THEAKSTON ENVIRONMENTAL

Consulting Engineers • Environmental Control Specialists

REPORT

PEDESTRIAN LEVEL WIND STUDY

2105, 2087, 2097, 2077 Royal Windsor Drive

Mississauga, Ontario

CRW 1 LP and CRW 2 LP

REPORT NO. 22889wind **December 9, 2022**

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1. EXECUTIVE SUMMARY

The 2105, 2087, 2097, 2077 Royal Windsor Drive Development proposed by CRW 1 LP and CRW 2 LP, located to the west of the intersection of Southdown Road and Royal Windsor Drive in the City of Mississauga, has been assessed for environmental standards with regard to pedestrian level wind velocities relative to comfort and safety. The pedestrian level wind and gust velocities measured for the fifty-two (52) locations tested were within safety criteria and most are within the comfort criteria described within.

The proposed Development involves the removal of four existing 1 storey commercial buildings on site and construction of a mixed-use development with the west block consisting of two high-rise residential buildings connected by an 8 storey podium with retail and live/ work units at grade, and the east block consisting of two high-rise residential buildings connected by an 8 storey podium with retail and live/work units at grade. The property is, for all intents and purposes, surrounded to prevailing windward directions by a mix of low-rise residential and commercial buildings and related open areas, with high-rise residential buildings to the northeast. These buildings and related open areas have a sympathetic relationship with the pending wind climate.

Urban developments provide surface roughness, which induces turbulence that can be wind friendly, while suburban settings similarly, though to a lesser extent, prevent wind from accelerating as the wind's boundary layer profile thins at the pedestrian level. Conversely, open settings afford wind the opportunity to accelerate. High-rise buildings typically exacerbate wind conditions within their immediate vicinity, to varying degrees, by redirecting wind currents to the ground level and along streets and open areas. Transition zones from open, and/or suburban, to urban settings often prove problematic, as winds exacerbated by relatively more open settings are redirected to flow over, around, down, and between buildings.

The proposed Development penetrates winds that formerly flowed over the site, the increased blockage relative to the existing setting causing wind to redirect to flow over the buildings, without consequence, and/or, depending upon the angle of incidence, around, or down the towers towards the pedestrian level, as downwash. The Development features stepped conditions that intercept downwash associated with prevailing winds, deflecting a portion of said flows around the building at elevations above the pedestrian level. This mitigative design feature as well as other wind friendly design elements: narrow/textured façades, balconies, landscaping, and others, when considered in concert, further moderate wind. This results in somewhat moderate changes to the impending wind climate realised at the site with inclusion of the proposed Development, relative to the existing setting.

Winds are mitigated to varying degrees by the existing and proposed surrounds, and as such, upon impact with the proposed Development, tend to split, flowing over, and/or around and down the buildings' faces. At the pedestrian level, the winds redirect to travel horizontally along the buildings, around the corners and beyond, creating localised windswept areas at building corners and gaps in between. As such, the site and surrounds are predicted mainly suitable for walking, standing, or better, throughout the year and generally remain comfortable and appropriate to the areas' intended purposes, with exceptions. Localised uncomfortable conditions are realised through the winter season proximate to the southmost corner of the proposed Development, and within the gap between buildings. These uncomfortable conditions are relatively near the transition to walking conditions, and with consideration of fine design and landscape elements, they are expected to be suitable as such throughout large portions of the year. Where mitigation was required, it was included in the following design features:

- narrow/textured façades
- stepped façades
- podiums
- balconies
- landscaping

and others, that were incorporated into the proposed Development's massing and landscape design. Additional mitigation is recommended proximate to the southmost corner of the building as well as at the various residential, retail, and live/work entrances to the proposed Development in order to achieve more comfortable conditions that are seasonally suitable for the intended uses. Mitigation plans are similarly recommended for the 8th level Outdoor Amenity Spaces in order to achieve seasonally appropriate conditions. The proposed Development will realize wind conditions mainly acceptable to a typical suburban context.

Respectfully submitted,

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2. INTRODUCTION

CRW 1 LP and CRW 2 LP retained Theakston Environmental to study the pedestrian level wind environment for the proposed Development, municipally known as 2105, 2087, 2097, 2077 Royal Windsor Drive, in the City of Mississauga, as shown on the aerial photo in Figure 2a. The Development involves a proposal to build 29, 27, 25 and 23 storey residential towers, respectively denoted Towers 1 through 4, in a configuration shown in Figure 2b.

Gensler provided architectural drawings. The co-operation and interest of the Client and their sponsors in all aspects of this study is gratefully acknowledged.

The specific objective of the study is to determine areas of higher than normal wind velocities induced by the shape and orientation of the proposed Development and surroundings. The wind velocities are rated in accordance with the safety and comfort of pedestrians, notably at entrances to the buildings, sidewalks, courtyards on the property, as well as other buildings in the immediate vicinity.

In order to obtain an objective analysis of the wind conditions for the property, the wind environment was tested in two configurations. The existing configuration included the current buildings on site as well as existing and proposed buildings in the surrounding area. The proposed configuration included the subject Development. Mitigation procedures were assessed during these tests to determine their impact on the various wind conditions.

The laboratory techniques used in this study are established procedures that have been developed specifically for analyses of this kind. The methodology, summarized herein, describes criteria used in the determination of pedestrian level wind conditions. The facilities used by Theakston are ideal for observance of the Development at various stages of testing, and the development of wind mitigation measures, if necessary.

3. OBJECTIVES OF THE STUDY

1. To quantitatively assess, by model analyses, the pedestrian level wind environment under existing conditions and future conditions with the proposed Development.

2. To assess mitigative solutions.

3. To publish a Consultant’s report documenting the findings and recommendations.

4. METHOD OF STUDY

4.1 General

The Theakston Environmental wind engineering facility was developed for the study of, among other sciences, the pedestrian level wind environment occurring around buildings, with focus on the safety and comfort of pedestrians. To this end, physical scale models of proposed Development sites, and immediate surroundings, are built, instrumented and tested at the facility with resulting wind speeds measured for different wind directions at various locations likely to be frequented by pedestrians. This quantitative analysis provides predictions of wind speeds for various probabilities of occurrence and for various percentages of time that are ultimately weighted relative to a historical range of wind conditions, and provided to the client.

The techniques applied to wind and other studies carried out at the facility, utilise a boundary layer wind tunnel and/or water flume (Figure 1). The testing facility has been developed for these kinds of environmental studies, and has been adapted with equipment, testing procedures and protocols, in order to provide results comparable to full scale. The Boundary Layer Wind Tunnel lends itself well to the simultaneous acquisition of large data streams while the water flume is excellent for flow visualisation.

The purpose of this Pedestrian Level Wind Study is to evaluate the pedestrian level wind speeds for a full range of wind directions. To accomplish this, the wind's mean speed boundary layer profiles are simulated and applied to a site-specific model under test, instrumented with differential pressure probes at locations of interest. During testing, pressure readings are taken over a one-hour model scale period of time, at a full-scale height of approximately 1.8m and correlated to mean and gust wind speeds, expressed as ratios of the gradient wind speed.

The mean and gust wind speeds at the fifty-two (52) points tested were subsequently combined with the design probability distribution of gradient wind speed and direction, (wind statistics) recorded at Airports in the vicinity, to provide predictions of the full-scale pedestrian level wind environment. Predictions of the full-scale pedestrian level wind environment are presented as the wind speed exceeded 20% of the time, based on the winter and summer seasons in Figures 6a and 6b. Criterion employed by Theakston Environmental was developed by others and us and published in the attached references. The methodology has been applied to over 800 projects on this continent and abroad.

4.2 Meteorological Data

The wind climate for the Mississauga region that was used in the analysis was based on historical records of wind speed and direction measured at Billy Bishop Airport for the period between 1989 and 2017. The meteorological data includes hourly wind records and annual extremes. The analysis of the hourly wind records provides information to develop the statistical climate model of wind speed and direction. From this model, predicted wind speeds regardless of wind direction for various return periods can be derived. The record of annual extremes was also used to predict wind speeds at various return periods. Based on the analysis of the hourly records, the predicted hourly-mean wind speed at 10m, corrected for a standard open exposure definition, is 25 m/s for a return period of 50 years.

4.3 Statistical Wind Climate Model

For the analysis of the data, the wind climate model is converted to a reference height of 500*m* using a standard open exposure wind profile. The mean-hourly wind speed at a 500*m* reference height used for this study is 45.6*m/s* for a return period of 50 years. The corresponding 1-year return period wind speed at the 500*m* height is 36*m/s*.

The design probability distribution of mean-hourly wind speed and wind direction at reference height is shown for Billy Bishop Airport in Figure 5. Both winter and summer seasonal distributions are shown. From this it is apparent that winds can occur from any direction, however, historical data indicates the directional characteristics of strong winds are from the east as well as west through southwest and said winds are most likely to occur during the winter season.

4.4 Wind Simulation

To simulate the correct macroclimate, the upstream flow passes over conditioning features placed upstream of the model, essentially strakes and an appropriately roughened surface, as required to simulate the full-scale mean speed boundary layer approach flow profiles occurring at the site.

4.5 Pedestrian Level Wind Velocity Study

A physical model of the proposed Development and pertinent surroundings, including existing buildings, roadways, pathways, terrain and other features, was constructed to a scale of 1:500. The model is based upon information gathered during a virtual site visit to the proposed Development site, and surrounding area. Gensler provided architectural drawings. City of Mississauga aerial photographs were also used in development of the model to ensure the model reasonably represents conditions at the proposed Development. The model is constructed on a circular base so that, by rotation, any range of wind directions can be assessed. Structures and features that are deemed to have an impact on the wind flows are included upwind of the scale model.

In these studies, the effects of wind were analysed using omni-directional wind velocity probes that are placed on the model and located at the usual positions of pedestrian activity. The probes measure both mean and fluctuating wind speeds at a height of approximately 1.8m. During testing, the model sample period is selected to represent 1hr of sampling time at full scale. The velocities measured by the probes are recorded by a computerized data acquisition system and combined with historical meteorological data via a post-processing program.

4.6 Pedestrian Comfort Criteria

The assignment of pedestrian comfort takes into consideration pedestrian safety and comfort attributable to mean and gust wind speeds. Gusts have a significant bearing on safety, as they can affect a person's balance, while winds flowing at or near mean velocities have a greater influence upon comfort.

Figure 6 presents results for the mean wind speed that is exceeded 20% of the time. These speeds are directly related to the pedestrian comfort at a particular point. The overall comfort rating, for existing and proposed, are depicted in Figure 7. A comparison of pedestrian level comfort conditions for each probe is shown in a table in Figure 10. Table 1, below, summarizes the comfort criteria used in the presentation of the results depicted in Figures 6 and 7.

Table 1: Comfort Criteria

ACTIVITY	Gust Equivalent Mean Speed Exceeded 20% of the Time	Description
COMFORT	***km/h***	
Sitting	0-10	Calm or light breezes desired for outdoor restaurants and seating areas where one can read a paper without having it blown away.
Standing	0-15	Gentle breezes suitable for main building entrances and bus stops.
Walking	0-20	Relatively high speeds that can be tolerated if one's objective is to walk, run or cycle without lingering.
Uncomfortable	>20	Strong winds of this magnitude are considered a nuisance for most activities, and wind mitigation is typically recommended.

The activities are described as suitable for Sitting, Standing, Walking, or Uncomfortable, depending on average wind speed exceeded 20% of the time. For a point to be rated as suitable for Sitting, for example, the wind conditions must not exceed 10*km/h*, more than 20% of the time. Thus, in the plots (Figure 6), the upper limit of each bar ends within the range described by the comfort category. For sitting, the rating would include conditions ranging from calm up to wind speeds that would rustle tree leaves or wave flags slightly, as presented in the Beaufort Scale included in the Appendices. As the name infers, the category is recommended for outdoor space where people might sit for extended periods.

The Standing category is slightly more tolerant of wind, including wind speeds from calm up to 15*km/h*. In this situation, the wind would rustle tree leaves and, on occasion, move smaller branches while flags flap. This category would be suitable for locations where people might sit for short periods or stand in relative comfort. The Walking category includes wind speeds from calm up to 20*km/h*. These winds would set tree limbs in motion, lift leaves, litter and dust, and the locations are suitable for activity areas. The Uncomfortable category covers a broad range of wind conditions that are generally a nuisance for most activities, including wind speeds above 20*km/h*.

In Figure 6, the probe locations are listed along the bottom of the chart; beneath the graphical representation of the Mean Wind Speed exceeded 20% of the time. Along the right edge of the plot the comfort categories are shown. The background of the plot is lightly shaded in colours corresponding to the categories shown in Table 1. Each category represents a 5*km/h* (or more) interval. The location is rated as suitable for Sitting, Standing, Walking, or Uncomfortable, if the bar extends into the corresponding interval.

The charts represent the average person's response to wind force. Effects such as wind chill and humidex (based on perception) are not considered. Clothing is not considered, since clothing and perceived comfort varies greatly among the population. There are many variables that contribute to a person's perception of the wind environment beyond the seasonal variations presented. While people are generally more tolerant of wind during the summer months, than during the winter, due to the wind cooling effect, people become acclimatized to a particular wind environment. Persons dwelling near the shore of an ocean, large lake or open field are more tolerant of wind than someone residing in a sheltered wind environment.

4.7 Pedestrian Safety Criteria

Safety criteria are also included in the analysis to ensure that strong winds do not cause a loss of balance to individuals occupying the area. The safety criteria are based on wind speeds exceeded nine times per year as shown in Table 2.

Both the Comfort and Safety Criteria are based on those described in the City's Terms of Reference for Wind.

Table 2: Safety Criteria

ACTIVITY	**Mean Wind Speed Exceeded 9 Times per year**	**Description**
SAFETY	***km/h***	
All-Weather Areas	0 - 90	Acceptable gust speeds that will not adversely affect a pedestrian's balance and footing.
Exceeding All-Weather Areas	>90	Excessive gust speeds that can adversely affect a pedestrian's balance and footing. Wind mitigation is typically required.

4.8 Pedestrian Comfort Criteria – Seasonal Variation

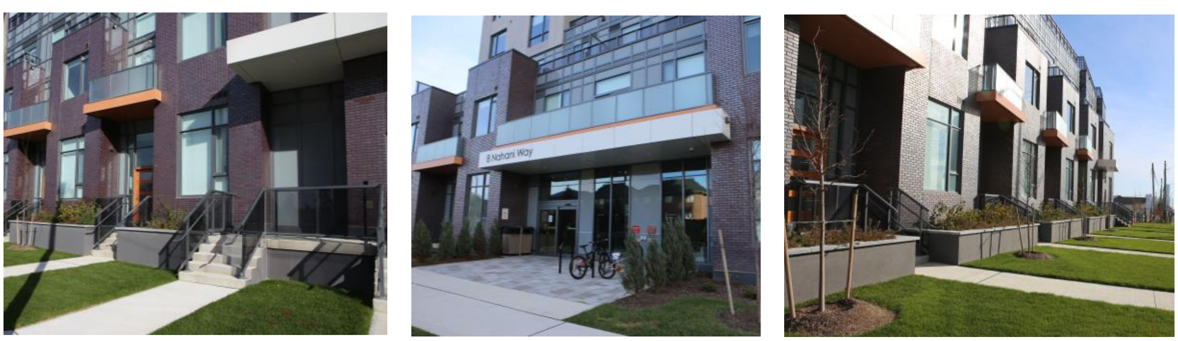
The level of comfort perceived by an individual is highly dependent on seasonal variations of climate. Perceived comfort is also specific to each individual, and depends on the clothing choices. The comfort criterion that is being used averages the results across the general population to remove effects of individuals and clothing choices, however, seasonal effects are important. For instance, a terrace or outdoor amenity space may have limited use during the winter season, but require acceptable comfort during the summer.

When compared to the annual average wind speed, winter winds are about 12.5% higher and summer winds are about 16% lower.

4.9 Wind Mitigation Strategies

Wind mitigative features such as podiums, setbacks, stepped façades, balconies, notches, overhangs, canopies, and others, assist in discouraging downwash associated with prevailing winds. These features deflect portions of said winds around buildings at elevations well above the pedestrian level, and moderate upsets to wind conditions with inclusion of new developments. Additional mitigative features may also be applied for localised areas that experience conditions that are inappropriate for the intended use. These features, discussed below, add roughness into wind streamlines and protect exposed areas from high pedestrian level winds.

Entrances to buildings may be mitigated by locating them away from building corners and through recessing the entrances into the façades of the building. Additional mitigative features such as railings, canopies, coarse plantings, porous wind screens, and others, would further assist in mitigating said areas. Examples of these wind mitigation measures are shown below.



Examples of Wind Mitigative Measures at Entrances (recessed entrances, railings, canopies, raised planters, coniferous trees).

Activity areas such as Outdoor Amenity Spaces may similarly be mitigated through implementation of 1.8m – 2.4m high perimeter wind screens, trellises, raised planters, coarse plantings, and others, situated about the spaces as practical. Examples of these wind mitigative measures are shown below.

Examples of Wind Mitigative Measures at Activity Spaces (wind screens, raised planters, trellises)

The model was assessed with selected mitigation strategies during these tests to determine their impact on the various wind conditions. Further testing may be required in order to determine the effectiveness of any additionally proposed wind mitigative features, if desired.

5. RESULTS

5.1 Study Site and Test Conditions

Proposed Development

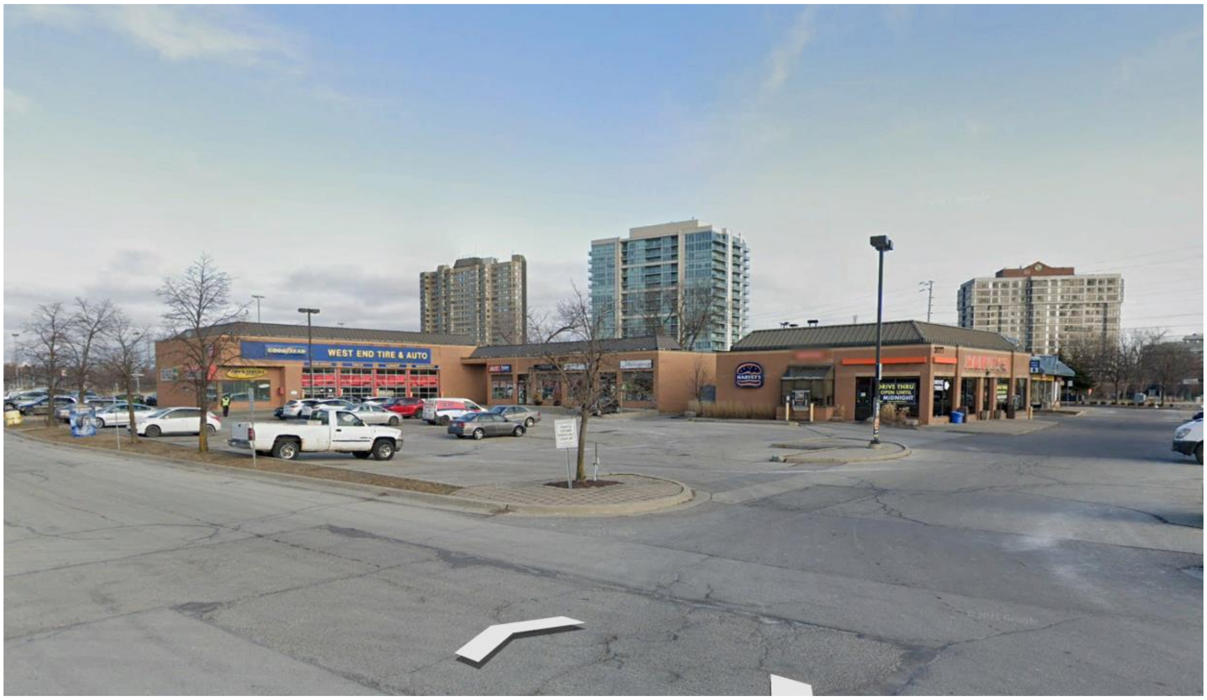
The 2105, 2087, 2097, 2077 Royal Windsor Drive property is located to the west of the intersection of Royal Windsor Drive and Southdown Road, in the City of Mississauga. The subject property is currently occupied by four one-storey brick buildings, associated asphalt parking lots, and a private road, with an easement in favour of Metrolinx, to provide access to Royal Windsor Drive to the south and Clarkson GO Station to the north, as depicted in the Aerial Photo in Figure 2a. Note: Mississauga's street orientation is relative to the Lake Ontario Shoreline resulting in east/west orientated streets in the subject area being offset by approximately 45 degrees north.

