Pedestrian Level Wind Study

350 Sparks Street

Ottawa, Ontario

REPORT: GWE15-029-PLW

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EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind comfort for 350 Sparks Street, a proposed dual tower redevelopment project by Morguard Developments 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. Grade-level pedestrian areas considered in this study include nearby sidewalks, walkways, building access points, the future pedestrian plaza at the northwest corner of the development site, the public park to the northwest of the site, and the existing hotel patio at the southwest corner of Bay Street and Queen Street. Wind conditions are also determined over the outdoor amenity terrace located on the fourth level, north of the hotel tower. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report.

This study was performed in accordance with the scope of work described in GWE proposal #14-170-P R1 dated March 6, 2015. The work is based on industry standard wind tunnel testing and data analysis procedures, architectural drawings provided by WZMH Architects in March 2015, surrounding street layouts as well as existing and approved future building massing information obtained from the City of Ottawa, and recent site imagery. All wind comfort conditions are evaluated according to the City of Ottawa Terms of Reference for Wind Analysis.

A complete summary of the predicted pedestrian 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, and experience with similar developments in Ottawa, we conclude that the wind conditions at 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. As well, no areas within or surrounding the study site were found to experience conditions too windy for walking, or that are considered unsafe.

For the tested configuration of the fourth level outdoor amenity area, wind conditions near the northwest and southeast corners of the terrace will achieve the sitting criterion during the summer months and shoulder seasons of spring and autumn. The remaining terrace areas will experience sitting conditions between 75% and 79% of the time during the same period.

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1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by WZMH Architects to undertake microclimate studies to support the SPA submission for 350 Sparks Street, a proposed dual tower redevelopment project by Morguard Developments in Ottawa, Ontario. The complete scope of work within our mandate, as outlined in GWE proposal #14-170-P R1 dated March 6, 2015, includes studies of pedestrian level winds, stationary noise of neighbouring buildings, traffic noise, and ground vibrations. This report summarizes the methodology, results, and recommendations related to the pedestrian level wind (PLW) study, while the remaining studies are presented in separate reports. Our work is based on industry standard wind tunnel testing techniques, architectural drawings provided by WZMH Architects in March 2015, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery.

2. TERMS OF REFERENCE

The focus of this PLW study is the planned dual-tower mixed-use redevelopment project located at 350 Sparks Street in Ottawa, Ontario. The study site is located on the west half of the city block bounded by Queen Street to the south, Bay Street to the west, Sparks Street to the north, and Lyon Street North to the east. Local surroundings comprise a moderate-density concentration of low, medium, and high-rise buildings, with a greater density of taller buildings in the downtown Ottawa core to the east. The Ottawa River and Lebreton Flats are at a lower elevation to the west and north of the study site.

Upon completion, the development will feature two tall buildings rising from a common multi-level podium. The residential tower on the north side of the site contains 24 storeys, rising to a total height of approximately 78.45 metres above local grade. At the south side of the site, the hotel tower contains 26 storeys and rises to a height of approximately 84 metres above local grade. Above three levels of below-grade parking, the L-shaped podium contains shared hotel and residential uses and integrates with the existing structure on the east portion of the site. The ground floor of the new development contains separate residential and hotel lobbies, retail space, service entrances, as well as reconfigured entrances to the existing office building at the east side of the site. A vehicular drop-off plaza, with access from Queen Street, is integrated within the podium. The second and third levels of the podium contain hotel uses on the south side and residential units on the north side. Above the third level, the residential and hotel towers rise from the north and south sides of the podium, respectively. An outdoor amenity terrace is located on the fourth level between the towers. Above the podium, the hotel and residential buildings each rise with a consistent floor plate above to the full height of the building, and are topped by a mechanical penthouse

Residential lobby entrances are located near the centre of the north elevation with access from Sparks Street, and at the north side of the vehicular drop-off plaza, while the hotel and office entrances are located at the west and east sides of the drop-off plaza, respectively. The parking garage entrance is located at the west side of the north elevation with access from Sparks Street, and the service entrances are along the west elevation with access from Bay Street.

Grade-level pedestrian areas considered in this study include nearby sidewalks, walkways, building access points, the future pedestrian plaza at the northwest corner of the development site, the public park to the northwest of the site, and the existing hotel patio at the southwest corner of Bay Street and Queen Street. Wind conditions are also measured across the fourth level outdoor amenity terrace. Figure 1 illustrates the study site and surrounding context. 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 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 PLW study is performed to determine the influence of local winds at the pedestrian level for a proposed development. The physical model, illustrated in Photographs 1 through 4 (following the main text) of the proposed development and relevant surroundings 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. For this study, the wind tunnel was configured to simulate atmospheric velocity profiles consistent with suburban upwind 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, and because this approach produces slightly less conservative results.

4.2 Wind Speed Measurements

The PLW study was performed by testing a total of 54 sensor locations on the scale model in GWE's wind tunnel. Of the 54 sensors, 49 were placed at grade level, with the remaining five on the elevated outdoor amenity area. Wind speed measurements were performed for each of the 56 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 2010 and of 'Wind Tunnel Studies of Buildings and Structures', ASCE Manual 7 Reports on Engineering Practice No 67.

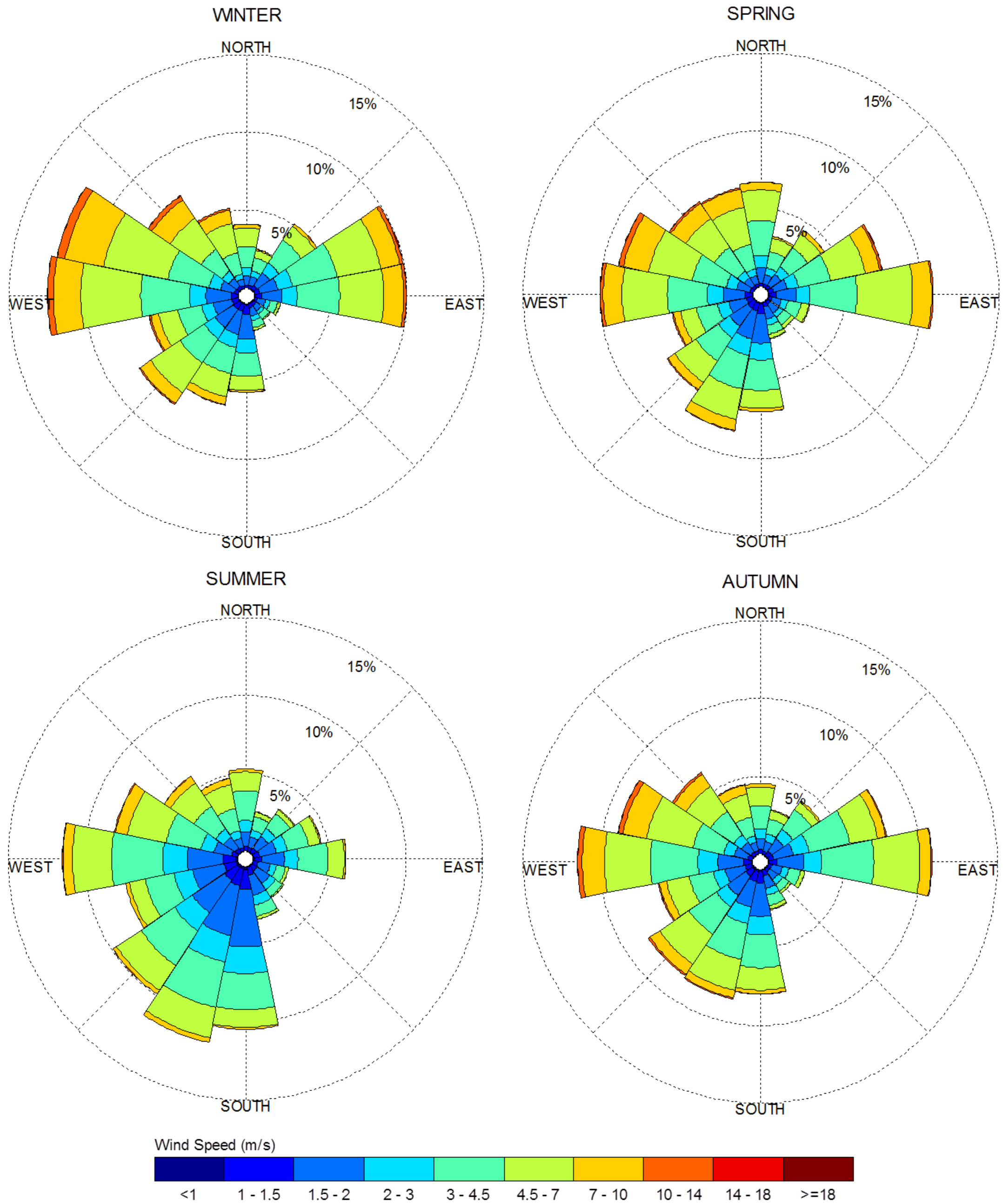
4.3 Meteorological Data Analysis

A statistical model for winds in Ottawa was developed from approximately 40-years of hourly meteorological wind data recorded at Ottawa 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 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 meters per second. 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 as the length of the bar where the given bar has the largest length. For Ottawa, the most common winds occur for west and east quadrants; and the most common wind speeds are below 10 meters per second. However, it is noted that the most prominent wind direction for higher wind speeds originates from the west during the winter months. The directional preference and relative magnitude of the wind speed varies somewhat from season to season, with the summer months displaying the calmest winds relative to the remaining seasonal periods.

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES

OTTAWA INTERNATIONAL AIRPORT, OTTAWA, ONTARIO



Notes:

1. Radial distances indicate percentage of time of wind events.
2. Wind speeds represent mean hourly wind speeds measured at 10 m above the ground.

4.4 Pedestrian Comfort Guidelines

Pedestrian comfort guidelines are based on mechanical wind effects without consideration of other meteorological conditions (i.e. temperature, relative humidity). The guidelines provide an assessment of comfort, assuming that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Six 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; (v) Uncomfortable; and (vi) Dangerous. More specifically, the comfort classes, associated wind speed ranges, and limiting guidelines are summarized as follows:

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

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

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

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

(vi) **Dangerous** – Gust wind speeds greater than or equal to 90 km/h, occurring at least 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 guidelines 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 gust speed ranges are selected based on 'The Beaufort Scale' (presented on the following page), which describes the effects of forces produced by varying wind speed levels on objects.

THE BEAUFORT SCALE

Number	Description	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% or 30% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if wind speeds of 14 km/h were exceeded for more than 30% 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 at tested locations, the assessment of pedestrian comfort involves determining the suitability of the predicted wind conditions for their associated spaces. This step involves comparing the predicted comfort class to the desired comfort class, which is dictated by the location type. An overview of common pedestrian location types and their desired comfort classes are summarized on the following page.

DESIRED PEDESTRIAN COMFORT CLASSES FOR VARIOUS LOCATION TYPES

Location Types	Desired Comfort Classes
Major Building Entrance	Standing
Secondary Building Access Points	Walking
Primary Public Sidewalks	Strolling
Secondary Public Sidewalks / Bicycle Paths	Walking
Outdoor Amenity Spaces	Sitting
Cafés / Patios / Benches / Gardens	Sitting
Transit Shelters	Standing
Public Parks / Plazas	Strolling
Garage / Service Entrances	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 14, beginning on the following page, provide a summary of seasonal comfort predictions for each sensor location. The Tables indicate the predicted percentages of time that wind speeds will fall into the ranges defined in the guidelines. 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, 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 14, 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 with yellow, strolling with blue, and walking with magenta. 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)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #1	**Spring**	70	85	92	96	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	83	92	96	98	Sitting			
	Autumn	75	88	93	96	Standing			
	Winter	68	83	90	94	Standing			
Sensor #2	**Spring**	86	96	99	100	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	92	98	99	100	Sitting			
	Autumn	88	96	99	99	Sitting			
	Winter	84	95	98	99	Sitting			
Sensor #3	**Spring**	71	85	91	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	80	91	95	97	Sitting			
	Autumn	73	86	91	94	Standing			
	Winter	68	82	88	92	Standing			
Sensor #4	**Spring**	67	81	88	92	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	77	88	93	96	Standing			
	Autumn	71	83	89	93	Standing			
	Winter	65	79	85	90	Strolling			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

