EXPERIMENTAL SITE WIND AVAILABILITY DATA FOR CENTRAL WATERFRONT

INVESTIGATION REPORT WWTF007-2006

July 2006

submitted to Planning Department,

The Government of the Hong Kong Special Administrative Region

CLP Power
Wind/Wave Tunnel Facility

The Hong Kong University
of Science and Technology

EXECUTIVE SUMMARY

At the request of Planning Department, The Government of Hong Kong Special Administrative Region (PlanD), a study of wind availability and characteristics for the Central Waterfront was conducted by the CLP Power Wind/Wave Tunnel Facility at The Hong Kong University of Science and Technology. The study was undertaken in accordance with the current best international practice requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999). The study was also conducted in accordance with the recommendations of Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005) and Technical Guide for Air Ventilation Assessment for Developments in Hong Kong (2005).

A 1:2000 scale topographical study was undertaken to determine the effects of local topography and the surrounding urban environment on mean wind speed, mean wind direction and turbulence intensity at four positions, agreed with PlanD on 23 May 2006, in the study area.

A miniature pressure probe was used to take measurements of three components, longitudinal, lateral and vertical, of wind speed at 22.5º increments for the full 360º azimuth, i.e. for 16 wind directions, and at eight (8) heights to determine profiles of mean wind speed and turbulence intensity above the measurement positions that should be used as input boundary conditions for later more detailed site studies that are not part of the current study. The 1:2000 scale topographical model included the surrounding area up to a distance of approximately 10 km from the study area.

The topographical study results were combined with a statistical model of the Hong Kong wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island during the period of 1953 – 2000 inclusive, to determine wind roses corresponding to annual mean wind speeds at the measurement positions.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

At the request of Planning Department, The Government of Hong Kong Special Administrative Region (PlanD), a wind engineering study was conducted by the CLP Power Wind/Wave Tunnel Facility, The Hong Kong University of Science and Technology for the Central Waterfront. The study was undertaken in accordance with the current best international practice requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999). The study was also conducted in accordance with the recommendations of Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Final Report (2005) and Technical Guide for Air Ventilation Assessment for Developments in Hong Kong (2005).

The study area stretches from the east of Fleming Road in Wan Chai to Rumsey Street in Sheung Wan, as shown in Figure 1. A 1:2000 scale topographical study was undertaken to determine the effects of local topography and the surrounding urban environment on mean wind speeds and turbulence intensities at four positions, agreed with PlanD on 23 May 2006 and also indicated in Figure 1, within the study area:

- Ferry pier east of the Hong Kong Convention and Exhibition Centre (Position 1 in Figure 1);
- At the centre of the Tamar site (Position 2 in Figure 1);
- Approximately 300 m to the east of International Finance Centre 2 (IFC2) (Position 3 in Figure 1);

- Pier Number 4 of the Central District (Position 4 in Figure 1).

The topographical study results were combined with a statistical model of the Hong Kong wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island during the period of 1953 – 2000 inclusive, to determine site-specific wind roses for annual hourly mean wind speeds.

2. ANALYSIS OF THE HONG KONG WIND CLIMATE

Waglan Island, located approximately 5 km southeast of Hong Kong Island, has been used by Hong Kong Observatory, formerly The Royal Observatory, Hong Kong, for the collection of long-term wind data since December 1952 and that data is considered to be of the highest quality available for wind engineering purposes for Hong Kong. Due to its location, relative lack of development over the past 50 years and its generally uninterrupted exposure to winds, data collected at Waglan Island is considered to be representative of winds approaching the Hong Kong region. For other HKO measurement and monitoring sites, such as at Tsim Sha Tsui and the Central and Kowloon Star Ferry Piers, the amount and variety of nearby development that has taken place during their operational life makes them unsuitable for use for wind engineering applications.

Waglan Island wind records have been analysed previously in studies of the Hong Kong wind climate, most notably by Davenport et al. (1984), Melbourne (1984) and Hitchcock et al. (2003). Melbourne (1984) conducted wind tunnel model studies to determine directional factors relating wind speeds at each anemometer location to the wind speed at a height equivalent to 50 m in the freestream flow and concluded that:

- Measurements taken during the period 1 January 1964 to 11 July 1966 inclusive were adversely affected by the anemometer location.
- The anemometer correction factors for mean wind speeds show some sensitivity to the modelled approach flow but they are not strongly dependent on the modelled approach profiles.

- The largest magnitude speed-up effects occur for winds approaching from approximately 67.5°, 180°, 270° and 360°.
- The largest magnitude slow-down effects occur for winds approaching from approximately 112.5°, 225° and 315°.

In the study conducted by Hitchcock et al. (2003), wind tunnel tests were undertaken to correct wind records for position and topographical effects at the four anemometer locations used since 1952, with the exception of the location used during the period 1 January 1964 to 11 July 1966 inclusive. In that study, thermal (hotwire) anemometer measurements were taken at 22.5° intervals for the full 360° azimuth relating wind speeds at anemometer height to wind speeds at a height equivalent to 200 m in the freestream. The directional characteristics of the former anemometer sites were found to be similar to those discussed by Melbourne (1984), whereas the current anemometer site is much less affected than its predecessors, due mainly to its additional height.

Correction factors were determined and subsequently applied to non-typhoon wind data collected at Waglan Island to determine a wind rose corresponding to annual mean wind speeds at a height equivalent to 500 m above Waglan Island. The annual wind rose is presented in Figure 2 and indicates that prevailing and strong non-typhoon winds approaching Hong Kong occur mainly from the north-east quadrant and, to a lesser extent, the south-west.

In Figure 2, mean wind speeds are segregated into four categories (0 – 3.3 m/s, 3.4 – 7.9 m/s, 8.0 – 13.8 m/s and greater than 13.8 m/s) that are indicated by the thickness of the bars for the 16 cardinal wind directions. The length of the bars indicates the average percentage of occurrence per year. For example, Figure 2 illustrates that, on an annual basis, east winds occur approximately 24% of the time and hourly mean wind speeds exceed 13.8 m/s approximately 6% of the time at a height of 500 m.

3. WIND TUNNEL STUDY

The wind tunnel test techniques used in this investigation were undertaken in accordance with the procedures and recommendations of the Australasian Wind Engineering Society Quality Assurance Manual, AWES QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999).

3.1 Modelling the Natural Wind

Air moving relative to the Earth's surface has frictional forces imparted on it, which effectively cause it to be slowed down. These forces have a decreasing effect on air flow as the height above ground increases, generally resulting in mean wind speed increasing with height to a point where the effects of surface drag become negligible. In wind engineering, a convenient measure of the thickness of the atmospheric boundary layer is commonly referred to as the gradient height which will vary depending on the surrounding surface roughness over which the air will flow. Obstacles to air flow can vary from relatively large expanses of smooth, open water, to vegetation such as forests, built-up environments such as city centres, and large, rugged mountain ranges. The resulting gradient heights typically vary from several hundred metres to in excess of 1000 m.

Winds within the atmospheric boundary layer are also usually highly turbulent or gusty. Turbulence intensity is a measure of the gustiness of wind due to eddies and vortices generated by frictional effects at surface level, the roughness of the terrain over which air is flowing and convective effects due to opposing movements of air masses of different temperature. In typical atmospheric boundary layer flow, turbulence intensity generally decreases with height. Closer to the ground, at pedestrian level for example, the magnitude of the turbulence intensity can be very large due to the effects of wind flowing around buildings and other structures.

In conducting wind tunnel model studies of wind characteristics and wind effects on tall buildings and other structures on the surface of the Earth, it is necessary to adequately simulate the atmospheric boundary layer. WWTF's boundary layer wind tunnel test sections can be used to simulate atmospheric boundary layer flow over various types of terrain, ranging from open terrain, such as open water, to urban or mountainous terrain.

WWTF comprises two long fetch boundary layer wind tunnel test sections as shown in Figure 3. The 28 m long high-speed test section has a 3 m wide × 2 m high working section and a maximum freestream wind speed of approximately 30 m/s. The 40 m long low-speed test section has a 5 m wide × 4 m high working section and a maximum freestream wind speed of approximately 10 m/s. Various terrain simulations can be modelled in either test section at length scales ranging from approximately 1:5000 to 1:50.

The wind in the low-speed test section of the WWTF can be modified through the use of devices such as spires, grids, and fences to model different scale atmospheric boundary layer flows. For the current study, WWTF's low-speed test section was calibrated, by using appropriate combinations of roughness elements and fences, to simulate the characteristics of winds approaching Hong Kong through mean wind speed and turbulence intensity profiles corresponding to wind flowing over open water. The mean wind speed profile of the wind flow approaching the study area is in accordance with the power law expression, defined in Equation (1), specified in Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005).

$$\frac{\bar{u}(z)}{\bar{u}_{ref}} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad (1)$$

where:

$\bar{u}(z)$ = mean wind speed at a height z (m/s);

$\bar{u}_{ref}$ = mean wind speed at a suitable reference height (m/s);

z = height above zero plane displacement height (m);

z_{ref} = a suitable reference height (m);

α = the power law exponent, which is a constant commensurate with the terrain roughness, taken as approximately 0.15 for this study.

The turbulence intensity profile of the approaching wind flow was simulated in accordance with Terrain category 2 stipulated in Australian/New Zealand Standard AS/NZS 1170.2:2002, i.e. corresponding to non-typhoon wind flow above rough open water surfaces.

The simulated mean wind speed and turbulence intensity profiles are generally within ±10% of the target profiles defined in Equation (1) and AS/NZS 1170.2:2002 category 2 terrain and are presented in Figure 4. The spectrum of longitudinal turbulence of the approach flow measured at a height equivalent to 200 m in prototype scale is presented in Figure 5.

3.2 Physical Model of the Study Area

WWTF has a 1:2000 scale topographical model of Kowloon and Hong Kong Island fabricated at 20 m contour intervals from information acquired from the HKSAR's Survey and Mapping Office, Lands Department.

The topographical model included the major topographical features and urban landscapes of Hong Kong Island and Kowloon Peninsula. For all wind directions tested, the wind tunnel model included surrounding areas within a distance of up to approximately 10 km from the study area.

The topographical model was updated to include greater detail within a zone from 500 m up to approximately 1000 m from the measurement positions. In accordance with information supplied by PlanD on 17, 26 and 29 May 2006, all known existing and planned buildings and structures at the time of testing were included in the model to represent their effects on wind flow approaching the study area. Beyond the 1000 m radius, the topographical model included roughness representative of the surrounding areas. A representative view of the 1:2000 scale topographical model for testing is shown in Figure 6. A closer view of the modelled Central Waterfront study area is shown in Figure 7.

3.3 Experimental and Analysis Procedures

The terrain surrounding the study area comprises complex mixtures of open water, urban and built-up environment, and mountainous areas on Hong Kong Island and Kowloon Peninsula. Winds approaching the modelled region were scaled to simulate non-typhoon winds flowing over open water and the topographical model was used to determine the modifying effects of the surrounding complex terrain on the wind speed and turbulence intensity above the four measurement positions.

Wind tunnel measurements were taken at 22.5° intervals for the full 360° azimuth (i.e. 16 wind directions), where a wind direction of 0° or 360° corresponds to an incident wind approaching the study area directly from the north, 90° corresponds to an incident wind approaching the study area directly from the east, etc. For each wind direction tested, mean wind speeds and turbulence intensities were determined at heights equivalent to 25, 50, 75, 100, 200, 300, 400 and 500 m in prototype scale, above the measurement positions within the study area.

While measurements were taken at one position, all buildings within a radius of 500 m of the position being tested were removed from the wind tunnel model for all measured wind directions but the buildings surrounding the adjacent positions were included. For example, while measurements were being taken at Position 1, buildings at the other three positions were included in the model although buildings within a radius of 500m of the centre of Position 1 were not included. It is expected that buildings within the radii of 500 m will be included in proximity models for more detailed and larger scale studies to be conducted by the project proponents for development projects to directly account for their effects on the wind flow at each site.

4. EXPERIMENTAL RESULTS AND DISCUSSION

For each wind direction tested, results of the 1:2000 scale topographical study are presented in graphical format in Figures 8 to 71 inclusive and in tabular format in Appendix C. In Figures 8a to 71a, the normalised wind characteristics include mean wind speed profiles and turbulence intensity profiles. Mean wind speed profiles were determined by normalising the local mean wind speeds with respect to the mean wind speed of the approaching wind flow measured at a height equivalent to 500 m, as defined in Equation (1). Vertical profiles of turbulence intensity, defined in Equation (2), are also presented in Figures 8a to 71a. Mean yaw angles, i.e. the deviation of the local mean wind direction relative to the approaching mean wind direction, are presented relative to the approaching mean wind speed in Figures 8b to 71b inclusive. The sign convention used to express yaw angle is provided in Appendix A. It is expected that the vertical profiles of mean wind speed and turbulence intensity will be used as input boundary conditions for more detailed site studies conducted by the project proponents for development projects.

$$\text{normalised wind velocity} = \frac{\overline{V}_z(\theta)}{\overline{V}_{500,\text{approach}}(\theta)} \qquad (1)$$

$$\text{turbulence intensity} = \frac{\sigma_{V,z}(\theta)}{\overline{V}_z(\theta)} \qquad (2)$$

In Equations (1) and (2):

$\overline{V}_z(\theta)$ = mean wind speed at a height z (z = 25, 50, 75, 100, 200, 300, 400 or 500 m in prototype scale) for an approaching wind direction θ (θ = 22.5º, 45º, 67.5º, 90º, 112.5º, 135º, 157.5º, 180º, 202.5º, 225º, 247.5º, 270º, 292.5º, 315º, 337.5º or 360º);

$\overline{V}_{500,\text{approach}}(\theta)$ = mean wind speed of the approaching wind at a height equivalent to 500 m in prototype scale for an approaching wind direction θ;

$\sigma_{V,z}(\theta)$ = the standard deviation of the fluctuating wind speed V_z for an approaching wind direction θ.

The topographical study measurements were also used to determine directional factors for the 16 measured wind directions, relating the mean wind speed at a height equivalent to 500 m above the four measurement positions in the study area to the mean wind speed of the approach flow at a reference height of 500 m. These directional factors were then applied to WWTF's Hong Kong non-typhoon wind climate model, derived from HKO's Waglan Island wind data as discussed in Section 2 of this report, to determine site-specific wind roses pertaining to annual hourly mean wind speeds at a height of 500 m above the measurement positions. The wind roses are presented in Figures 72 to 75 inclusive for a height of 500 m.

