GRADIENT WIND ENGINEERING INC

Pedestrian Level Wind Study

Tellus Towers Telefonplan

Stockholm, Sweden

REPORT: GWE16-015-PLW R1

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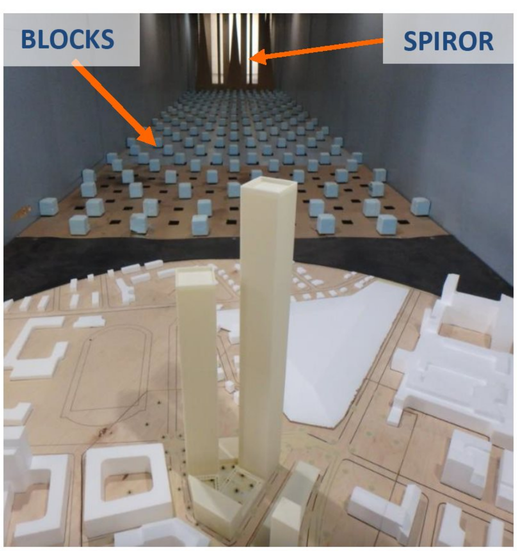
EXEKUTIV SAMMANFATTNING

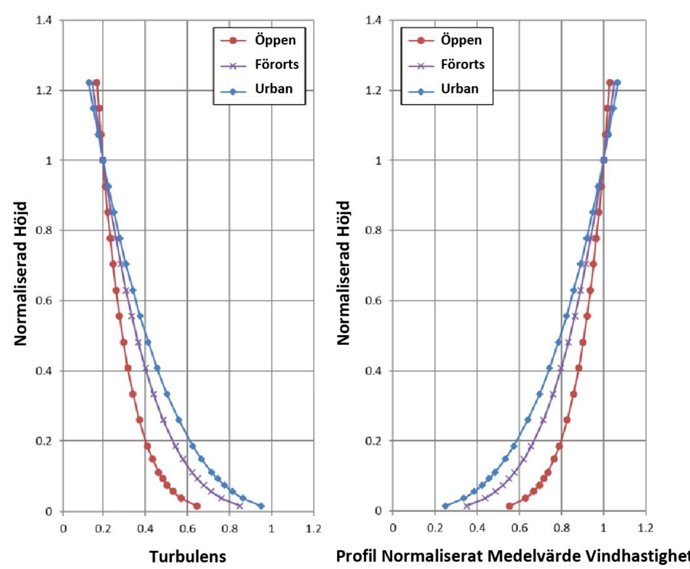
Denna rapport beskriver en vindundersökning för fotgängare som har genomförts av Gradiant Wind Engineering Inc. (GWE) för att bedöma vindbekvämlighet för ett förslaget landmärke som skall utvecklas i Stockholm, Sverige. Undersökningen involverar vindtunnelmått av vindhastigheter genom att använda en fysisk modell, kombinerat med metereologisk data för att bedöma hur bekvämt och säkert det är för fotgängare vid nyckelområden inom och runtomkring byggplatsen. Områden för fotgängare i denna undersökning inkluderar omkringliggande trottoarer och gångvägar, åtkomstpunkter till byggnaden, uteplatsen i det nordvästra hörnet av tornet med 78 våningar, det sydöstra området intill Telefonplans tunnelbanestation, områdena intill Apoteks Gruppen apotek, så väl som skolgården ovanpå tvåvånings podium som kopplar samman tornet med 78 våningar och det med 7 våningar. Bakgrundsinformation så väl som resultaten av rekommendationerna som har framkomit av denna undersökning, sammanfattas i de följande paragraferna, där resultat och rekommendationer förklaras mer i detalj i en senare rapport.

Bakgrundsinformation

- Vindstudier för fotgängare är baserade på standardiserade tekniker för tester in vindtunnlar so har används i årtionden för att informera designen av stora byggprojekt.
- Tester i vindtunnlar genom att använda fysiska modeller är det mest exakta och pålitliga sättet för att presentera ett fullskaligt vindbeteende på byggnader och andra konstruktioner.
- Vindbeteende på den fullskaliga siten simuleras i vindtunneln genom att använda spiror och block, vilka justerar hastigheten och turbulensen som en funktion av höjd ovanför marken.

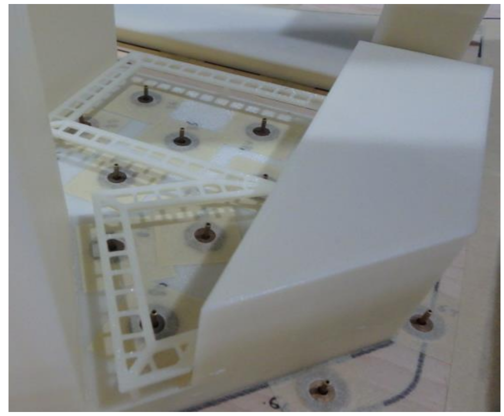


FIGUR I: MODELL FÖR VINDTUNNEL

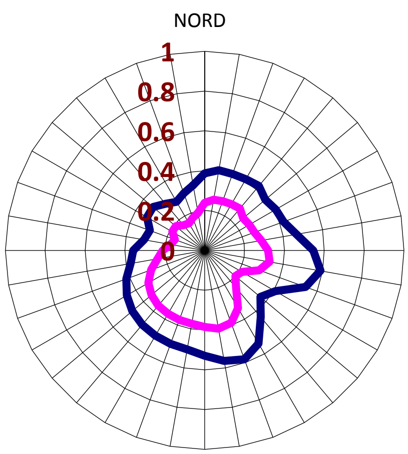


FIGUR II: VARIATION AV TURBULENS (VANSTER) OCH MEDELVÄRDE VINDHASTIGHET (HÖGER) MED HÖJD

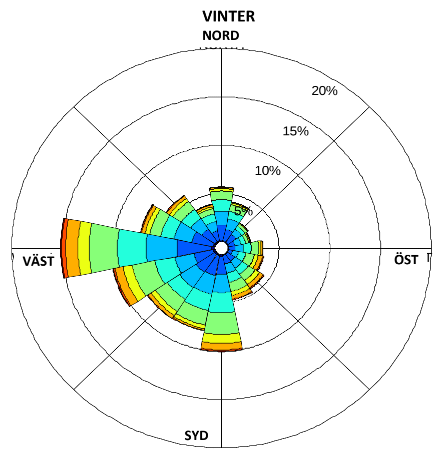
- Data för vindhastighet uppmäts av diskreta sensorer (Figur III) som täcker känsliga områden på siten och intilliggande områden. Mått uppmäts till 10 graders interval för de fulla 360 graders kompassasimut.
- Förutsägelser om komfort fås genom att kombinera den uppmätta vinddatan från vindtunneln med den statistiska modellen för Stockholms vindklimat, som visas nedan. Sensor 6 (Figur IV) har en radial skala på 0 till 1.0 som hänvisas till gradient vindhastighet för Stockholm. Gradient vindhastighet är vindhastigheten på en höjd som är över marknivå som inte längre påverkas av byggnader eller jordens topografi.



FIGUR III: SENSORER VID MARKNIVÅ OCH FÖRHÖJD TERRAS I MODELLEN



FIGUR IV: EXEMPEL VINDTUNNELDATA FÖR SENSOR 6



FIGUR V: VÄDERSTATISTIK STOCKHOLM

- Resultaten jämförs med GWEs riktlinjer för aktiviteter utomhus (sitta, stå, gå, obekvämt; visas i tabell 1) så väl som riktlinjer för säkerhet.

TABELL 1: GWE RIKTLINJER FÖR AKTIVITETER UTOMHUS

Bekvämlighetsnivå	Tröskel vindhastighet
Sitta	< 14 km/m mer än 70 % av tiden
Stå	< 22 km/m mer än 80 % av tiden
Gå	< 30 km/m mer än 80 % av tiden
Obekvämt	> 30 km/m mer än 80 % av tiden

Sammanfattning av Resultaten

En fullständig undersökning av förväntade vindförhållanden baserat ovan nämnt tillvägagångssätt i Sektion 5.1 och 5.2 i denna rapport, även illustrerad i Figur 2A till 5B (efter huvudtexten). Baserad på resultat av tester i vindtunnel, analys av metereologisk data samt erfarenheter från ett stort antal liknande projekt, kan vi sammanfattningsvis säga att vindförhållandena för de, för fotgängare, känsliga områden inom och omkring siten är acceptabla för de områden de förväntas användas av fotgängare på säsongs- och årsbasis. Såväl som i samband med typiska vädermönster, som utesluter högst ovanliga loka stormhändelser som tornados eller kraftiga vindar. Inga områden visade tecken på att de skulle vara för blåsigt för att gå, eller de skulle anses vara osäkra. Detta då Stockholm har ett blygsamt vindklimat jämfört med andra städer.

Det möjliga undantaget från ovanstående uttalande (dvs. förutsättningar som är acceptabla för avsedd användning) innebär att torget intill 78-våningstornet längs Mikrofonvägen, där förutsägelser indikerar stående komfort under hela året. Om förhållanden som är lämpliga för sittande är nödvändiga för detta område, kommer lokaliserad begränsning att behövas. Vindtunnelprovningen visade att direkt horisontella vindar från sydliga riktningar var främst ansvariga för starka vindar över torget, och att nedvattningen längs tornets västra fasad inte var betydande. Som ett resultat av det bör begränsningar i form av vertikala barriärer fokusera på att blockera horisontella vindar från sydvästkvadrant under större delen av året och från norr under sommaren. Godtagbar vindkomfort kommer att uppnås efter introduktionen av (i) fasta vertikala barriärer, (ii) täta barrträd, eller (iii) en kombination av de två alternativen. Barriärens höjd beror på det område som ska skyddas för sittande och densiteten som landskapsarkitekten har valt, men bör inte vara mindre än 1,8 meter hög. Uppgifter om begränsningsalternativ kommer att diskuteras med designteamet före utfärdandet av en slutrapport.

Vindförhållanden inom skolgården ovanpå det tvåvåningspodiet sammanför de 78- och 58-vånings torn till 7-våningsbyggnaden antas vara anpassad för att man ska kunna stå under hela året. De noterade förhållandena anses vara acceptabla för båda entréerna till 7-våningsbyggnaden, så väl som för området med skolgården. Men om lugnar förhållanden krävs bör andra begränsningsåtgärder diskuteras med designteamet.

EXECUTIVE SUMMARY

This report describes a pedestrian level wind study undertaken by Gradient Wind Engineering Inc. (GWE) to assess wind comfort for a proposed landmark mixed-use high-rise development in Stockholm, Sweden. The study involves wind tunnel measurements of pedestrian wind speeds using a physical scale model, combined with meteorological data, to assess pedestrian comfort and safety at key areas within and surrounding the development site. Grade-level pedestrian areas considered in this study include surrounding sidewalks and walkways, building access points, the patio area at the northwest corner of the 78-storey tower, the southeast area adjacent to the Telefonplan T-bana building, the areas adjacent to the Apoteks Gruppen pharmacy, as well as the school yard atop the 2-storey podium connecting the 78- and 58-storey towers to the 7-storey building. Background information, as well as results and recommendations derived from the study, are summarized in the following paragraphs, with results and recommendations further detailed in the subsequent report.

Background Information

- Pedestrian wind studies are based on industry standard wind tunnel testing techniques that have been used for decades to inform the design of major developments.
- Wind tunnel testing using physical models is the most accurate and reliable means of representing full-scale wind behaviour over buildings and other structures.
- Wind behaviour at the full-scale site is simulated in the wind tunnel using spires and roughness elements, which adjust mean speed and gustiness (turbulence) as a function of height above ground.

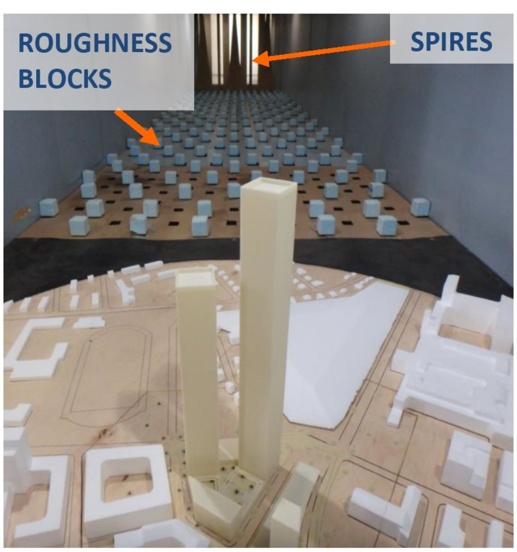


FIGURE I: WIND TUNNEL MODEL

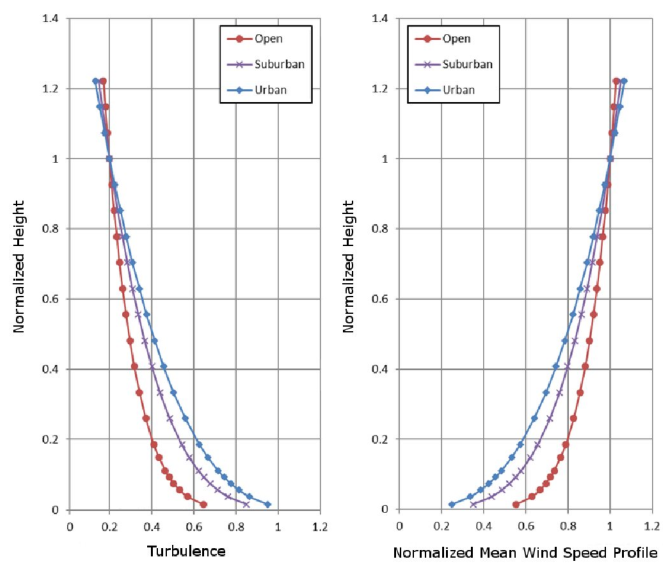


FIGURE II: VARIATION OF TURBULENCE (LEFT) AND MEAN WIND SPEED (RIGHT) WITH HEIGHT

- Wind velocity data is measured by discrete sensors (Figure III) representing sensitive areas over the development site and surrounding areas. Measurements are recorded at 10^{O} intervals for the full 360^{O} compass azimuth.
- Comfort predictions are obtained by combining the measured wind data from the wind tunnel with the statistical model of the Stockholm wind climate, as shown below. The polar plot for Sensor 6 (Figure IV) has a radial scale of 0 to 1.0, which is referenced to the gradient wind velocity for Stockholm. The gradient wind velocity is the wind speed at a height above ground level that is no longer influenced by buildings and the topography on the earth's surface.

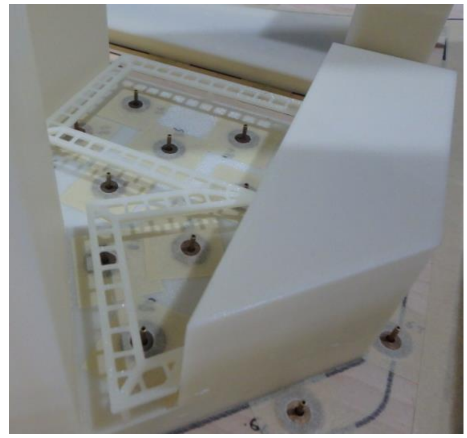


FIGURE III: SENSORS AT GRADE AND ELEVATED TERRACE OF MODEL

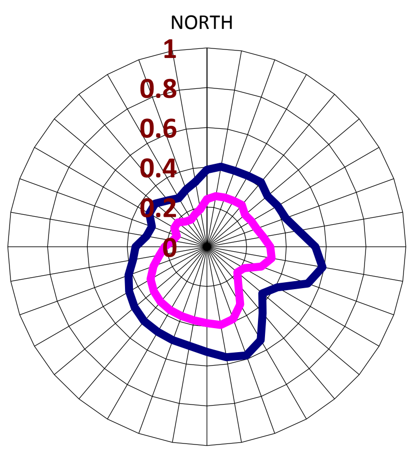


FIGURE IV: SAMPLE WIND TUNNEL DATA FOR SENSOR 6

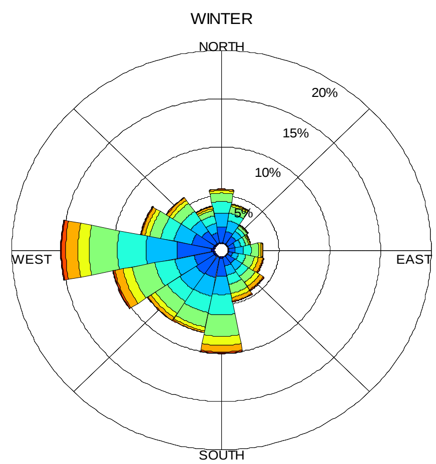


FIGURE V: WEATHER STATISTICS, STOCKHOLM

- The results are compared to GWE's comfort guidelines for outdoor functions (sitting, standing, walking, uncomfortable; shown in Table 1) as well as safety guidelines.

TABLE I: GWE COMFORT GUIDELINES FOR OUTDOOR FUNCTIONS

Comfort Level	Threshold Wind Speeds
Sitting	< 14 km/m more than 70% of the time
Standing	< 22 km/m more than 80% of the time
Walking	< 30 km/m more than 80% of the time
Uncomfortable	> 30 km/m more than 20% of the time

Summary of Results

A complete summary of predicted wind conditions based on the above procedure is provided in Sections 5.1 and 5.2 of this report and is also illustrated in Figures 2A through 5B (following the main text). Based on wind tunnel test results, meteorological data analysis, and experience with numerous similar developments, we conclude that wind conditions over most grade-level pedestrian-sensitive areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal and annual basis. As well, within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas at grade were found to experience conditions too windy for walking, or that could be considered unsafe. This generally favourable outcome is a result Stockholm's modest wind climate as compared to other cities.

The possible exception to the above statement (ie. conditions as acceptable for intended use) involves the grade-level plaza adjacent to the 78-storey tower along Mikrofonvägen, where predictions indicate standing comfort throughout the year. If conditions suitable for sitting are required over this area, localized mitigation will be required. Notedly, wind tunnel testing revealed that direct horizontal winds from southerly directions were mainly responsible for strong winds over the plaza, and that downwash along the west façade of the tower was not significant. As a result, mitigation in the form of vertical barriers should focus on blocking horizontal winds from the southwest quadrant for the majority of the year, and from the north during the summer. Acceptable wind comfort would be achieved following the introduction of (i) solid vertical wind barriers, (ii) dense coniferous plantings, or (iii) a combination of the two options. The height of the barriers will depend on the area to be protected for sitting and the density selected by the landscape architect, but should not be less than 1.8 metres above grade. Details relating to mitigation options will be discussed with the design team prior to issuance of a final report.

Wind conditions within the school yard atop the 2-storey podium connecting the 78- and 58-storey towers to the 7-storey building are predicted to be suitable for standing or better throughout the year. The noted conditions are considered acceptable for both entrances serving the 7-storey building, as well as for the school yard area. However, if calmer conditions are required, parapet details and other localized mitigation efforts would need to be discussed with the design team.

TABLE OF CONTENTS

1. INTRODUCTION

Gradient Wind Engineering Inc. (GWE) was retained by SSM Bygg & Fastighets AB to undertake wind engineering studies for a proposed landmark mixed-use high-rise development in Stockholm, Sweden. The scope of work within our mandate is outlined in GWE proposal #16-005P. This report summarizes the methodology, results and recommendations related to the pedestrian level wind (PLW) conditions over the study site and neighbouring properties.

Our work is based on industry standard wind tunnel testing techniques, architectural drawings and surrounding building massing information provided by Wingårdhs on February 12, 2016, as well as recent site imagery as referenced from Google Earth.

2. TERMS OF REFERENCE

The focus of this PLW study is Tellus Towers Telefonplan, a proposed mixed-use high-rise development located in a suburban area of Liljeholmen, a district of the Hägersten-Liljeholmen borough in Söderort, 5 kilometers (km) southwest of Stockholm proper, Sweden. The subject site is bounded by Telefonvägen to the north, Mikrofonvägen to the west, Cembalogatan to the south, and Flygelgatan to the east. The site is also situated approximately 1.25 km southwest of European route E4 and approximately 350 meters (m) northwest of European route E20.

Regarding wind exposures, the near-field surroundings of the development, defined as an area falling within a 200 m radius from the subject site, are characterized by residential dwellings from south-southwest clockwise to west, the low-to-medium-rise Telefonplan T-bana building to the west-northwest, the Apoteks Gruppen pharmacy to the northwest, low-rise residential dwellings from northwest clockwise to east-northeast, a mix of low- and medium-rise buildings from east-northeast clockwise to south-southeast, and the football pitch / running track that defines the remaining directions. The far-field surroundings, defined as the area beyond the near field and within a 2 km radius, are characterized by mostly low-rise buildings from southeast clockwise to east-northeast, and a mix of low- and medium-rise buildings for the remaining compass azimuth.

Of particular importance, a large 9 m tall hill is located to the west of the subject site and Mikrofonvägen. The hill approximately spans the width of the development in the north-south direction. Additionally, the topography of the area includes moderate slopes in most directions. The only exception concerns the noted hill, which includes an approximate slope of 5.8% when measured from its peak towards Mikrofonvägen. The resulting wind exposures are consistent with a hybrid suburban-open terrain roughness for the full compass azimuth.

Upon completion, the fully-developed site will provide two square plan form towers of 78- and 58-storeys on the west side separated by approximately one tower width, as well as a single 7-storey building on the east side, all connected by a large 2-storey podium. The corresponding heights above local grade of the noted buildings are 236.9 m, 176.9 m, and 21 m, respectively. At 6 m above grade the 2-storey podium roof provides a playground which serves the school in the 7-storey building. On the west side, a 4-storey tall building section, rising above the podium roof, serves as an enclosed walkway (bostadslobby or housing lobby) between the towers at level 3, as well as a canopy protecting the main entrances and pedestrian plaza below. The noted collection of buildings is located within the south half of the site plan, which is bounded by Cembalogatan to the south and an interior laneway to the north. Both tall towers have smooth facades that extend uninterrupted from grade on two of the four sides, and from the 2-storey podium on the remaining two sides to roof levels. The main entrances of both towers are accessed from Mikrofonvägen and are located beneath the noted 4-storey building overhang, while various building access points are provided around the perimeter of the development. The south elevation provides access to 2 levels of below-grade parking from Cembalogatan.

The site plan also includes a bus station to the immediate north, which is bounded by the laneway to the south and Telefonvägen to the north. The bus station integrates with a 17-storey residential building at the northeast corner of the site rising through a 2-storey podium, which spans the full width of the site parallel to Telefonvägen. The podium houses the bus station (busstation), which includes a concourse (vänthall), two stores (butiker), a café (kafé), and a kiosk. Access to 2 levels of below-grade parking is provided from Flygelgatan.

Grade-level pedestrian areas considered in this study include surrounding sidewalks and walkways, building access points, the plaza area at the northwest corner of the 78-storey tower, the southeast area adjacent to the Telefonplan T-bana building, the areas adjacent to the Apoteks Gruppen pharmacy, as well as the playground atop the 2-storey podium. Figure 1 illustrates the study site and surrounding context, while Photographs 1 through 4 depict the wind tunnel model used to conduct the study.

