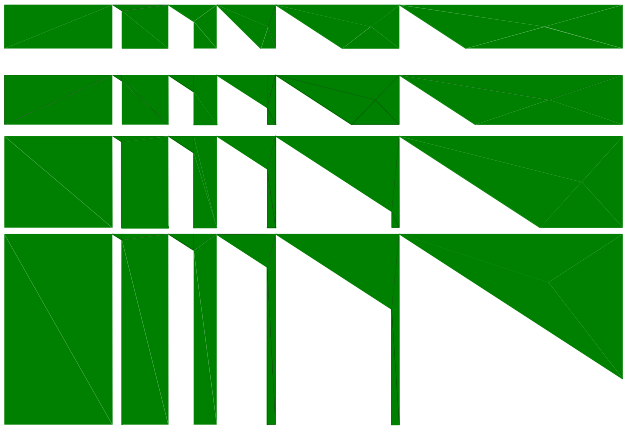
THEAKSTON ENVIRONMENTAL
Consulting Engineers • Environmental Control Specialists

REPORT

FINAL PEDESTRIAN LEVEL WIND STUDY

1970703 Ontario Inc.
154 Main Street East, 49 Walnut Street South
HAMILTON, ONTARIO



Vrancor Group
+
Brooklyn Contracting Inc.

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1. EXECUTIVE SUMMARY

The mixed-use residential Development proposed by 1970703 Ontario Inc., municipally known as 154 Main Street East and 49 Walnut Street South, and located on the south side of Main Street East, east of Walnut Street South and north of Jackson Street East, in the City of Hamilton, 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 thirty-eight (38) locations tested were well within safety criteria and most are within the comfort criteria described within.

The proposed 154 Main Street East Development site is currently occupied by a two storey office building, which will be removed in order to facilitate the development proposed. The Development involves a proposal to build a mixed-use residential building comprised of a 25 storey tower including a 7 storey parking podium. The Development is, for all intents and purposes, surrounded to prevailing windward directions by an urban/suburban mix of buildings supporting residential, and commercial uses, with large open areas assigned to surface parking. Low-rise development dominates much of the immediate surrounds and is interspersed with mid to high-rise urban buildings.

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 comprised of large single storey buildings with related parking lots 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 existing causing wind to redirect to flow over the building, without consequence, and/or, depending upon the angle of incidence, around, or down the tower towards the pedestrian level, as downwash. The Development features significant stepped conditions at the podium adjacent to the tower's south and east façades that transition to shallower steps along the west and north sides. The steps in the building's façades intercept downwash associated with winds approaching from near perpendicular directions, deflecting said flows around the building at elevations well above the pedestrian level. This mitigative design feature as well as other wind friendly design elements: slender tower, angular, notched, façades, overhangs, balconies, canopies, and others, when considered in concert, present a superior design. This results in realisation of a wind climate at the site with inclusion of the proposed development, that is similar 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 to a lesser extent around and down the building's faces. At the pedestrian level, the winds redirect to travel horizontally along the building, around the corners and beyond, creating windswept areas at or near the building's northwest corner. The retail entrance located at the corner will be exposed to said winds resulting in conditions suitable for walking on an annual basis, uncomfortable on occasion during the winter. Wind conditions comfortable for standing are preferable at building entrances, while conditions suitable for walking are suitable for walkways. Conditions at the corner entrance are inappropriate to the area's intended purpose and we recommend the entrance be moved to a more central location along Main Street East and/or be set into the façade of the building such that winds deflected to flow along the street do not act upon the door leafs.

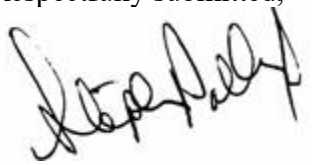
Comfort conditions expected at the proposed Development site are similar, relative to the existing setting, and considered acceptable to the urban context. Where mitigation was recommended, it was achieved through the following design features:

- parapet walls
- stepped façades
- overhangs
- canopies
- balconies
- landscaping
- plantings

These items have all been incorporated into the proposed Development's massing and landscape design.

In summary, the proposed Development's stepped facades, podium, and other design features will contribute to anticipated pedestrian comfort conditions that are suitable to the context. Minor variations of the aforementioned landscape plan, designed in consultation with the architects, and applied to the outdoor amenity space, might extend its seasonal functionality further into the shoulder seasons. The proposed Development will realize wind conditions acceptable to a typical urban context. Pedestrian comfort conditions will likely moderate with ongoing wind appropriate urban intensification that, considered collectively, will cause the wind's boundary layer profile to thicken, or when considered specific to the site, reduce the propensity for wind to downwash to the pedestrian level.

Respectfully submitted,



Stephen Pollock, P. Eng. Paul Kankainen, M.A.Sc.

2. INTRODUCTION

Vrancor Group and Brooklyn Contracting Inc. retained Theakston Environmental to study the pedestrian level wind environment for the proposed 154 Main Street East Development located in the City of Hamilton as shown on the aerial photo in Figure 2a. The Development involves a proposal to build a mixed-use residential building comprised of a 25 storey tower, that includes a 7 storey parking podium, in a configuration as shown in Figure 2b. Milan Marsic of Brooklyn Contracting Inc. initiated the request and WZMH Architects provided 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 building and surroundings. The wind velocities are rated in accordance with the safety and comfort of pedestrians, notably at entrances to the building, 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 building currently on the study site as well as existing and proposed buildings in the surrounding area. The proposed configuration included the subject 154 Main Street East 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 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. Predictions of wind speeds for various probabilities of occurrence and for various percentages of time are then 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 open channel water flume, the ultimate known as the "Snow and Wind Simulator", in which flowing water is conditioned to represent wind movement (Figure 1). This procedure is based on the fact that air (wind) is a fluid and obeys all the principles and laws contained in Fluid Mechanics and Hydraulics disciplines. The open channel water flume and boundary layer wind tunnel have been developed for these kinds of environmental studies, and have been adapted with equipment, testing procedures and protocols, in order to provide results comparable to full scale. The water flume test is a particularly useful tool where visual examination and qualitative analysis are advantageous in decision making, whereas the Boundary Layer Wind Tunnel lends itself well to the simultaneous acquisition of large data streams.

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 2m and correlated to mean and gust wind speeds, expressed as ratios of the gradient wind speed.

The mean and gust wind speeds at the thirty-eight (38) points tested were subsequently combined with the design probability distribution of gradient wind speed and direction, (wind statistics) recorded at John C. Munro Hamilton International Airport, to provide predictions of the full-scale pedestrian level wind environment. The statistical wind data graphically depicted in Figure 5 indicates the mean wind speed and directionality of winds analysed annually and for each of the four seasons. Historical weather data presented as mean wind speeds in Figure 5 wind roses indicate that winds exceeding 30km/h occur approximately 11 percent of the time during the winter months and 1 percent of the time during the summer. Winds can occur from any direction, however, historical data indicates they are most likely to occur from north to southwesterly directions during the fall, north and west during the winter, northerly and westerly in the spring, and vary between north through west to southerly directions, during the summer months.

Predictions of the full-scale pedestrian level wind environment are presented as a percentage of time that is comfortable for a given activity, based on annual and seasonal winds, in Figures 6a – 6e. 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 Wind Simulation

To simulate the correct macroclimate, the upstream flow passes over a roughened surface that develops the full-scale mean speed boundary layer approach flow profiles occurring at the site. Conditioning features placed upstream of the modelled site simulate full-scale wind conditions.

4.3 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 site visit to the proposed Development site, and surrounding area. WZMH Architects provided architectural drawings. City of Hamilton context drawings, aerial photographs, and site photos, 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 a full suite of wind directions are 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 2m. 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.

4.4 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. The effects of mean and gust wind conditions are weighted, combined and are plotted in Figures 6a – 6e for predicted comfort conditions.

Figures 7a – 7j are a representation of the percentage of time that a given point is comfortable for a given activity. The activities are described as suitable for Sitting or Standing or Walking over 80% of the time. In order for a point to be rated as suitable for Sitting, for example, the wind conditions must be less than 10 km/h. 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 14km/h. In this situation, the wind would rustle tree leaves and, on occasion, move smaller branches while flags would be partially extended. 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 19km/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, including wind speeds above 19km/h.

In the Figures, the probe locations and test configuration are listed along the bottom of the chart, beneath the graphical representation of the percentage of time that the winds are expected to fall within each category. The location is rated as suitable for sitting, standing or walking if the appropriate bar extends above the 80% level and is Uncomfortable if the bar for the category extends above 20%. Activities other than those indicated by the rating can take place at the points of interest, however, the time period will be less, as indicated in the percentage of time in the chart's abscissa axis. For example, a point that is rated as uncomfortable may be suitable for walking 75% of the time, standing 60% of the time and sitting 45% of the time.

The charts represent the average person's response to wind for four seasons and annually. 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.

5. RESULTS

5.1 Study Site and Test Conditions

Proposed Development

The proposed 154 Main Street East Development is comprised of a 25 storey residential tower with a 7 storey parking podium that presents a rectangular shaped massing with the tower's long axis oriented perpendicular to Walnut Street South. Jackson Street East provides vehicular access to the parking garage. The Tower component of the building is situated proximate to the north and west boundaries of the Development site in a configuration as shown in Figure 2b. The building features significant stepped conditions at the podium adjacent to the tower's south façade and extends along the west, north and east sides.

The first floor accommodates retail, the residential lobby, amenity space, access to parking, and services; the 2nd floor accommodates the building management, common rooms (fitness, yoga, games, cinema, etc.) and an outdoor terrace on the east side of the tower; the 3rd floor and above consist of residential, with parking assigned to the 2nd through 7th levels of the podium. Outdoor Terraces are proposed at the 2nd level to the east of the tower and the 8th level to the south of the Tower.

154 Main Street East Development Site Looking South

Surrounding Area

The proposed 154 Main Street East Development is located within the City of Hamilton and occupies the block of land bound by Jackson Street East to the South, Walnut Street South to the West, Main Street East to the North and Ferguson Avenue South to the East. 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. The proposed 154 Main Street East Development is flanked by a mix of buildings that are predominantly low-rise residential, street related retail and industrial buildings with street related commercial, parking, and green space, to much of the prevailing wind climate, with the exception of taller buildings that for the most part flank Main Street East and King Street East. The surrounds display a propensity towards higher density development with urban intensification encroaching.

The 154 Main Street East Development is, for all intents and purposes, exposed to a mid-density surround to lands north of Main Street East and both east and west of Walnut Street South, while lands to the south and west of the above named are predominately low-density residential and commercial, with several parking lots (with a few taller buildings flanking Main Street East). The penultimate type of terrain presents a number of extensive parking lots to winds, affording wind opportunity to accelerate on approach, while the terrain to the west by northwest (Hamilton's core) will reduce or maintain the wind's energy at the pedestrian level.

Macroclimate

For the proposed Development, the upstream wind flow during testing was conditioned to simulate an atmospheric boundary layer passing over urban/suburban terrain. The terrain within the site's immediate vicinity was incorporated into the proximity model. Historical meteorological data recorded from the John C. Munro Hamilton International Airport was used in this analysis, approximately 11*km* to the southwest. For studies in the City of Hamilton, the data is presented annually as well as for the four seasons, winter, spring, summer, and fall; the resulting wind roses are presented as mean velocity and percent frequency in Figures 5a-e. The mean velocities presented in the wind roses are measured at an elevation of 10m. Thus, representative ground level velocities at a height of 2*m*, 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 this area is dependent upon wind direction and varies with direction but is considered urban/suburban.

Winter (November 16 to March 31) has the highest mean velocities of the seasons with prevailing winds from the west to southwest quadrant, with significant components from northeast as indicated in Figure 5b. Spring (April 1 to June 15) has the second highest mean wind velocities and the prevailing winds tend to be from the northeast quadrant and the south west to a lesser degree (Figure 5c). Summer (June 16 to September 15) has the lowest mean wind velocities of the seasons with prevailing winds from the southwest as

indicated in Figure 5d. During the fall, (September 16 to November 15) the possible directions for prevailing winds include the Southwest sector and the northeast to a lesser degree (Figure 5e). The magnitudes of the mean wind velocities are between spring and summer winds. Reported pedestrian comfort conditions generally pertain to annual, unless stated otherwise.

5.2 Pedestrian Level Wind Velocity Study

On the site model thirty-eight (38) wind velocity measurement probes were located on and around the proposed Development, 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 subject building was removed and the site model retested with the existing building.

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 is applied.

The design probability distribution gradient wind speed and direction, taken from historical meteorological data for the area (Figures 5a – 5e) 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 on an annual and seasonal basis in Figures 6a - 6e.

The ratings for a given location are conservative by design, and those ratings that are Uncomfortable, when close to a transition between Walking and Uncomfortable, will not pose a problem, from a pedestrian comfort point of view. 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 surrounded by an urban/suburban setting to prevailing and remaining compass points with winds generally flowing over low-rise residential, retail and industrial buildings and parking lots. As such, the surroundings can be expected to influence wind at the site to varying degrees.

It should be noted that the probes are positioned at points typically subject to windy conditions in an urban environment in order to determine the worst-case scenario.

Review of Probe Results

The probe results, as follows, were clustered into groups comprised of Public Street Conditions, Outdoor Terrace Space, and Pedestrian Entrance Conditions. The measurement locations are depicted in Figure 4 and are listed in Figures 6a – 6e annually and for the seasons for the proposed configuration. The results are also graphically depicted for the existing and proposed configurations annually, and for the seasons in Figures 7a – 7j. The following discusses anticipated wind conditions and suitability for the points' intended use.

Public Street Conditions

King Street East
Probes 1 through 6 were located along King Street East, within the zone of influence of the proposed 154 Main Street East Development. Their locations are depicted in Figure 4, their comfort ratings are listed annually and for each of the seasons in Figures 6a – 6e and depicted in Figures 7a through 7j. Probes situated on King Street East indicate annually averaged wind conditions in the existing setting that vary from sitting to standing to walking. The windier conditions tend to be near the corner of the 10 storey residential building at 260 King Street East, and/or near intersections while the more comfortable areas are along the street, removed from the intersections and isolated from the wind climate by buildings.

With inclusion of the proposed Development a subtle improvement to predicted pedestrian comfort conditions was noted, for the most part, but sufficient at probe locations 3, 4, and 6, to change their annual comfort ratings from standing to sitting or walking to standing.

Main Street East
Probes 7 through 21 were located along Main Street East. Of these points, all were rated as suitable for sitting or standing in the existing setting, annually, with exception; probe location 9, which was rated as suitable for walking, and probe 14 which was uncomfortable. The windy conditions predicted at point 14 can be attributed to the 43 storey Landmark Place Tower at 100 Main Street East and the 16 and 17 storey Effort Square buildings at 105 and 115 Main Street East, which collectively downwash winds emanating from several compass points to the pedestrian level where they are deflected to flow through the gap between the

buildings and ultimately along Main Street East, resulting in the prediction of uncomfortable conditions much of the time.

The proposed Development's tower penetrates winds that have to date been deflected to flow over the site, the increased blockage causing wind to redirect to flow over the building, without consequence, and/or depending upon the angle of incidence, around or down the tower. This will result in localized windy conditions, as discussed above, and often a moderation of winds at points more removed.

The tower's mitigative design features moderate wind effects realised at the pedestrian level resulting in the relatively minor upset to wind conditions noted. As such only probe locations 16 and 17, situated at the intersection of Main Street East with Walnut Street South, realised an appreciable increase in windiness, the penultimate becoming uncomfortable and the ultimate suitable for walking, on an annual basis, however, the points were respectively predicted suitable for walking and standing during the summer months. The uncomfortable rating for point 16 was sufficiently close to the transition to walking that consideration of fine design details that were too fine to incorporate into the model and landscaping will likely change it's rating to walking on an annual basis.

Wind conditions will moderate with ongoing urban intensification that, considered collectively, will cause the wind's boundary layer profile to thicken, reducing wind velocity at the pedestrian level and encouraging winds to pass over or around the buildings as opposed to down, however, it is reasonable to expect localised windy conditions that often occur at corners and in gaps between buildings.

Conversely, several probes situated along Main Street East indicate slightly calmer conditions with inclusion of the proposed Development, points 20 and 21 realising sufficient improvement to change their comfort ratings from standing to sitting, on an annual basis. The above noted improvements, while minor, can be attributed to the proposed Development causing a realignment of winds that reduces apparent wind effects at the pedestrian level for points removed from the proposed Development. Increased winds are attributed to the proposed Development redirecting winds through downwash and other phenomena, to flow along portions of the flanking streets.

The subtle changes to wind conditions realised along Main Street East are a reasonable expectation understanding that the proposed Development, while involving a substantial change to the streetscape that extends well above the massing currently on site, employs an overall wind mitigative design that is in some ways aerodynamically superior to the existing low flat roofed building. The features include a rectangular tower component that is slender and features reasonable setbacks at the podium adjacent to the tower's broad façades, stepped conditions, overhangs, canopies and others.

As such, Main Street East remains suitable for its intended purpose and for activities requiring longer exposure times during the summer, standing or better, and consideration of

existing and proposed building elements that are too fine to incorporate into the model, and landscaping, will result in more comfortable conditions than those reported.

Jackson Street East

Probes 22 through 30 were situated along Jackson Street East and their predicted comfort ratings, as depicted in Figures 7a through 7j, were rated as generally suitable for standing in the existing setting, on an annual basis, with localised areas suitable for walking or sitting.

Conditions at said points along the street realised a slight to significant improvement with inclusion of the proposed development, with point 27 realising sufficient improvement to change its rating from to walking to standing. Similarly points 29 and 30 realised an improved rating, however, the points were at the transition between ratings and the difference is not likely perceptible. A rating of walking is appropriate for streets.

Walnut Street South

In addition to the probes located at the intersections of Jackson Street East, Main Street East and King Street East, probes 31 through 36 were located along Walnut Street South. The street realises comfortable conditions in the existing setting, generally suitable for sitting or standing on an annual basis. This can be attributed to the orientation of the street whereby a large percentage of the prevailing wind climate is deflected by buildings flanking the street to flow over the pedestrian level.

With inclusion of the proposed Development the street realised a relatively minor upset with only probe locations 32 and 33, situated adjacent to the proposed Development tower, changing annual ratings from sitting to standing, and these remain appropriate to the area's intended purpose.

Ferguson Avenue South

In addition to the probes located at the intersections of Jackson Street East, Main Street East and King Street East, probes 37 and 38 were located along Ferguson Avenue South. Of these, location 37 was rated uncomfortable and 38 as suitable for standing. With inclusion of the proposed Development the wind conditions did not significantly change and the pedestrian comfort ratings were unchanged.

Outdoor Terraces

An outdoor terrace is proposed at the second level in a recessed area along the east side of the tower and at the 8th level adjacent to the south side of the tower. Note: the spaces would not accommodate conventional probes and as a result alternate means of assessing comfort conditions were employed.

The 2nd level terrace as proposed, recessed into the east façade of the tower, will be in the aerodynamic shade region of the building with northerly, westerly and southerly winds and is therefore protected from said winds. Easterly winds, and components thereof, will flow over portions of the space, however, given the terrace's situation within the confines of the building, and consideration of the historical wind climate, conditions are expected to be comfortable and suitable for sitting during the summer months under normal to moderate ambient wind conditions, standing during the winter and on occasion during the shoulder seasons.

The terrace situated to the south of the tower is in the wake of the tower with northerly winds, and is therefore protected from said winds. Easterly, southerly, westerly winds, and components thereof, will flow over portions of the roof, resulting in localised windy conditions, on the occasion of high ambient winds from said directions. Conditions are expected to be windy and comfort conditions will be suitable for standing during the summer months under normal to moderate ambient wind conditions, walking during the winter and on occasion during the shoulder seasons. The rating is dependent upon wind directionality and speed, and also proximity to the Building's tower that will cause a downwash of southerly winds to the amenity space, and vortices are likely to occur from time to time near the tower's corners with strong near southwesterly and easterly winds.

The wind conditions realised at the amenity space are not inordinate, however, a mitigation plan is recommended, and should be incorporated into the architectural and landscaping plans for the amenity area. This might include screen walls about the perimeter, windscreens, canopies, trellises, recessed seating, plantings in raised planters, and others. Mitigation plans for this Amenity Space, if desired, will be developed through further study. We expect the space will be subject to seasonal use and will, with mitigation in place, be suitable for its intended purpose.

Pedestrian Entrance Conditions

Probe 32 was situated at the Main Residential Entrance to the building, which features vestibules that are connected to a lobby. The retail components fronting Main Street East and Walnut Street South were similarly instrumented, as indicated in Figure 4.

The Main Residential Entrance is situated to the leeside of the subject building and neighbouring building to the west, to much of the prevailing wind climate. In addition, the entrance is beneath an overhang and has a vestibule, and as such, is sheltered from significant portions of the wind climate and will be comfortable, annually suitable for standing, and appropriate to the area's intended purpose, most of the time.

The building has retail components along Main Street East that are accessed from the corner of the building near the intersection with Walnut Street South. The entrances are similarly set beneath the building above.

The retail entrance located at the corner of the proposed Development (Probe 17) will be exposed to winds emanating from specific directions that are deflected to flow along Main Street East. As such, the retail entrance at the corner will be windy, suitable for walking on an annual basis, uncomfortable on occasion during the winter. Wind conditions comfortable for standing are preferable at building entrances, while conditions suitable for walking are suitable for walkways. Conditions at the corner entrance are considered inappropriate to the area's intended purpose. We recommend the entrance be moved to a more central location along Main Street East and/or be set into the façade of the building such that winds deflected to flow along the street do not act upon the door leafs.