An example application demonstrating the use of the normalised mean wind speed profiles and the wind roses is included in Appendix B.

4.1 Wind characteristics at Position 1

For Position 1, located at the ferry pier of the eastern side of the Hong Kong Convention and Exhibition Centre, a comparison between Figure 2 and Figure 72 indicates that, for the wind directions tested, the surrounding terrain has the overall effect of reducing mean wind speeds, although the general trend of prevailing northerly and easterly winds remains.

For heights below 200 m, significant reductions in mean wind speed were measured for wind directions ranging from approximately 90º to 270º inclusive (Figures 11 to 19), which are attributed to the nearby mountains such as Braemar Hill, Mount Parker, Violet Hill and Victoria Peak, and from approximately 337.5º to 360º inclusive (Figures 22 and 23), which are attributed to the effects of mountains on Kowloon such as Lion Rock. Similarly, significant increases in turbulence intensity were also measured for those wind directions. Winds flowing from the north-westerly directions, i.e. corresponding to wind directions of 292.5ºand 315º (Figures 20 and 21), were the least affected of the wind directions tested due to the comparatively uninterrupted exposures in those directions.

4.2 Wind characteristics at Position 2

At Position 2, located at the centre of the Tamar site, the various effects of the surrounding mountains and close proximity to nearby buildings are responsible for significant reduction in mean wind speeds below heights of 200 m. In comparing the wind rose for Waglan Island (Figure 2) to that for this position (Figure 73), it can be seen that winds from all directions demonstrate a reduction in mean wind speeds due to the surrounding tall buildings and mountains. Due to its current relatively close proximity to nearby tall buildings, wind characteristics at Position 2 are the most affected of the four measurement positions.

Mean wind speed and turbulence intensity profiles measured for wind directions of 180º to 225º (Figures 31 to 33) illustrate characteristics that typically occur in the wake of large mountains. Below heights of approximately 300 m, the marked increases in turbulence intensity and large reductions of mean wind speed are indicative of recirculating wind flow caused by Victoria Peak.

4.3 Wind characteristics at Position 3

For Position 3, located approximately 300 m to the east of International Finance Centre 2 (IFC2), prevailing winds occur for northerly and easterly winds and a comparison between Figure 2 and Figure 74 indicates that the surrounding terrain has the overall effect of reducing the magnitude of the mean wind speeds.

Significant reductions in mean wind speed were measured for wind directions ranging from approximately 112.5º to 270º inclusive (Figures 44 to 51), which are attributed to the nearby mountains such as Braemar Hill, Mount Parker, Violet Hill and Victoria Peak. Similarly, significant increases in turbulence intensity were also measured for those wind directions. Winds flowing from the north-westerly directions, i.e. corresponding to wind directions of 315ºand 337.5º (Figures 53 and 54), were the least affected of the wind directions tested due to the comparatively uninterrupted exposures in those directions.

4.4 Wind characteristics at Position 4

For Position 4, located at Pier Number 4 of the Central District, wind characteristics are the least affected of the four measurement position. The corresponding wind rose (Figure 75) exhibits similar characteristics to that for Waglan Island (Figure 2).

The increased exposure of Position 4 to winds approaching from the north-westerly directions, i.e. ranging from 270º to 337.5º inclusive, is reflected in the steeper mean wind speed profiles in Figures 67 to 70 inclusive.

5. CONCLUSIONS

A study of wind availability and characteristics was conducted by the CLP Power Wind/Wave Tunnel Facility at The Hong Kong University of Science and Technology for the Central Waterfront, Hong Kong.

A 1:2000 scale topographical study was undertaken to determine the effects of local topography and the surrounding urban environment on mean wind speeds and turbulence intensities at four measurement positions within the study area. The topographical study results were subsequently combined with a statistical model of the Hong Kong wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island, to determine wind roses at the four measurement positions for annual hourly mean wind speeds.

The following general conclusions are drawn from the current study:

- Prevailing and strong non-typhoon winds approaching Hong Kong occur mainly from northerly, easterly and south-westerly directions.
- In the vicinity of the eastern side of Hong Kong Convention and Exhibition Centre, for heights below 200 m, mean wind speeds are significantly reduced for southerly and westerly wind directions, predominantly due to effects of the mountains on Hong Kong Island, such as Mount Cameron, Mount Kellet and Victoria Peak, and for northerly wind directions, probably due to the combined effects of the built environment and mountains, such as Lion Rock, on Kowloon.

- At the centre of the Tamar site, due to its current relatively close proximity to nearby tall buildings, wind characteristics at this position are the most affected of the four measurement positions.
- In the vicinity of the eastern side of IFC2, significant reductions in mean wind speed were measured for wind directions ranging from south-easterly to westerly wind directions, which are attributed to the nearby mountains such as Violet Hill, Mount Cameron and Victoria Peak.
- At Pier Number 4 in the Central District, wind characteristics were found to be the least affected of the four measurement positions due to its current relatively exposed location.

6. REFERENCES

Australasian Wind Engineering Society (2001), Wind Engineering Studies of Buildings, AWES-QAM-1-2001.

Buildings Department (HKSAR) (2004), Code of Practice on Wind Effects in Hong Kong.

Davenport, A.G., Georgiou, P.N., Mikitiuk, M., Surry, D. and Kythe, G. (1984), The wind climate of Hong Kong, Proceedings of the Third International Conference on Tall Buildings, Hong Kong and Guangzhou, pp 454 – 460.

Hitchcock, P.A., Kwok, K.C.S. and Yu, C.W. (2003), A study of anemometer measurements at Waglan Island, Hong Kong, Technical Report WWTF002-2003, CLP Power Wind/Wave Tunnel Facility, The Hong Kong University of Science and Technology.

Manual of practice for wind tunnel studies of buildings and structures (1999), Editor Nicholas Isyumov, Task Committee on Wind Tunnel Testing of Buildings and Structures, Aerodynamics Committee, Aerospace Division, American Society of Civil Engineers.

Melbourne, W.H. (1984), Design wind date for Hong Kong and surrounding coastline, Proceedings of the Third International Conference on Tall Buildings, Hong Kong and Guangzhou, pp 461 – 467.

Planning Department, The Government of the Hong Kong Special Administrative Region (2005), Feasibility Study for Establishment of Air Ventilation Assessment – Final Report, Department of Architecture, The Chinese University of Hong Kong.

Planning Department, The Government of the Hong Kong Special Administrative Region (2005), Technical Guide for Air Ventilation Assessment for Developments in Hong Kong.

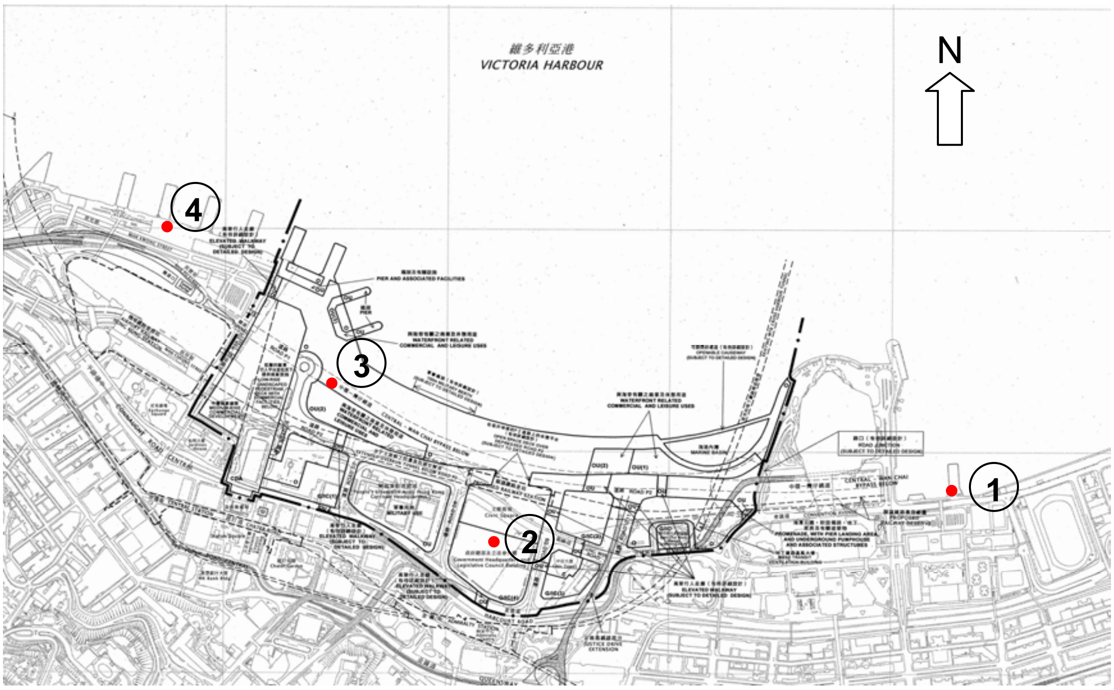

Figure 1: Measurement positions

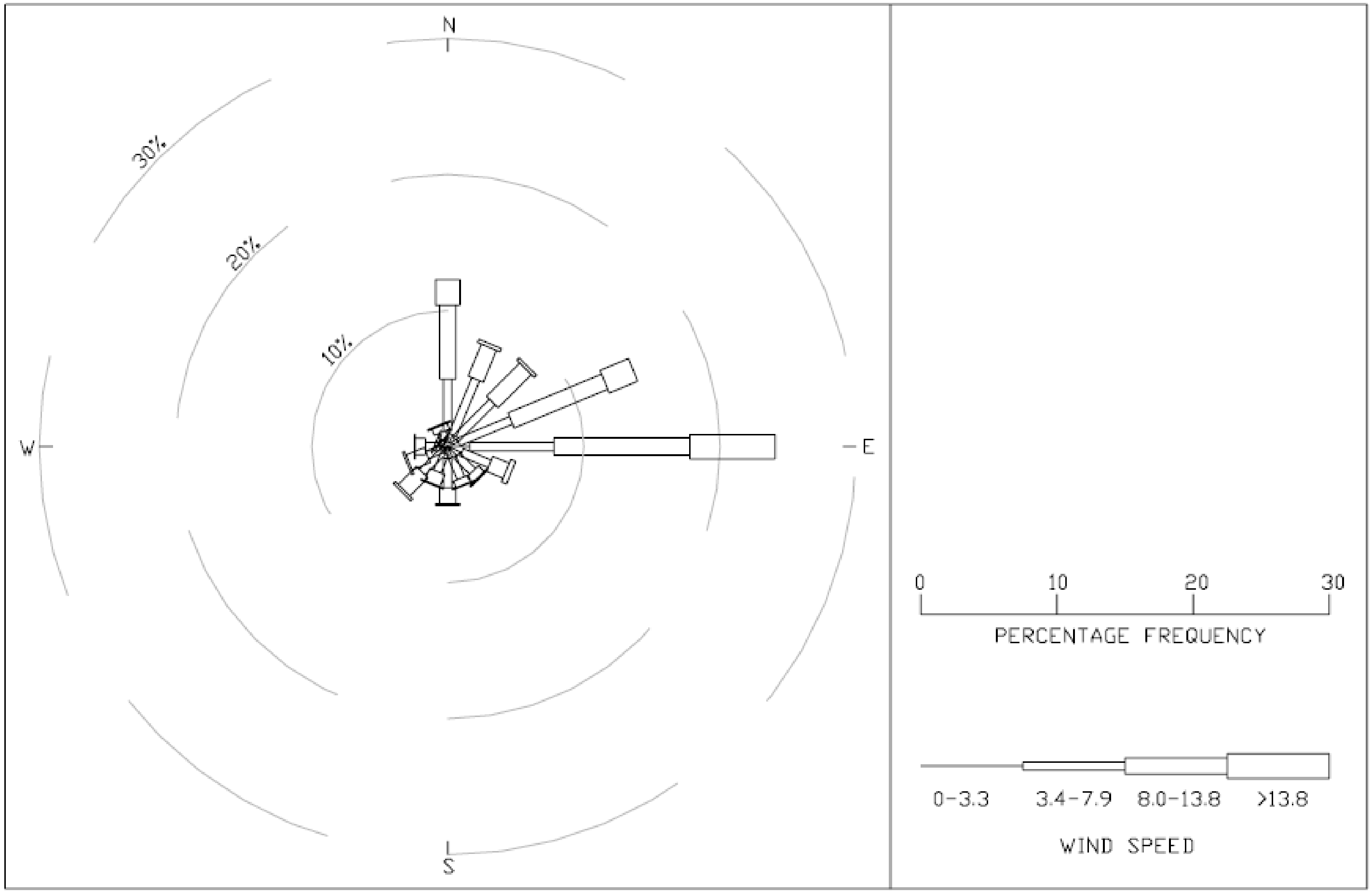

Figure 2: Wind rose for annual, non-typhoon winds, Waglan Island, corrected to 500m, 1953-2000