3. OBJECTIVES

The principal objectives of this study are to: (i) determine pedestrian level wind comfort and safety conditions at key areas within and surrounding the development site; (ii) identify areas where wind conditions may interfere with the intended uses of outdoor spaces; and (iii) recommend suitable mitigation measures, where required.

4. METHODOLOGY

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

4.1 Wind Tunnel Context Modelling

A detailed PLW study is performed to determine the influence of local winds at the pedestrian level for a proposed development. A physical model of the proposed development and relevant surroundings, illustrated in Photographs 1 through 4 following the main text, was fabricated at a scale of 1:400. The wind tunnel model includes all existing buildings and approved future developments within a full-scale diameter of approximately 840 m. The general concept and approach to wind tunnel modelling is to provide building and topographic detail in the immediate vicinity of the study site on the surrounding model, and to rely on a length of wind tunnel upwind of the model to develop wind properties consistent with known turbulent intensity profiles that represent the surrounding terrain. For this study, the wind tunnel was configured to simulate atmospheric velocity profiles consistent with a hybrid suburban-open upwind terrain.

An industry standard practice is to omit trees and landscape elements from the wind tunnel model due to the difficulty of providing accurate seasonal representation and lack of significant influence. The omission of trees and other landscaping elements produces slightly more conservative wind speeds. For the subject site, the hill to the immediate west, adjacent to Mikrofonvägen, was modelled.

4.2 Wind Speed Measurements

The PLW study was performed by testing a total of 90 sensor locations on the scale model in GWE's wind tunnel. Of the 90 sensors, 79 were placed at grade level, with the remaining 11 on the elevated school yard area. Wind speed measurements were performed for each of the sensors for 36 wind directions at 10° intervals. Figure 1 illustrates a plan of the site and relevant surrounding context, while sensor locations used to investigate wind conditions are illustrated in Figures 2A through 5B, and in reference images provided throughout the report.

Mean and peak wind speed values for each location and wind direction were calculated from real-time pressure measurements, recorded at a sample rate of 500 samples per second, and taken over a 60-second time period. This period at model-scale corresponds approximately to one hour in full-scale, which matches the time frame of full-scale meteorological observations. Measured mean and gust wind speeds at grade were referenced to the wind speed measured near the ceiling of the wind tunnel to generate mean and peak wind speed ratios. Ceiling height in the wind tunnel represents the depth of the boundary layer of wind flowing over the earth's surface, referred to as the gradient height. Within this boundary layer, mean wind speed increases up to the gradient height and remains constant thereafter. Appendices A and B provide greater detail of the theory behind wind speed measurements. Wind tunnel measurements for this project, conducted in GWE's wind tunnel facility, meet or exceed guidelines found in the American Society of Civil Engineers (ASCE) standards[1].

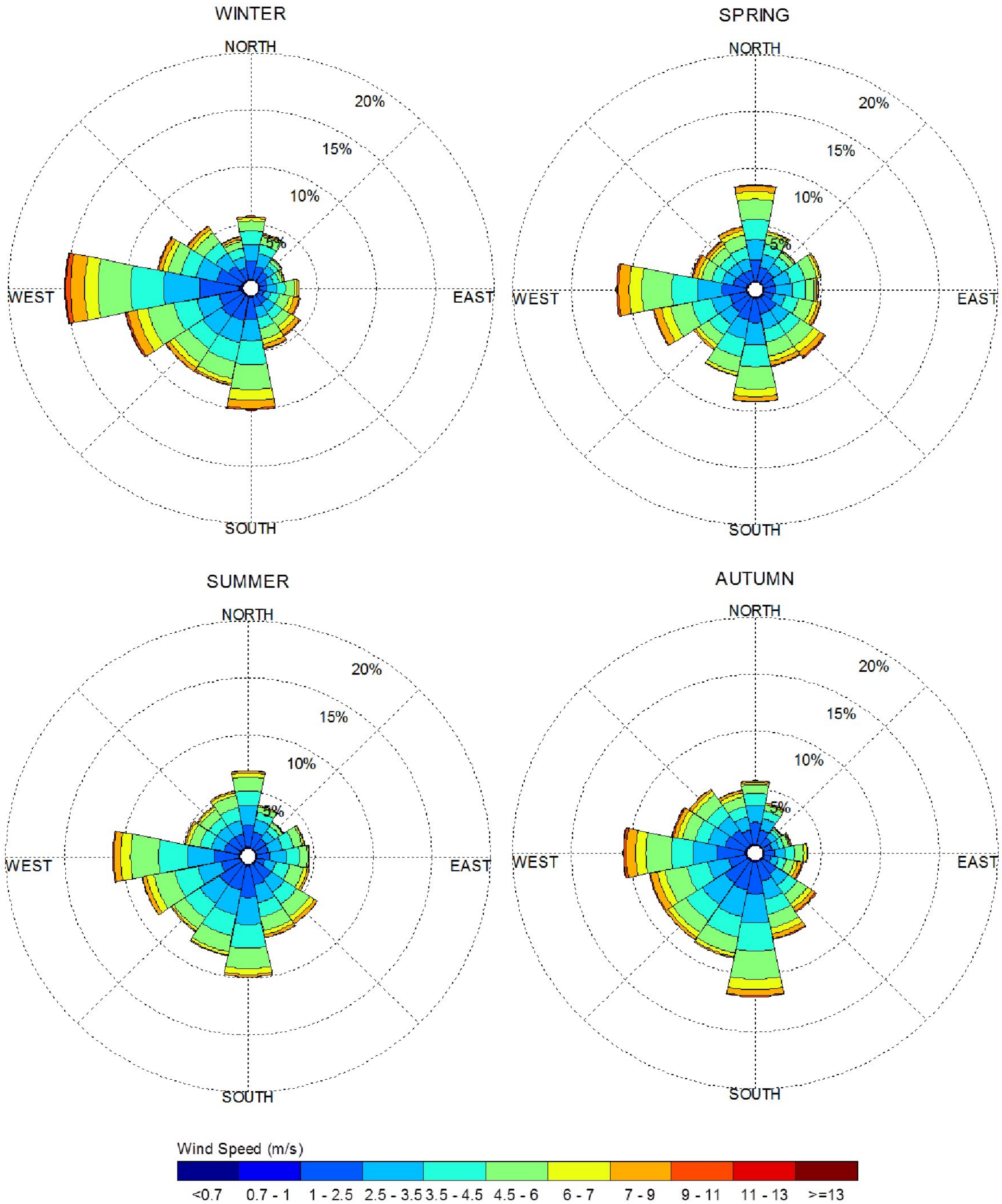
[1] American Society of Civil Engineers (ASCE), *Wind Tunnel Studies of Buildings and Structures*, Manual 7 Reports on Engineering Practice No 67.

4.3 Meteorological Data Analysis

A statistical model for winds in Stockholm was developed from 35 years of hourly meteorological wind data recorded at Bromma Airport in Stockholm, and obtained from the National Oceanic and Atmospheric Administration (NOAA). Wind speed and direction data were analyzed for each month of each 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 Gregorian calendar.

The statistical model of the Stockholm 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 (m/s). Probabilities of occurrence of different wind speeds are represented as stacked polar bars in sixteen azimuth divisions. The radial direction represents the percentage of time for various wind speed ranges per wind direction during the measurement period. The preferred wind speeds and directions can be identified by the longer length of the bars. Therefore, for Stockholm, the most common winds concerning pedestrian comfort occur from the west, followed by south, southwest, and northwest. The directional preference and relative magnitude of the wind speed varies somewhat from season to season, with the summer and winter seasons displaying the calmest and strongest winds relative to the remaining seasonal periods, respectively.

SEASONAL DISTRIBUTION OF WINDS FOR VARIOUS PROBABILITIES
BROMMA AIRPORT, STOCKHOLM, SWEDEN (ICAO: ESSB)



NOTES:

1. Radial distances indicate percentage of time of wind events.
2. Wind speeds (m/s) are mean hourly 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. 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, associated wind speed ranges, and limiting guidelines are summarized as follows:

(i) **Sitting** – Wind speeds below 14 kilometers per hour (i.e. 0-14 km/h, or 3.9 m/s) that occur more than 80% of the time would be considered acceptable for sedentary activities, including sitting.

(ii) **Standing** – Wind speeds below 22 km/h (i.e. 0-22 km/h or 6.1 m/s) that occur more than 80% of the time are acceptable for activities such as standing, strolling or more vigorous activities.

(iii) **Walking** – Wind speeds below 30 km/h (i.e. 0-30 km/h or 8.3 m/s) 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.

(v) **Dangerous** – Wind speeds greater than 90 km/h (25 m/s), occurring more than 0.1% of the time, are classified as dangerous. From calculations of stability, it can be shown that gust wind speeds of 90 km/h would be the approximate threshold wind speed that would cause an average elderly person in good health to fall.

The wind speeds associated with the above categories are gust wind speeds. 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 the perception of pedestrians to mechanical wind effects has shown that if, for example, a wind speed of 14 km/h was exceeded for more than 20% of the time most pedestrians would judge that location to be too windy for sitting or more sedentary activities. Similarly, if 30 km/h at a location was exceeded for more than 20% of the time, walking or less vigorous activities would be considered uncomfortable. As most of these guidelines 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 discrete 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
Building Entrance with a Vestibule	Walking
Building Entrance without a Vestibule	Standing
Building Exits	Walking
Public Sidewalks / Pedestrian Walkways	Walking
Outdoor Amenity Spaces	Sitting / Standing
Cafés / Patios / Benches / Gardens	Sitting / Standing
Playgrounds / Children's Activity Areas	Sitting / Walking
Public Plazas and Public Parks	Sitting / Walking
Transit Stops	Standing
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

Tables 1 through 23, 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, walking, etc.), the location type, the desired comfort class, and a suitability descriptor. The predicted comfort class is defined by the predicted wind speed range percentages, while the location type and the desired comfort class relate to the sensor placement on the wind tunnel model. The suitability descriptor is assigned based on the relationship between the predicted comfort class (for each seasonal period) and the desired comfort class.

Following presentation of the tables, 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 is represented by yellow, and walking by blue. Plots of measured mean and gust wind speed ratios versus wind direction, which constitute the raw data upon which the comfort predictions are based, are illustrated in Appendix C.

TABLE 1: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #1	Spring	86	97	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	89	97	99	Sitting			
	Autumn	88	97	99	Sitting			
	Winter	86	97	99	Sitting			
Sensor #2	Spring	86	97	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	89	97	99	Sitting			
	Autumn	88	97	99	Sitting			
	Winter	86	97	99	Sitting			
Sensor #3	Spring	82	95	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	85	96	99	Sitting			
	Autumn	83	95	99	Sitting			
	Winter	81	95	99	Sitting			
Sensor #4	Spring	82	96	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	85	97	99	Sitting			
	Autumn	83	96	99	Sitting			
	Winter	82	95	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

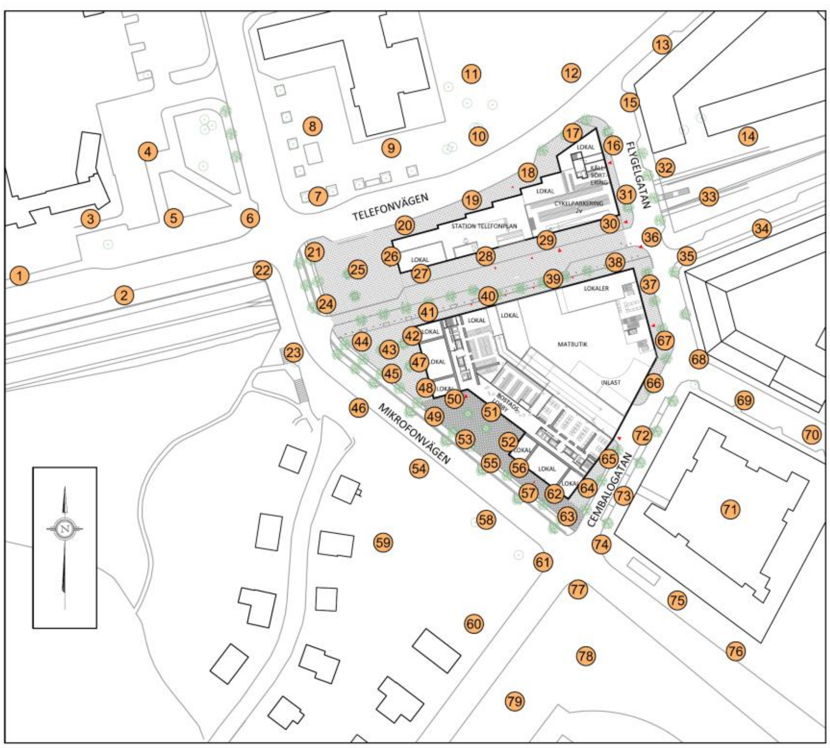


TABLE 2: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #5	Spring	80	95	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	83	96	99	Sitting			
	Autumn	81	95	99	Sitting			
	Winter	79	95	99	Standing			
Sensor #6	Spring	76	94	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	80	95	99	Sitting			
	Autumn	77	94	98	Standing			
	Winter	75	93	98	Standing			
Sensor #7	Spring	75	93	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	79	95	99	Standing			
	Autumn	76	93	98	Standing			
	Winter	73	92	98	Standing			
Sensor #8	Spring	86	96	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	88	97	99	Sitting			
	Autumn	86	96	99	Sitting			
	Winter	85	96	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

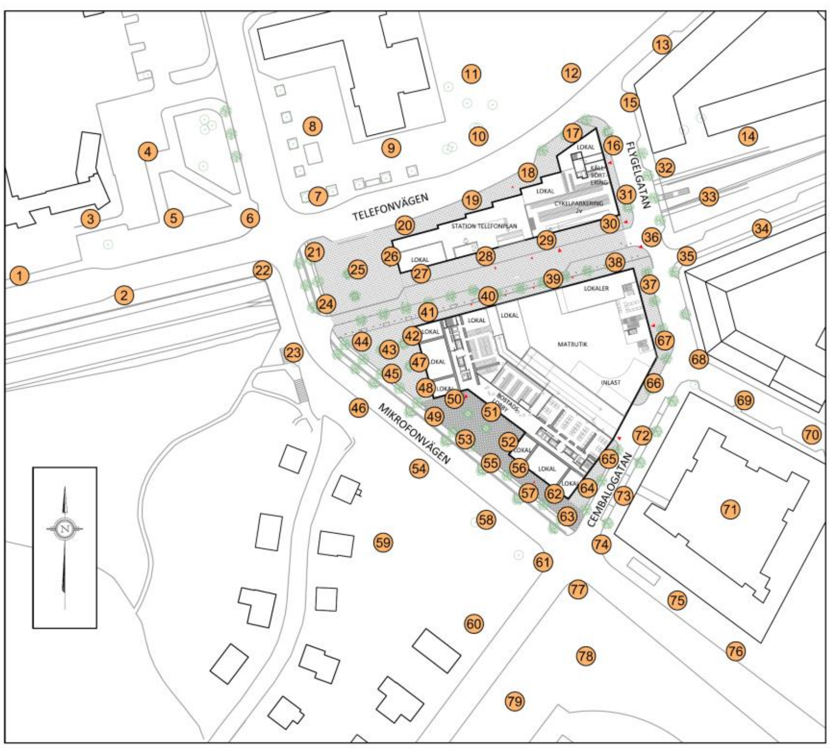


TABLE 3: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #9	**Spring**	75	93	98	Standing	Building Entrance	Standing	Acceptable
	Summer	79	95	99	Standing			
	Autumn	77	94	98	Standing			
	Winter	73	92	98	Standing			
Sensor #10	**Spring**	71	90	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	75	92	97	Standing			
	Autumn	71	90	97	Standing			
	Winter	68	88	96	Standing			
Sensor #11	**Spring**	80	95	98	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	83	96	99	Sitting			
	Autumn	80	94	98	Sitting			
	Winter	78	94	98	Standing			
Sensor #12	**Spring**	71	91	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	74	93	98	Standing			
	Autumn	71	91	97	Standing			
	Winter	68	89	97	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

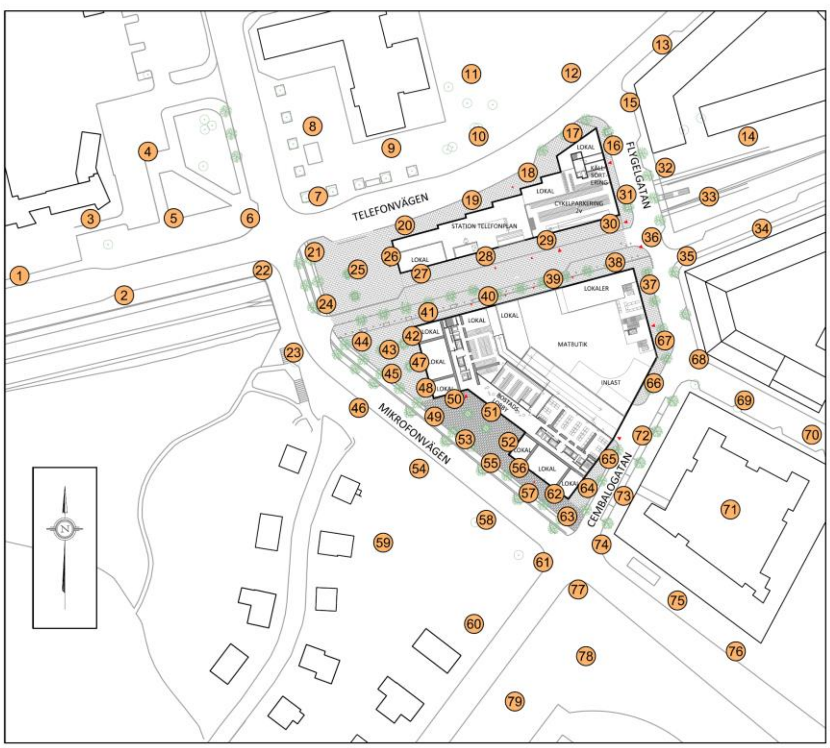


TABLE 4: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #13	Spring	81	93	98	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	83	94	98	Sitting			
	Autumn	81	93	98	Sitting			
	Winter	78	92	97	Standing			
Sensor #14	Spring	88	97	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	90	97	99	Sitting			
	Autumn	88	97	99	Sitting			
	Winter	87	97	99	Sitting			
Sensor #15	Spring	79	94	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	83	96	99	Sitting			
	Autumn	80	94	98	Sitting			
	Winter	77	94	98	Standing			
Sensor #16	Spring	76	92	98	Standing	Building Entrance	Standing	Acceptable
	Summer	79	94	98	Standing			
	Autumn	75	92	98	Standing			
	Winter	74	92	97	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

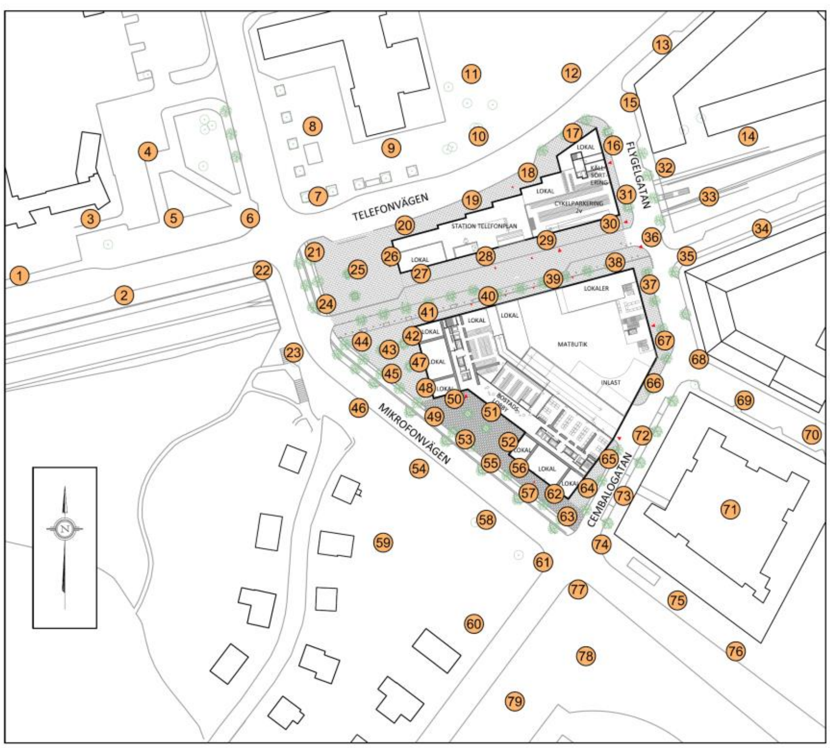


TABLE 5: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #17	Spring	81	94	98	Sitting	Building Entrance	Standing	Acceptable
	Summer	83	95	98	Sitting			
	Autumn	82	94	98	Sitting			
	Winter	78	93	98	Standing			
Sensor #18	Spring	88	97	99	Sitting	Building Entrance	Standing	Acceptable
	Summer	91	97	99	Sitting			
	Autumn	90	97	99	Sitting			
	Winter	88	97	99	Sitting			
Sensor #19	Spring	85	97	99	Sitting	Pedestrian Walkway / Transit Stop	Standing	Acceptable
	Summer	88	97	99	Sitting			
	Autumn	86	97	99	Sitting			
	Winter	85	97	99	Sitting			
Sensor #20	Spring	87	96	99	Sitting	Pedestrian Walkway / Transit Stop	Standing	Acceptable
	Summer	90	97	99	Sitting			
	Autumn	90	97	99	Sitting			
	Winter	88	97	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

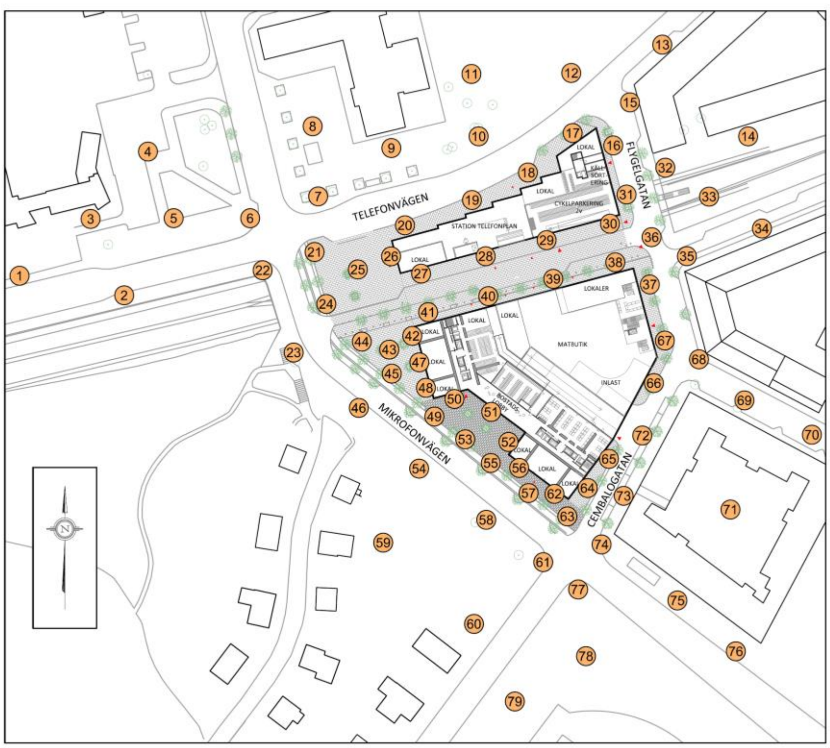


TABLE 6: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #21	**Spring**	70	91	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	74	93	98	Standing			
	Autumn	72	91	98	Standing			
	Winter	69	90	97	Standing			
Sensor #22	**Spring**	76	94	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	81	95	99	Sitting			
	Autumn	79	94	98	Standing			
	Winter	77	94	98	Standing			
Sensor #23	**Spring**	74	93	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	78	94	99	Standing			
	Autumn	76	93	98	Standing			
	Winter	75	93	98	Standing			
Sensor #24	**Spring**	66	89	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	71	91	98	Standing			
	Autumn	68	89	97	Standing			
	Winter	66	88	96	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