The mixed-use development proposal: the west block consists of two high-rise residential buildings connected by an 8 storey podium with retail and live/ work units at grade, and the east block consists of two high-rise residential buildings connected by an 8 storey podium with retail and live/work units at grade. There are approximately 5 levels of underground proposed on the west block and 3 levels of underground on the east block. Vehicular access to the site is provided via a relocation of the Metrolinx easement through the centre of the site.

Tower 1 occupies the west corner of the site, is 29 storeys in height, and is connected by an 8 storey podium to Tower 2, which is 27 storeys in height and located in the south corner of the site. Tower 3 and Tower 4 are similarly connected by an 8 storey podium, are 25 and 23 storeys in height, and are situated at the north and east corners of the site, respectively. Outdoor Amenity Spaces are proposed on the 8th level of connective podiums.

The Main Residential Lobby Entrances to the Development are proposed between the buildings, near the northwest and southeast corners of the buildings. Retail and live/work entrances are proposed along the central easement, as well as along the outer façades of the Development.

The site plan is shown in Figure 2b, and the model, shown in Figure 3, is built to a scale of 1:500.



View of the proposed Development Site Looking North (Google)

Surrounding Area

The proposed Development site, for all intents and purposes, is surrounded to prevailing windward directions by low-rise suburban development and open areas, as indicated in Figure 2a.

The Clarkson GO Parking Garage and surface parking lots occupy lands to the northwest through north of the proposed Development site, with low-rise commercial buildings fronting Southdown Road to the immediate north of the site. High-rise residential buildings are located farther to the north through northeast, beyond Southdown Road, including the approved 18 storey S2 at Stonebrook Condos. Low-rise residential neighbourhoods dominate lands to the north beyond. Lands to the east of the intersection of Southdown Road and Royal Windsor Drive are similarly occupied by a mix of commercial and low-rise residential buildings, with a few high-rise residential buildings beyond. Low-rise commercial buildings and related surface parking occupy the lands to the southeast through west of the site.

In summary, suburban development mainly comprised of low-rise commercial buildings, residential neighbourhoods, and open spaces occupy lands to all compass points relative to the subject site, with the exception of high-rise residential buildings to the northeast of Southdown Road. The suburban landscape has mitigative effects upon the wind climate to varying degrees, providing surface roughness that reduces the wind's energy at the pedestrian level. Conversely, open areas present a relatively smooth surface to approaching winds, affording wind opportunity to accelerate. Figures 2a and 2b depict the site and its immediate context. The site model, shown in Figure 3, is built to a scale of 1:500.

Macroclimate

For the proposed Development, the upstream wind flow during testing was conditioned to simulate an atmospheric boundary layer passing over suburban terrain. The terrain within the site's immediate vicinity was incorporated into the proximity model. Historical meteorological data recorded from Billy Bishop Airport was used in this analysis. For studies in the City of Mississauga, the data is presented for the winter and summer seasons; the resulting wind roses are presented as mean velocity and percent frequency in Figures 5a and 5b. The mean velocities presented in the wind roses are measured at an elevation of 10m. Thus, representative ground level velocities at a height of 2m, for an urban macroclimate, are 52% of the mean values indicated on the wind rose (for suburban and rural macroclimates the values are 63% and 78% respectively). The macroclimate for the area varies, with the terrain types associated with wind direction, resulting in what is generally considered suburban terrain.

Winter (November through April) has the higher mean velocities of the seasons with prevailing winds from the west through southwest, with significant components also from the northwest and east through northeast as indicated in Figure 5a. Summer (May through October) has lower mean wind velocities with prevailing winds from the east through northeast as well, as indicated in Figure 5b. Reported pedestrian comfort conditions pertain to the winter season, unless stated otherwise.

5.2 Pedestrian Level Wind Velocity Study

On the site model, fifty-two (52) wind velocity measurement probes were located around the proposed Development and other buildings and activity areas to determine conditions related to comfort and safety. Figure 4 depicts probe locations at which pedestrian level wind velocity measurements were taken in the existing and proposed scenarios. For the existing setting, the proposed Development was removed and the "existing" site model retested with the current site.

Measurements of pedestrian level mean and gust wind speeds at the various locations shown were taken over a period of time equivalent to one hour of measurements at full-scale. The mean ground level wind velocity measured is presented as a ratio of gradient wind speed, in the plots of Figure B in the Appendix, for each point in the existing and proposed scenarios. These relative wind speeds are presented as polar plots in which the radial distance for a particular wind direction represents the wind speed at the location for that wind direction, expressed as a ratio of the corresponding wind speed at gradient height. They do not assist in assessing wind comfort conditions until the probability distribution gradient wind speed and direction are applied.

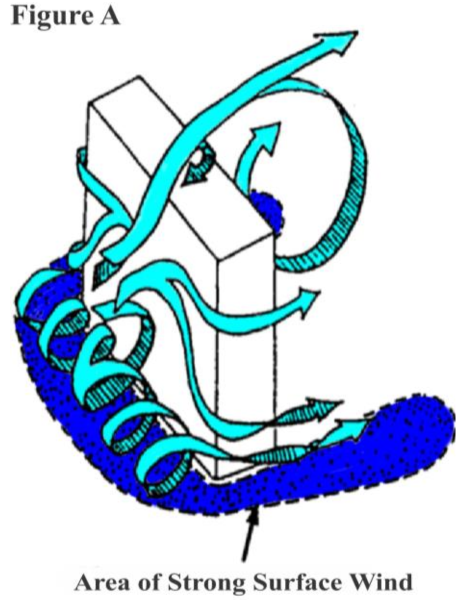
The design probability distribution gradient wind speed and direction, taken from historical meteorological data for the area (see Figure 5) was combined with pedestrian level mean and gust wind speeds measured at each point to provide predictions of the percentage of time a point will be comfortable for a given activity. These predictions of mean and maximum or "gust" wind speeds are provided for the winter and summer seasons in Figures 6a and 6b. A table comparing comfort and safety ratings for each probe is provided in Figure 10.

The ratings for a given location are conservative by design; when the existing surroundings and proposed buildings' fine massing details and actual landscaping are taken into consideration, the results tend toward a more comfortable site than quantitative testing alone would indicate.

Venturi action, scour action, downwash and other factors, as discussed in the Appendix on wind flow phenomena, can be associated with large buildings, depending on their orientation and configuration. These serve to increase wind velocities. Open areas within a heavily developed area may also encounter high wind velocities. Consequently, wind force effects are common in heavily built-up areas. The Development site is open to a predominantly suburban setting to prevailing and remaining compass points with winds flowing over and between mature vegetation, low to high-rise buildings and open spaces. As such, the surroundings can be expected to influence wind at the site to varying degrees. Note: Probes are positioned at points typically subject to windy conditions in an urban environment in order to determine the worst-case scenario.

High-rise buildings may exacerbate wind conditions within their immediate vicinity, to varying degrees, by redirecting wind currents to the ground level and along streets and open areas. In general, wind will split upon impact with a high-rise building, with portions flowing down the face of the building to the pedestrian level as downwash, where it is deflected, or otherwise redirected to flow along the building and around its corners, creating localized zones of increased pedestrian level wind (Figure A). Conversely, points situated to the leeside, or in the wake of buildings will often enjoy an improvement in pedestrian comfort. As such, it is reasonable to expect inclusion of the proposed development will alter wind conditions under specific wind directions and velocities from those of the existing site condition, resulting in an improvement over the existing conditions at some points, with more windy conditions at others.

Figure A



5.3 Review of Probe Results

The probe results, as follows, were clustered into groups comprised of Public Street Conditions, Neighbouring Site Conditions, Internal Site Conditions, Pedestrian Entrance Conditions, and Outdoor Amenity Space Conditions. The measurement locations are depicted in Figure 4 and are listed in Figures 6a and 6b for the winter and summer seasons for the existing and proposed configurations. The results are also graphically depicted in Figures 7a – 7d, and compared in a table in Figure 10. The following discusses anticipated wind conditions and suitability for the points' intended use.

Public Street Conditions

Royal Windsor Drive

Probes 1 through 12 were located along Royal Windsor Drive, within the zone of influence of the proposed Development site. Their locations are depicted in Figure 4, their comfort ratings are listed for the winter and summer seasons in Figures 6a and 6b and depicted in Figures 7a through 7d. In the existing setting the probes indicate conditions along Royal Windsor Road that are mainly suitable for standing in the existing setting, with exceptions. Probes 1 and 9, located at the intersection with Southdown Road, realise windier conditions suitable for walking in the winter months, and probes 8, 10, 11, and 12 realise slightly more comfortable conditions in the summer months, rated suitable for sitting. The low-rise buildings along the street deflect portions of the wind climate to flow up and over the pedestrian level, resulting in fairly comfortable conditions, whereas areas proximate to the intersection with Southdown Road are exposed to larger portions of the wind climate.

With inclusion of the proposed Development a realignment of winds was noted along Royal Windsor Drive. This can be attributed to the proposed Development causing a realignment of winds that reduces apparent wind effects at the pedestrian level for several wind directions, but causes an increase to winds for others, as indicated in the Appendices Figure B, Ground Level Wind Velocity Plots presented as a ratio of gradient wind velocity. Increased winds are attributed to the proposed Development redirecting winds through downwash and other phenomena, to flow along portions of Royal Windsor Drive. Conversely, improvements in wind conditions can be attributed to the proposed Development effectively reducing the propensity for specific winds being deflected to flow along the street and over the areas.

In the proposed setting, probe 5 realised increases in winds from easterly and westerly winds that are directed to flow around the southmost corner of the proposed Development, sufficient to change the standing ratings to uncomfortable in the winter and walking in the summer. In the winter months, probe 2 similarly changed from standing to walking, and in the summer probes 8, 10, and 12 changed from sitting to standing. The uncomfortable winter rating is near the transition to walking conditions, and with consideration of fine design and landscape elements, it is expected to be suitable as such throughout the majority of the year.

As such, with inclusion of the proposed Development, Royal Windsor Drive will remain mostly comfortable and suitable for the intended purpose throughout the year, with the above-noted exception. Consideration of design and landscape elements that were too fine to incorporate into the massing model will result in more comfortable conditions.

Royal Windsor Drive remains within the pedestrian level wind velocity safety criteria as an All-Weather Area, as described in Section 4.7 and depicted in Figure 9.

Southdown Road

In addition to the probes situated at the intersection with Royal Windsor Drive, and discussed above, probes 13 through 16 were located along Southdown Road within the zone of influence of the proposed Development site. Probes situated on Southdown Road indicate wind conditions in the existing setting that are suitable for standing throughout the year, with the exception of probe 13 that is rated as uncomfortable in the winter and suitable for walking in the summer. The relatively open surrounds transitioning to high-rise buildings along the northeast side of Southdown Road contribute to the localised windy areas proximate to said high-rise buildings.

In the proposed setting, areas to the north through northeast of the proposed Development realised increases in westerly through northwesterly and southeasterly winds that are directed to flow around the proposed Development and over the street. These increases in winds were sufficient to change the winter ratings from standing to walking at probes 14 and 15. Conversely, probe 16, located to the east of the proposed Development, realised additional blockage from dominant westerly winds in the proposed setting, sufficient to improve the summer rating from standing to sitting.

As such, Southdown Road will remain comfortable and suitable for the intended use throughout the year in the proposed setting, with exception. The existing uncomfortable winter conditions at probe 13 remain with inclusion of the proposed Development, however the rating is relatively near the transition to walking conditions and with consideration of fine design and landscape elements, is expected to be suitable as such through the majority of the year.

With inclusion of the proposed Development, Southdown Road will remain within safety criteria as an All-Weather Area.

Neighbouring Site Conditions

Probe 17 was located within the neighbouring GO Station parking lot to the northwest of the proposed Development site. The area was rated suitable for standing throughout the year in both the existing and proposed settings and will remain suitable for the intended use throughout the year. Consideration of fine design and landscape elements will result in more comfortable conditions than reported.

Probes 18 and 19 were located within the neighbouring commercial parking lots to the southeast of the proposed Development site. The area was rated suitable for standing year-round in the existing setting. With inclusion of the proposed Development, the area realises improvements in portions of the northwesterly and southeasterly wind climate that were sufficient to change the summer rating at probe 19 from standing to sitting. The area will realise similar conditions to the existing setting and will experience more comfortable conditions with consideration of fine design and landscape elements.

Probe 20 was located within Twin Spruce Park, to the north of the intersection of Royal Windsor Drive and Southdown Road. The area is exposed to large portions of the westerly and northeasterly wind climate that are directed to flow around the neighbouring high-rise building to the northwest. The area realises similar conditions in the existing and proposed settings and is rated as uncomfortable in the winter months and suitable for standing in the summer. The uncomfortable winter rating is near the transition to walking conditions and with consideration of fine design and landscape elements, is expected to be suitable as such through the majority of the year.

Probes 21 through 25 were located around the neighbouring low-rise commercial buildings to the immediate southwest of the proposed Development site. In the existing setting, the area is fairly well protected by the low-rise surrounds, resulting in conditions suitable for sitting throughout the year, with the exception of probes 21, 23, and 24 that were rated for standing in the winter season. With inclusion of the proposed Development, the neighbouring area realises increases in winds that are directed to flow down and around the proposed buildings and through the gap between the proposed and existing buildings. As such probes 22 and 25 change ratings from sitting to standing through the winter, and probe 24 changes from standing to walking in the winter and sitting to standing through the summer. The areas will remain suitable for the intended uses and consideration of existing and proposed fine design and landscape features will result in more comfortable conditions than reported.

With inclusion of the proposed Development, the above-mentioned neighbouring sites will remain within the pedestrian level safety criteria as All-Weather Areas.

Internal Site Conditions

Probes 27 through 29, and 48 through 50, were situated on walkways along the easement between Towers 1 & 2 and Towers 3 & 4. The areas are exposed to large portions of the westerly through northwesterly and easterly through southeasterly wind climate that are directed to flow down and around the towers and through the gaps in between. As such, the space is mainly rated for standing in the summer and walking in the winter, with the exception of probes 29 and 48 that are rated for walking in the summer and uncomfortable in the winter. The uncomfortable ratings are near the transition to walking conditions, and with consideration of fine design and landscape elements, are expected to be suitable as such throughout the majority of the year. As such, the walkway between the buildings will be windy from time to time, but will generally remain suitable for the intended use throughout the year, with the above-noted exceptions.

Probes 31 through 33 were placed along a walkway adjacent to the southeast façade of Tower 2, fronting Royal Windsor Drive. The area realises fairly windy conditions as it is exposed to large portions of the wind climate that are directed to flow around the corners of

Tower 2. As such, probe 31 is rated for standing in the summer and walking through the winter, and probes 32 and 33 are rated for walking in the summer and uncomfortable through the winter. Mitigation is recommended for the southmost corner of the building, in order to achieve more comfortable conditions along the walkway. This may be achieved with the addition of a large canopy/trellis element and/or porous wind screens situated along the building façade. Consideration of appropriate mitigative features in the area will result in more comfortable conditions throughout the year.

Probes 34 through 36 were located along a walkway adjacent to the southwest façade of Towers 1 and 2. The area is exposed to northerly through northwesterly and southerly through southeasterly winds that are directed to flow down and around the building façades and over the walkway. As such, the area is rated suitable for walking throughout the year, with the exception of probes 34 and 35 that were rated for standing in the summer months. The area will be suitable for the intended use as a walkway and will realise more comfortable conditions with consideration of fine design and landscape elements.

Probes 37 and 38 were located along the northwestern façade of Tower 1, and probes 52 and 39 were similarly located along the northwestern façade of Tower 3. The area realises fairly comfortable conditions, suitable for standing throughout much of the year, with exceptions. Probe 39 is exposed to westerly winds that are directed to flow around the northmost corner of the proposed Development, resulting in slightly windier conditions, rated for walking through the winter, and probes 38 and 52 realise more comfortable conditions rated for sitting in the summer season. The area will be suitable for the intended use as a walkway and will realise more comfortable conditions with consideration of fine design and landscape elements.

Probes 40 through 42 and 43 through 46 were respectively located along the northeast façade of Towers 3 and 4 and southeast façade of Tower 4. The areas are fairly well protected from large portions of the dominant westerly wind climate, and as such realise conditions suitable for standing throughout the majority of the year, with exceptions. Probes 43 and 46, located adjacent to corners of Tower 4, realise slightly windier conditions in the winter, rated for walking. Probes 42, 44, and 45 realise more comfortable conditions, rated for sitting throughout the summer season. The area will be suitable for the intended use as a walkway and will realise more comfortable conditions with consideration of fine design and landscape elements.

The above-mentioned internal site areas fall within the pedestrian level safety criteria as All-Weather Areas.

Pedestrian Entrance Conditions

Probe 26 was situated adjacent to the Main Residential Entrance to Tower 1, accessed at the northmost corner of the building. The entrance is exposed to large portions of the wind climate emanating from the northwest and southeast that are directed to flow down and around the buildings and through the gap in between. As such, the entrance is rated suitable for standing in the summer and walking through the winter months. Relocating the entrance away from the building corner and gap between buildings would be ideal, however alternate means of mitigating the Residential Entrance may also be explored including recessing the entrance into the façade, and/or the addition of porous wind screens adjacent to the entrance along the building façade. Consideration of an appropriate mitigation plan for the entrance will result in more comfortable conditions that are suitable for the intended use throughout the year.

Probe 30 was similarly situated adjacent to the Main Residential Entrance to Tower 2, accessed at the eastmost corner of the building. The entrance is exposed to large portions of the wind climate emanating from the west through northwest and south that are directed to flow down and around the buildings and through the gap in between. As such, the entrance is rated suitable for standing in the summer and walking through the winter months. Relocating the entrance away from the building corner and gap between buildings would be ideal, however alternate means of mitigating the Residential Entrance may also be explored including recessing the entrance into the façade, and/or the addition of porous wind screens adjacent to the entrance along the building façade. Consideration of an appropriate mitigation plan for the entrance will result in more comfortable conditions that are suitable for the intended use throughout the year.