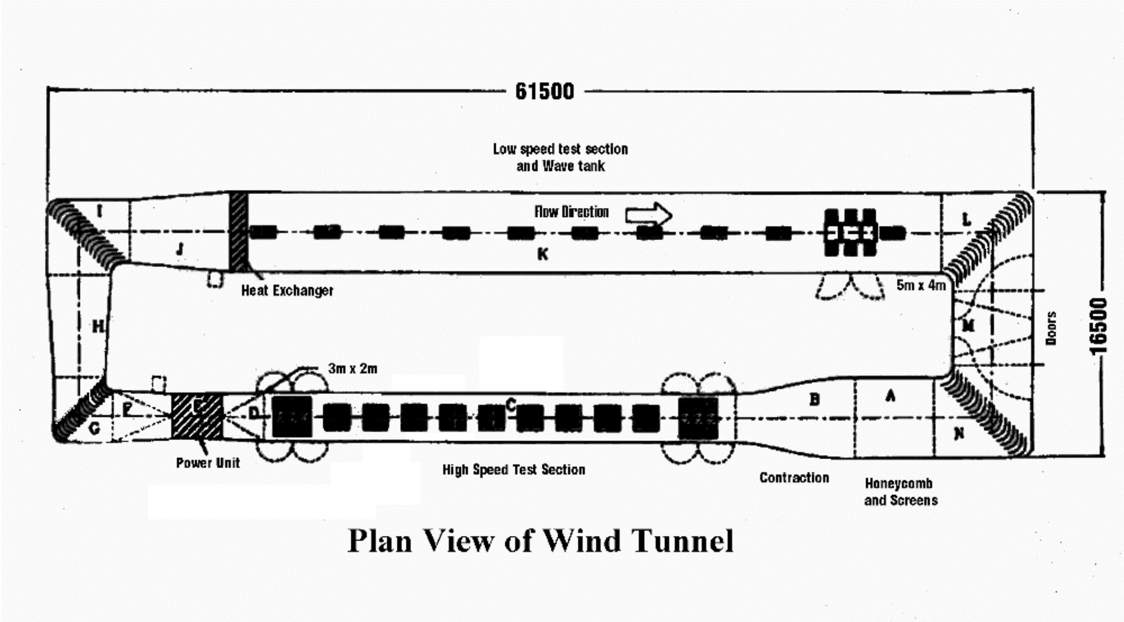

Figure 3: Test sections at the CLP Power Wind/Wave Tunnel Facility

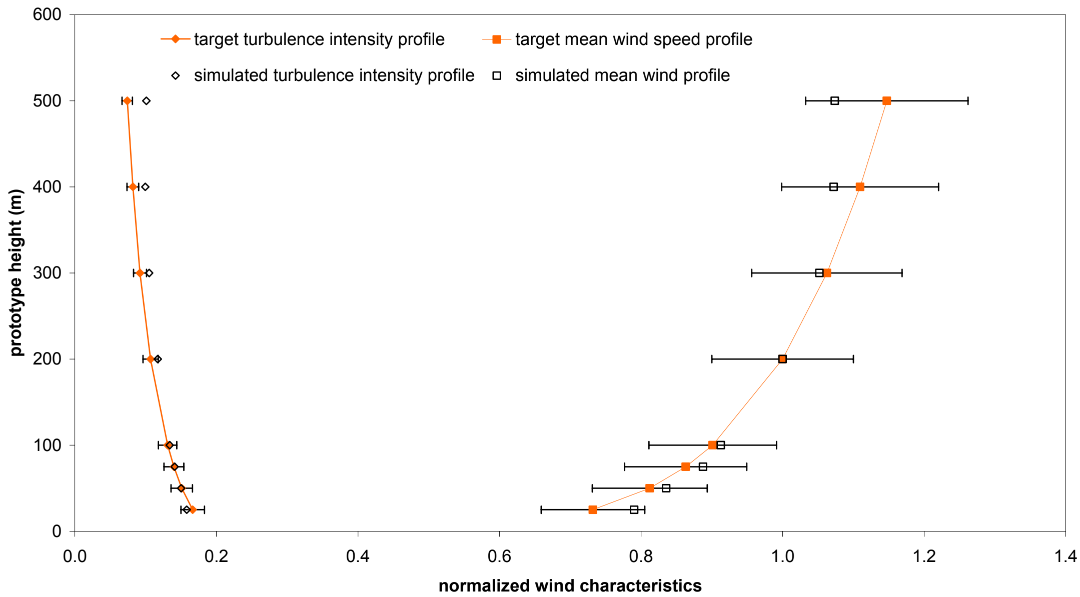

Figure 4: Simulated mean wind speed and turbulence intensity profiles – approach wind

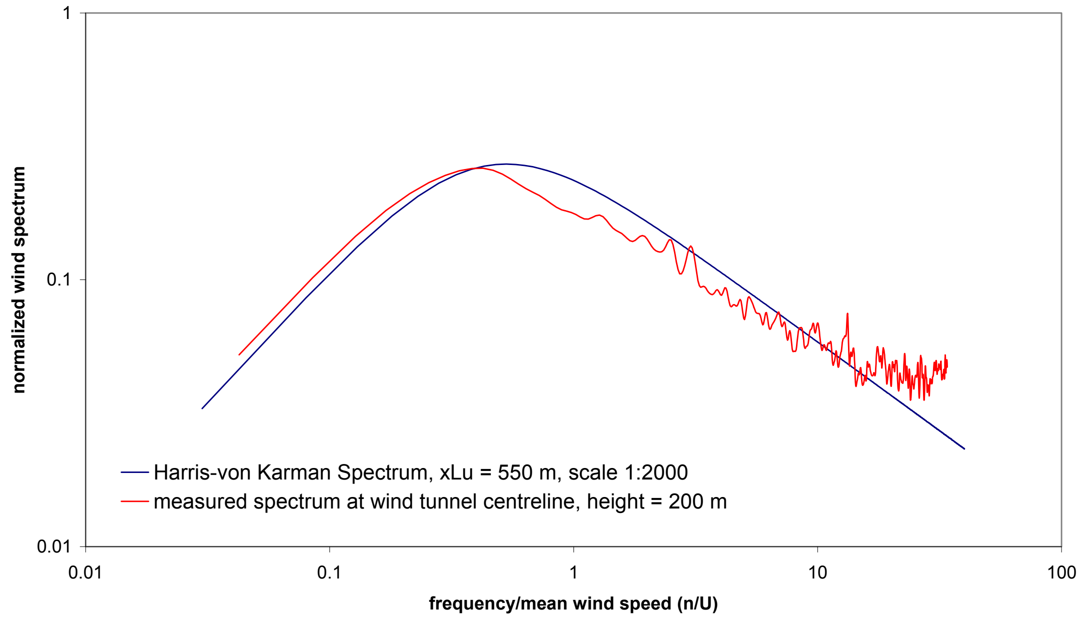

Figure 5: Longitudinal turbulence spectrum – approach wind

Figure 6: A 1:2000 scale topographical model of the Central Waterfront, Hong Kong in the low-speed test section of the CLP Power Wind/Wave Tunnel Facility (East wind direction, 90º)