Summary

The observed wind velocity and flow patterns at the 154 Main Street East Development are largely influenced by approach wind characteristics that are dictated by the relatively open surrounding areas to prevailing and less dominant wind directions. These surroundings afford much of the prevailing wind climate opportunity to flow in streamlines near the pedestrian level, resulting in localised windy conditions in open areas. Historical weather data recorded at Hamilton International Airport indicates that strong winds of a mean wind speed greater than 30 km/h occur approximately 11 percent of the time during the winter months and 1 percent of the time during the summer.

Once the subject site is developed, ground level winds at many locations will improve, with occasional localized areas of higher pedestrian level winds, resulting in wind conditions that are predicted as windy at times, but generally remain comfortable and appropriate to the areas' intended purpose throughout the year. The relationship between surface roughness and wind is discussed in the Appendix and shown graphically in Figure A of the same section.

As such, the site is predicted suitable for Standing or Walking under normal wind conditions; however, under high ambient winter wind conditions with winds emanating from specific directions the northwest corner of the proposed Development may be windy from time to time, but otherwise appropriate to the intended purpose. The consideration of proposed surface roughness will result in conditions more comfortable than those reported herein.

The outdoor amenities area will require wind mitigation. This should be designed with input from the consultant, and might be accomplished with screen walls, appropriate plantings and other elements situated to windward directions.

6. NOTES

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Figure 1: Laboratory Testing Facility

Figure 2a: Site Aerial Photo

Figure 2b: Site Plan

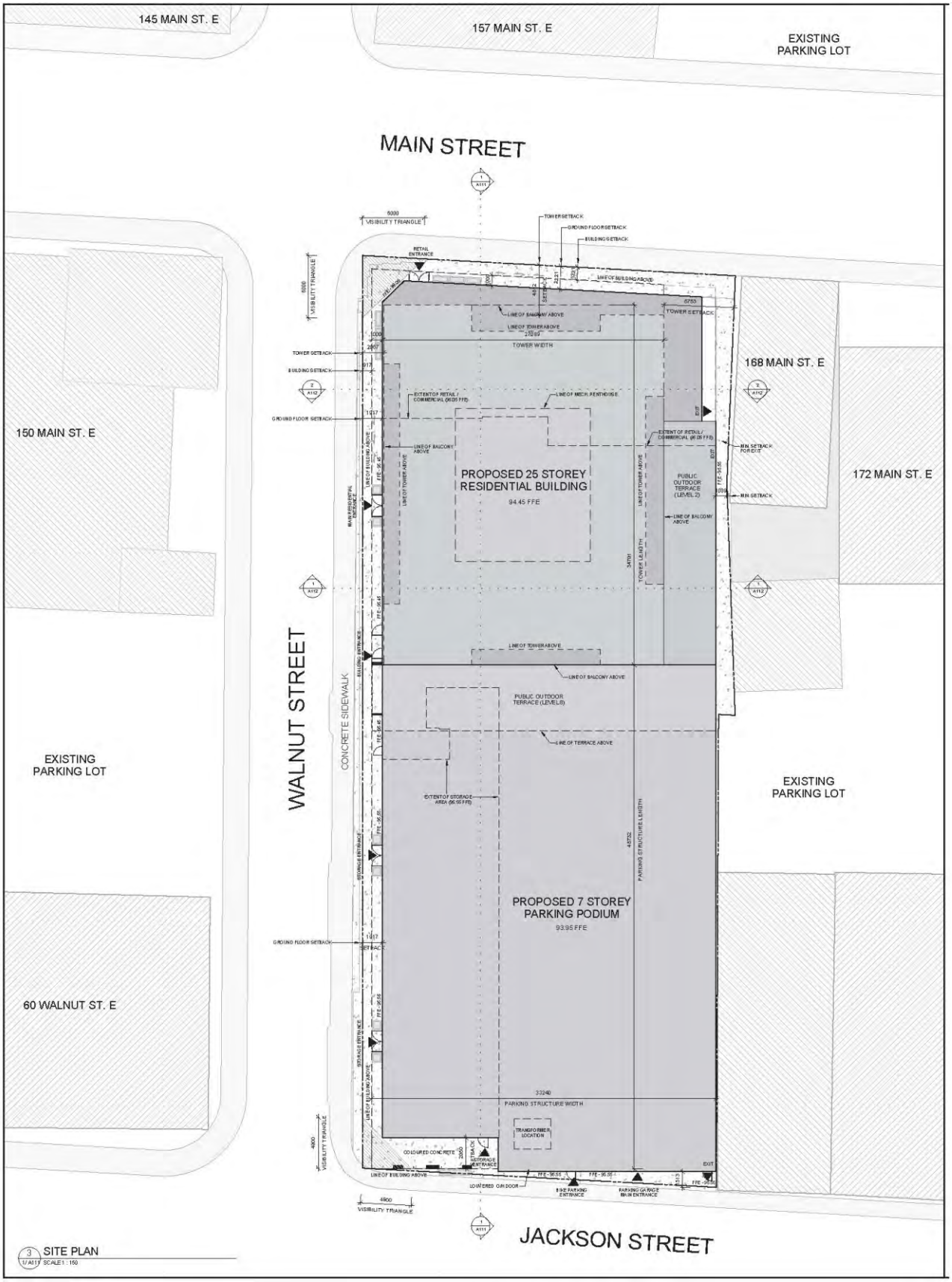
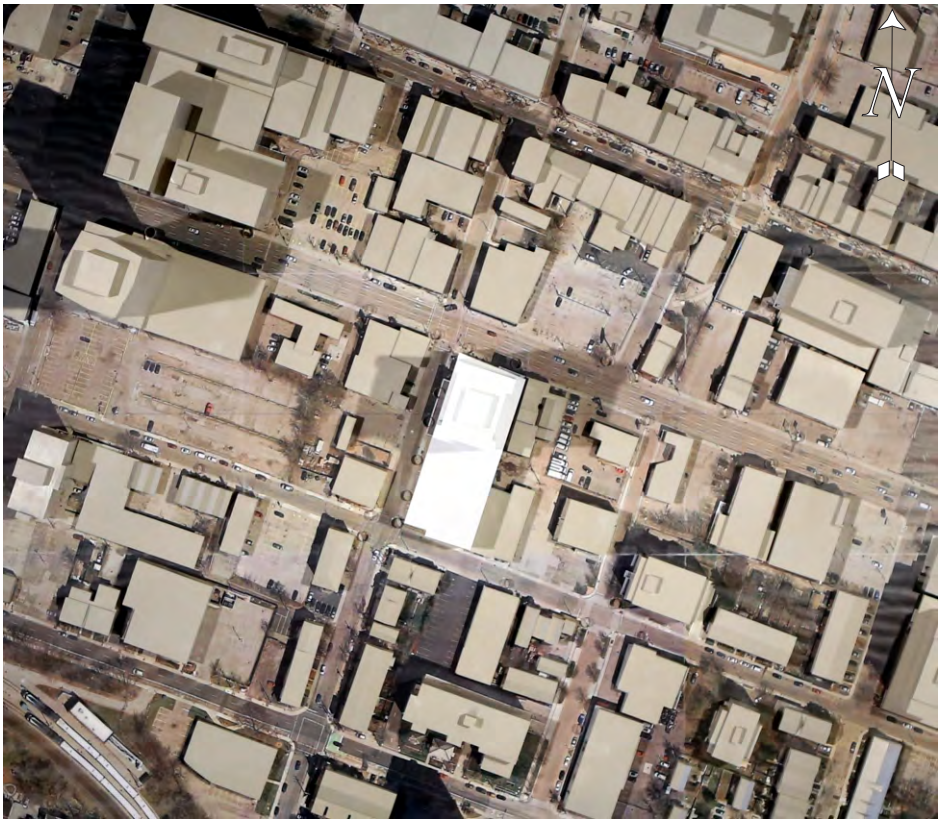
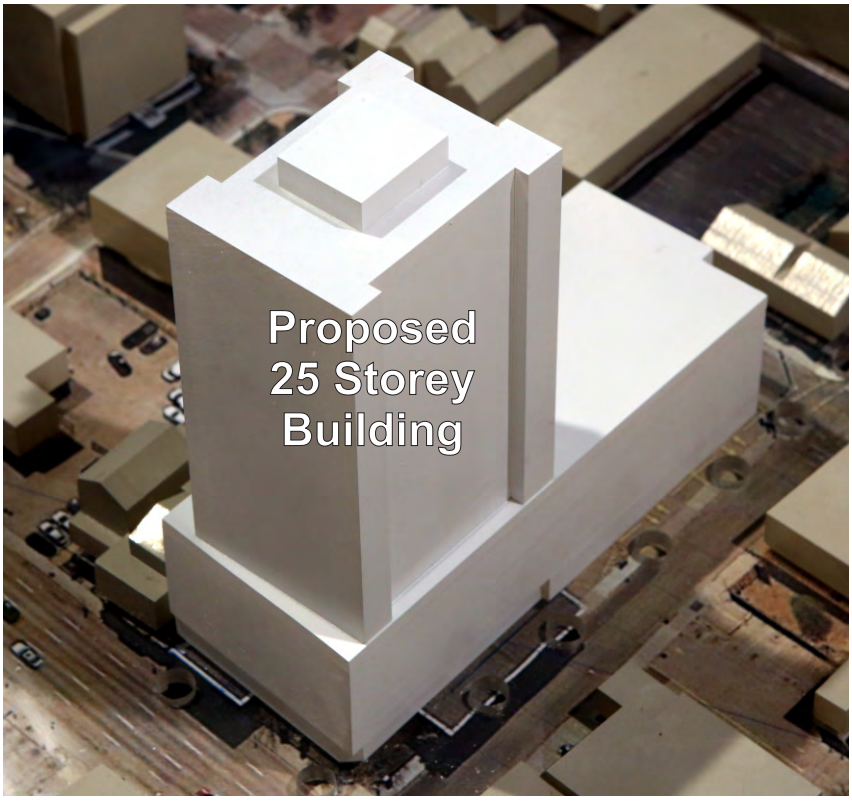


Figure 3: 1:500 Scale model of test site



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.

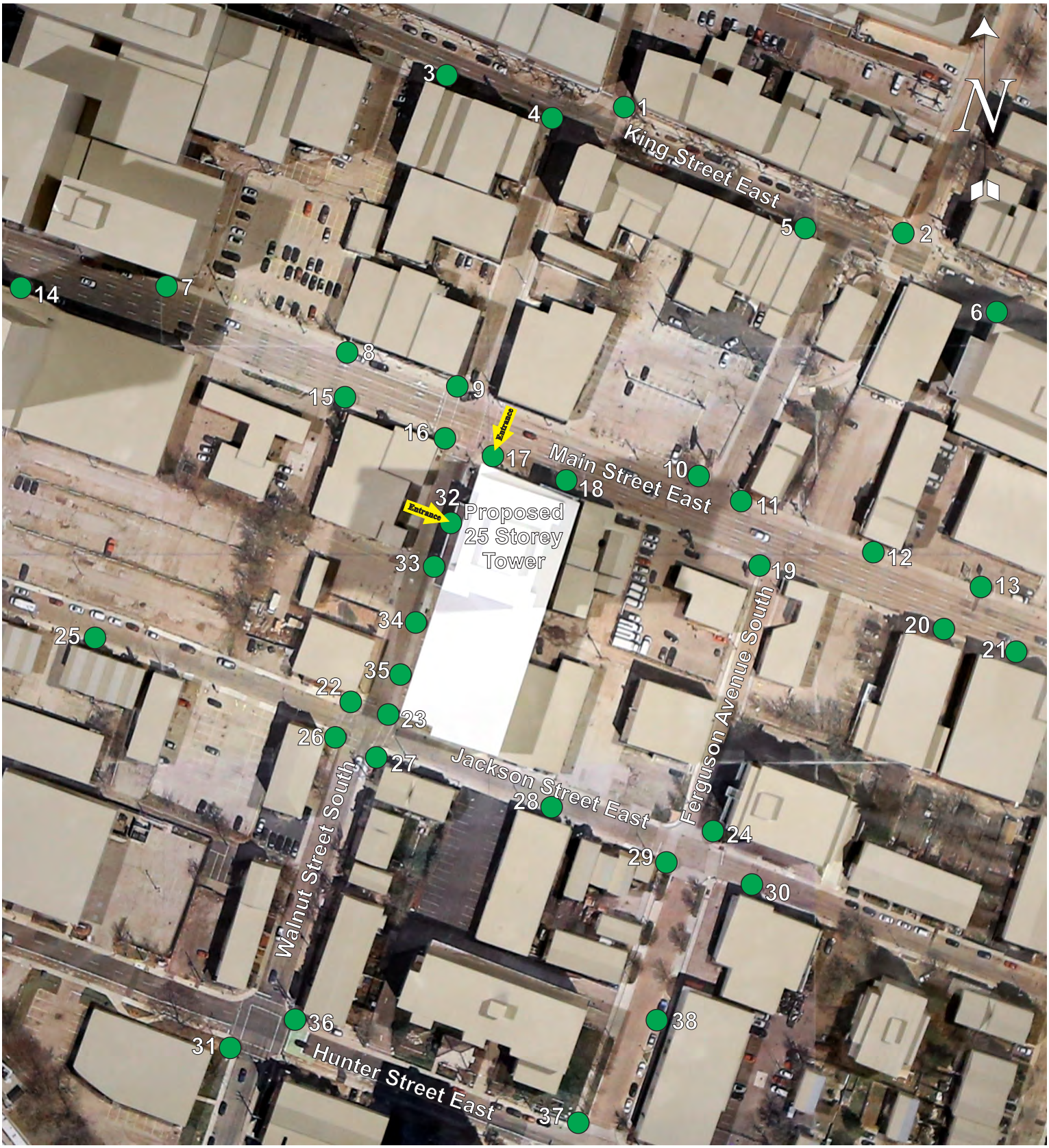


Figure 5a: Annual Wind Rose - Hamilton International Airport.

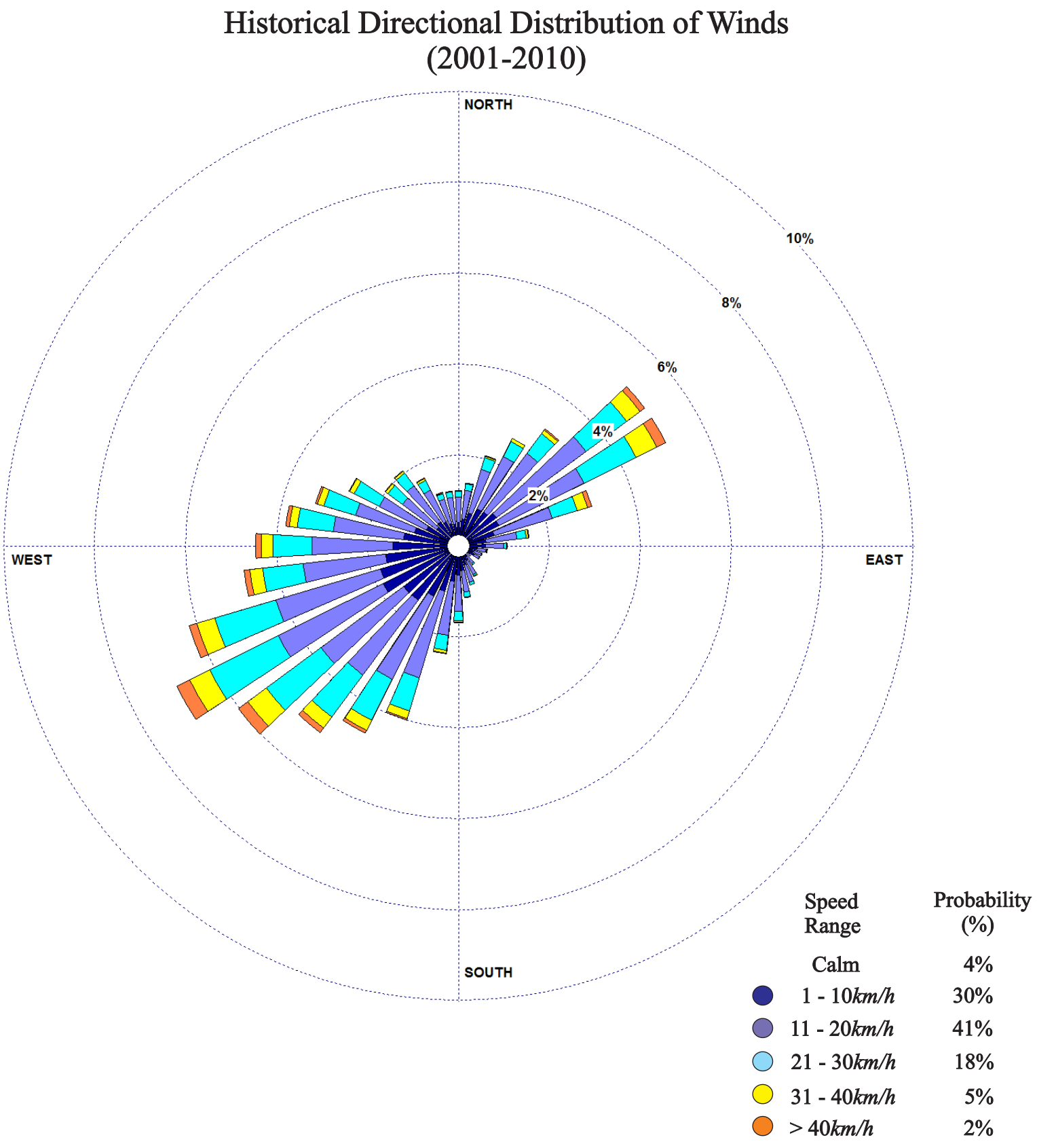
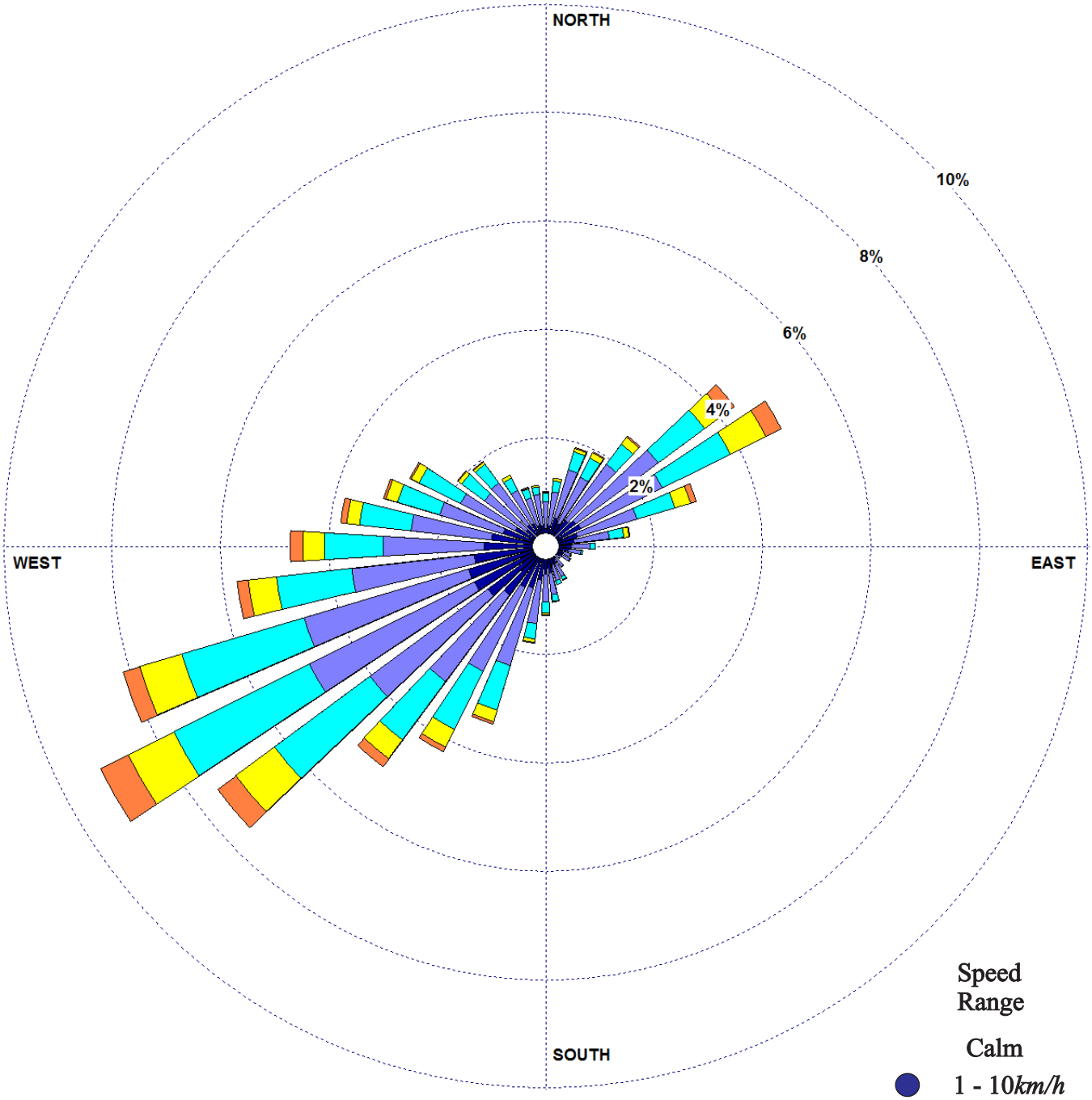


Figure 5b: Winter Wind Rose - Hamilton International Airport.

Historical Directional Distribution of Winds
November 16 through March 31 (2001-2010)



Speed Range	Probability (%)
Calm	3%
1 - 10*km/h*	24%
11 - 20*km/h*	39%
21 - 30*km/h*	23%
31 - 40*km/h*	8%
> 40*km/h*	3%

Figure 5c: Spring Wind Rose - Hamilton International Airport.