Probe 51 was similarly situated adjacent to the Main Residential Entrance to Tower 3, accessed at the westmost corner of the building. The entrance is exposed to large portions of the wind climate emanating from the west through northwest and south through east that are directed to flow down and around the buildings and through the gap in between. As such, the entrance is rated suitable for walking in the summer and uncomfortable through the winter months. Relocating the entrance away from the building corner and gap between buildings would be ideal, however alternate means of mitigating the Residential Entrance may also be explored including recessing the entrance into the façade, and/or the addition of porous wind screens adjacent to the entrance along the building façade. Consideration of an appropriate mitigation plan for the entrance will result in more comfortable conditions that are suitable for the intended use throughout the year.

Probe 47 was similarly situated adjacent to the Main Residential Entrance to Tower 4, accessed at the southmost corner of the building. The entrance is exposed to large portions of the wind climate emanating from the west through north and south through east that are directed to flow down and around the buildings and through the gap in between. As such, the entrance is rated suitable for walking year-round. Relocating the entrance away from the building corner and gap between buildings would be ideal, however alternate means of mitigating the Residential Entrance may also be explored including recessing the entrance into the façade, and/or the addition of porous wind screens adjacent to the entrance along the building façade. Consideration of an appropriate mitigation plan for the entrance will result in more comfortable conditions that are suitable for the intended use throughout the year.

Various probes were located on walkways adjacent to the façades of the proposed Development, as discussed above. Many of these probes were located proximate to retail and live/work entrances to the buildings. While the areas are generally suitable as walkways, many realise windy conditions for use as entrances, and require mitigation in order to achieve more comfortable conditions throughout the year. Entrances located within the gap between buildings and/or proximate to corners of the buildings would most benefit from said mitigation plans. Mitigative features may include recessing the entrances into the façades, overhead canopies, vestibules, revolving doors, and/or the addition of porous wind screens adjacent to the entrances along the building façades. Consideration of appropriate mitigation plans for the retail and live/work entrances will result in more comfortable conditions that are suitable for the intended uses throughout the year.

Wind conditions comfortable for standing or better are preferable at building entrances, while conditions suitable for walking are suitable for walkways. Mitigation plans are recommended for the various residential, retail, and live/work entrances to the proposed Development in order to achieve more comfortable conditions that are suitable for the intended purposes throughout the year. The entrances to the proposed Development fall within pedestrian safety criteria as All-Weather Areas.

Outdoor Amenity Space Conditions

Outdoor Amenity Space is proposed on the 8th level of the connective podiums of both Towers 1 & 2 and Towers 3 & 4. The areas were unable to accommodate conventional probes and as such alternate means of assessing the areas were applied. The areas will be sheltered from portions of the wind climate by the proposed buildings, however they will be exposed to winds that are directed to flow down and around the towers and over the areas. As such, the spaces are expected to be suitable for walking throughout large portions of the year, particularly near the corners of the towers, with localised standing conditions in more sheltered areas. Mitigation plans are recommended for the spaces which may include 2.0m high perimeter wind screens, coniferous trees, raised planters populated with coarse plantings, canopies/trellises over seating areas, and/or others situated throughout the spaces as practical. Consideration of appropriate mitigation plans will result in more comfortable conditions than reported that are seasonally suitable for the intended uses.

The proposed Outdoor Amenity Spaces are expected to fall within the pedestrian safety criteria as All-Weather Areas.

5.4 Summary

The observed wind velocity and flow patterns at the proposed Development site are largely influenced by approach wind characteristics that are dictated by the mainly suburban surrounding areas to prevailing and less dominant wind directions. These surroundings moderate wind flow in streamlines near the pedestrian level from some directions and allow winds to accelerate upon approach from over more open surrounds, resulting in somewhat windy conditions at the existing site and in the surrounds. Historical weather data recorded at Billy Bishop Airport indicates that strong winds of a mean wind speed greater than 30 km/h occur approximately 20 percent of the time during the winter months and 6 percent of the time during the summer.

Once the subject site is developed, ground level winds at some locations remain similar to the existing setting, with localised areas of higher pedestrian level winds. As such, the site and surrounds are predicted mainly suitable for walking, standing, or better, throughout the year and generally remain comfortable and appropriate to the areas' intended purposes, with exceptions. Localised uncomfortable conditions are realised through the winter season proximate to the southmost corner of the proposed Development, and within the gap between buildings. These uncomfortable conditions are relatively near the transition to walking conditions and consideration of proposed surface roughness features such as fine design and landscape elements will result in conditions more comfortable than those reported herein. The relationship between surface roughness and wind is discussed in the Appendix and shown graphically in Figure A of the same section.

Additional mitigation is recommended proximate to the southmost corner of the building as well as at the various residential, retail, and live/work entrances to the proposed Development in order to achieve more comfortable conditions that are seasonally suitable for the intended uses. Mitigation plans are similarly recommended for the 8th level Outdoor Amenity Spaces in order to achieve seasonally appropriate conditions.

The proposed Development and surrounds are expected to realise wind conditions mainly suitable to a typical suburban context.

6. FIGURES:

Figure 1: Laboratory Testing Facility

Figure 2a: Site Aerial Photo

Figure 2b: Site Plan

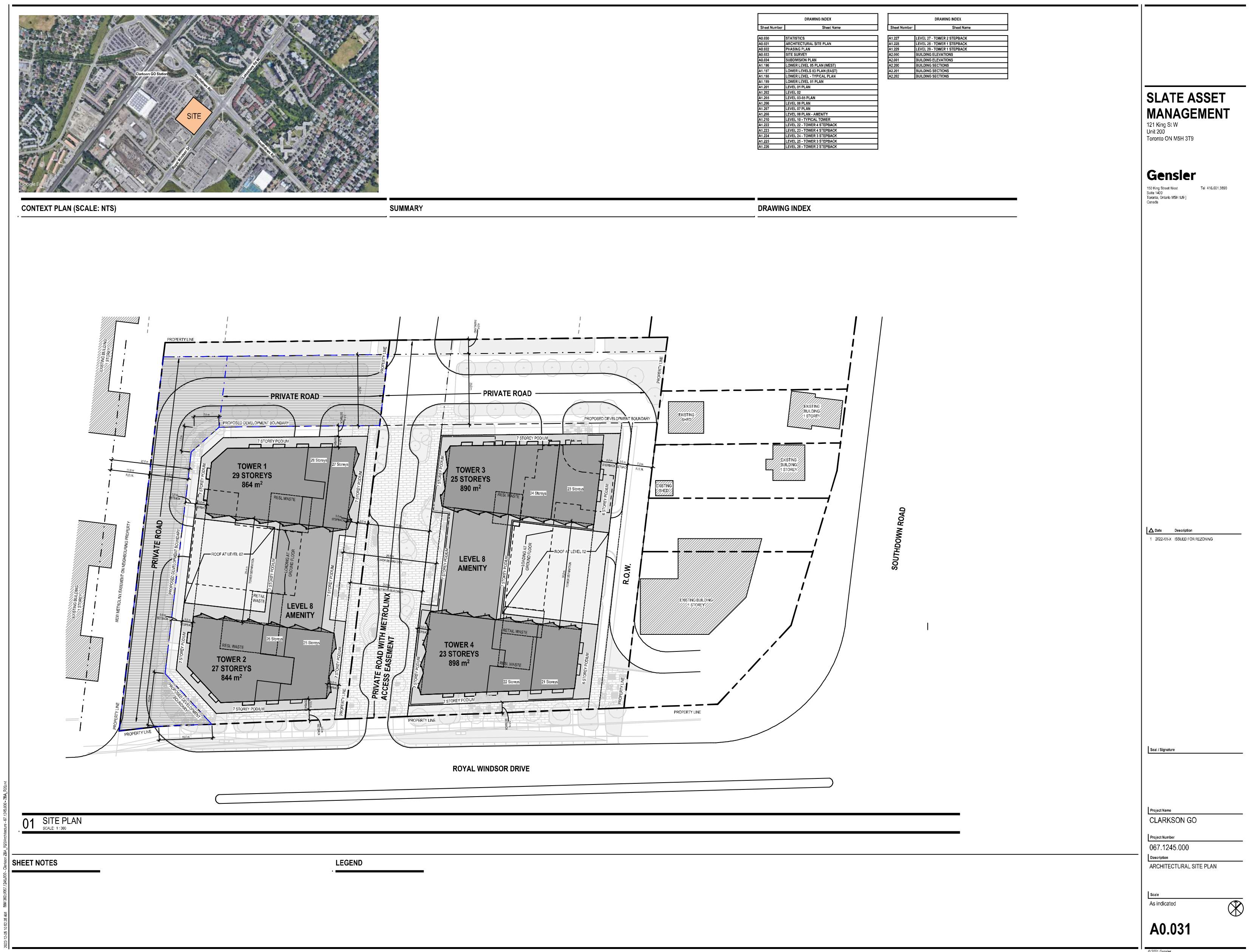
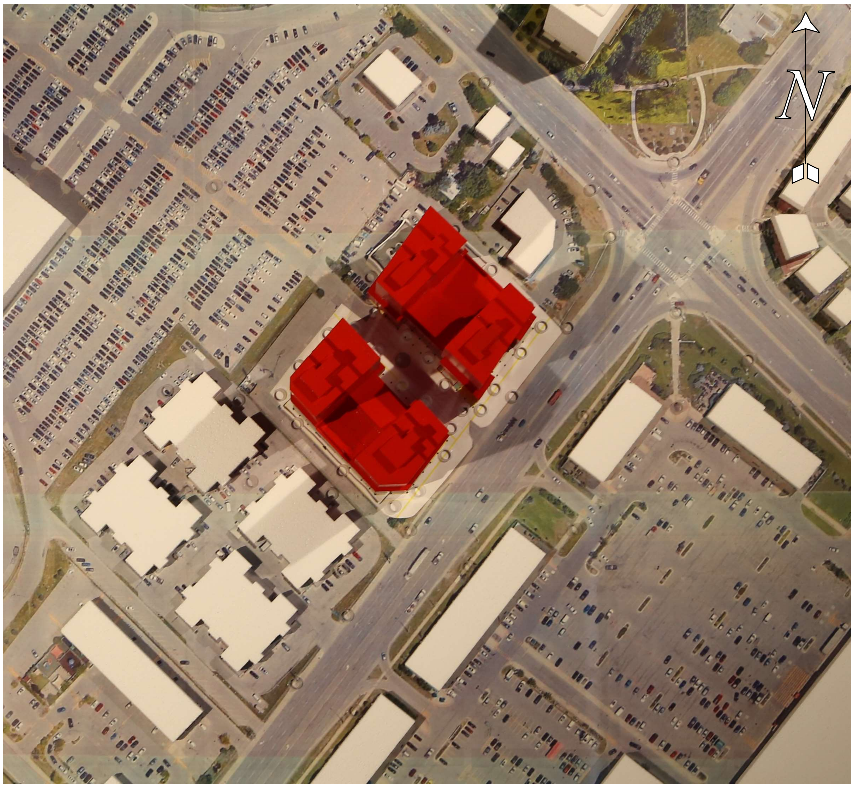
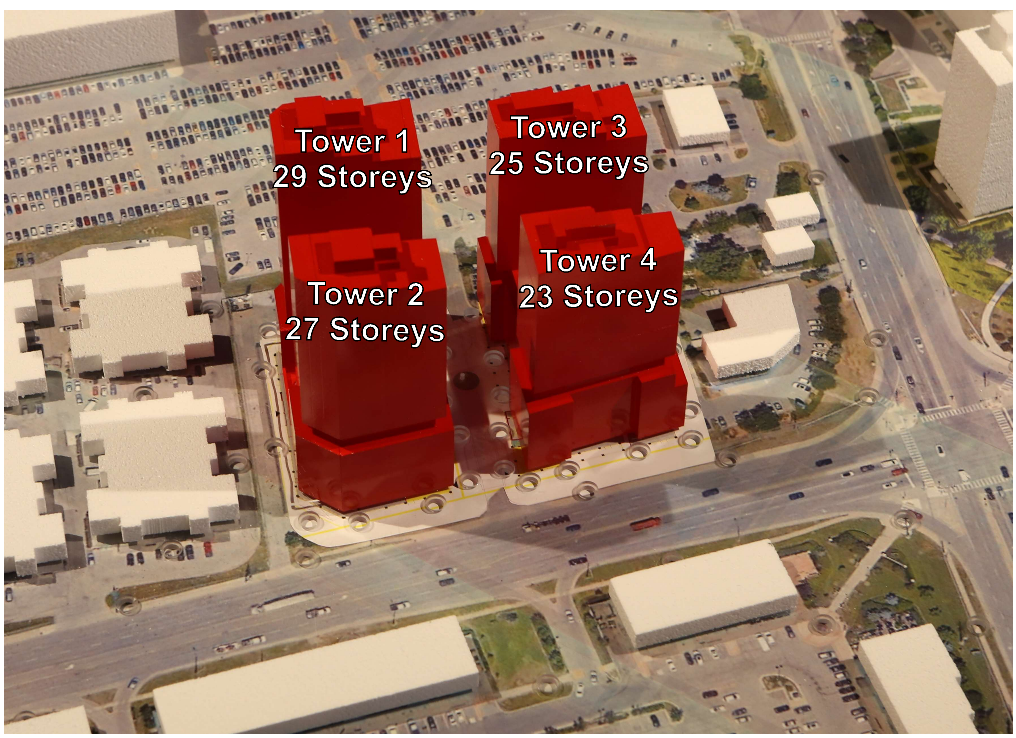


Figure 3: 1:500 Scale model of test site



a) Overall view of model - Proposed Site

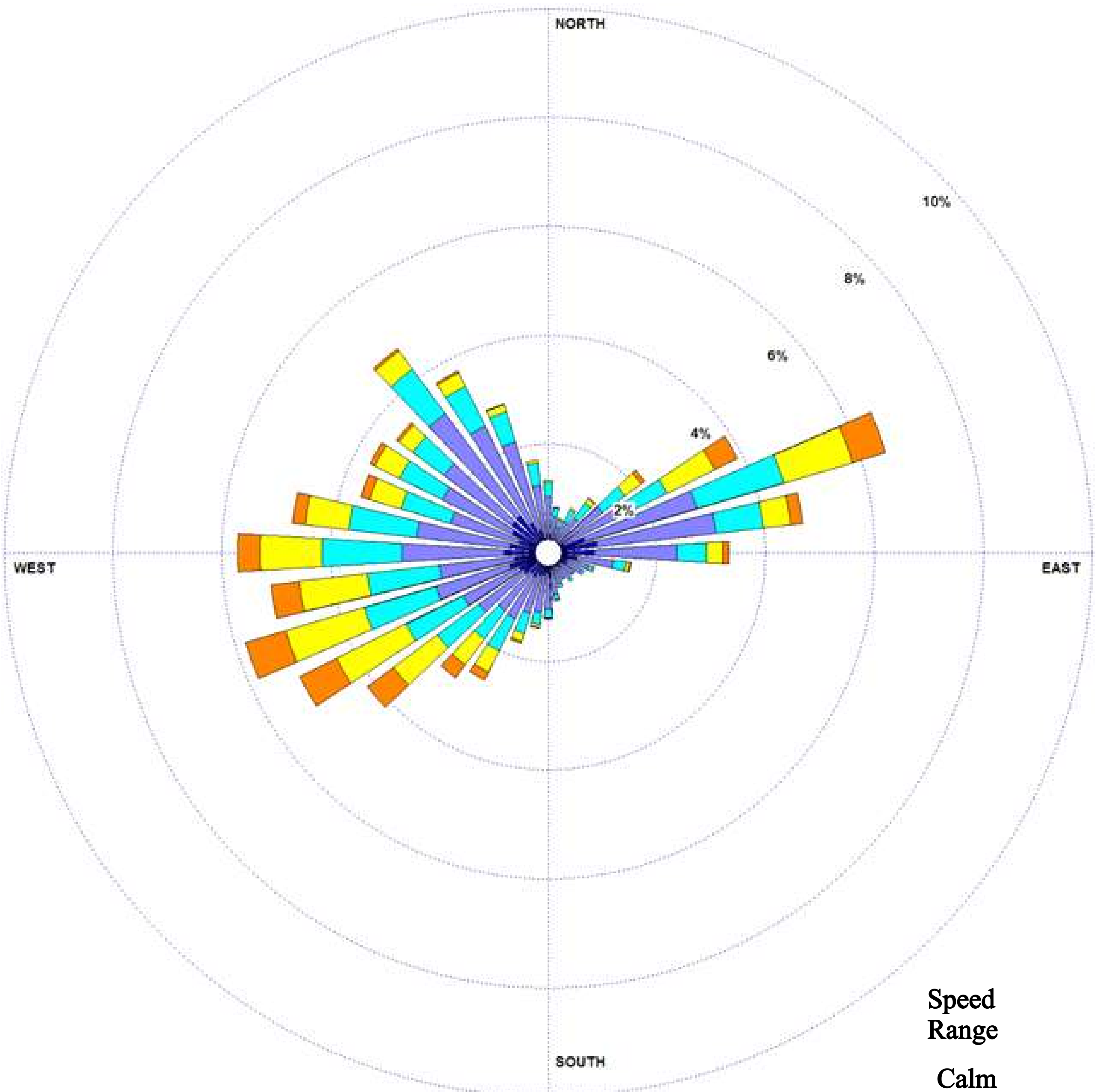


b) Close-up view of model - Proposed Site

Figure 4: Location plan for pedestrian level wind velocity measurements.

Figure 5a: Winter Wind Rose - Billy Bishop Airport.

