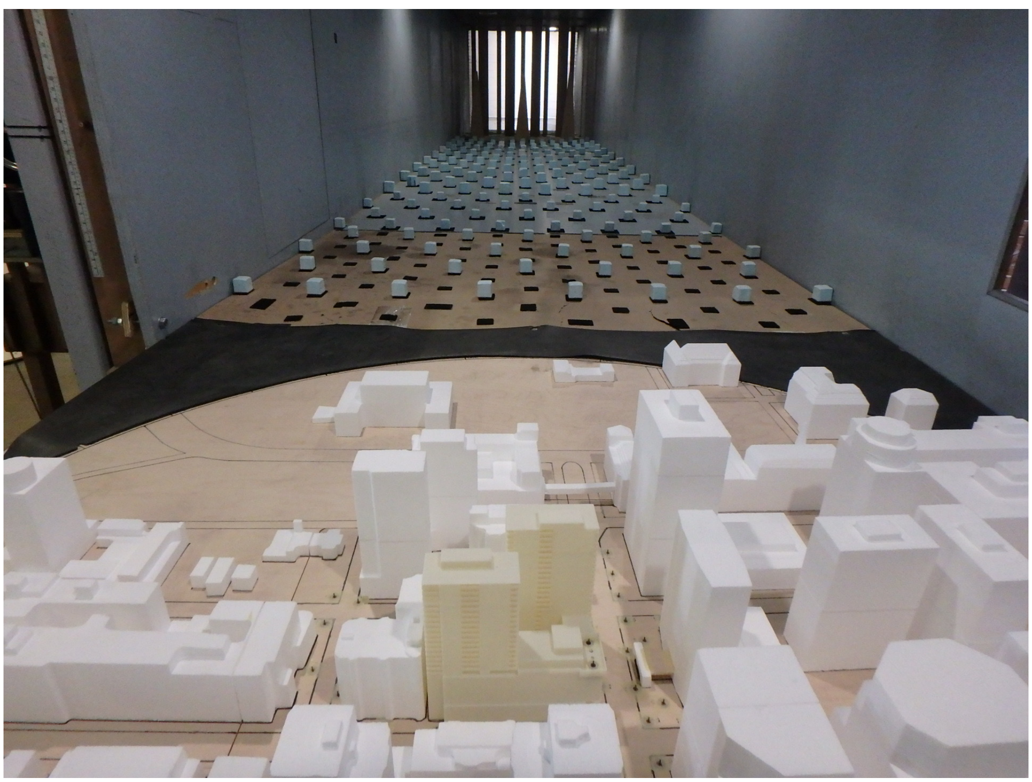
Nick Petersen, B.Eng., EIT
Junior Wind Scientist