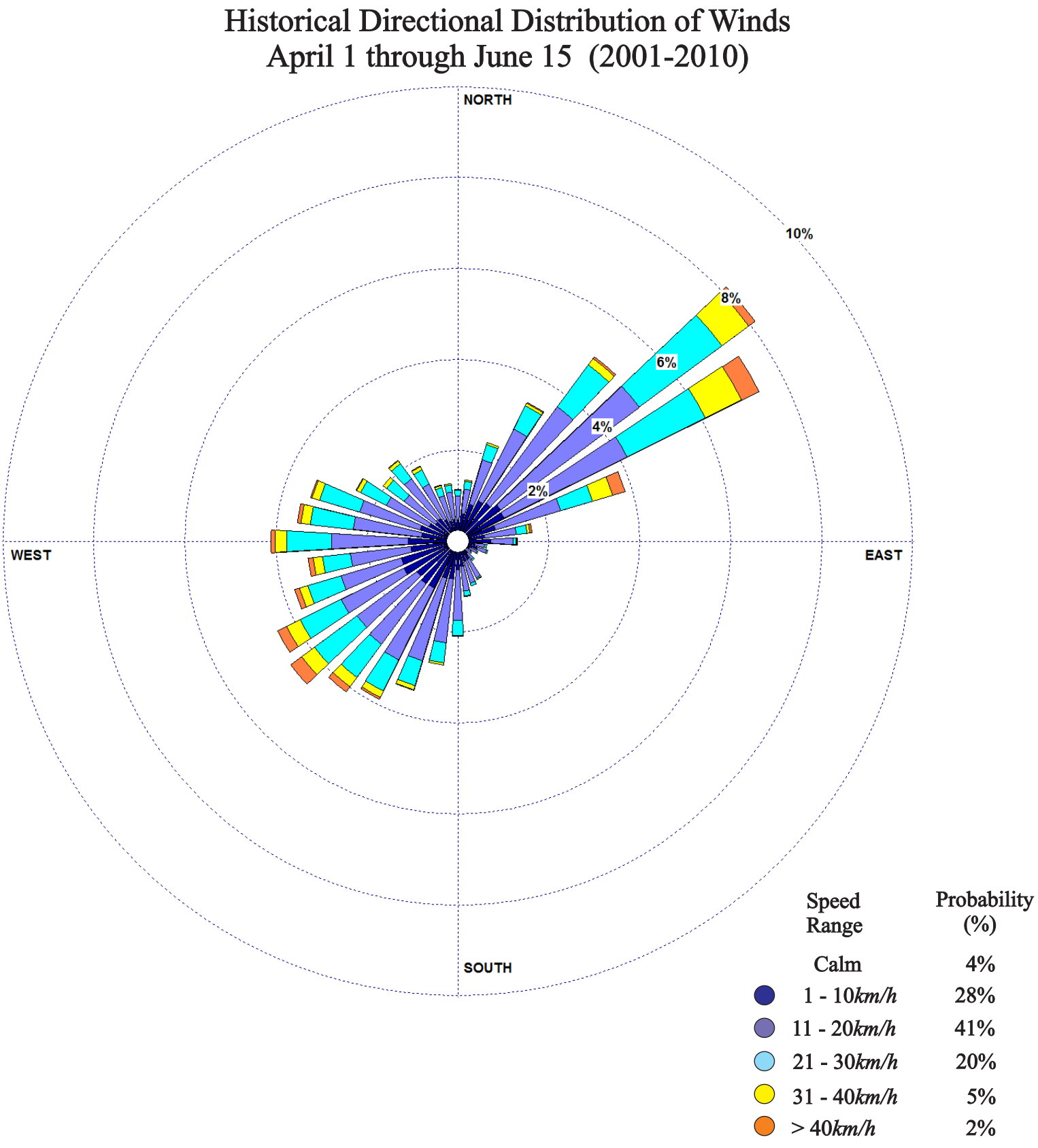
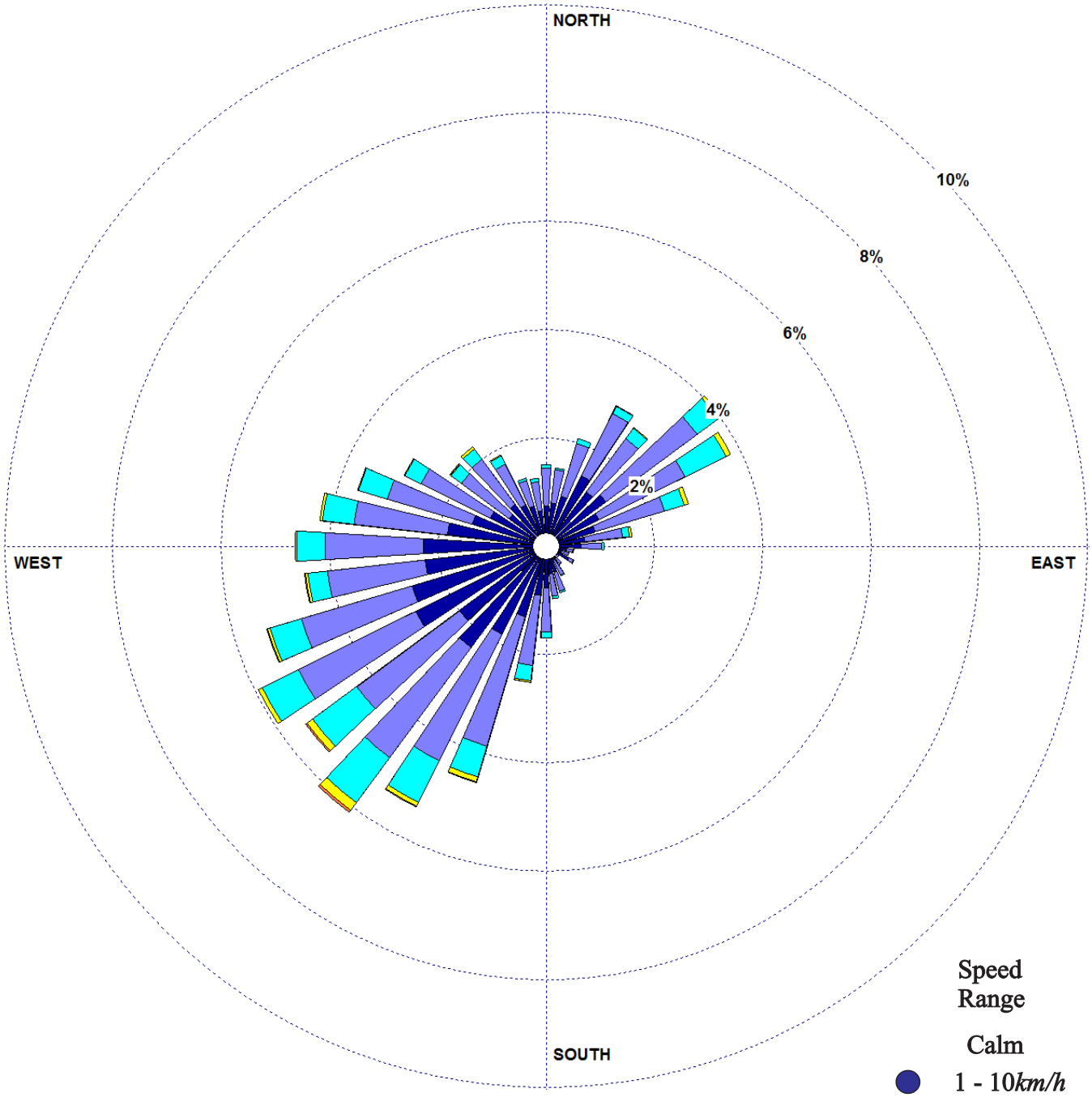


Figure 5d: Summer Wind Rose - Hamilton International Airport.

Historical Directional Distribution of Winds
June 16 through September 15 (2001-2010)



Speed Range	Probability (%)
Calm	5%
1 - 10*km/h*	41%
11 - 20*km/h*	42%
21 - 30*km/h*	11%
31 - 40*km/h*	1%
> 40*km/h*	<1%

Figure 5e: Fall Wind Rose - Hamilton International Airport.

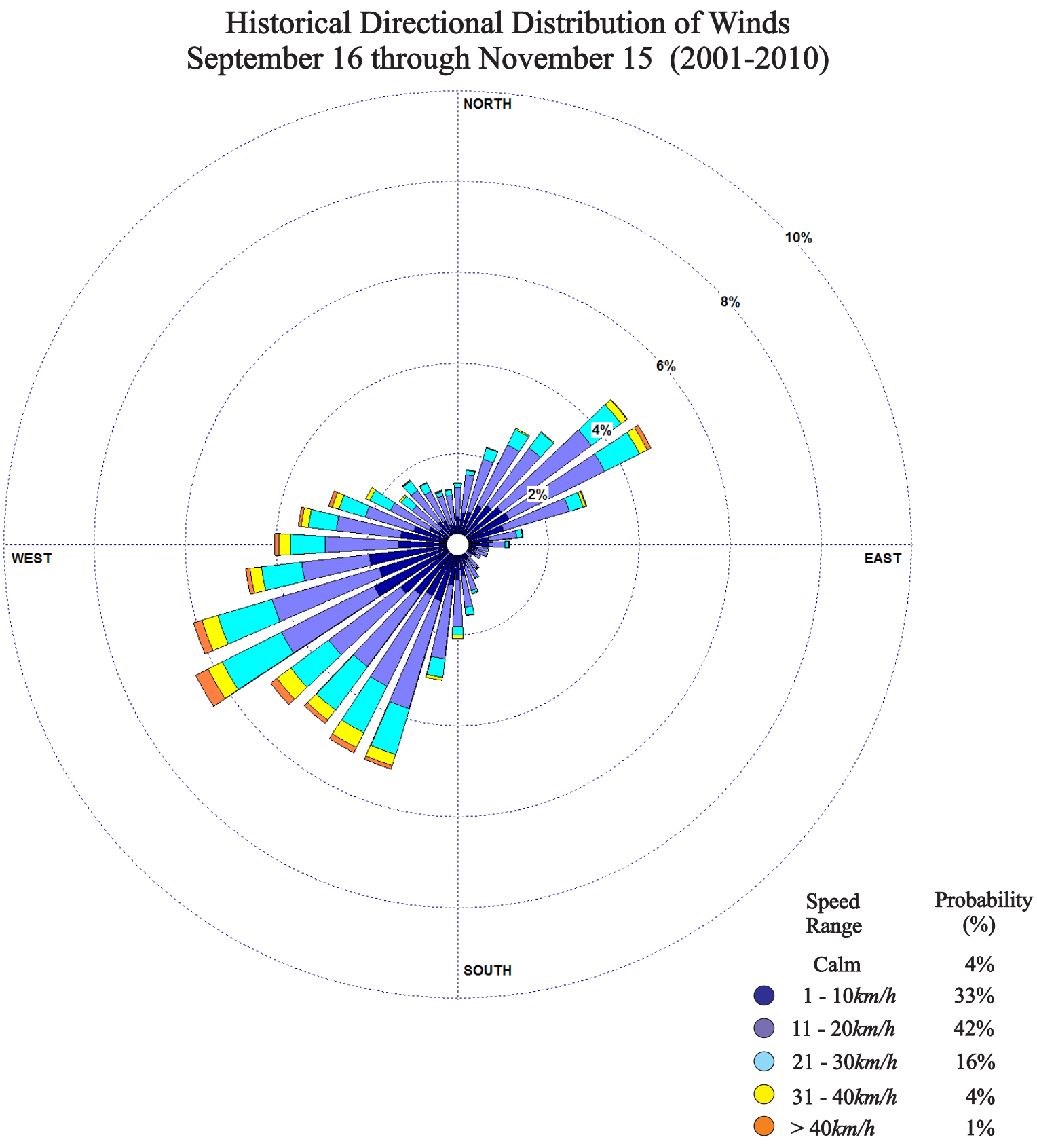


Figure 6a: ANNUAL - Percentage of time comfortable for a given activity (Locations 1 to 15).

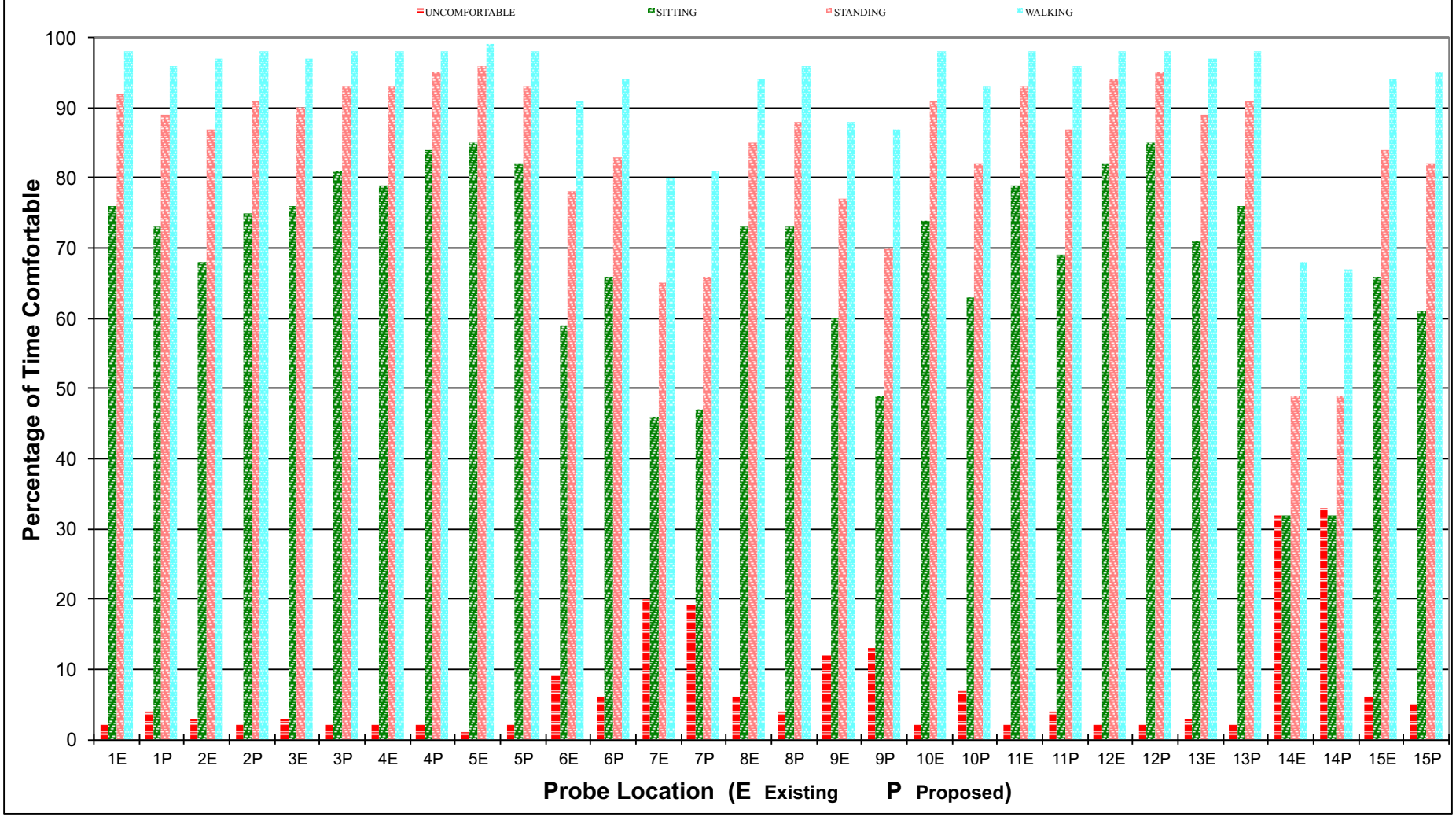


Figure 6a: ANNUAL - Percentage of time comfortable for a given activity (Locations 16 to 30).

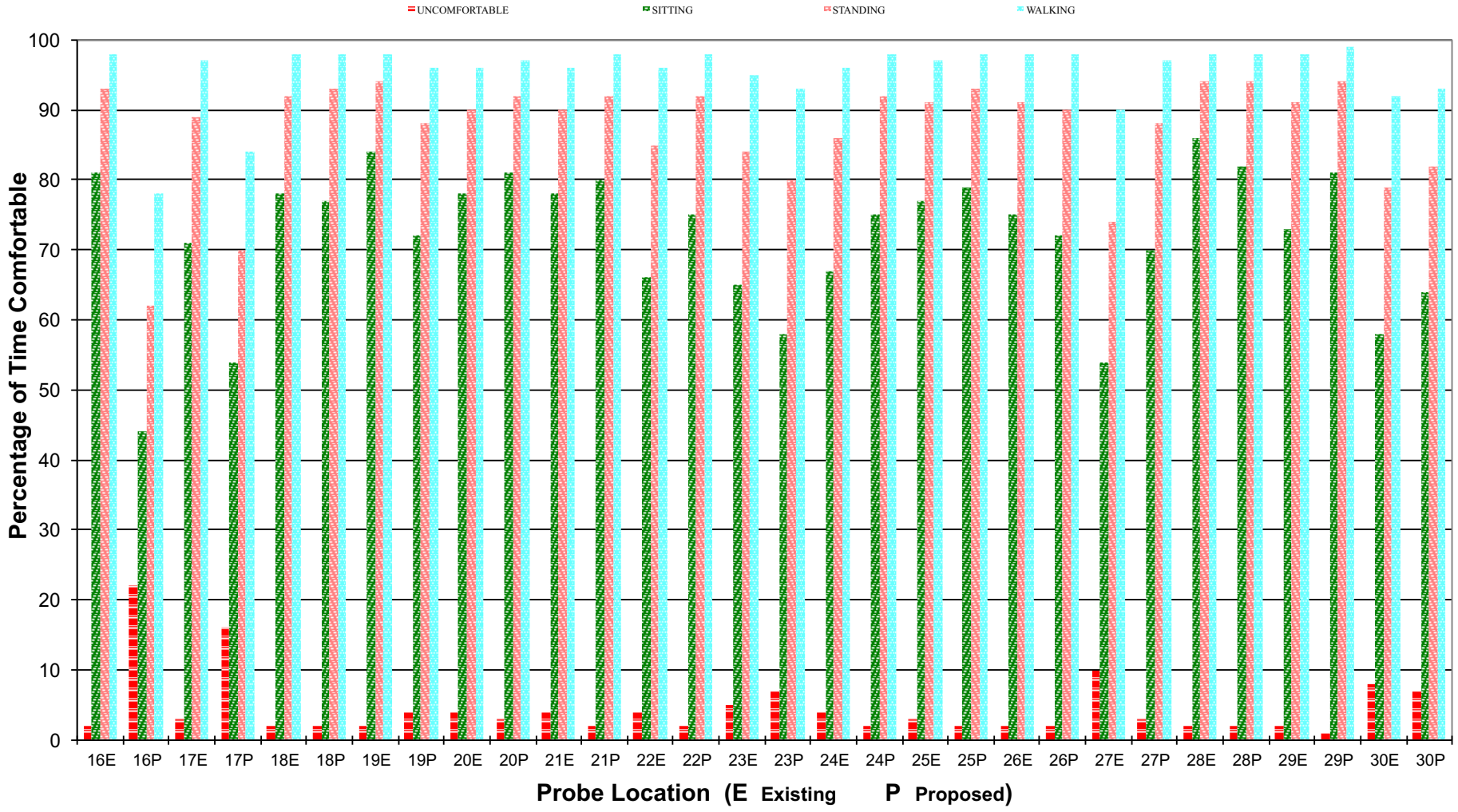


Figure 6a: ANNUAL - Percentage of time comfortable for a given activity (Locations 31 to 38).

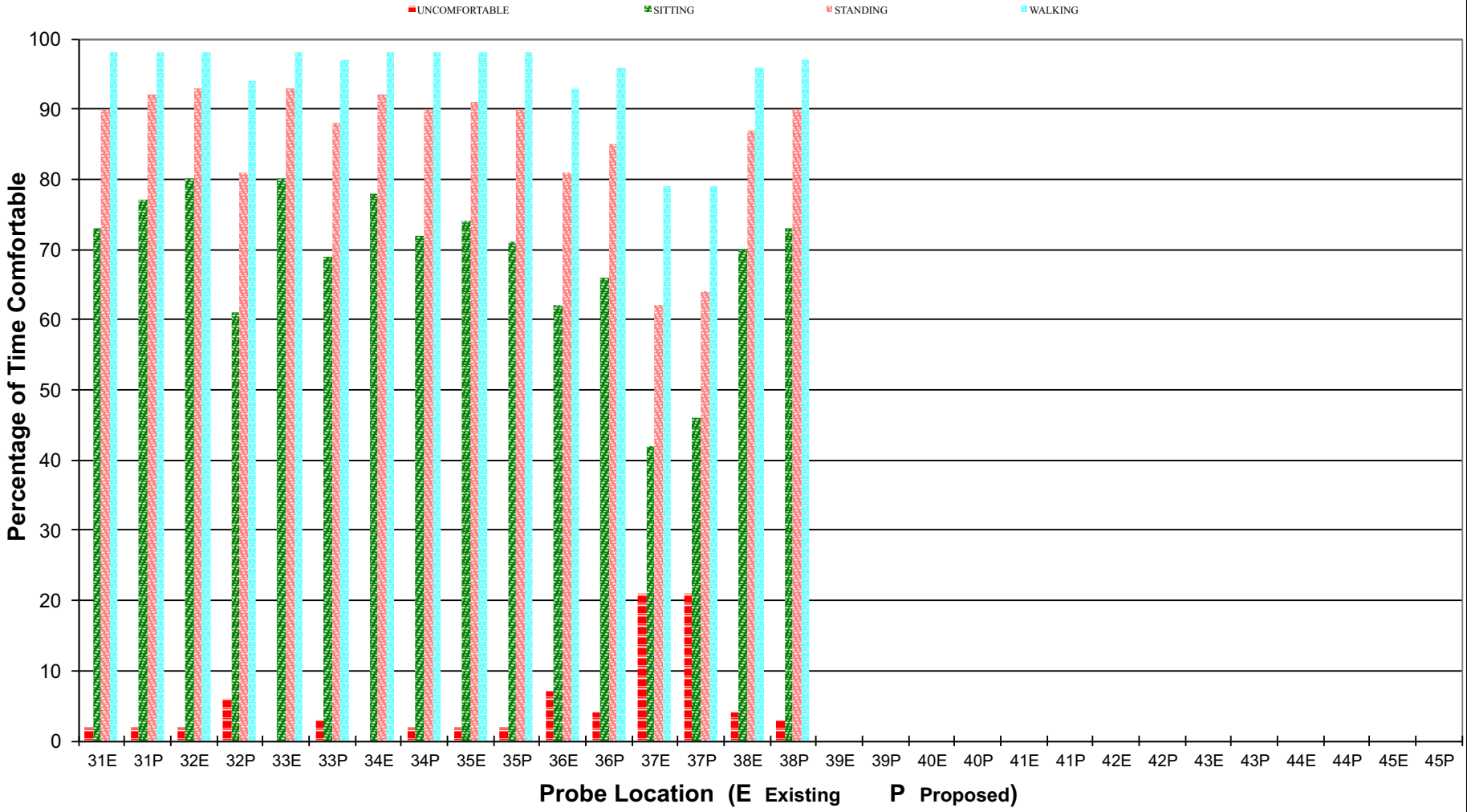


Figure 6b: WINTER - Percentage of time comfortable for a given activity (Locations 1 to 15).

