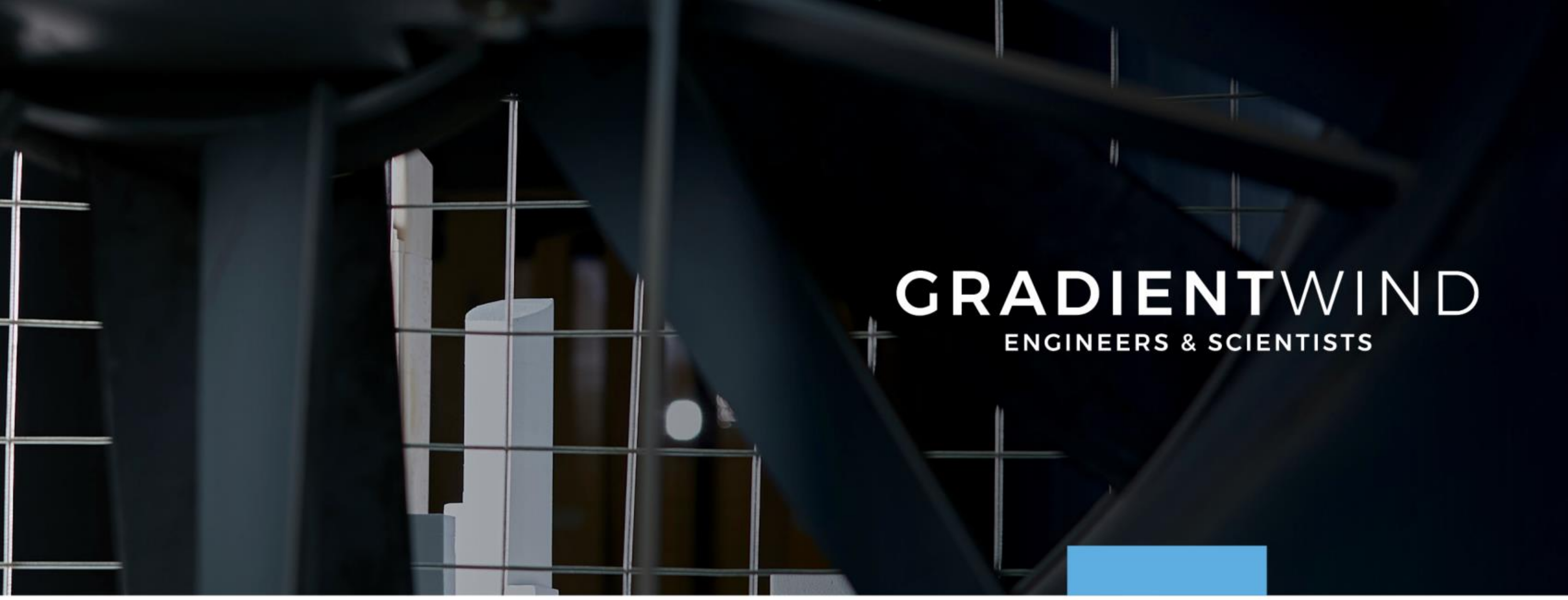
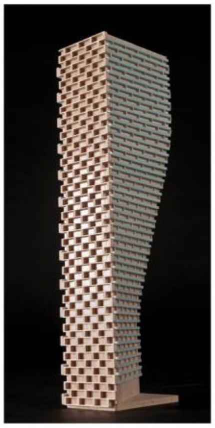


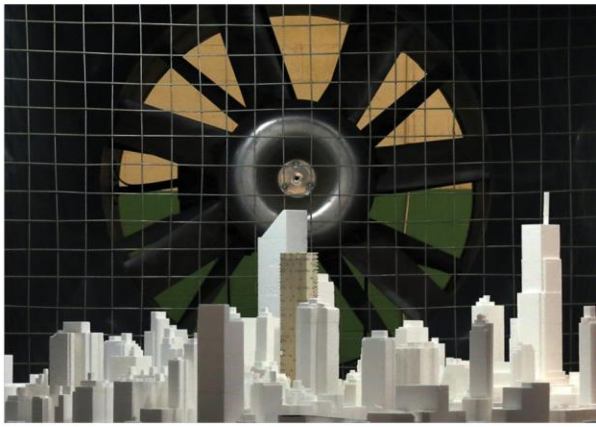
GRADIENTWIND
ENGINEERS & SCIENTISTS

# PEDESTRIAN LEVEL WIND STUDY

55 Port Street East
Mississauga, Ontario

REPORT: GWE17-184-WTPLW





December 7, 2018

PREPARED FOR
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# EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed condominium development located at 55 Port Street East in Mississauga, Ontario. The study involves wind tunnel measurements of pedestrian wind speeds using a physical scale model, combined with meteorological data integration, to assess pedestrian comfort at key areas within and surrounding the study site. Grade-level pedestrian areas investigated include nearby sidewalks, building access points, parking areas, laneways, and the grade-level outdoor amenity areas, as well as the St. Lawrence Park and Waterfront Trail. To evaluate the influence of the proposed development on the existing wind conditions surrounding the site, two massing configurations were studied: (i) existing conditions without the proposed development, and (ii) conditions with the proposed development in place. The results and recommendations derived from these considerations are summarized in the following paragraphs and detailed in the subsequent report.

Our work is based on industry standard wind tunnel testing and data analysis procedures, City of Mississauga wind criteria, architectural drawings provided by Giannone Petricone Associates Inc. Architects in November 2018, surrounding street layouts, as well as existing and approved future building massing information and recent site imagery.

A complete summary of the predicted wind conditions under the proposed massing scenario is provided in Section 5.2 of this report, and is also illustrated in Figures 2 and 3, as well as Tables A1 - A4 in Appendix A. Based on wind tunnel test results, meteorological data analysis, and experience with similar developments in Mississauga, we conclude that conditions over the majority of pedestrian-sensitive areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal basis. Exceptions include several of the outdoor amenity areas surrounding the development site at grade. Recommended mitigation for these areas is detailed in Section 5.2.

As compared to the existing site conditions, wind comfort at surrounding grade-level areas further removed from the study site will largely remain unchanged upon the introduction of the proposed development. Although the Port Street East sidewalk areas on the same side of the street as the proposed development will see a modest reduction in wind comfort, conditions remain acceptable for the intended pedestrian uses on a seasonal basis. Of particular interest, some improvement to existing wind conditions occur along Waterfront Trail upon the development of the study site.

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.

# TABLE OF CONTENTS

## 1. INTRODUCTION

This report describes a pedestrian level wind study undertaken to assess wind conditions for a proposed condominium development referred to as 55 Port Street East in Mississauga, Ontario. The study is based on industry standard wind tunnel testing techniques, City of Mississauga wind criteria, architectural drawings provided by Giannone Petricone Associates Inc. Architects in November 2018, surrounding street layouts and existing and approved future building massing information, as well as recent site imagery.

## 2. TERMS OF REFERENCE

The focus of this pedestrian wind study is the proposed condominium development located at 55 Port Street East in Mississauga, Ontario. The development, located in the Port Credit neighbourhood, is situated on the southwest portion of a parcel of land bounded by Helene Street South to the southwest, Port Street East to the northwest, St. Lawrence Drive to the northeast, and the St. Lawrence Park to the southeast, beyond which is Lake Ontario. Port Street East is defined as project north.

The study site is generally surrounded in the near-field and far-field by a suburban mix of low- and mid-rise developments in all directions, except for the open exposure of Lake Ontario to the south. The proposed development is a 10-storey building with a two-storey podium. At Level 1 the floorplan features a lobby with wraparound outdoor amenity space at the west corner, indoor and outdoor amenity space along the southeast side of the development, and access to loading space, as well as a single level of below-grade parking from a laneway along the east elevation. The remaining floorplans comprise residential occupancy. At Level 2 a setback from the east elevation accommodates private terrace space, and at Level 3 the podium steps back from the south and west elevations to the base of the nearly rhombus-shaped building, creating additional private terraces. The building continues to rise with varying residential floorplan and balcony configurations to the green roof, where it steps back from all elevations to the base of a mechanical penthouse, achieving a maximum building height of 39.89 metres as measured from local grade to the mechanical penthouse roof.

Grade-level areas investigated include sidewalks, building access points, parking areas, laneways, and the grade-level outdoor amenity areas, as well as the St. Lawrence Park and Waterfront Trail. Figure 1 illustrates the study site and surrounding context, and 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; (iii) recommend suitable mitigation measures, where required; and (iv) evaluate the influence of the proposed development on the existing wind conditions surrounding the site.

## 4. METHODOLOGY

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

### 4.1 Wind Tunnel Context Modelling

A detailed pedestrian level wind (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 metres. The general concept and approach to wind tunnel modelling is to provide building and topographic detail in the immediate vicinity of the study site on the surrounding model, and to rely on a length of wind tunnel upwind of the model to develop wind properties consistent with known turbulent intensity profiles that represent the surrounding terrain.