Vincent Ferraro, M.Eng., P.Eng.
Managing Principal

LICENSED PROFESSIONAL ENGINEER
V. M. FERRARO
PROVINCE OF ONTARIO
Sept 26, 2018

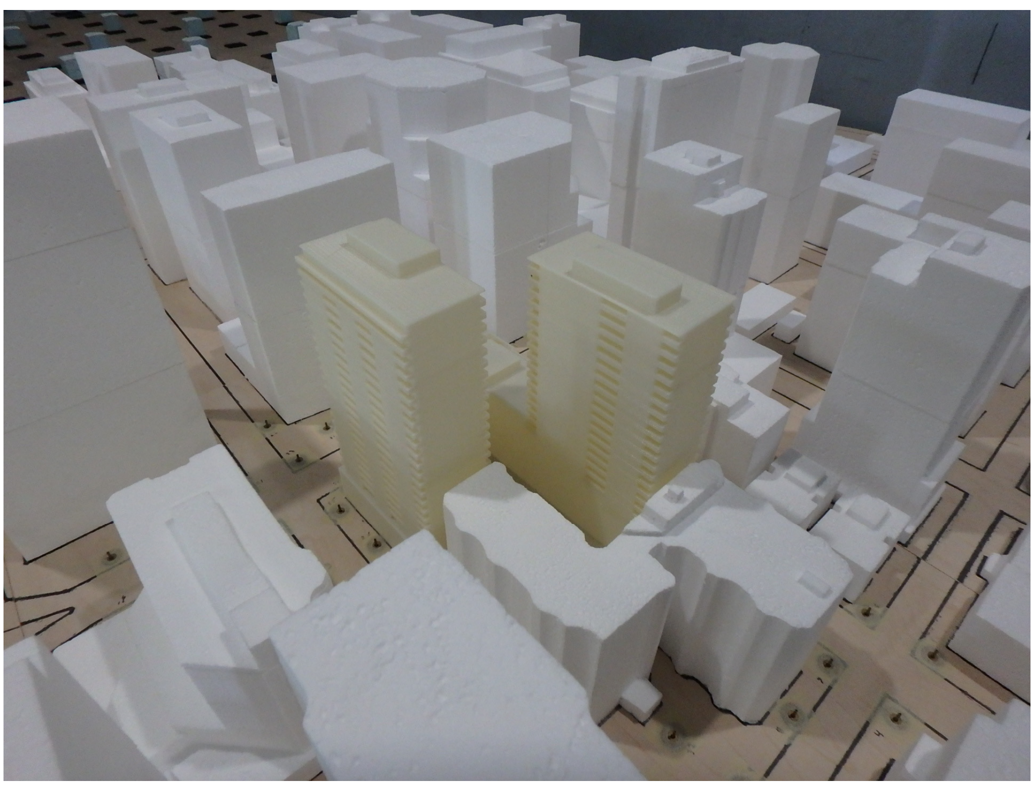
GWE18-111-PLW

PHOTOGRAPH 1: VIEW OF STUDY MODEL LOOKING DOWNWIND



PHOTOGRAPH 2: VIEW OF STUDY MODEL LOOKING UPWIND

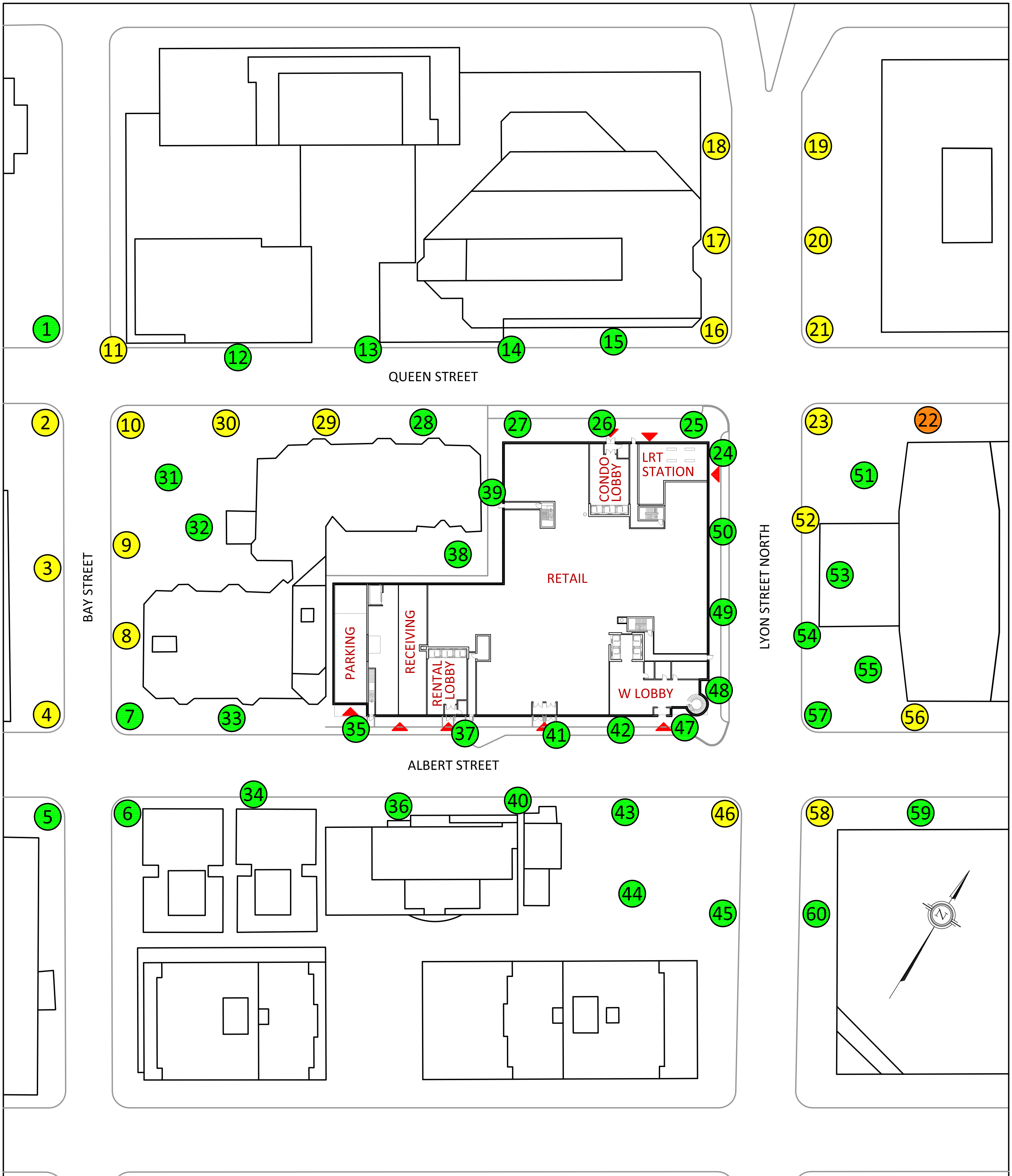
PHOTOGRAPH 3: VIEW OF STUDY MODEL LOOKING NORTHWEST



PHOTOGRAPH 4: CLOSE-UP VIEW OF STUDY MODEL LOOKING SOUTHEAST

127 Walgreen Road
Ottawa, Ontario
(613) 836 0934
GRADIENT WIND ENGINEERING INC

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:2500 (APPROX.)
DRAWING NO.	GWE18-111-PLW-1
DATE	AUGUST 3, 2018
DRAWN BY	K.A.
DESCRIPTION	FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT