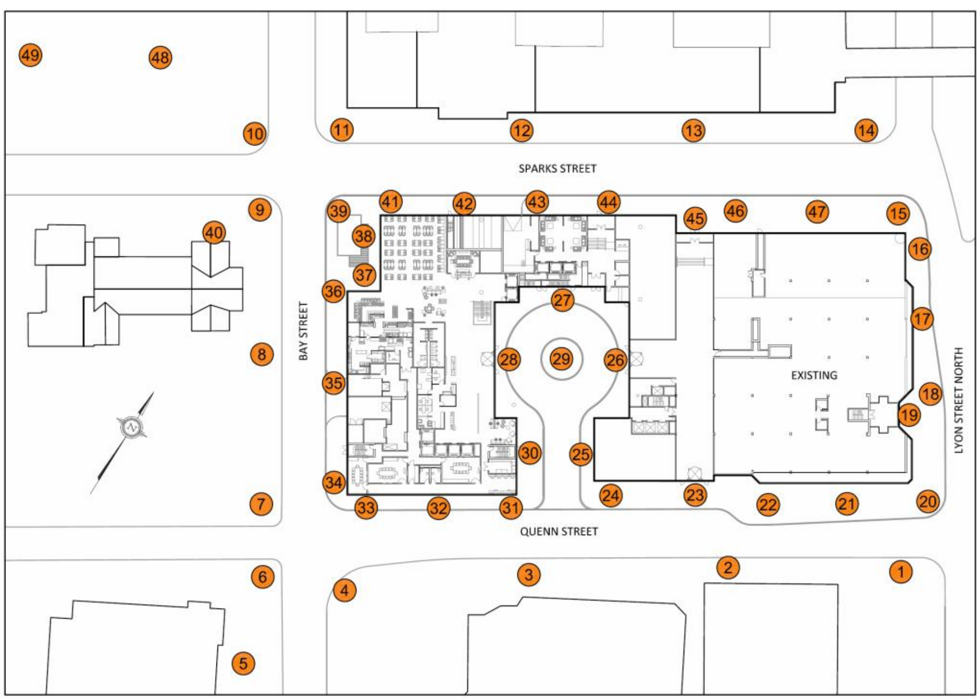


TABLE 2: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #5	**Spring**	80	89	94	96	Sitting	Existing Patio	Sitting	Acceptable (See §5.2)
	Summer	88	94	97	98	Sitting			
	Autumn	82	91	95	97	Sitting			
	Winter	77	88	92	95	Standing			
Sensor #6	**Spring**	70	84	91	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	80	91	95	97	Sitting			
	Autumn	74	86	92	95	Standing			
	Winter	69	83	89	93	Standing			
Sensor #7	**Spring**	70	85	91	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	80	91	95	97	Sitting			
	Autumn	74	86	92	95	Standing			
	Winter	69	83	89	93	Standing			
Sensor #8	**Spring**	66	82	89	93	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	78	89	94	96	Standing			
	Autumn	71	84	90	94	Standing			
	Winter	65	80	87	92	Standing			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

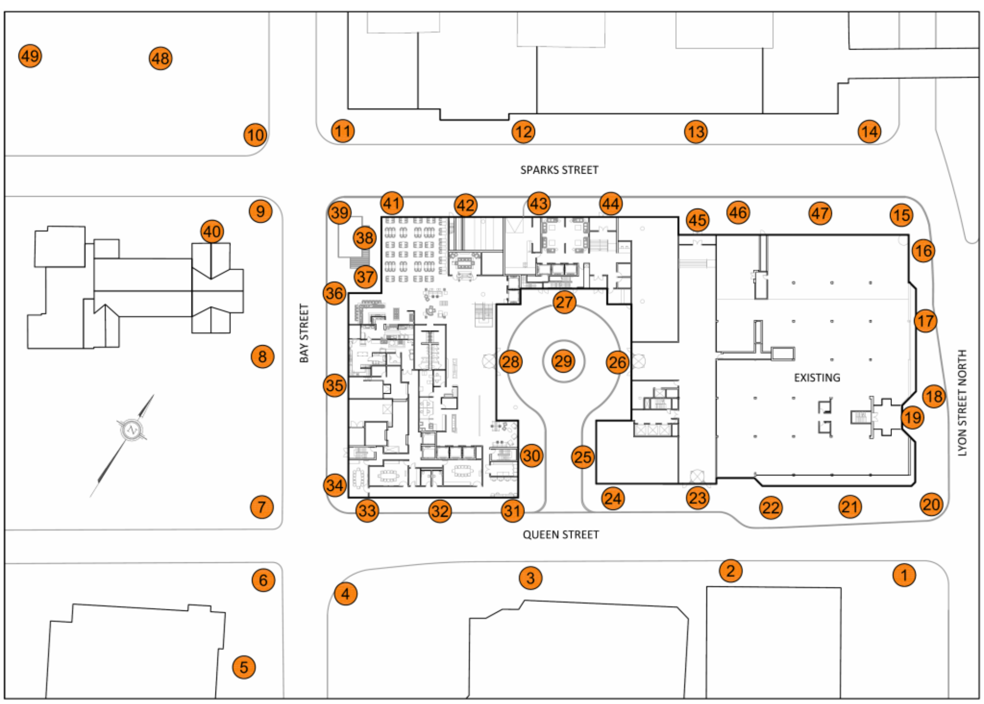


TABLE 3: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #9	**Spring**	71	86	93	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	81	92	96	98	Sitting			
	Autumn	74	88	94	97	Standing			
	Winter	70	85	92	96	Standing			
Sensor #10	**Spring**	73	88	94	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	83	93	97	99	Sitting			
	Autumn	77	90	95	98	Standing			
	Winter	73	87	94	97	Standing			
Sensor #11	**Spring**	67	83	90	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	78	90	95	98	Standing			
	Autumn	71	85	91	95	Standing			
	Winter	66	81	89	94	Standing			
Sensor #12	**Spring**	84	95	98	100	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	90	97	99	100	Sitting			
	Autumn	86	95	98	99	Sitting			
	Winter	84	95	98	99	Sitting			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

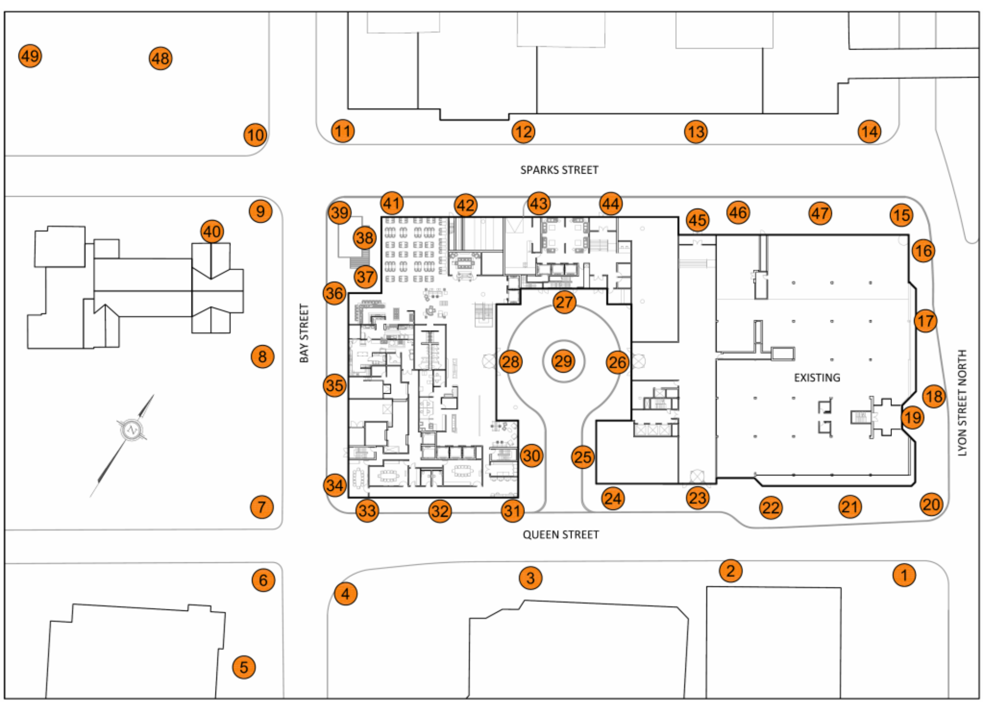


TABLE 4: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #13	**Spring**	76	90	96	98	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	85	95	98	99	Sitting			
	Autumn	79	91	96	98	Standing			
	Winter	75	89	95	98	Standing			
Sensor #14	**Spring**	69	86	93	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	81	93	97	99	Sitting			
	Autumn	73	88	94	97	Standing			
	Winter	67	85	92	96	Standing			
Sensor #15	**Spring**	74	89	94	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	86	95	97	99	Sitting			
	Autumn	78	90	95	97	Standing			
	Winter	72	86	92	96	Standing			
Sensor #16	**Spring**	74	88	94	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	86	94	97	99	Sitting			
	Autumn	79	91	95	98	Standing			
	Winter	73	88	94	97	Standing			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

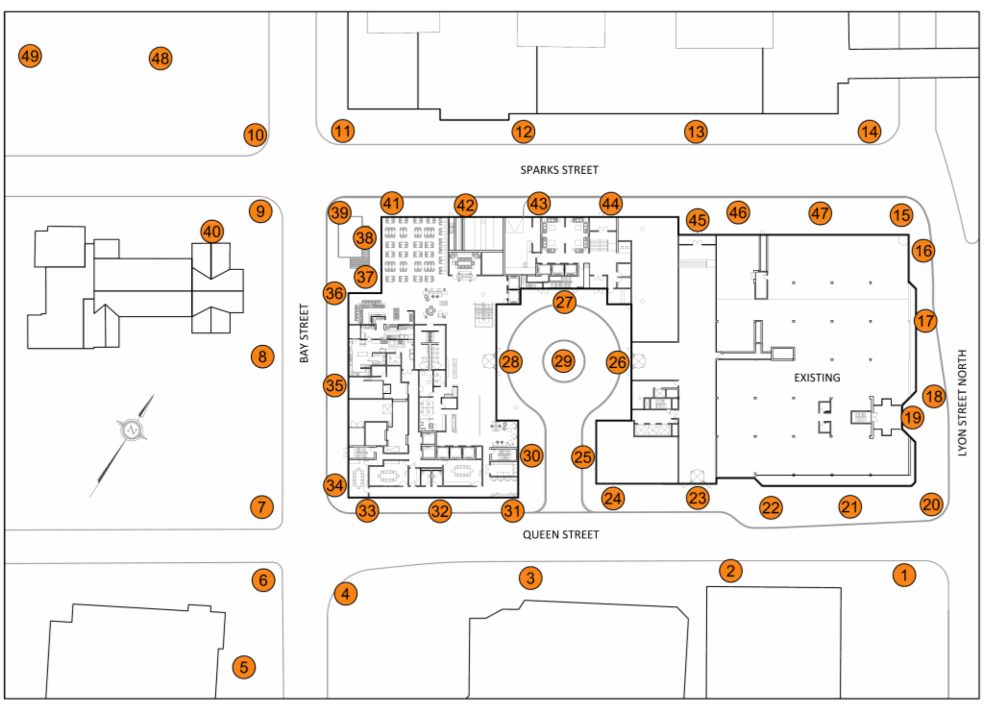


TABLE 5: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #17	Spring	73	86	92	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	84	92	96	97	Sitting			
	Autumn	77	89	93	96	Standing			
	Winter	71	84	90	94	Standing			
Sensor #18	Spring	66	81	88	93	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	80	89	94	96	Sitting			
	Autumn	71	84	90	94	Standing			
	Winter	64	79	86	91	Strolling			
Sensor #19	Spring	75	89	94	97	Standing	Office Entrance	Standing	Acceptable
	Summer	87	95	97	99	Sitting			
	Autumn	80	91	96	98	Sitting			
	Winter	74	88	93	97	Standing			
Sensor #20	Spring	65	81	89	93	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	78	89	94	96	Standing			
	Autumn	70	84	90	94	Standing			
	Winter	64	80	87	91	Standing			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

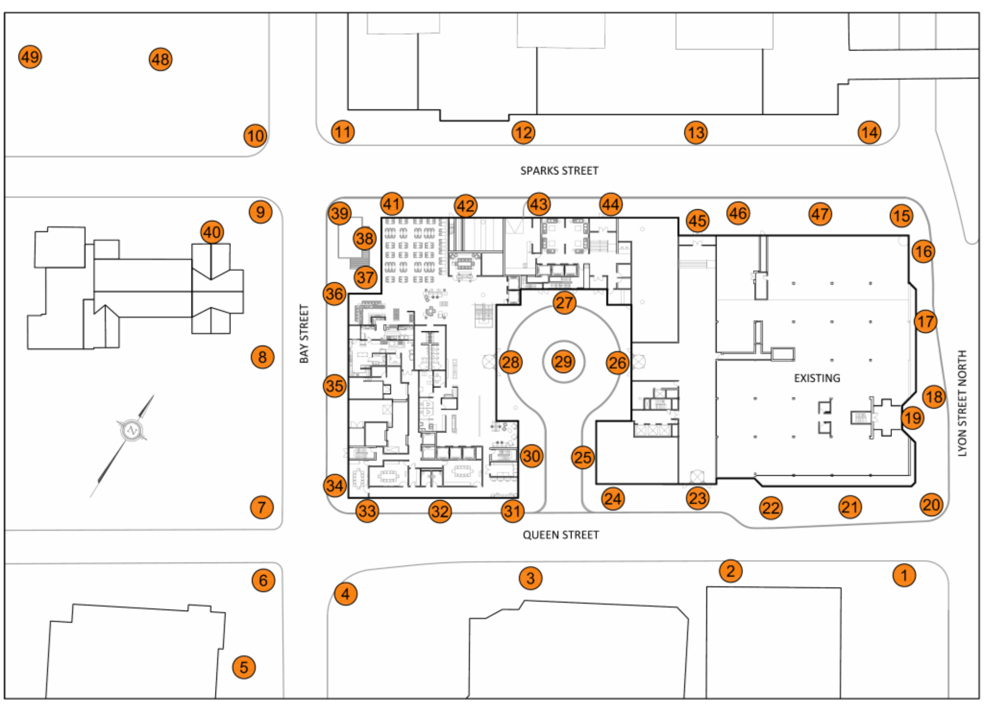


TABLE 6: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #21	Spring	91	98	100	100	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	96	99	100	100	Sitting			
	Autumn	92	98	100	100	Sitting			
	Winter	90	98	100	100	Sitting			
Sensor #22	Spring	88	97	99	100	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	93	98	100	100	Sitting			
	Autumn	88	96	99	100	Sitting			
	Winter	86	96	99	100	Sitting			
Sensor #23	Spring	83	94	97	99	Sitting	Office Entrance	Standing	Acceptable
	Summer	88	96	99	100	Sitting			
	Autumn	83	93	97	99	Sitting			
	Winter	81	92	97	99	Sitting			
Sensor #24	Spring	87	97	99	100	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	93	98	100	100	Sitting			
	Autumn	88	96	99	100	Sitting			
	Winter	86	96	98	99	Sitting			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