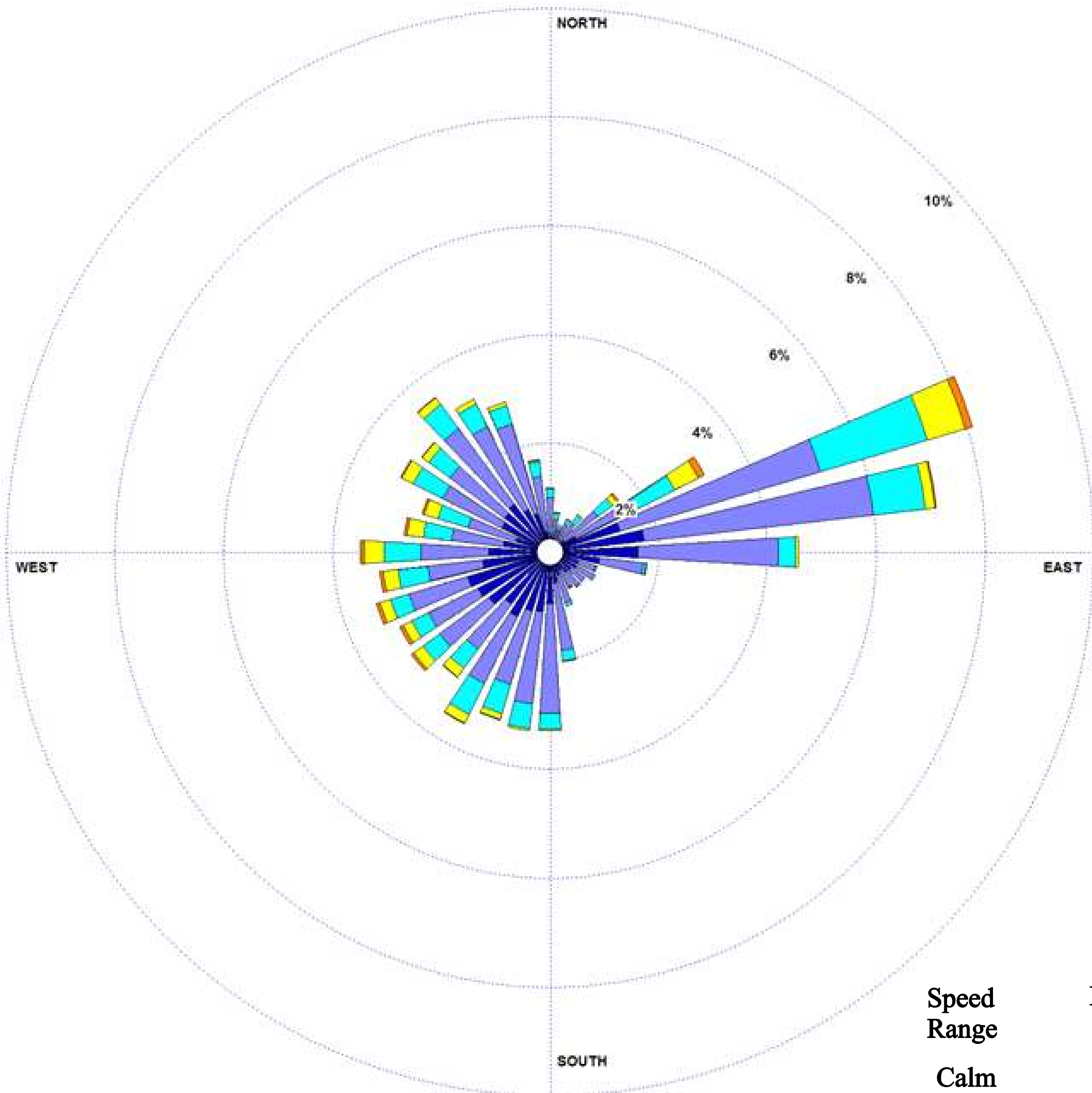
Historical Directional Distribution of Winds (@ 10*m* height)
November through April (1989 - 2017)



Speed Range	
Calm	4%
1 - 10*km/h*	17%
11 - 20*km/h*	38%
21 - 30*km/h*	21%
31 - 40*km/h*	14%
> 40*km/h*	6%

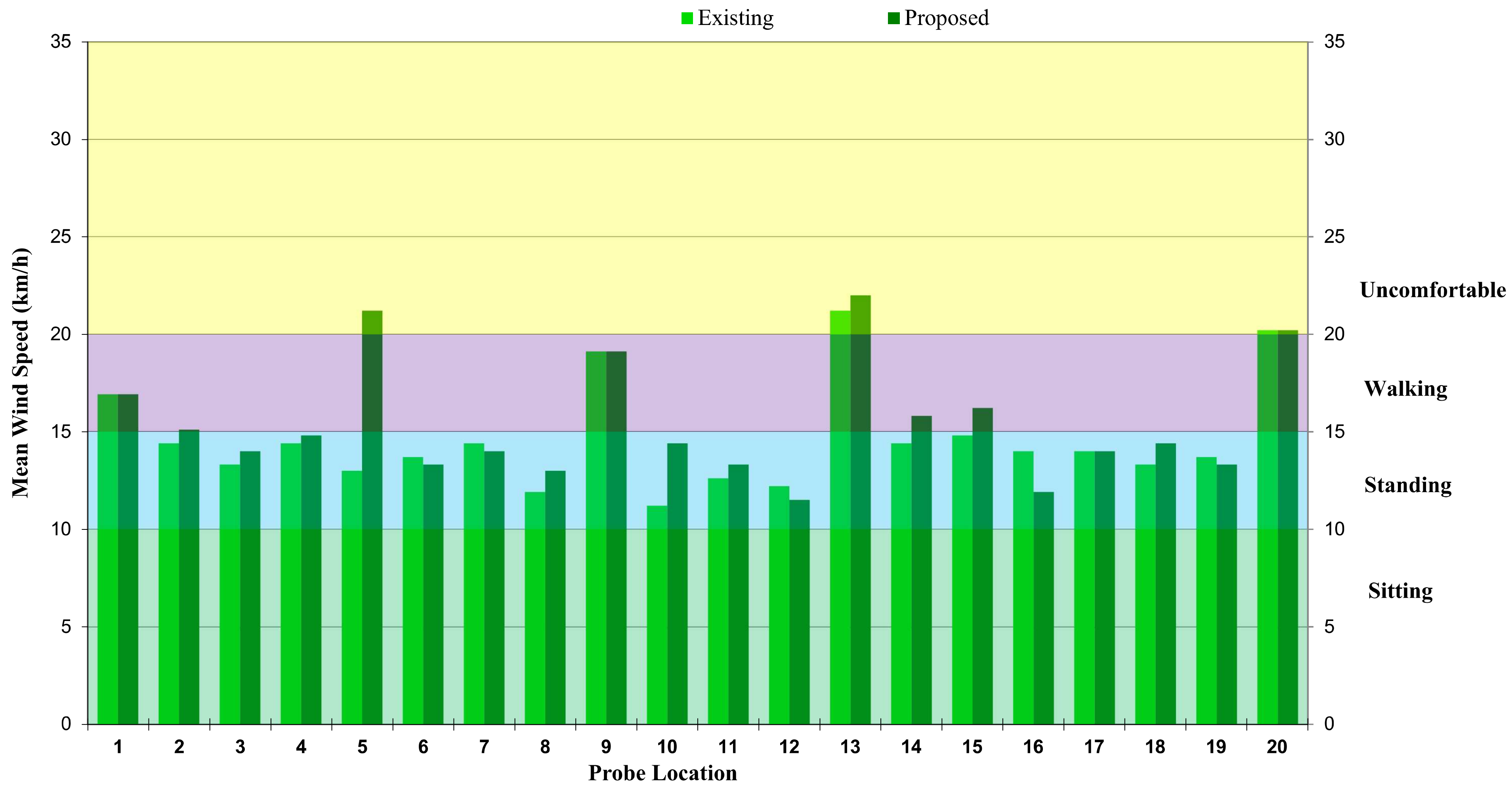
Figure 5b: Summer Wind Rose - Billy Bishop Airport.

Historical Directional Distribution of Winds (@ 10*m* height)
May through October (1989 - 2017)



Speed Range	Probability (%)
Calm	7%
1 - 10*km/h*	30%
11 - 20*km/h*	43%
21 - 30*km/h*	14%
31 - 40*km/h*	5%
> 40*km/h*	1%

Figure 6a: WINTER - Wind Speed Exceeded 20% of the Time (Locations 1 to 20).



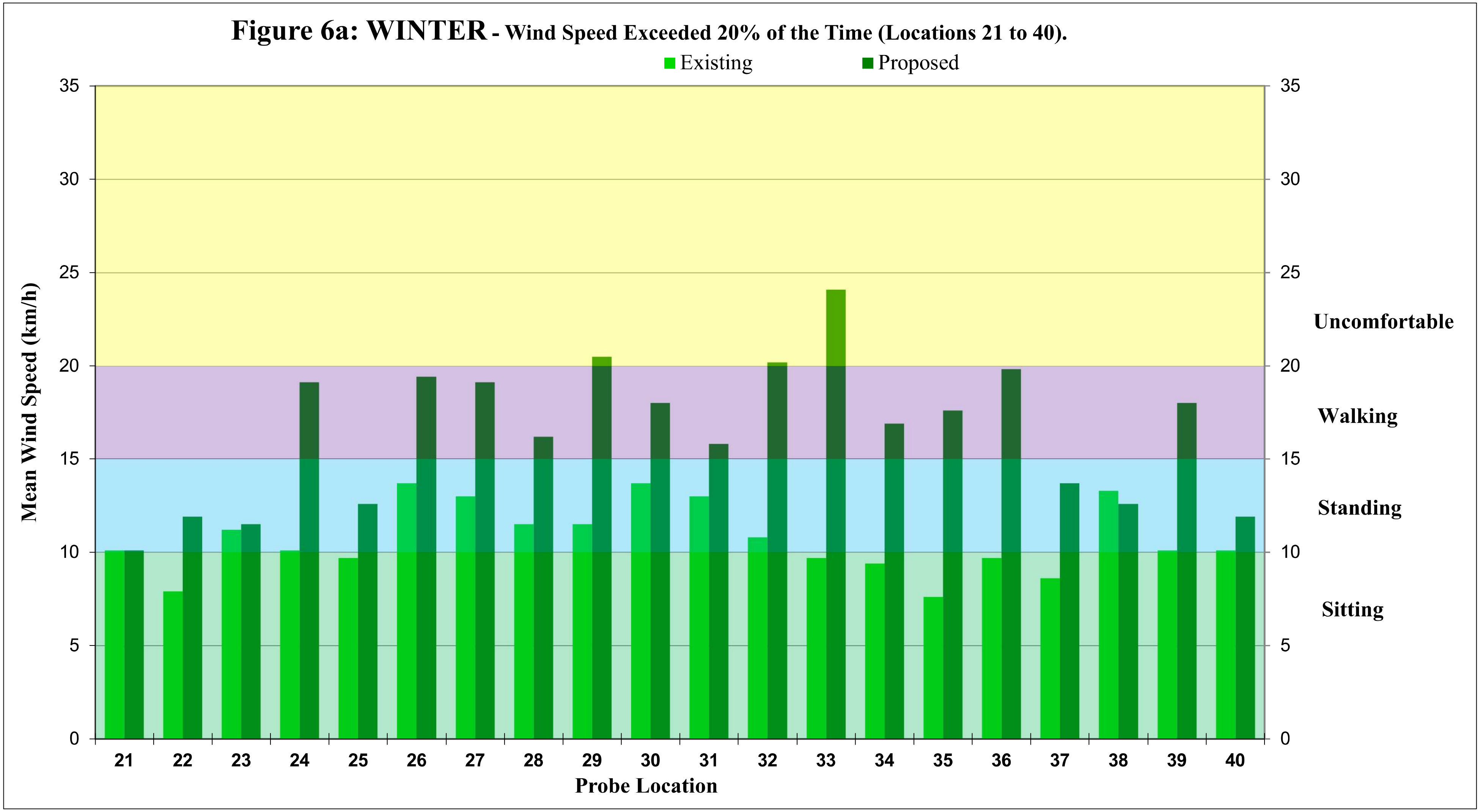


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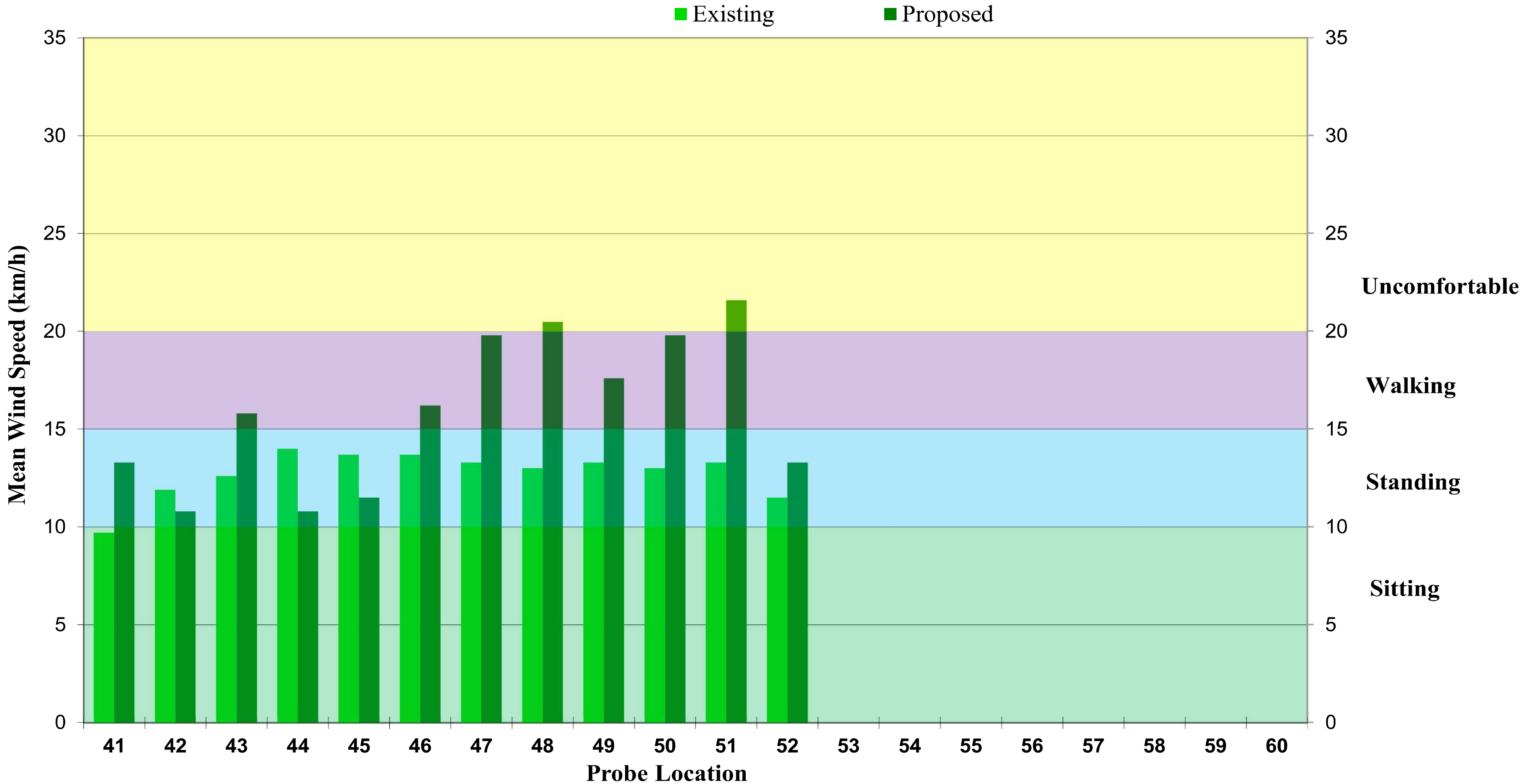
Figure 6a: WINTER - Wind Speed Exceeded 20% of the Time (Locations 41 to 52).



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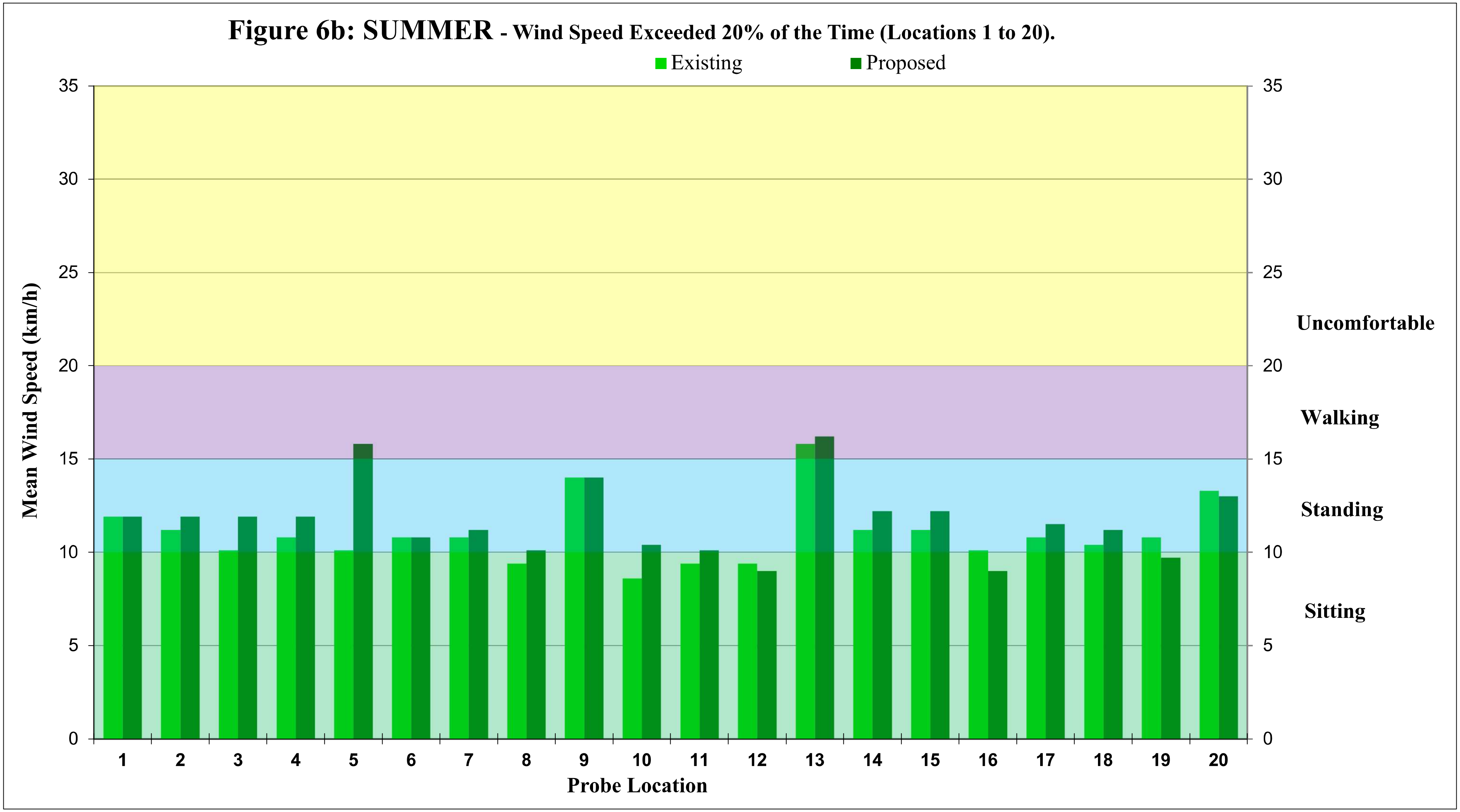

Figure 6b: SUMMER - Wind Speed Exceeded 20% of the Time (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (km/h)
Probe Location
Uncomfortable
Walking
Standing
Sitting
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