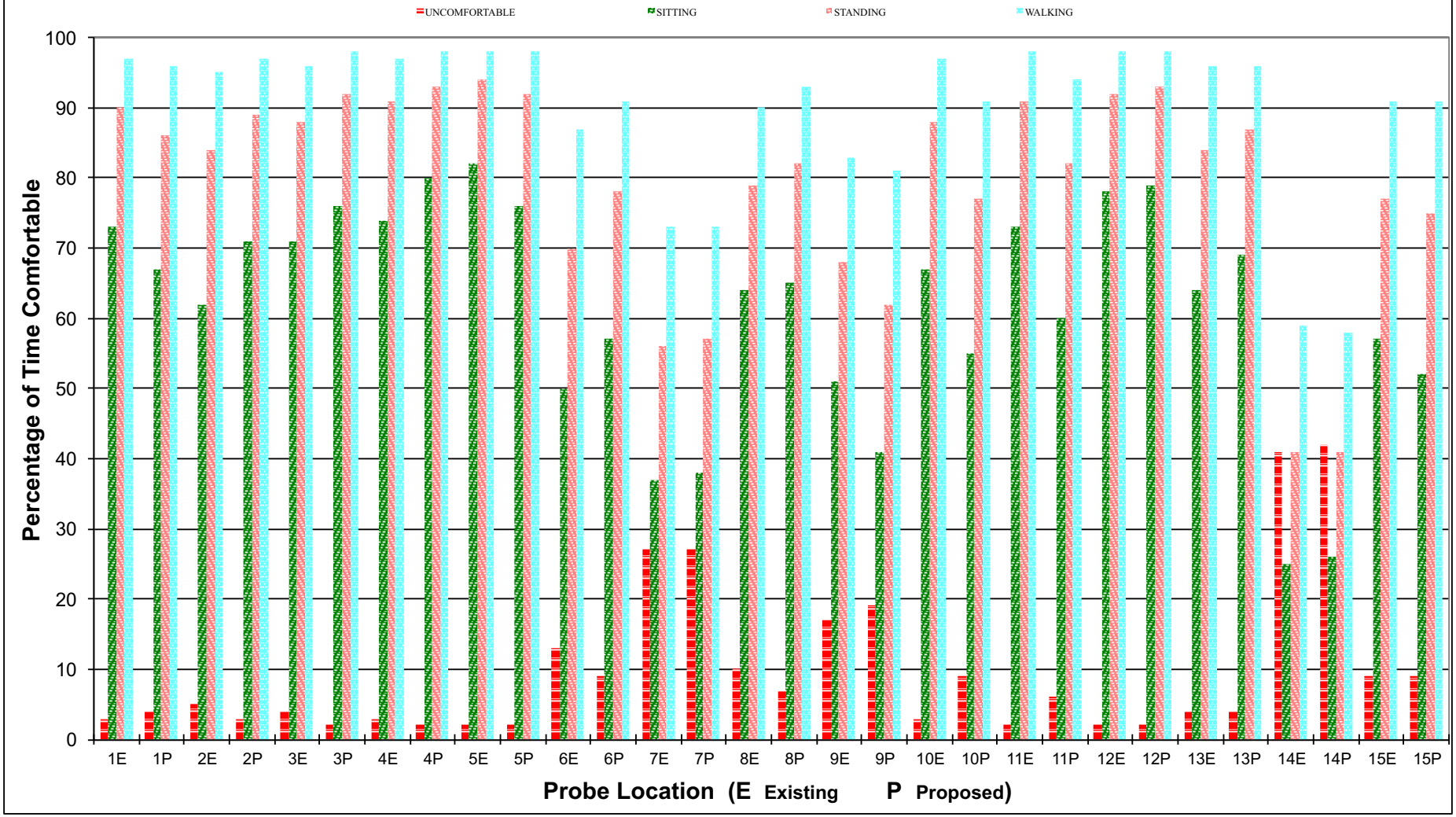


Figure 6b: WINTER - Percentage of time comfortable for a given activity (Locations 16 to 30).

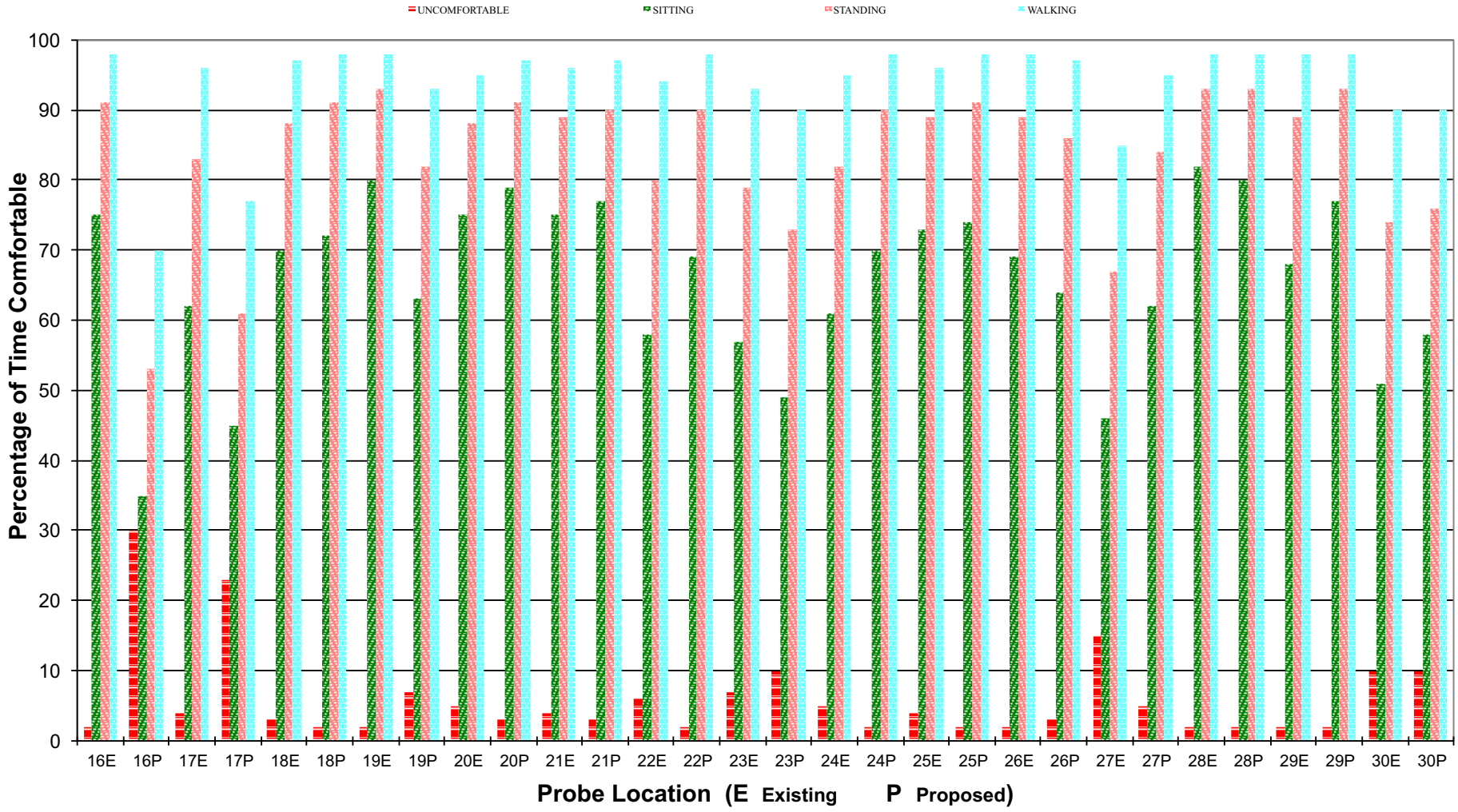


Figure 6b: WINTER - Percentage of time comfortable for a given activity (Locations 31 to 38).

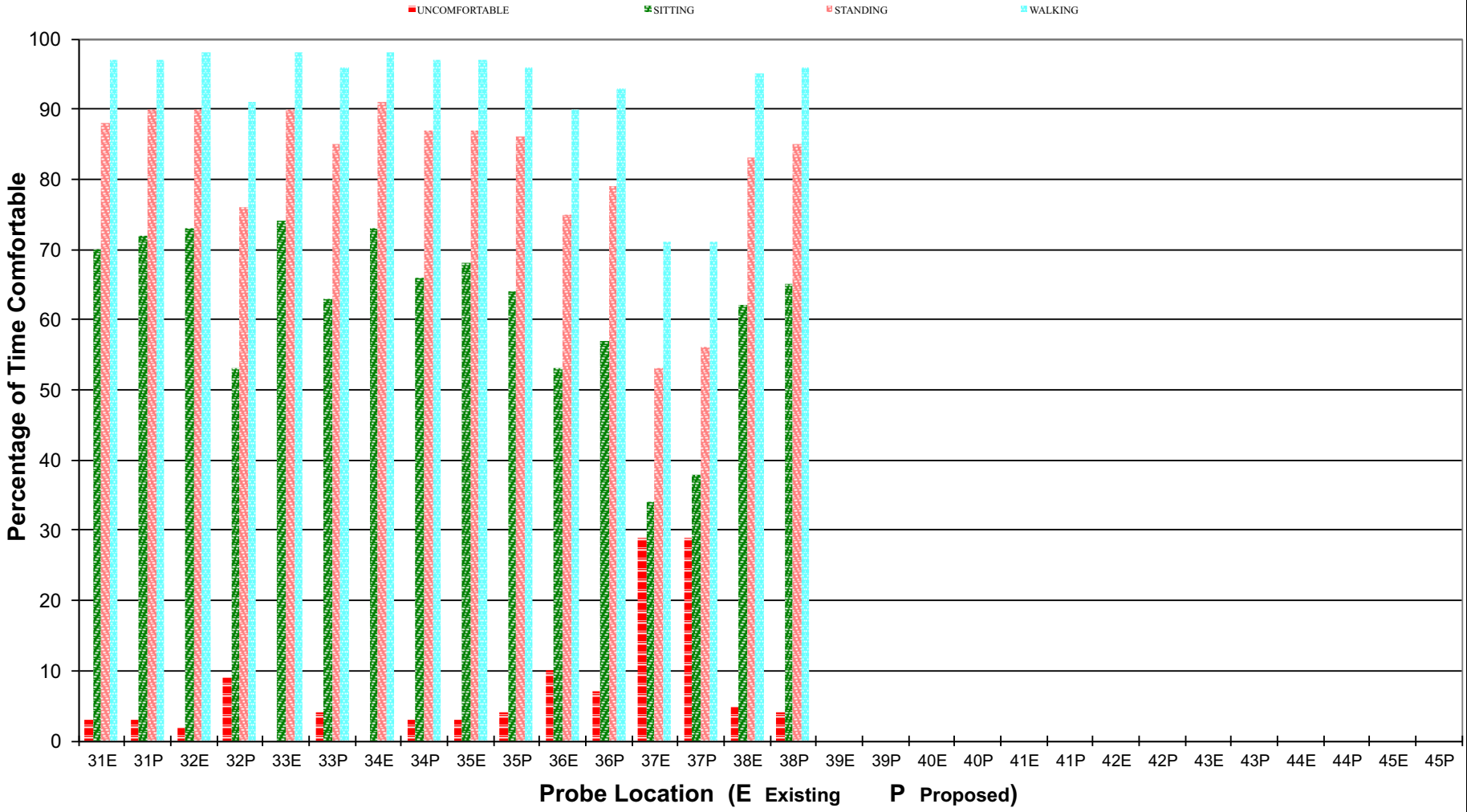


Figure 6c: SPRING - Percentage of time comfortable for a given activity (Locations 1 to 15).

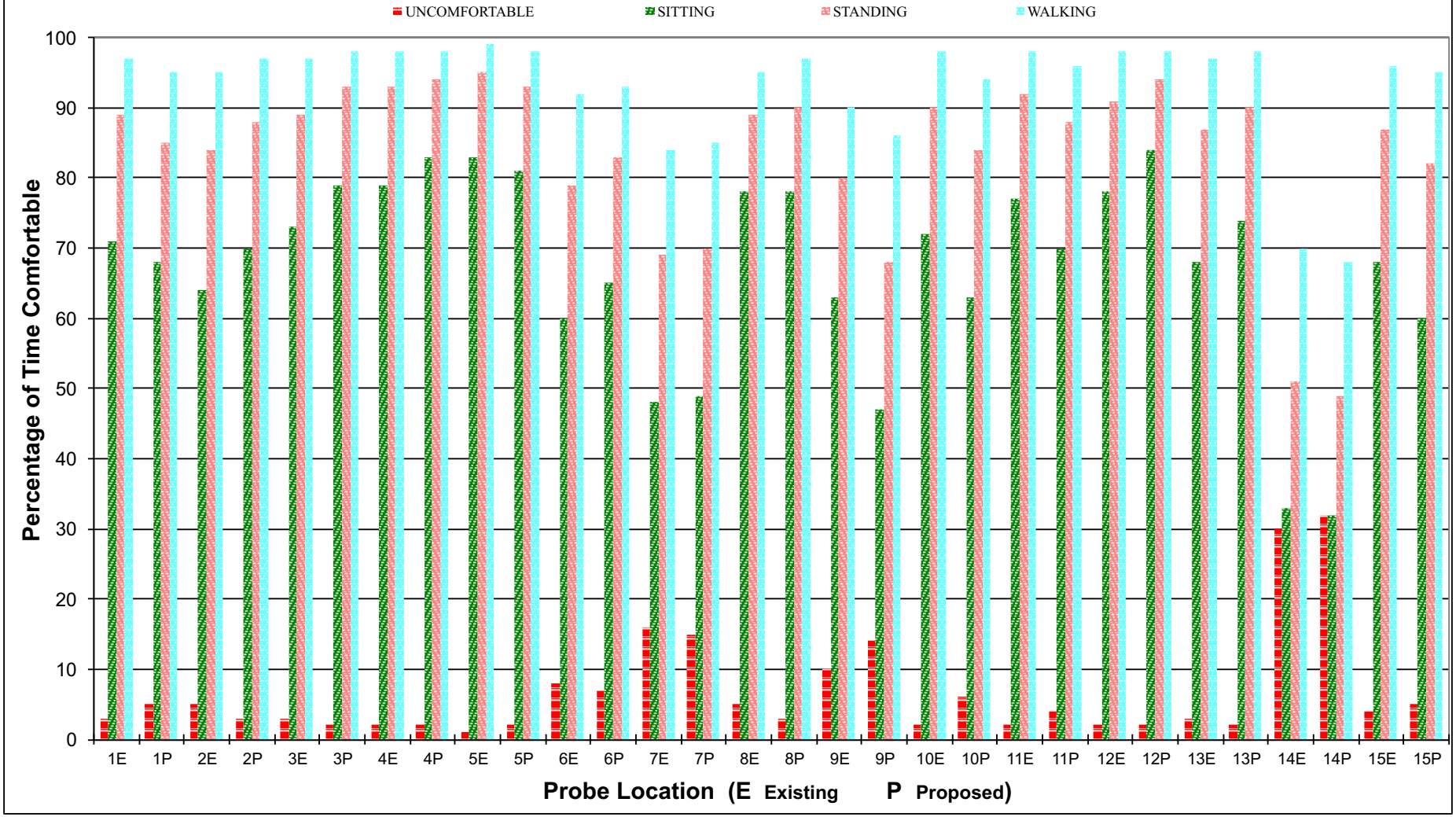


Figure 6c: SPRING - Percentage of time comfortable for a given activity (Locations 16 to 30).

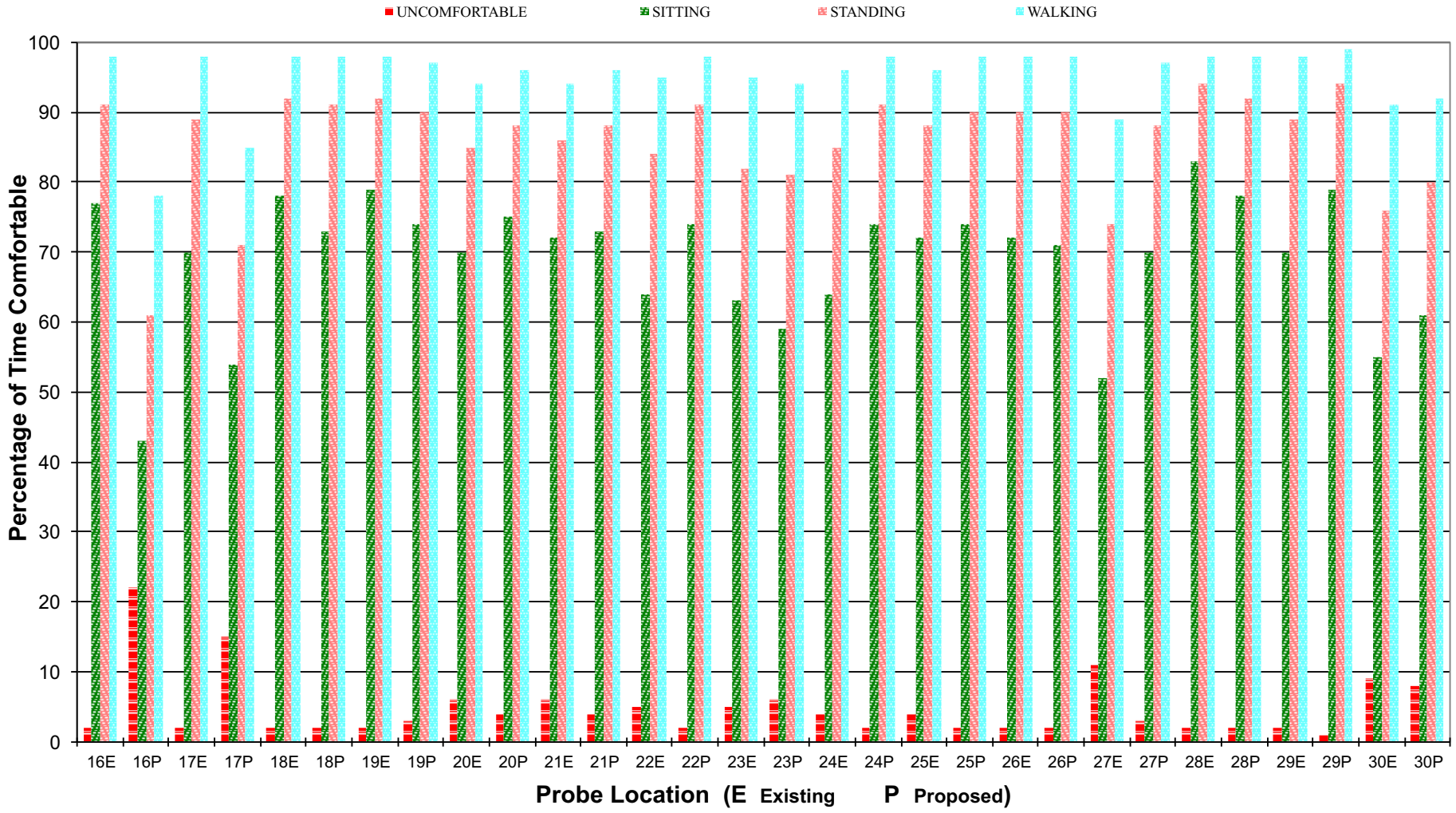


Figure 6c: SPRING - Percentage of time comfortable for a given activity (Locations 31 to 38).