An industry standard practice is to omit trees, vegetation, and other existing and planned landscape elements from the wind tunnel model due to the difficulty of providing accurate seasonal representation

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[1] City of Mississauga Urban Design Terms of Reference, Wind Comfort and Safety Studies, June 2014

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 35 grade-level sensor locations on the scale model in Gradient Wind's wind tunnel. Wind speed measurements were performed for each of the 35 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 2 and 3.

Mean and peak wind speed values for each location and wind direction were calculated from real-time pressure measurements, recorded at a sample rate of 500 samples per second, and taken over a 60-second time period. This period at model-scale corresponds approximately to one hour in full-scale, which matches the time frame of full-scale meteorological observations. Measured mean and gust wind speeds at grade were referenced to the wind speed measured near the ceiling of the wind tunnel to generate mean and peak wind speed ratios. Ceiling height in the wind tunnel represents the depth of the boundary layer of wind flowing over the earth's surface, referred to as the gradient height. Within this boundary layer, mean wind speed increases up to the gradient height and remains constant thereafter. Appendices C and D provide greater detail of the theory behind wind speed measurements. Wind tunnel measurements for this project, conducted in Gradient Wind's wind tunnel facility, meet or exceed guidelines found in the National Building Code of Canada 2015 and of 'Wind Tunnel Studies of Buildings and Structures', ASCE Manual 7 Reports on Engineering Practice No 67.

## 4.3 Meteorological Data Analysis

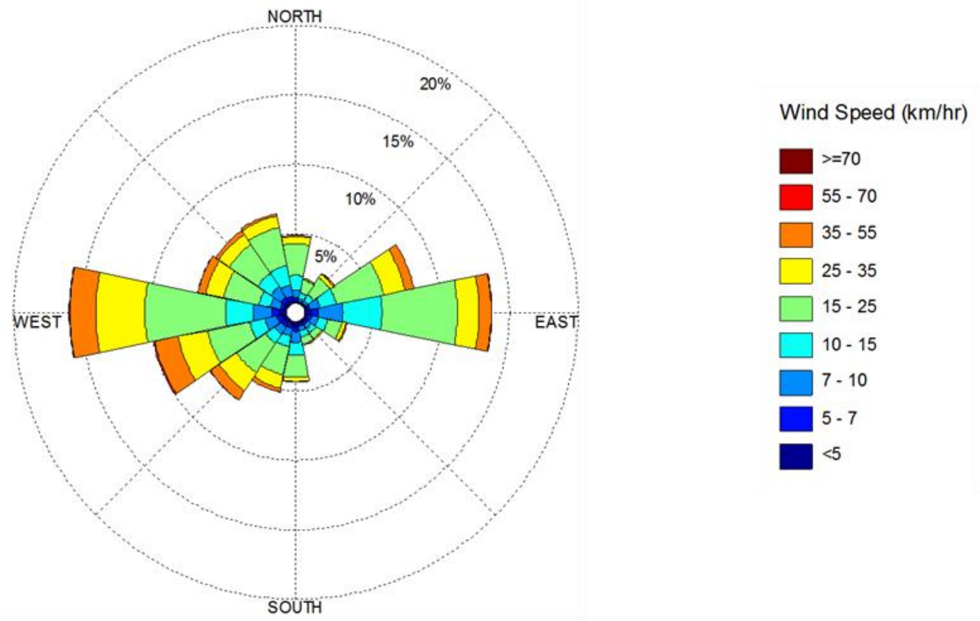
A statistical model for winds in Mississauga was developed from approximately 35-years of hourly meteorological wind data recorded at Toronto Island Billy Bishop Airport. Wind speed and direction data were analyzed during the appropriate hours of pedestrian usage (i.e., between 06:00 and 23:00) and divided into two distinct seasons, as stipulated in the noted City of Mississauga Urban Design Terms of Reference[1]. More specifically, the summer season is defined as May through October, while the winter season is defined as November through April, inclusive.

The statistical model of the Mississauga area wind climate, which indicates the directional character of local winds on a seasonal basis, is illustrated on the following page. The plots illustrate seasonal distribution of measured wind speeds and directions in kilometers per hour (km/h). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. For Mississauga (south of the Queen Elizabeth Way), the most common winds concerning pedestrian comfort during the winter season occur for westerly wind directions, followed by those from the east. The most common winds during the summer season occur for easterly wind directions. The directional preference and relative magnitude of the wind speed varies somewhat from season to season. Also, by convection in microclimate studies, wind direction refers to the wind origin (e.g., a north wind blows from north to south).

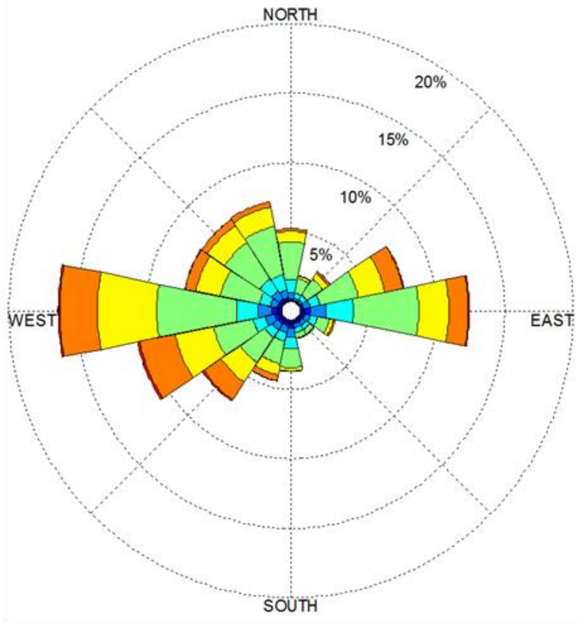
## SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES

## TORONTO ISLAND BILLY BISHOP AIRPORT, TORONTO

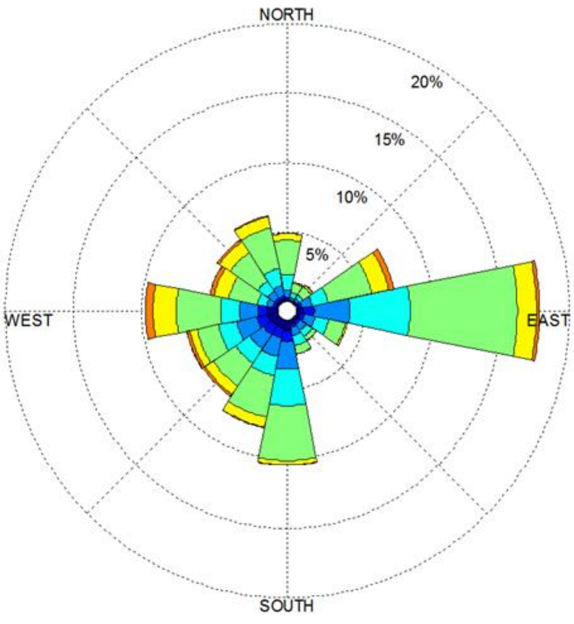
ANNUAL[1]



WINTER[2]



SUMMER[2]



**Notes:**

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

## 4.4 Pedestrian Comfort and Safety Guidelines

Pedestrian comfort and safety guidelines are based on the mechanical effects of wind without consideration of other meteorological conditions (i.e. temperature, relative humidity). The comfort guidelines assume that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Since both mean and gust wind speeds affect pedestrian comfort, their combined effect is defined in the City of Mississauga Urban Design Terms of Reference[1]. More specifically, the criteria are defined as a Gust Equivalent Mean (GEM) wind speed, which is the greater of the mean wind speed or the gust wind speed divided by 1.85. The wind 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.

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

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

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

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

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

**Dangerous** – Wind speeds greater than 90 km/h, occurring more than 0.1% of the time on an annual basis, are classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause a vulnerable member of the population to fall.

## 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 80% of the time, the activity level would be judged to be uncomfortable by most people. For instance, if GEM wind speeds of 10 km/h were exceeded for more than 20% of the time, most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if GEM wind speeds of 20 km/h at a location were exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As most of these criteria are based on subjective reactions of a population to wind forces, their application is partly based on experience and judgment.