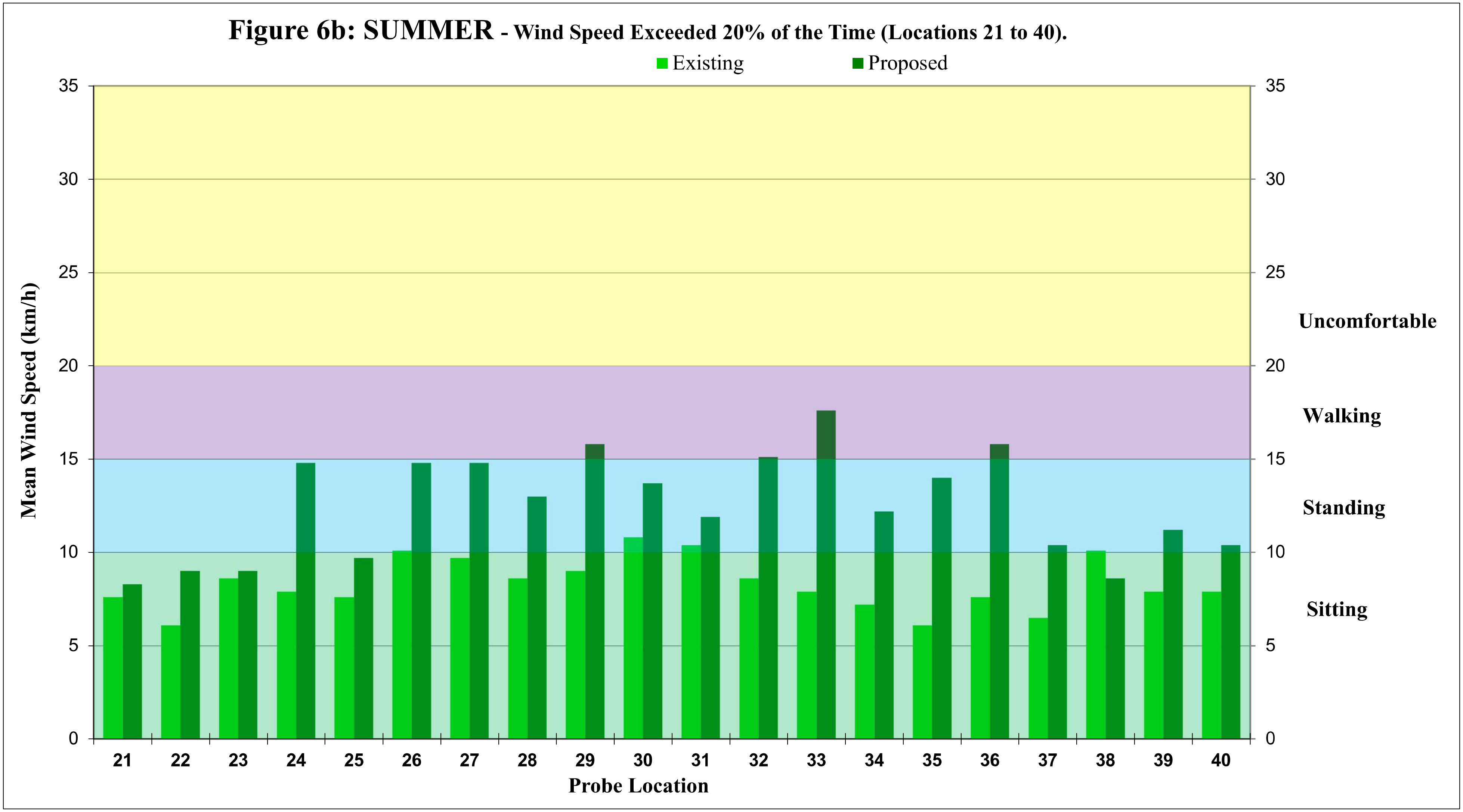

Figure 6b: SUMMER - Wind Speed Exceeded 20% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (km/h)
0
5
10
15
20
25
30
35
Uncomfortable
Walking
Standing
Sitting
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Probe Location

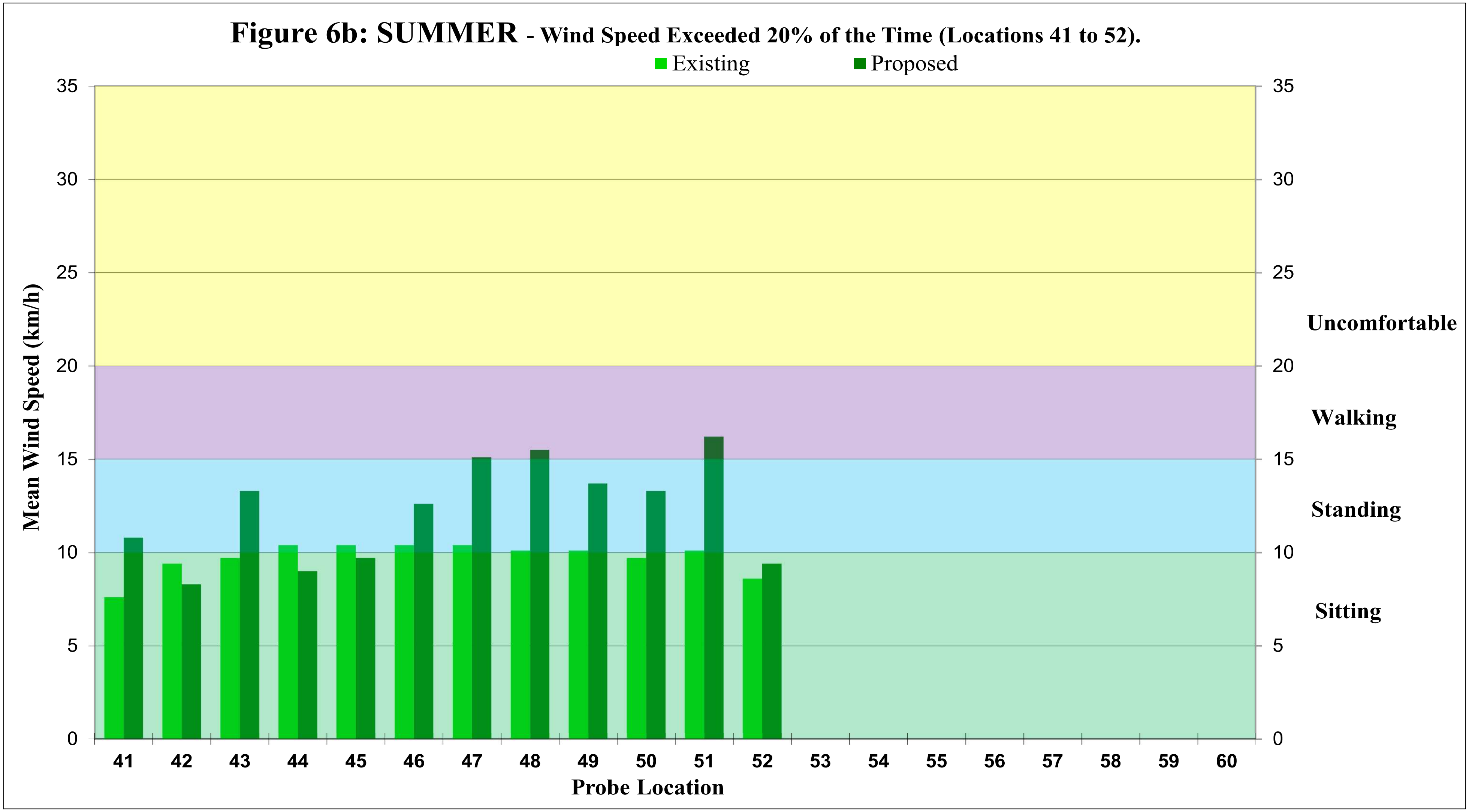

Figure 6b: SUMMER - Wind Speed Exceeded 20% of the Time (Locations 41 to 52).
Existing
Proposed
Mean Wind Speed (km/h)
0
5
10
15
20
25
30
35
Uncomfortable
Walking
Standing
Sitting
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Probe Location

Figure 7a: Pedestrian level wind velocity comfort categories.

Comfort Categories - Winter - Existing

Sitting Standing Walking Uncomfortable

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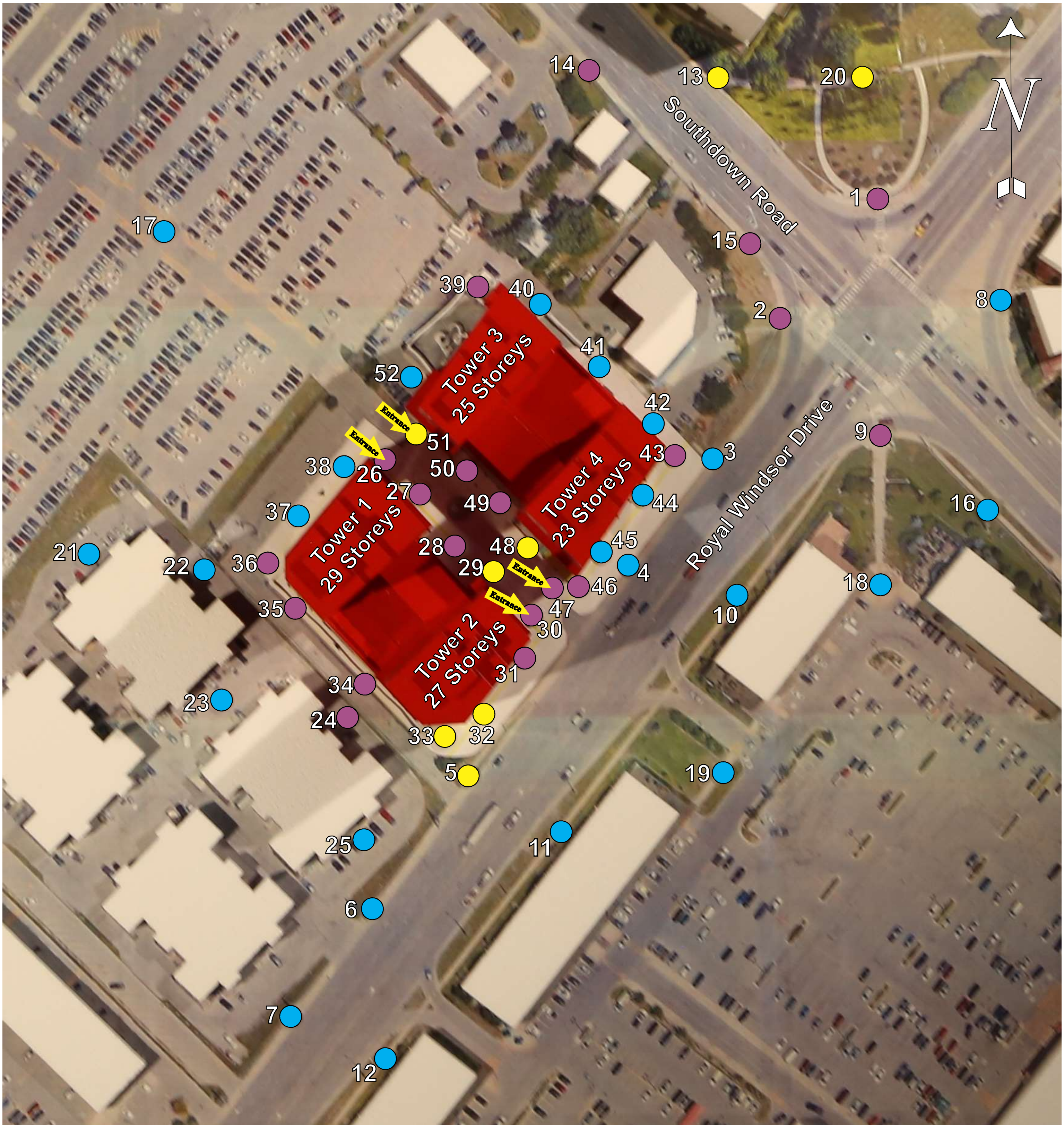
Figure 7b: Pedestrian level wind velocity comfort categories.



Comfort Categories - Winter - Proposed

Sitting   Standing   Walking   Uncomfortable

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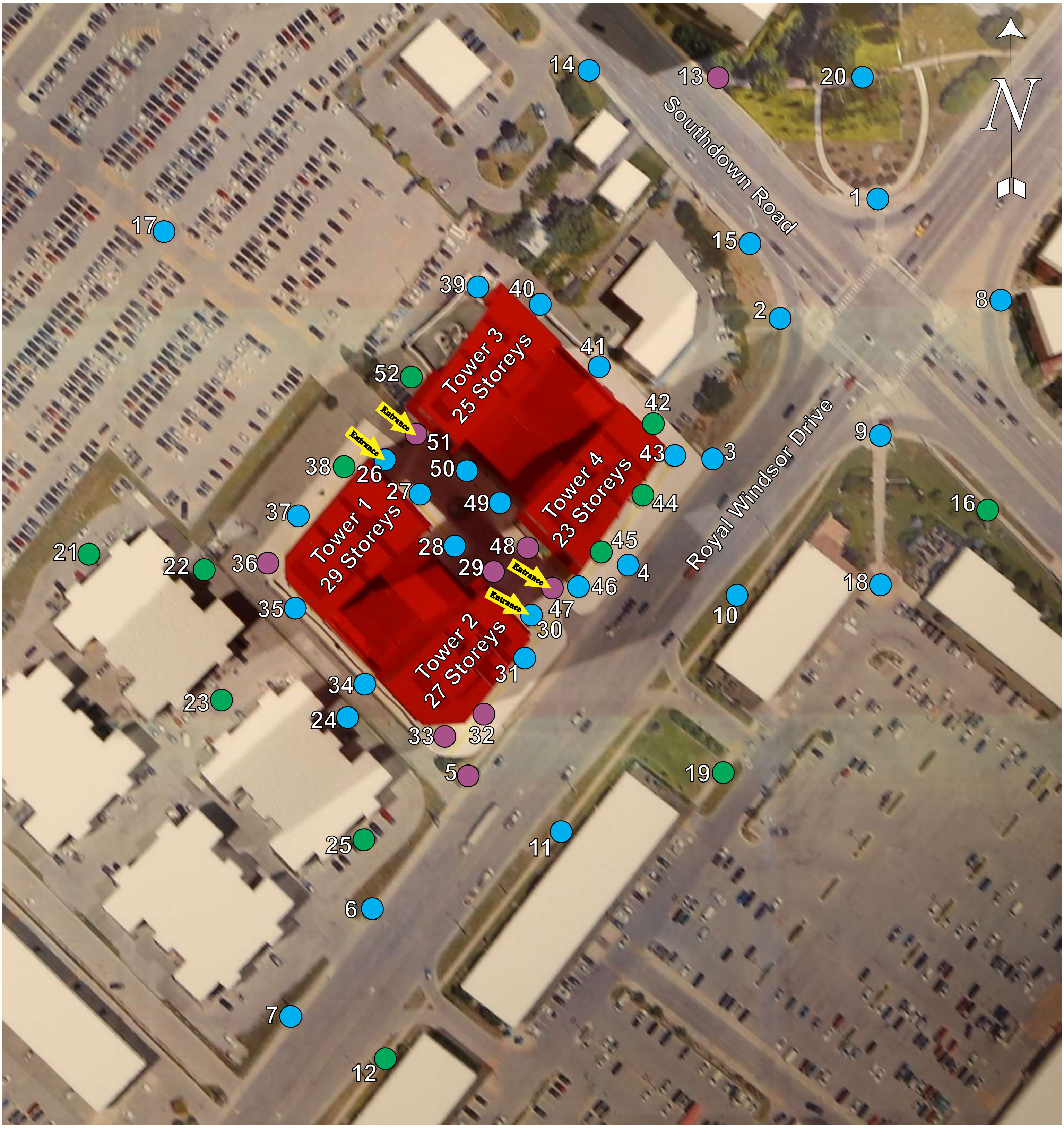
Figure 7c: Pedestrian level wind velocity comfort categories.

Comfort Categories - Summer - Existing

Sitting Standing Walking Uncomfortable

Figure 7d: Pedestrian level wind velocity comfort categories.