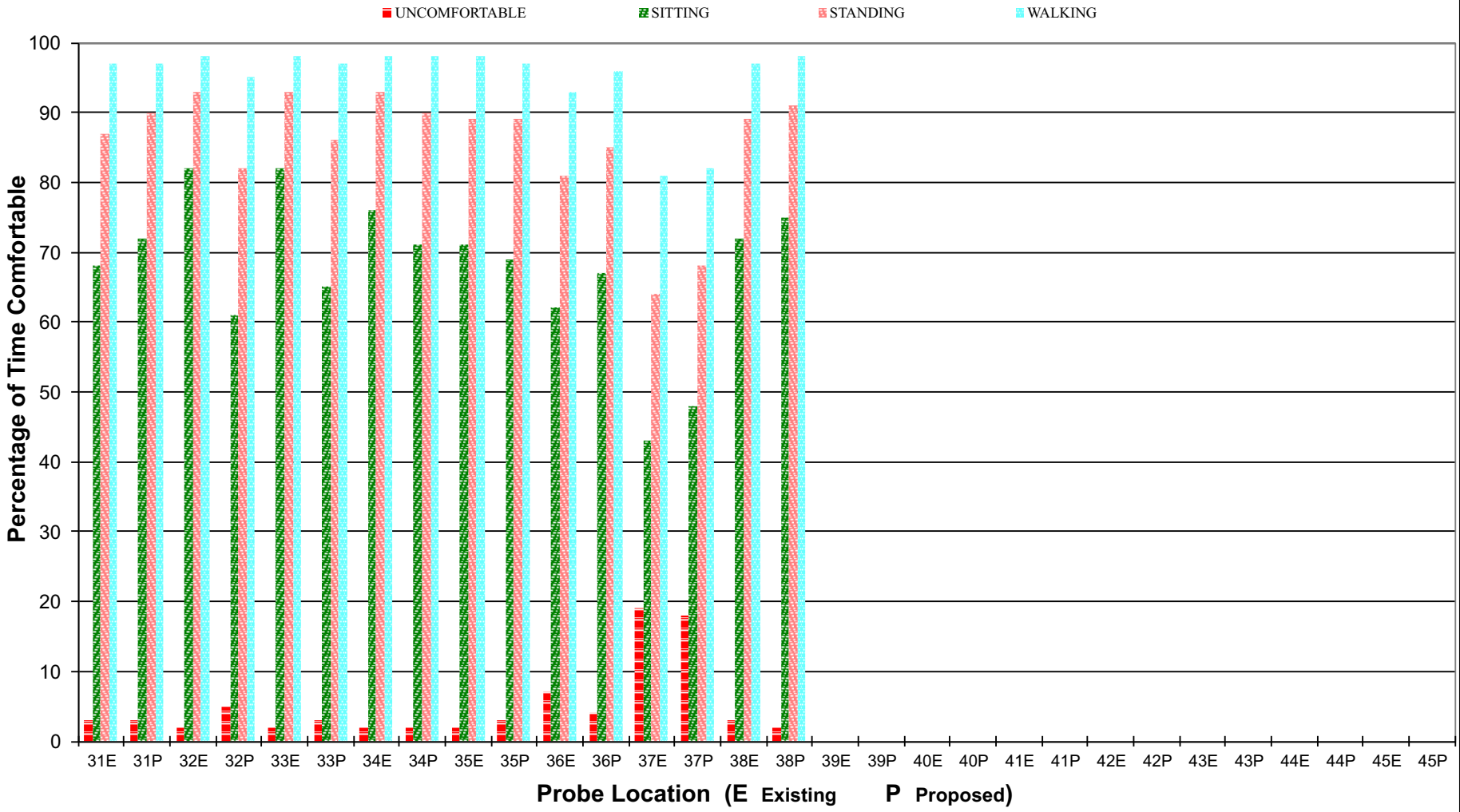


Figure 6d: SUMMER - Percentage of time comfortable for a given activity (Locations 1 to 15).

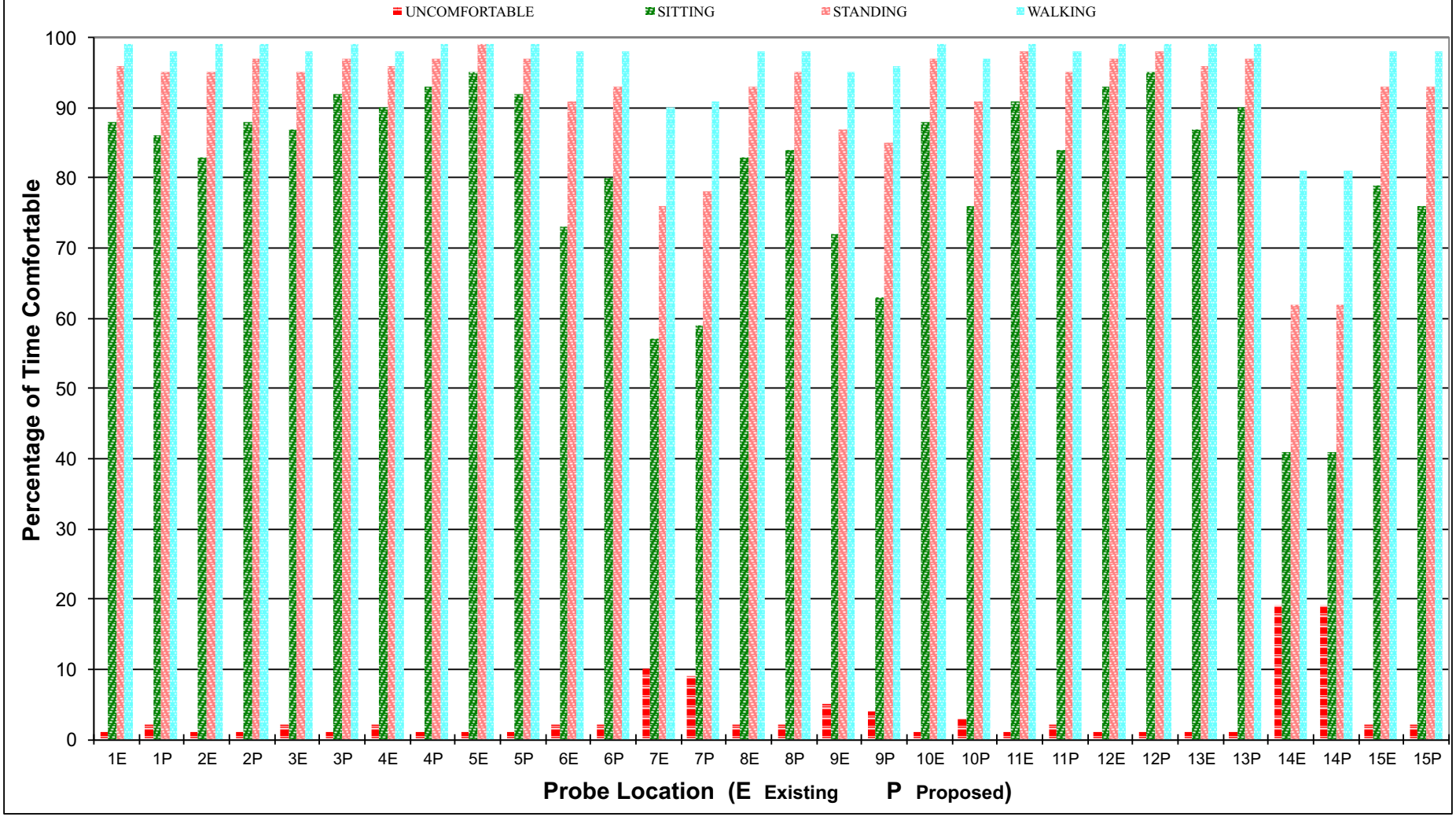


Figure 6d: SUMMER - Percentage of time comfortable for a given activity (Locations 16 to 30).

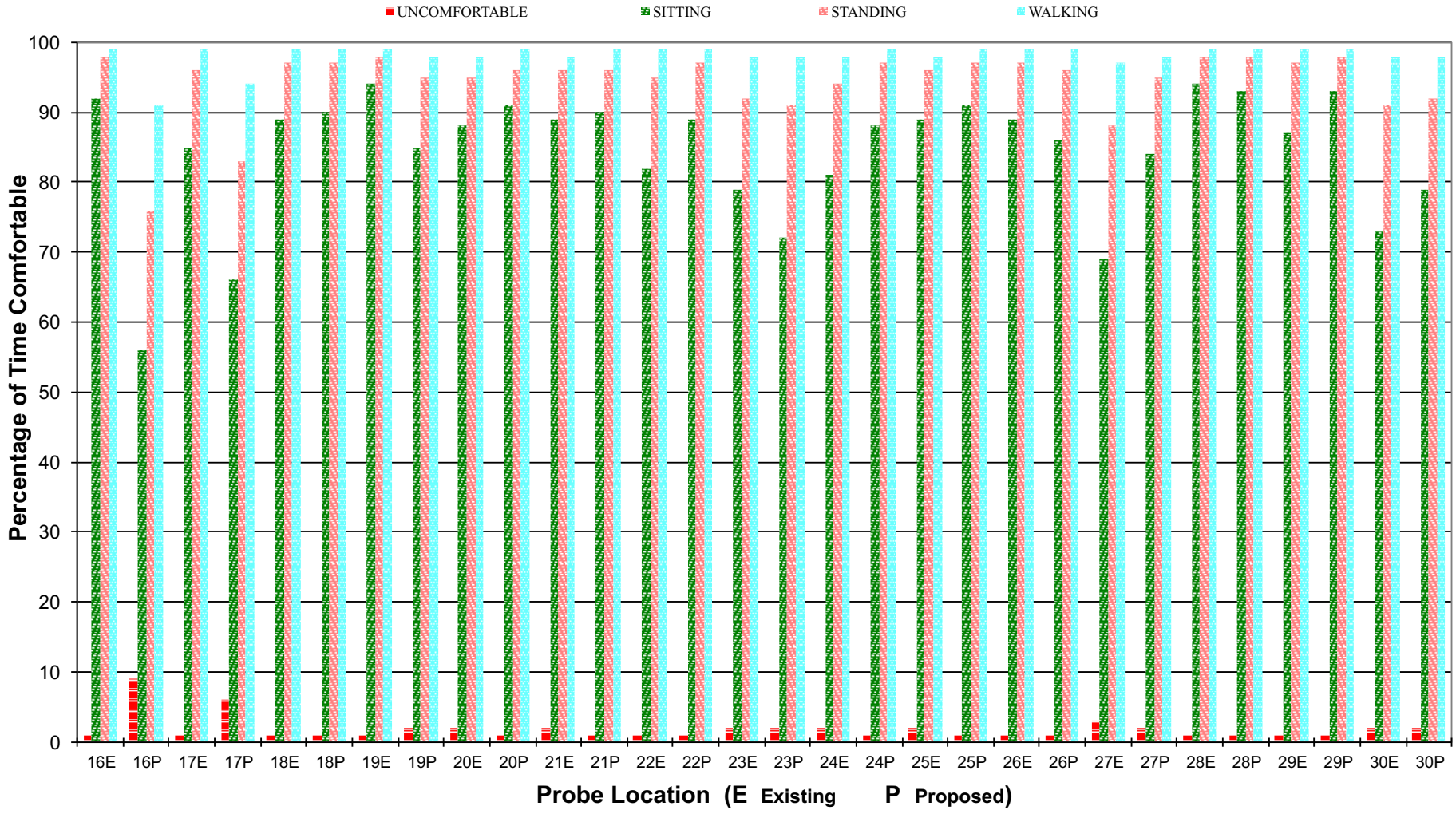


Figure 6d: SUMMER - Percentage of time comfortable for a given activity (Locations 31 to 38).

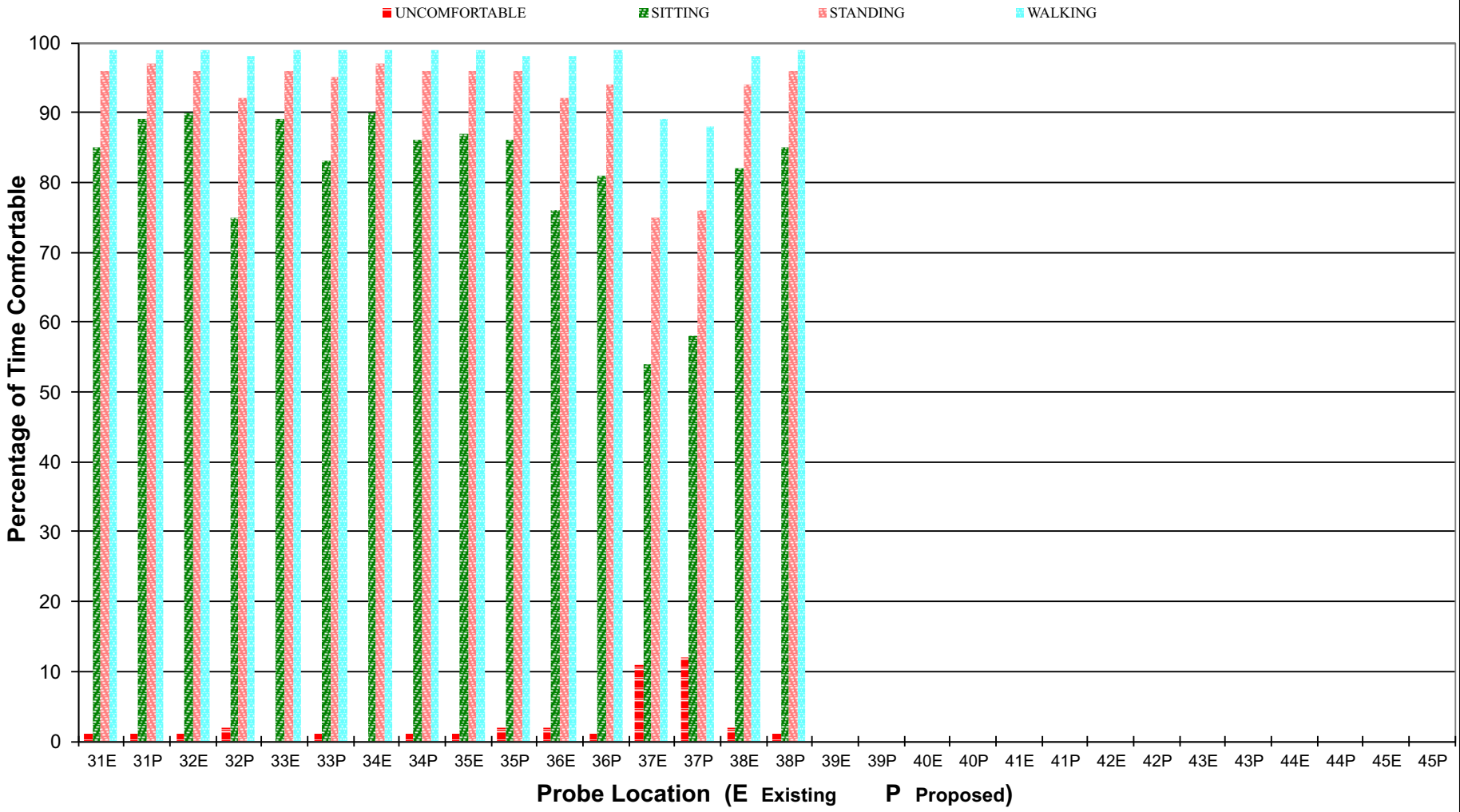


Figure 6e: FALL - Percentage of time comfortable for a given activity (Locations 1 to 15).

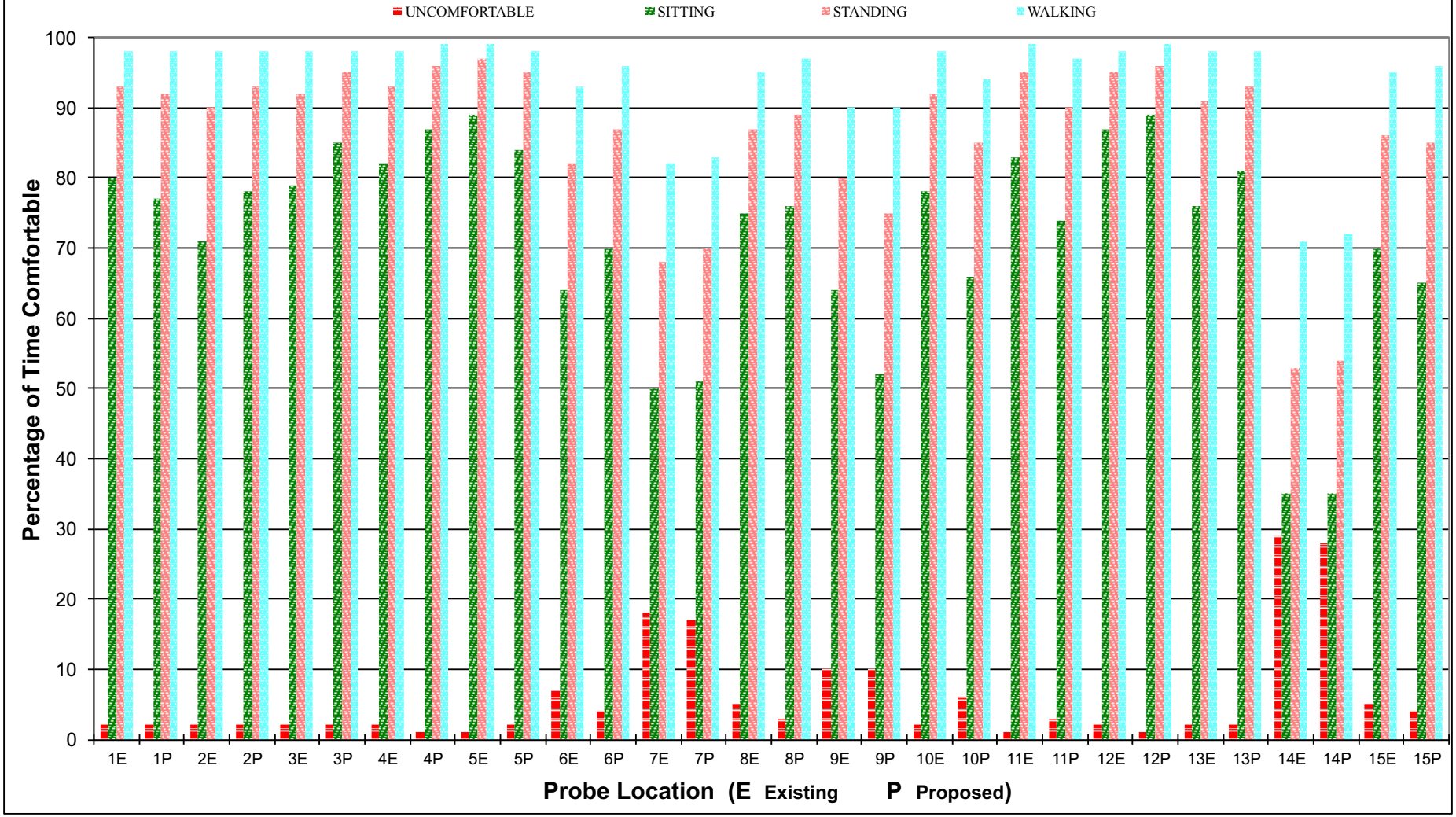


Figure 6e: FALL - Percentage of time comfortable for a given activity (Locations 16 to 30).

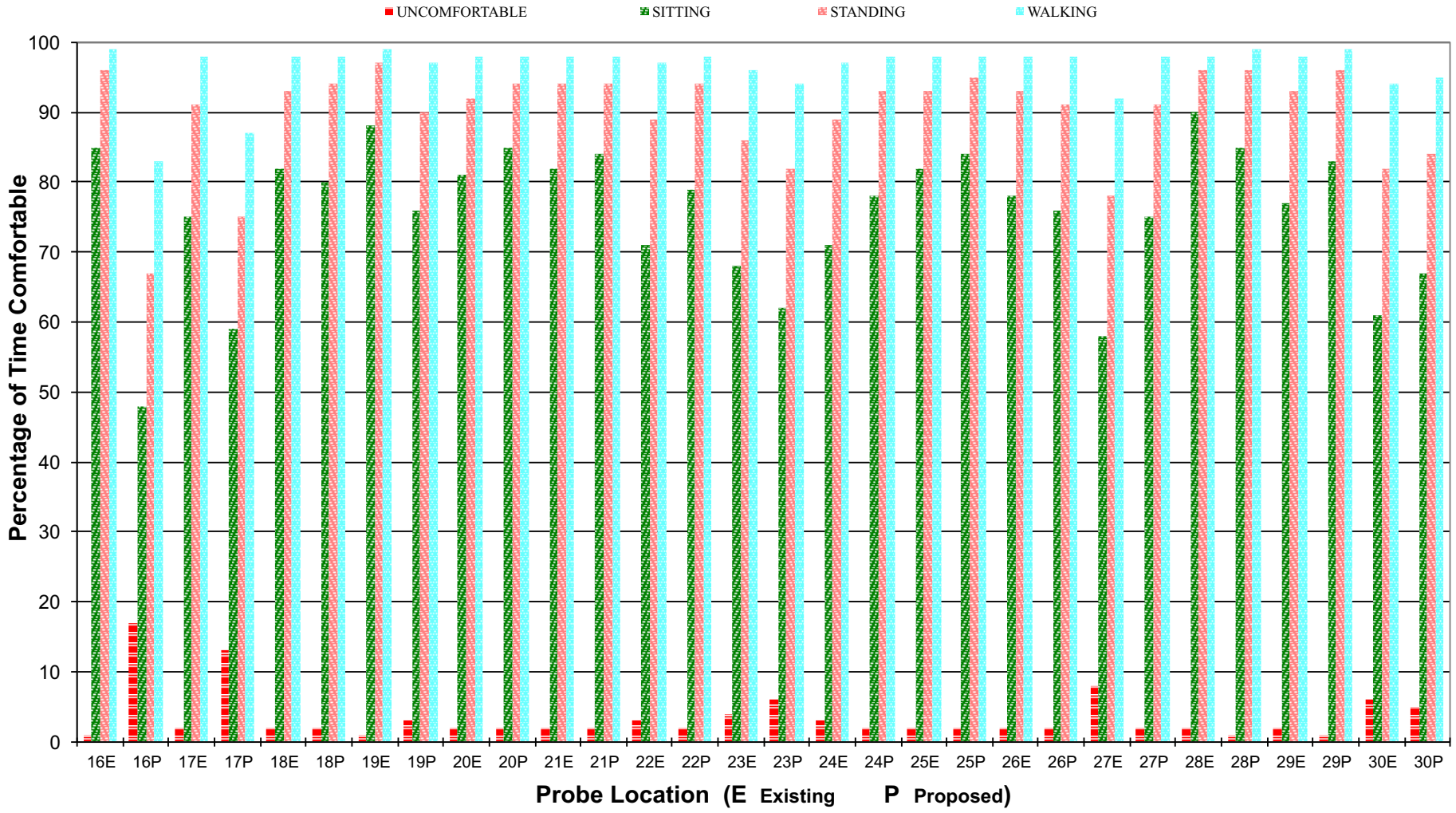


Figure 6e: FALL - Percentage of time comfortable for a given activity (Locations 31 to 38).