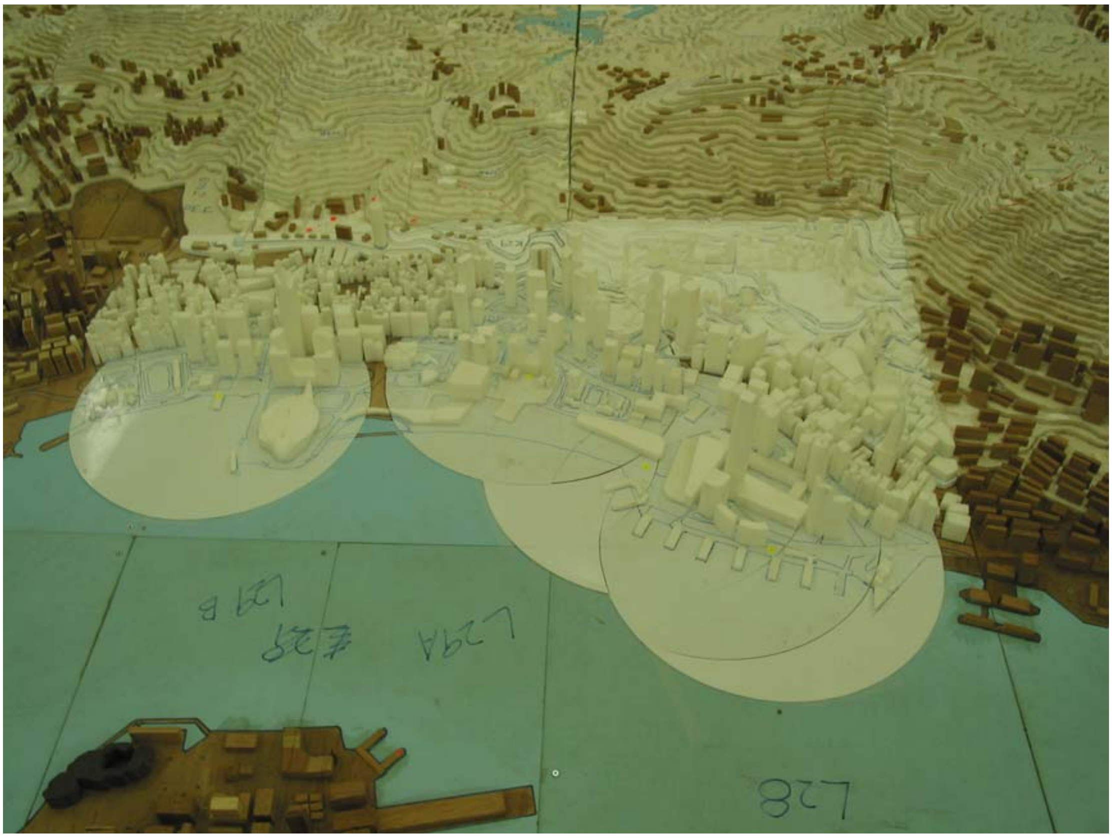

Figure 7: A 1:2000 scale model of the Central Waterfront study area

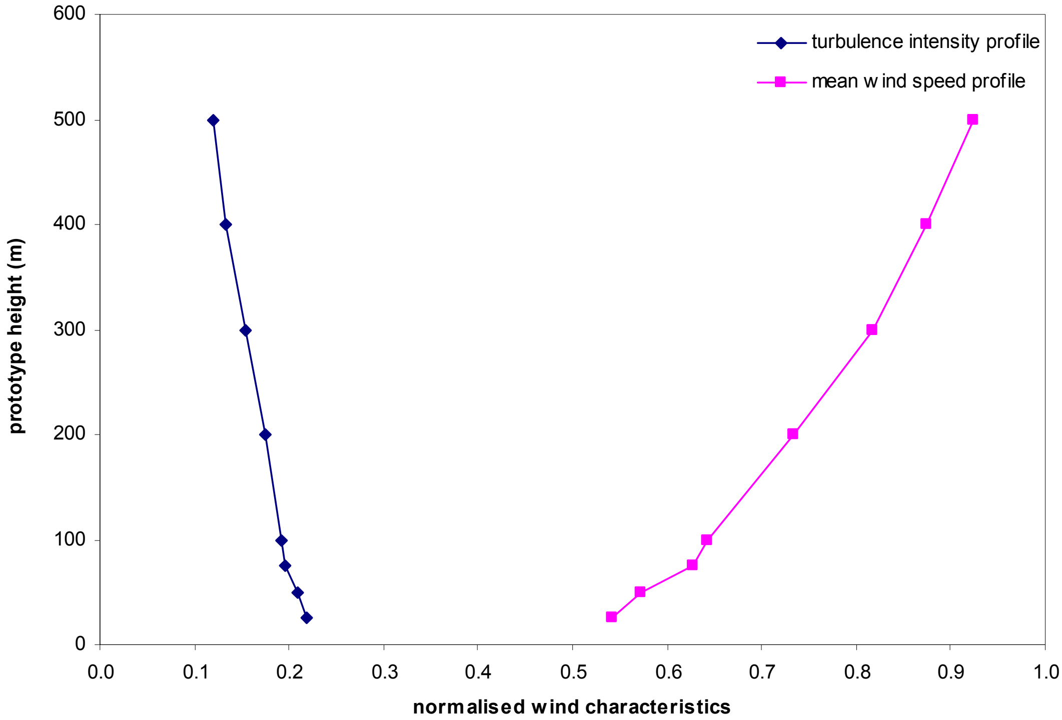

Figure 8a: Wind characteristics, Position 1, 22.5°

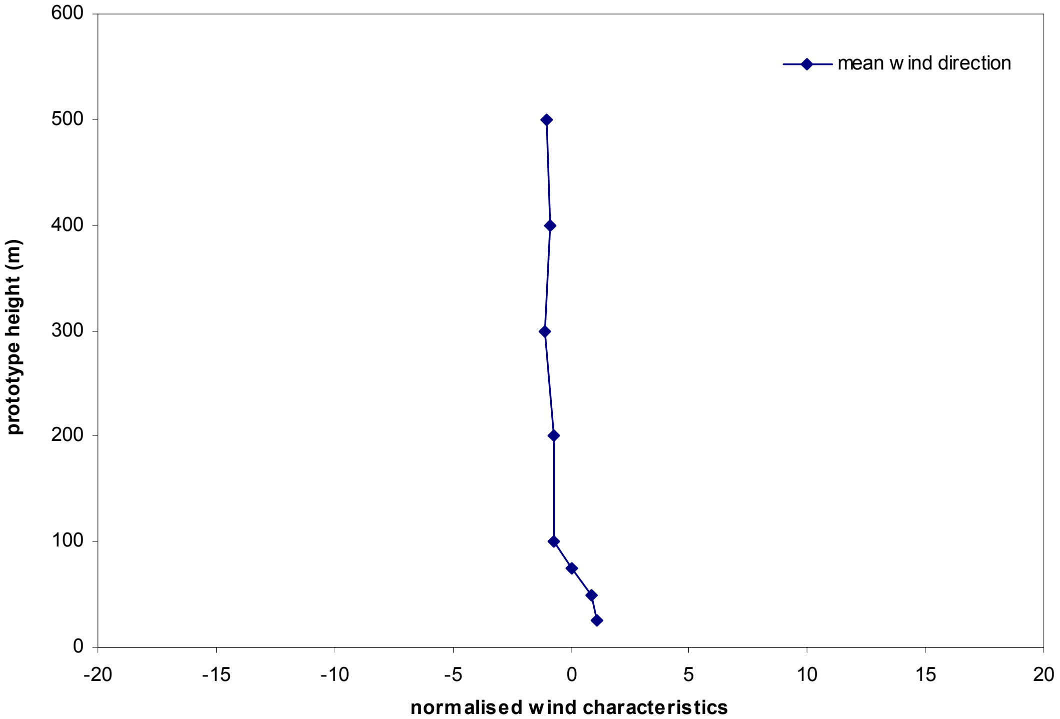

Figure 8b: Mean wind direction, Position 1, 22.5°

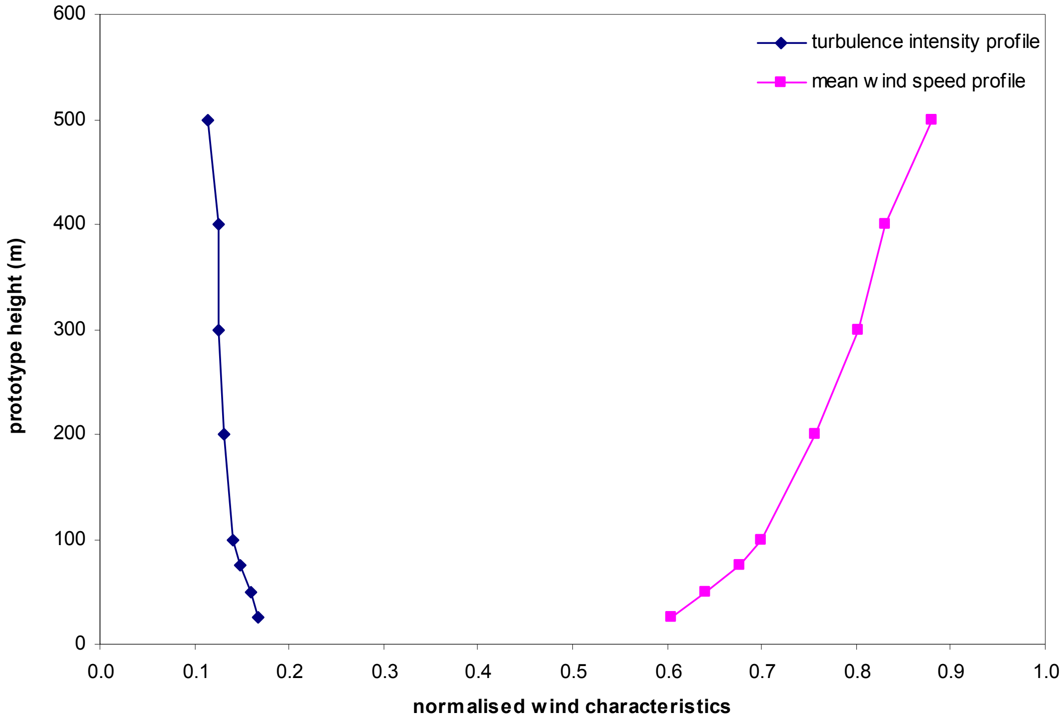

Figure 9a: Wind characteristics, Position 1, 45°

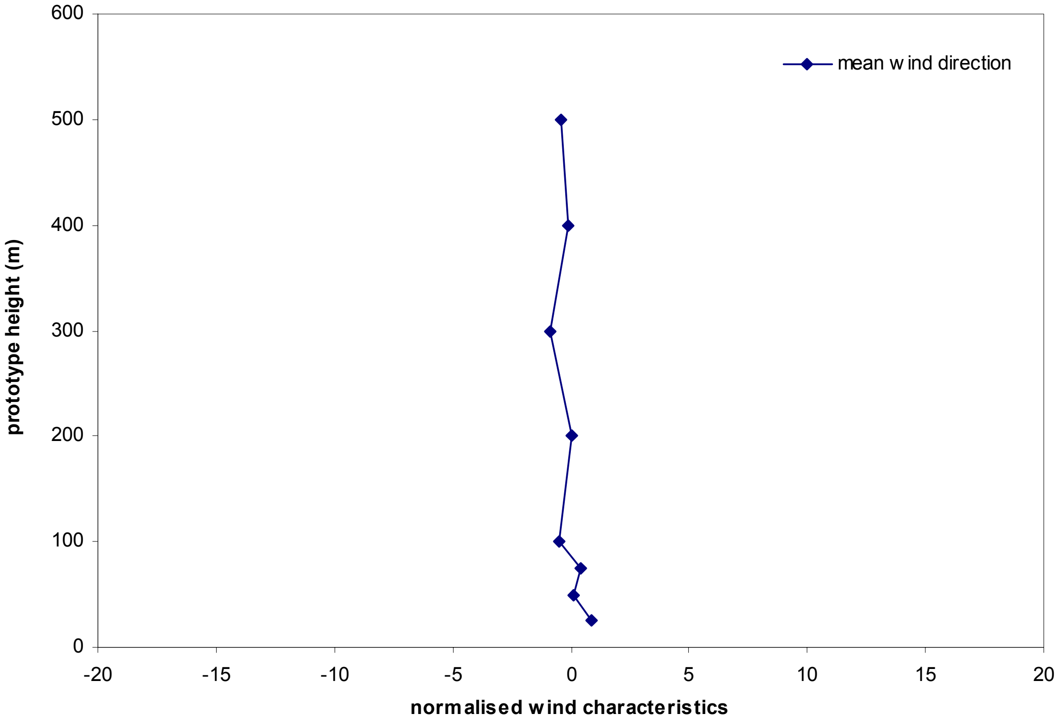

Figure 9b: Mean wind direction, Position 1, 45°

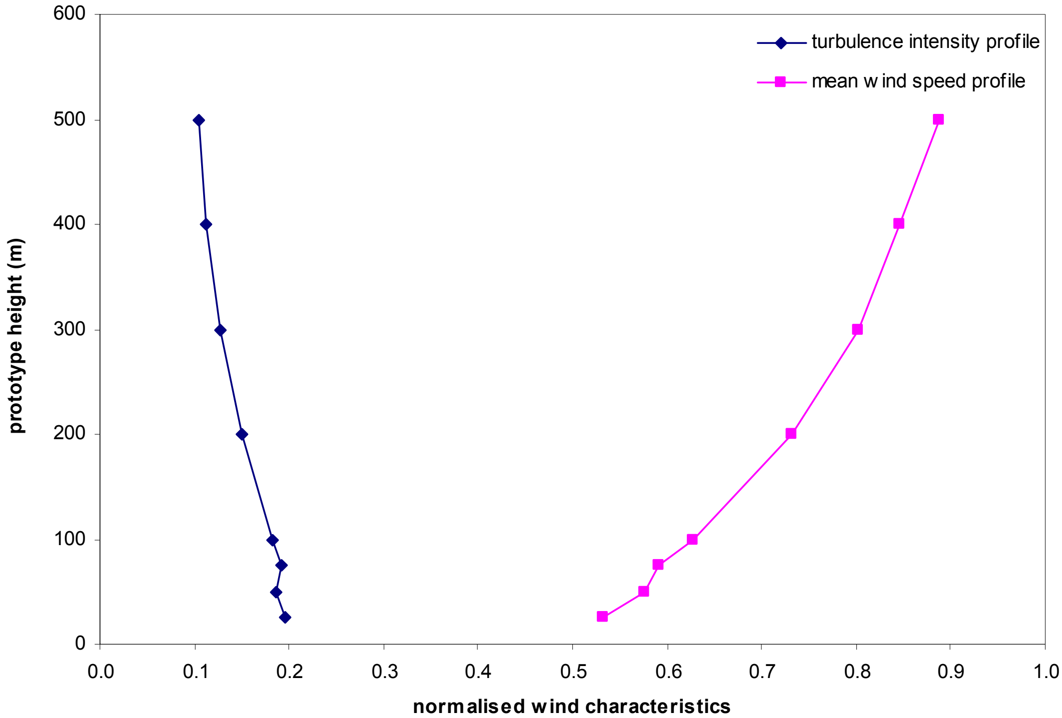

Figure 10a: Wind characteristics, Position 1, 67.5°

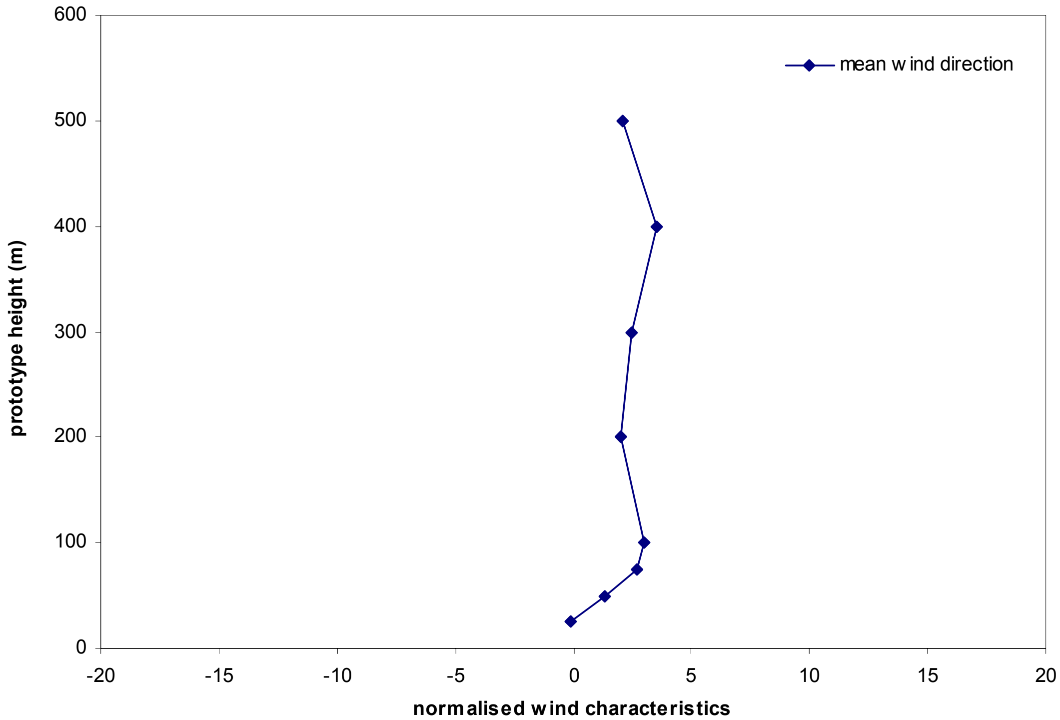