Once the pedestrian wind speed predictions have been established 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 |
|---|---|
| Primary Building Entrance | Standing |
| Secondary Building Access Point | Walking |
| Public Sidewalks / Pedestrian Walkways | Walking |
| Outdoor Amenity Spaces | Sitting / Standing |
| Cafés / Patios / Benches / Gardens | Sitting / Standing |
| Plazas | Standing / Walking |
| Transit Stops | Standing |
| Public Parks | Sitting / Walking |
| Garage / Service Entrances | Walking |
| Vehicular Drop-Off Zones | Walking |
| Laneways / Loading Zones | Walking |

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 –Future Conditions

Tables A1 - A4 in Appendix A provide a summary of seasonal comfort predictions for each sensor location under the proposed massing scenario, considering the study building and all approved surrounding developments. The tables indicate the 80% non-exceedance gust wind speeds and corresponding comfort classifications as defined in Section 4.4. In other words, a gust wind speed threshold of 12.1 for the summer season indicates that 80% of the measured data falls at or below 12.1 km/h during the summer months and conditions are therefore suitable for standing, as the 80% threshold value falls within the exceedance range of 10-15 km/h for standing.

The tables include the predicted threshold values for each sensor location during each season, accompanied by the corresponding predicted comfort class (i.e. sitting, standing, walking, etc.). Sensor locations with a predicted comfort class that is windier than the desired comfort class for that location type are highlighted in red.

The most significant findings of the PLW are summarized in the Section 5.2. To assist with understanding and interpretation, predicted conditions for the proposed development are also illustrated in colour-coded format in Figures 2 and 3. Conditions suitable for sitting are represented by the colour green, while standing is represented by yellow, walking by blue, and uncomfortable by magenta. Measured mean and gust velocity ratios, which constitutes the raw data upon which the results are based, will be made available upon request.

## 5.2 Summary of Findings – Future Conditions

Based on the analysis of the measured data, consideration of local climate data, and the suitability descriptors provided in Tables A1 - A4 in Appendix A, this section summarizes the most significant findings of the PLW study with respect to proposed massing scenario, as follows:

1. All public sidewalks within and surrounding the study site will be suitable for walking or better throughout each seasonal period, which is acceptable.
2. The majority of surrounding laneways, loading areas, and parking spaces will experience wind conditions suitable for walking or better on a seasonal basis, which is considered appropriate for

the intended uses of the spaces. An exception occurs along the laneway near the northeast side of the study building (Sensor 34), where conditions are marginally uncomfortable for walking during the winter season. As this area is not subject to frequent pedestrian activity, a minor exceedance of the walking comfort threshold is considered acceptable.

3. The Waterfront Trail fronting the development site (Sensors 8-11 & 14) will be comfortable for walking or better during the winter months, becoming suitable for standing or better throughout the rest of the year, which is appropriate.

   The adjacent St. Lawrence Park space (Sensors 12 & 13) will be comfortable for standing or better throughout each seasonal period, which is considered acceptable.

4. The main lobby entrance fronting Port Street East (Sensor 32) will be calm and suitable for sitting on a seasonal basis. All secondary and service entrances will be comfortable for walking or better throughout the year. The noted conditions are considered acceptable.

5. All private amenity and landscaped spaces surrounding the development site will experience wind conditions suitable for standing or better throughout the year, which is appropriate.

6. Regarding the outdoor amenity areas at grade, to ensure the space at the west corner of the development (Sensors 30-32) will be calm and suitable for sitting throughout the typical use period of late spring to early autumn, it is recommended to install a 1.6-metre-tall vertical wind barrier along the full perimeter. This barrier may comprise high-solidity windscreens, dense coniferous plantings, or a combination thereof.

   For the amenity spaces along the southeast side of the development, areas close to the building façade directly southeast of the development (Sensors 24 & 26) will be calm and suitable for sitting throughout the year without the need for mitigation. At greater distances from the façade (Sensor 25), if designated seating areas will be provided, then clustering 1.6 metre-tall high-solidity wind screens or raised planters with coniferous plantings to the west of such locations would ensure calm conditions suitable for sitting.

   The amenity space at the south corner (Sensors 27 & 28) will be exposed to salient winds accelerating around the building corner, and it is recommended to install a 1.8-metre-tall vertical wind barrier around the west and south perimeter of the space to ensure wind conditions suitable for sitting are experienced.

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.

### 5.3 Pedestrian Comfort Suitability – Existing Versus Future Conditions

To evaluate the influence of the subject building on the existing wind conditions at and near the study site, a comparative study was performed considering two massing scenarios: (i) existing conditions without the proposed development, and (ii) conditions with the proposed development in place. A comparison of wind comfort results for both configurations is provided in Tables B1 & B2 in Appendix B. The tested massing scenarios are shown in Photographs 3 and 4 following the main text.

Pedestrian wind comfort resulting from the construction of the study building and future surrounding developments may be described as being *unchanged*, *improved*, or *reduced* as compared to the existing conditions. These designations are not strictly determined by the predicted percentage values, rather by the change to the predicted comfort class.

A review of Tables B1 & B2 indicates that wind comfort at surrounding grade-level areas further removed from the study site will largely remain unchanged upon the introduction of the proposed development. Although the Port Street East sidewalk areas on the same side of the street as the proposed development will see a modest reduction in wind comfort, conditions remain acceptable for the intended pedestrian uses on a seasonal basis. Of particular interest, some improvement to existing wind conditions occur along Waterfront Trail upon the development of the study site.

## 6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the methodology, results, and recommendations related to a pedestrian level wind study for the proposed condominium development located at 55 Port Street East in Mississauga, Ontario. The study was performed in accordance with industry standard wind tunnel testing and data analysis procedures.

A complete summary of the predicted wind conditions under the proposed massing scenario is provided in Section 5.2 of this report, and is also illustrated in Figures 2 and 3, as well as Tables A1 - A4 in Appendix A. Based on wind tunnel test results, meteorological data analysis, and experience with similar developments in Mississauga, we conclude that conditions over most pedestrian-sensitive areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal basis. Exceptions include several of the outdoor amenity areas surrounding the development site at grade. Recommended mitigation for these areas is detailed in Section 5.2.

As compared to the existing site conditions, wind comfort at surrounding grade-level areas further removed from the study site will largely remain unchanged upon the introduction of the proposed development. Although the Port Street East sidewalk areas on the same side of the street as the proposed development will see a modest reduction in wind comfort, conditions remain acceptable for the intended pedestrian uses on a seasonal basis. Of particular interest, some improvement to existing wind conditions occur along Waterfront Trail upon the development of the study site.

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.