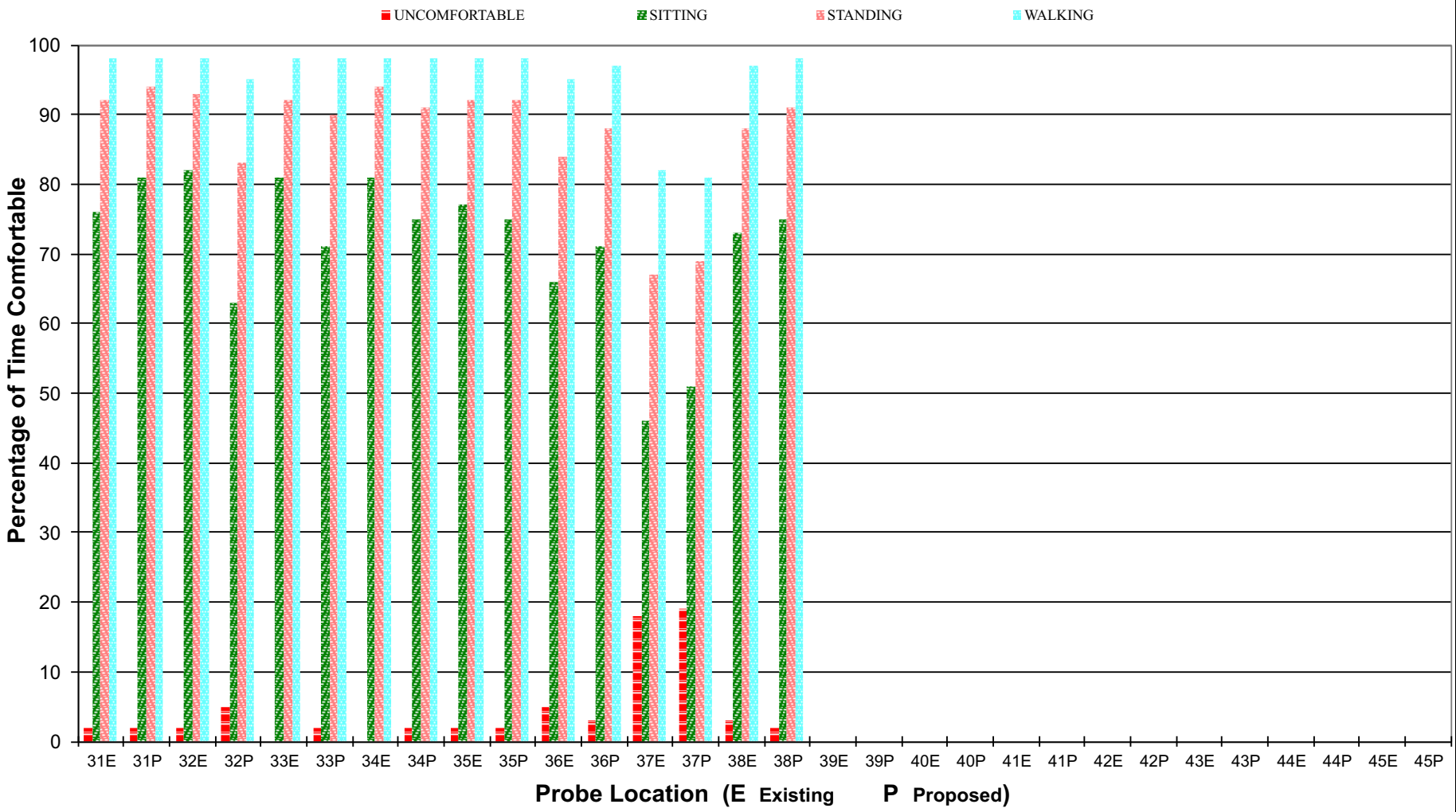
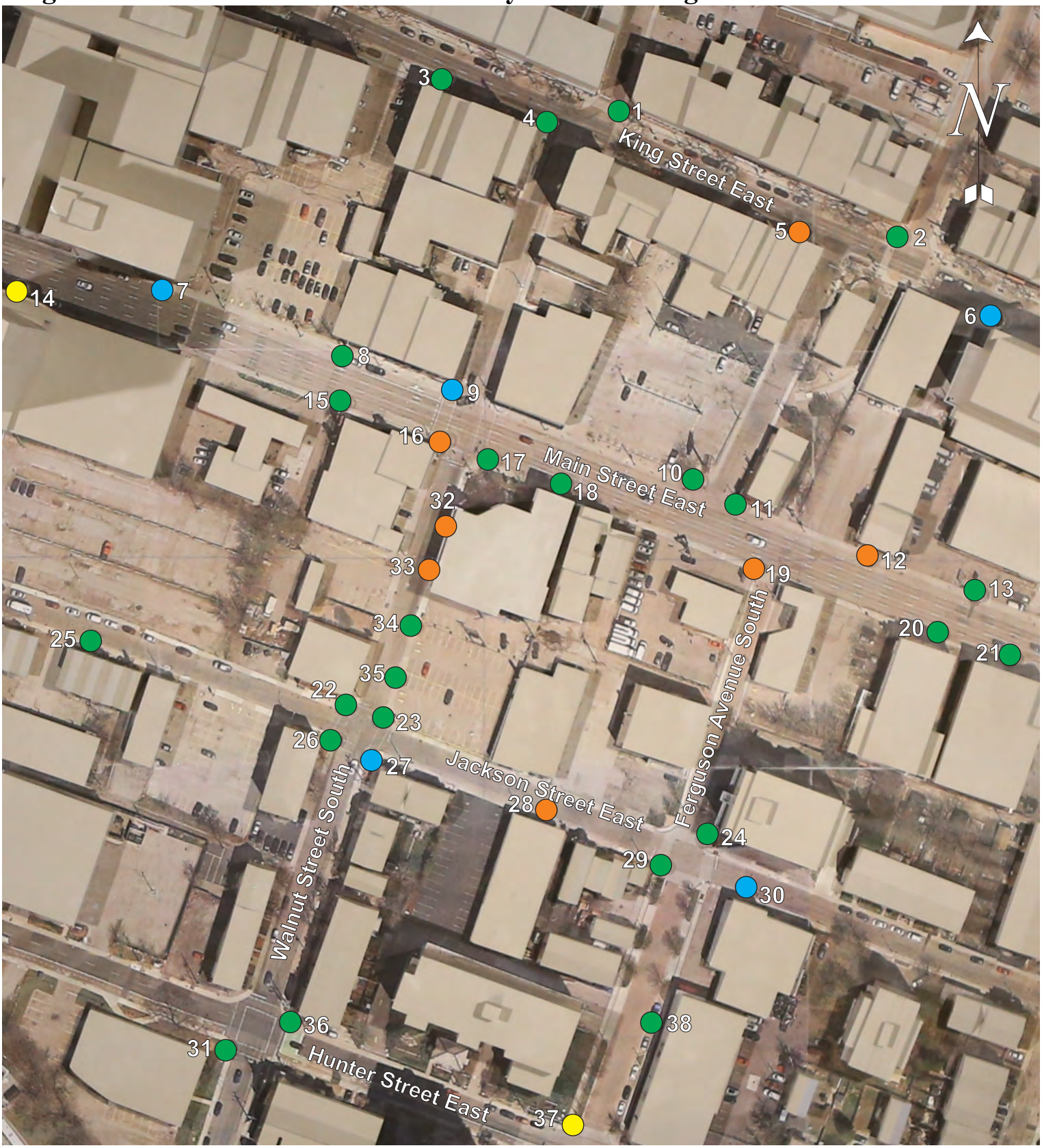


Figure 7a: Pedestrian level wind velocity comfort categories.



Comfort Categories - Annual - Existing

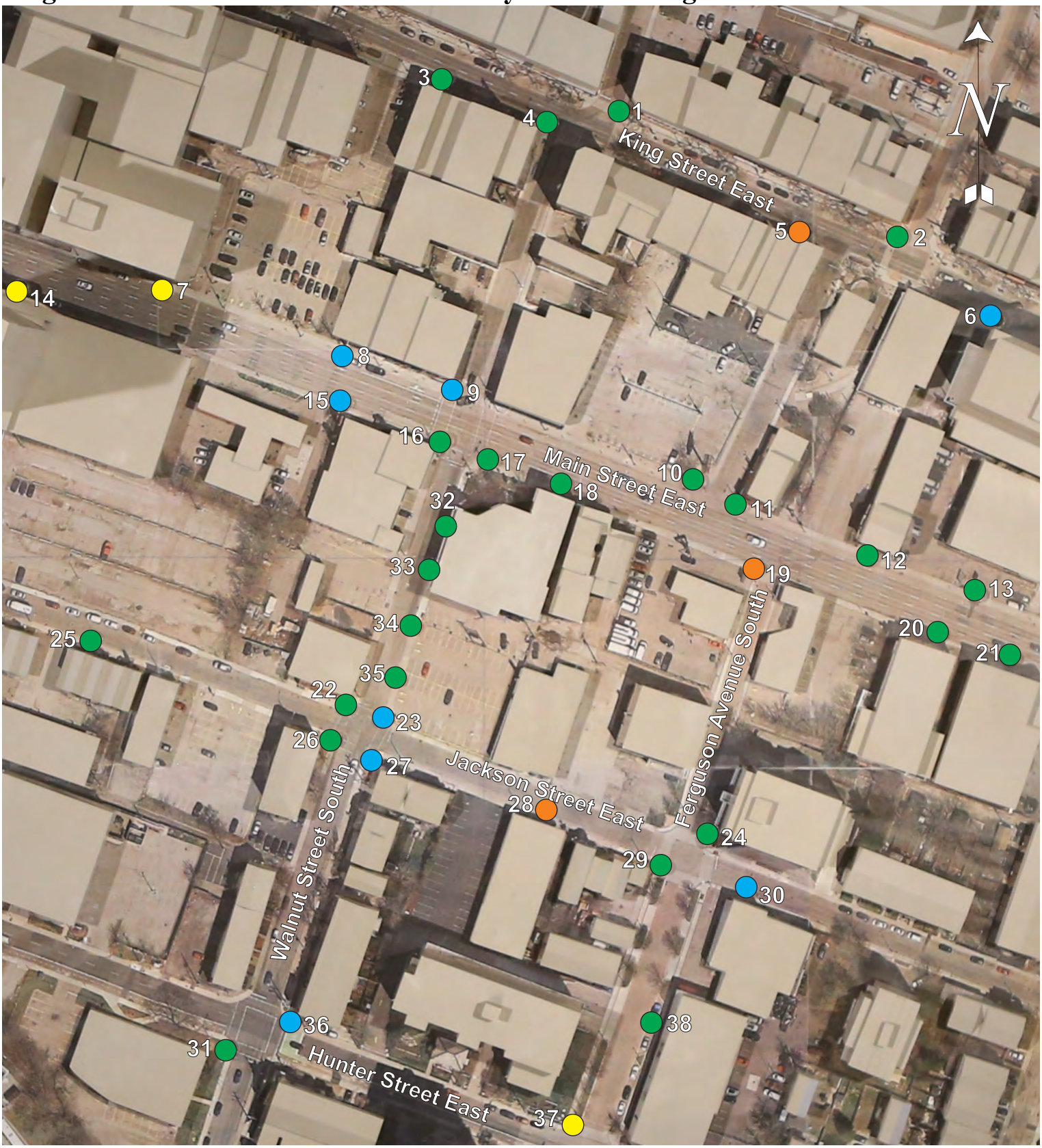
Sitting Standing Walking Uncomfortable

Figure 7b: Pedestrian level wind velocity comfort categories.

Comfort Categories - Annual - Proposed

Sitting Standing Walking Uncomfortable

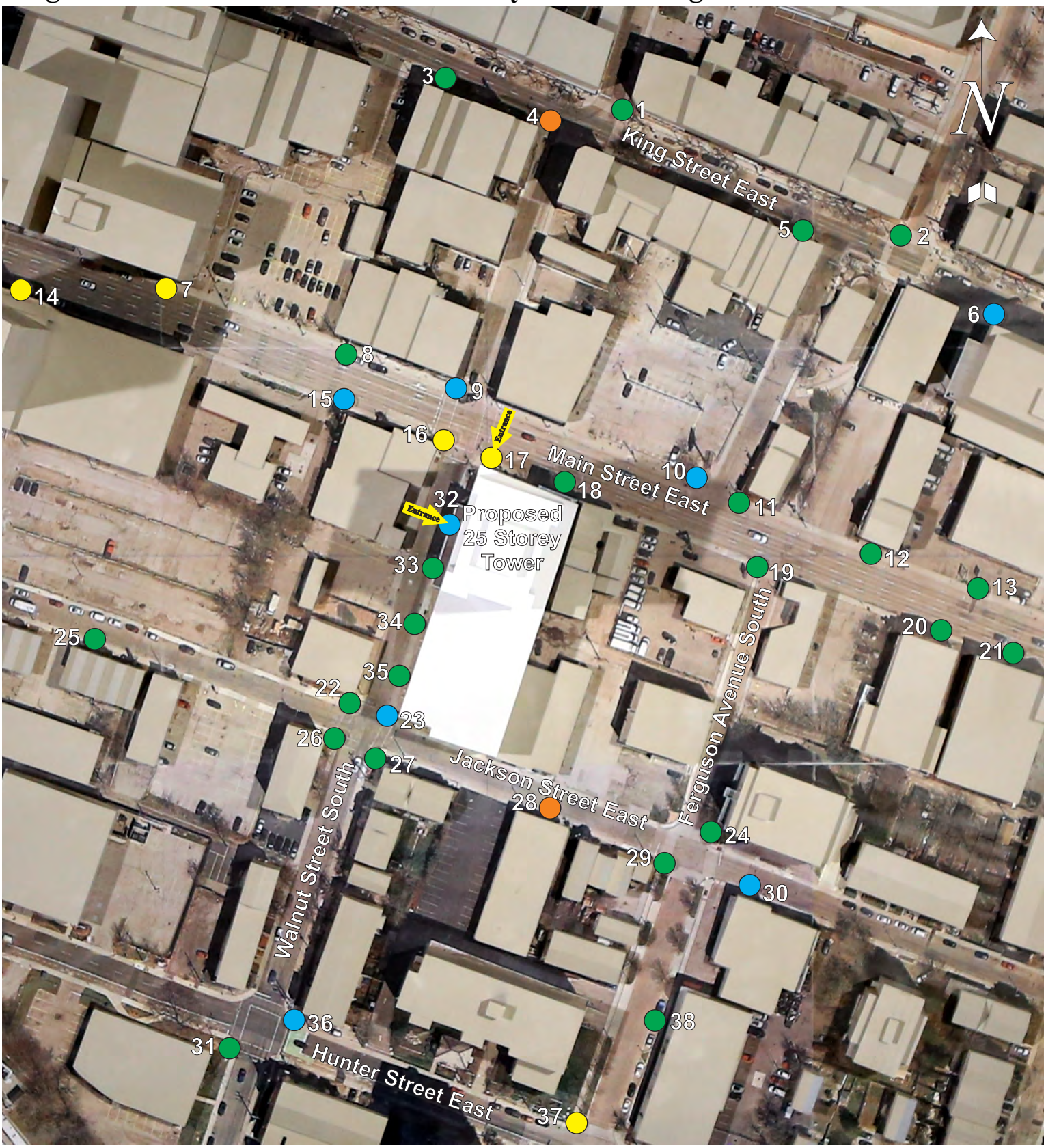
Figure 7c: Pedestrian level wind velocity comfort categories.



Comfort Categories - Winter - Existing

Sitting Standing Walking Uncomfortable

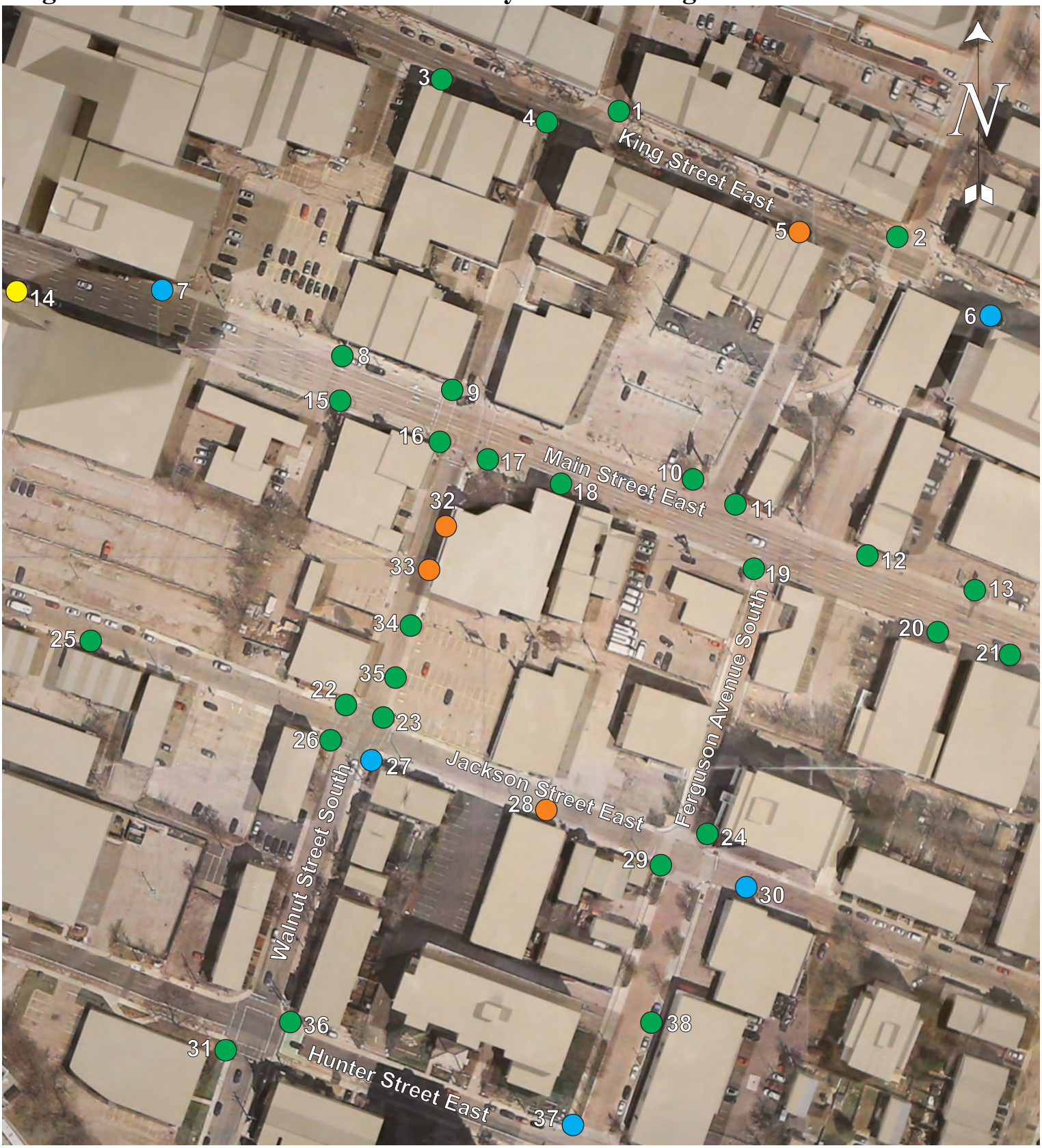
Figure 7d: Pedestrian level wind velocity comfort categories.



Comfort Categories - Winter - Proposed

Sitting Standing Walking Uncomfortable

Figure 7e: Pedestrian level wind velocity comfort categories.