PREDICTED COMFORT CLASSES
- # SITTING
- # STANDING
- # STROLLING

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

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Ottawa, Ontario
(613) 836 0934

GRADIENT WIND ENGINEERING INC

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1100 (APPROX.)
DRAWING NO.	GWE18-111-PLW-2A
DATE	AUGUST 3, 2018
DRAWN BY	K.A.
DESCRIPTION	FIGURE 2A: SPRING GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS

PREDICTED COMFORT CLASSES	
# (green)	SITTING
# (yellow)	STANDING
# (orange)	STROLLING

NOTES:

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

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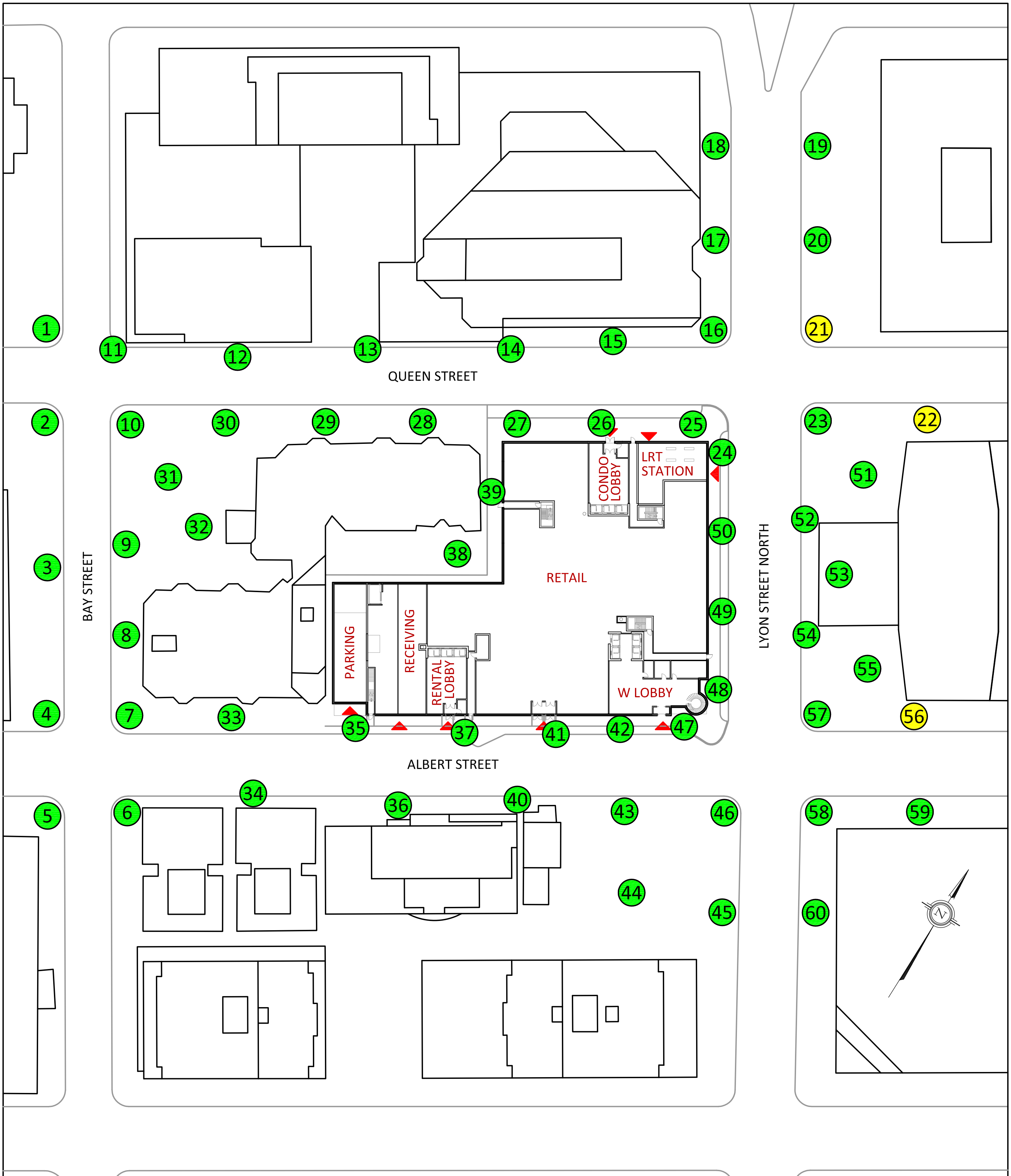
(613) 836 0934

GWE GRADIENT WIND ENGINEERING INC

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:500 (APPROX.)	DRAWING NO.	GWE18-111-PLW-2B
DATE	AUGUST 3, 2018	DRAWN BY	K.A.