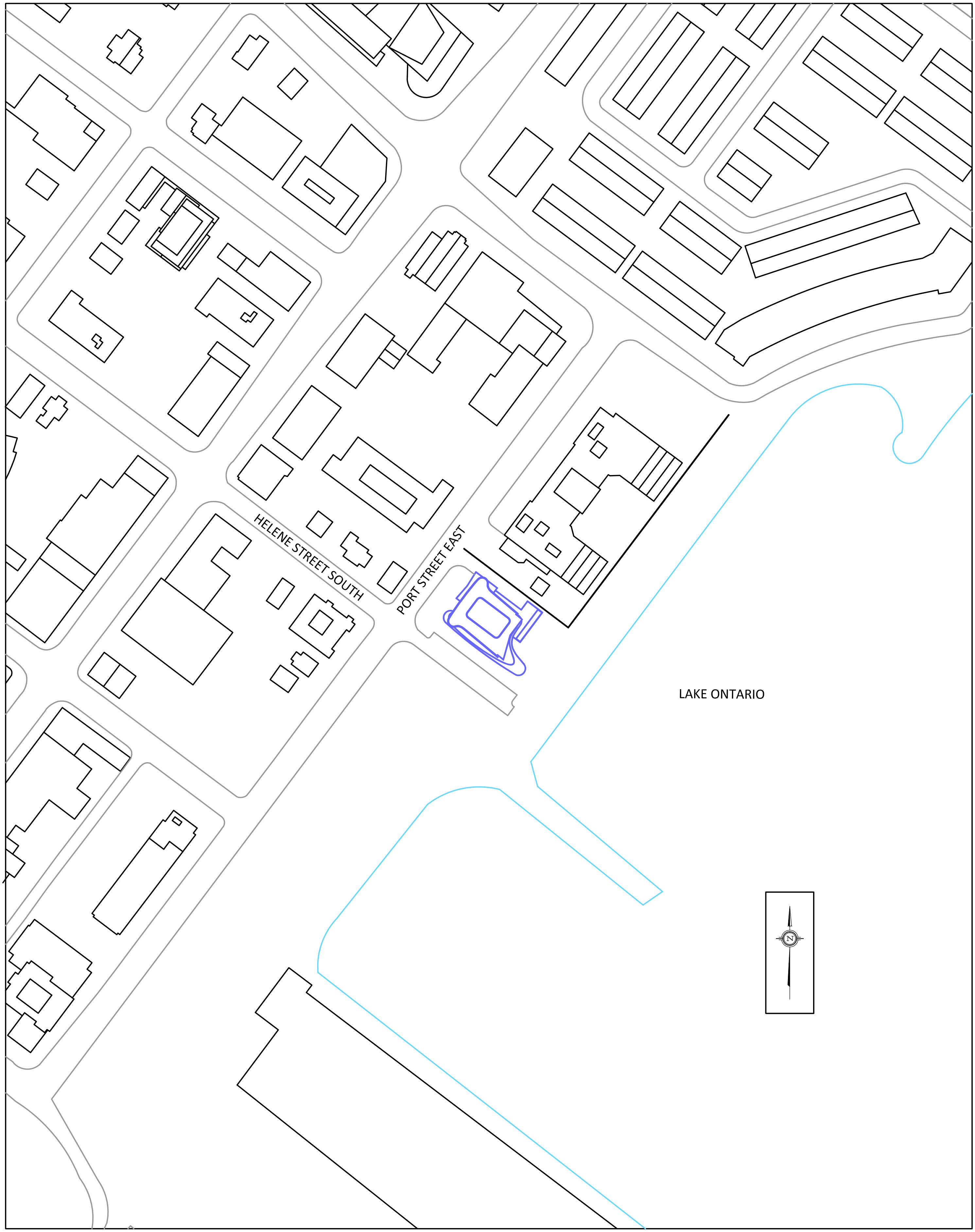
Sincerely,

***Gradient Wind Engineering Inc.***

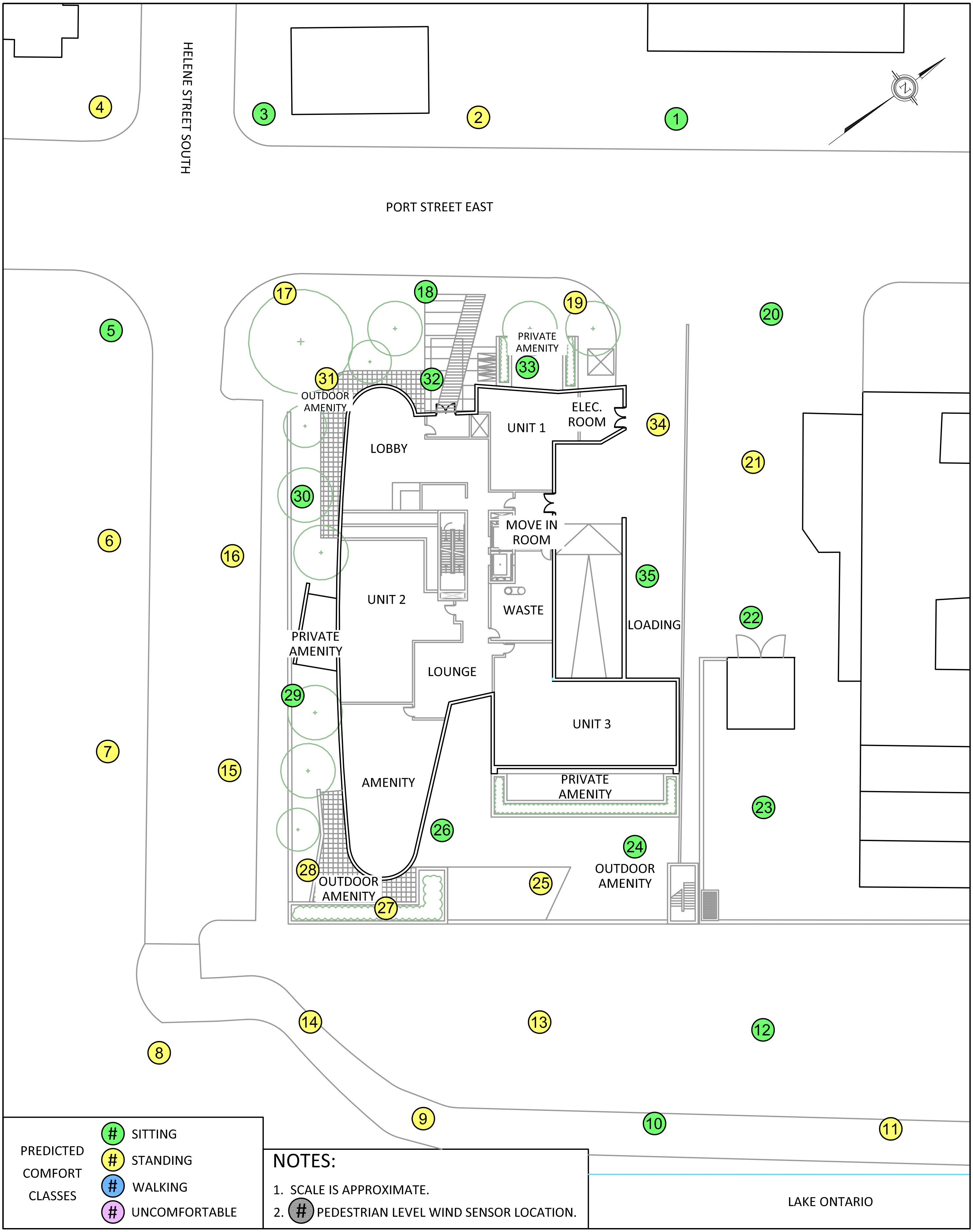
Nick Petersen, B.Eng., EIT
Junior Wind Scientist

Andrew Sliasas, M.A.Sc., P.Eng.,
Principal

*GWE17-184-WTPLW*



| | | | |
|---|---|---|---|
| **GRADIENTWIND**<br>ENGINEERS & SCIENTISTS<br>127 WALGREEN ROAD , OTTAWA, ON<br>613 836 0934 • GRADIENTWIND.COM | PROJECT<br>55 PORT STREET EAST, MISSISSAUGA<br>PEDESTRIAN LEVEL WIND STUDY | | DESCRIPTION<br>FIGURE 1:<br>SITE PLAN AND SURROUNDING CONTEXT |
| | SCALE<br>1:2500 (APPROX.) | DRAWING NO.<br>GWE17-184-PLW-1 | |
| | DATE<br>DECEMBER 7, 2018 | DRAWN BY<br>S.R. | |



PREDICTED COMFORT CLASSES

🟢 # SITTING
🟡 # STANDING
🔵 # WALKING
🟣 # UNCOMFORTABLE

NOTES:

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

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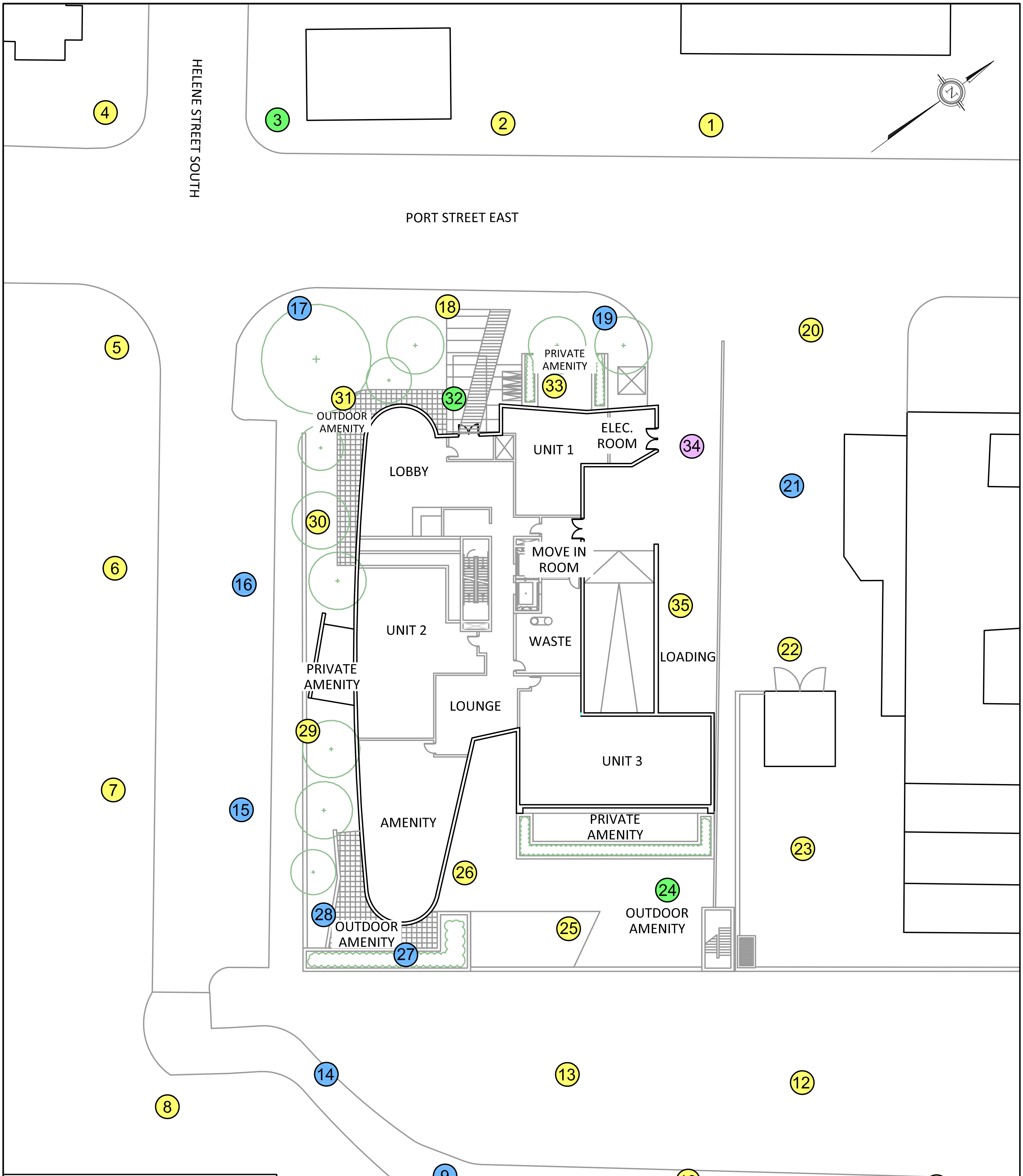
| | | |
|---|---|---|
| PROJECT 55 PORT STREET EAST, MISSISSAUGA<br>PEDESTRIAN LEVEL WIND STUDY | | DESCRIPTION FIGURE 2: SUMMER<br>GROUND FLOOR PLAN<br>PEDESTRIAN COMFORT PREDICTIONS |
| SCALE 1:500 (APPROX.) | DRAWING NO. GWE17-184-PLW-2 | |
| DATE DECEMBER 7, 2018 | DRAWN BY S.R. | |