Comfort Categories - Spring - Existing

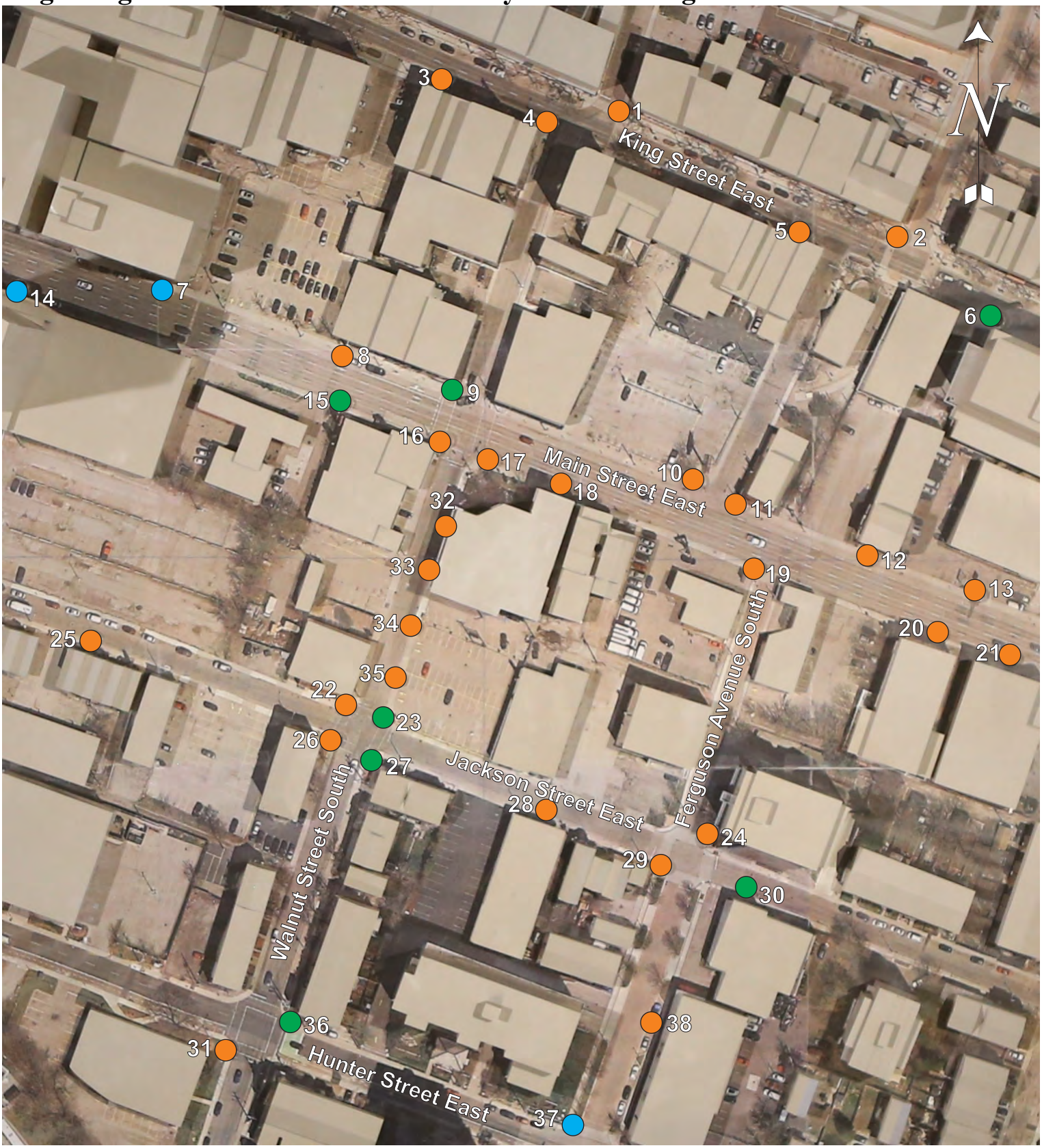
Sitting Standing Walking Uncomfortable

Figure 7f: Pedestrian level wind velocity comfort categories.

Comfort Categories - Spring - Proposed

Sitting Standing Walking Uncomfortable

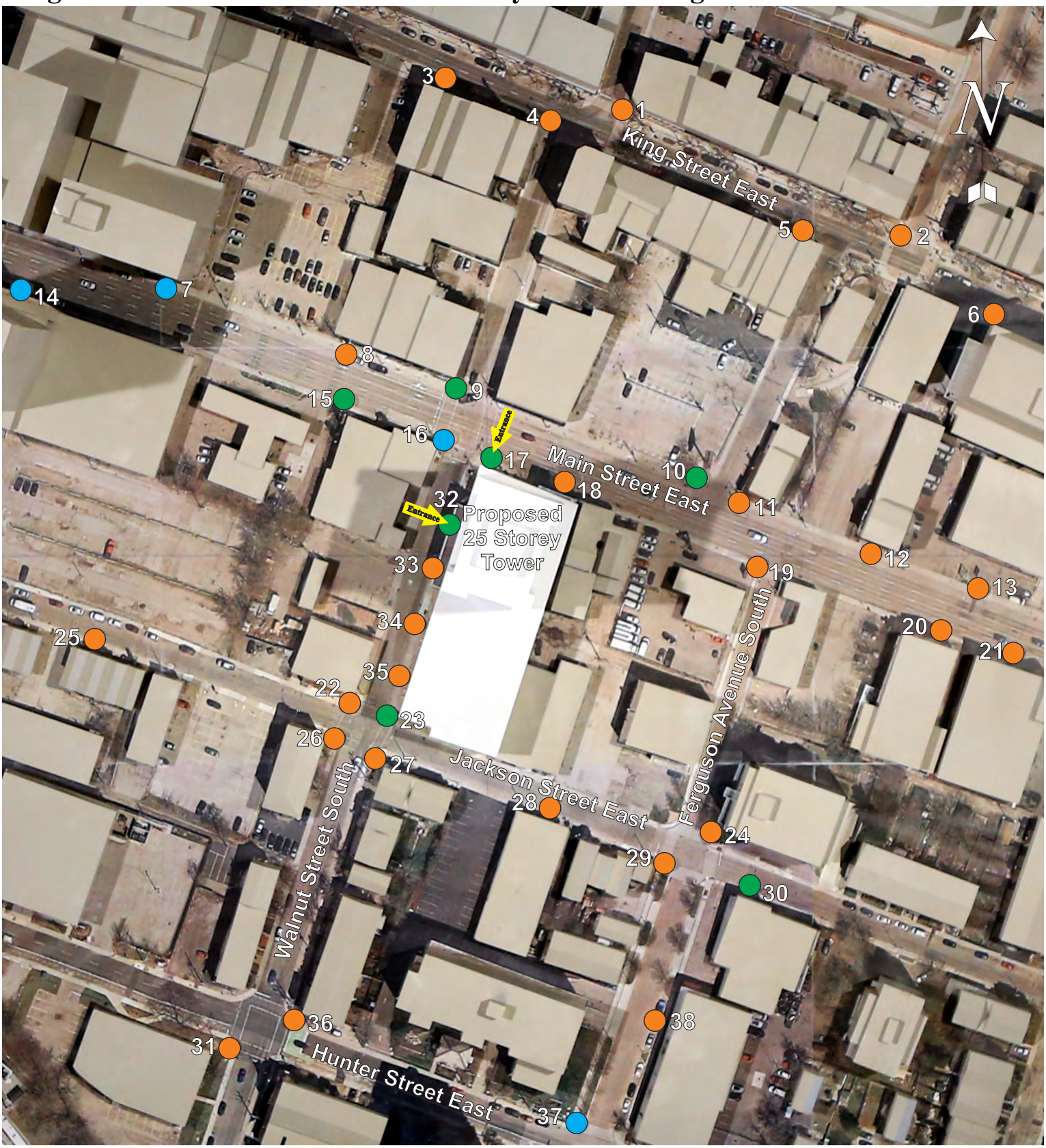
Figure 7g: Pedestrian level wind velocity comfort categories.



Comfort Categories - Summer - Existing

Sitting Standing Walking Uncomfortable

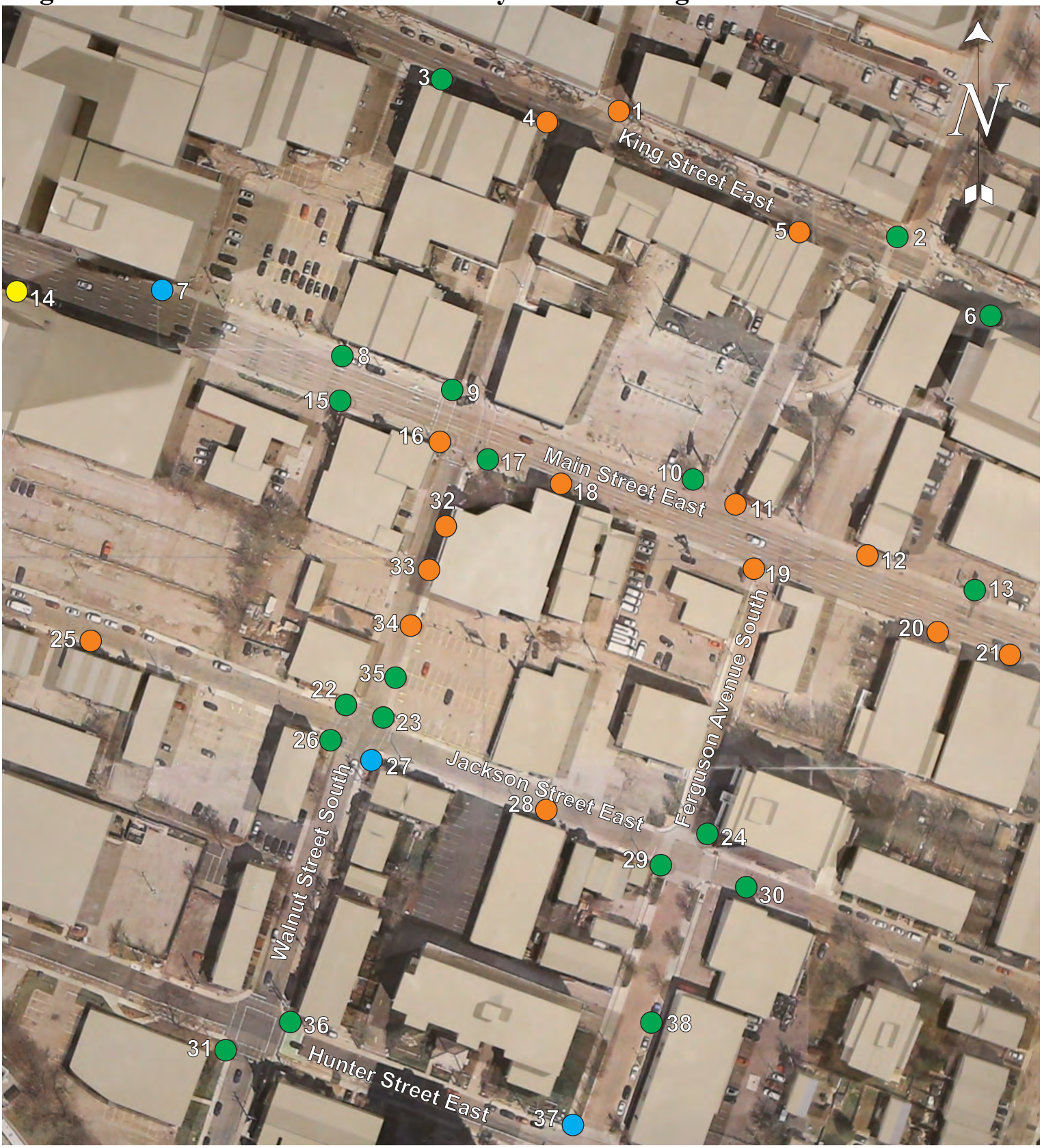
Figure 7h: Pedestrian level wind velocity comfort categories.



Comfort Categories - Summer - Proposed

Sitting Standing Walking Uncomfortable

Figure 7i: Pedestrian level wind velocity comfort categories.



Comfort Categories - Fall - Existing

Sitting Standing Walking Uncomfortable

Figure 7j: Pedestrian level wind velocity comfort categories.

Comfort Categories - Fall - Proposed

Sitting Standing Walking Uncomfortable

8. 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:

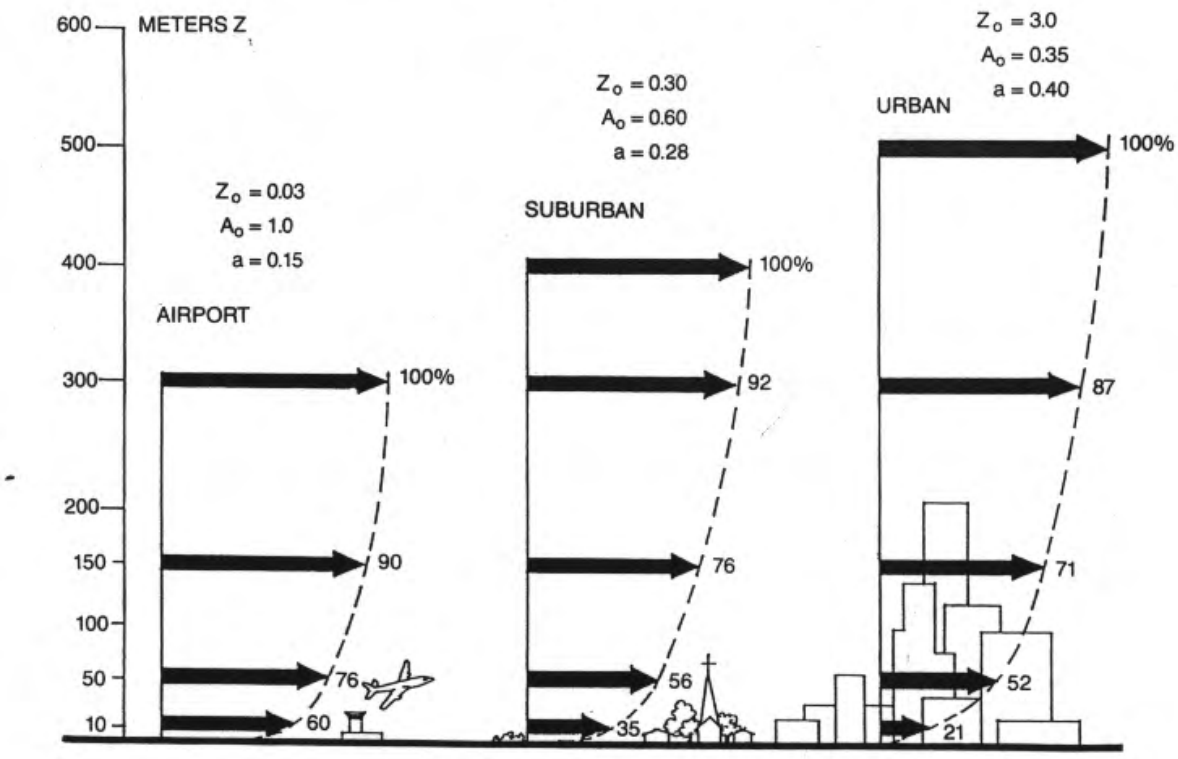


Figure A: Mean wind speed profiles for various terrain (from ASHRAE 1989).

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.

The Beaufort Scale

Beaufort Number	Description	Wind Speed			Observations
		mph	km/h	Knots	
0	Calm	0	0	0	Tree leaves don't move; smoke rises vertically; sea is calm, mirror like.
1	Light Air	1-3	1-5	1-3	Tree leaves don't move; smoke drifts slowly; direction of wind shown by smoke, not by vane; sea is lightly rippled.
2	Slight Breeze	4-7	6-11	4-6	Tree leaves rustle; flags wave slightly; vanes show wind direction; small wavelets or scale waves.
3	Gentle Breeze	8-12	12-19	7-10	Leaves and twigs in constant motion; small flags extended; long unbreaking waves.
4	Moderate Breeze	13-18	20-29	11-16	Small branches move; flags flap; waves with whitecaps.
5	Fresh Breeze	19-24	30-38	17-21	Small trees sway; flags flap and ripple; moderate waves with many whitecaps.
6	Strong Breeze	25-31	39-50	22-27	Large branches sway; umbrellas used with difficulty; flags beat and pop; larger waves with regular whitecaps.
7	Moderate Gale	32-38	51-61	28-33	Sea heaps up, white foam streaks; whole trees sway; difficult to walk; large waves.
8	Fresh Gale	39-46	62-74	34-40	Twigs break off trees; moderately high sea with blowing foam.
9	Strong Gale	47-54	75-86	41-47	Branches break off trees; tiles blown from roofs; high crested waves.
10	Whole Gale	55-63	87-101	48-55	Some trees blown down; damage to buildings; high churning white seas and exceptionally high waves hiding ships from view.
11	Storm	64-74	102-120	56-63	Widespread damage to trees and buildings; mountainous waves. Sea covered in white foam.
12	Hurricane	75+	120+	64+	Severe and extensive damage.

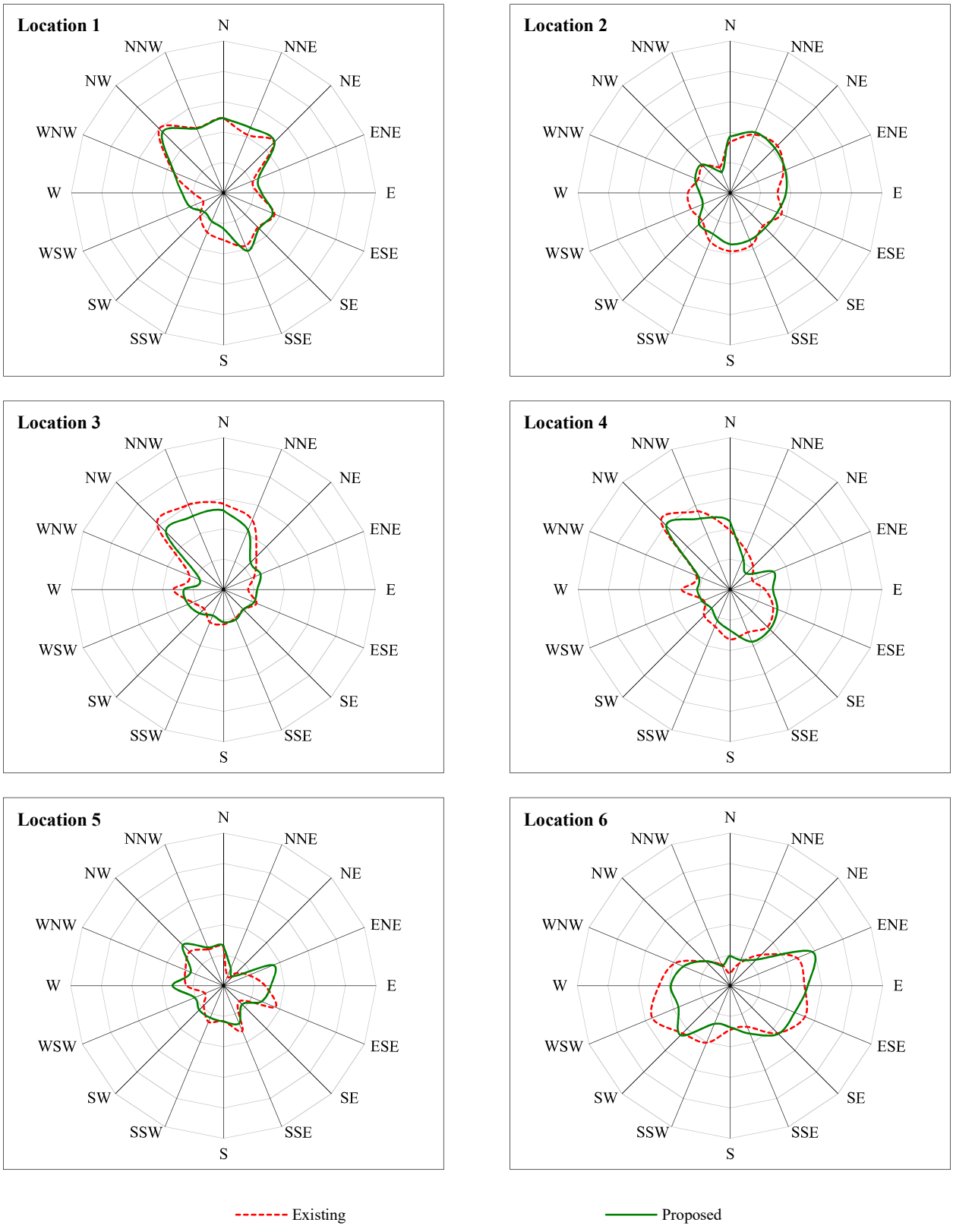
Wind speeds indicated above are at a reference height of 10 metres, as are the wind speeds indicated on the Figure 5 wind roses. The mean wind speeds at pedestrian level would be approximately 80% of these values. The relationship between wind speed and height relative to terrain is discussed in the appendices.

The table below correlates the Beaufort Scale with the average pedestrian comfort response as listed in Figure 6 and depicted in Figure 7, of the report, which provide an indication of the safety and comfort of pedestrians. The scale reflected on the figures takes into consideration the area around the subject building and in the immediate vicinity of the subject building, as affected by the wind patterns induced by the location, orientation and configuration of the proposed structure. At each point, as the wind velocity increases, the comfort level decreases. Also, at lower

temperatures, relative comfort level might be expected to be reduced by one Beaufort number for every 20 degrees Celsius reduction in temperature, however, this is not applied to the wind driven results provided.