DESCRIPTION

FIGURE 2B: SPRING
9TH FLOOR TERRACE
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

- (#) SITTING
- (#) STANDING
- (#) STROLLING

NOTES:

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

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Ottawa, Ontario
(613) 836 0934

PROJECT: 383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 3A: SUMMER GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS
SCALE: 1:1100 (APPROX.)	DRAWING NO.: GWE18-111-PLW-3A	
DATE: AUGUST 3, 2018	DRAWN BY: K.A.	

PREDICTED COMFORT CLASSES
- # SITTING
- # STANDING
- # STROLLING

NOTES:

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

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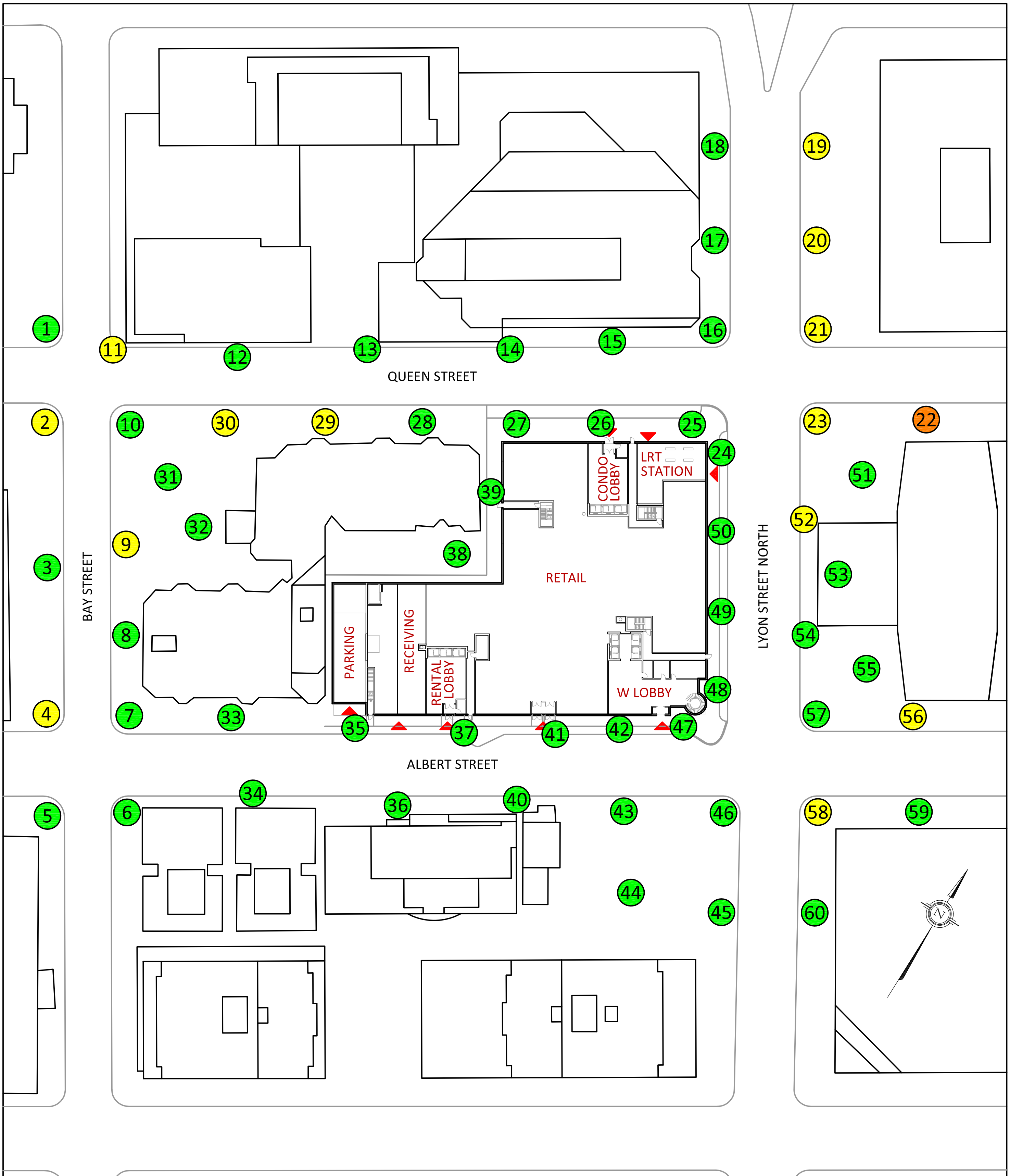
(613) 836 0934
GRADIENT WIND ENGINEERING INC