PREDICTED COMFORT CLASSES
- 🟩 # SITTING
- 🟨 # STANDING
- 🟦 # WALKING
- 🟪 # UNCOMFORTABLE

NOTES:

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

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PROJECT
55 PORT STREET EAST, MISSISSAUGA
PEDESTRIAN LEVEL WIND STUDY

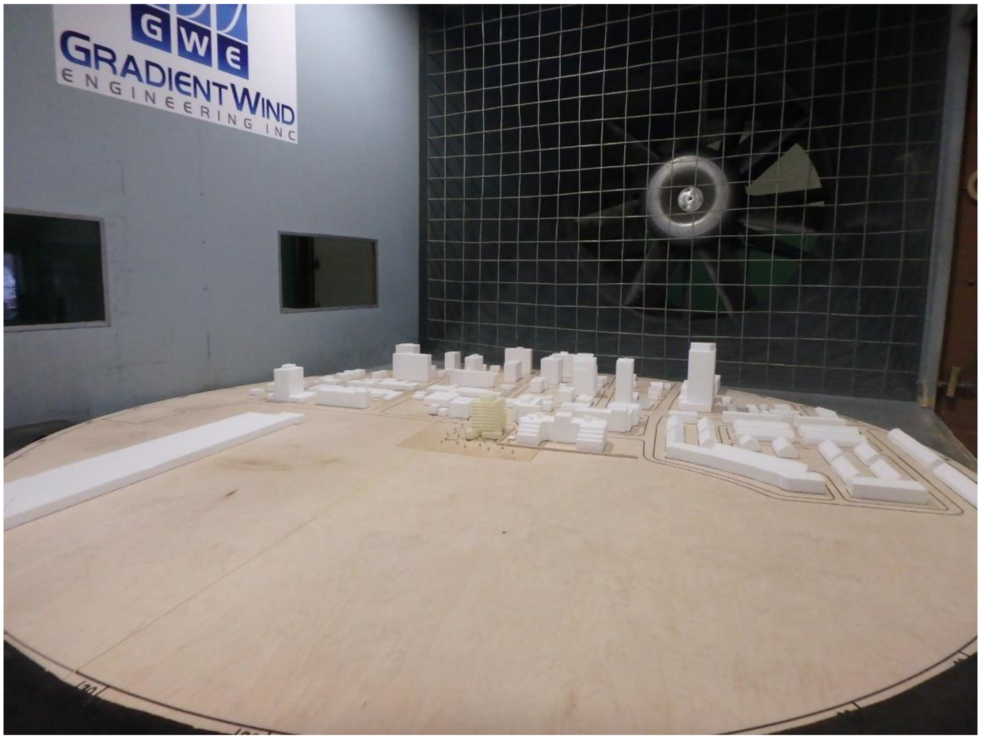
SCALE
1:500 (APPROX.)

DRAWING NO.
GWE17-184-PLW-3

DATE
DECEMBER 7, 2018

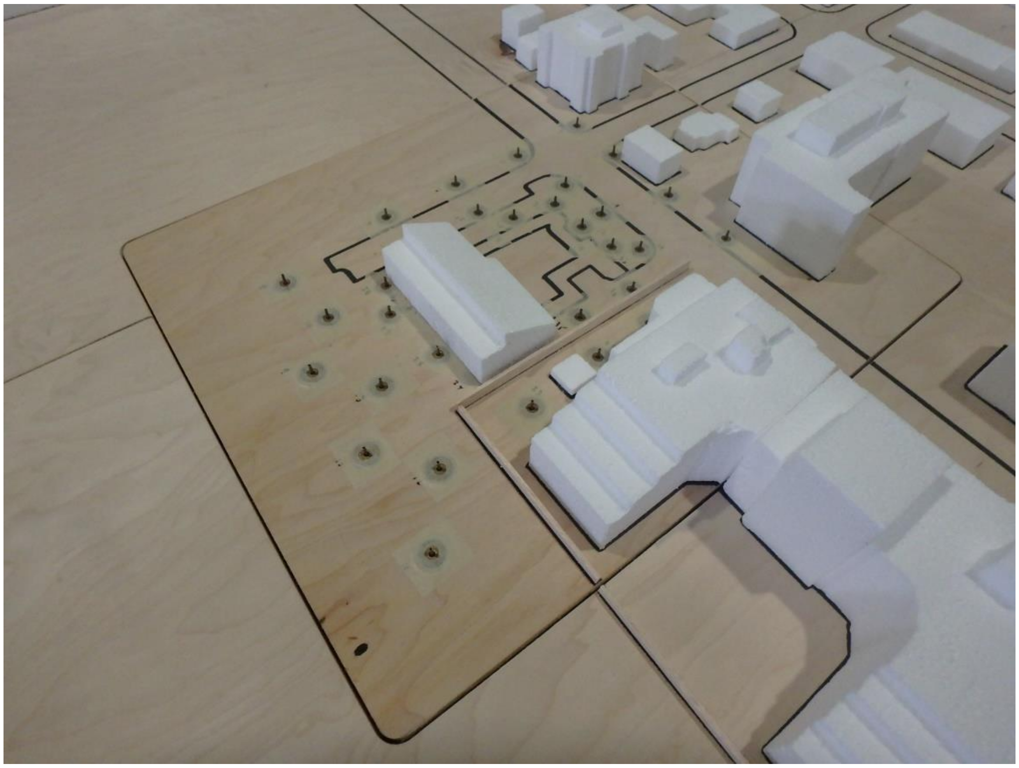
DRAWN BY
S.R.