Figure 10b: Mean wind direction, Position 1, 67.5°

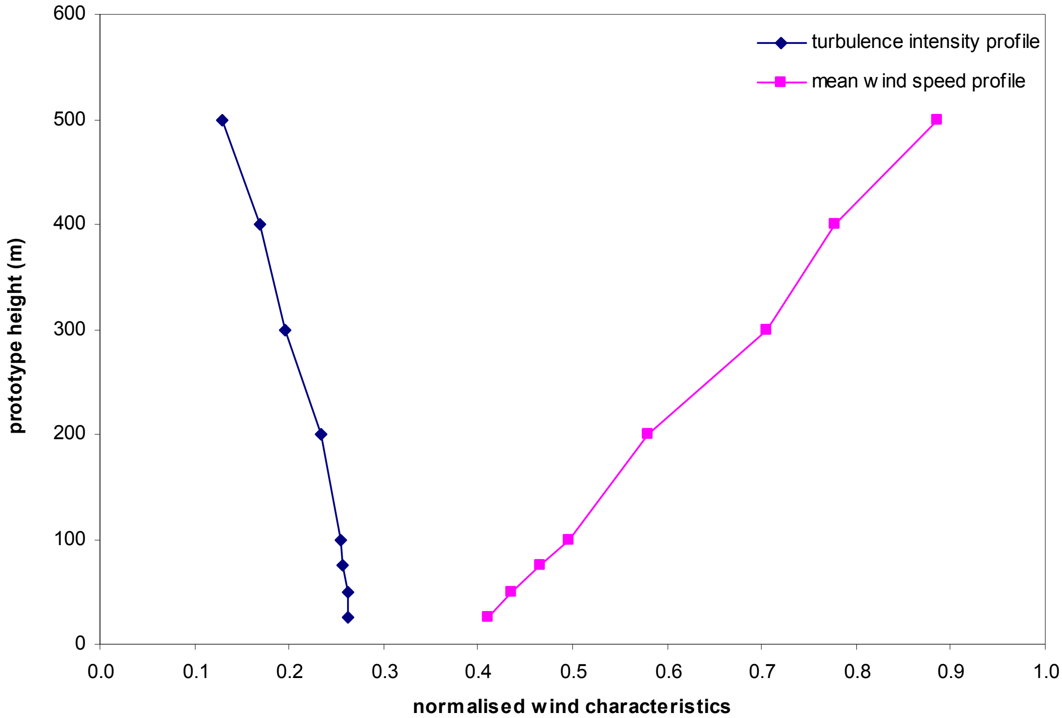

Figure 11a: Wind characteristics, Position 1, 90°

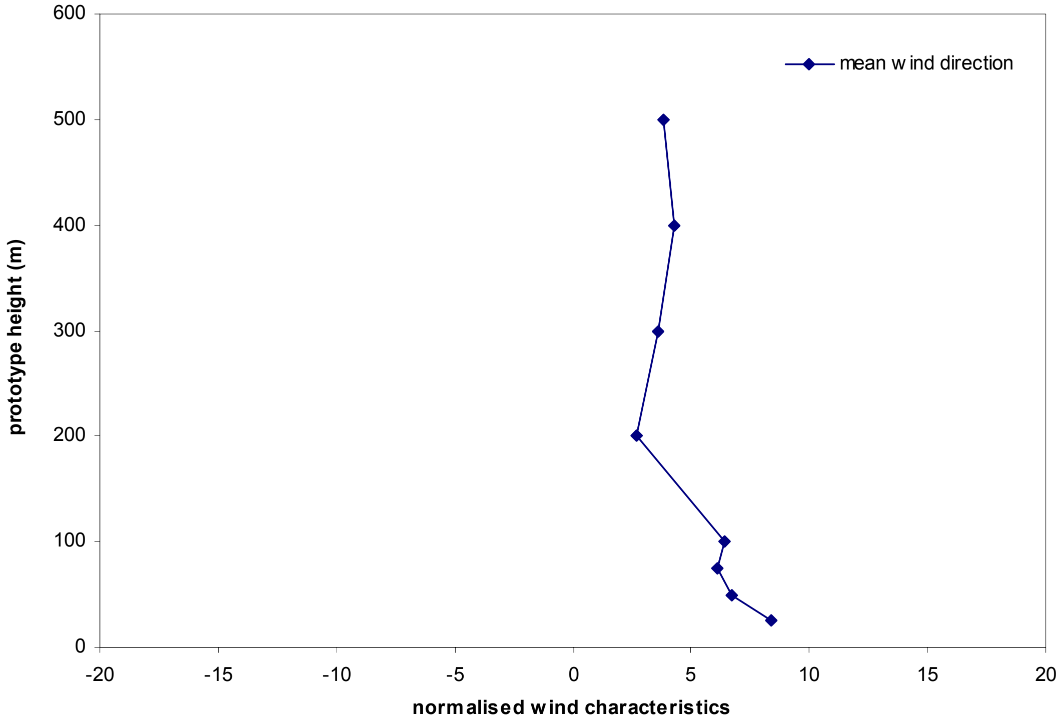

Figure 11b: Mean wind direction, Position 1, 90°

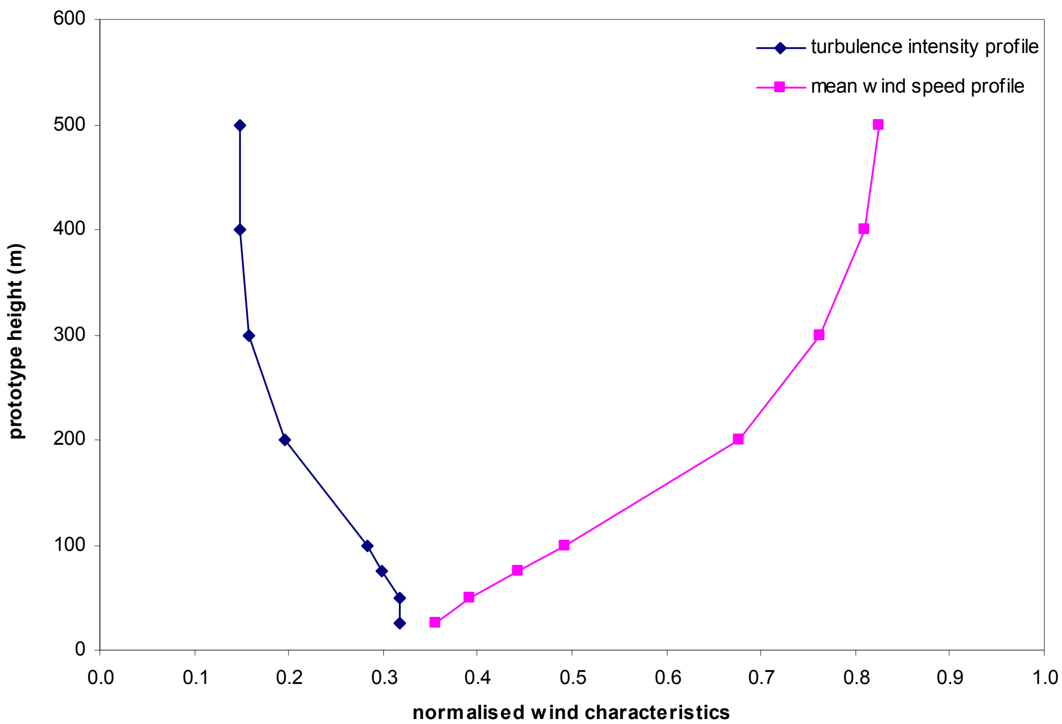

Figure 12a: Wind characteristics, Position 1, 112.5°

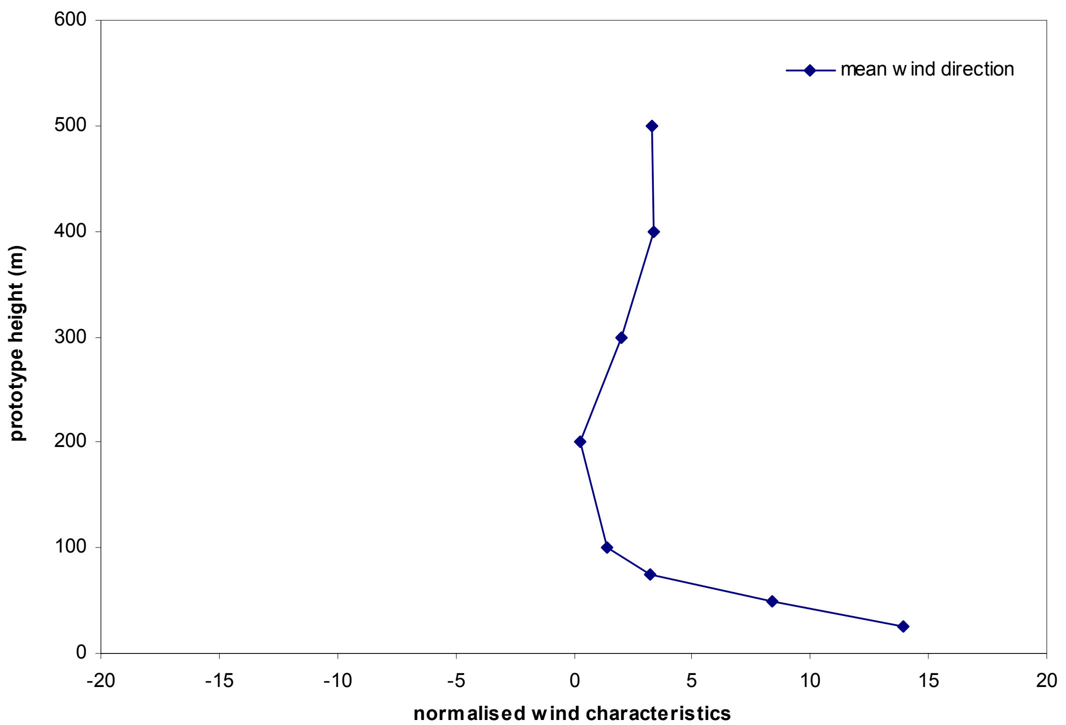

Figure 12b: Mean wind direction, Position 1, 112.5°

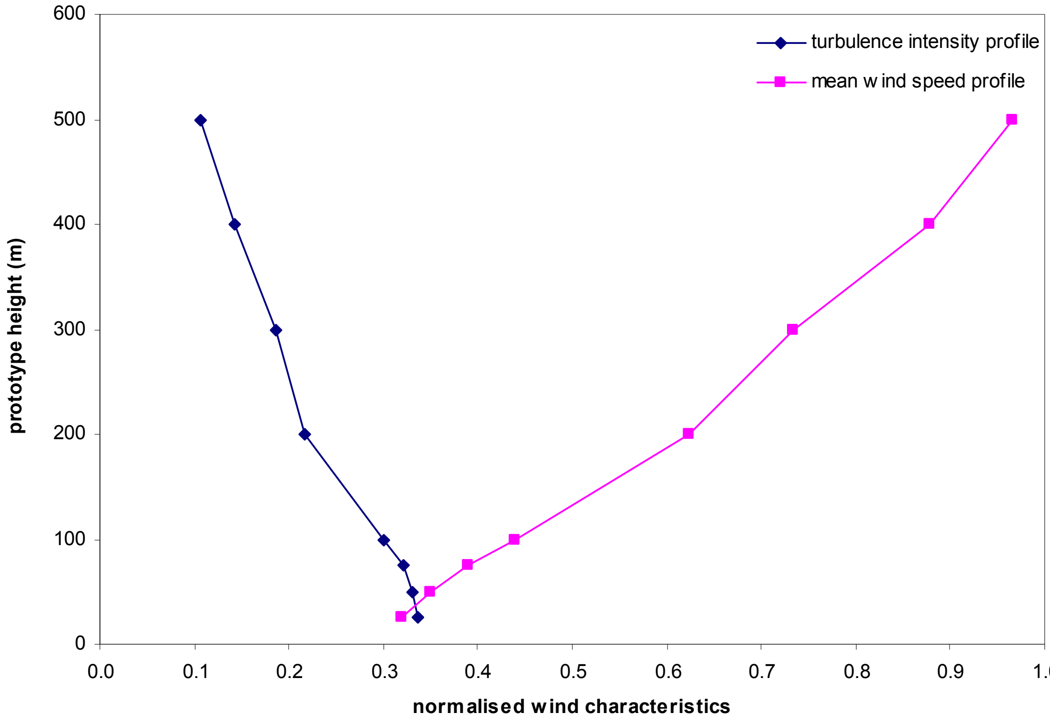

Figure 13a: Wind characteristics, Position 1, 135°

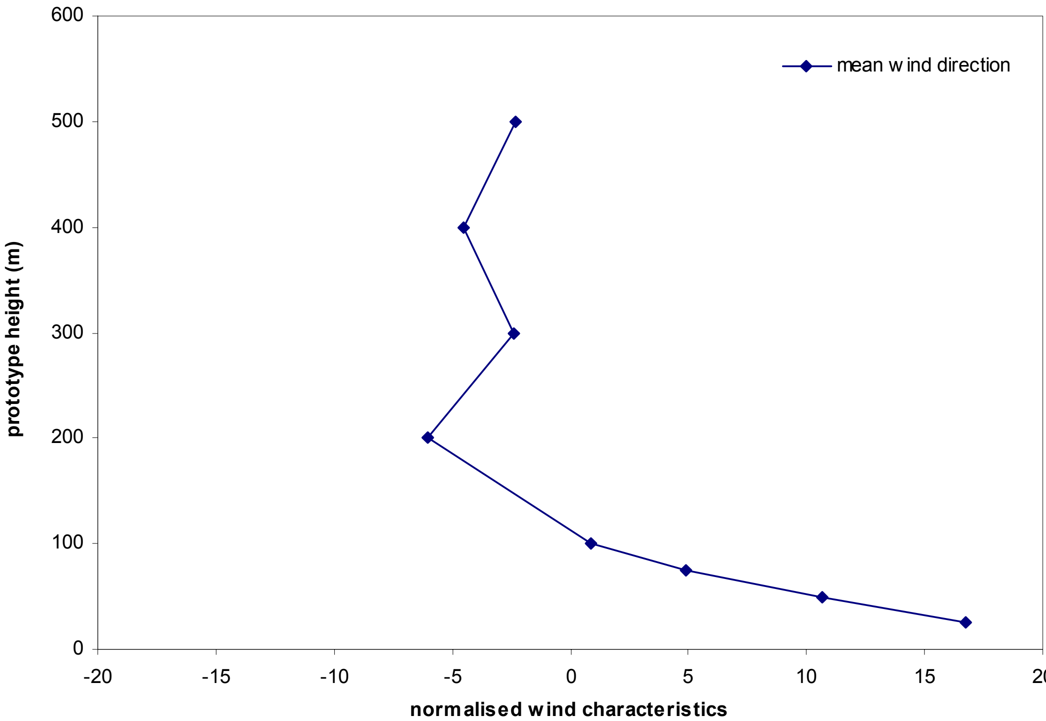

Figure 13b: Mean wind direction, Position 1, 135°