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:500 (APPROX.)
DRAWING NO.	GWE18-111-PLW-3B
DATE	AUGUST 3, 2018
DRAWN BY	K.A.
DESCRIPTION	FIGURE 3B: SUMMER 9TH FLOOR TERRACE PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

- (#) SITTING
- (#) STANDING
- (#) STROLLING

NOTES:

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

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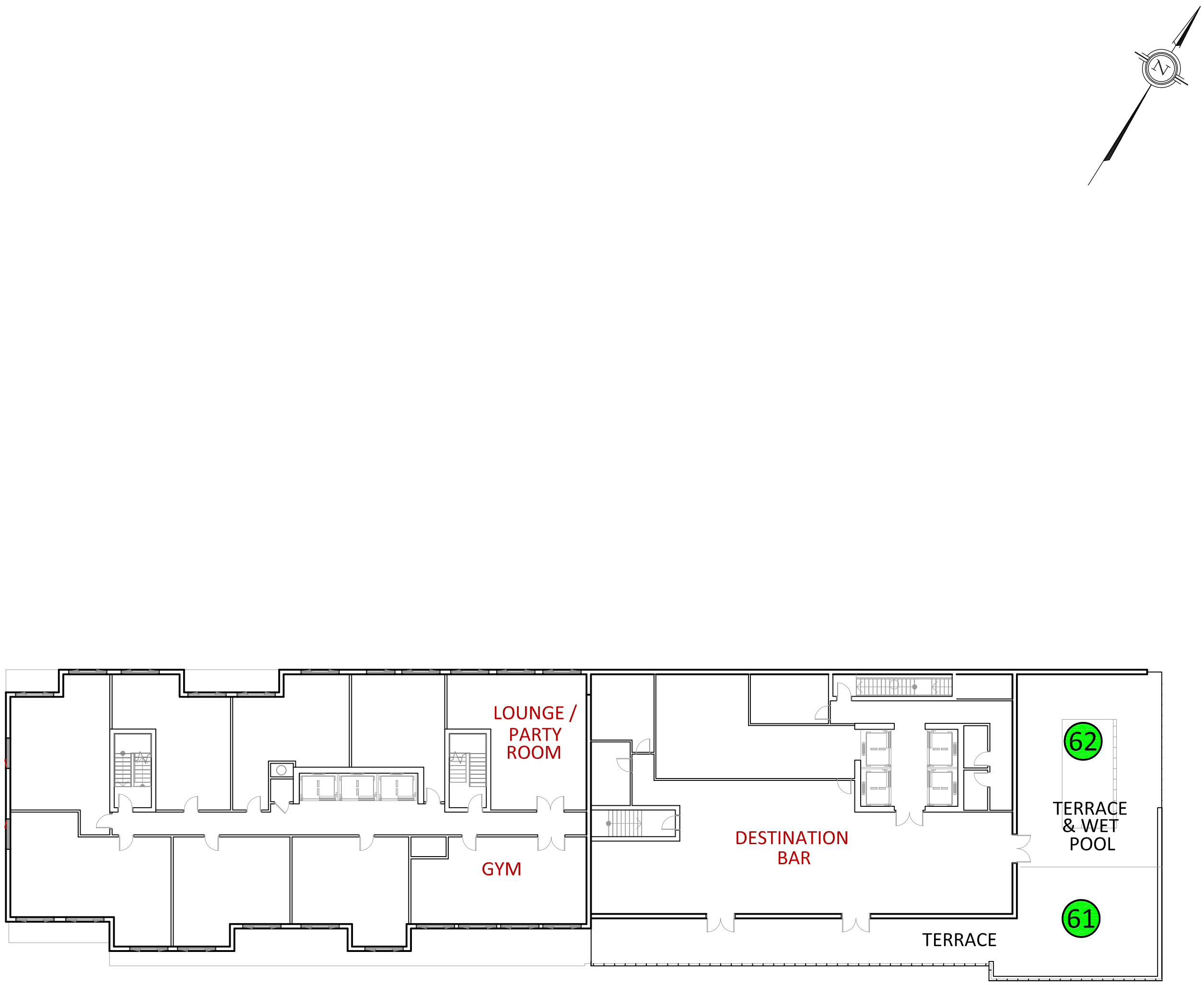
Ottawa, Ontario
(613) 836 0934

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:1100 (APPROX.)	DRAWING NO.	GWE18-111-PLW-4A
DATE	AUGUST 3, 2018	DRAWN BY	K.A.