DESCRIPTION
FIGURE 3: WINTER
GROUND FLOOR PLAN
PEDESTRIAN COMFORT PREDICTIONS

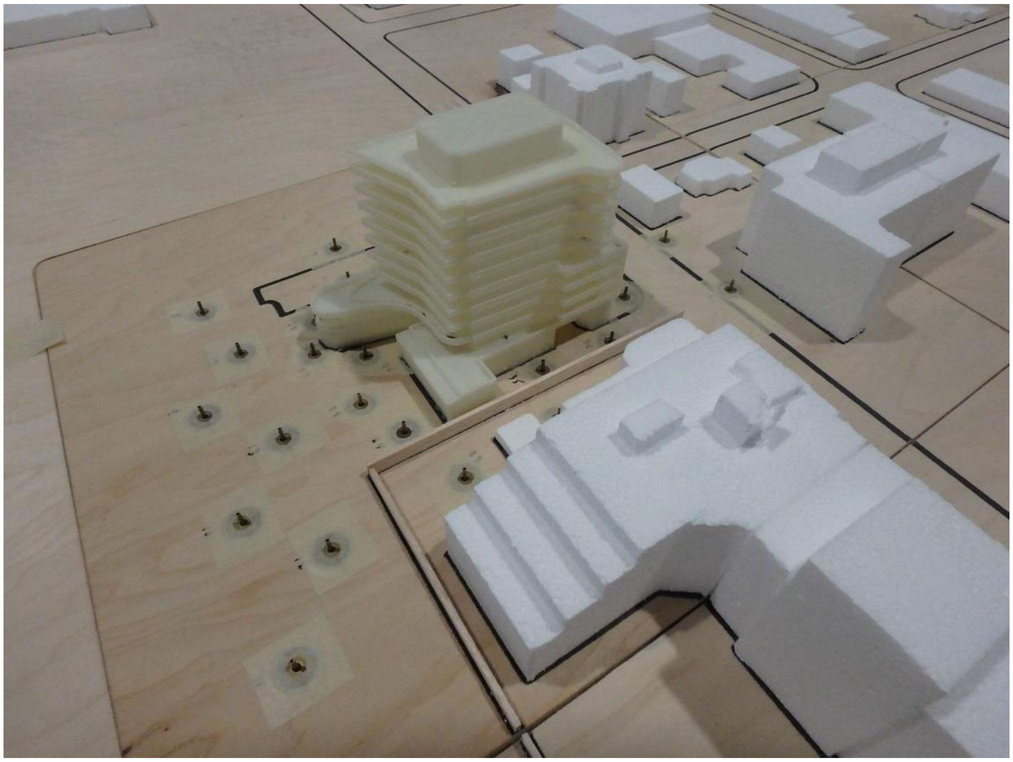


PHOTOGRAPH 1: CLOSE-UP VIEW OF PROPOSED CONTEXT MODEL LOOKING DOWNWIND

PHOTOGRAPH 2: CLOSE-UP VIEW OF PROPOSED CONTEXT MODEL LOOKING UPWIND



PHOTOGRAPH 3: CLOSE-UP VIEW OF EXISTING CONTEXT LOOKING WEST



PHOTOGRAPH 4: CLOSE-UP VIEW OF PROPOSED STUDY MODEL LOOKING WEST

# APPENDIX A

## PEDESTRIAN COMFORT SUITABILITY, TABLES A1-A4 (FUTURE CONDITIONS)

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# TABLE A1: SUMMARY OF PEDESTRIAN COMFORT (FUTURE CONDITIONS)

| Activity Type | | Sitting | Standing | Walking | Predicted Comfort Class | Location Type | Desired Comfort Class | Suitability |
|---|---|---|---|---|---|---|---|---|
| Wind Speed | | ≤ 10 | ≤ 15 | ≤ 20 | | | | |
| Guideline (% of | | ≥80% | | | | | | |
| Sensor #1 | Summer | 81 | 94 | 98 | Sitting | Public Sidewalk | Walking | Acceptable |
| | Winter | 67 | 85 | 94 | Standing | | | |
| Sensor #2 | Summer | 78 | 92 | 98 | Standing | Public Sidewalk | Walking | Acceptable |
| | Winter | 69 | 87 | 94 | Standing | | | |
| Sensor #3 | Summer | 95 | 100 | 100 | Sitting | Public Sidewalk | Walking | Acceptable |
| | Winter | 88 | 98 | 100 | Sitting | | | |
| Sensor #4 | Summer | 74 | 91 | 97 | Standing | Public Sidewalk | Walking | Acceptable |
| | Winter | 61 | 85 | 95 | Standing | | | |
| Sensor #5 | Summer | 83 | 96 | 99 | Sitting | Public Sidewalk | Walking | Acceptable |
| | Winter | 70 | 91 | 98 | Standing | | | |
| Sensor #6 | Summer | 76 | 91 | 96 | Standing | Public Sidewalk | Walking | Acceptable |
| | Winter | 65 | 85 | 93 | Standing | | | |
| Sensor #7 | Summer | 73 | 89 | 96 | Standing | Public Sidewalk | Walking | Acceptable |
| | Winter | 56 | 80 | 90 | Standing | | | |
| Sensor #8 | Summer | 77 | 91 | 97 | Standing | Walkway | Walking | Acceptable |
| | Winter | 60 | 81 | 91 | Standing | | | |
| Sensor #9 | Summer | 71 | 89 | 96 | Standing | Walkway | Walking | Acceptable |
| | Winter | 53 | 74 | 87 | Walking | | | |
| Sensor #10 | Summer | 81 | 94 | 98 | Sitting | Walkway | Walking | Acceptable |
| | Winter | 69 | 85 | 93 | Standing | | | |

## TABLE A2: SUMMARY OF PEDESTRIAN COMFORT (FUTURE CONDITIONS)

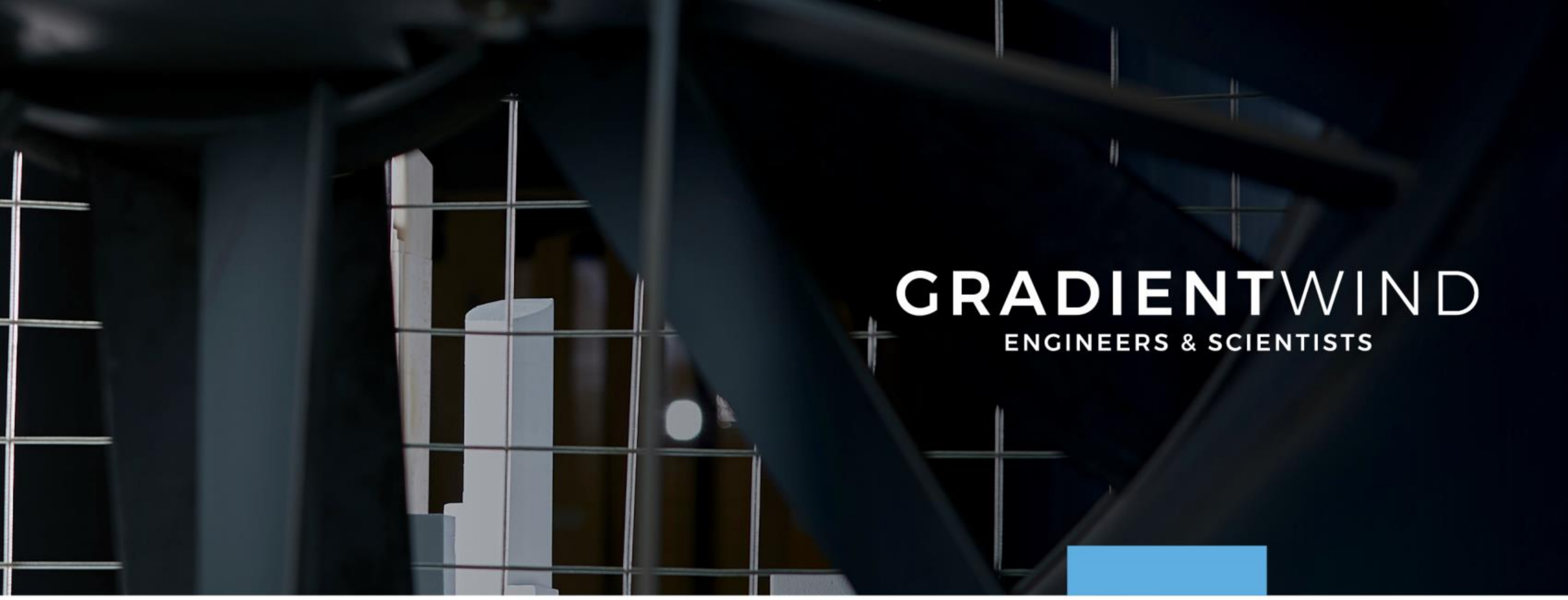
| Activity Type | | Sitting | Standing | Walking | Predicted Comfort Class | Location Type | Desired Comfort Class | Suitability |
|---|---|---|---|---|---|---|---|---|
| Wind Speed | | ≤ 10 | ≤ 15 | ≤ 20 | | | | |
| Guideline (% of | | ≥80% | | | | | | |
| Sensor #11 | Summer | 73 | 91 | 97 | Standing | Walkway | Walking | Acceptable |
| | Winter | 59 | 82 | 92 | Standing | | | |
| Sensor #12 | Summer | 81 | 94 | 98 | Sitting | Park | Sitting/ Walking | Acceptable |
| | Winter | 71 | 87 | 94 | Standing | | | |
| Sensor #13 | Summer | 74 | 92 | 98 | Standing | Park | Sitting/ Walking | Acceptable |
| | Winter | 57 | 81 | 92 | Standing | | | |
| Sensor #14 | Summer | 70 | 87 | 95 | Standing | Walkway | Walking | Acceptable |
| | Winter | 51 | 71 | 84 | Walking | | | |
| Sensor #15 | Summer | 77 | 92 | 97 | Standing | Parking | Walking | Acceptable |
| | Winter | 56 | 78 | 90 | Walking | | | |
| Sensor #16 | Summer | 65 | 85 | 94 | Standing | Parking | Walking | Acceptable |
| | Winter | 47 | 71 | 86 | Walking | | | |
| Sensor #17 | Summer | 68 | 88 | 96 | Standing | Public Sidewalk | Walking | Acceptable |
| | Winter | 49 | 75 | 90 | Walking | | | |
| Sensor #18 | Summer | 85 | 95 | 98 | Sitting | Public Sidewalk | Walking | Acceptable |
| | Winter | 76 | 91 | 96 | Standing | | | |
| Sensor #19 | Summer | 73 | 88 | 95 | Standing | Public Sidewalk | Walking | Acceptable |
| | Winter | 52 | 73 | 86 | Walking | | | |
| Sensor #20 | Summer | 80 | 94 | 99 | Sitting | Laneway | Walking | Acceptable |
| | Winter | 67 | 88 | 96 | Standing | | | |