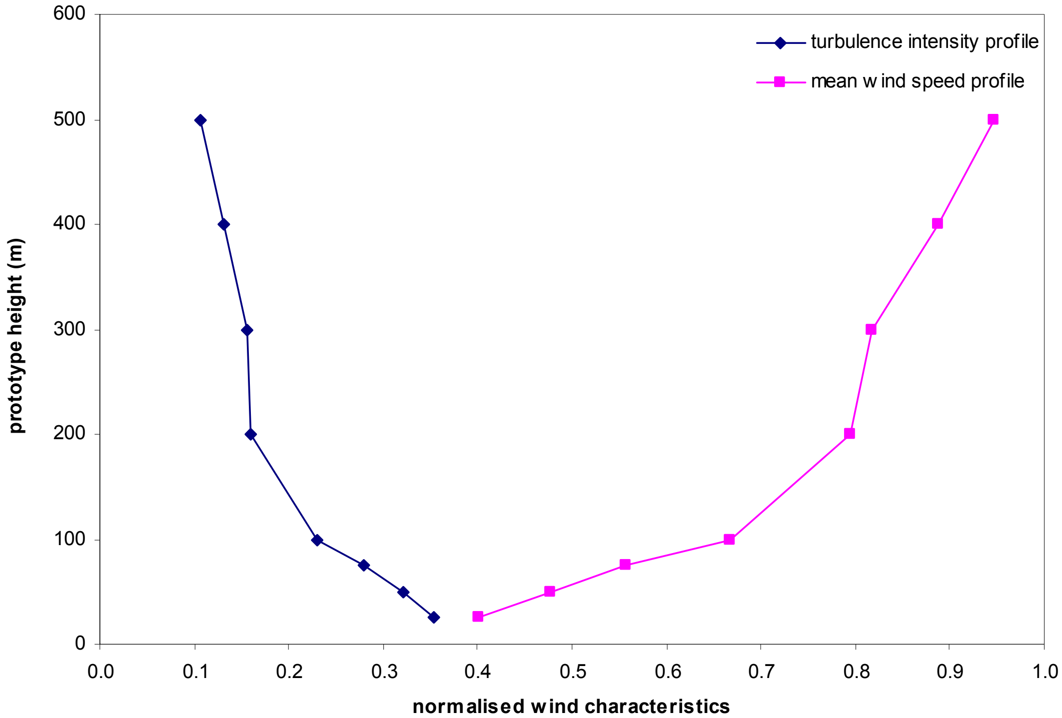

Figure 14a: Wind characteristics, Position 1, 157.5°

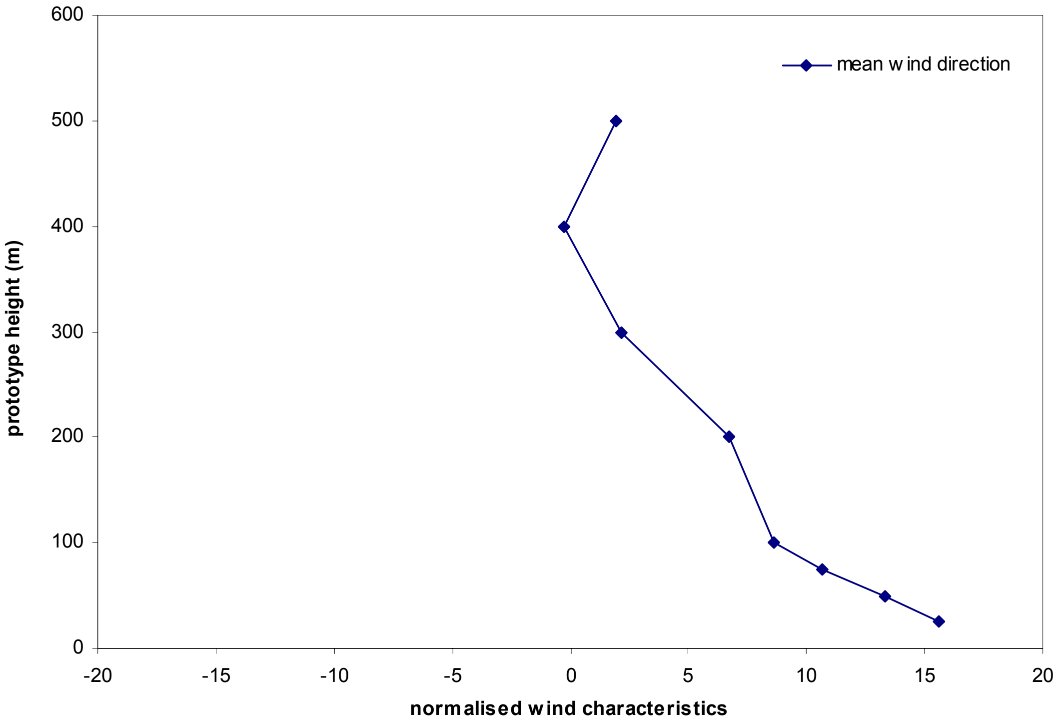

Figure 14b: Mean wind direction, Position 1, 157.5°

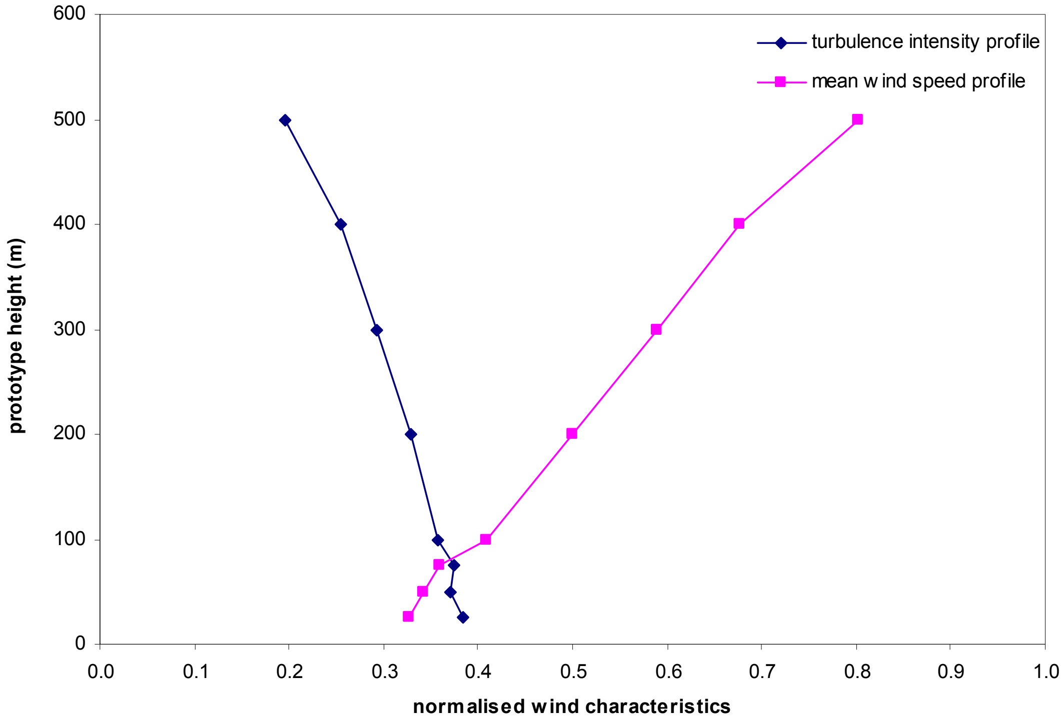

Figure 15a: Wind characteristics, Position 1, 180°

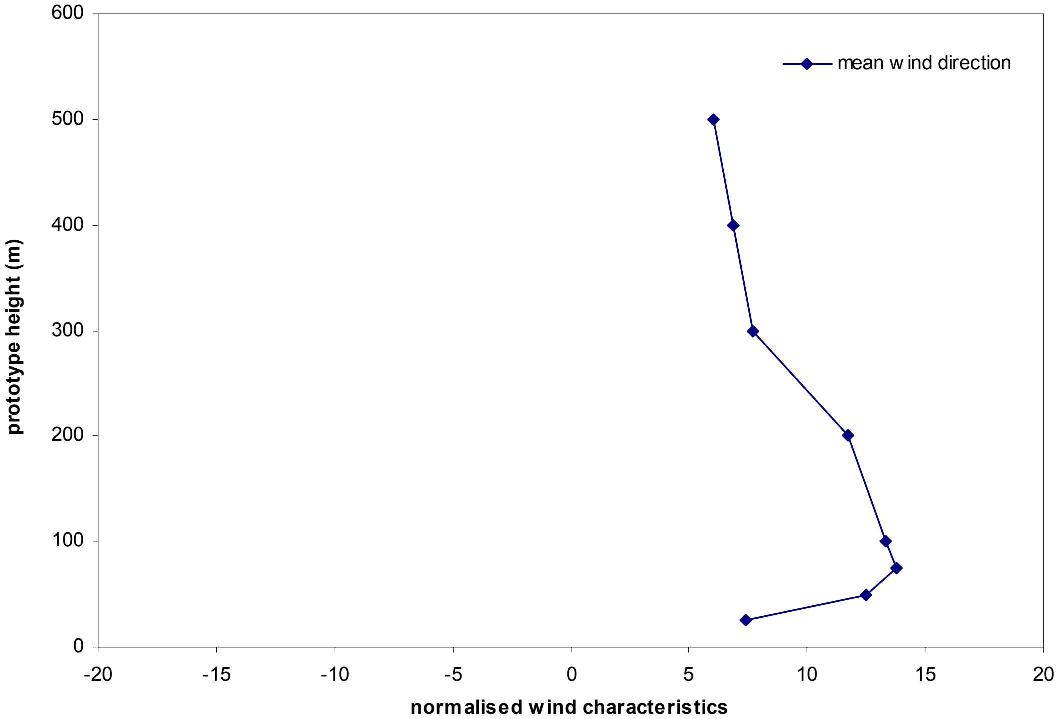

Figure 15b: Mean wind direction, Position 1, 180°

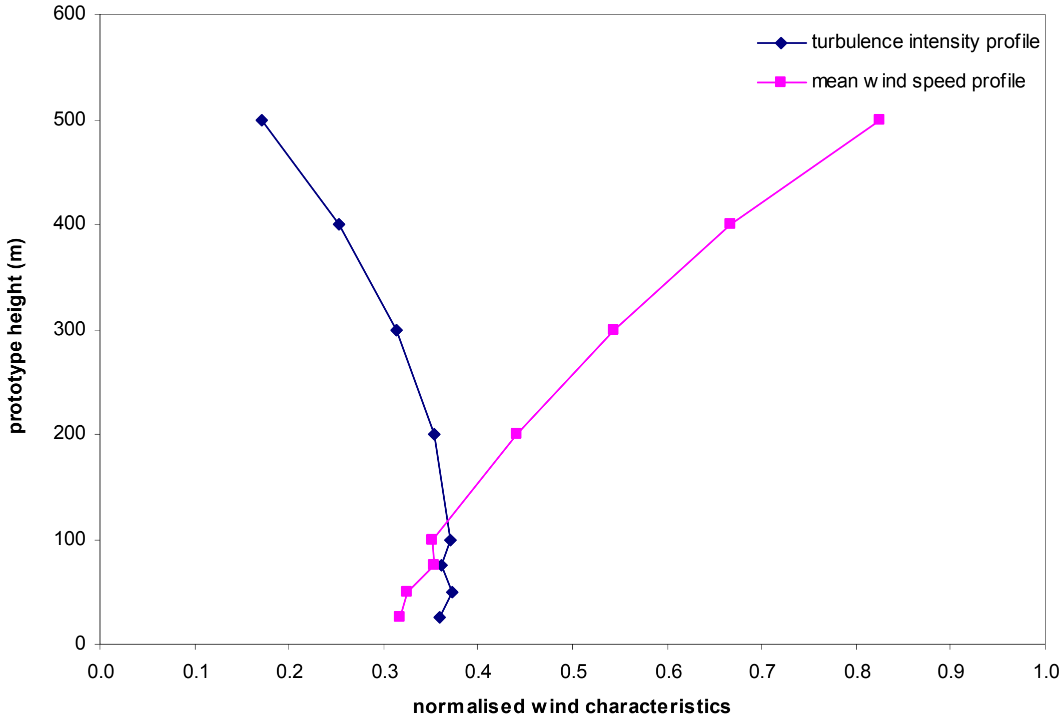

Figure 16a: Wind characteristics, Position 1, 202.5°

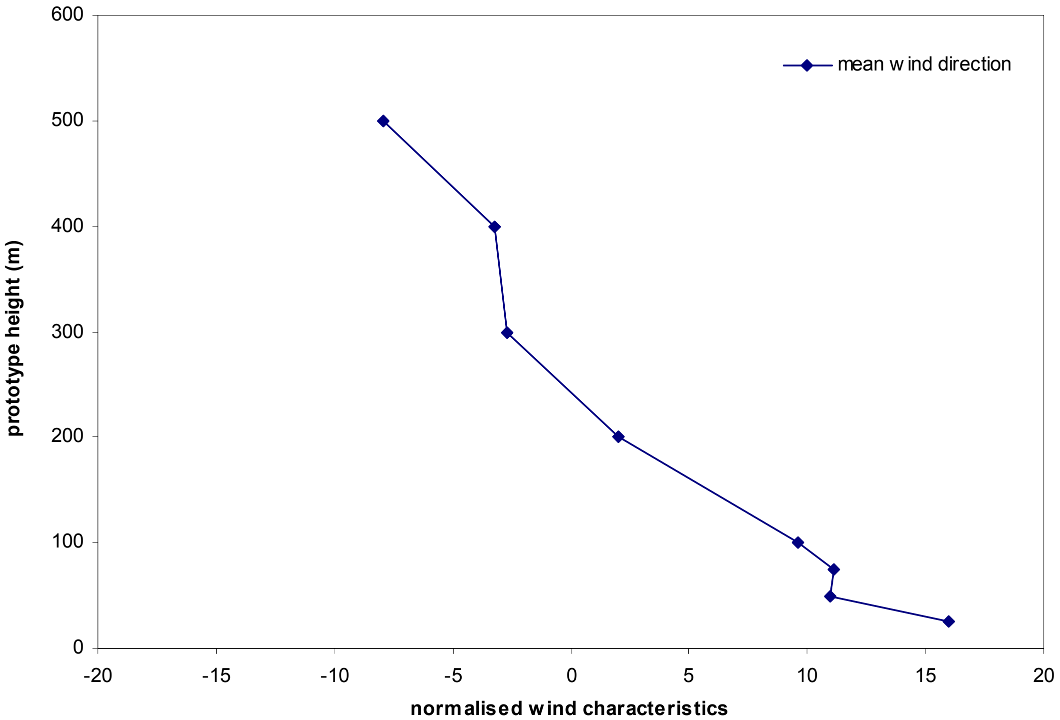

Figure 16b: Mean wind direction, Position 1, 202.5°