DESCRIPTION

FIGURE 4A: AUTUMN
GROUND FLOOR PLAN
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES
SITTING
STANDING
STROLLING

NOTES:

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

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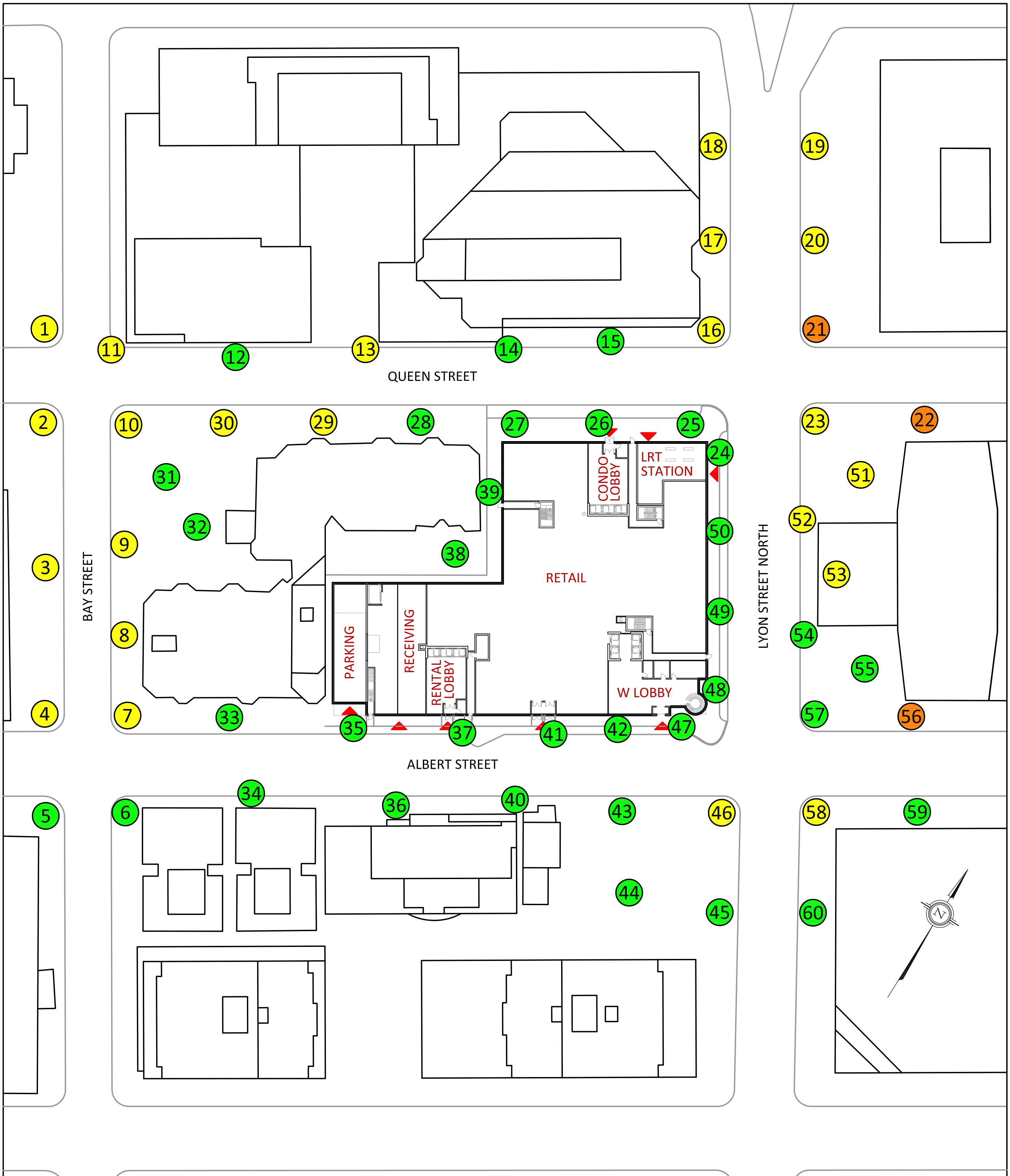
GRADIENT WIND ENGINEERING INC

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:500 (APPROX.)	DRAWING NO.	GWE18-111-PLW-4B
DATE	AUGUST 3, 2018	DRAWN BY	K.A.

DESCRIPTION

FIGURE 4B: AUTUMN
9TH FLOOR TERRACE
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