## TABLE A3: SUMMARY OF PEDESTRIAN COMFORT (FUTURE CONDITIONS)

| Activity Type | | Sitting | Standing | Walking | Predicted Comfort Class | Location Type | Desired Comfort Class | Suitability |
|---|---|---|---|---|---|---|---|---|
| Wind Speed | | ≤ 10 | ≤ 15 | ≤ 20 | | | | |
| Guideline (% of | | ≥80% | | | | | | |
| Sensor #21 | Summer | 73 | 90 | 97 | Standing | Laneway | Walking | Acceptable |
| | Winter | 54 | 76 | 88 | Walking | | | |
| Sensor #22 | Summer | 82 | 94 | 98 | Sitting | Laneway | Walking | Acceptable |
| | Winter | 64 | 83 | 92 | Standing | | | |
| Sensor #23 | Summer | 84 | 96 | 99 | Sitting | Landscaped Area | Sitting/ Walking | Acceptable |
| | Winter | 75 | 92 | 97 | Standing | | | |
| Sensor #24 | Summer | 92 | 98 | 100 | Sitting | Outdoor Amenity Space | Sitting/ Standing | Acceptable |
| | Winter | 80 | 95 | 99 | Sitting | | | |
| Sensor #25 | Summer | 75 | 92 | 98 | Standing | Outdoor Amenity Space | Sitting/ Standing | Acceptable with Mitigation (See S. 5.2) |
| | Winter | 55 | 80 | 93 | Standing | | | |
| Sensor #26 | Summer | 91 | 99 | 100 | Sitting | Outdoor Amenity Space | Sitting/ Standing | Acceptable |
| | Winter | 78 | 96 | 99 | Standing | | | |
| Sensor #27 | Summer | 66 | 84 | 93 | Standing | Outdoor Amenity Space | Sitting/ Standing | Acceptable with Mitigation (See S. 5.2) |
| | Winter | 56 | 78 | 88 | Walking | | | |
| Sensor #28 | Summer | 62 | 83 | 93 | Standing | Outdoor Amenity Space | Sitting/ Standing | Acceptable with Mitigation (See S. 5.2) |
| | Winter | 43 | 64 | 80 | Walking | | | |
| Sensor #29 | Summer | 80 | 91 | 97 | Sitting | Private Amenity/ Landscaped Area | Sitting/ Walking | Acceptable |
| | Winter | 67 | 85 | 93 | Standing | | | |
| Sensor #30 | Summer | 86 | 96 | 99 | Sitting | Outdoor Amenity Space | Sitting/ Standing | Acceptable |
| | Winter | 76 | 93 | 98 | Standing | | | |

## TABLE A4: SUMMARY OF PEDESTRIAN COMFORT (FUTURE CONDITIONS)

| Activity Type | | Sitting | Standing | Walking | Predicted Comfort Class | Location Type | Desired Comfort Class | Suitability |
|---|---|---|---|---|---|---|---|---|
| Wind Speed | | ≤ 10 | ≤ 15 | ≤ 20 | | | | |
| Guideline (% of | | ≥80% | | | | | | |
| Sensor #31 | Summer | 76 | 92 | 98 | Standing | Outdoor Amenity Space | Sitting/ Standing | Acceptable With Mitigation (See S. 5.2) |
| | Winter | 61 | 84 | 94 | Standing | | | |
| Sensor #32 | Summer | 93 | 99 | 100 | Sitting | Outdoor Amenity/ Lobby Entrance | Sitting/ Standing | Acceptable |
| | Winter | 82 | 95 | 98 | Sitting | | | |
| Sensor #33 | Summer | 89 | 97 | 99 | Sitting | Private Amenity/ Landscaped Area | Sitting/ Walking | Acceptable |
| | Winter | 76 | 91 | 96 | Standing | | | |
| Sensor #34 | Summer | 62 | 82 | 92 | Standing | Laneway | Walking | Acceptable (See S. 5.2) |
| | Winter | 40 | 61 | 76 | Uncomfortable | | | |
| Sensor #35 | Summer | 85 | 95 | 98 | Sitting | Laneway/ Loading | Walking | Acceptable |
| | Winter | 65 | 84 | 93 | Standing | | | |



# APPENDIX B

## PEDESTRIAN COMFORT SUITABILITY, TABLES B1-B2 (EXISTING VS FUTURE CONDITIONS)

## TABLE B1: COMPARATIVE SUMMARY OF PEDESTRIAN COMFORT

| Sensor | Massing Scenario | Summer Pedestrian Comfort | | Winter Pedestrian Comfort | |
|---|---|---|---|---|---|
| | | Predicted Comfort Class | Future Comfort Class Compared to Existing | Predicted Comfort Class | Future Comfort Class Compared to Existing |
| **1** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Standing | Unchanged |
| **2** | Existing | Sitting | - | Standing | - |
| | Future | Standing | Reduced | Standing | Unchanged |
| **3** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Sitting | Improved |
| **4** | Existing | Standing | - | Standing | - |
| | Future | Standing | Unchanged | Standing | Unchanged |
| **5** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Standing | Unchanged |
| **6** | Existing | Standing | - | Standing | - |
| | Future | Standing | Unchanged | Standing | Unchanged |
| **7** | Existing | Sitting | - | Standing | - |
| | Future | Standing | Reduced | Standing | Unchanged |
| **8** | Existing | Standing | - | Standing | - |
| | Future | Standing | Unchanged | Standing | Unchanged |
| **9** | Existing | Standing | - | Walking | - |
| | Future | Standing | Unchanged | Walking | Unchanged |
| **10** | Existing | Standing | - | Standing | - |
| | Future | Sitting | Reduced | Standing | Unchanged |
| **11** | Existing | Standing | - | Walking | - |
| | Future | Standing | Unchanged | Standing | Improved |
| **12** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Standing | Unchanged |
| **13** | Existing | Standing | - | Standing | - |
| | Future | Standing | Unchanged | Standing | Unchanged |
| **14** | Existing | Standing | - | Walking | - |
| | Future | Standing | Unchanged | Walking | Unchanged |
| **15** | Existing | Sitting | - | Standing | - |
| | Future | Standing | Reduced | Walking | Reduced |
| **16** | Existing | Standing | - | Standing | - |
| | Future | Standing | Unchanged | Walking | Reduced |
| **17** | Existing | Sitting | - | Standing | - |
| | Future | Standing | Reduced | Walking | Reduced |
| **18** | Existing | Sitting | - | Sitting | - |
| | Future | Sitting | Unchanged | Standing | Reduced |
| **19** | Existing | Sitting | - | Standing | - |
| | Future | Standing | Reduced | Walking | Reduced |

# TABLE B2: COMPARATIVE SUMMARY OF PEDESTRIAN COMFORT

| Sensor | Massing Scenario | Summer Pedestrian Comfort | | Winter Pedestrian Comfort | |
|---|---|---|---|---|---|
| | | Predicted Comfort Class | Future Comfort Class Compared to Existing | Predicted Comfort Class | Future Comfort Class Compared to Existing |
| **20** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Standing | Unchanged |
| **21** | Existing | Sitting | - | Standing | - |
| | Future | Standing | Reduced | Walking | Reduced |
| **22** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Standing | Unchanged |
| **23** | Existing | Sitting | - | Standing | - |
| | Future | Sitting | Unchanged | Standing | Unchanged |

# APPENDIX C

## WIND TUNNEL SIMULATION OF THE NATURAL WIND

# WIND TUNNEL SIMULATION OF THE NATURAL WIND

Wind flowing over the surface of the earth develops a boundary layer due to the drag produced by surface features such as vegetation and man-made structures. Within this boundary layer, the mean wind speed varies from zero at the surface to the gradient wind speed at the top of the layer. The height of the top of the boundary layer is referred to as the gradient height, above which the velocity remains more-or-less constant for a given synoptic weather system. The mean wind speed is taken to be the average value over one hour. Superimposed on the mean wind speed are fluctuating (or turbulent) components in the longitudinal (i.e. along wind), vertical and lateral directions. Although turbulence varies according to the roughness of the surface, the turbulence level generally increases from nearly zero (smooth flow) at gradient height to maximum values near the ground. While for a calm ocean the maximum could be 20%, the maximum for a very rough surface such as the center of a city could be 100%, or equal to the local mean wind speed. The height of the boundary layer varies in time and over different terrain roughness within the range of 400 metres (m) to 600 m.