Comfort Categories - Summer - Proposed

Sitting Standing Walking Uncomfortable

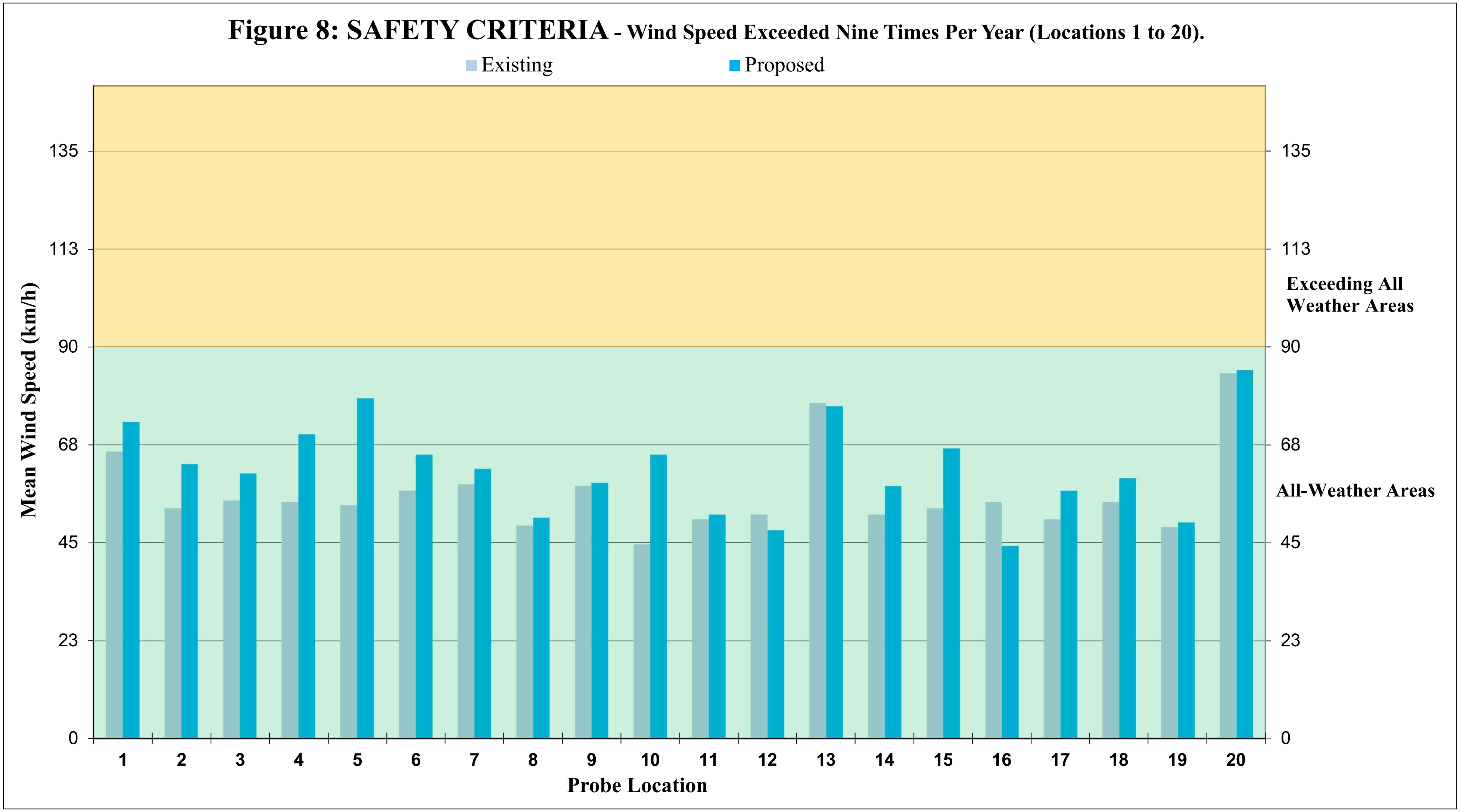


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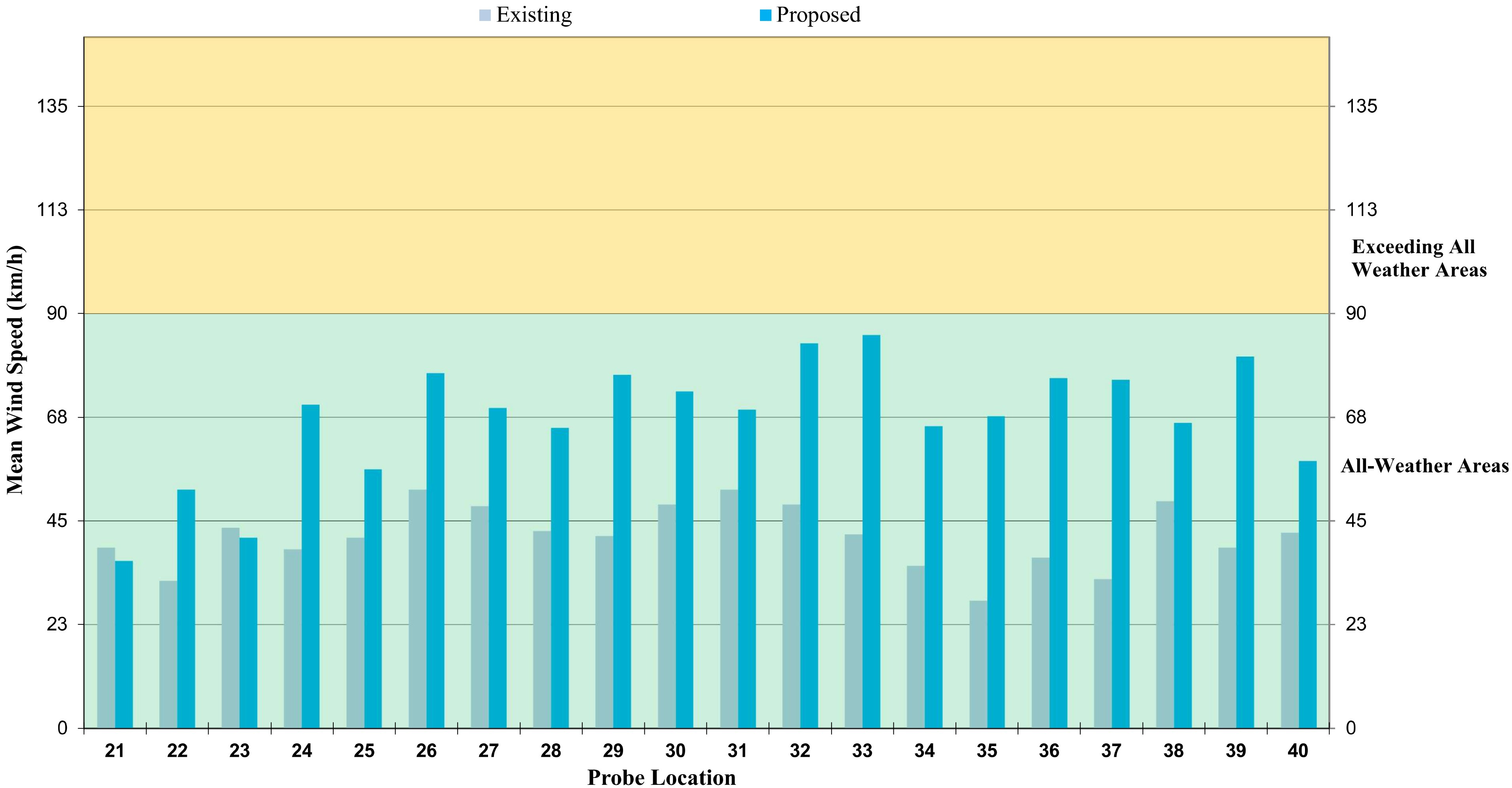
Figure 8: SAFETY CRITERIA - **Wind Speed Exceeded Nine Times Per Year (Locations 21 to 40).**



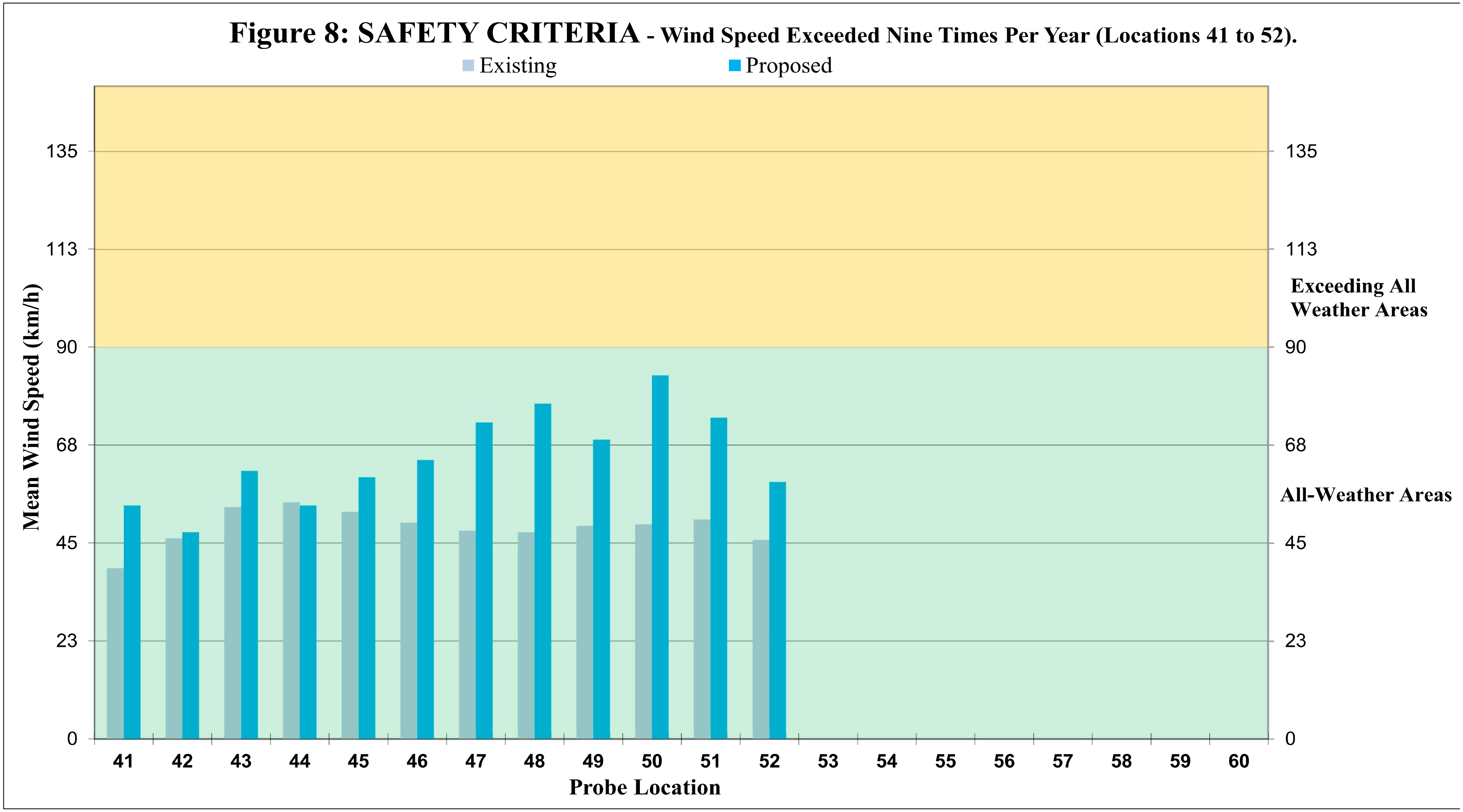


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Nine Times Per Year (Locations 41 to 52).
Existing
Proposed
Mean Wind Speed (km/h)
135
113
90
68
45
23
0
Exceeding All Weather Areas
All-Weather Areas
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Probe Location

Figure 9a: Pedestrian level wind velocity safety criteria.

Safety Criteria - Existing

All-Weather Areas   Exceeding All-Weather Areas

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Figure 9b: Pedestrian level wind velocity safety criteria.

Safety Criteria - Proposed

All-Weather Areas | Exceeding All-Weather Areas

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Figure 10: Pedestrian Level Wind Comfort and Safety Comparison Table

	Mean Wind Speed (km/h)					
	Winter		Summer		Safety	
Probe	Existing	Proposed	Existing	Proposed	Existing	Proposed
1	16.9	16.9	11.9	11.9	65.9	72.7
2	14.4	15.1	11.2	11.9	52.9	63.0
3	13.3	14.0	10.1	11.9	54.7	60.8
4	14.4	14.8	10.8	11.9	54.4	69.8
5	13.0	21.2	10.1	15.8	53.6	78.1
6	13.7	13.3	10.8	10.8	56.9	65.2
7	14.4	14.0	10.8	11.2	58.3	61.9
8	11.9	13.0	9.4	10.1	49.0	50.8
9	19.1	19.1	14.0	14.0	58.0	58.7
10	11.2	14.4	8.6	10.4	44.6	65.2
11	12.6	13.3	9.4	10.1	50.4	51.5
12	12.2	11.5	9.4	9.0	51.5	47.9
13	21.2	22.0	15.8	16.2	77.0	76.3
14	14.4	15.8	11.2	12.2	51.5	58.0
15	14.8	16.2	11.2	12.2	52.9	66.6
16	14.0	11.9	10.1	9.0	54.4	44.3
17	14.0	14.0	10.8	11.5	50.4	56.9
18	13.3	14.4	10.4	11.2	54.4	59.8
19	13.7	13.3	10.8	9.7	48.6	49.7
20	20.2	20.2	13.3	13.0	83.9	84.6
21	10.1	10.1	7.6	8.3	39.2	36.4
22	7.9	11.9	6.1	9.0	32.0	51.8
23	11.2	11.5	8.6	9.0	43.6	41.4
24	10.1	19.1	7.9	14.8	38.9	70.2
25	9.7	12.6	7.6	9.7	41.4	56.2
26	13.7	19.4	10.1	14.8	51.8	77.0
27	13.0	19.1	9.7	14.8	48.2	69.5
28	11.5	16.2	8.6	13.0	42.8	65.2
29	11.5	20.5	9.0	15.8	41.8	76.7
30	13.7	18.0	10.8	13.7	48.6	73.1
31	13.0	15.8	10.4	11.9	51.8	69.1
32	10.8	20.2	8.6	15.1	48.6	83.5
33	9.7	24.1	7.9	17.6	42.1	85.3
34	9.4	16.9	7.2	12.2	35.3	65.5
35	7.6	17.6	6.1	14.0	27.7	67.7
36	9.7	19.8	7.6	15.8	37.1	76.0
37	8.6	13.7	6.5	10.4	32.4	75.6
38	13.3	12.6	10.1	8.6	49.3	66.2
39	10.1	18.0	7.9	11.2	39.2	80.6
40	10.1	11.9	7.9	10.4	42.5	58.0

	Mean Wind Speed (km/h)					
	Winter		Summer		Safety	
Probe	Existing	Proposed	Existing	Proposed	Existing	Proposed
41	9.7	13.3	7.6	10.8	39.2	53.6
42	11.9	10.8	9.4	8.3	46.1	47.5
43	12.6	15.8	9.7	13.3	53.3	61.6
44	14.0	10.8	10.4	9.0	54.4	53.6
45	13.7	11.5	10.4	9.7	52.2	60.1
46	13.7	16.2	10.4	12.6	49.7	64.1
47	13.3	19.8	10.4	15.1	47.9	72.7
48	13.0	20.5	10.1	15.5	47.5	77.0
49	13.3	17.6	10.1	13.7	49.0	68.8
50	13.0	19.8	9.7	13.3	49.3	83.5
51	13.3	21.6	10.1	16.2	50.4	73.8
52	11.5	13.3	8.6	9.4	45.7	59.0
53	0.0	0.0	0.0	0.0	0.0	0.0
54	0.0	0.0	0.0	0.0	0.0	0.0
55	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0
58	0.0	0.0	0.0	0.0	0.0	0.0
59	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0
66	0.0	0.0	0.0	0.0	0.0	0.0
67	0.0	0.0	0.0	0.0	0.0	0.0
68	0.0	0.0	0.0	0.0	0.0	0.0
69	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0
71	0.0	0.0	0.0	0.0	0.0	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0
76	0.0	0.0	0.0	0.0	0.0	0.0
77	0.0	0.0	0.0	0.0	0.0	0.0
78	0.0	0.0	0.0	0.0	0.0	0.0
79	0.0	0.0	0.0	0.0	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0

Comfort (km/h)				Safety (km/h)	
0 - 10	Sitting	15 - 20	Walking	0 - 90	Pass
10 - 15	Standing	20 +	Uncomf	90 +	Fail

7. APPENDIX

BACKGROUND AND THEORY OF WIND MOVEMENT

During the course of a modular analysis of an existing or proposed site, pertinent wind directions must be analysed with regard to the macroclimate and microclimate. In order for the results of the study to be valid, the effects of both climates must be modelled in test procedures.

Macroclimate

Wind velocity, frequency and directions are used in tests with models to establish part of the macroclimate. These variables are determined from meteorological data collected at the closest weather monitoring station. This information is used in the analysis of the site to establish upstream (approach) wind and weather conditions.

When evaluating approach wind velocities and characteristic profiles in the field it is necessary to evaluate certain boundary conditions. At the earth's surface, "no slip" conditions require the wind speed to be zero. At an altitude of approximately one kilometre above the earth's surface, the motion of the wind is governed by pressure distributions associated with large-scale weather systems. Consequently, these winds, known as "geostrophic" or "freestream" winds, are independent of the surface topography. In model simulation, as in the field, the area of concern is the boundary layer between the earth's surface and the geostrophic winds. The term boundary layer is used to describe the velocity profile of wind currents as they increase from zero to the geostrophic velocity.

The approach boundary layer profile is affected by specific surface topography upstream of the test site. Over relatively rough terrain (urban) the boundary layer is thicker and the wind speed increases rather slowly with height. The opposite is true over open terrain (rural). The following power law equation is used to represent the mean velocity profile for any given topographic condition:

$$\frac{U}{U_F} = \left(\frac{z}{z_F}\right)^a$$

where U = wind velocity (m/s) at height z (m)
a = power law exponent
and subscript $_F$ refers to freestream conditions

Typical values for a and z_F are summarized below:

Terrain	a	z_F (m)
Rural	0.14 - 0.17	260 - 300
Suburban	0.20 - 0.28	300 - 420
Urban	0.28 - 0.40	420 - 550

Wind data is recorded at meteorological stations at a height z_{ref} , usually equal to about 10m above grade. This historical mean wind velocity and frequency data is often presented in the form of a wind rose. The mean wind velocity at z_{ref} , along with the appropriate constants based on terrain type, are used to determine the value for U_F , completing the definition of the boundary layer profile specific to the site. The following Figure shows representations of the boundary layer profile for each of the above terrain conditions:

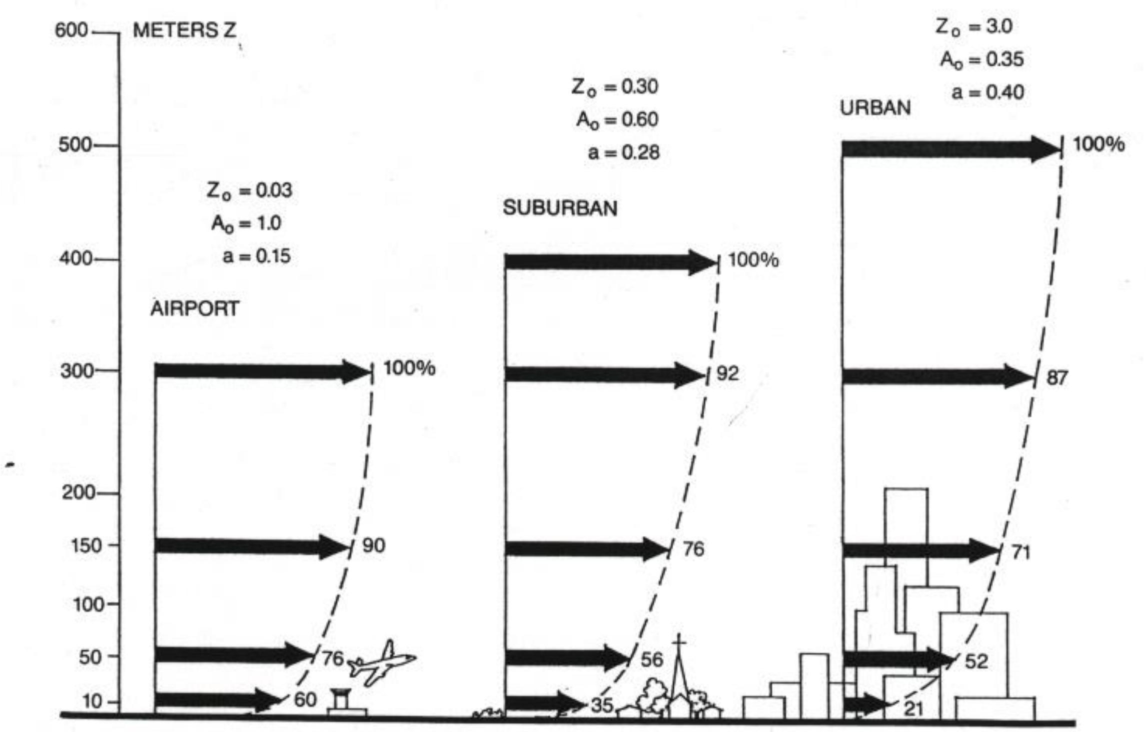


Figure A: Mean wind speed profiles for various terrain (from ASHRAE 1989).

For the above velocity profiles, ground level velocities at a height of $z = 2m$, for an urban macroclimate are approximately 52% of the mean values recorded at the meteorological station at a height equal to $z_{ref} = 10m$. For suburban and rural conditions, the values are 63% and 78% respectively. Thus, for a given wind speed at z_{ref} open terrain or fields (rural) will experience significantly higher ground level wind velocities than suburban or urban areas.

When a boundary layer wind flows over one terrain onto another, the boundary layer profile shape rapidly changes to that dictated by the new terrain. If the preceding wind flow is over rough suburban terrain and an open area is encountered a rapid increase in ground level winds will be realized. A similar effect will occur when large low-density residential areas are demolished to accommodate high-rise developments. The transitional open area will experience significantly higher pedestrian level winds than the previous suburban setting. Once the high-rise development is established, ground level winds will moderate with localized areas of higher pedestrian level winds likely to occur. Pedestrian level wind velocities respond to orientation and shape of the development and if the site is not appropriately engineered or mitigated, pedestrian level wind may be problematic.

Microclimate

The specific wind conditions related to the study site are known as the microclimate, which are dictated mainly by the following factors:

- The orientation and conformation of buildings within the vicinity of the site.
- The surrounding contours and pertinent landscape features.