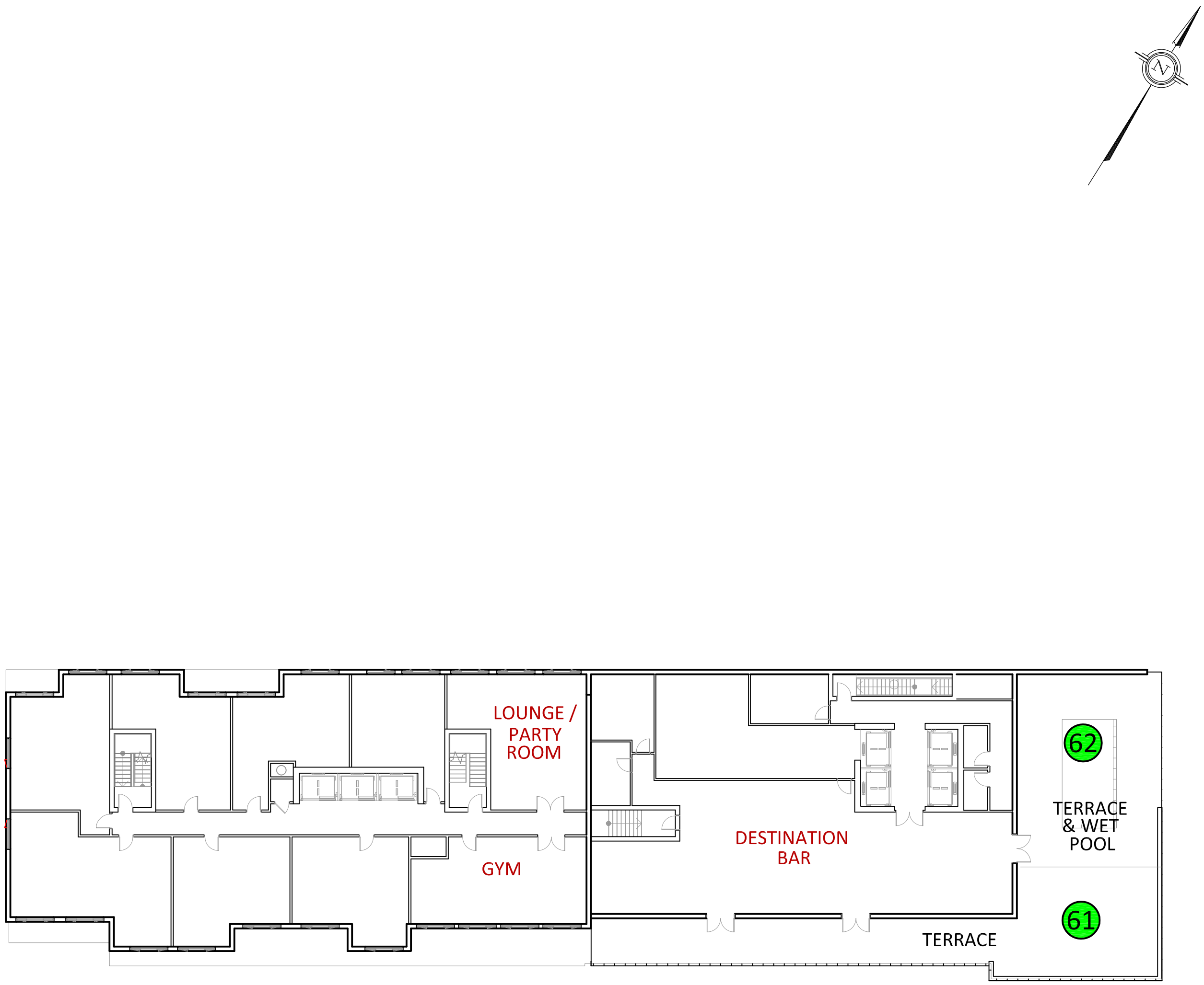
- # SITTING
- # STANDING
- # STROLLING

NOTES:

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

GRADIENT WIND ENGINEERING INC
127 Walgreen Road
Ottawa, Ontario
(613) 836 0934

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1100 (APPROX.)
DRAWING NO.	GWE18-111-PLW-5A
DATE	AUGUST 3, 2018
DRAWN BY	K.A.
DESCRIPTION	FIGURE 5A: WINTER GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES
- # SITTING
- # STANDING
- # STROLLING

NOTES:

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

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GRADIENT WIND ENGINEERING INC

PROJECT	383 ALBERT STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:500 (APPROX.)
DRAWING NO.	GWE18-111-PLW-5B
DATE	AUGUST 3, 2018
DRAWN BY	K.A.
DESCRIPTION	FIGURE 5B: WINTER 9TH FLOOR TERRACE PEDESTRIAN COMFORT PREDICTIONS

APPENDIX A

WIND TUNNEL SIMULATION OF THE NATURAL WIND

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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 centre 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 meters (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 A1 plots three such profiles for the open country, suburban and urban exposures.

The exponent α varies according to the type of terrain; α = 0.14, 0.25 and 0.33 for open country, suburban and urban exposures respectively. Figure A2 illustrates the theoretical variation of turbulence in full scale and some wind tunnel measurement for comparison.

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***, U_{10} 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.