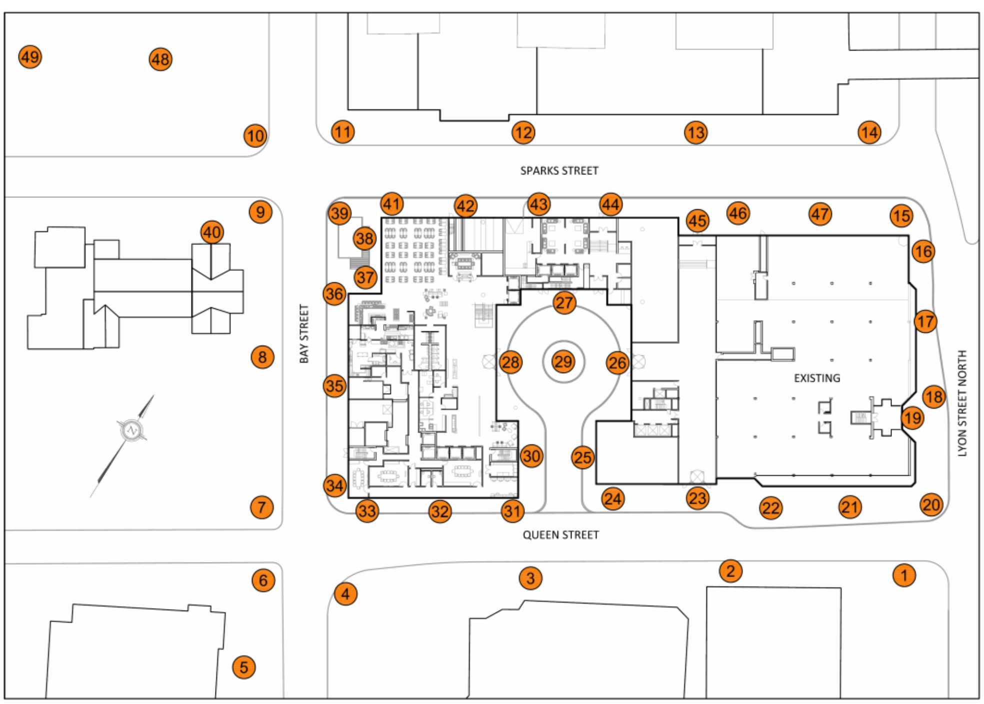


TABLE 7: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #25	Spring	75	89	94	97	Standing	Pedestrian Walkway	Walking	Acceptable
	Summer	81	92	97	99	Sitting			
	Autumn	76	89	94	97	Standing			
	Winter	74	87	94	97	Standing			
Sensor #26	Spring	84	94	97	99	Sitting	Office Entrance	Standing	Acceptable
	Summer	90	96	98	99	Sitting			
	Autumn	85	94	97	98	Sitting			
	Winter	81	92	96	98	Sitting			
Sensor #27	Spring	90	98	99	100	Sitting	Residential Entrance	Standing	Acceptable
	Summer	95	99	100	100	Sitting			
	Autumn	92	98	99	100	Sitting			
	Winter	90	97	99	100	Sitting			
Sensor #28	Spring	89	97	99	100	Sitting	Hotel Entrance	Standing	Acceptable
	Summer	94	99	100	100	Sitting			
	Autumn	91	98	99	100	Sitting			
	Winter	89	97	99	100	Sitting			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

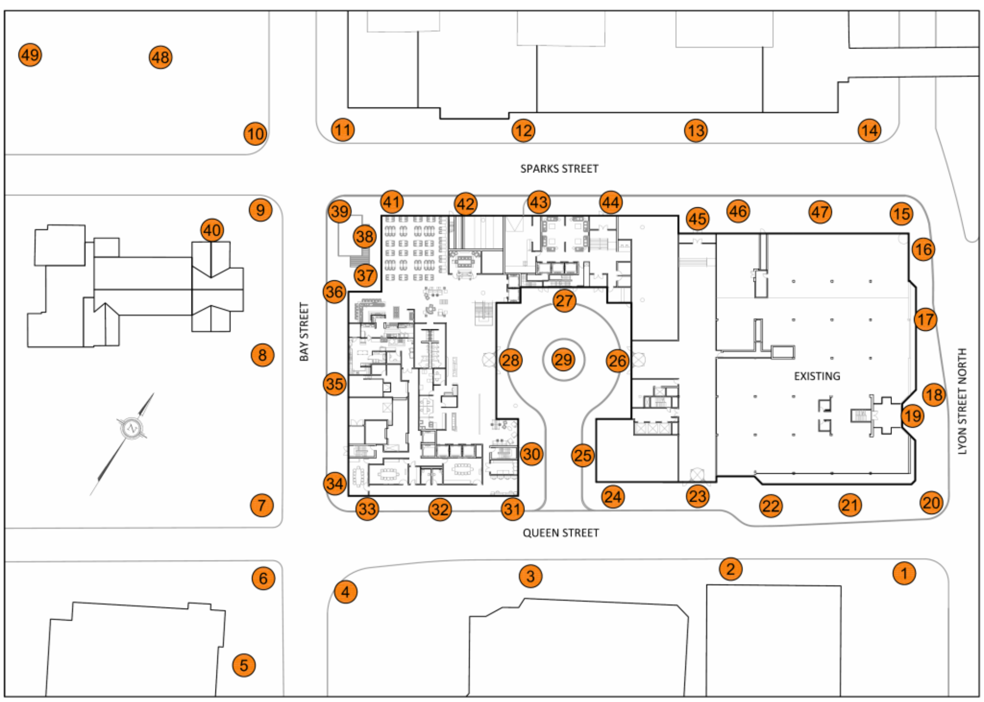


TABLE 8: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #29	Spring	77	90	95	97	Standing	Vehicular Drop-Off	Walking	Acceptable
	Summer	84	94	97	99	Sitting			
	Autumn	79	90	95	97	Standing			
	Winter	75	88	93	96	Standing			
Sensor #30	Spring	80	91	95	97	Sitting	Pedestrian Walkway	Walking	Acceptable
	Summer	87	95	97	99	Sitting			
	Autumn	83	92	96	98	Sitting			
	Winter	80	90	95	97	Sitting			
Sensor #31	Spring	80	93	97	99	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	89	96	99	100	Sitting			
	Autumn	82	93	97	99	Sitting			
	Winter	77	91	96	98	Standing			
Sensor #32	Spring	83	94	97	99	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	90	97	99	100	Sitting			
	Autumn	85	94	97	99	Sitting			
	Winter	81	92	96	98	Sitting			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

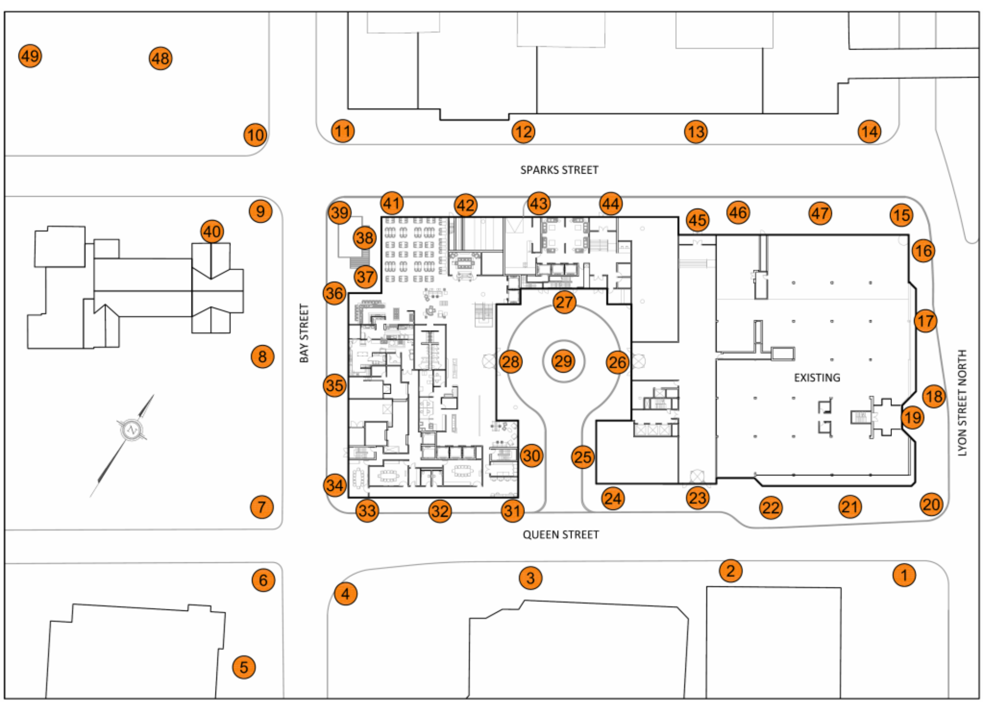


TABLE 9: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #33	Spring	87	97	99	100	Sitting	Public Sidewalk	Strolling	Acceptable
	Summer	93	98	100	100	Sitting			
	Autumn	88	96	99	100	Sitting			
	Winter	85	95	98	99	Sitting			
Sensor #34	Spring	68	81	88	92	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	78	88	92	95	Standing			
	Autumn	71	83	88	92	Standing			
	Winter	66	78	85	89	Strolling			
Sensor #35	Spring	78	91	96	98	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	86	95	98	99	Sitting			
	Autumn	80	91	96	98	Sitting			
	Winter	76	89	94	97	Standing			
Sensor #36	Spring	72	86	92	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	81	91	95	98	Sitting			
	Autumn	74	87	92	95	Standing			
	Winter	70	83	90	93	Standing			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

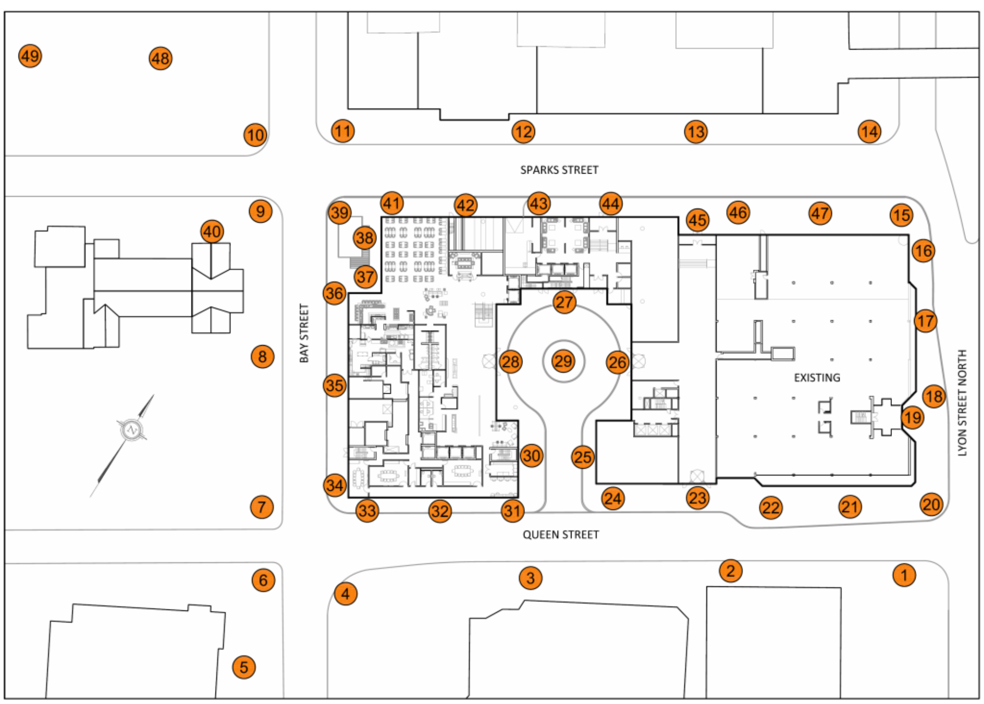


TABLE 10: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #37	Spring	90	97	99	100	Sitting	Plaza	Standing	Acceptable
	Summer	95	99	100	100	Sitting			
	Autumn	91	97	99	100	Sitting			
	Winter	88	96	99	100	Sitting			
Sensor #38	Spring	85	95	98	100	Sitting	Plaza	Standing	Acceptable
	Summer	90	98	99	100	Sitting			
	Autumn	85	95	98	99	Sitting			
	Winter	83	94	98	99	Sitting			
Sensor #39	Spring	71	86	93	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	82	93	97	98	Sitting			
	Autumn	75	89	94	97	Standing			
	Winter	71	86	93	97	Standing			
Sensor #40	Spring	74	88	93	97	Standing	Existing Building Entrance	Standing	Acceptable
	Summer	84	93	97	98	Sitting			
	Autumn	78	89	94	97	Standing			
	Winter	72	86	92	96	Standing			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