The microclimate establishes the effect that surrounding buildings or landscape features have on the subject building and the effect the subject building has on the surrounds. For the majority of urban test sites the proper microclimate can be established by modelling an area of 300*m* in radius around the subject building. If extremely tall buildings are present then the study area must be larger, and if the building elevations are on the order of a few floors, smaller areas will suffice to establish the required microclimate.

General Wind Flow Phenomena

Wind flow across undulating terrain contains parallel streamlines with the lowest streamline adjacent to the surface. These conditions continue until the streamlines approach vertical objects. When this occurs there is a general movement of the streamlines upward ("Wind Velocity Gradient") and as they reach the top of the objects turbulence is generated on the lee side. This is one of the reasons for unexpected high wind velocities as this turbulent action moves to the base of the objects on the lee side.

Other fluid action occurs through narrow gaps between buildings (Venturi Action) and at sharp edges of a building or other vertical objects (Scour Action). These conditions are predictable at selected locations but do not conform to a set direction of wind as described by a macroclimate condition. In fact, the orientation and conformation of buildings, streets and landscaping establish a microclimate.

Because of the "Wind Velocity Gradient" phenomena, there is a "downwash" of wind at the face of buildings and this effect is felt at the pedestrian level. It may be experienced as high gusty winds or drifting snow. These effects can be obviated by windbreak devices on the windward side or by canopies over windows and doors on the lee side of the building.

The intersection of two streets or pedestrian walkways have funnelling effects of wind currents from any one of the four directions and is particularly severe at corners if the buildings project to the street line or are close to walkways.

Some high-rise buildings have gust effects as the wind velocities are generated suddenly due to the orientation and conformation of the site. Since wind velocities are the result of energy induced wind currents the solution to most problems is to reduce the wind energy at selected locations by carefully designed windbreak devices, often landscaping, to blend with the surrounds.

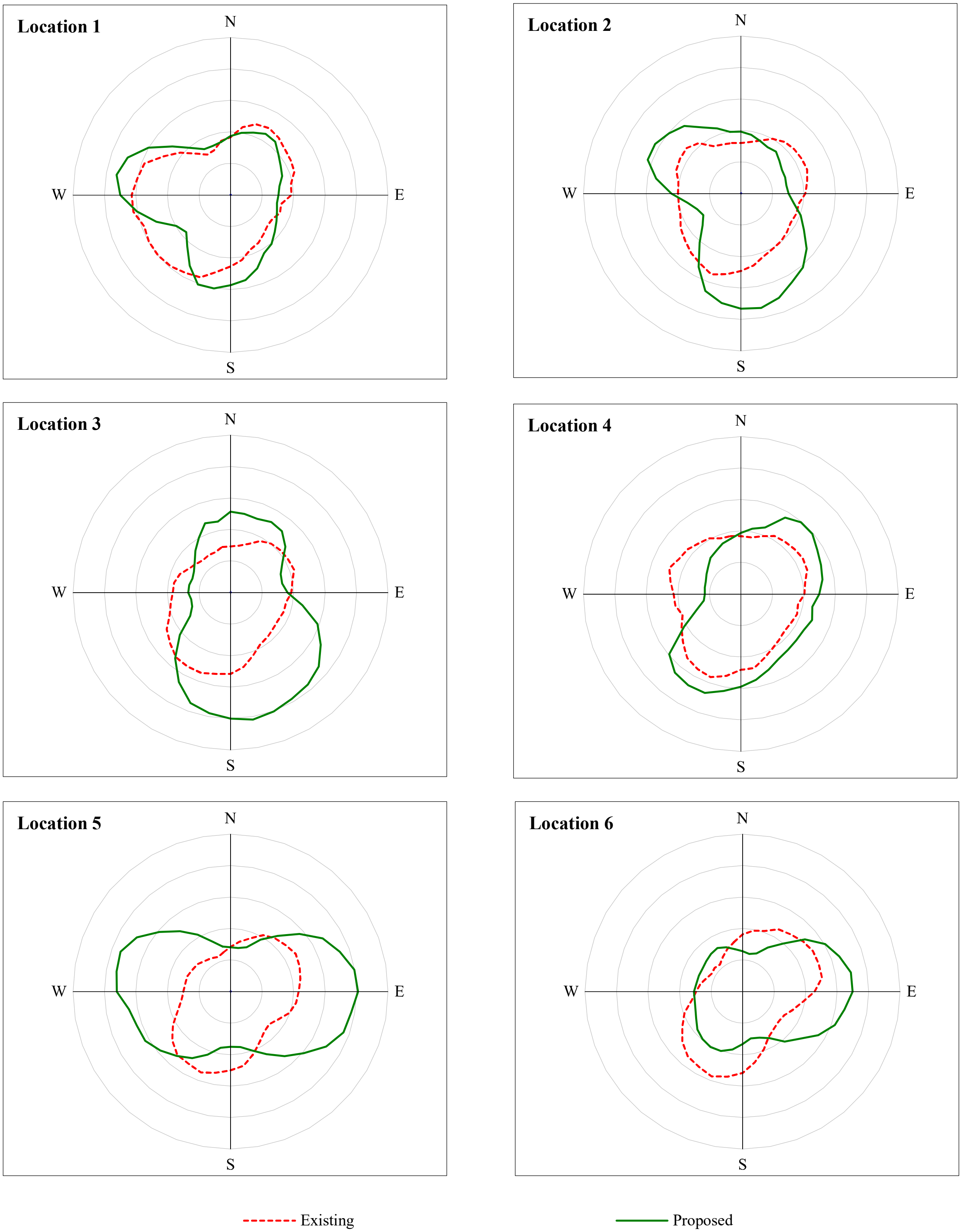
The Beaufort Scale is often used as a numerical relationship to wind speed based upon an observation of the effects of wind. Rear-Admiral Sir Francis Beaufort, commander of the Royal Navy, developed the wind force scale in 1805, and by 1838 the Beaufort wind force scale was made mandatory for log entries in ships of the Royal Navy. The original scale was an association of integers from 0 to 12, with a description of the effect of wind on the behaviour of a full-rigged man-of-war. The lower Beaufort numbers described wind in terms of ship speed, mid-range numbers were related to her sail carrying ability and upper numbers were in terms of survival. The Beaufort Scale was adopted in 1874 by the International Meteorological Committee for international use in weather telegraphy and, with the advent of anemometers, the scale was eventually adopted for meteorological purposes. Eventually, a uniform set of equivalents that non-mariners could relate to was developed, and by 1955, wind velocities in knots had replaced Beaufort numbers on weather maps. While the Beaufort Scale lost ground to technology, there remains the need to relate wind speed to observable wind effects and the Beaufort Scale remains a useful tool.

Abbreviated Beaufort Scale

Beaufort Number	Description	Wind Speed			Observations
		km/h	*m/s*	h=2*m* for Urban *m/s*	
2	Slight Breeze	6-11	1.6-3.3	< ~2	Tree leaves rustle; flags wave slightly; vanes show wind direction; small wavelets or scale waves.
3	Gentle Breeze	12-19	3.4-5.4	< ~3	Leaves and twigs in constant motion; small flags extended; long unbreaking waves.
4	Moderate Breeze	20-28	5.5-7.9	< ~4	Small branches move; flags flap; waves with whitecaps.
5	Fresh Breeze	29-38	8.0-10.7	< ~6	Small trees sway; flags flap and ripple; moderate waves with many whitecaps.
6	Strong Breeze	39-49	10.8-13.8	< ~8	Large branches sway; umbrellas used with difficulty; flags beat and pop; larger waves with regular whitecaps.
7	Moderate Gale	50-61	13.9-17.1	< ~10	Sea heaps up, white foam streaks; whole trees sway; difficult to walk; large waves.
8	Fresh Gale	62-74	17.2-20.7	> ~10	Twigs break off trees; moderately high sea with blowing foam.
9	Strong Gale	75-88	20.8-24.4		Branches break off trees; tiles blown from roofs; high crested waves.

Wind speeds indicated above, in *km/h* and *m/s*, are at a reference height of 10 metres, as are the wind speeds indicated on the Figure 5 wind roses. The mean wind speeds at pedestrian level, for an urban climate, would be approximately 56% of these values. The 3rd column for wind speed is shown for reference, at a height of 2*m*, in an urban setting. The approximate Comfort Category Colours are shown above. The relationship between wind speed and height relative to terrain is discussed in the appendices.

Figure B : Ground level wind velocity as a ratio of gradient wind velocity.



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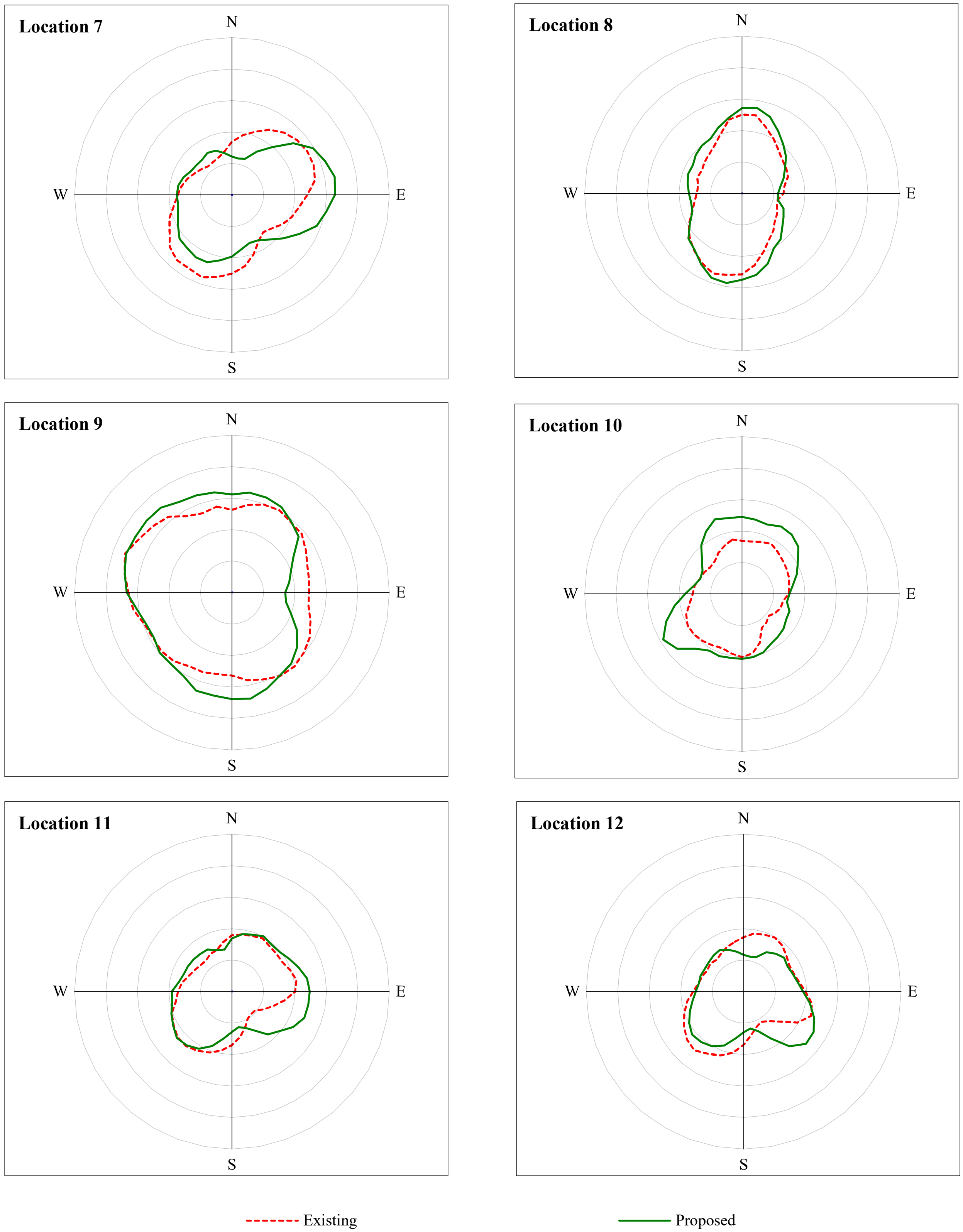

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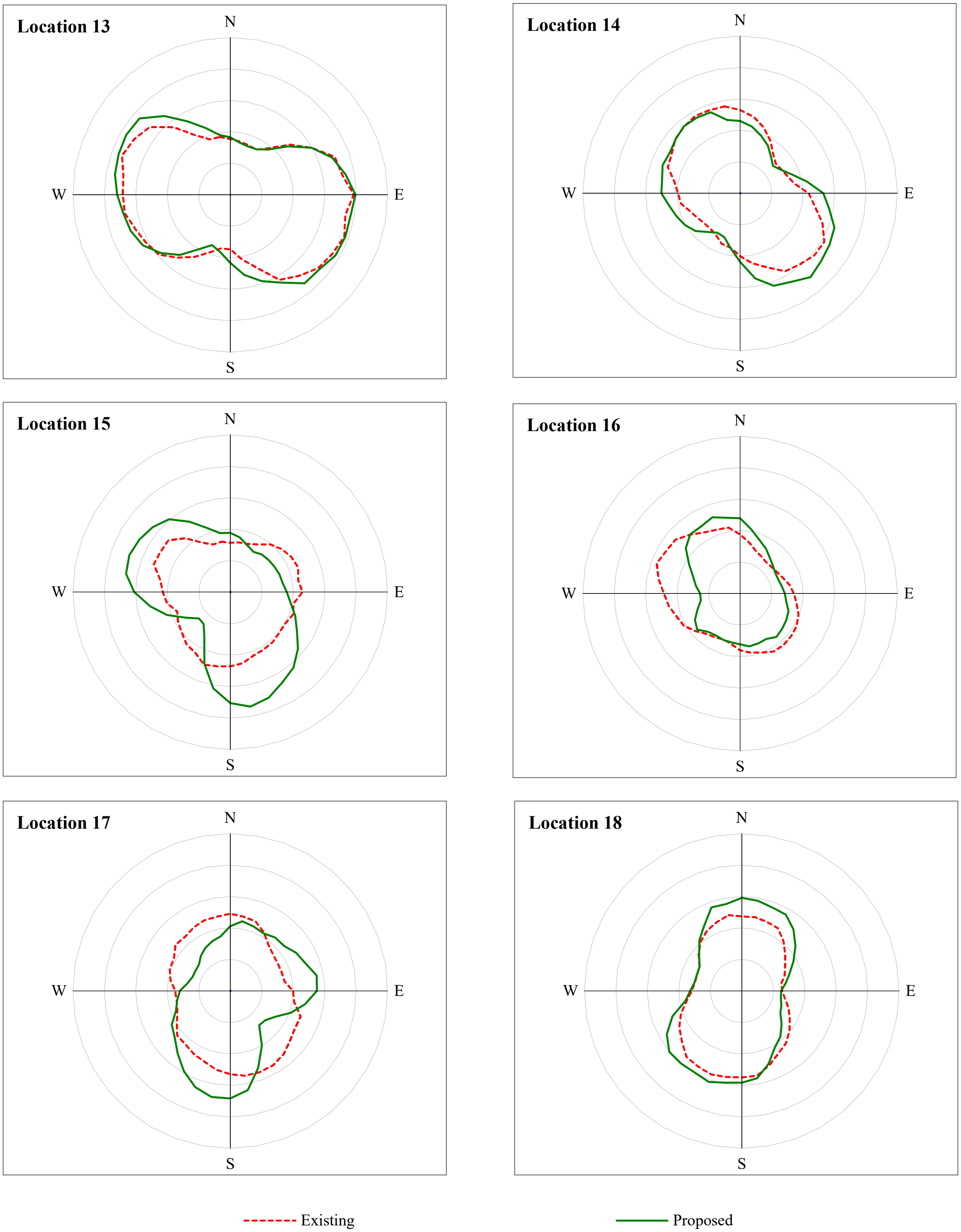

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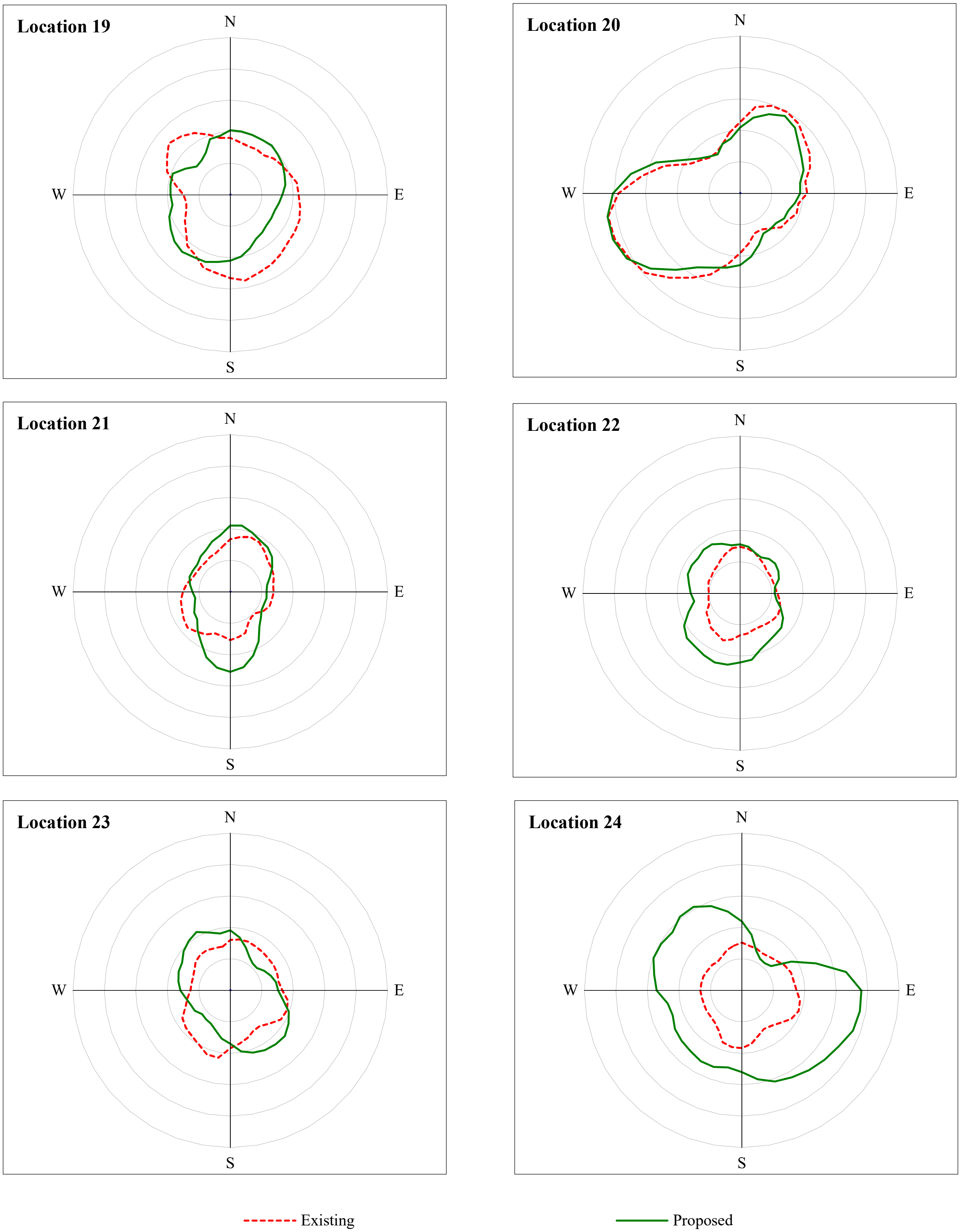