		Relative Comfort		
Activity	Areas Applicable	Perceptible	Tolerable	Uncomfortable
Occasional Use	Sidewalks	6	7	8
Walking	Sidewalks, Parking Lots	5	6	7
Strolling	Parks, Entrances	4	5	6
Standing, Sitting, Short exp.	Parks, Plaza areas	3	4	5
Standing, Sitting, Long exp.	Outdoor Restaurants	2	3	4
Representative criteria for acceptability			< 1 occn./week	< 1 occn./month

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



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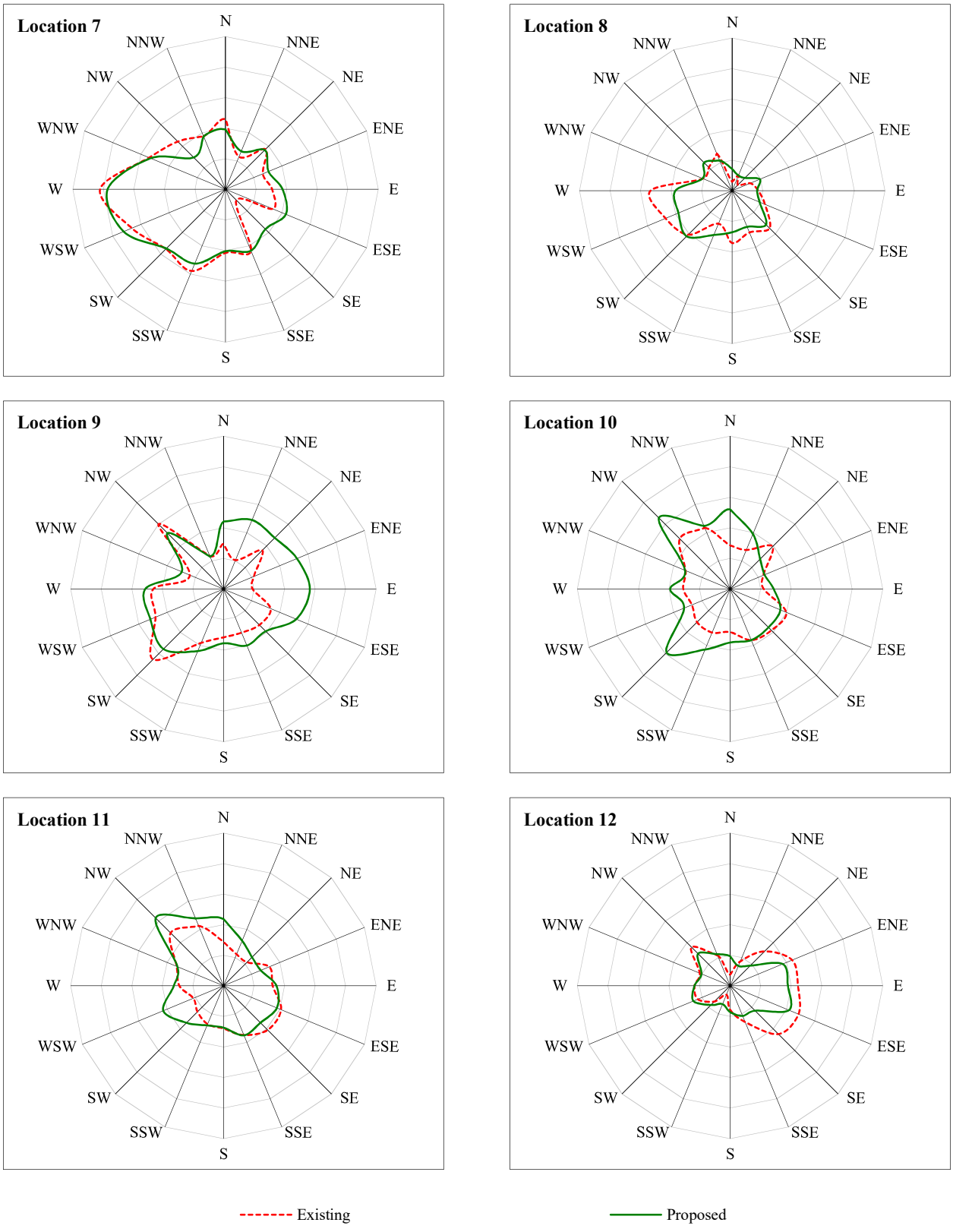

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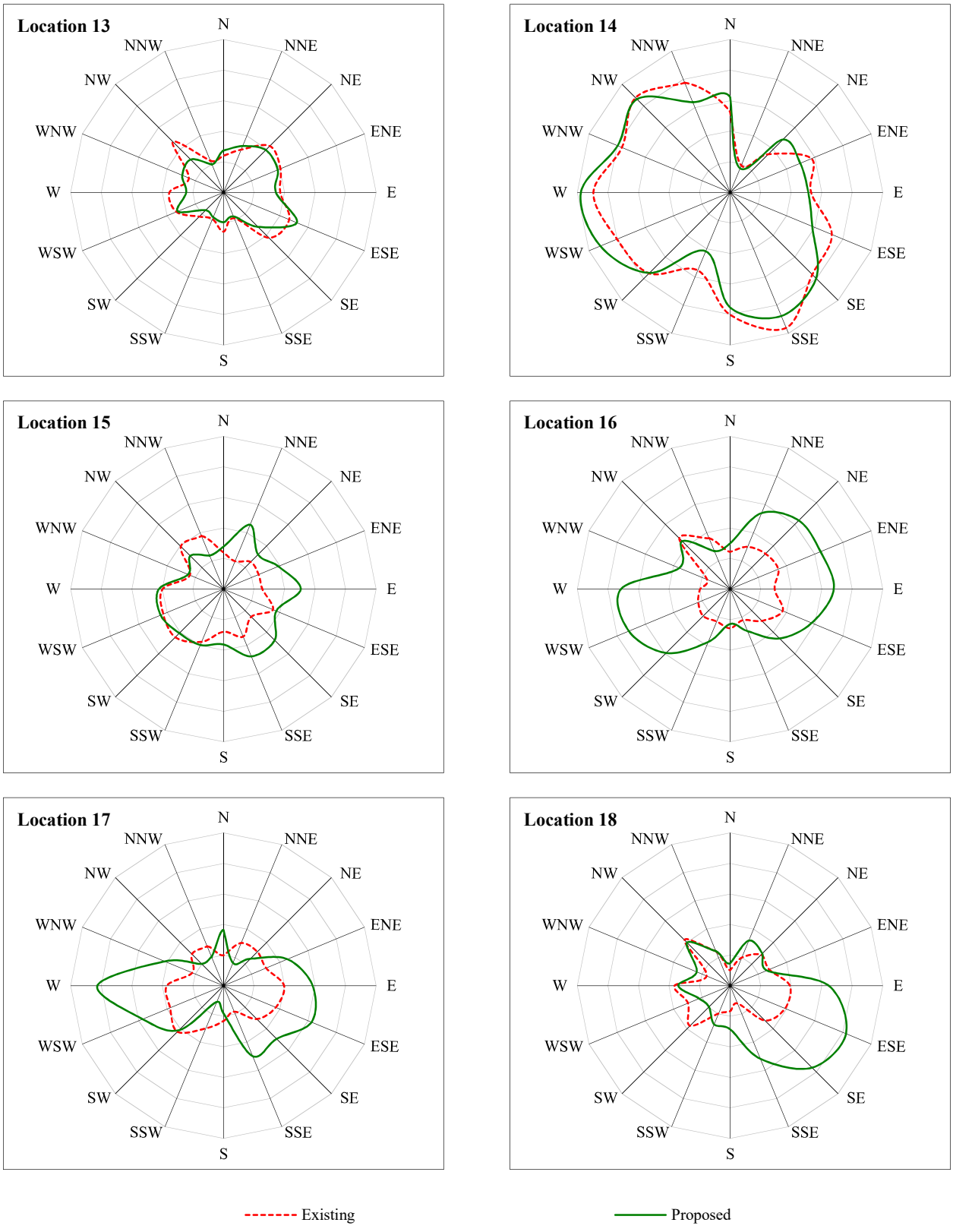

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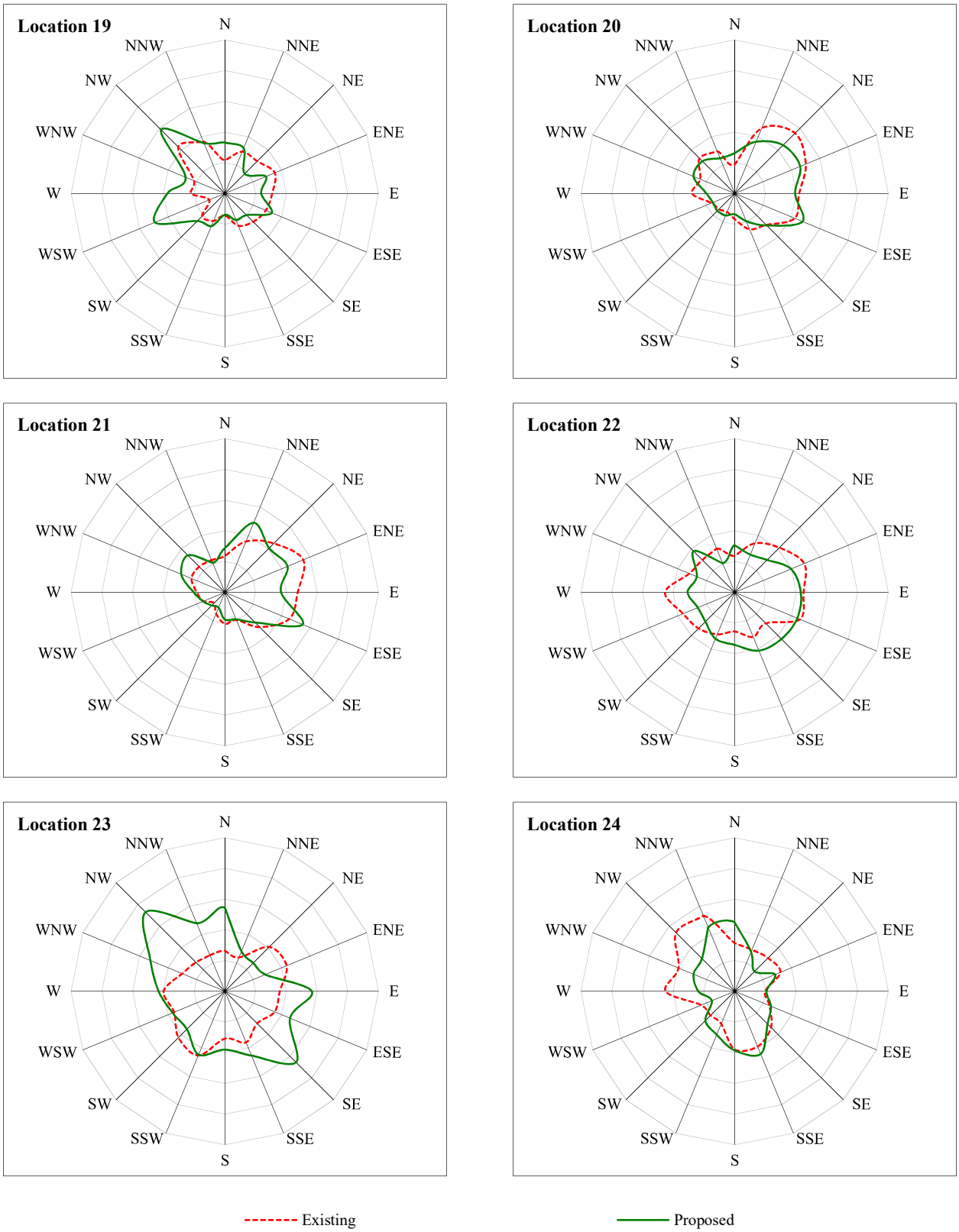

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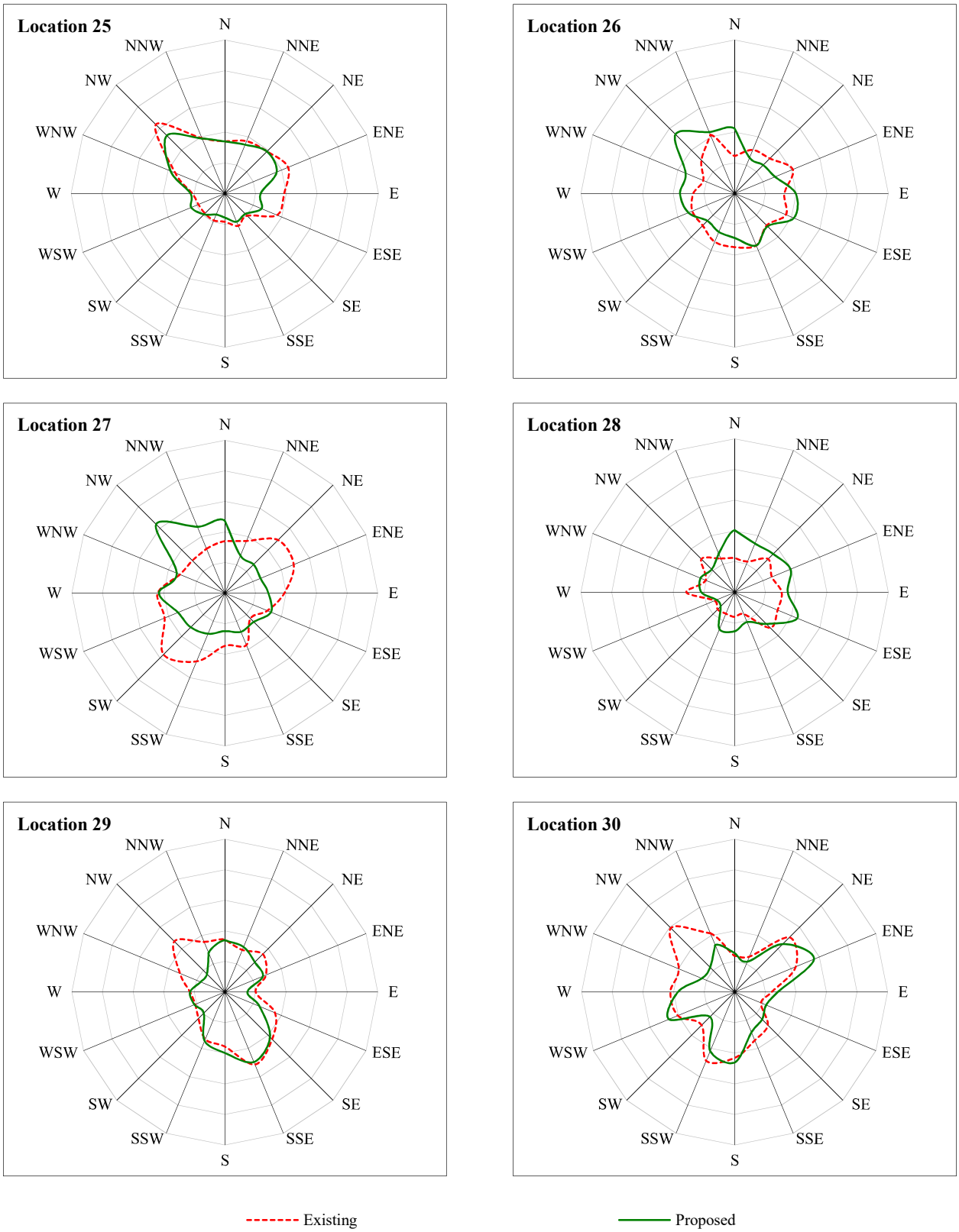

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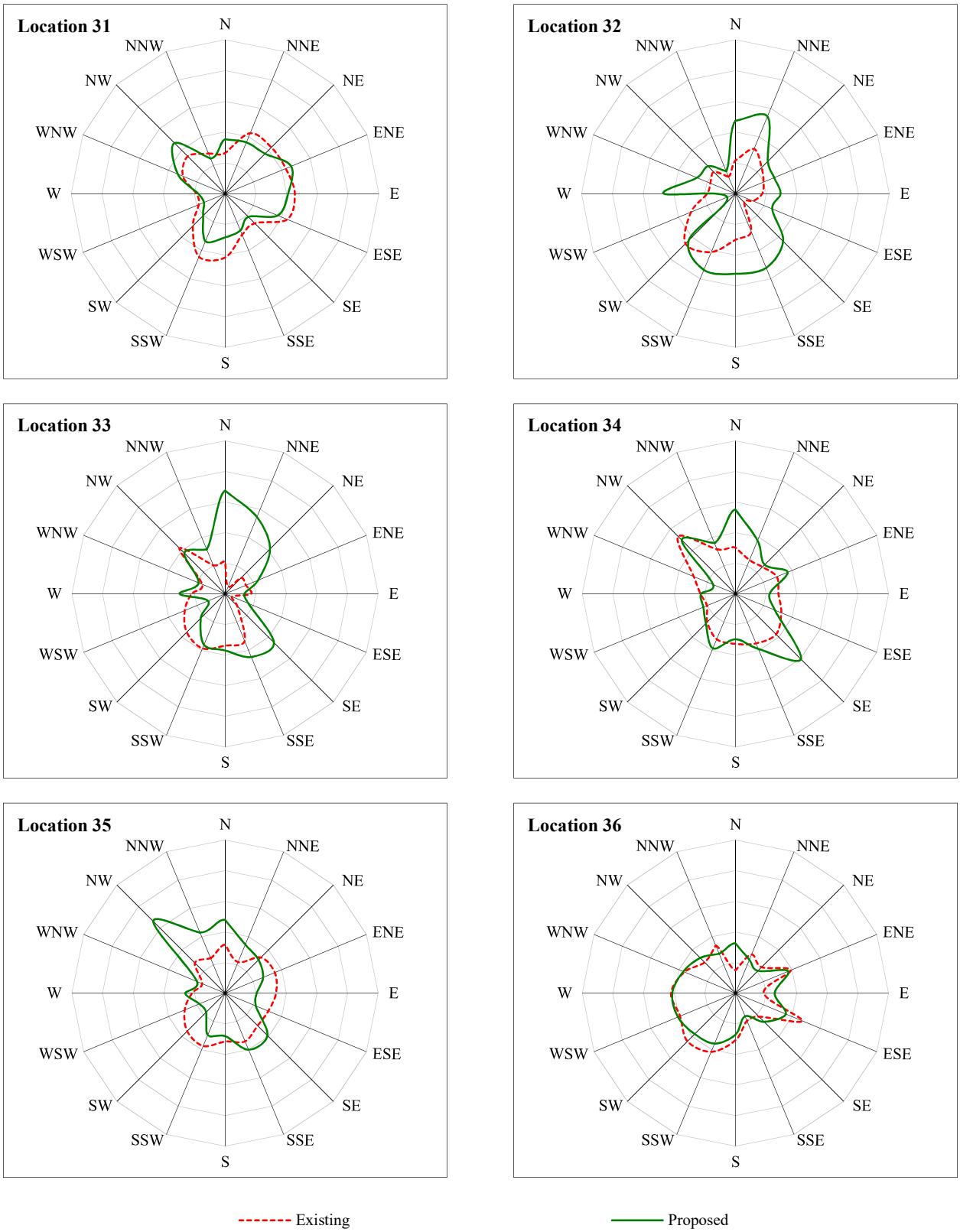

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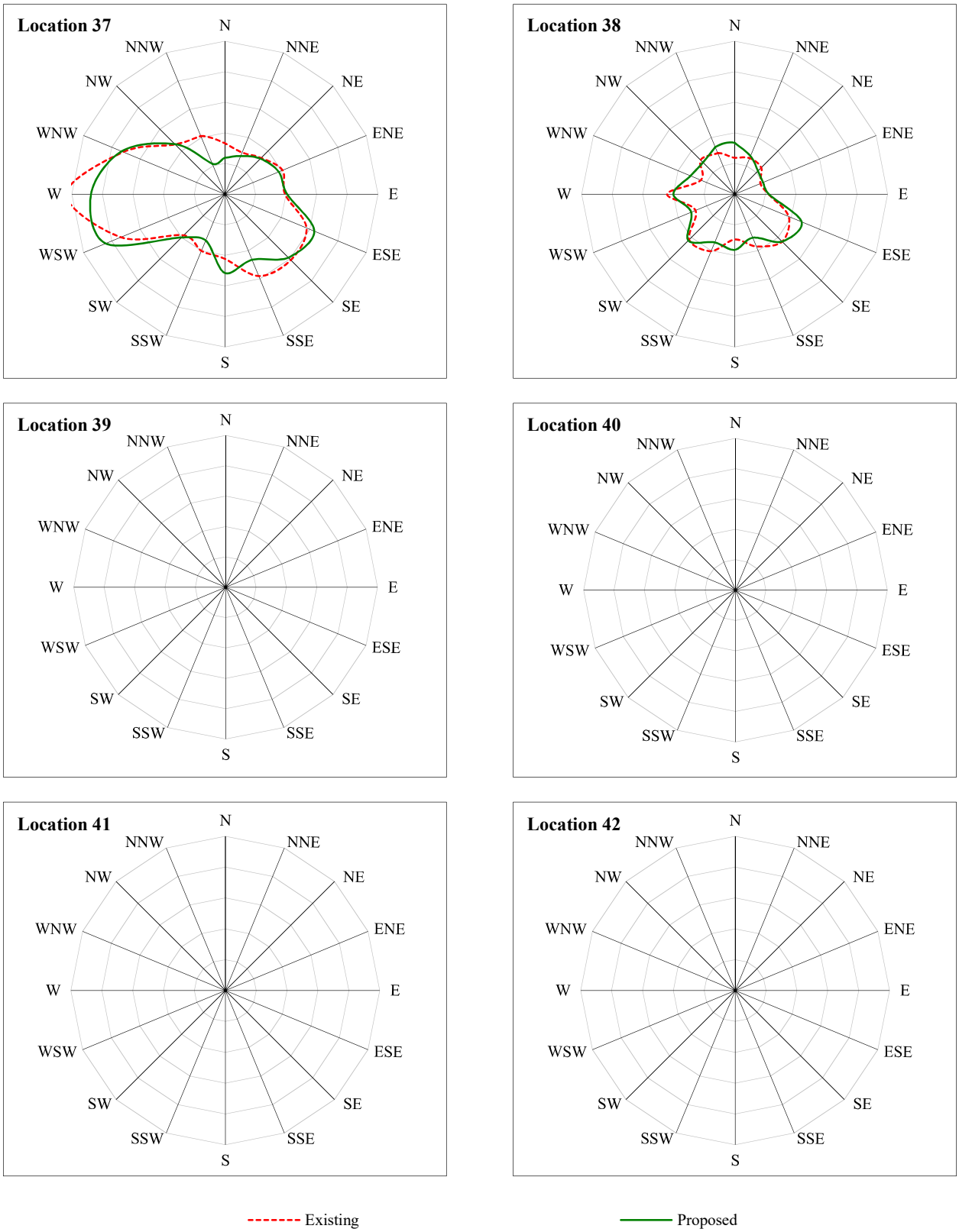

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