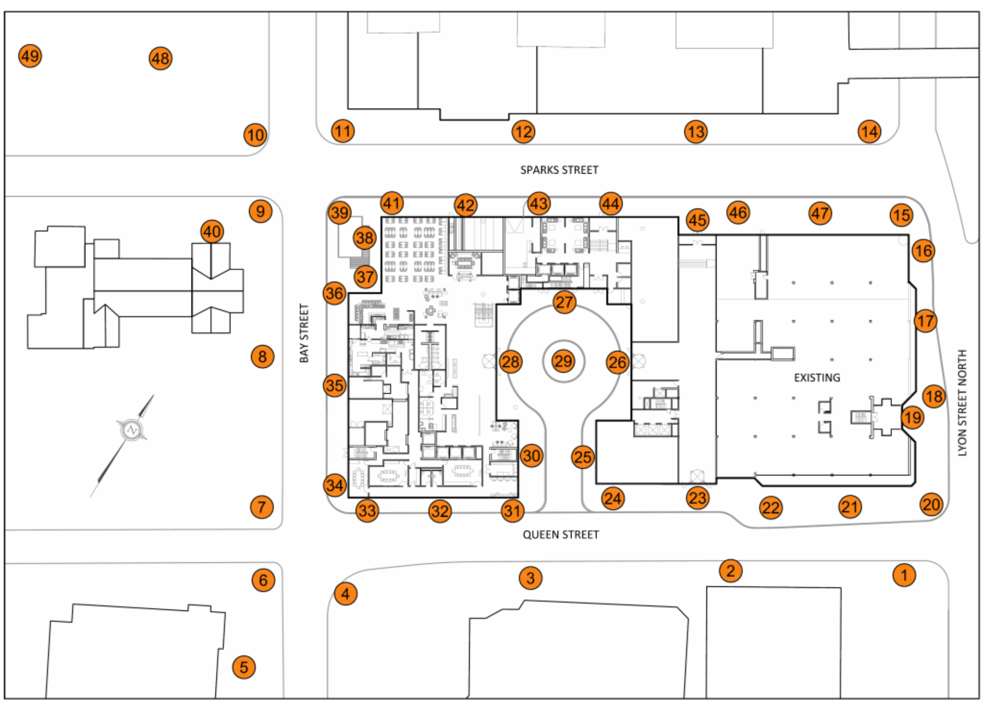


TABLE 11: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #41	**Spring**	66	82	90	95	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	77	89	95	98	Standing			
	Autumn	70	84	91	95	Standing			
	Winter	65	81	89	94	Standing			
Sensor #42	**Spring**	73	87	93	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	82	92	96	98	Sitting			
	Autumn	76	88	94	97	Standing			
	Winter	71	85	92	95	Standing			
Sensor #43	**Spring**	78	92	97	99	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	88	96	99	100	Sitting			
	Autumn	81	93	97	99	Sitting			
	Winter	77	91	96	98	Standing			
Sensor #44	**Spring**	84	95	98	100	Sitting	Residential Entrance	Standing	Acceptable
	Summer	91	98	99	100	Sitting			
	Autumn	85	95	98	99	Sitting			
	Winter	82	94	98	99	Sitting			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

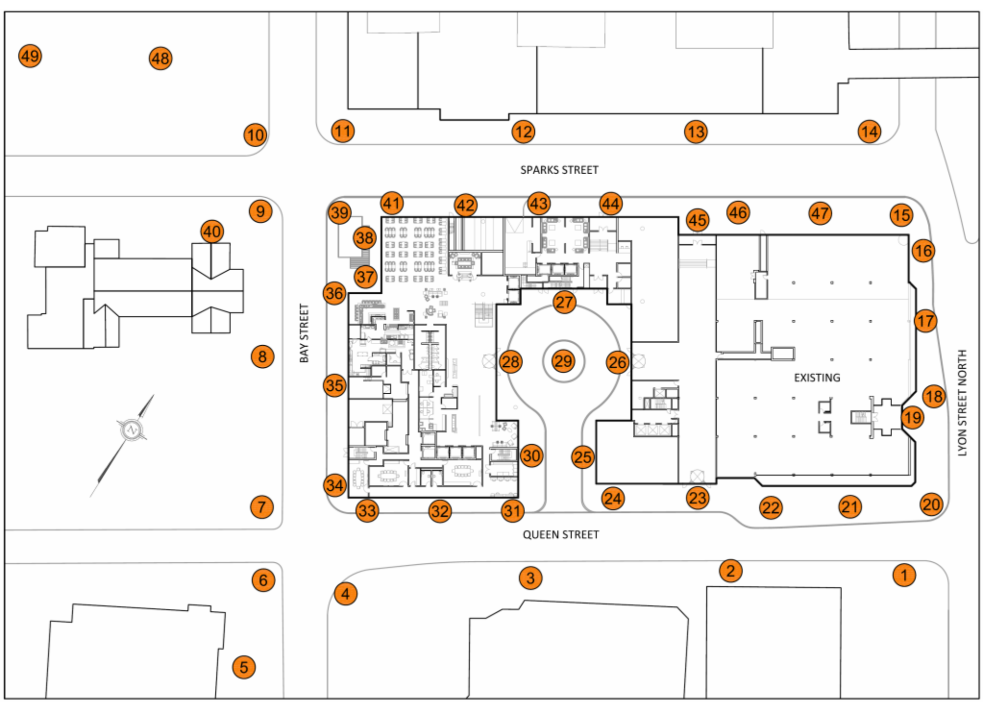


TABLE 12: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #45	Spring	85	95	98	99	Sitting	Office Entrance	Standing	Acceptable
	Summer	93	98	99	100	Sitting			
	Autumn	88	96	98	99	Sitting			
	Winter	84	94	97	99	Sitting			
Sensor #46	Spring	75	89	94	97	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	84	94	97	99	Sitting			
	Autumn	78	90	94	97	Standing			
	Winter	73	86	92	96	Standing			
Sensor #47	Spring	77	91	96	98	Standing	Public Sidewalk	Strolling	Acceptable
	Summer	88	96	98	99	Sitting			
	Autumn	81	92	96	98	Sitting			
	Winter	75	89	94	97	Standing			
Sensor #48	Spring	81	93	97	99	Sitting	Public Park	Standing	Acceptable
	Summer	89	96	99	99	Sitting			
	Autumn	83	93	97	99	Sitting			
	Winter	80	91	96	98	Sitting			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

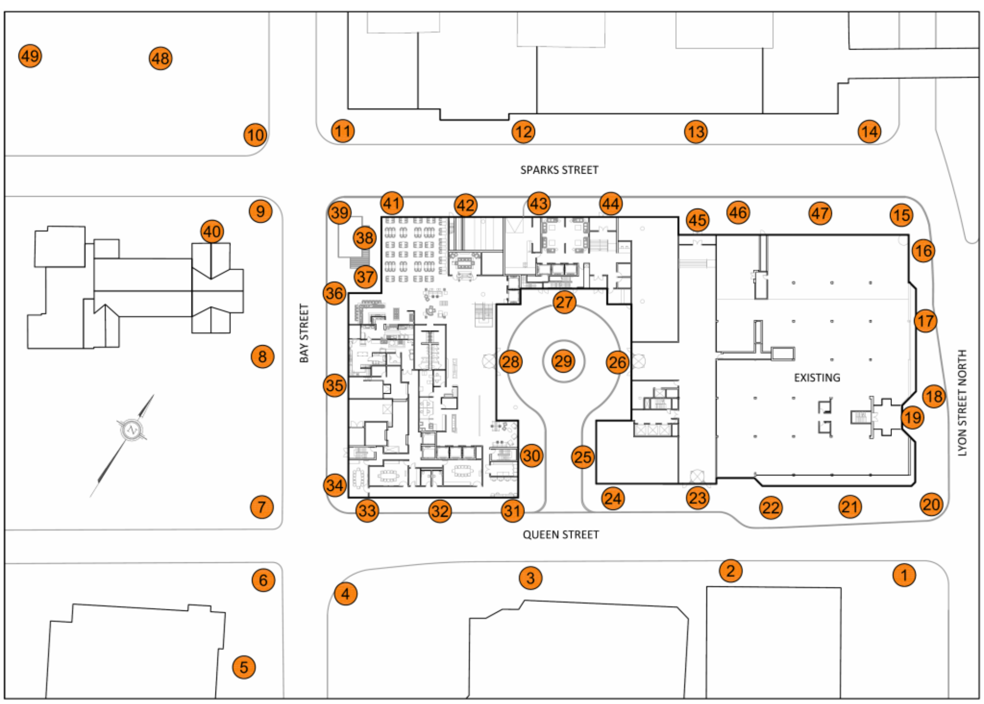


TABLE 13: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #49	Spring	77	91	96	98	Standing	Public Park	Standing	Acceptable
	Summer	87	95	98	99	Sitting			
	Autumn	81	92	96	98	Sitting			
	Winter	76	89	95	98	Standing			
Sensor #50	Spring	65	81	89	94	Standing	4th Level Outdoor Amenity Terrace	Sitting	Acceptable with Mitigation (See §5.2)
	Summer	75	88	94	97	Standing			
	Autumn	68	83	90	94	Standing			
	Winter	64	80	88	93	Standing			
Sensor #51	Spring	71	85	92	95	Standing	4th Level Outdoor Amenity Terrace	Sitting	Acceptable (See §5.2)
	Summer	80	91	95	98	Sitting			
	Autumn	74	86	92	95	Standing			
	Winter	69	83	90	94	Standing			
Sensor #52	Spring	68	83	90	94	Standing	4th Level Outdoor Amenity Terrace	Sitting	Acceptable with Mitigation (See §5.2)
	Summer	78	89	94	97	Standing			
	Autumn	71	84	90	94	Standing			
	Winter	66	80	87	92	Standing			

350 SPARKS STREET, OTTAWA: PLW SENSOR LOCATIONS

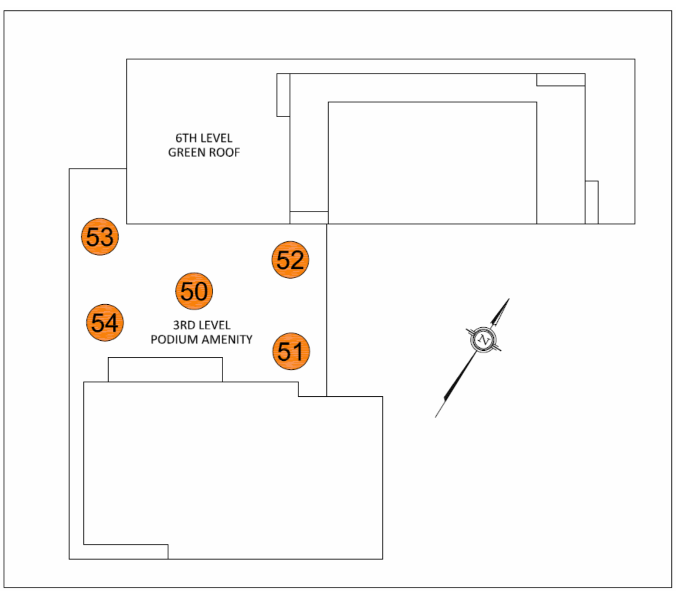
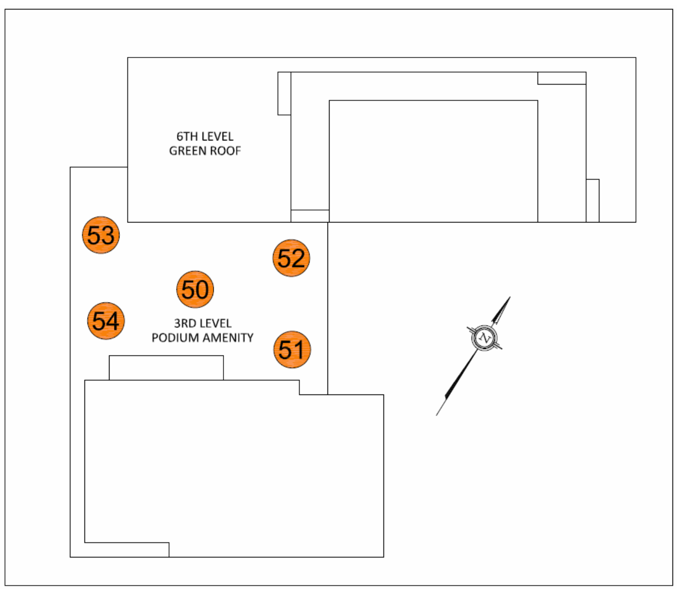


TABLE 14: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Strolling	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 20	≤ 25	≤ 30				
Guideline (% of Time)		≥ 80							
Sensor #53	Spring	77	91	96	99	Standing	4th Level Outdoor Amenity Terrace	Sitting	Acceptable (See §5.2)
	Summer	87	96	98	99	Sitting			
	Autumn	80	92	97	99	Sitting			
	Winter	76	90	95	98	Standing			
Sensor #54	Spring	70	85	92	96	Standing	4th Level Outdoor Amenity Terrace	Sitting	Acceptable with Mitigation (See §5.2)
	Summer	79	90	95	98	Standing			
	Autumn	72	86	92	96	Standing			
	Winter	69	83	91	95	Standing			

350 SPARKS STREET, OTTAWA: 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 14 in Section 5.1, this section summarizes the most significant findings of the PLW assessment, as follows:

1. All nearby public sidewalks and walkways surrounding the study site will experience wind conditions suitable for strolling, or better, on a seasonal and annual basis, which is considered acceptable for the intended uses of the spaces.
2. Within the public park at the northwest corner of the intersection of Sparks Street and Bay Street (Sensors 48 & 49), wind conditions will be comfortable for sitting during the summer months, and for standing or sitting during the remaining seasonal periods. The noted conditions are appropriate for a public park.
3. For the pedestrian plaza at the northwest corner of the study site (Sensors 37 & 38), wind conditions will be calm and suitable for sitting or more sedentary activities throughout the year.
4. The main entrance for St. Peter's Lutheran Church (Sensor 40), located to the west of the study site, will experience conditions suitable for standing or better during each seasonal period. The noted conditions are considered acceptable for major building entrances.
5. At the existing grade-level hotel patio to the southwest of the development site (Sensor 5), conditions will be suitable for sitting during the spring, summer, and autumn seasons, and for standing during the winter, which is acceptable.
6. Wind conditions at the existing office entrance from Lyon Street North (Sensor 19) will be comfortable for standing, or better, throughout the year. For the reconfigured office entrance along the south elevation (Sensor 23), wind speeds will be suitable for sitting during each seasonal period.
7. For the office entrance (Sensor 26), residential entrance (Sensor 27), and hotel entrance (Sensor 28) from the vehicular drop-off area (Sensor 29), wind conditions will be comfortable for standing, or better, throughout the year.
8. The residential and office entrances along the north elevation of the building (Sensors 44 & 45, respectively) will see wind conditions comfortable for sitting throughout the year.