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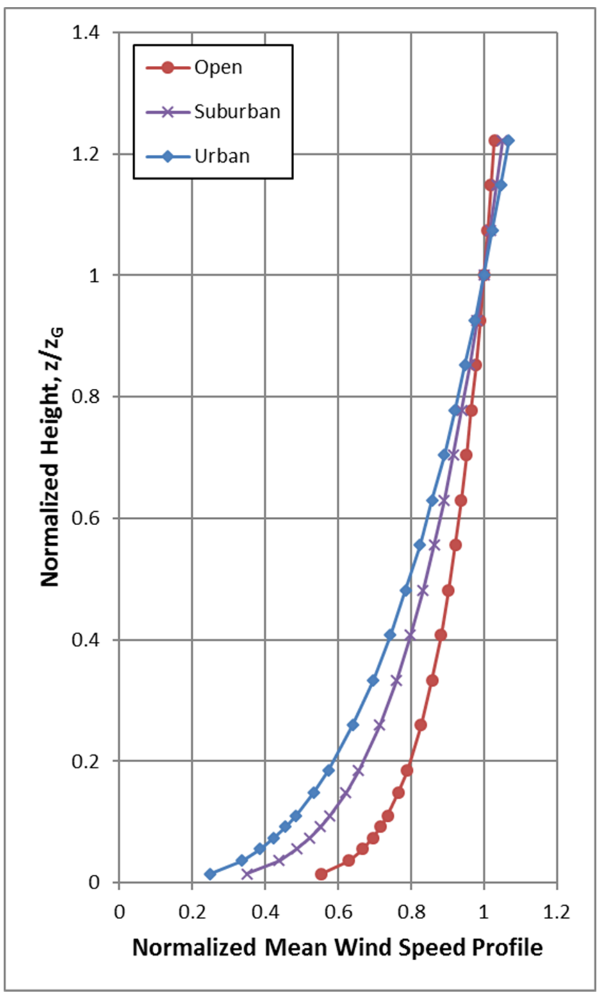

Figure A1: Mean Wind Speed Profiles

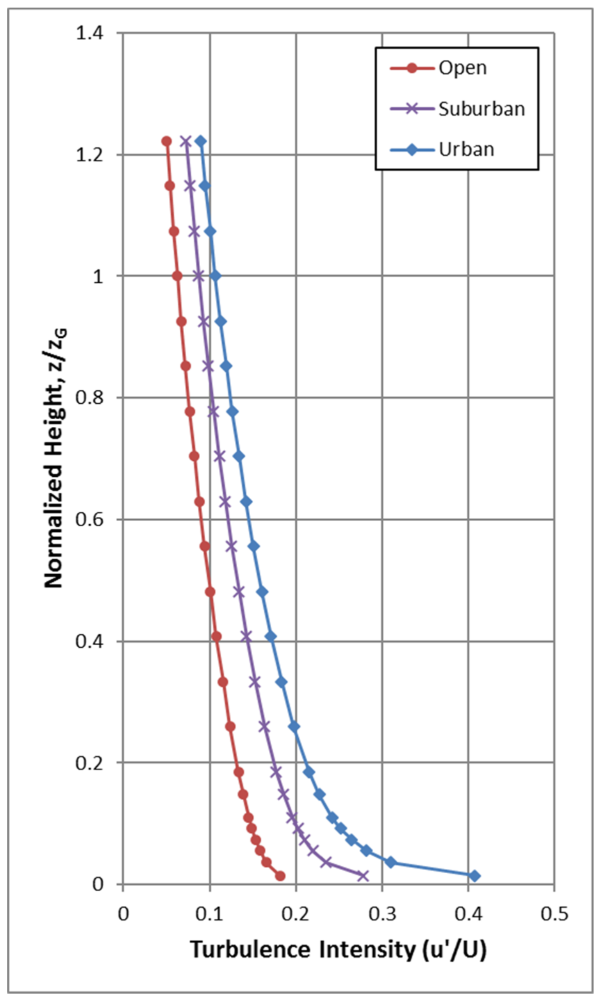

Figure A2: Turbulence Intensity Profiles

APPENDIX B

PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

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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 meters (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 B1. 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:

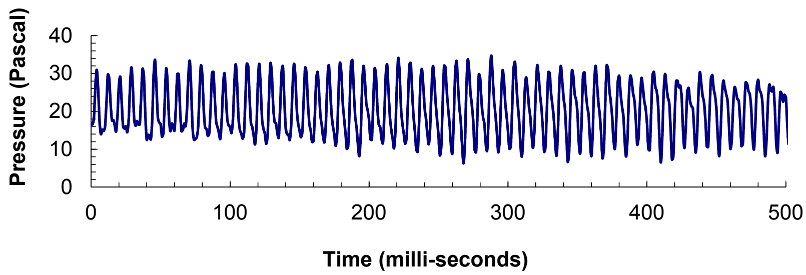
$$P_N\left(> 20\right) = \Sigma_\theta P\left[\frac{\left(> 20\right)}{\left(\frac{U_N}{U_g}\right)}\right]$$

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

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

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

FIGURE B1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR



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