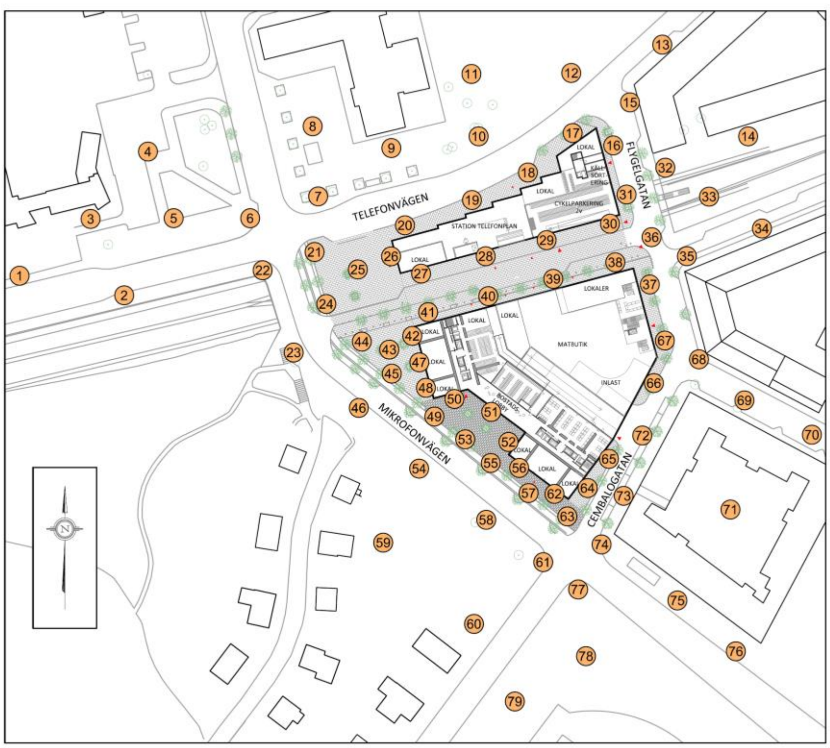


TABLE 7: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #25	Spring	72	90	97	Standing	Public Plaza	Standing	Acceptable
	Summer	75	91	97	Standing			
	Autumn	71	89	96	Standing			
	Winter	69	88	96	Standing			
Sensor #26	Spring	78	91	97	Standing	Building Entrance	Standing	Acceptable
	Summer	79	92	97	Standing			
	Autumn	76	90	97	Standing			
	Winter	73	88	96	Standing			
Sensor #27	Spring	58	83	95	Standing	Pedestrian Walkway / Transit Stop	Standing	Acceptable
	Summer	64	87	96	Standing			
	Autumn	63	86	95	Standing			
	Winter	59	83	94	Standing			
Sensor #28	Spring	63	84	93	Standing	Building Entrance / Transit Stop	Standing	Acceptable
	Summer	66	86	95	Standing			
	Autumn	62	83	93	Standing			
	Winter	58	80	91	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

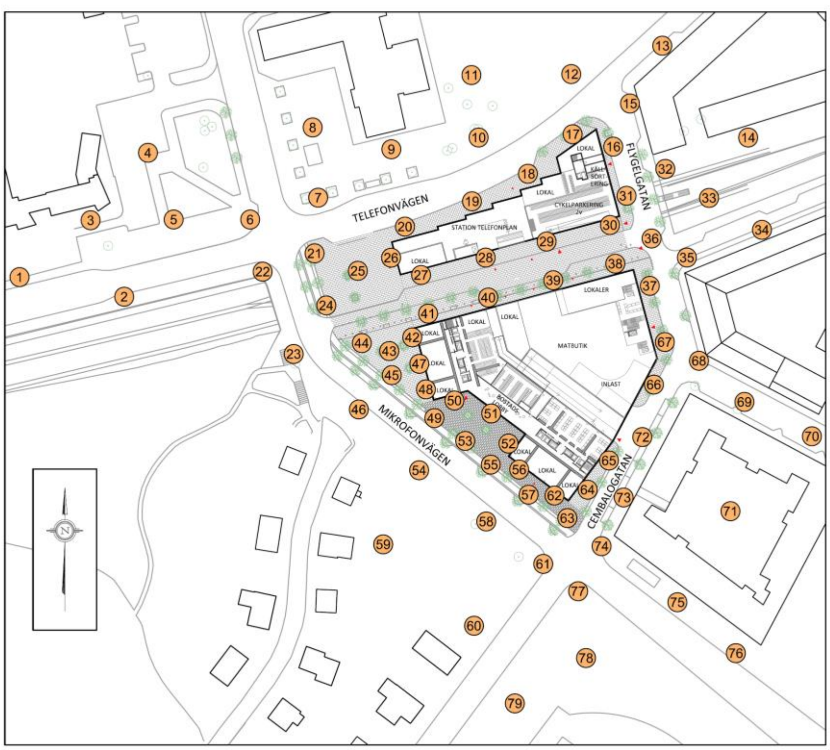


TABLE 8: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #29	**Spring**	70	89	96	Standing	Building Entrance / Transit Stop	Standing	Acceptable
	Summer	73	91	97	Standing			
	Autumn	69	88	96	Standing			
	Winter	66	87	96	Standing			
Sensor #30	**Spring**	76	92	98	Standing	Pedestrian Walkway / Transit Stop	Standing	Acceptable
	Summer	79	94	98	Standing			
	Autumn	75	92	98	Standing			
	Winter	72	91	97	Standing			
Sensor #31	**Spring**	80	95	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	83	96	99	Sitting			
	Autumn	80	95	99	Sitting			
	Winter	78	94	98	Standing			
Sensor #32	**Spring**	87	97	99	Sitting	Pedestrian Walkway	Walking	Acceptable
	Summer	89	97	99	Sitting			
	Autumn	87	97	99	Sitting			
	Winter	85	97	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

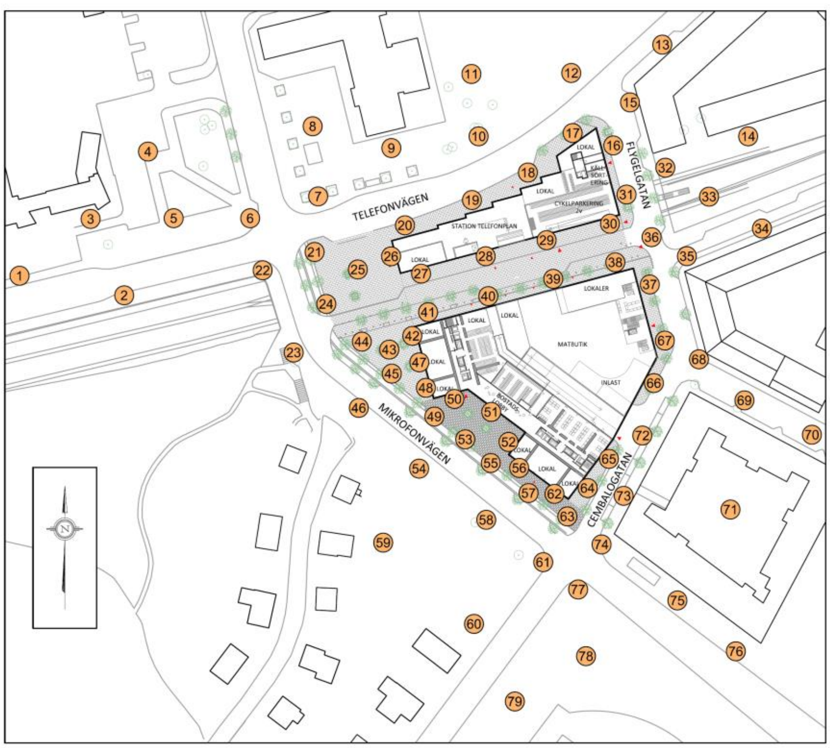


TABLE 9: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #33	Spring	84	96	99	Sitting	Pedestrian Walkway	Walking	Acceptable
	Summer	87	97	99	Sitting			
	Autumn	85	96	99	Sitting			
	Winter	83	95	99	Sitting			
Sensor #34	Spring	86	96	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	89	97	99	Sitting			
	Autumn	87	96	99	Sitting			
	Winter	85	96	99	Sitting			
Sensor #35	Spring	83	94	98	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	86	95	99	Sitting			
	Autumn	84	94	98	Sitting			
	Winter	81	93	98	Sitting			
Sensor #36	Spring	69	89	97	Standing	Pedestrian Walkway	Walking	Acceptable
	Summer	72	91	98	Standing			
	Autumn	68	89	97	Standing			
	Winter	65	87	96	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

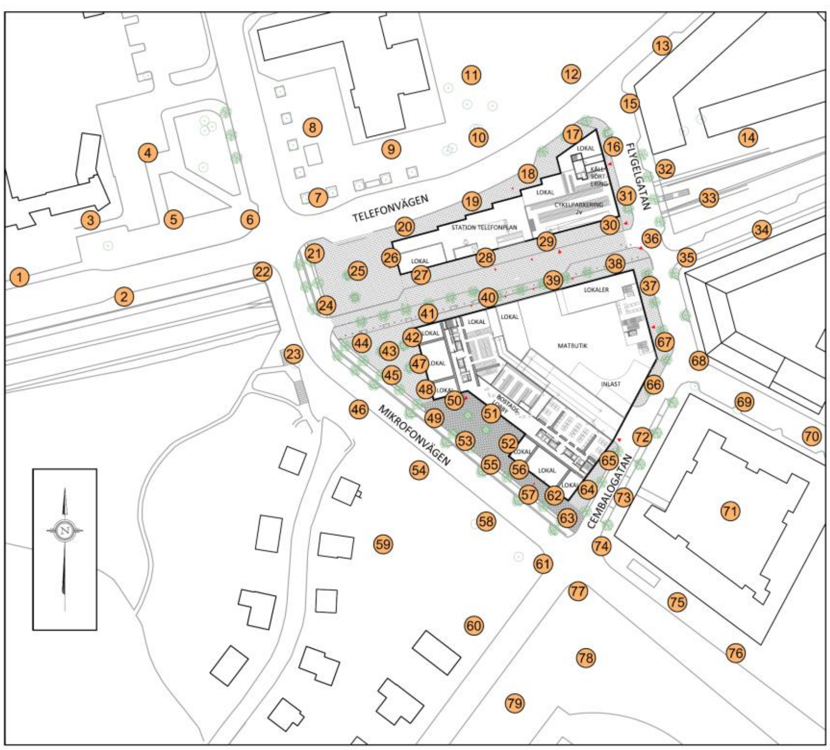


TABLE 10: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #37	**Spring**	82	95	99	Sitting	Building Entrance	Standing	Acceptable
	Summer	85	96	99	Sitting			
	Autumn	83	95	98	Sitting			
	Winter	82	95	98	Sitting			
Sensor #38	**Spring**	79	93	98	Standing	Building Entrance	Standing	Acceptable
	Summer	82	94	98	Sitting			
	Autumn	80	93	98	Sitting			
	Winter	76	92	97	Standing			
Sensor #39	**Spring**	72	91	97	Standing	Building Entrance	Standing	Acceptable
	Summer	76	94	98	Standing			
	Autumn	73	92	97	Standing			
	Winter	70	91	97	Standing			
Sensor #40	**Spring**	66	87	96	Standing	Building Entrance	Standing	Acceptable
	Summer	71	90	97	Standing			
	Autumn	70	89	96	Standing			
	Winter	66	87	96	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

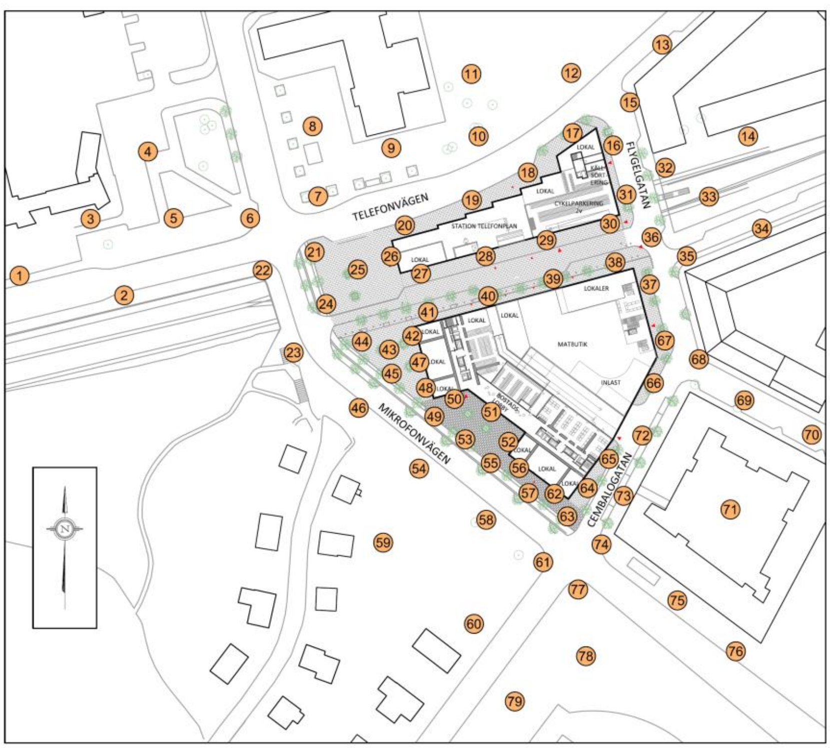


TABLE 11: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #41	Spring	74	91	97	Standing	Building Entrance	Standing	Acceptable
	Summer	79	94	98	Standing			
	Autumn	79	93	98	Standing			
	Winter	75	92	97	Standing			
Sensor #42	Spring	72	91	97	Standing	Building Entrance	Standing	Acceptable
	Summer	75	93	98	Standing			
	Autumn	72	91	98	Standing			
	Winter	69	90	97	Standing			
Sensor #43	Spring	57	82	93	Standing	Grade-Level Plaza	Sitting	Acceptable with Mitigation (see §5.2)
	Summer	63	86	95	Standing			
	Autumn	60	84	94	Standing			
	Winter	57	82	94	Standing			
Sensor #44	Spring	58	83	94	Standing	Grade-Level Plaza	Sitting	Acceptable with Mitigation (see §5.2)
	Summer	64	87	96	Standing			
	Autumn	62	85	95	Standing			
	Winter	59	84	95	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

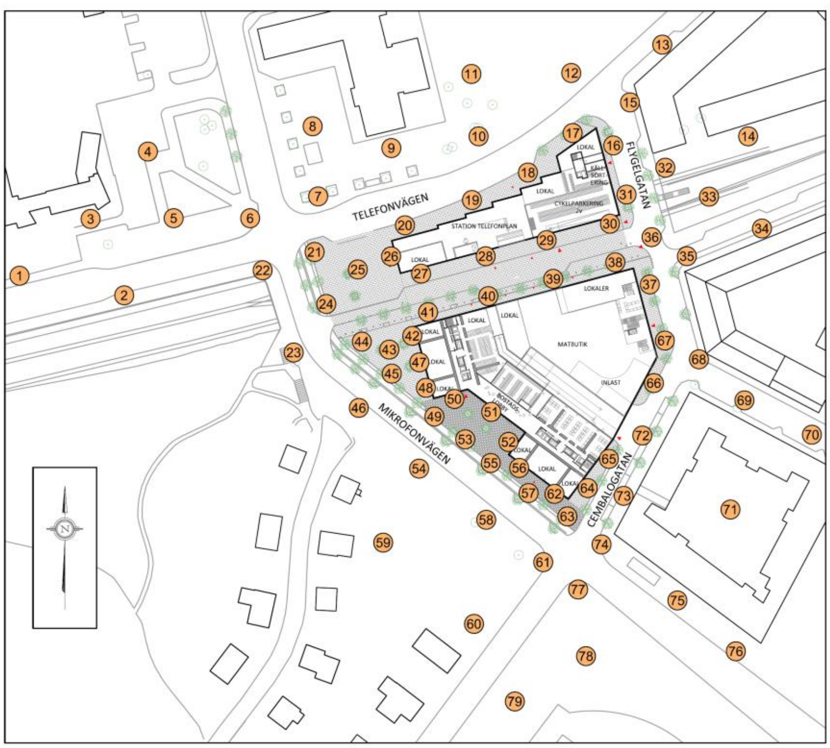


TABLE 12: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #45	Spring	59	83	93	Standing	Grade-Level Plaza	Sitting	Acceptable with Mitigation (see §5.2)
	Summer	64	87	95	Standing			
	Autumn	62	85	94	Standing			
	Winter	59	83	94	Standing			
Sensor #46	Spring	63	87	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	69	90	97	Standing			
	Autumn	67	89	97	Standing			
	Winter	64	88	96	Standing			
Sensor #47	Spring	78	94	98	Standing	Building Entrance	Standing	Acceptable
	Summer	82	95	99	Sitting			
	Autumn	80	95	98	Sitting			
	Winter	78	94	98	Standing			
Sensor #48	Spring	66	87	95	Standing	Building Entrance	Standing	Acceptable
	Summer	71	90	97	Standing			
	Autumn	67	87	95	Standing			
	Winter	66	87	95	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

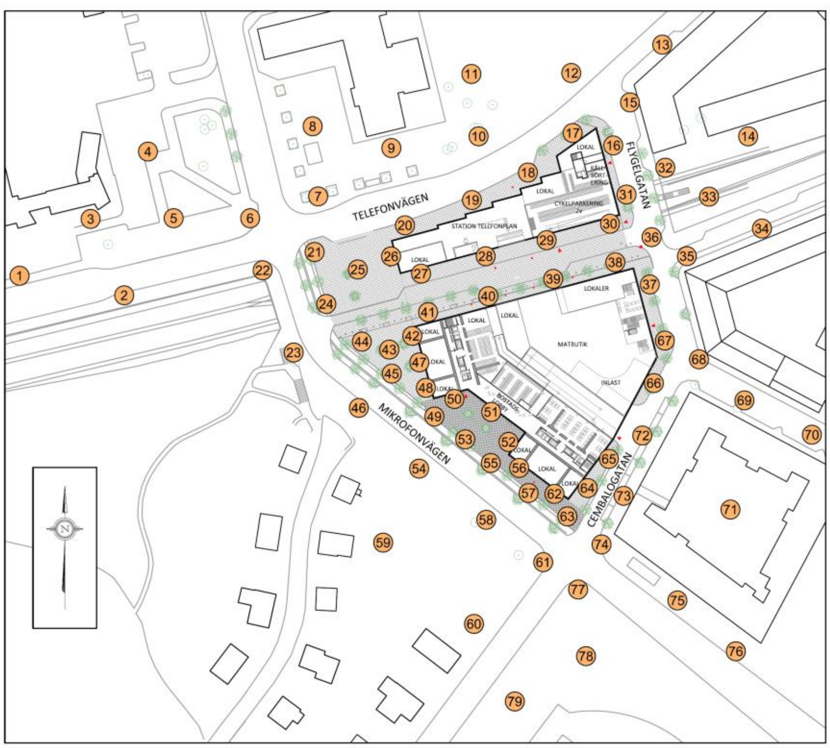


TABLE 13: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #49	**Spring**	68	88	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	72	91	97	Standing			
	Autumn	70	89	96	Standing			
	Winter	67	88	96	Standing			
Sensor #50	**Spring**	91	97	99	Sitting	Building Entrance	Standing	Acceptable
	Summer	93	98	99	Sitting			
	Autumn	91	97	99	Sitting			
	Winter	91	97	99	Sitting			
Sensor #51	**Spring**	90	97	99	Sitting	Building Entrance	Standing	Acceptable
	Summer	92	97	99	Sitting			
	Autumn	90	97	99	Sitting			
	Winter	89	97	99	Sitting			
Sensor #52	**Spring**	92	97	99	Sitting	Building Entrance	Standing	Acceptable
	Summer	93	98	99	Sitting			
	Autumn	92	97	99	Sitting			
	Winter	91	97	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

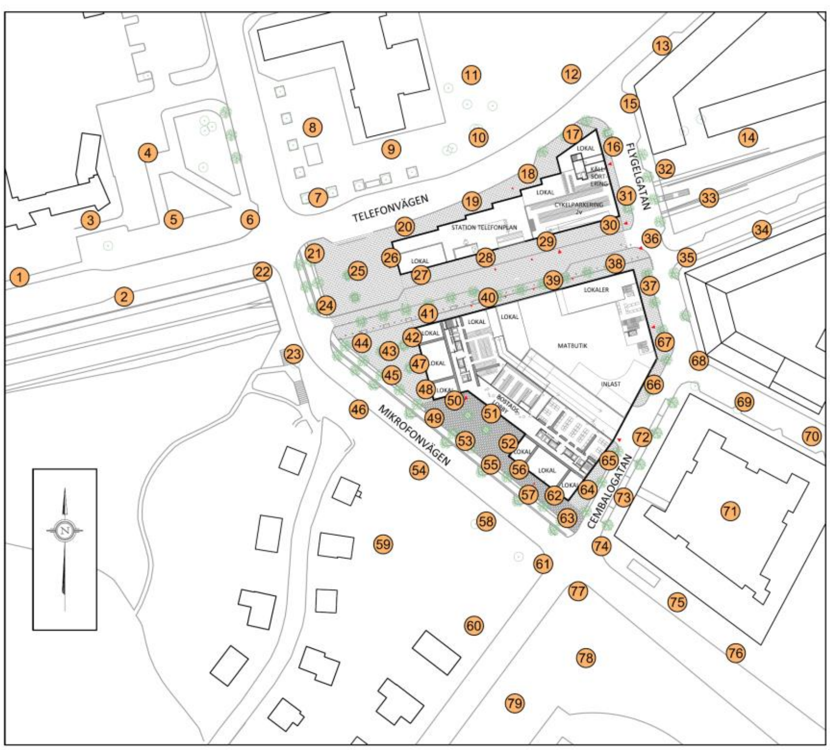


TABLE 14: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #53	Spring	69	89	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	74	91	97	Standing			
	Autumn	71	89	96	Standing			
	Winter	69	88	96	Standing			
Sensor #54	Spring	64	87	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	70	91	98	Standing			
	Autumn	68	89	97	Standing			
	Winter	65	88	97	Standing			
Sensor #55	Spring	73	91	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	77	93	98	Standing			
	Autumn	75	92	98	Standing			
	Winter	73	92	98	Standing			
Sensor #56	Spring	77	93	98	Standing	Building Entrance	Standing	Acceptable
	Summer	81	95	99	Sitting			
	Autumn	79	94	98	Standing			
	Winter	76	93	98	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