9. For the tested configuration of the fourth level outdoor amenity area, located on the podium roof between the hotel and residential towers, wind conditions near the northwest corner (Sensor 53) and near the southeast corner (Sensor 51) will achieve the sitting criterion during the typical use period, defined as the late spring through the early autumn. The remaining terrace spaces (Sensors 50, 52, 54) will experience sitting conditions between 75% and 79% of the time during the typical use period. Implementation of the planned terrace landscape design, as discussed with the design team, will serve to reduce wind speeds over the amenity area, and provide improved in pedestrian wind conditions as compared to the tested configuration.

10. 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 350 Sparks Street, a proposed dual tower redevelopment project by Morguard Developments in Ottawa, Ontario. This work was performed in accordance with the scope of work described in GWE proposal #14-170-P R1 dated March 6, 2015, and is based on industry standard wind tunnel testing and data analysis procedures, architectural drawings provided by WZMH Architects in March 2015, surrounding street layouts and existing and approved future building massing information obtained from the City of Ottawa, as well as recent site imagery. All wind comfort conditions are evaluated according to the City of Ottawa Terms of Reference for Wind Analysis.

A complete summary of the predicted pedestrian 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, and experience with similar developments in Ottawa, we conclude that the wind conditions at 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.

For the tested configuration of the fourth level outdoor amenity area, wind conditions near the northwest and southeast corners of the terrace will achieve the sitting criterion during the summer months and shoulder seasons of spring and autumn. The remaining terrace areas will experience sitting conditions between 75% and 79% of the time during the same period.

Additionally, 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 too windy for walking, or that are 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.

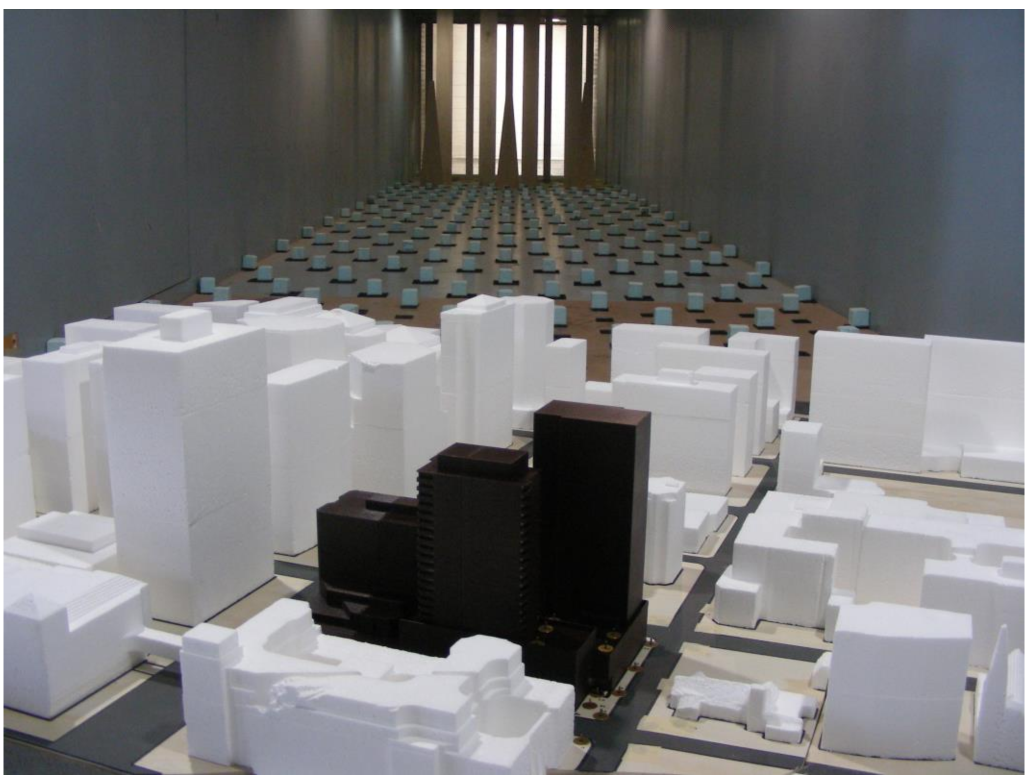
Andrew Sliasas, M.A.Sc.
Project Manager
GWE15-029-PLW

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

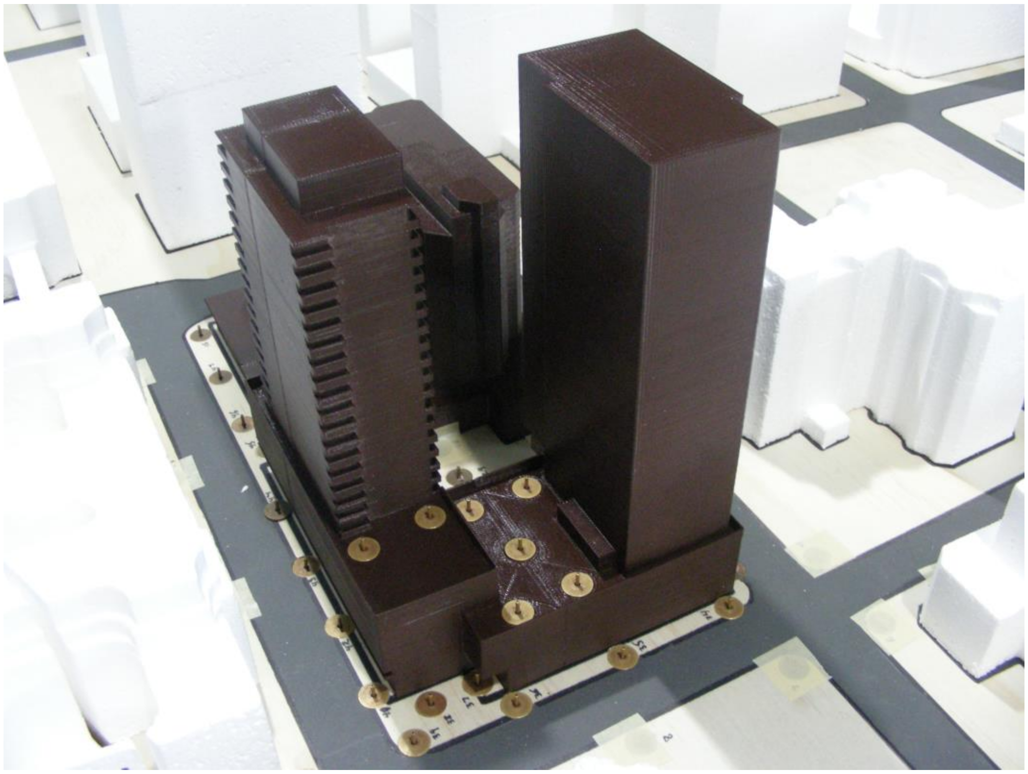
LICENSED PROFESSIONAL ENGINEER
V. M. FERRARO
PROVINCE OF ONTARIO

June 23/2015

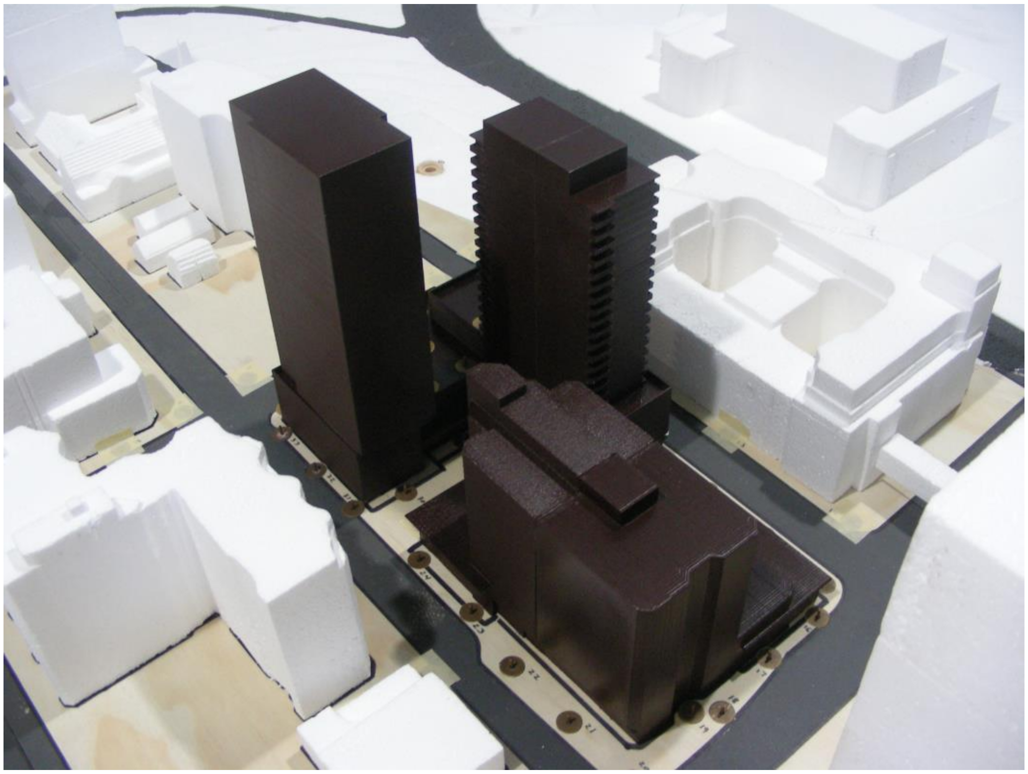
PHOTOGRAPH 1: STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING DOWNWIND



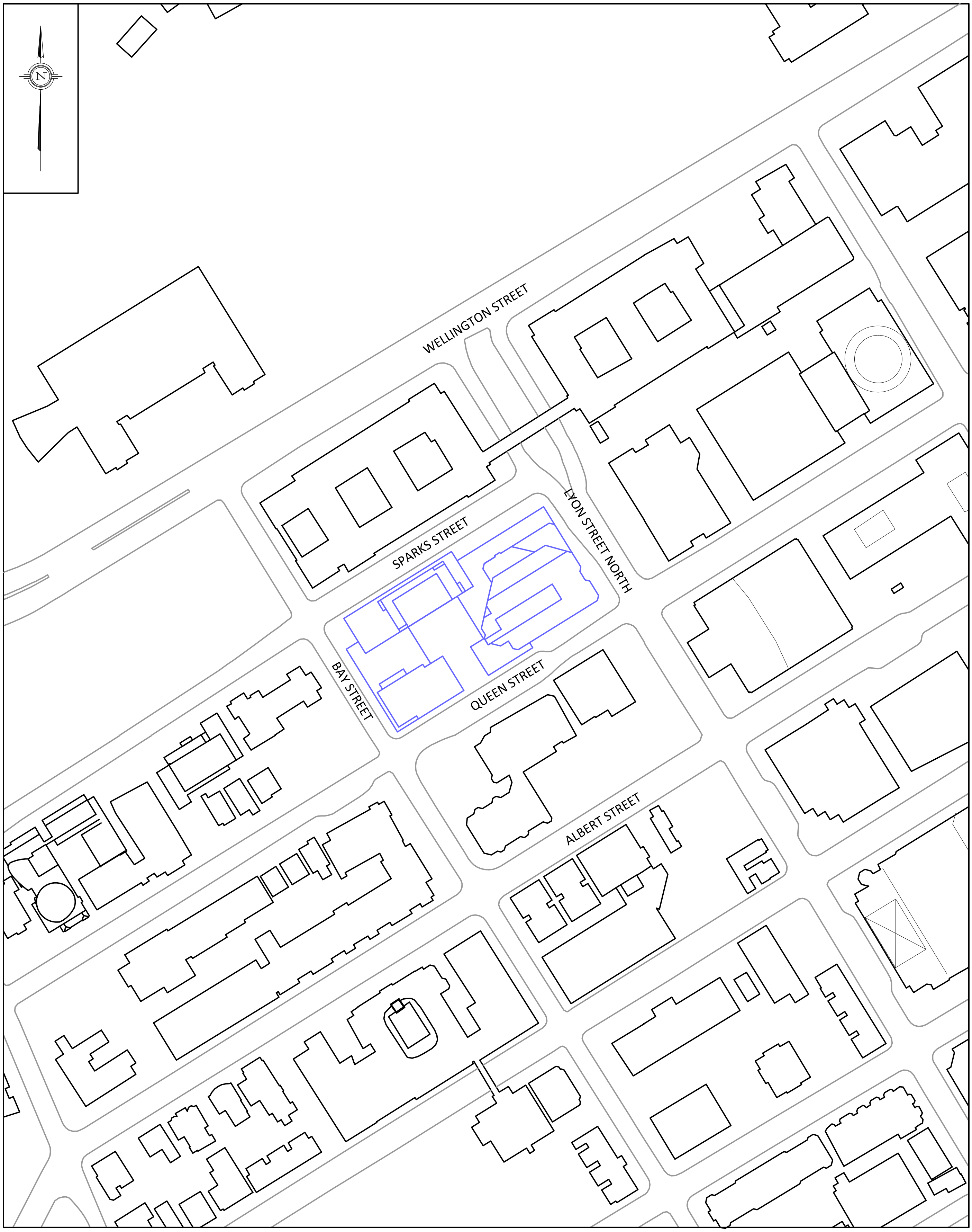
PHOTOGRAPH 2: STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING UPWIND