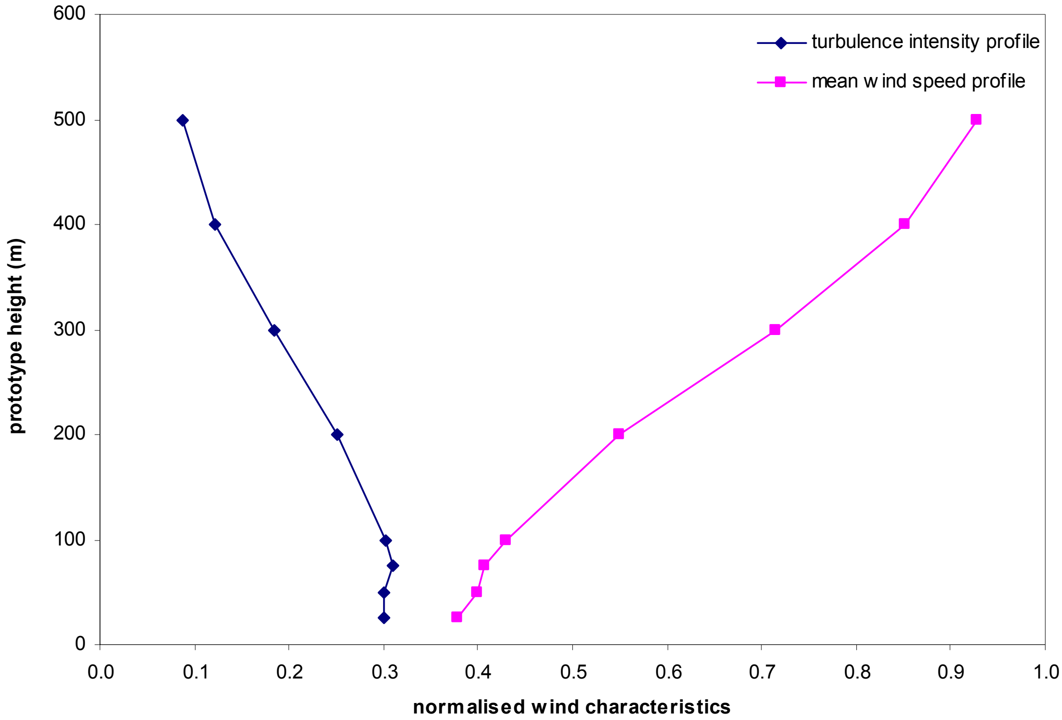

Figure 17a: Wind characteristics, Position 1, 225°

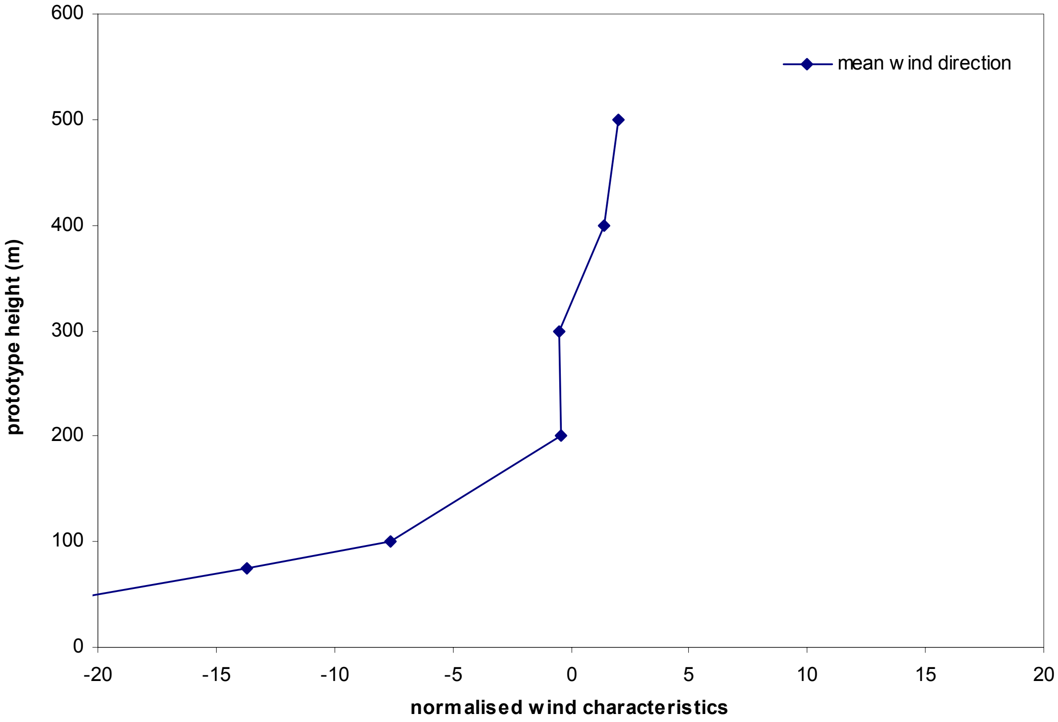

Figure 17b: Mean wind direction, Position 1, 225°

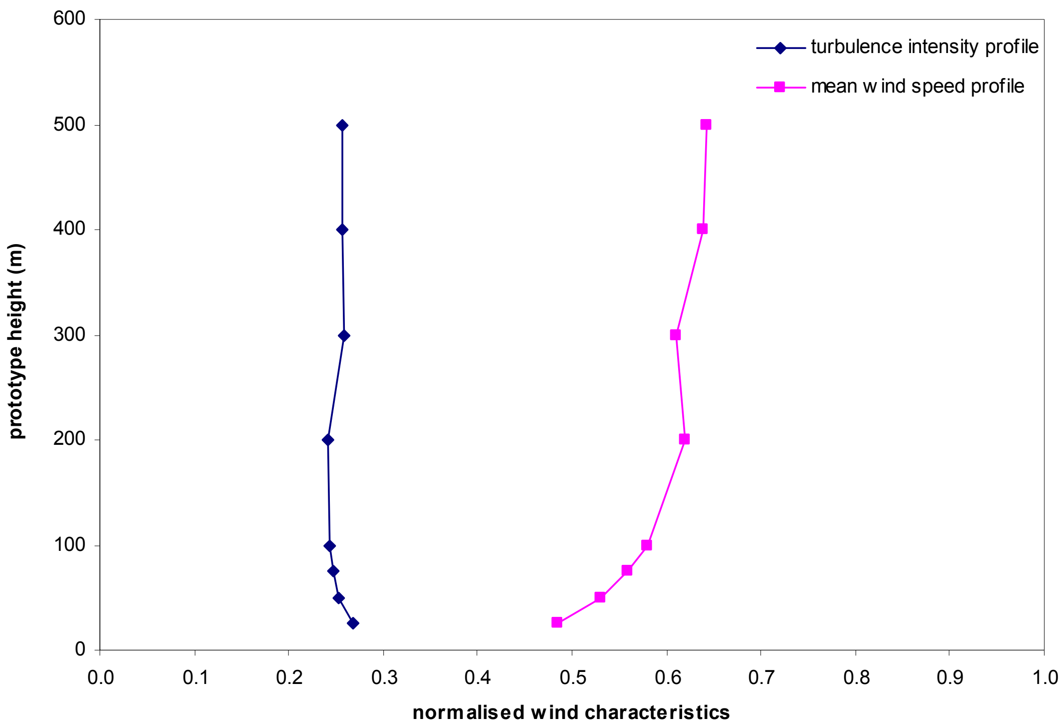

Figure 18a: Wind characteristics, Position 1, 247.5°

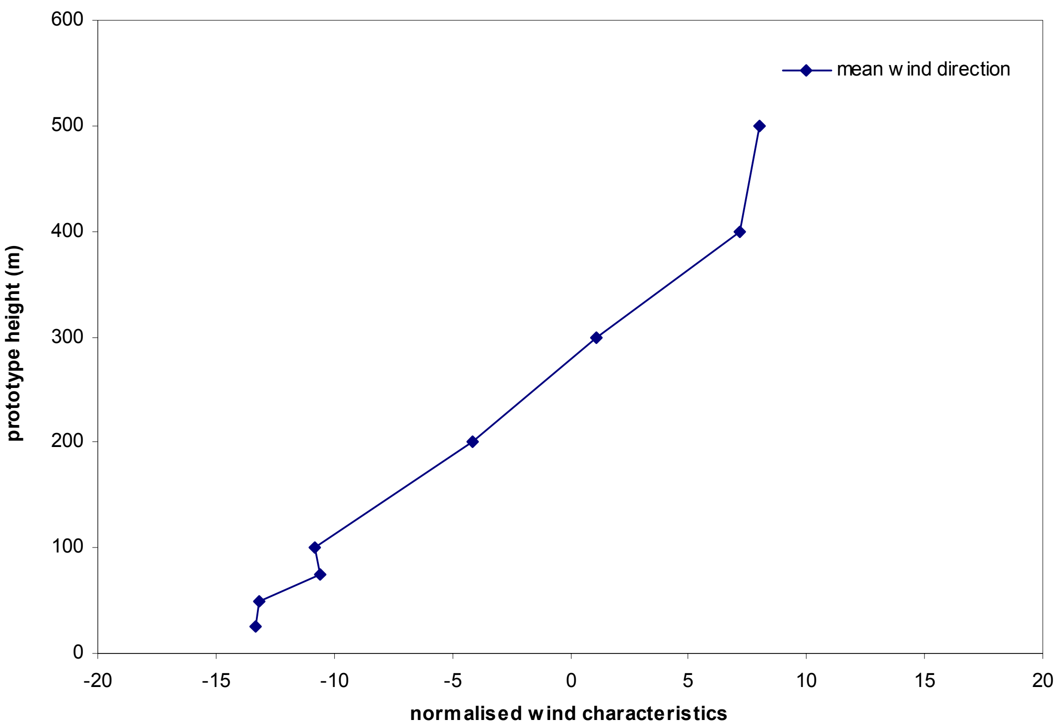

Figure 18b: Mean wind direction, Position 1, 247.5°

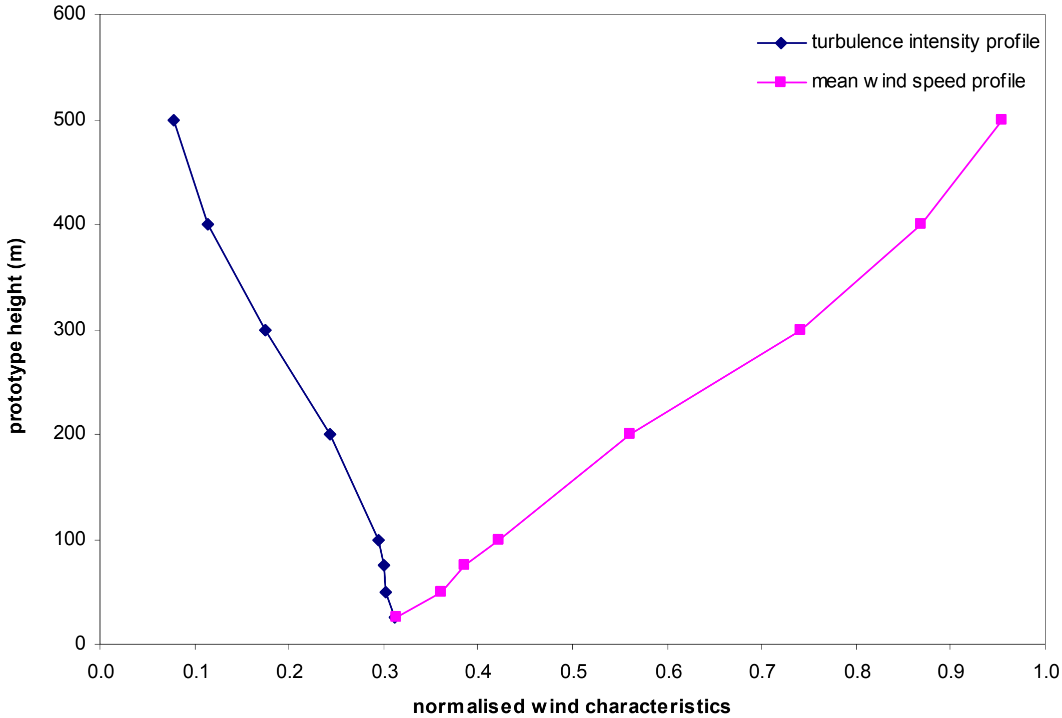

Figure 19a: Wind characteristics, Position 1, 270°

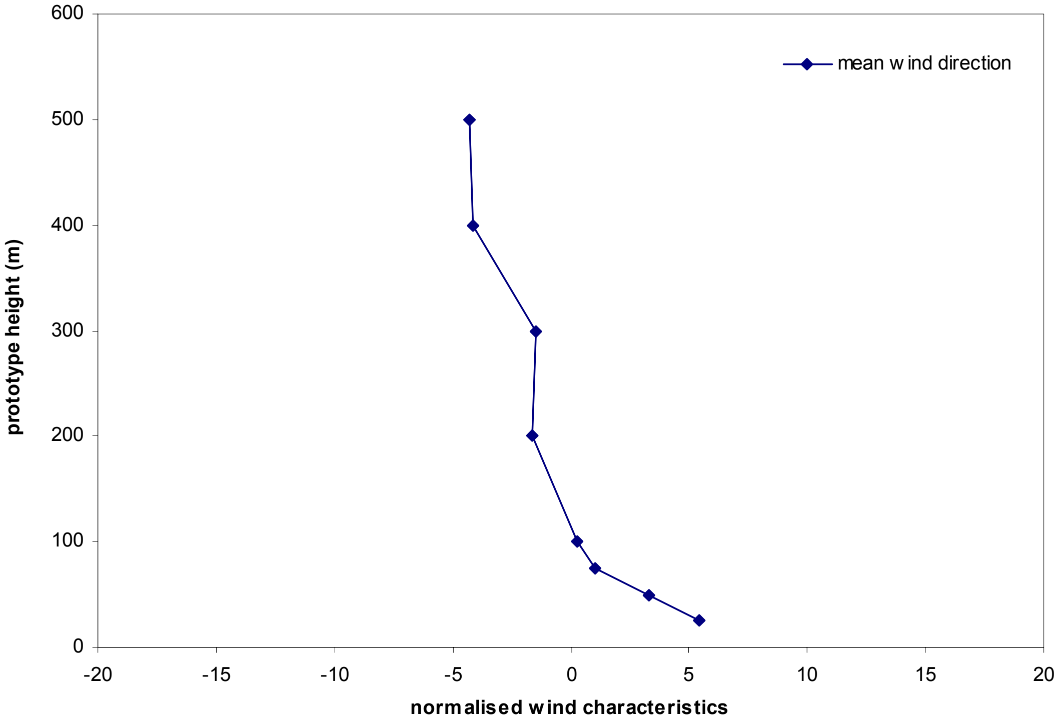

Figure 19b: Mean wind direction, Position 1, 270°

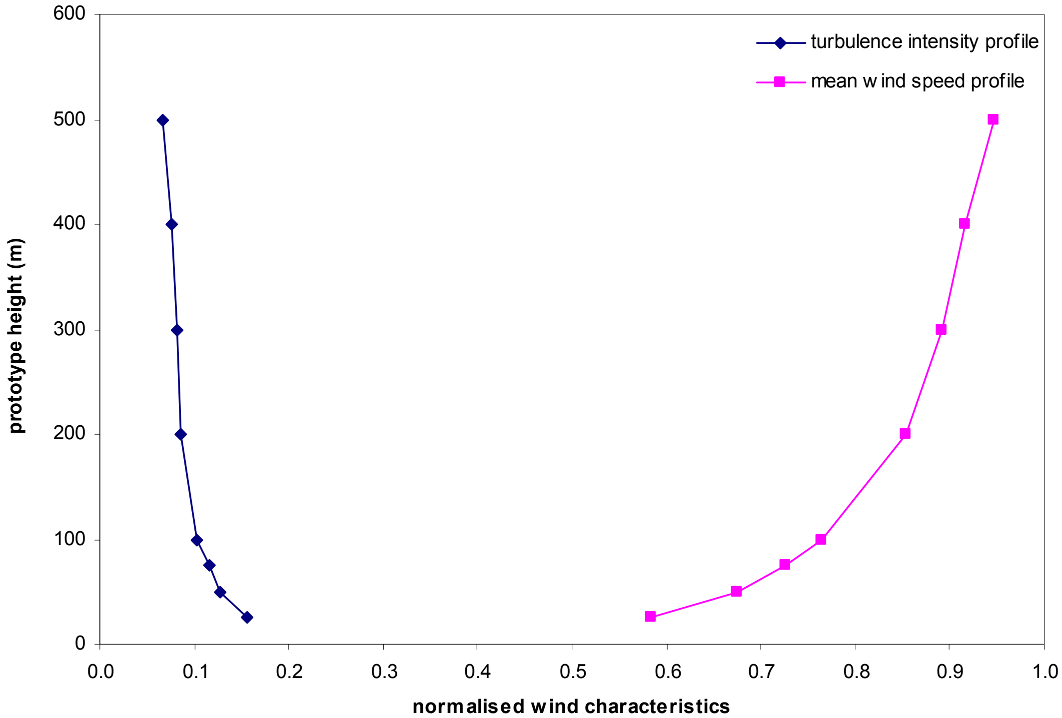