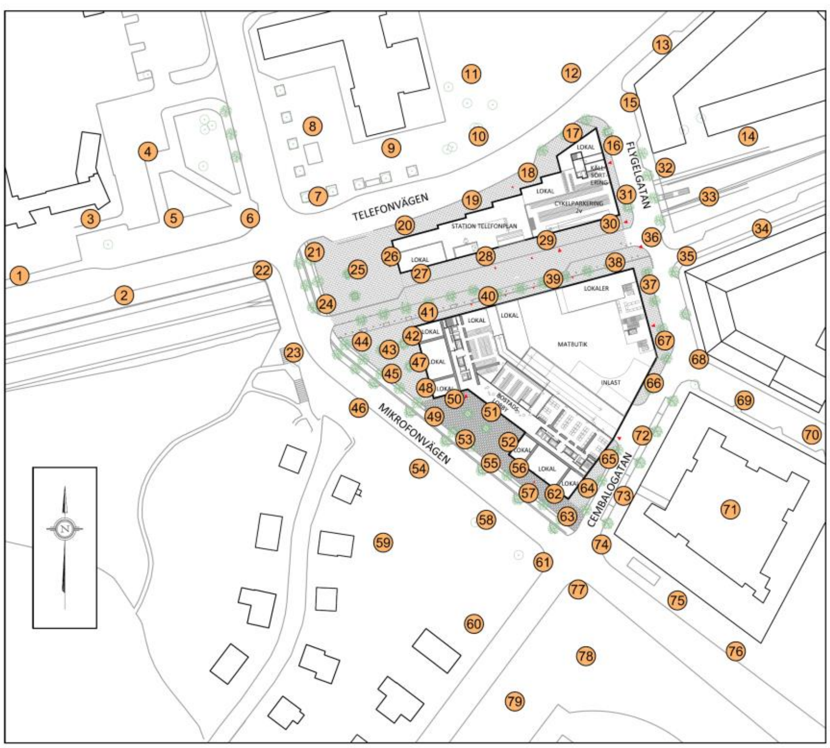


TABLE 15: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #57	Spring	71	91	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	76	93	98	Standing			
	Autumn	74	92	97	Standing			
	Winter	70	90	97	Standing			
Sensor #58	Spring	66	87	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	72	91	97	Standing			
	Autumn	71	90	97	Standing			
	Winter	67	89	97	Standing			
Sensor #59	Spring	76	93	98	Standing	Pedestrian Walkway	Walking	Acceptable
	Summer	81	95	99	Sitting			
	Autumn	80	94	98	Sitting			
	Winter	78	94	98	Standing			
Sensor #60	Spring	74	92	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	80	95	99	Sitting			
	Autumn	78	94	98	Standing			
	Winter	75	93	98	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

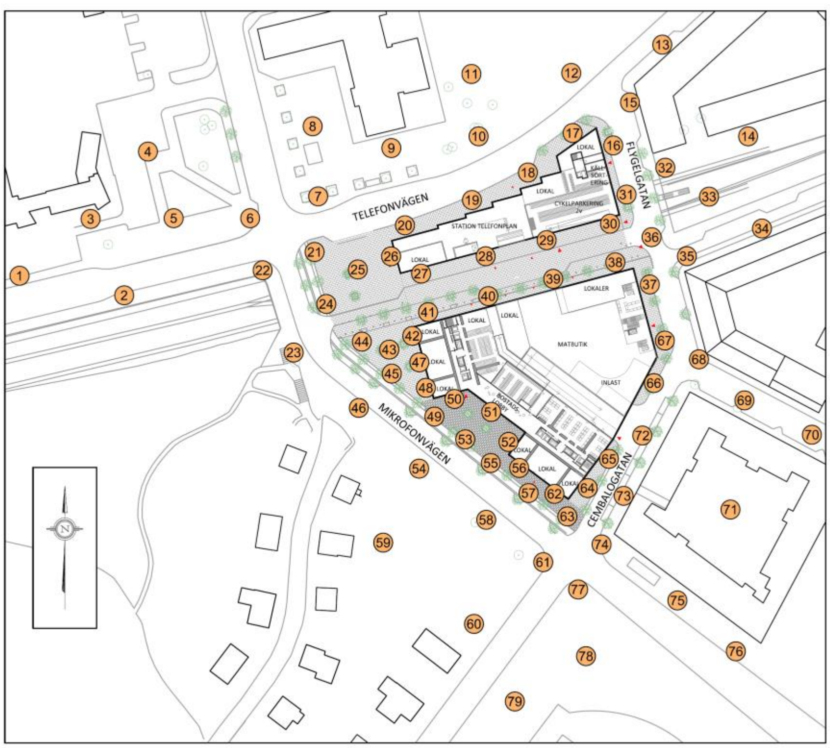


TABLE 16: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #61	Spring	65	88	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	71	91	98	Standing			
	Autumn	70	90	97	Standing			
	Winter	65	88	97	Standing			
Sensor #62	Spring	75	91	97	Standing	Building Entrance	Standing	Acceptable
	Summer	79	93	98	Standing			
	Autumn	77	92	97	Standing			
	Winter	72	90	97	Standing			
Sensor #63	Spring	61	86	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	67	89	97	Standing			
	Autumn	66	88	96	Standing			
	Winter	60	85	96	Standing			
Sensor #64	Spring	73	91	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	77	93	98	Standing			
	Autumn	75	92	98	Standing			
	Winter	73	91	97	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

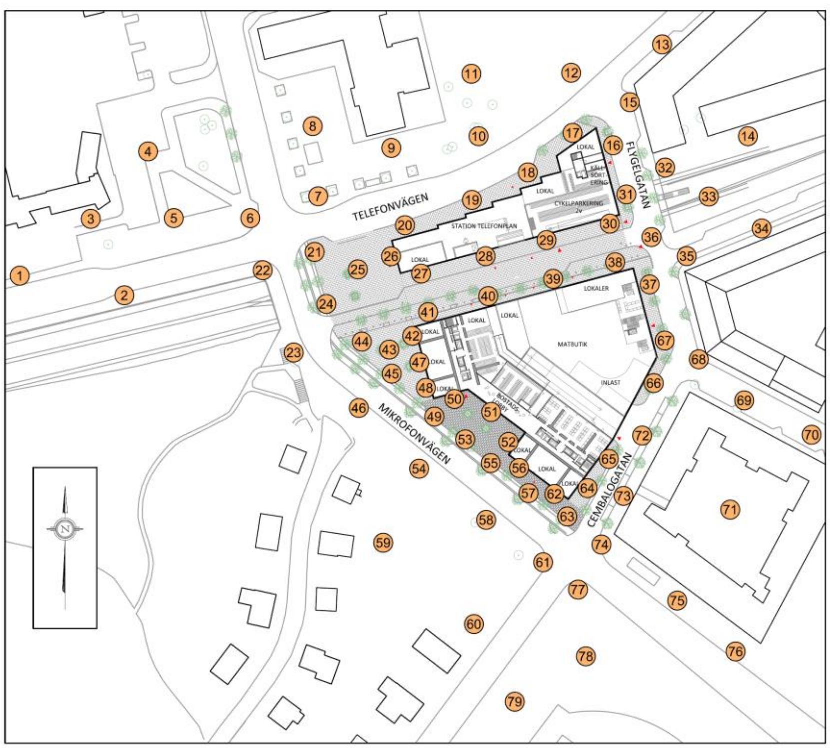


TABLE 17: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #65	Spring	66	88	96	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	71	90	97	Standing			
	Autumn	69	89	97	Standing			
	Winter	65	87	96	Standing			
Sensor #66	Spring	76	92	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	78	94	98	Standing			
	Autumn	75	92	98	Standing			
	Winter	72	90	97	Standing			
Sensor #67	Spring	76	92	97	Standing	Building Entrance	Standing	Acceptable
	Summer	79	93	98	Standing			
	Autumn	77	92	97	Standing			
	Winter	76	91	97	Standing			
Sensor #68	Spring	78	94	98	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	82	96	99	Sitting			
	Autumn	80	95	98	Sitting			
	Winter	76	94	98	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

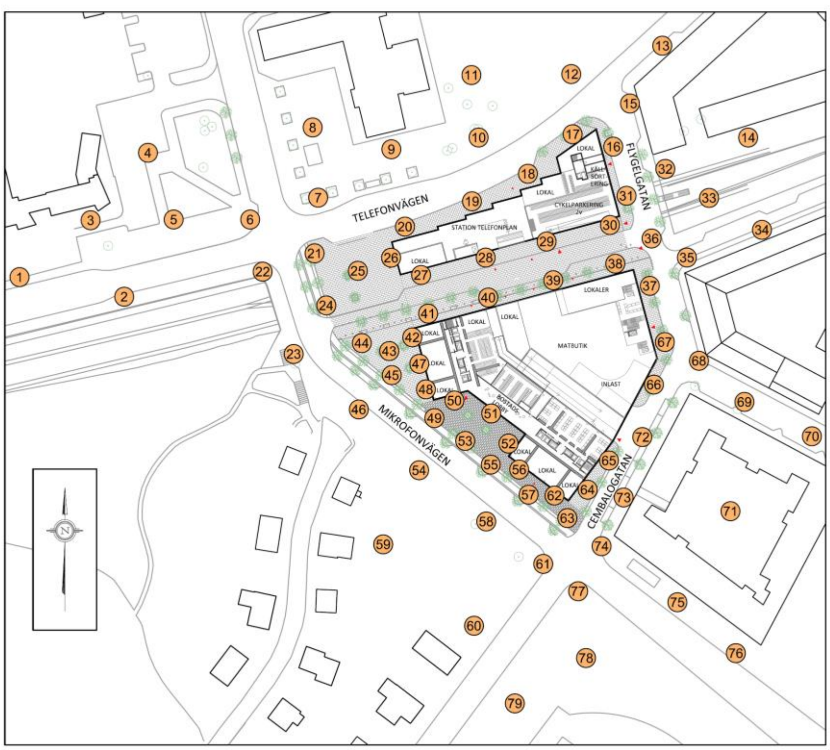


TABLE 18: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #69	**Spring**	86	97	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	89	97	99	Sitting			
	Autumn	87	97	99	Sitting			
	Winter	86	97	99	Sitting			
Sensor #70	**Spring**	87	97	99	Sitting	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	90	97	99	Sitting			
	Autumn	89	97	99	Sitting			
	Winter	88	97	99	Sitting			
Sensor #71	**Spring**	74	92	98	Standing	Interior Courtyard	Standing	Acceptable
	Summer	78	94	98	Standing			
	Autumn	76	93	98	Standing			
	Winter	72	92	98	Standing			
Sensor #72	**Spring**	58	82	93	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	62	85	95	Standing			
	Autumn	59	82	93	Standing			
	Winter	54	79	91	Walking			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

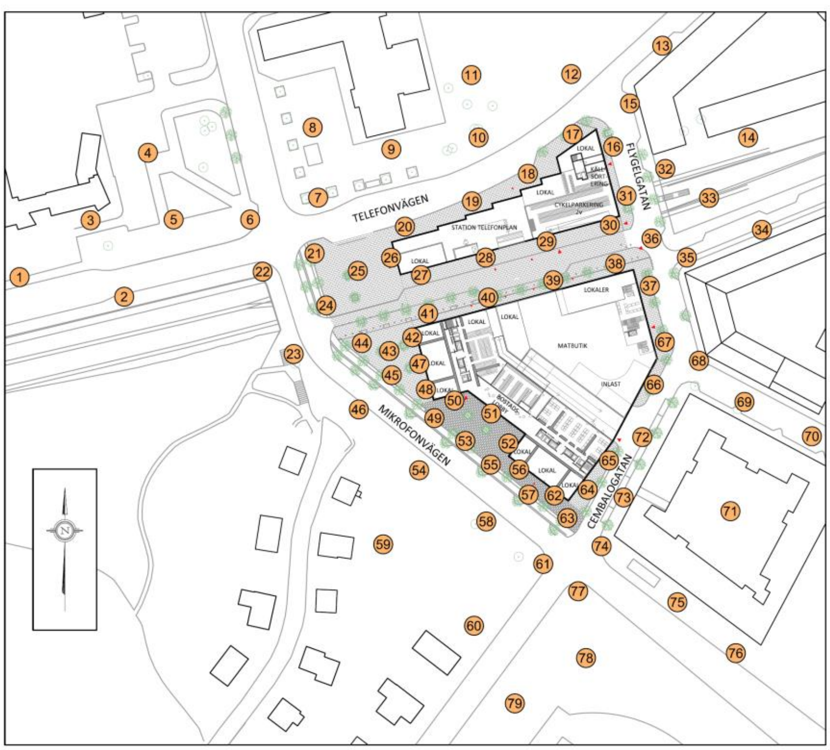


TABLE 19: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #73	Spring	53	79	92	Walking	Building Entrance / Access to Courtyard	Standing	Acceptable (see §5.2)
	Summer	59	83	94	Standing			
	Autumn	57	81	93	Standing			
	Winter	50	77	91	Walking			
Sensor #74	Spring	68	90	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	74	93	98	Standing			
	Autumn	73	92	98	Standing			
	Winter	68	91	98	Standing			
Sensor #75	Spring	75	91	97	Standing	Building Entrance	Standing	Acceptable
	Summer	79	93	98	Standing			
	Autumn	76	92	97	Standing			
	Winter	71	89	96	Standing			
Sensor #76	Spring	72	91	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	77	93	98	Standing			
	Autumn	75	92	97	Standing			
	Winter	69	90	97	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

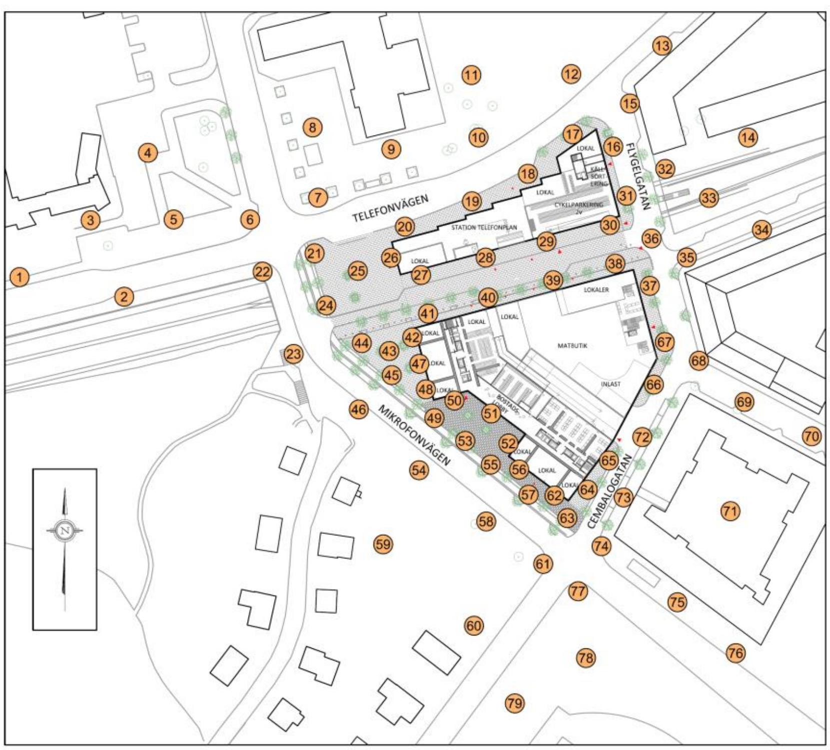


TABLE 20: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #77	Spring	72	90	97	Standing	Public Sidewalk / Pedestrian Walkway	Walking	Acceptable
	Summer	77	93	98	Standing			
	Autumn	75	92	98	Standing			
	Winter	70	90	97	Standing			
Sensor #78	Spring	74	93	98	Standing	Football Pitch / Running Track	Walking	Acceptable
	Summer	79	95	99	Standing			
	Autumn	77	94	98	Standing			
	Winter	73	93	98	Standing			
Sensor #79	Spring	79	95	99	Standing	Football Pitch / Running Track	Walking	Acceptable
	Summer	83	96	99	Sitting			
	Autumn	82	96	99	Sitting			
	Winter	80	95	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

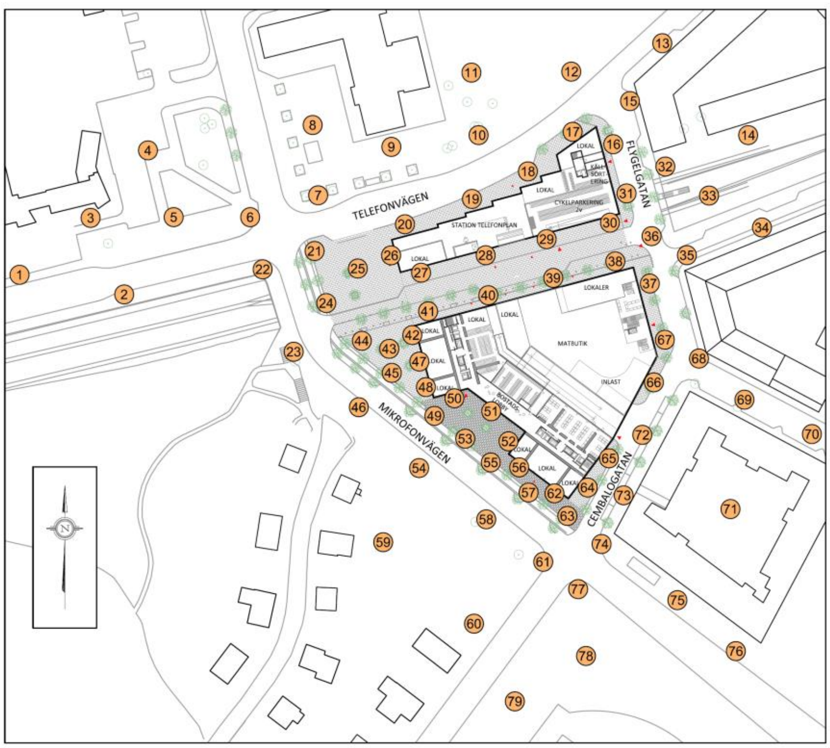


TABLE 21: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #80	Spring	64	86	95	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	69	89	96	Standing			
	Autumn	67	87	95	Standing			
	Winter	62	85	94	Standing			
Sensor #81	Spring	76	93	98	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	80	95	99	Sitting			
	Autumn	79	94	98	Standing			
	Winter	75	93	98	Standing			
Sensor #82	Spring	64	86	95	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	68	88	96	Standing			
	Autumn	64	85	95	Standing			
	Winter	59	82	93	Standing			
Sensor #83	Spring	69	89	97	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	73	91	98	Standing			
	Autumn	69	89	97	Standing			
	Winter	66	88	96	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

TABLE 22: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		**≤ 14**	**≤ 22**	**≤ 30**				
Guideline (% of Time)		**≥80%**						
Sensor #84	**Spring**	69	89	96	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	72	91	97	Standing			
	Autumn	67	88	96	Standing			
	Winter	64	86	95	Standing			
Sensor #85	**Spring**	64	86	95	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	67	89	97	Standing			
	Autumn	64	86	95	Standing			
	Winter	60	83	94	Standing			
Sensor #86	**Spring**	68	88	96	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	72	90	97	Standing			
	Autumn	69	88	96	Standing			
	Winter	65	86	95	Standing			
Sensor #87	**Spring**	81	95	99	Sitting	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	85	96	99	Sitting			
	Autumn	83	96	99	Sitting			
	Winter	81	95	99	Sitting			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: PLW SENSOR LOCATIONS

TABLE 23: SUMMARY OF PEDESTRIAN COMFORT

Activity Type		Sitting	Standing	Walking	Predicted Comfort Class	Location Type	Desired Comfort Class	Suitability
Wind Speed Range (km/h)		≤ 14	≤ 22	≤ 30				
Guideline (% of Time)		≥80%						
Sensor #88	Spring	67	87	95	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	70	89	97	Standing			
	Autumn	66	87	95	Standing			
	Winter	61	84	94	Standing			
Sensor #89	Spring	78	94	99	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	83	96	99	Sitting			
	Autumn	82	95	99	Sitting			
	Winter	79	95	99	Standing			
Sensor #90	Spring	76	94	98	Standing	School Yard atop 2-Storey Podium	Standing	Acceptable
	Summer	80	95	99	Sitting			
	Autumn	78	94	98	Standing			
	Winter	75	93	98	Standing			

TELLUS TOWERS TELEFONPLAN, STOCKHOLM: 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 23 in Section 5.1, this section summarizes the most significant findings of the PLW study, as follows:

1. All surrounding public sidewalks along Telefonvägen, Mikrofonvägen, Cembalogatan, Flygelgatan, as well as the east-west laneway to the south of the bus station, will experience wind conditions suitable for walking, or better. Also, many of the noted areas are predicted to be suitable for standing, or better. The noted conditions are considered appropriate for the intended uses of the spaces according to the pedestrian wind comfort guidelines presented in Section 4.4.

2. Pedestrian wind comfort at all entrances, as illustrated in Figures 2A-5B (following the main text), are predicted to be suitable for standing, or better, throughout the year.

3. The only exception to item (2) concerns the entrance / courtyard access serving the building to the immediate south of the subject site (i.e., the entrance fronting onto Cembalogatan and closest to the intersection with Mikrofonvägen, which is represented by sensor 73), where pedestrian comfort is predicted to be suitable for standing during the summer and autumn seasons, while conditions during the spring and winter seasons will be suitable for standing for 79% and 77% of the time. Despite the small deficiencies in comfort during the colder months, wind conditions at the entrance are considered to be acceptable.

4. The grade-level patio adjacent to the 78-storey tower along Mikrofonvägen, which is represented by sensors 43-45, is predicted to be suitable for standing throughout the year. The target comfort class is sitting from late spring through early autumn, which is considered the typical use period for outdoor patio areas. In order for an area to be defined as appropriate for sitting, wind speeds no greater than 14 km/h (3.9 m/s) must be present for at least 80% of the time. Wind comfort during the summer season will be suitable for sitting for 63% of the time. Conditions during the spring and autumn seasons will be suitable for sitting for 58% and 61% of the time, respectively.

5. Further to item (4), mitigation will be required to achieve the desired comfort class during the typical use period. In order to assist with the understanding of the wind directions that reduce pedestrian comfort with the patio area, inspection of the raw velocity ratio plots is required. The wind tunnel plots corresponding to the patio area are illustrated in Appendix C, Figures C8 (sensors 43-45). Inspection of the plots indicates strong north-south directionality for all noted sensors.

Additionally, inspection of the Stockholm seasonal wind climate plots in Section 4.3 indicates that south winds are prominent throughout the year, while north winds are most prominent during the spring season.