PHOTOGRAPH 3: CLOSE-UP VIEW OF STUDY MODEL LOOKING SOUTHEAST



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



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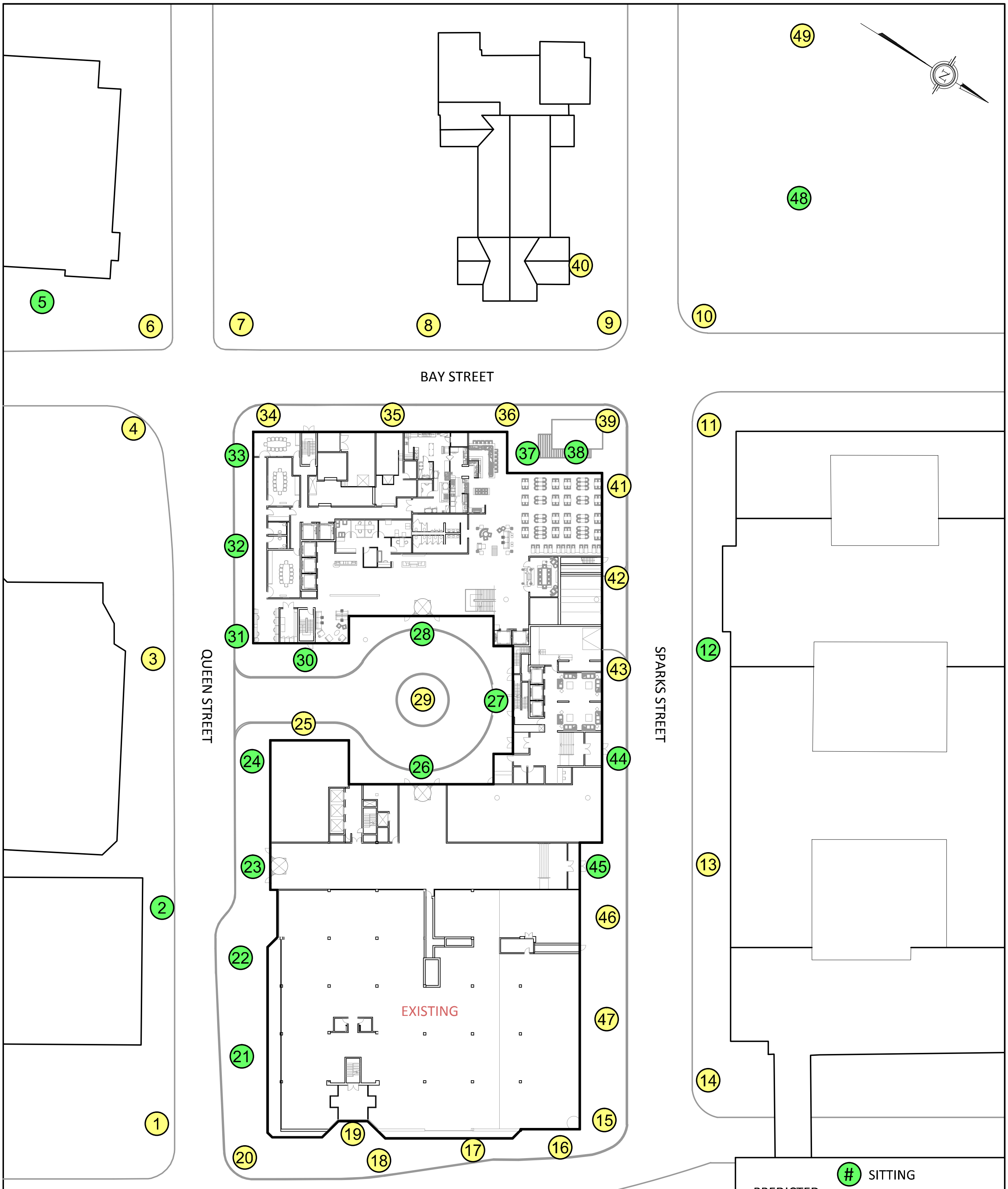
GRADIENT WIND
ENGINEERING INC

PROJECT		DESCRIPTION
350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
SCALE 1:2500 (APPROX.)	DRAWING NO. GWE15-029-PLW-1	
DATE APRIL 1, 2015	DRAWN BY K.A.	



NOTES:

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

PREDICTED COMFORT CLASSES

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

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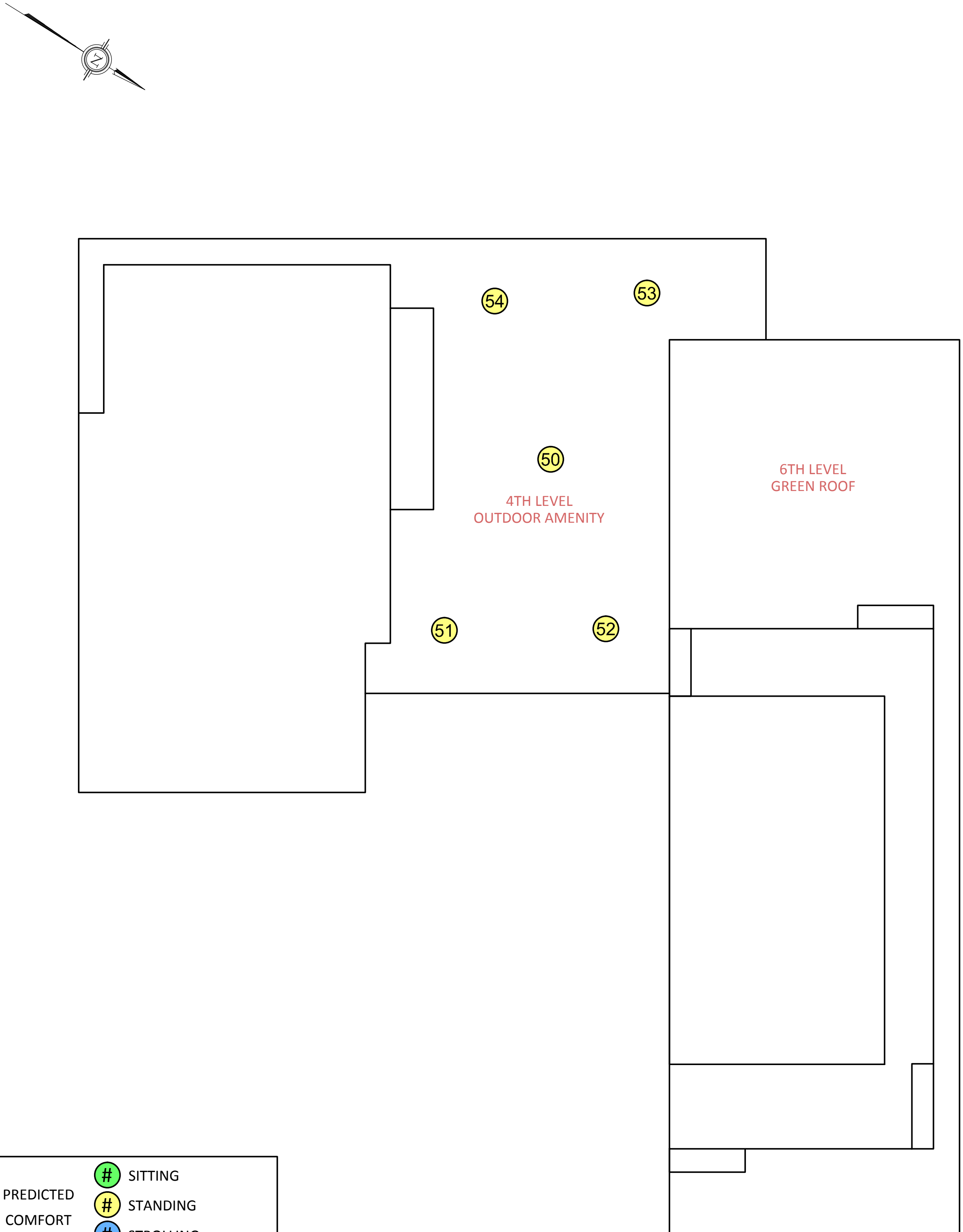
PROJECT	350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:900 (APPROX.)
DRAWING NO.	GWE15-029-PLW-2A
DATE	APRIL 21, 2015
DRAWN BY	K.A.

FIGURE 2A: SPRING
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

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

NOTES:

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

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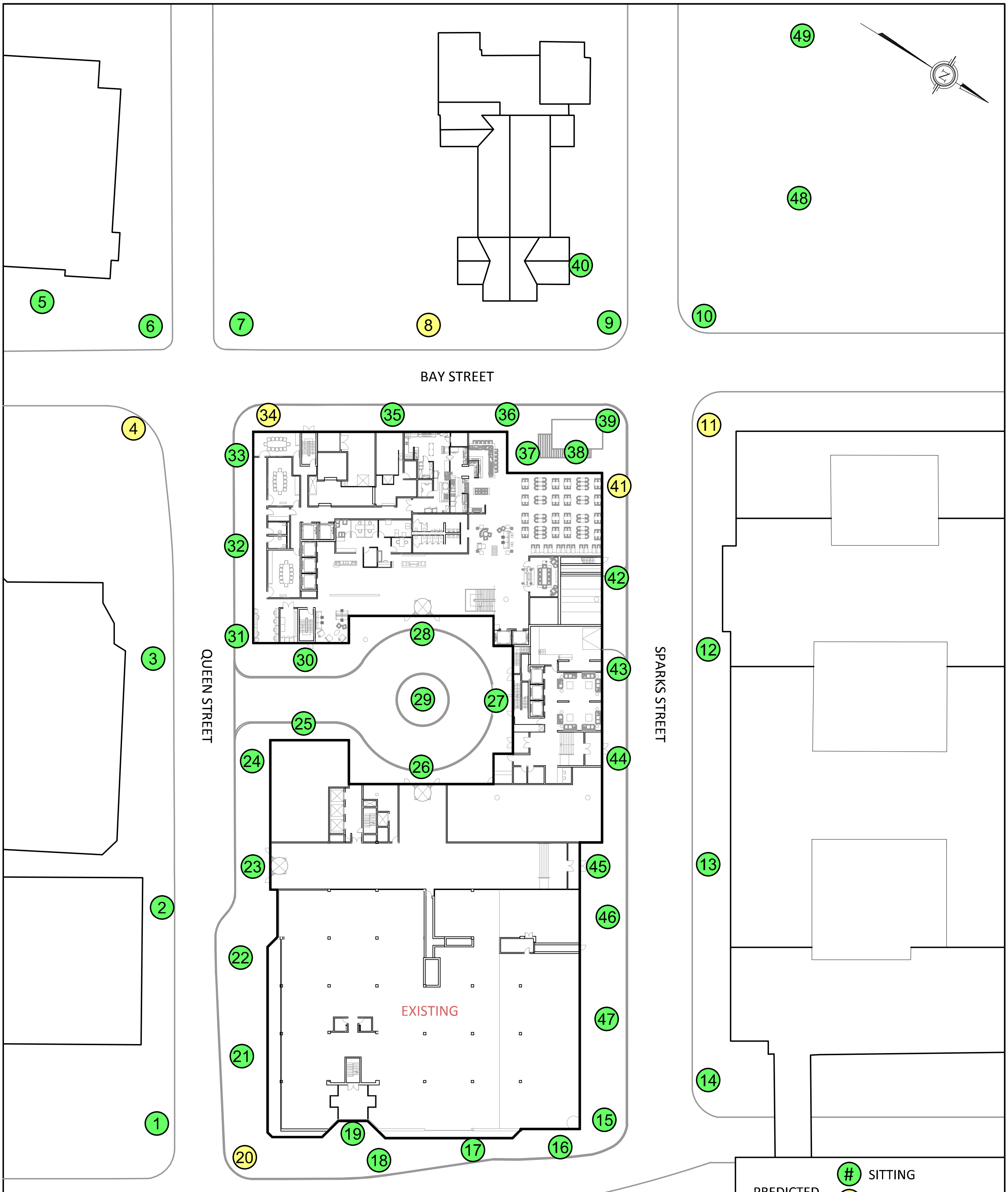
PROJECT	350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY	DESCRIPTION	FIGURE 2B: SPRING PEDESTRIAN COMFORT PREDICTIONS
SCALE	1:400 (APPROX.)	DRAWING NO.	GWE15-029-PLW-2B
DATE	APRIL 21, 2015	DRAWN BY	K.A.