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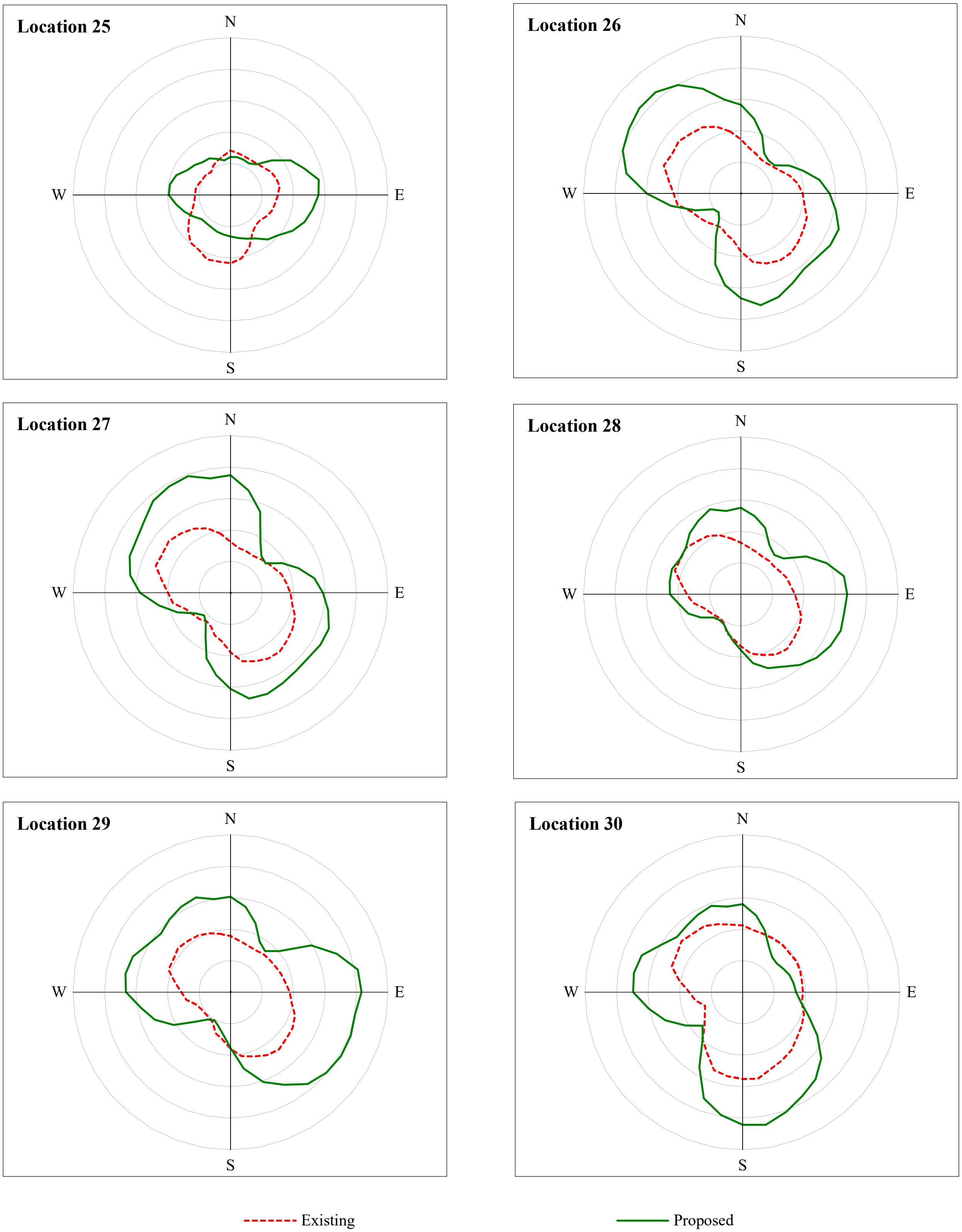

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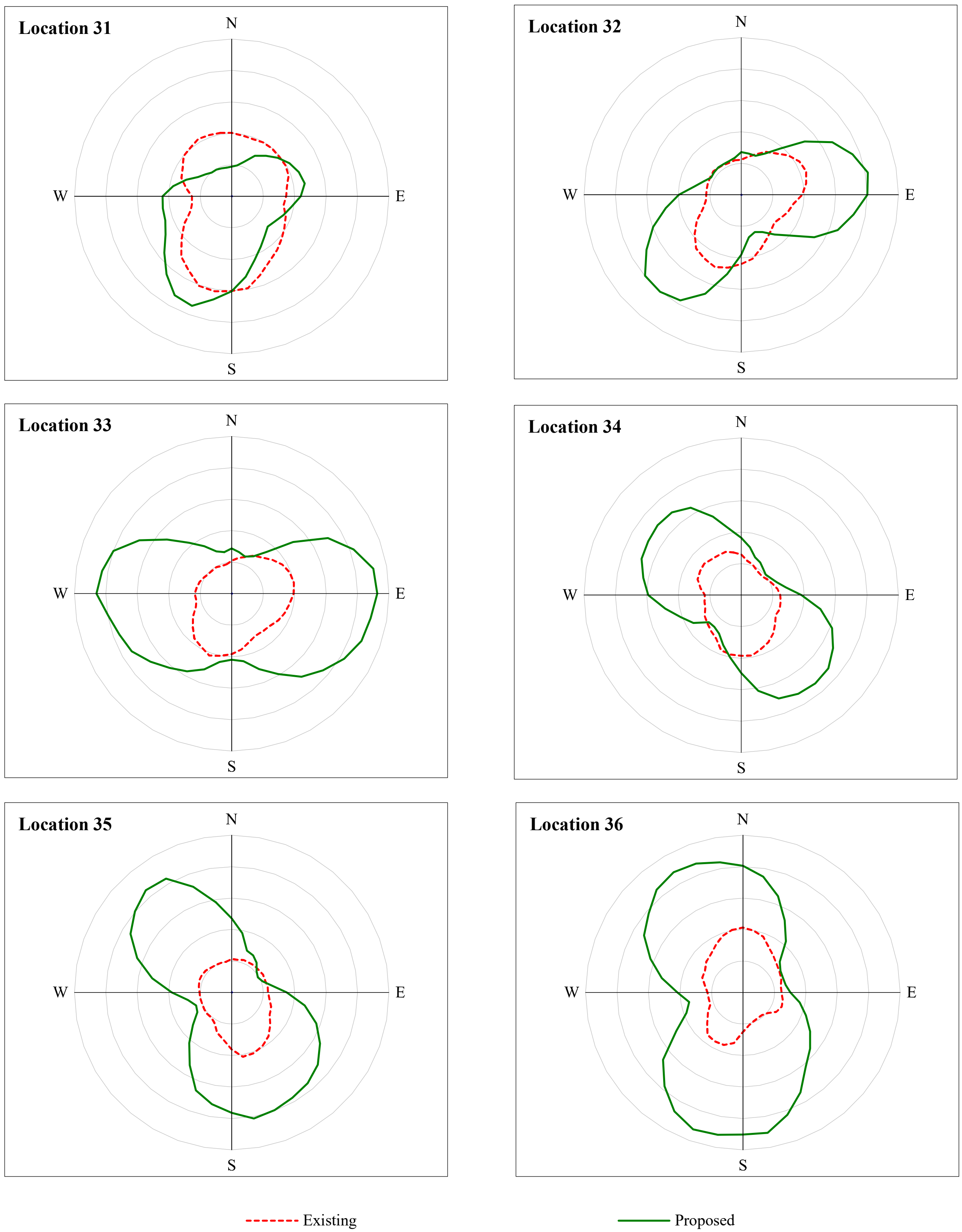

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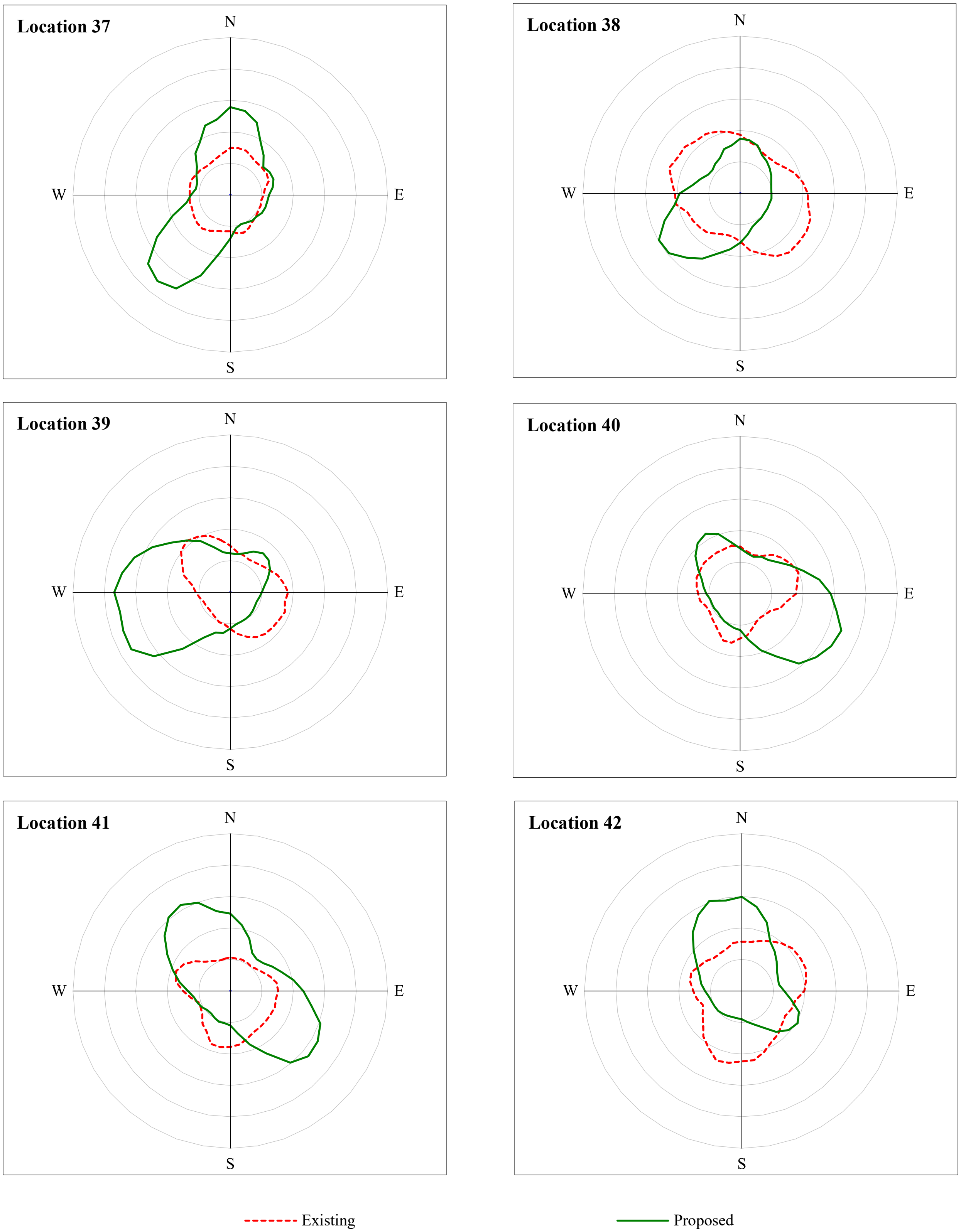

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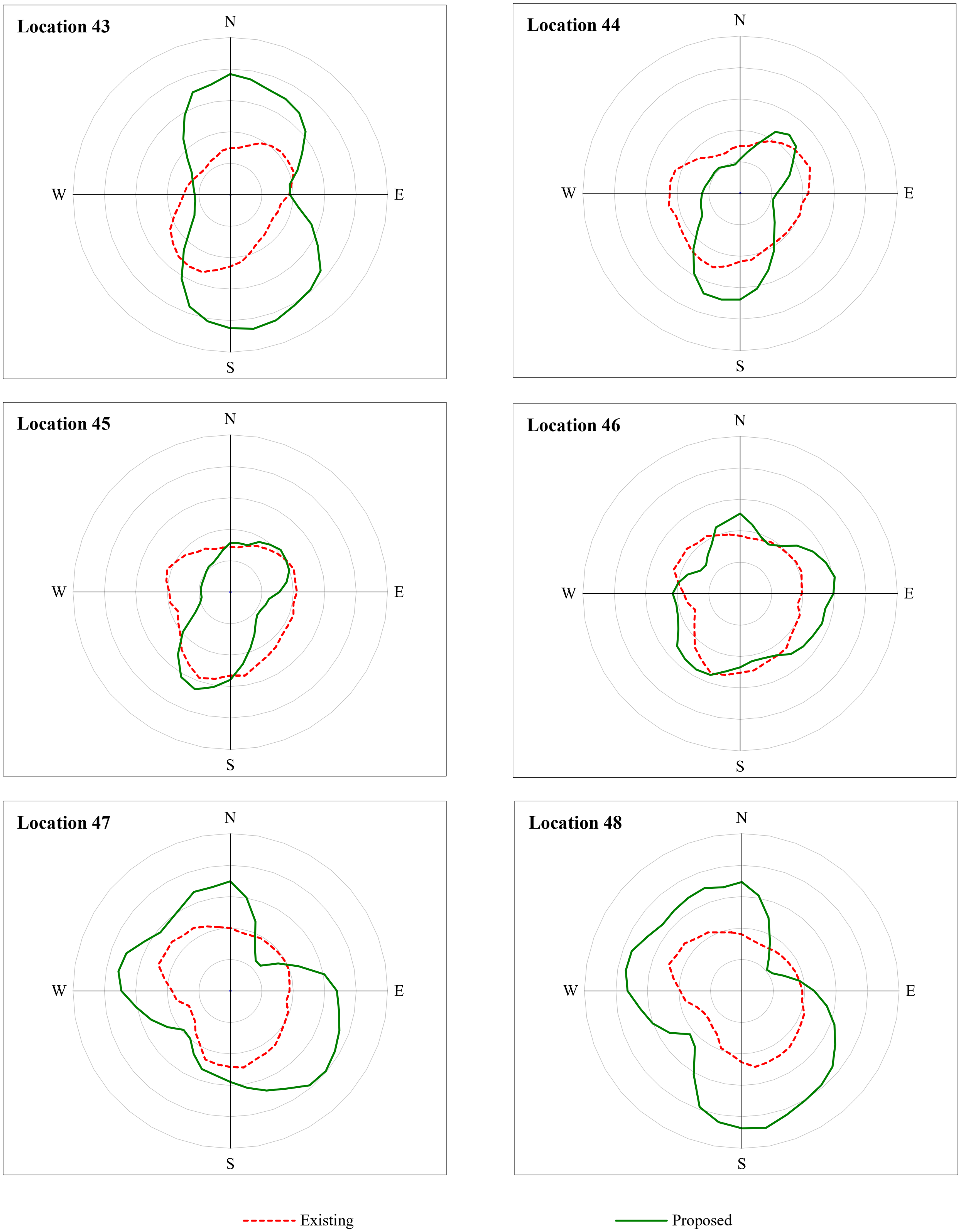

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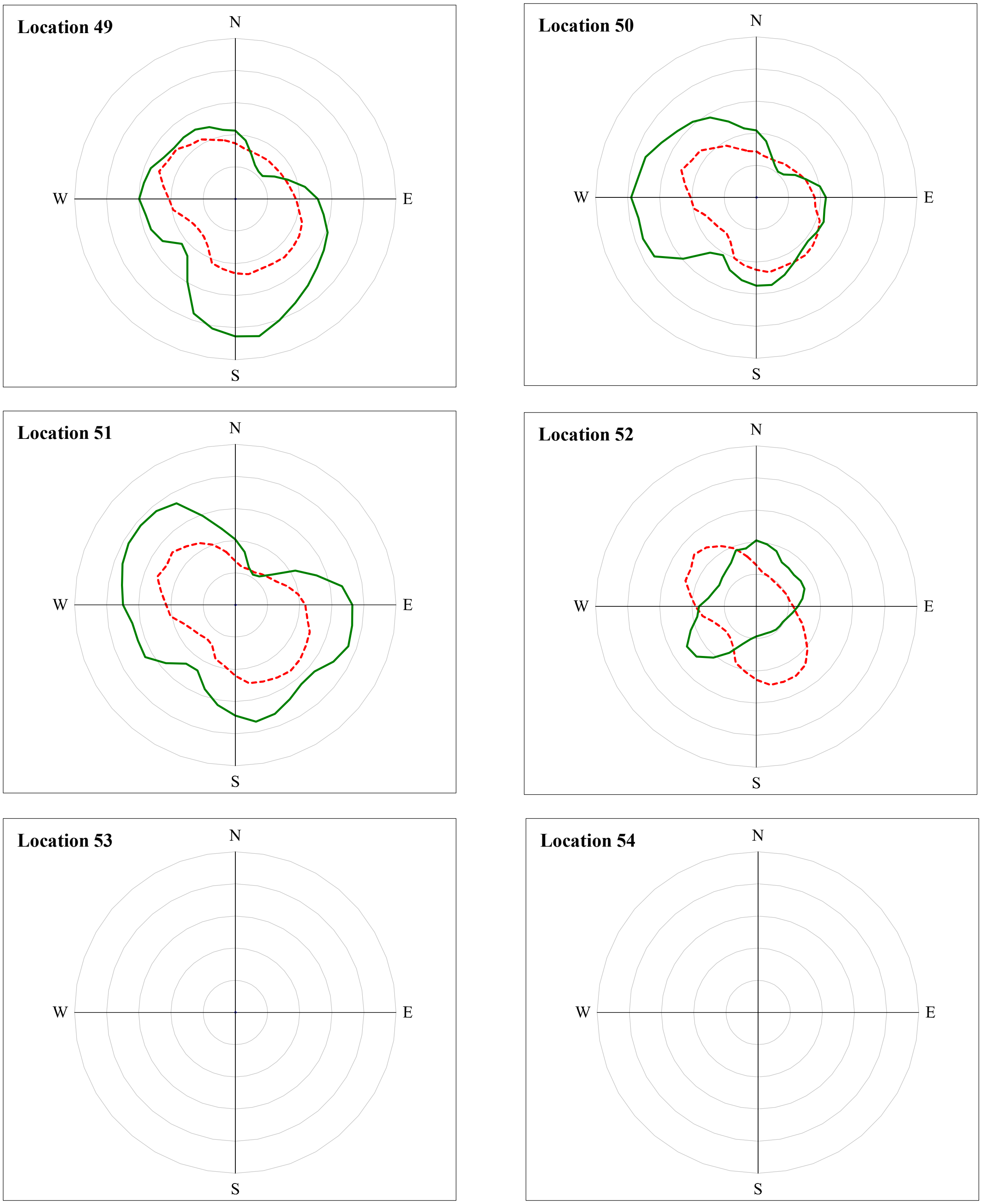

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