6. Further to item (5), given the noted directionality of the winds, the patio area is mostly impacted by horizontal winds which can be mitigated to achieve conditions suitable for sitting. Of particular importance, the separation between the 78- and 58-storey towers is a beneficial design feature as it somewhat relieves prominent south clockwise to northwest winds from grade level. Also, since downwash winds incident on the west façade of the 78-storey tower were not observed during testing, which was an initial concern of the design team, a canopy will not be required. However, mitigation arranged to primarily protect the patio area from horizontal south clockwise to southwest winds, as well as from horizontal north winds, is recommended. Acceptable wind comfort could be achieved following the introduction of (i) solid vertical wind barriers, (ii) dense coniferous plantings, or (iii) a combination of the two options. In order to ensure conditions are suitable for sitting during the typical use period, mitigation should achieve a minimum height of 1.8 m above local grade.

7. Wind conditions within the school yard atop the 2-storey podium connecting the 78- and 58-storey towers to the 7-storey building, represented by sensors 80-90, are predicted to be suitable for standing, or better, throughout the year. The noted conditions are considered acceptable for the entrances serving the 7-storey building, as well as for the school yard. The underlying assumption is that school children will mostly stand, walk, and run within the area. However, if calmer conditions are required, parapet details and other localized mitigation efforts would need to be discussed with the design team.

8. Within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas over the study site were found to experience wind conditions considered too windy for walking, or that could be considered unsafe.

6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the methodology, results, and recommendations related to a pedestrian level wind study for Tellus Towers Telefonplan, a proposed landmark mixed-use high-rise development in Stockholm, Sweden. This work was performed in accordance with the scope of work described in GWE proposal #16-005P, and is based on industry standard wind tunnel testing techniques, architectural drawings and surrounding building massing information provided by Wingårdhs on February 12, 2016, as well as recent site imagery as referenced from Google Earth.

A complete summary of the predicted wind conditions is provided in Sections 5.1 and 5.2 of this report, and is also illustrated in Figures 2A through 5B (following the main text). Based on wind tunnel test results, meteorological data analysis, and experience with numerous similar developments throughout North America, we conclude that wind conditions over most grade-level pedestrian-sensitive areas within and surrounding the development site will be acceptable for the intended pedestrian uses on a seasonal and annual basis. As well, within the context of typical weather patterns, which exclude anomalous localized storm events such as tornadoes and downbursts, no areas at grade were found to experience conditions too windy for walking, or that could be considered unsafe. This generally favourable outcome for the site as a whole results from the moderate wind climate of Stockholm when compared to other cities.

The possible exception to the above statements pertains to the grade-level plaza adjacent to the 78-storey tower along Mikrofonvägen, where predictions indicate standing comfort throughout the year. If conditions suitable for sitting are required over this area, localized mitigation will be required. Of particular importance, wind tunnel testing revealed that direct horizontal winds from southerly directions were mainly responsible for strong winds over the plaza, and that downwash along the west façade of the tower was not significant. As a result, mitigation in the form of vertical barriers should focus on blocking horizontal winds from the southwest quadrant for the majority of the year, and from the north during the summer. Acceptable wind comfort would be achieved following the introduction of (i) solid vertical wind barriers, (ii) dense coniferous plantings, or (iii) a combination of the two options. The height of the barriers will depend on the area to be protected for sitting and the density selected by the landscape architect, but should not be less than 1.8 m above grade. Details relating to mitigation options will be discussed with the design team prior to issuance of a final report.

Wind conditions within the school yard atop the 2-storey podium connecting the 78- and 58-storey towers to the 7-storey building are predicted to be suitable for standing, or better, throughout the year. The noted conditions are considered acceptable for both the entrances serving the 7-storey building, as well as for the school yard area. However, if calmer conditions are required, parapet details and other localized mitigation efforts would need to be discussed with the design team.

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

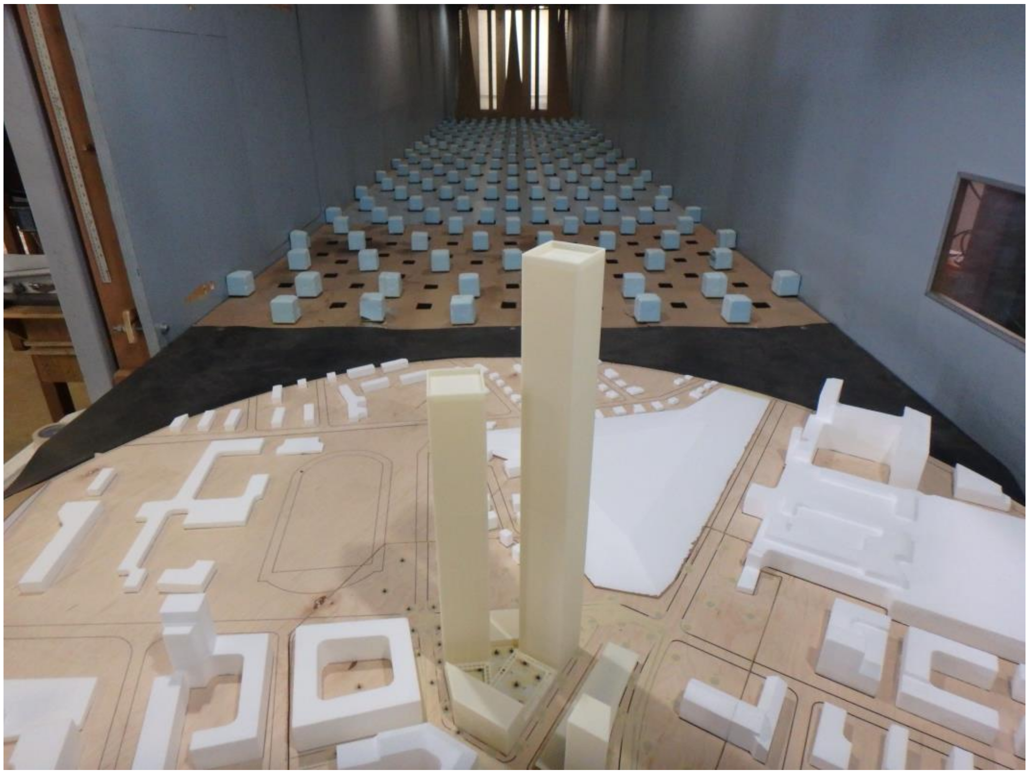
Sincerely,

Gradient Wind Engineering Inc.

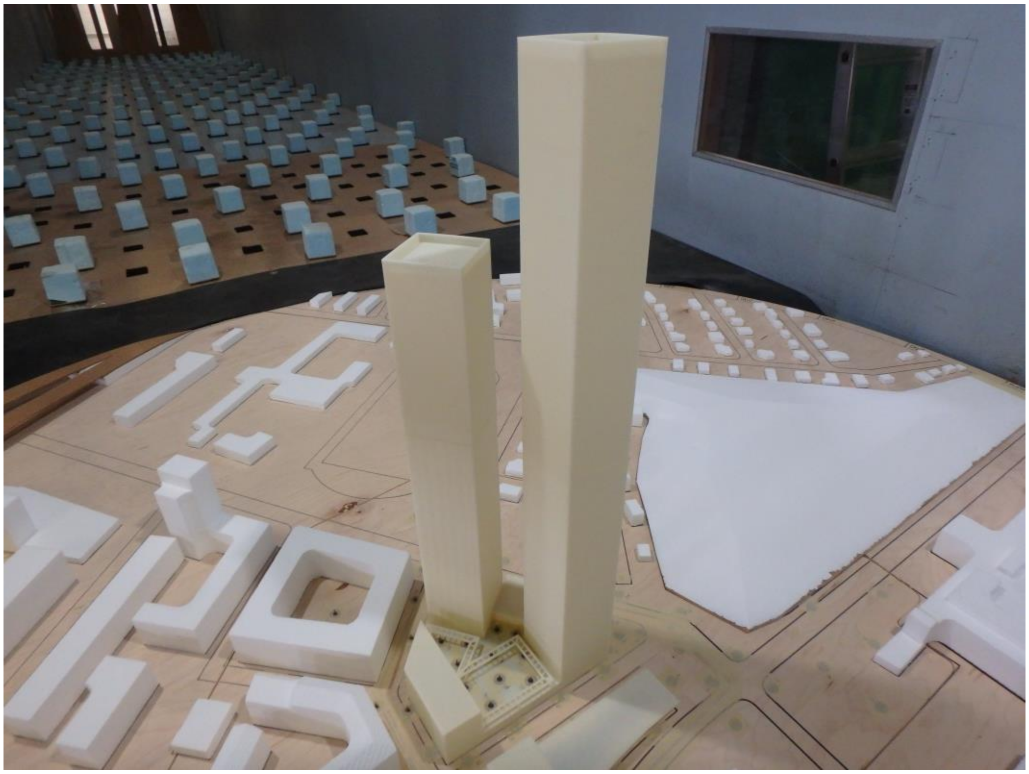
Justin Ferraro
Principal

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

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

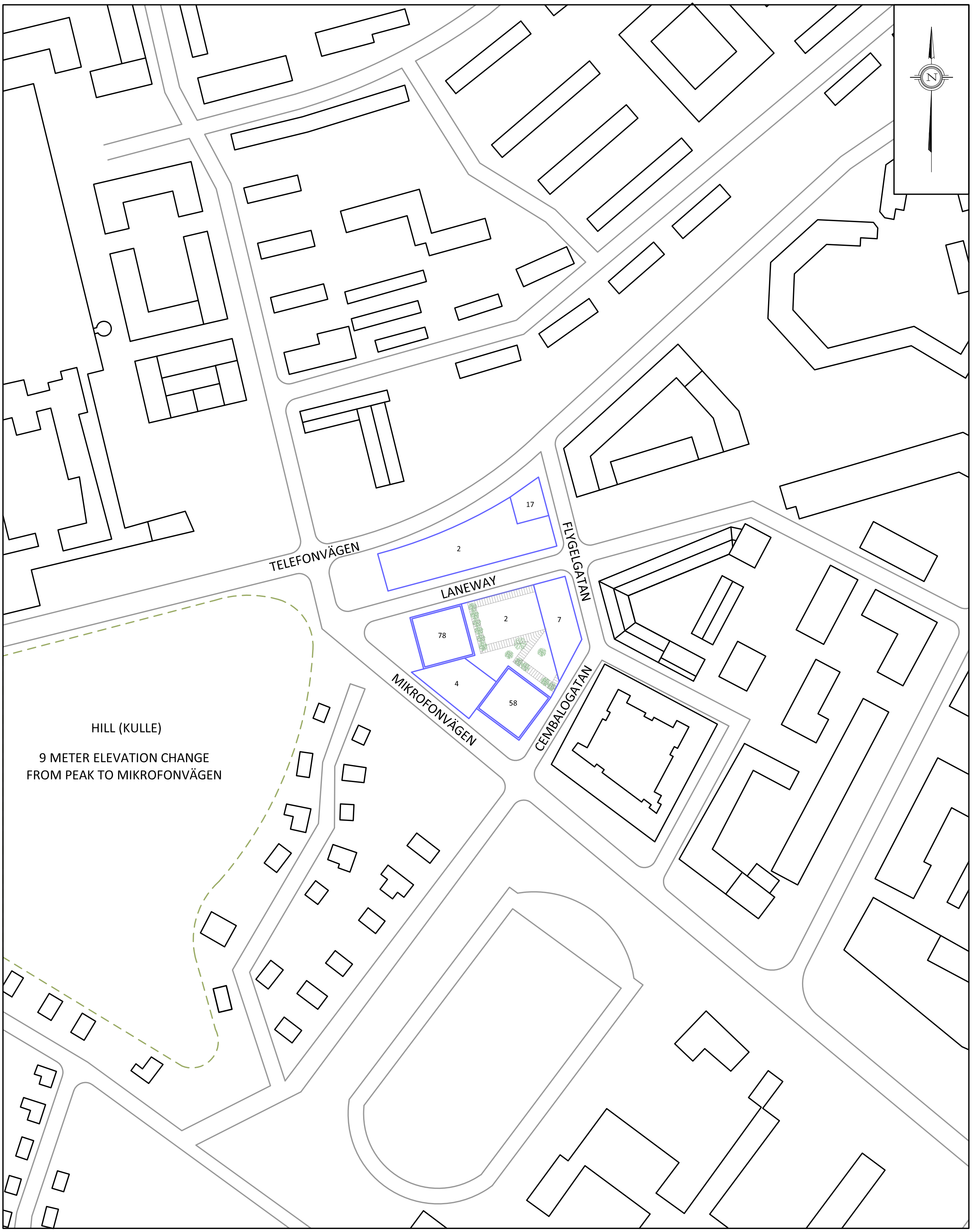


PHOTOGRAPH 2: STUDY MODEL INSIDE THE GWE WIND TUNNEL LOOKING UPWIND



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

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



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

PROJECT: TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY		DESCRIPTION: FIGURE 1: SITE PLAN AND SURROUNDING CONTEXT
SCALE: 1:2500 (APPROX.)	DRAWING NO.: GWE16-015-PLW-1	
DATE: MARCH 11, 2016	DRAWN BY: K.A.	

PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING

NOTES:

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

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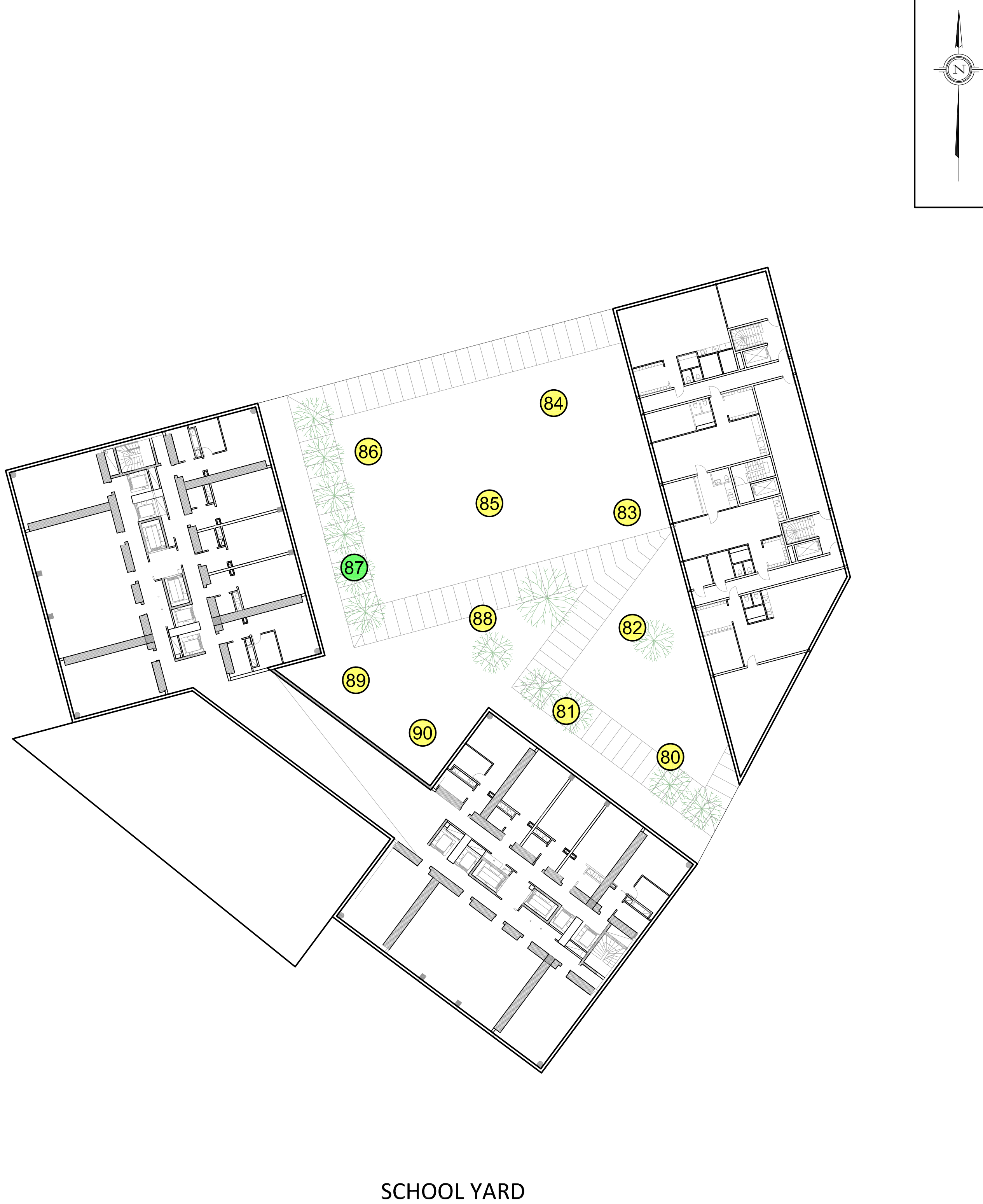
(613) 836 0934
GRADIENT WIND ENGINEERING INC

PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:1500 (APPROX.)	DRAWING NO.	GWE16-015-PLW-2A
DATE	MARCH 11, 2016	DRAWN BY	K.A.

DESCRIPTION

FIGURE 2A: SPRING
GROUND FLOOR PLAN
PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES
- # SITTING
- # STANDING

NOTES:

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

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Ottawa, Canada
(613) 836 0934

PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY
SCALE	1:600 (APPROX.)
DRAWING NO.	GWE16-015-PLW-2B
DATE	MARCH 11, 2016
DRAWN BY	K.A.
DESCRIPTION	FIGURE 2B: SPRING SCHOOL YARD PEDESTRIAN COMFORT PREDICTIONS

PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING

NOTES:

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

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Ottawa, Canada
(613) 836 0934

PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1500 (APPROX.)
DRAWING NO.	GWE16-015-PLW-3A
DATE	MARCH 11, 2016
DRAWN BY	K.A.
DESCRIPTION	FIGURE 3A: SUMMER GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS

SCHOOL YARD

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

NOTES:

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

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127 Walgreen Road
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(613) 836 0934

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SCALE	1:600 (APPROX.)	DRAWING NO.	GWE16-015-PLW-3B
DATE	MARCH 11, 2016	DRAWN BY	K.A.

DESCRIPTION

FIGURE 3B: SUMMER
SCHOOL YARD
PEDESTRIAN COMFORT PREDICTIONS

PREDICTED COMFORT CLASSES

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

NOTES:

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

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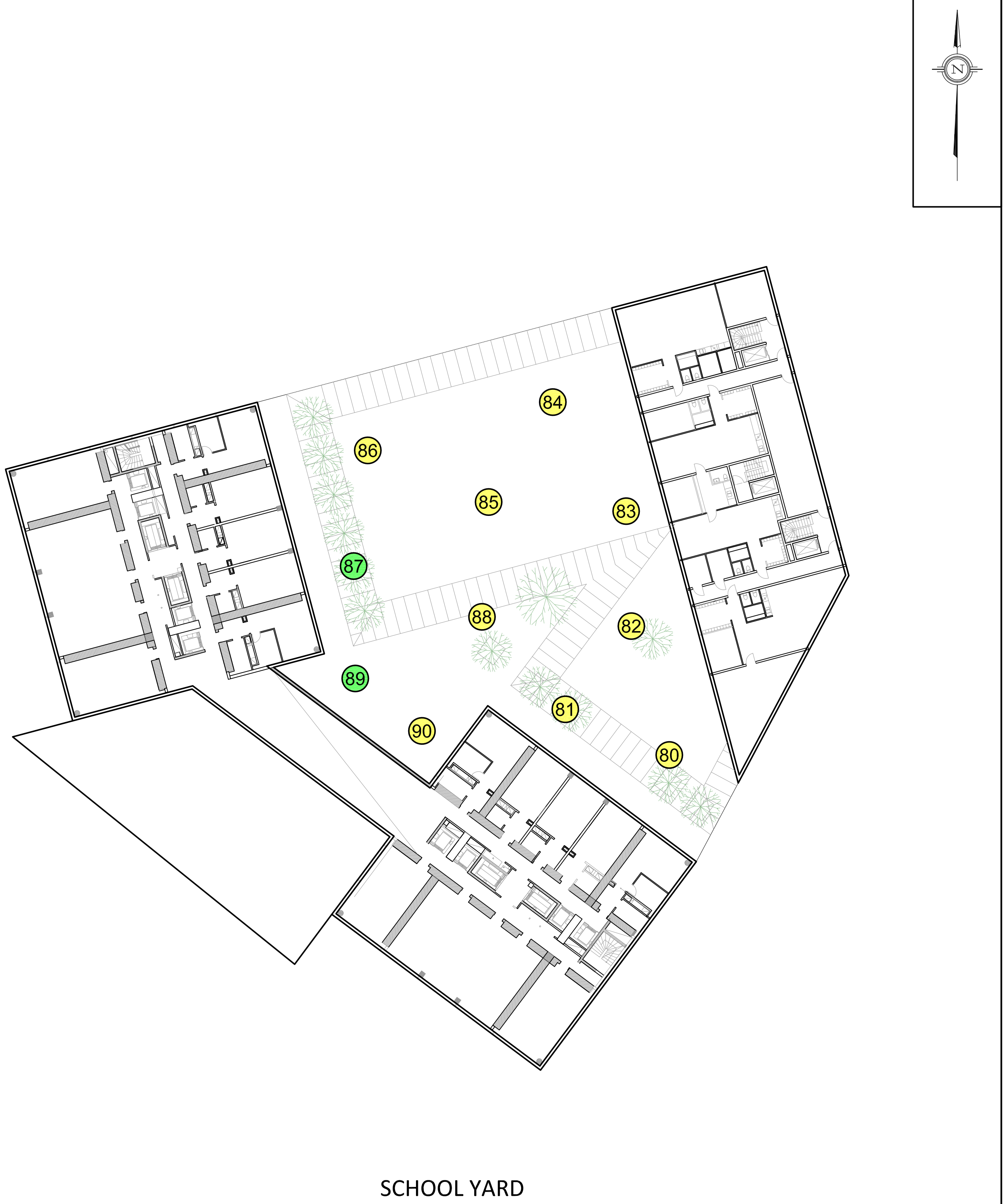
(613) 836 0934

PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY
SCALE	1:1500 (APPROX.)
DRAWING NO.	GWE16-015-PLW-4A
DATE	MARCH 11, 2016
DRAWN BY	K.A.
DESCRIPTION	FIGURE 4A: AUTUMN GROUND FLOOR PLAN PEDESTRIAN COMFORT PREDICTIONS



PREDICTED COMFORT CLASSES

- # SITTING
- # STANDING

NOTES:

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

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PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:600 (APPROX.)	DRAWING NO.	GWE16-015-PLW-4B
DATE	MARCH 11, 2016	DRAWN BY	K.A.