NOTES:

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

PREDICTED COMFORT CLASSES

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

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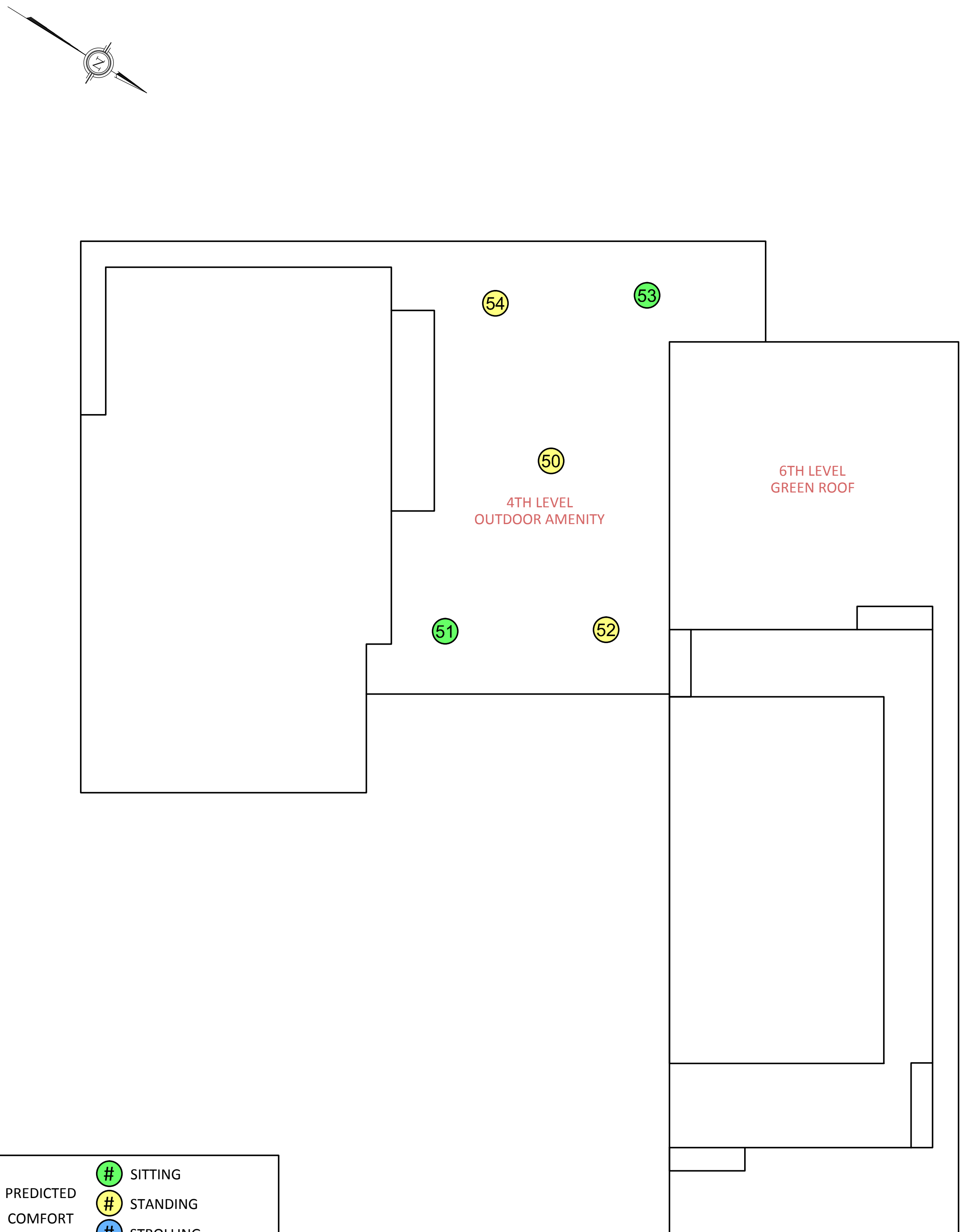
PROJECT	350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:900 (APPROX.)
DRAWING NO.	GWE15-029-PLW-3A
DATE	APRIL 21, 2015
DRAWN BY	K.A.

FIGURE 3A: SUMMER
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

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

NOTES:

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

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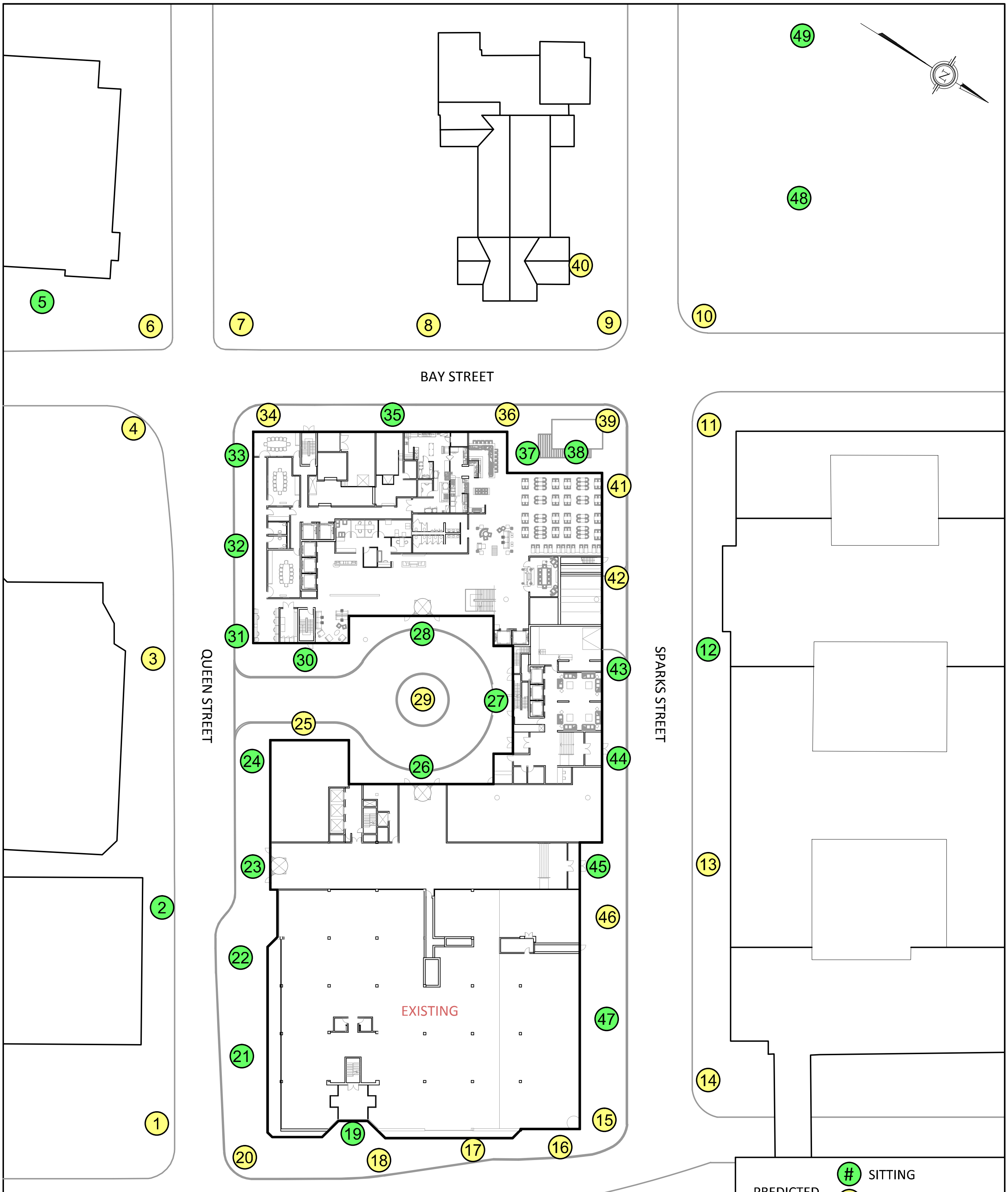
PROJECT: 350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 3B: SUMMER PEDESTRIAN COMFORT PREDICTIONS
SCALE: 1:400 (APPROX.)	DRAWING NO.: GWE15-029-PLW-3B	
DATE: APRIL 21, 2015	DRAWN BY: K.A.	



NOTES:

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

PREDICTED COMFORT CLASSES

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

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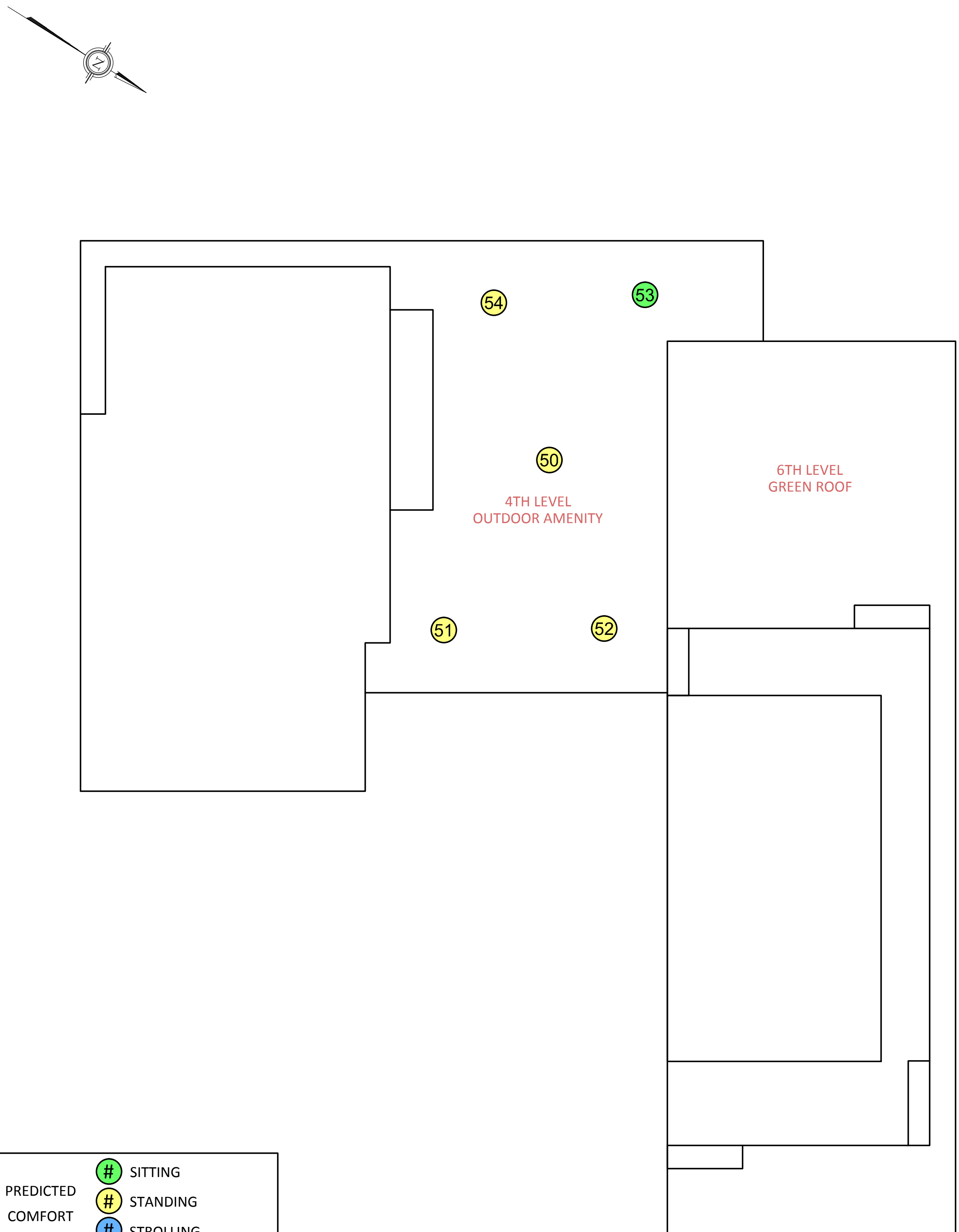
PROJECT: 350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		FIGURE 4A: AUTUMN PEDESTRIAN COMFORT PREDICTIONS
SCALE: 1:900 (APPROX.)	DRAWING NO.: GWE15-029-PLW-4A	
DATE: APRIL 21, 2015	DRAWN BY: K.A.	