Simulating real wind behaviour in a wind tunnel requires simulating the variation of mean wind speed with height, simulating the turbulence intensity, and matching the typical length scales of turbulence. It is the ratio between wind tunnel turbulence length scales and turbulence scales in the atmosphere that determines the geometric scales that models can assume in a wind tunnel. Hence, when a 1:200 scale model is quoted, this implies that the turbulence scales in the wind tunnel and the atmosphere have the same ratios. Some flexibility in this requirement has been shown to produce reasonable wind tunnel predictions compared to full scale. In model scale the mean and turbulence characteristics of the wind are obtained with the use of spires at one end of the tunnel and roughness elements along the floor of the tunnel. The fan is located at the model end and wind is pulled over the spires, roughness elements and model. It has been found that, to a good approximation, the mean wind profile can be represented by a power law relation, shown below, giving height above ground versus wind speed.

$$U = U_g \left( \frac{Z}{Z_g} \right)^{\alpha}$$

Where; ***U*** = mean wind speed, $\boldsymbol{U_g}$ = gradient wind speed, ***Z*** = height above ground, $\boldsymbol{Z_g}$ = depth of the boundary layer (gradient height) and $\alpha$ is the power law exponent.

Figure B1 on the following page plots three velocity profiles for open country, and suburban and urban exposures.

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

The integral length scale of turbulence can be thought of as an average size of gust in the atmosphere. Although it varies with height and ground roughness, it has been found to generally be in the range of 100 m to 200 m in the upper half of the boundary layer. Thus, for a 1:300 scale, the model value should be between 1/3 and 2/3 of a metre. Integral length scales are derived from power spectra, which describe the energy content of wind as a function of frequency. There are several ways of determining integral length scales of turbulence. One way is by comparison of a measured power spectrum in model scale to a non-dimensional theoretical spectrum such as the Davenport spectrum of longitudinal turbulence. Using the Davenport spectrum, which agrees well with full-scale spectra, one can estimate the integral scale by plotting the theoretical spectrum with varying L until it matches as closely as possible the measured spectrum:

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

Where, f is frequency, S(f) is the spectrum value at frequency f, U10 is the wind speed 10 m above ground level, and L is the characteristic length of turbulence.

Once the wind simulation is correct, the model, constructed to a suitable scale, is installed at the center of the working section of the wind tunnel. Different wind directions are represented by rotating the model to align with the wind tunnel center-line axis.

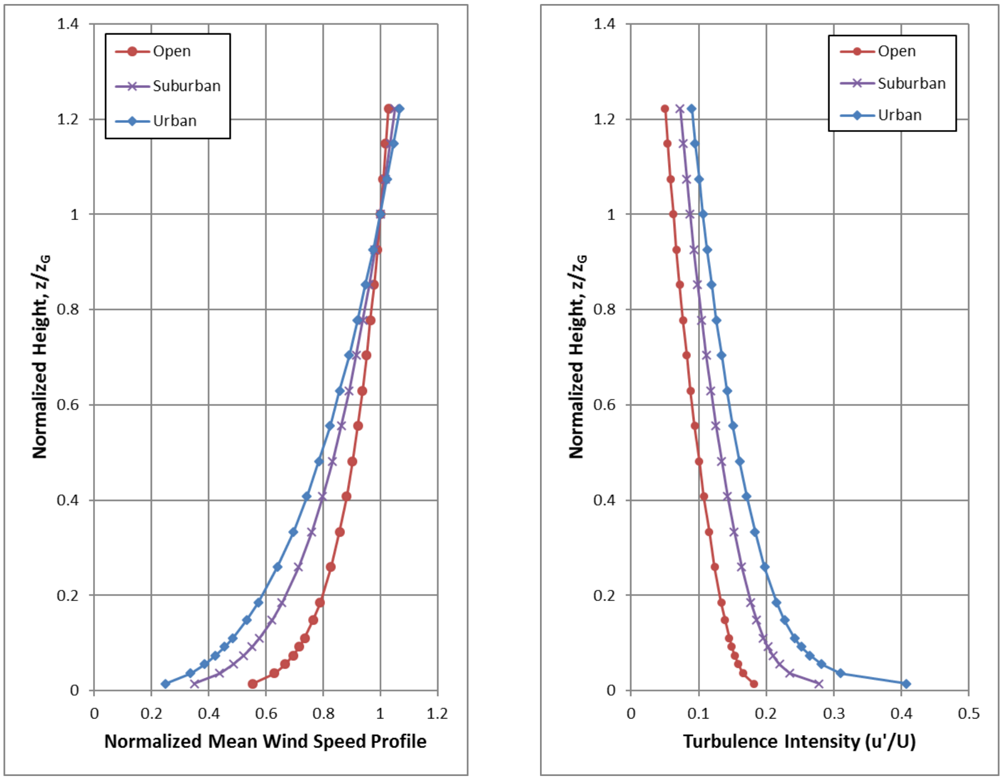


**FIGURE C1 (LEFT): MEAN WIND SPEED PROFILES;**
**FIGURE C2 (RIGHT): TURBULENCE INTENSITY PROFILES**

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# APPENDIX D

## PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

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# PEDESTRIAN LEVEL WIND MEASUREMENT METHODOLOGY

Pedestrian level wind studies are performed in a wind tunnel on a physical model of the study buildings at a suitable scale. Instantaneous wind speed measurements are recorded at a model height corresponding to 1.5 m full scale using either a hot wire anemometer or a pressure-based transducer. Measurements are performed at any number of locations on the model and usually for 36 wind directions. For each wind direction, the roughness of the upwind terrain is matched in the wind tunnel to generate the correct mean and turbulent wind profiles approaching the model.

The hot wire anemometer is an instrument consisting of a thin metallic wire conducting an electric current. It is an omni-directional device equally sensitive to wind approaching from any direction in the horizontal plane. By compensating for the cooling effect of wind flowing over the wire, the associated electronics produce an analog voltage signal that can be calibrated against velocity of the air stream. For all measurements, the wire is oriented vertically so as to be sensitive to wind approaching from all directions in a horizontal plane.

The pressure sensor is a small cylindrical device that measures instantaneous pressure differences over a small area. The sensor is connected via tubing to a transducer that translates the pressure to a voltage signal that is recorded by computer. With appropriately designed tubing, the sensor is sensitive to a suitable range of fluctuating velocities.

For a given wind direction and location on the model, a time history of the wind speed is recorded for a period of time equal to one hour in full-scale. The analog signal produced by the hot wire or pressure sensor is digitized at a rate of 400 samples per second. A sample recording for several seconds is illustrated in Figure D1. This data is analyzed to extract the mean, root-mean-square (rms) and the peak of the signal. The peak value, or gust wind speed, is formed by averaging a number of peaks obtained from sub-intervals of the sampling period. The mean and gust speeds are then normalized by the wind tunnel gradient wind speed, which is the speed at the top of the model boundary layer, to obtain mean and gust ratios. At each location, the measurements are repeated for 36 wind directions to produce normalized polar plots, which will be provided upon request.

In order to determine the duration of various wind speeds at full scale for a given measurement location the gust ratios are combined with a statistical (mathematical) model of the wind climate for the project site. This mathematical model is based on hourly wind data obtained from one or more meteorological stations (usually airports) close to the project location. The probability model used to represent the data is the Weibull distribution expressed as:

$$P\left(>U_g\right)=A_\theta \bullet \exp\left[\left(-\frac{U_g}{C\theta}\right)^{K\theta}\right]$$

Where,

***$P\ (>U_g)$*** is the probability, fraction of time, that the gradient wind speed ***$U_g$*** is exceeded; ***$\theta$*** 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). ***$A_\theta$*** is the fraction of time wind blows from a $10^\circ$ sector centered on ***$\theta$***.

Analysis of the hourly wind data recorded for a length of time, on the order of 10 to 30 years, yields the ***$A_\theta$***, ***$C_\theta$*** and ***$K_\theta$*** values. The probability of exceeding a chosen wind speed level, say 20 km/h, at sensor *N* is given by the following expression:

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

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

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

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

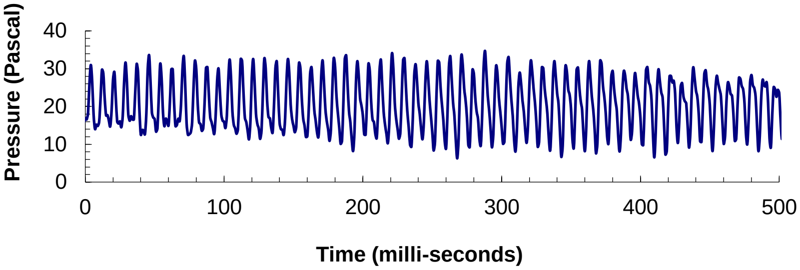

**FIGURE D1: TIME VERSUS VELOCITY TRACE FOR A TYPICAL WIND SENSOR**

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