DESCRIPTION

FIGURE 4B: AUTUMN
SCHOOL YARD
PEDESTRIAN COMFORT PREDICTIONS

PREDICTED COMFORT CLASSES	
#	SITTING
#	STANDING
#	WALKING

NOTES:

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

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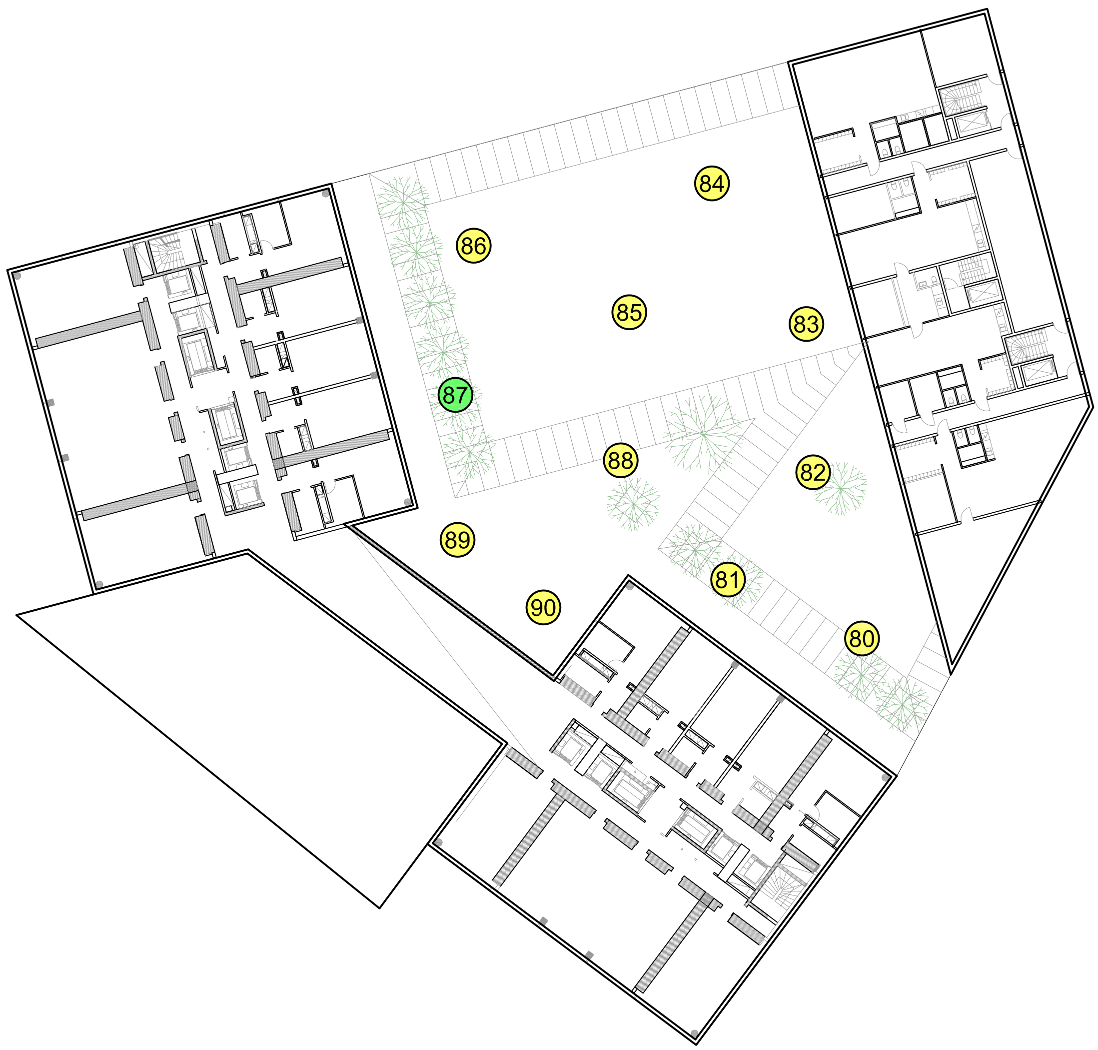
Ottawa, Canada
(613) 836 0934
GWE GRADIENT WIND ENGINEERING INC

PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:1500 (APPROX.)	DRAWING NO.	GWE16-015-PLW-5A
DATE	MARCH 11, 2016	DRAWN BY	K.A.

DESCRIPTION

FIGURE 5A: WINTER
GROUND FLOOR PLAN
PEDESTRIAN COMFORT PREDICTIONS



SCHOOL YARD

PREDICTED COMFORT CLASSES

- # SITTING
- # STANDING

NOTES:

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

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127 Walgreen Road
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(613) 836 0934

PROJECT	TELLUS TOWERS TELEFONPLAN, STOCKHOLM, SWEDEN PEDESTRIAN LEVEL WIND STUDY		
SCALE	1:600 (APPROX.)	DRAWING NO.	GWE16-015-PLW-5B
DATE	MARCH 11, 2016	DRAWN BY	K.A.

DESCRIPTION

FIGURE 5B: WINTER
SCHOOL YARD
PEDESTRIAN COMFORT PREDICTIONS

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 meters (m) to 600 m.

Simulating real wind behavior 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; $\boldsymbol{U}$ = mean wind speed, $\boldsymbol{U_g}$ = gradient wind speed, $\boldsymbol{Z}$ = height above ground, $\boldsymbol{Z_g}$ = 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, ***f*** is frequency, ***S(f)*** is the spectrum value at frequency ***f***, $\boldsymbol{U_{10}}$ is the wind speed 10 m above ground level, and ***L*** is the characteristic length of turbulence.

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

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

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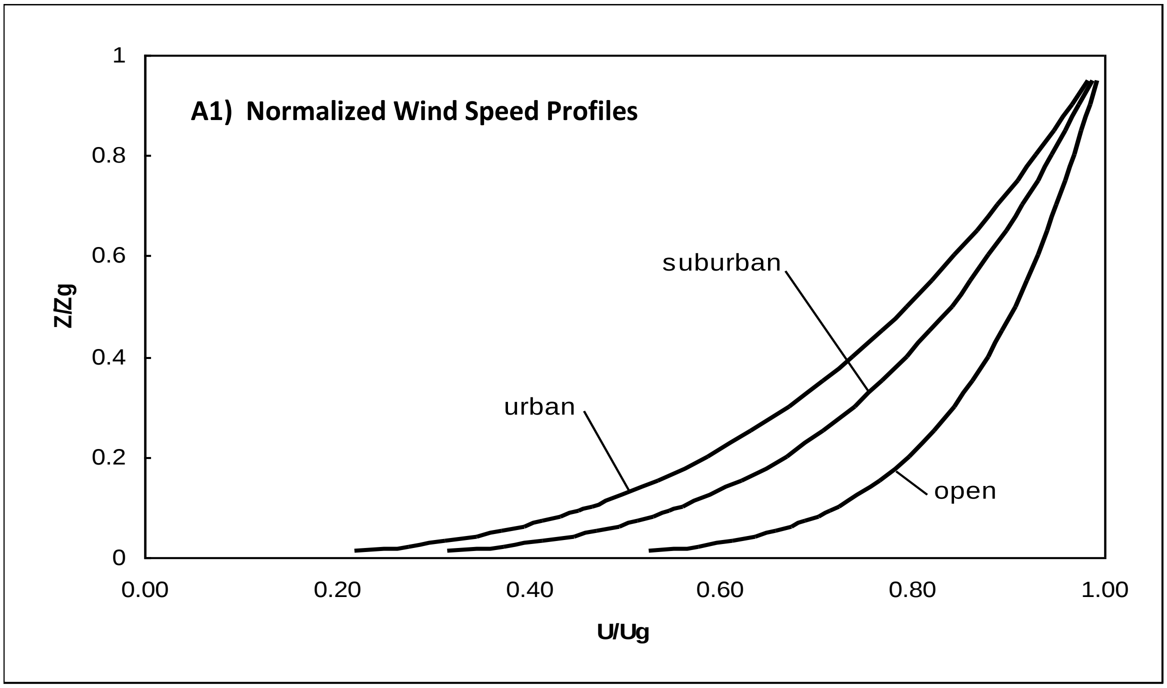


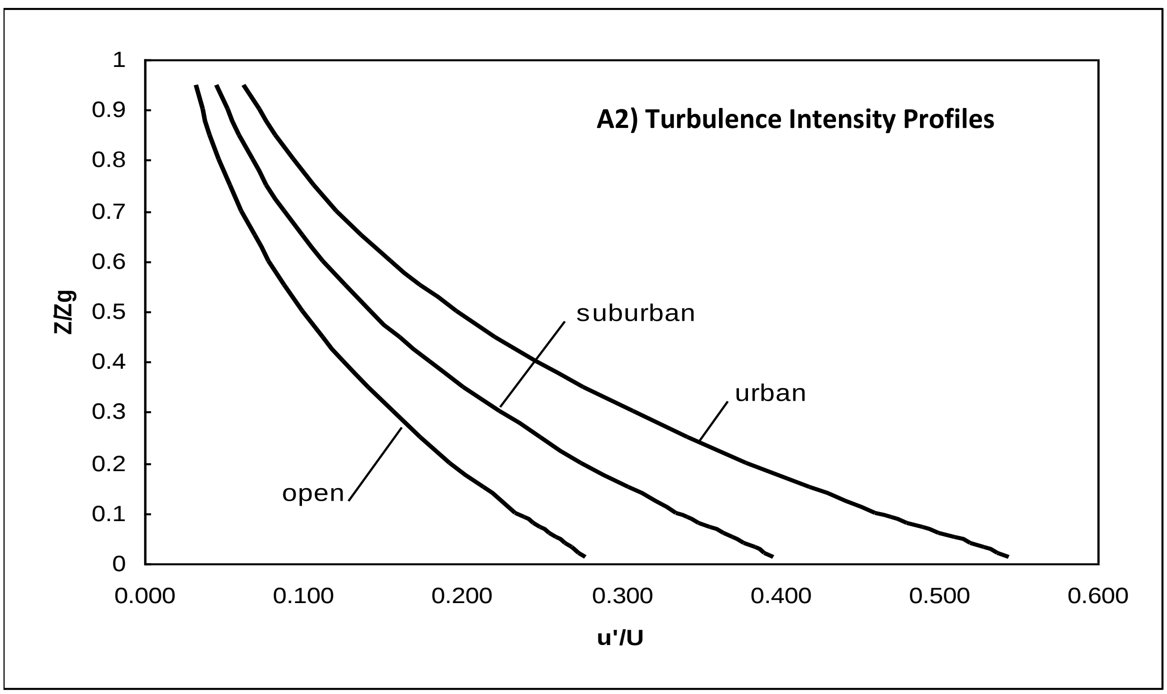


FIGURE A1 (TOP): MEAN WIND SPEED PROFILES

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:

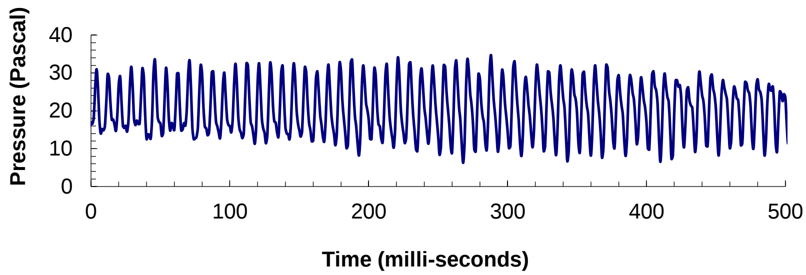
$$P_N(>20) = \Sigma_\theta P\left[\frac{(>20)}{\left(\frac{U_N}{U_g}\right)}\right]$$

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

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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APPENDIX C