PREDICTED COMFORT CLASSES

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

NOTES:

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

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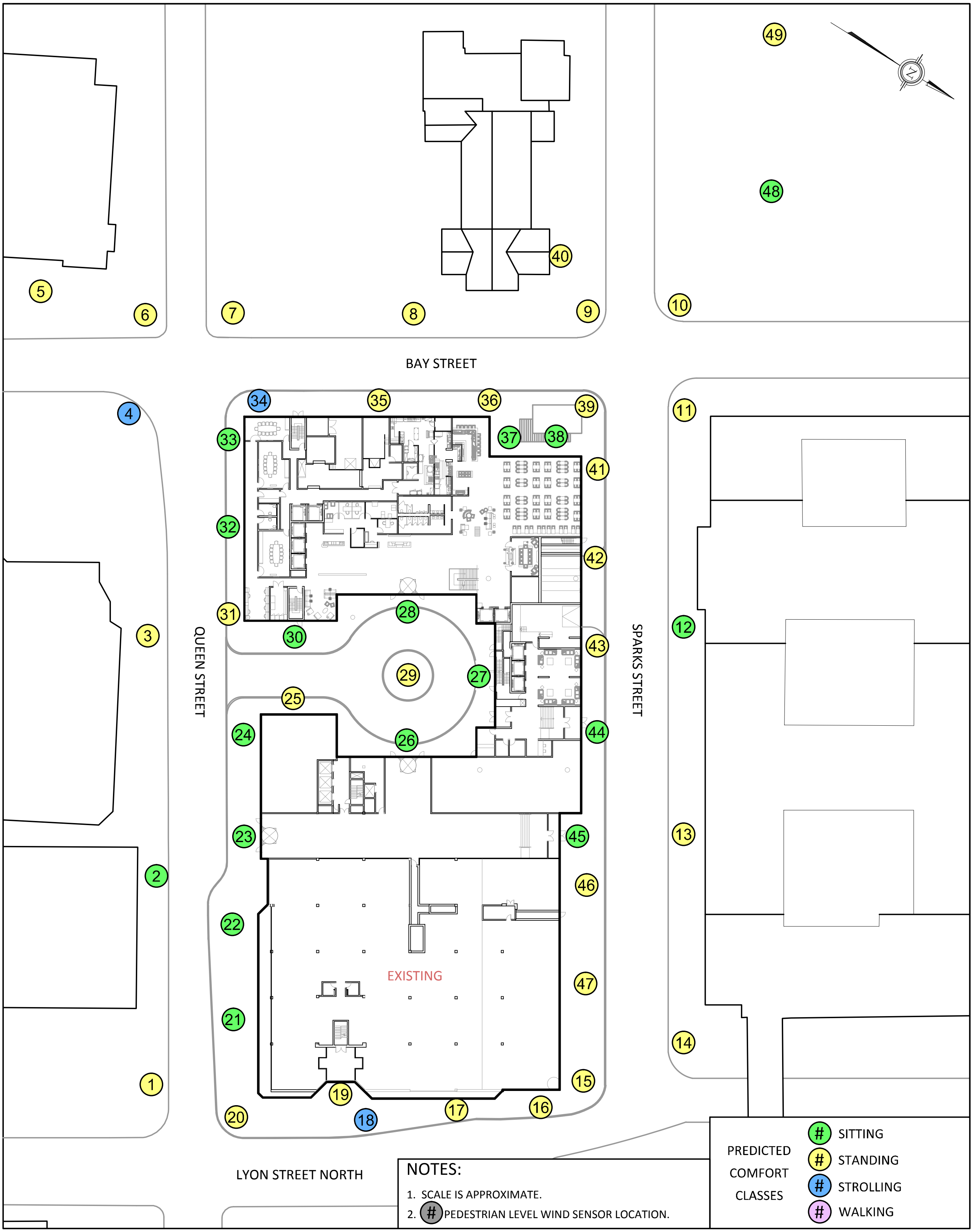
PROJECT	350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:400 (APPROX.)	DRAWING NO.	GWE15-029-PLW-4B
DATE	APRIL 21, 2015	DRAWN BY	K.A.

DESCRIPTION

FIGURE 4B: AUTUMN
PEDESTRIAN COMFORT PREDICTIONS



NOTES:

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

PREDICTED COMFORT CLASSES

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

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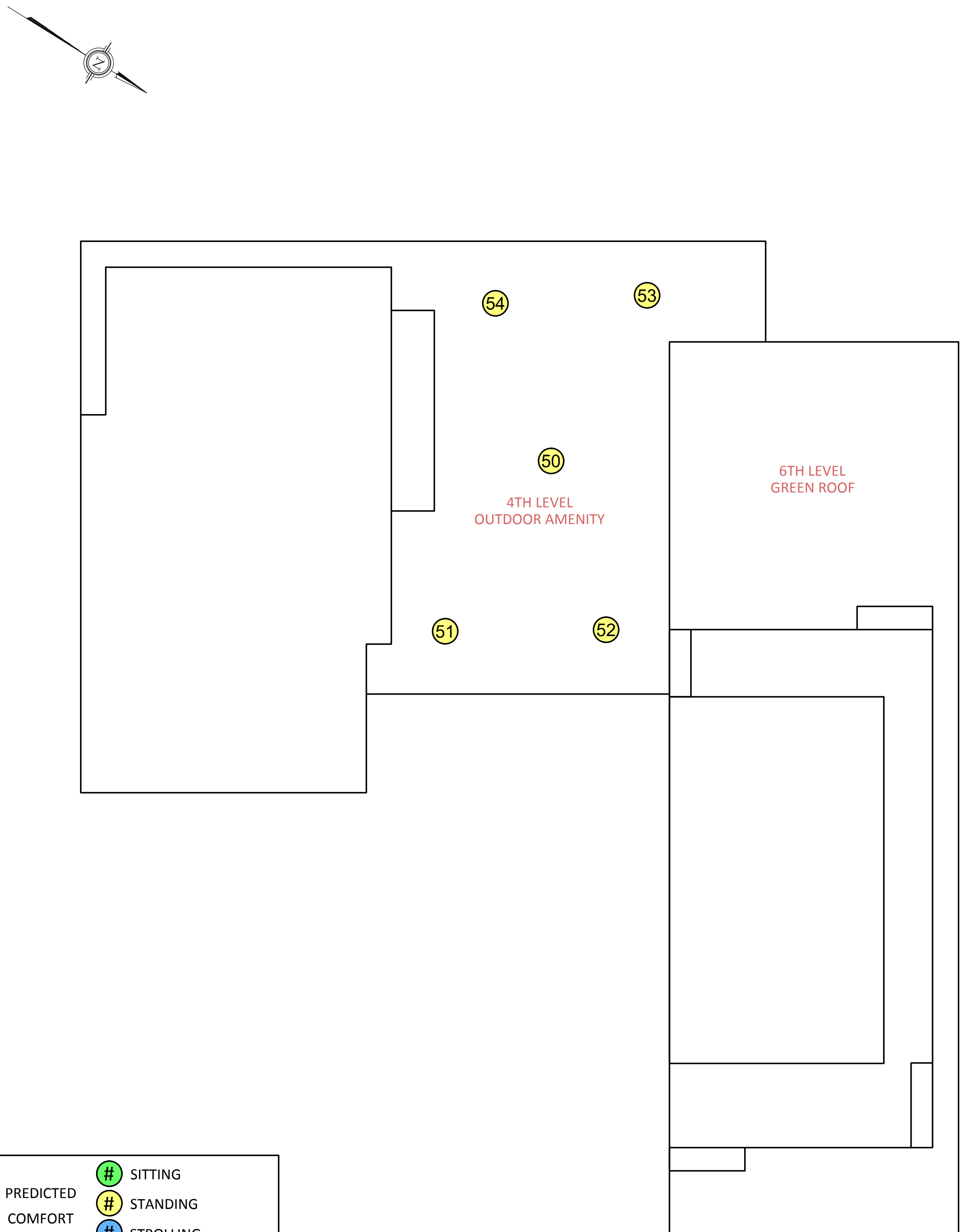
PROJECT	350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY
SCALE	1:900 (APPROX.)
DRAWING NO.	GWE15-029-PLW-5A
DATE	APRIL 21, 2015
DRAWN BY	K.A.

FIGURE 5A: WINTER
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

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

NOTES:

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

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GWE GRADIENT WIND ENGINEERING INC

PROJECT: 350 SPARKS STREET, OTTAWA PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 5B: WINTER PEDESTRIAN COMFORT PREDICTIONS
SCALE: 1:400 (APPROX.)	DRAWING NO.: GWE15-029-PLW-5B	
DATE: APRIL 21, 2015	DRAWN BY: K.A.	

APPENDIX A

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 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 meter. Integral length scales are derived from power spectra, which describe the energy content of wind as a function of frequency. There are several ways of determining integral length scales of turbulence. One way is by comparison of a measured power spectrum in model scale to a non-dimensional theoretical spectrum such as the Davenport spectrum of longitudinal turbulence. Using the Davenport spectrum, which agrees well with full-scale spectra, one can estimate the integral scale by plotting the theoretical spectrum with varying L until it matches as closely as possible the measured spectrum:

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

Where, $\boldsymbol{f}$ is frequency, $\boldsymbol{S(f)}$ is the spectrum value at frequency $\boldsymbol{f}$, $\boldsymbol{U_{10}}$ is the wind speed 10 m above ground level, and $\boldsymbol{L}$ 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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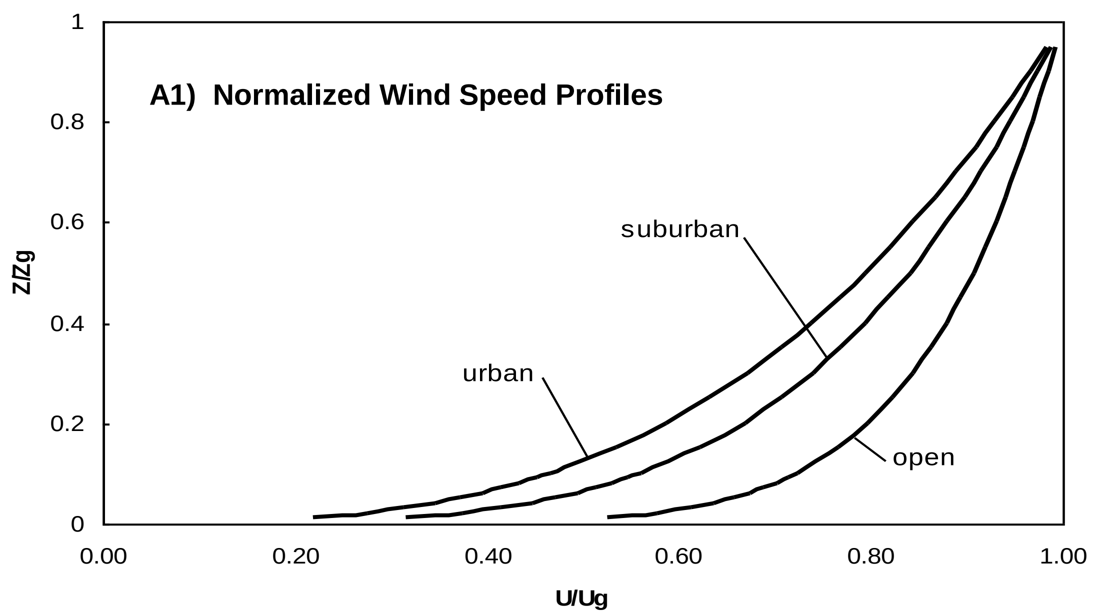


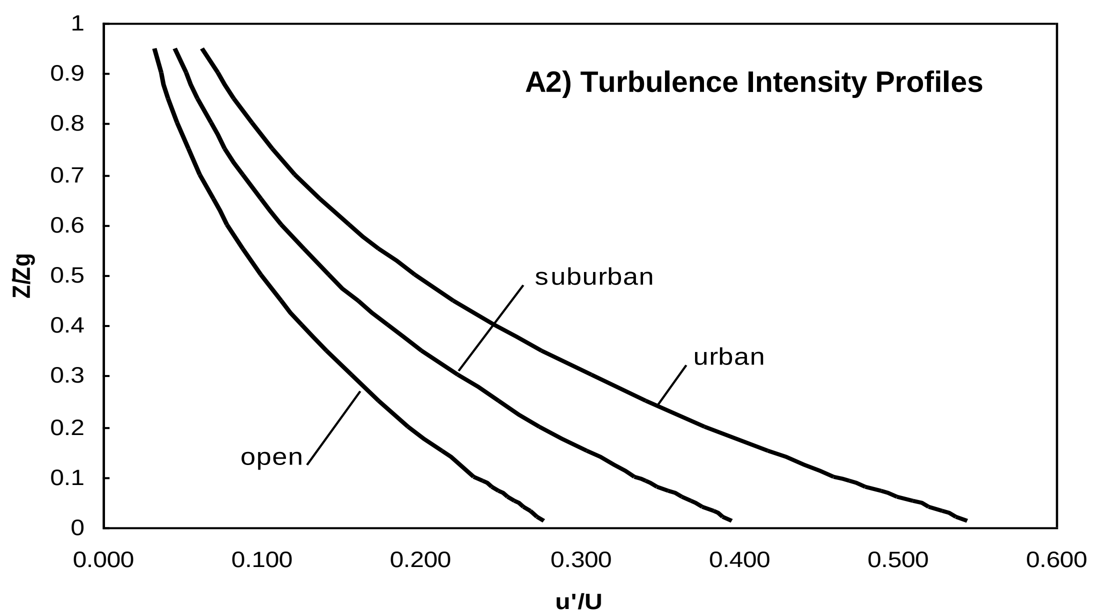


Figure A1 (Top): Mean Wind Speed Profiles

Figure A2 (Bottom): Turbulence Intensity Profiles (u' = fluctuation of mean velocity)

APPENDIX B

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 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:

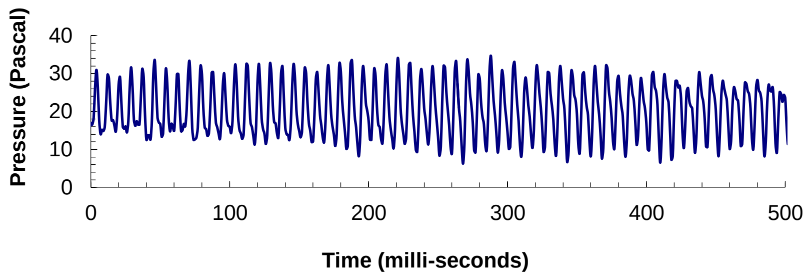
$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

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

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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