NORMALIZED WIND TUNNEL VELOCITY RATIO PLOTS

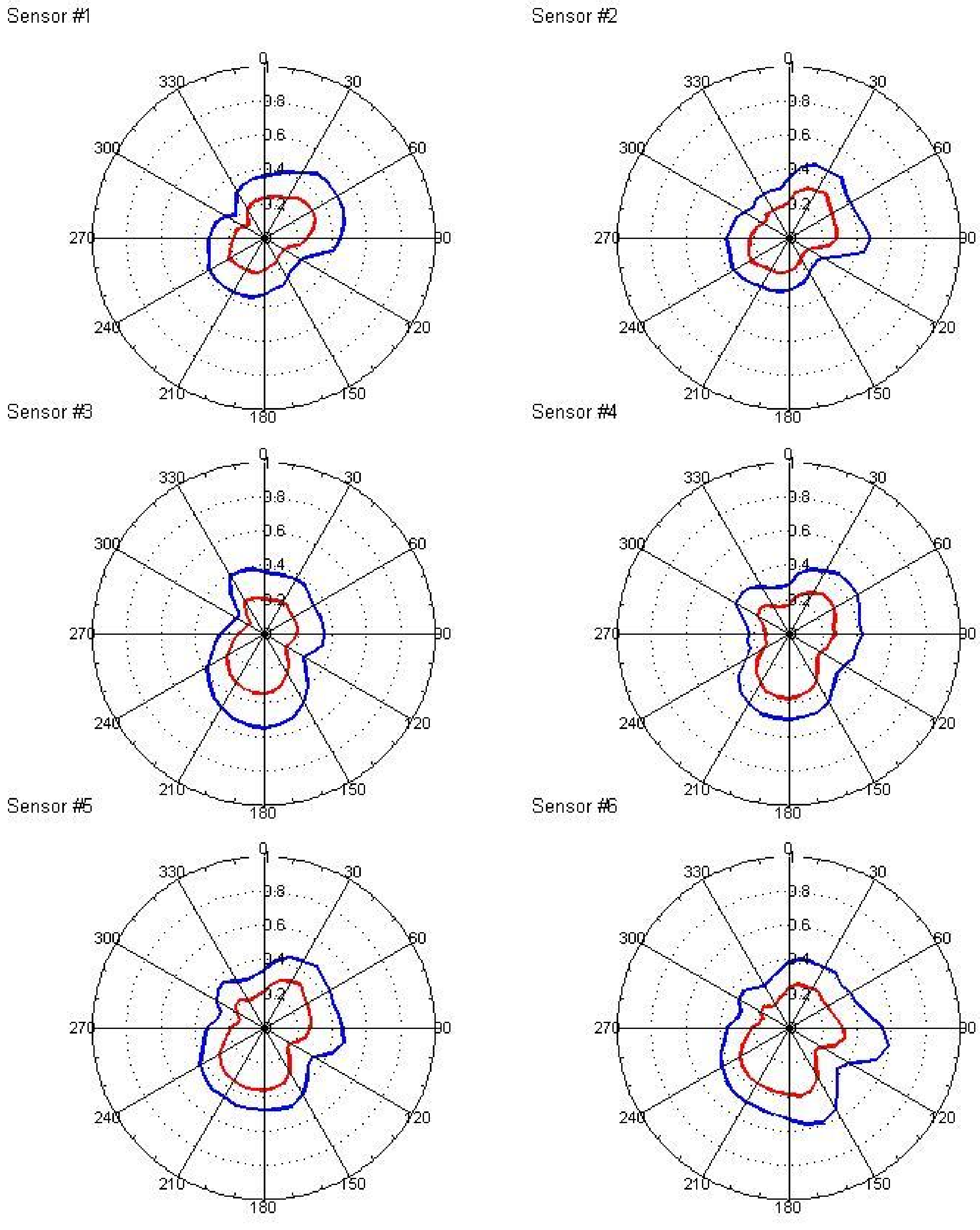


FIGURE C1: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 1-6

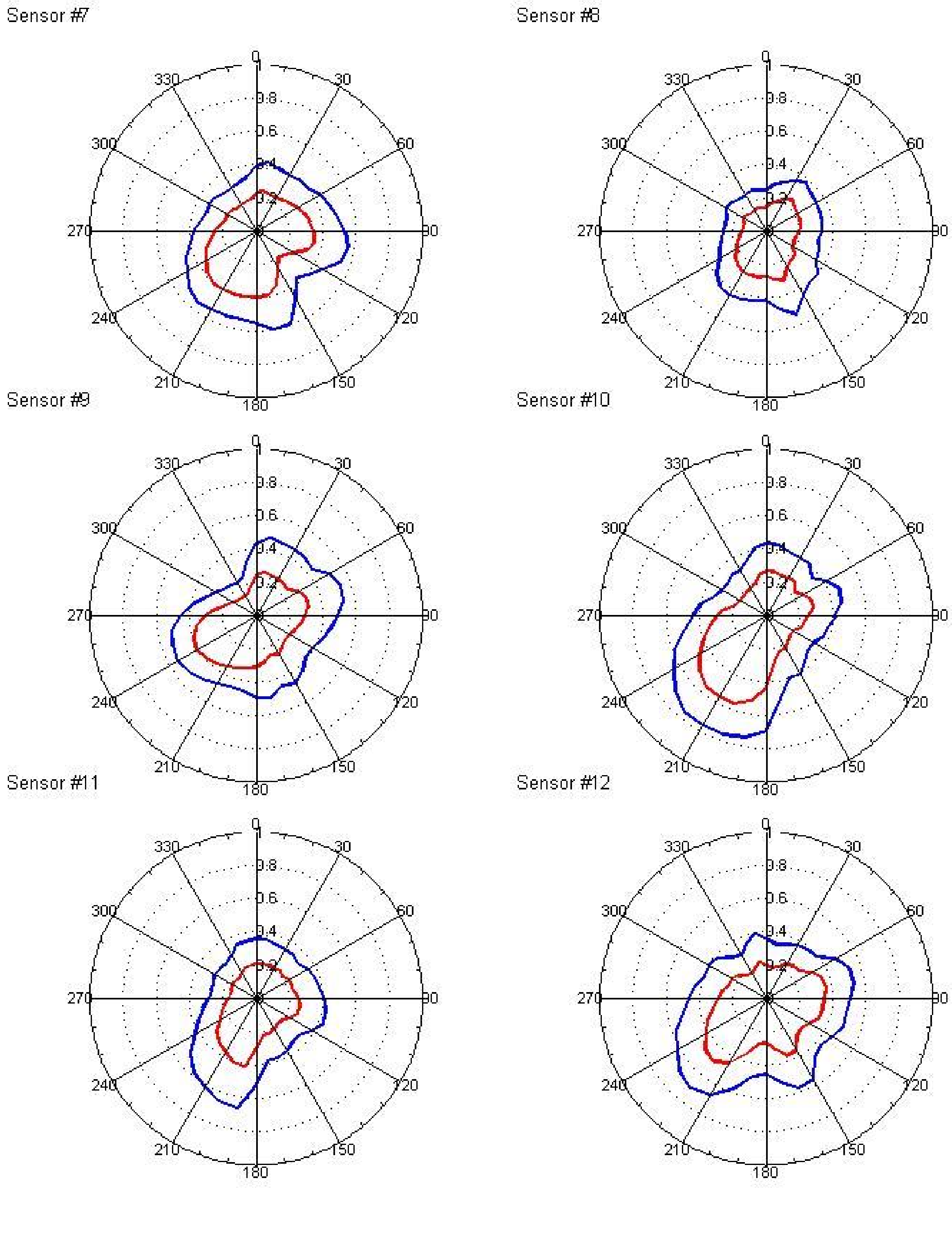


FIGURE C2: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 7-12

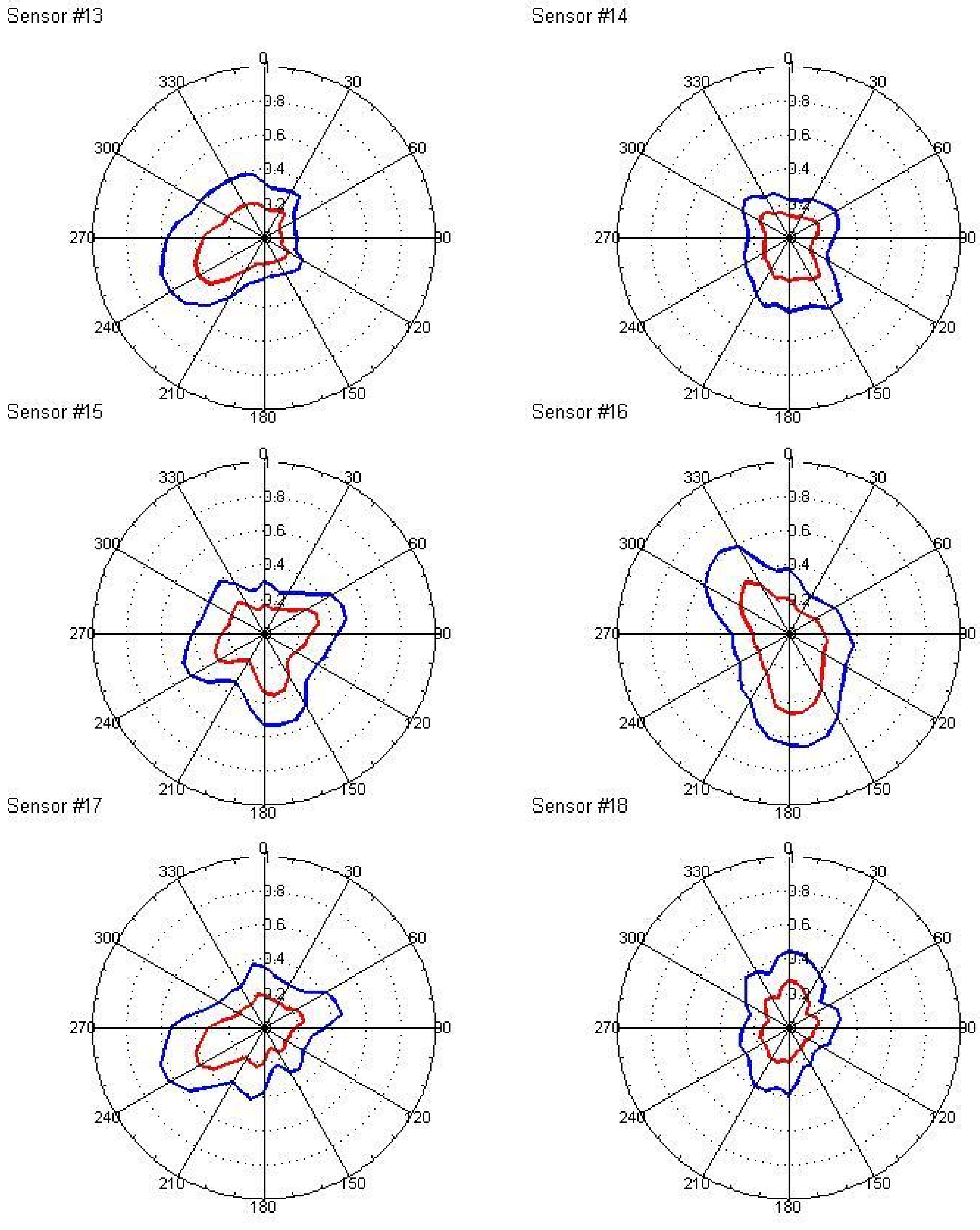


FIGURE C3: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 13-18

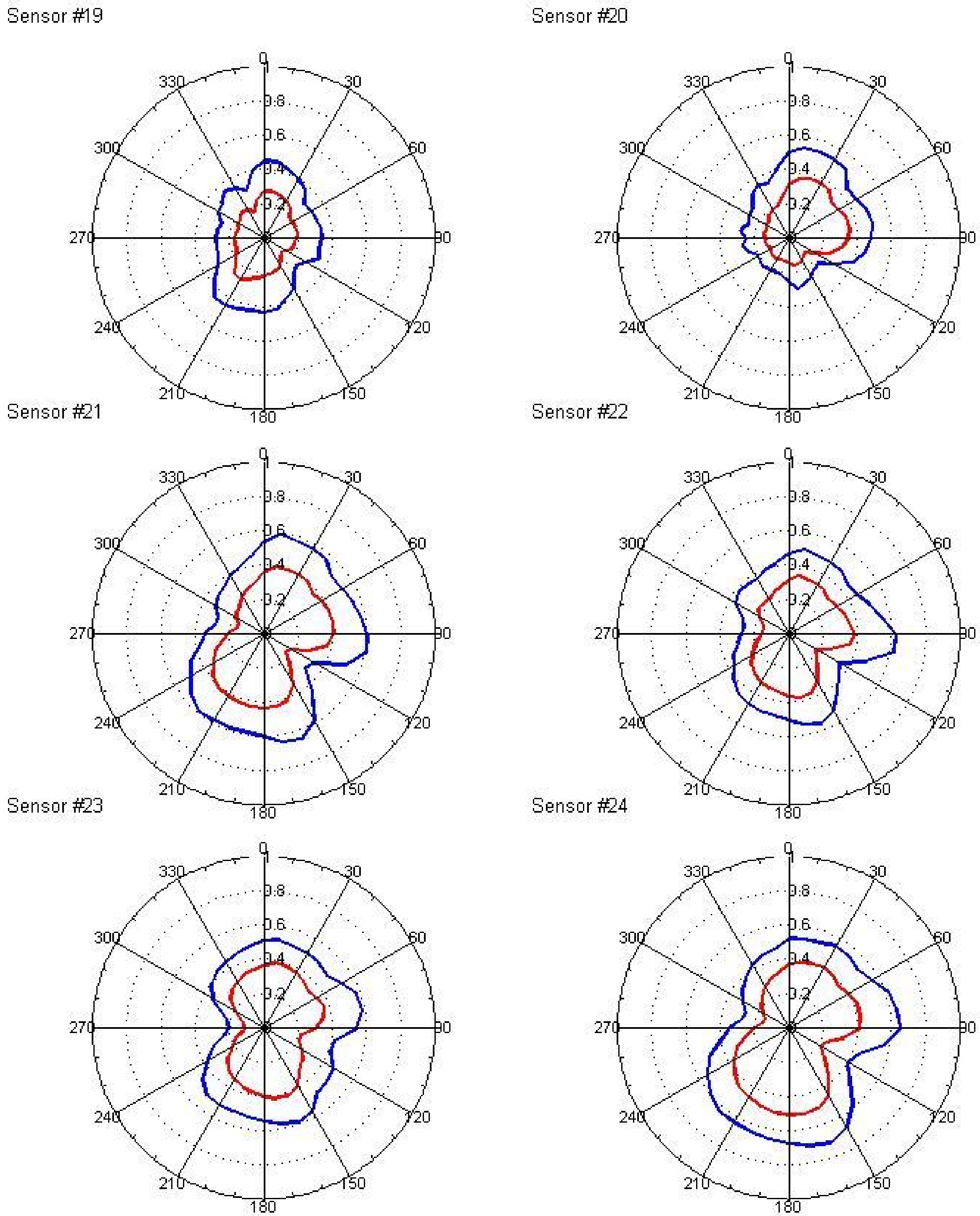
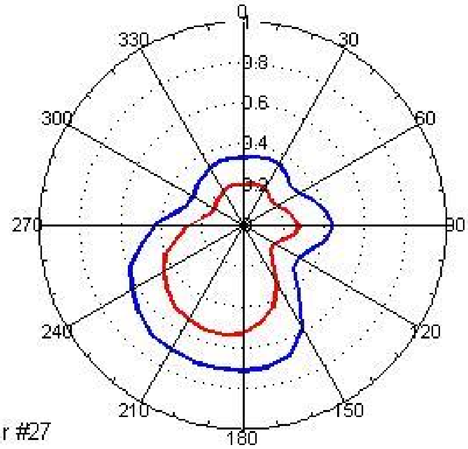


FIGURE C4: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 19-24

Sensor #25



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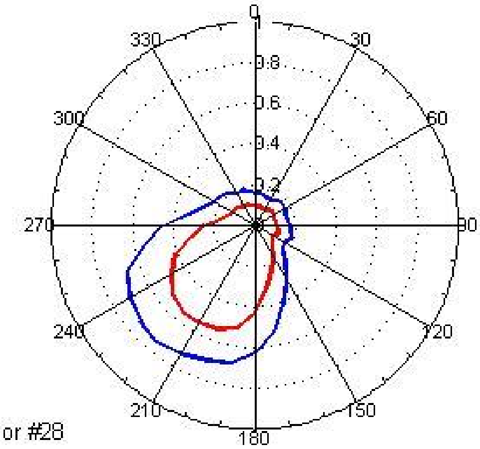

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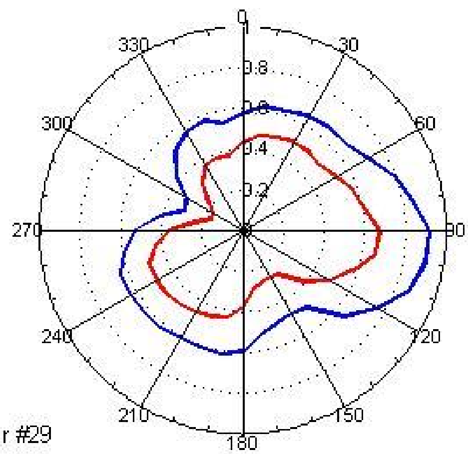

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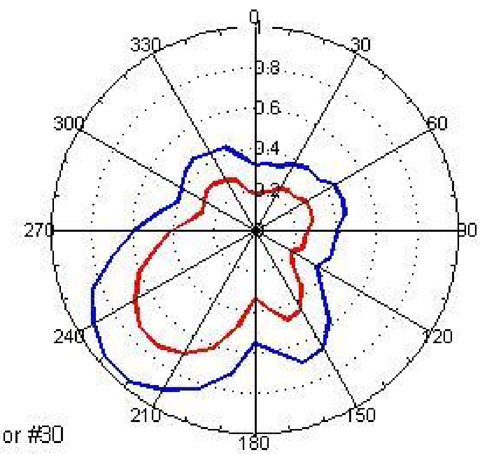

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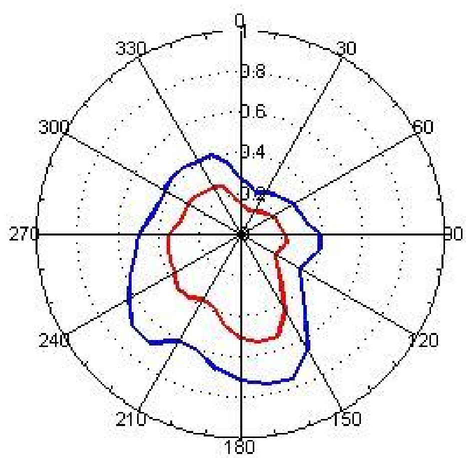

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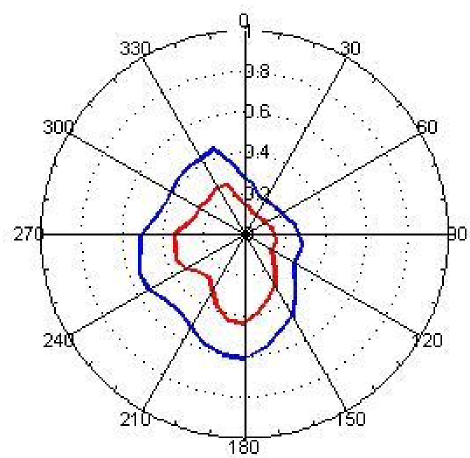


FIGURE C5: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 25-30

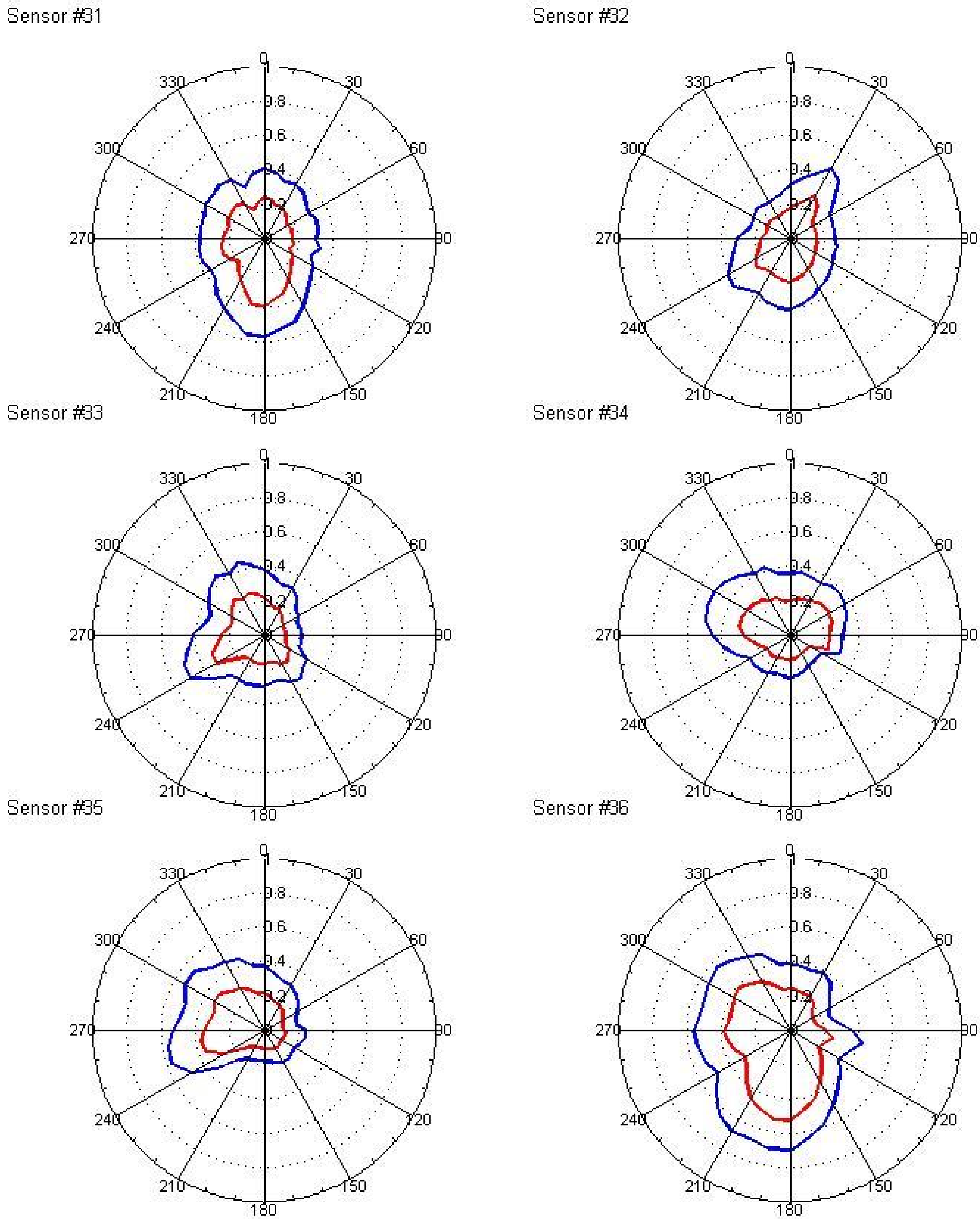


FIGURE C6: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 31-36

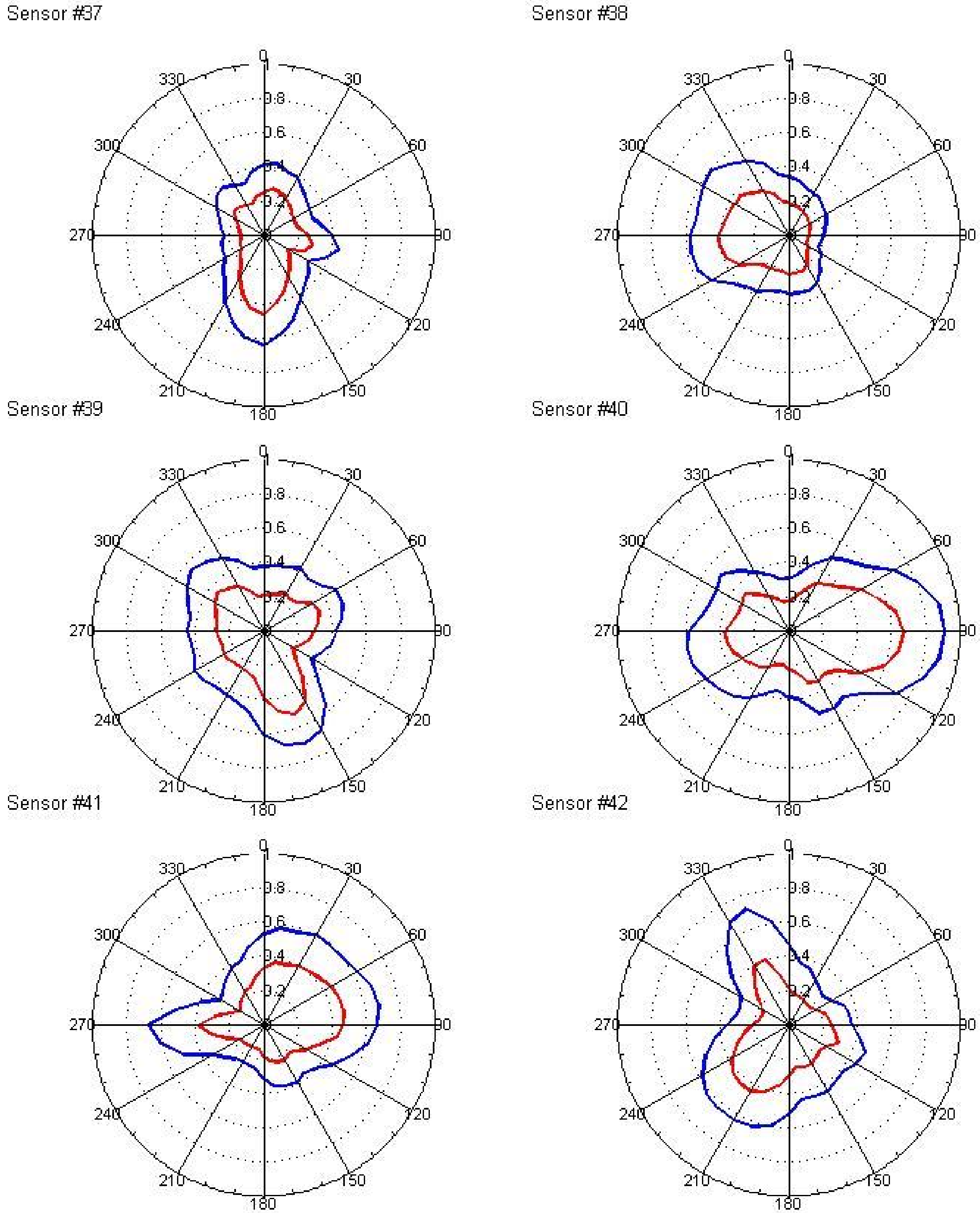


FIGURE C7: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 37-42

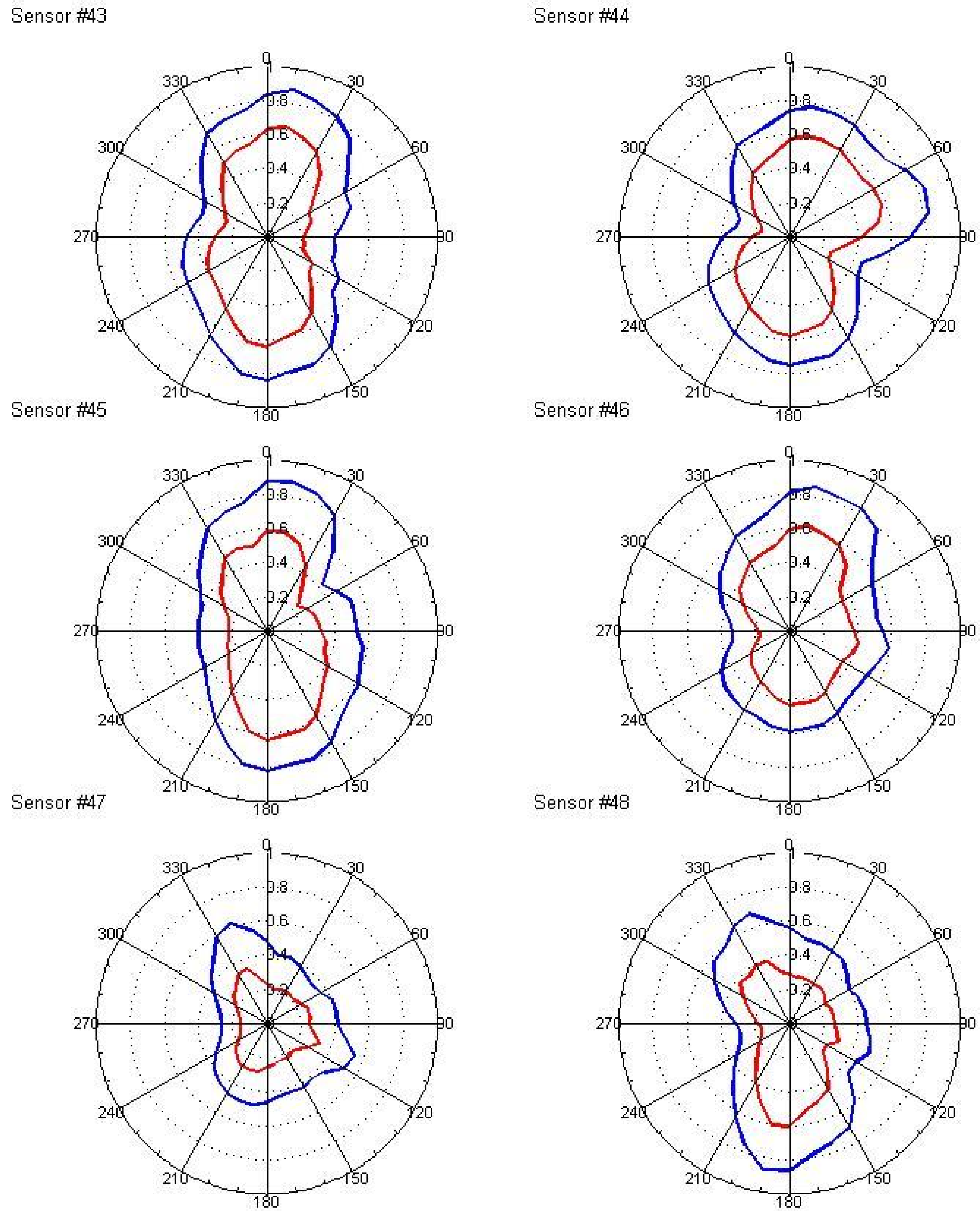


FIGURE C8: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 43-48

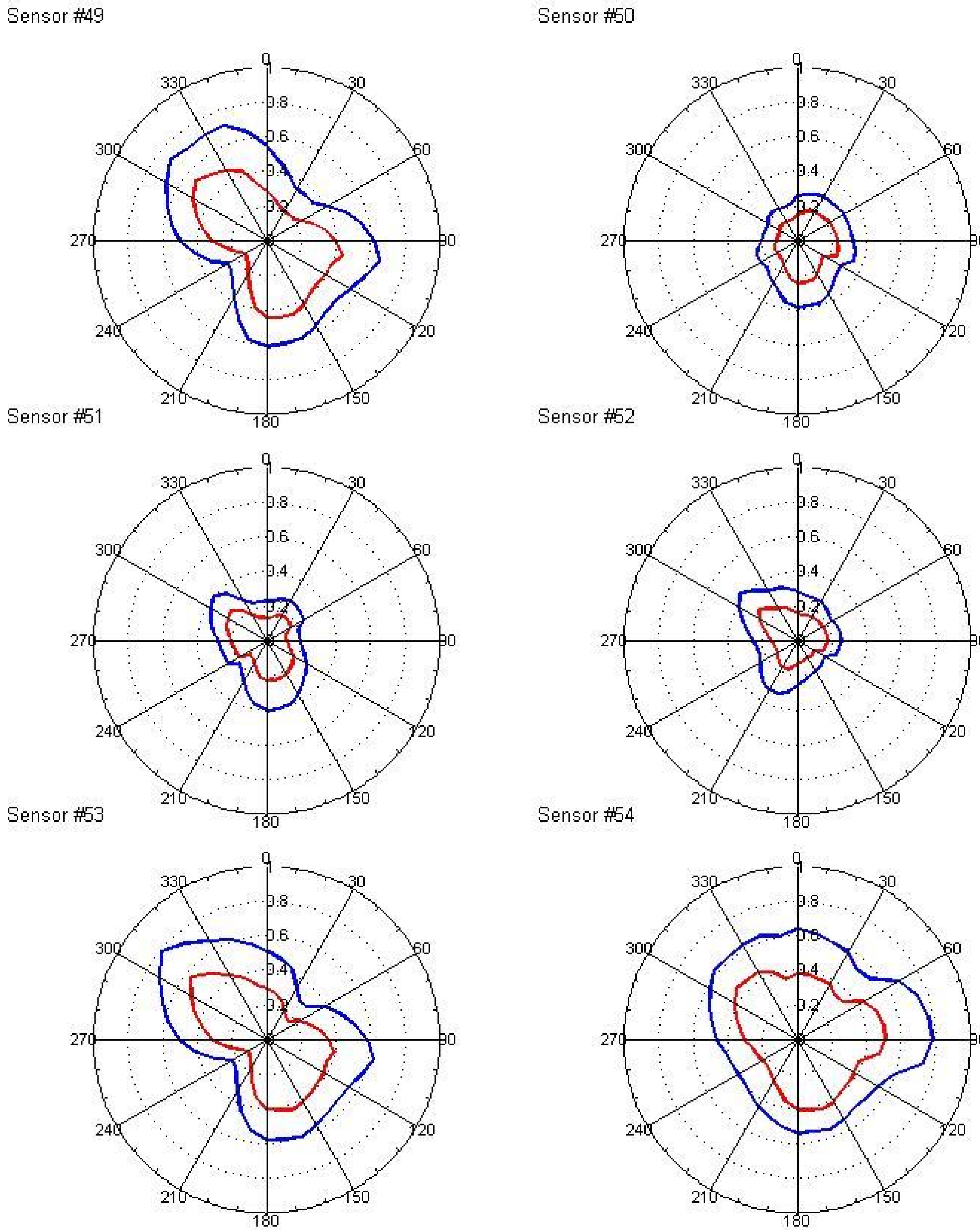


FIGURE C9: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 49-54

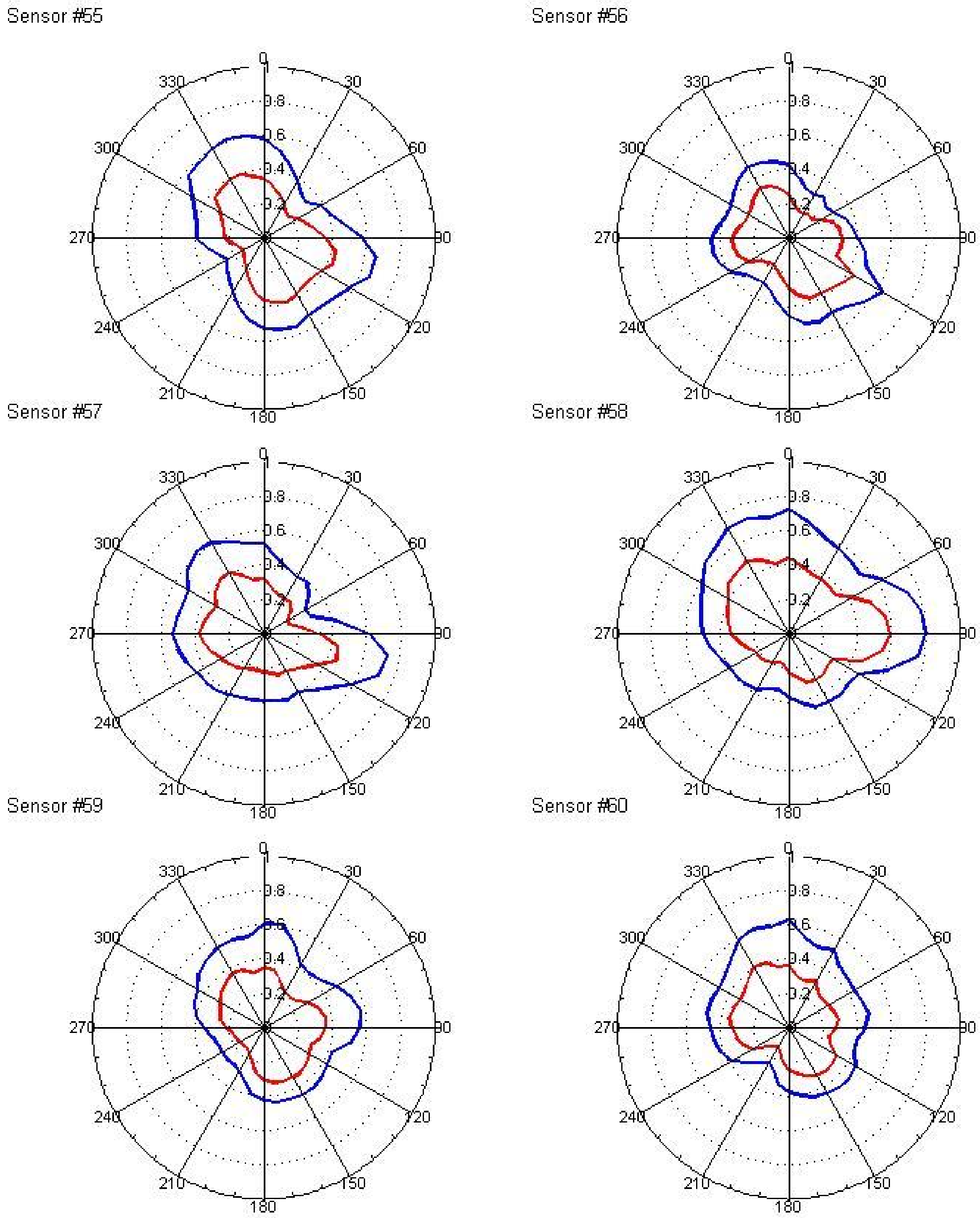


FIGURE C10: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 55-60

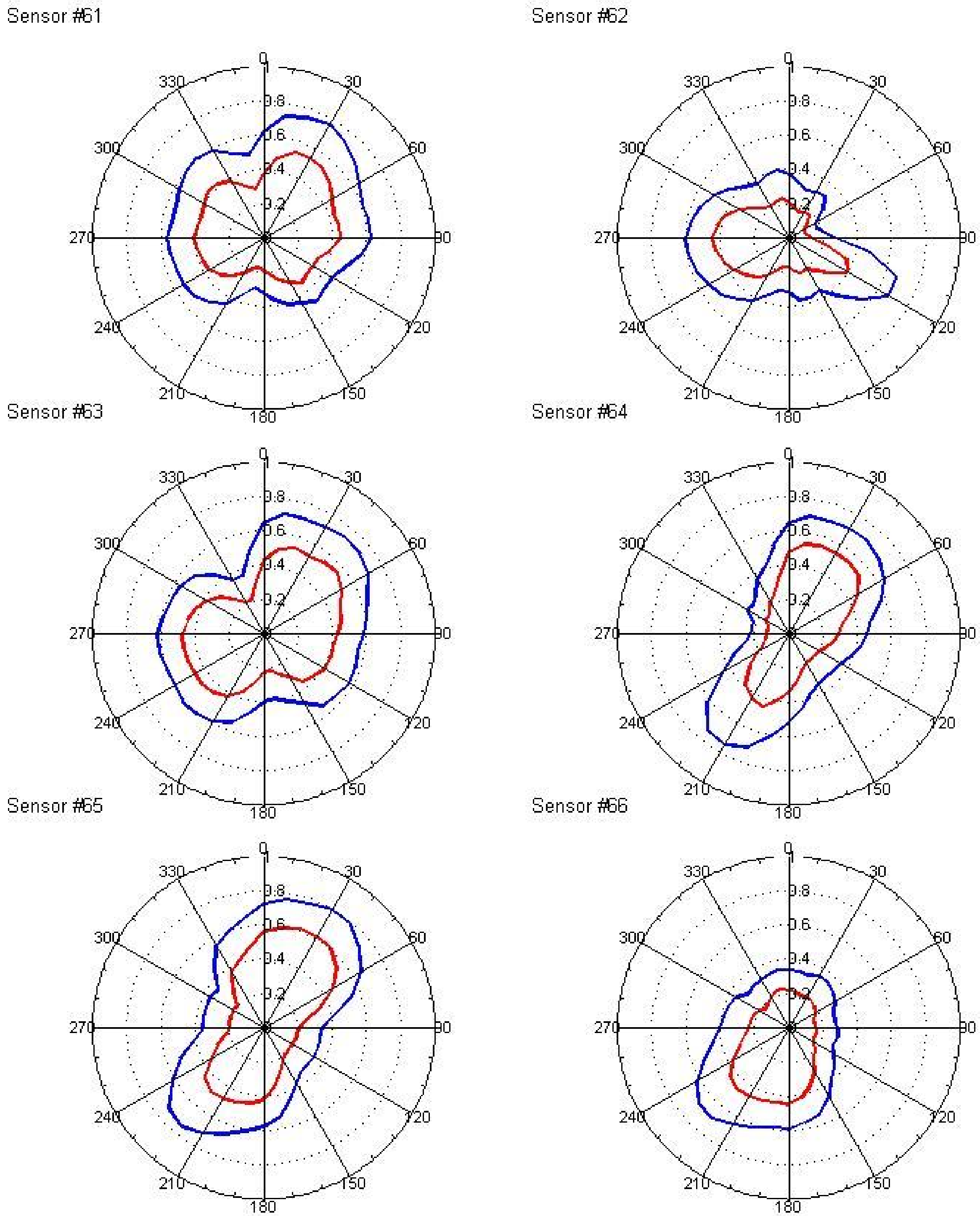


FIGURE C11: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 61-66

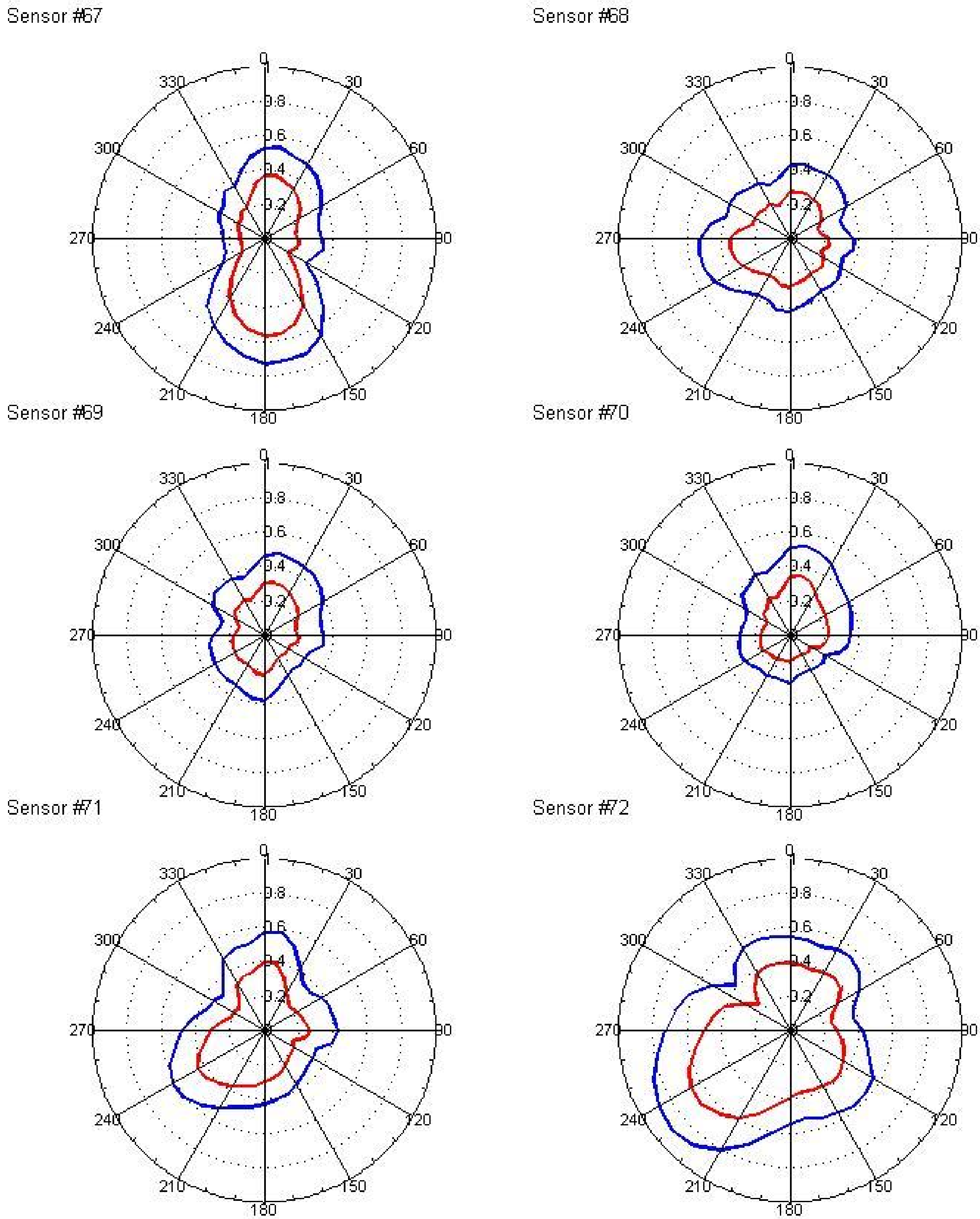


FIGURE C12: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 67-72

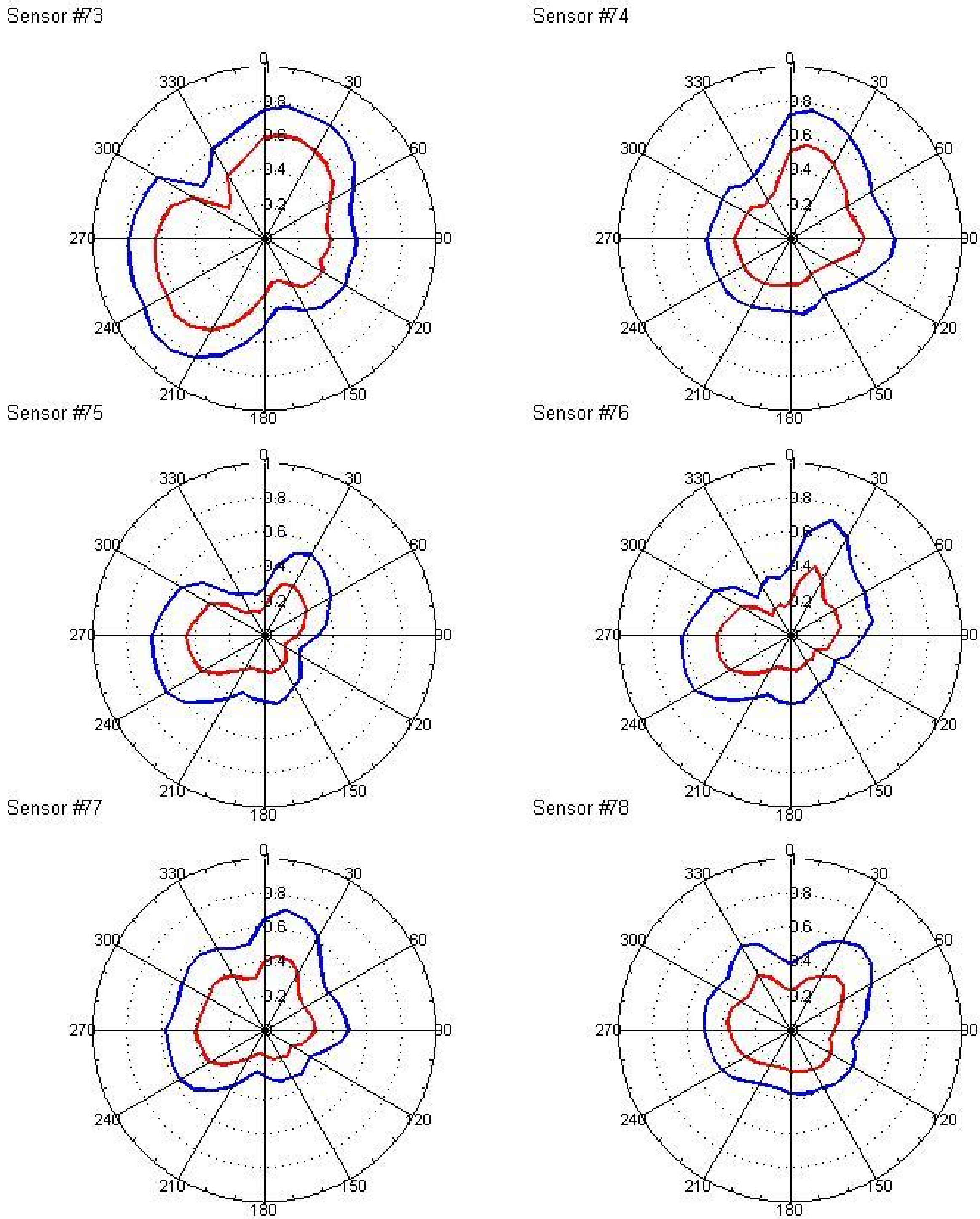
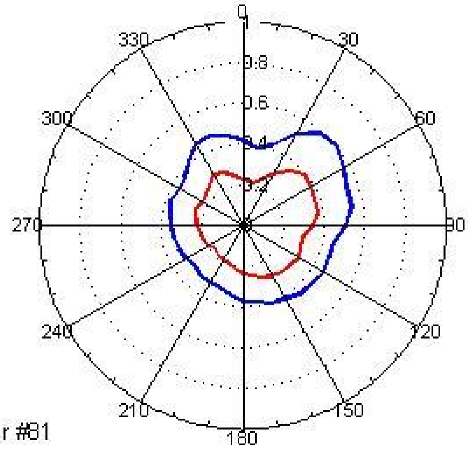


FIGURE C13: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 73-78

Sensor #79



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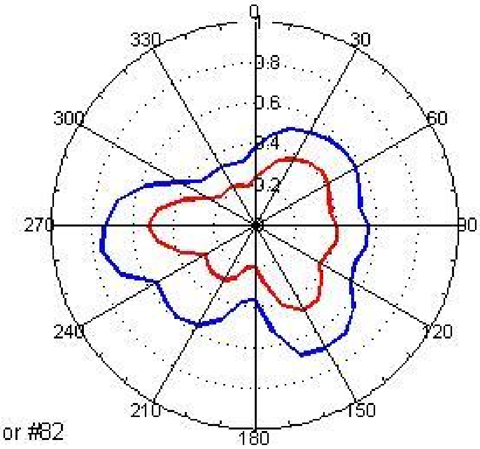

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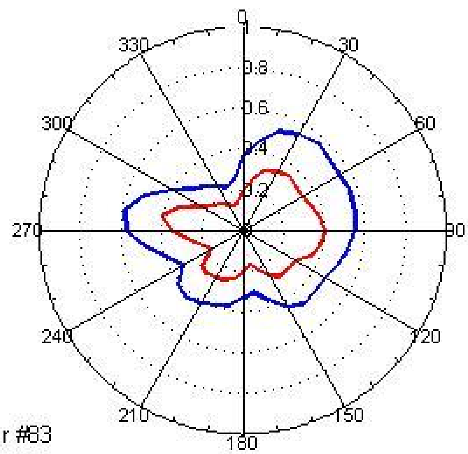

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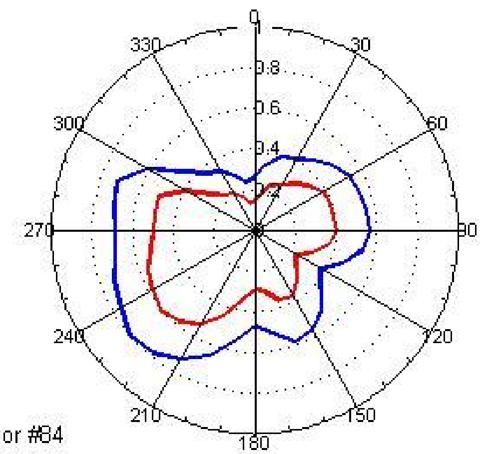

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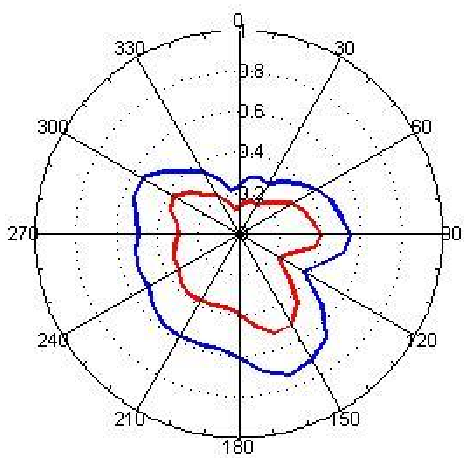

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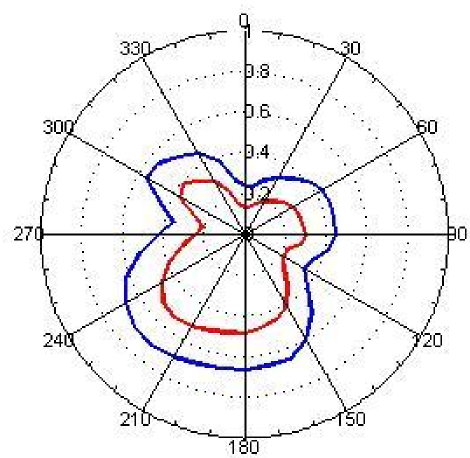

FIGURE C14: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 79-84

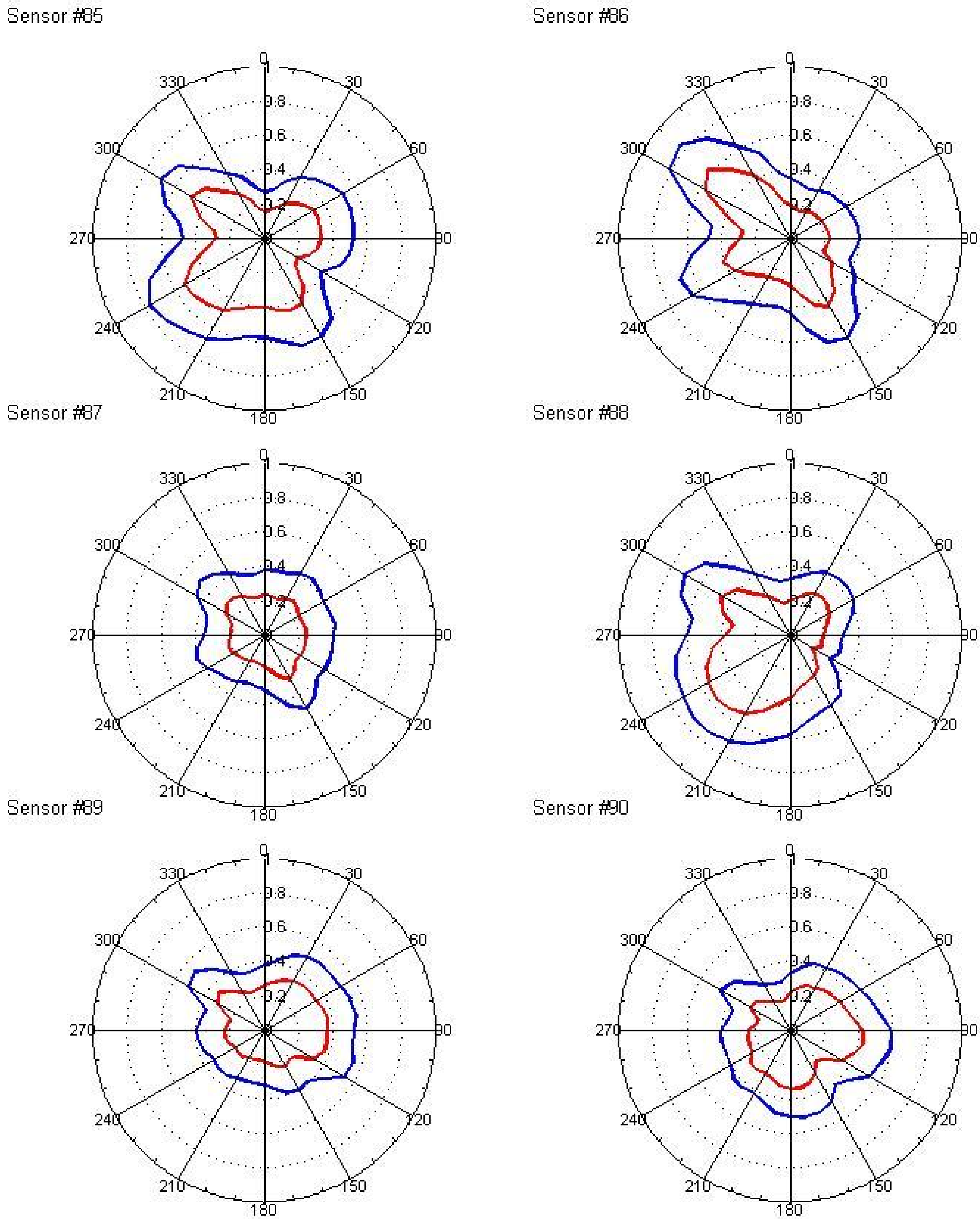

FIGURE C15: RAW WIND TUNNEL VELOCITY RATIO PLOTS, SENSORS 85-90