Figure 20a: Wind characteristics, Position 1, 292.5°

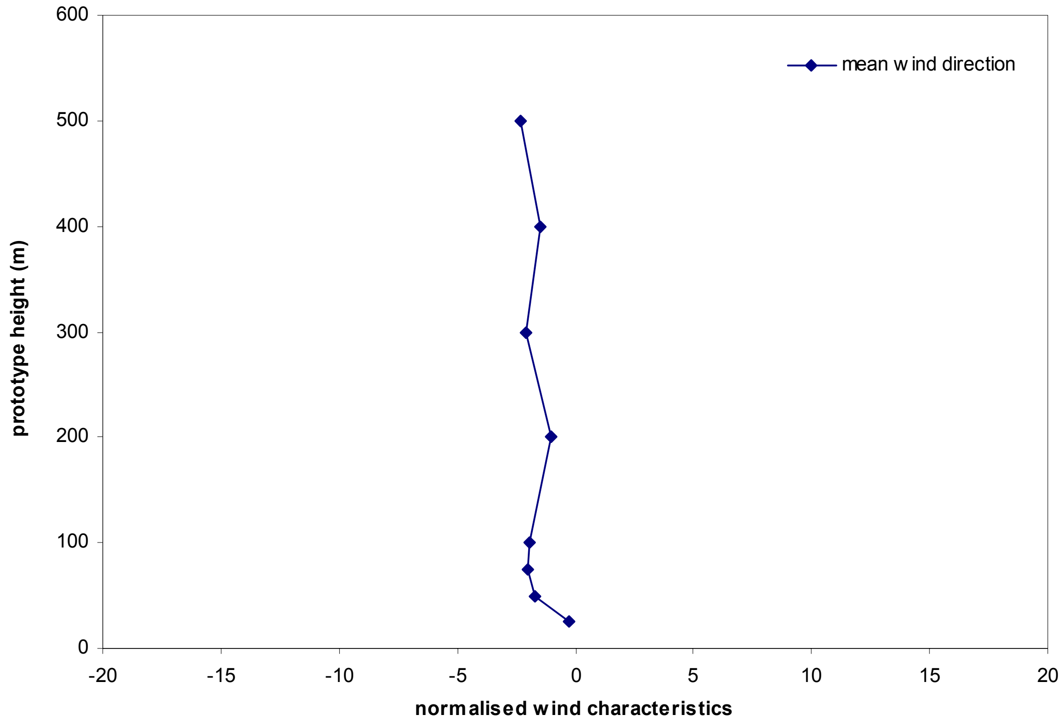

Figure 20b: Mean wind direction, Position 1, 292.5°

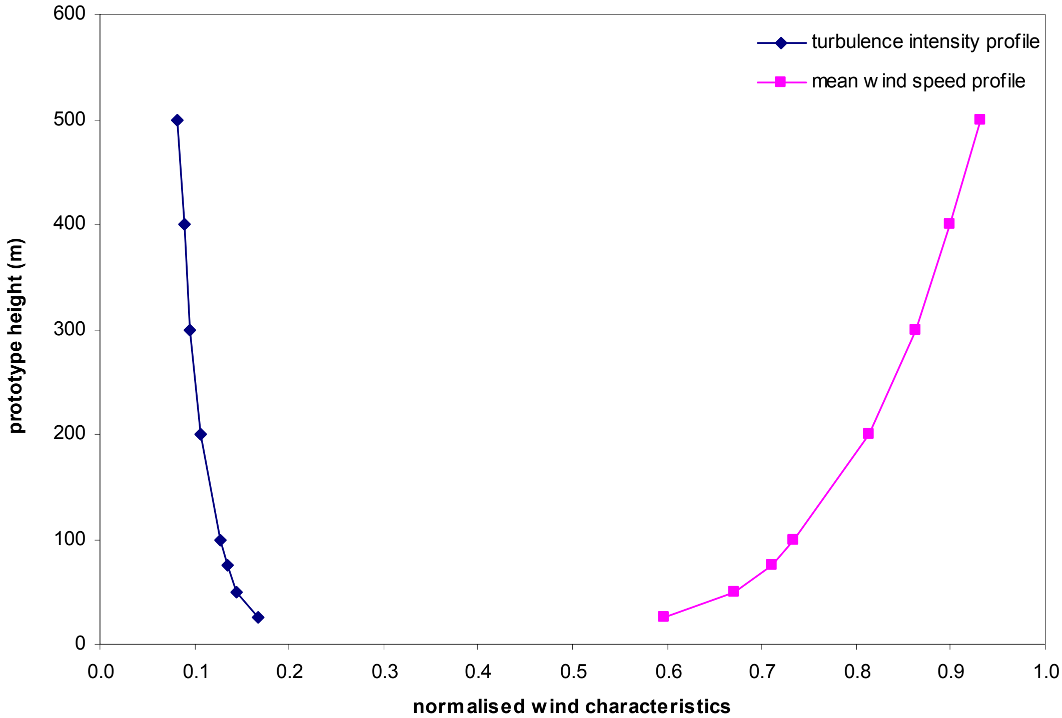

Figure 21a: Wind characteristics, Position 1, 315°

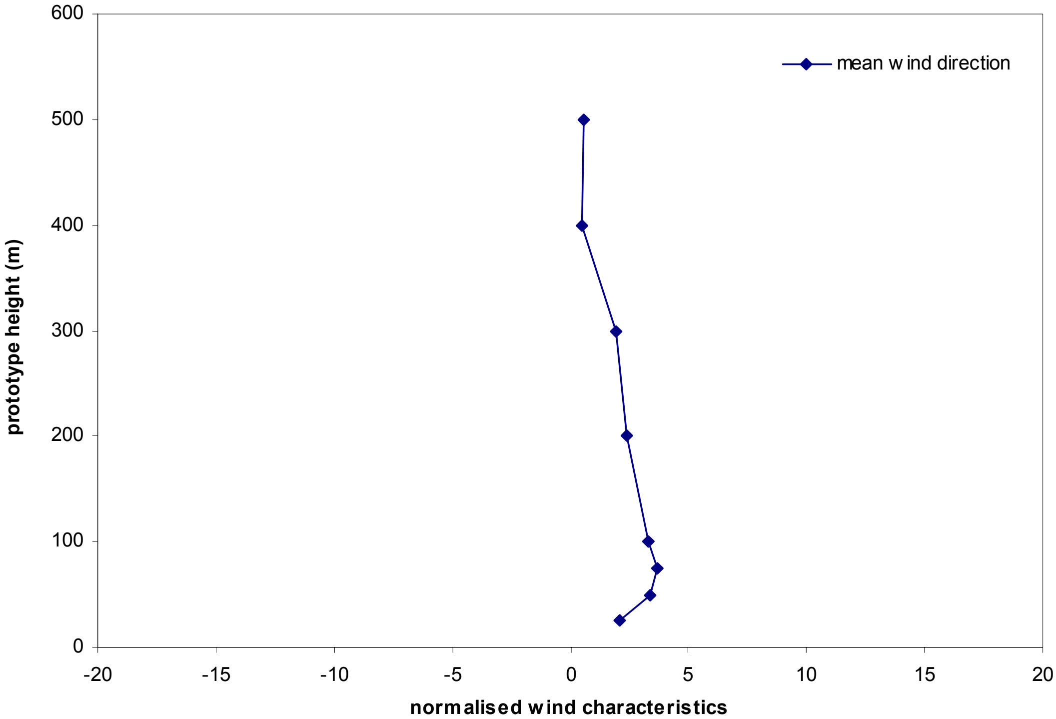

Figure 21b: Mean wind direction, Position 1, 315°

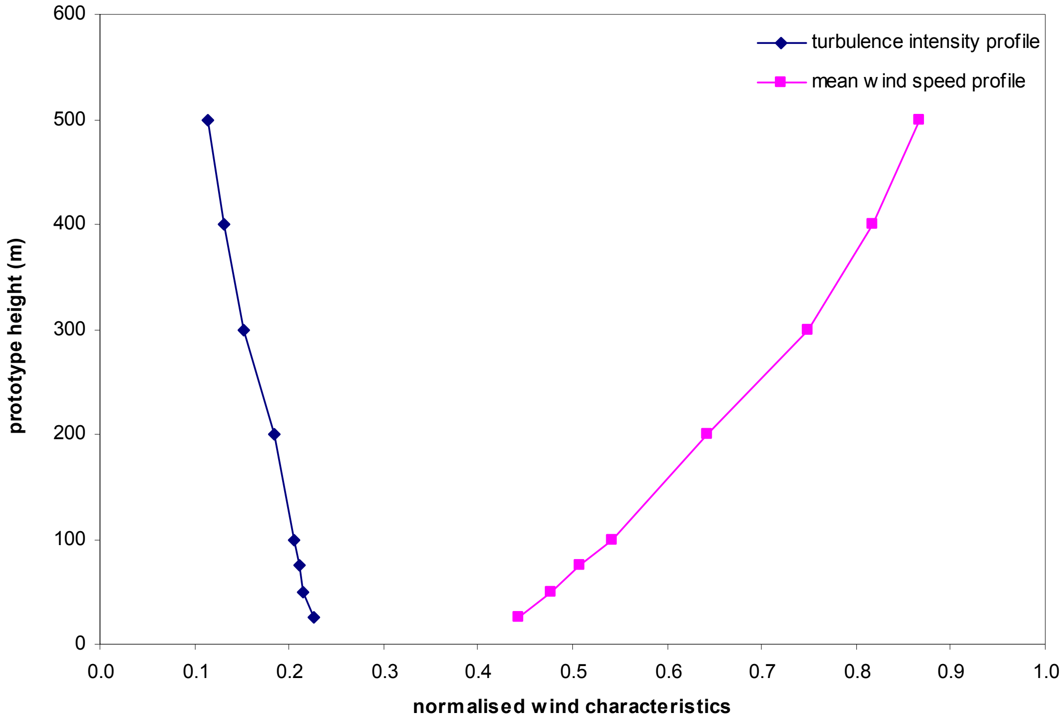

Figure 22a: Wind characteristics, Position 1, 337.5°

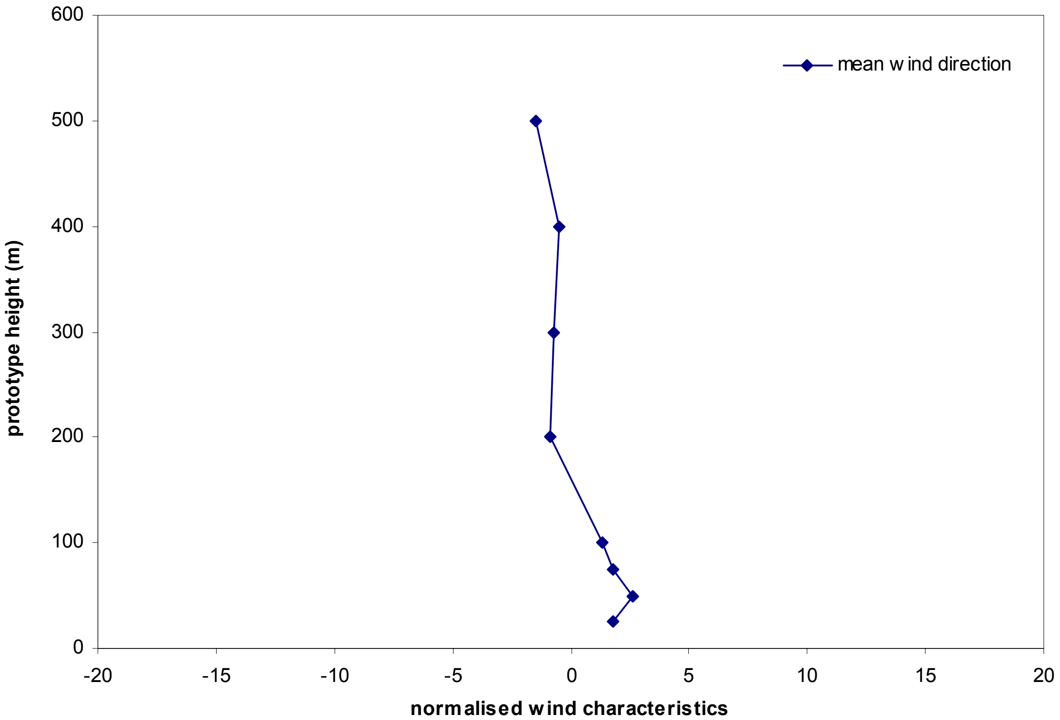

Figure 22b: Mean wind direction, Position 1, 337.5°

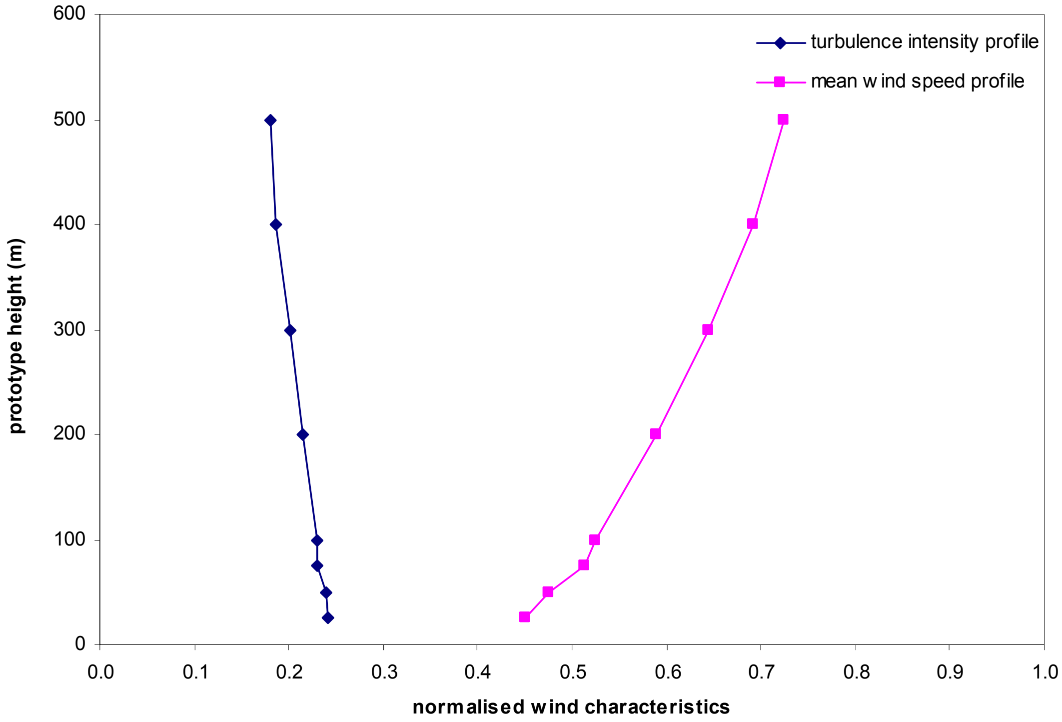

Figure 23a: Wind characteristics, Position 1, 360°

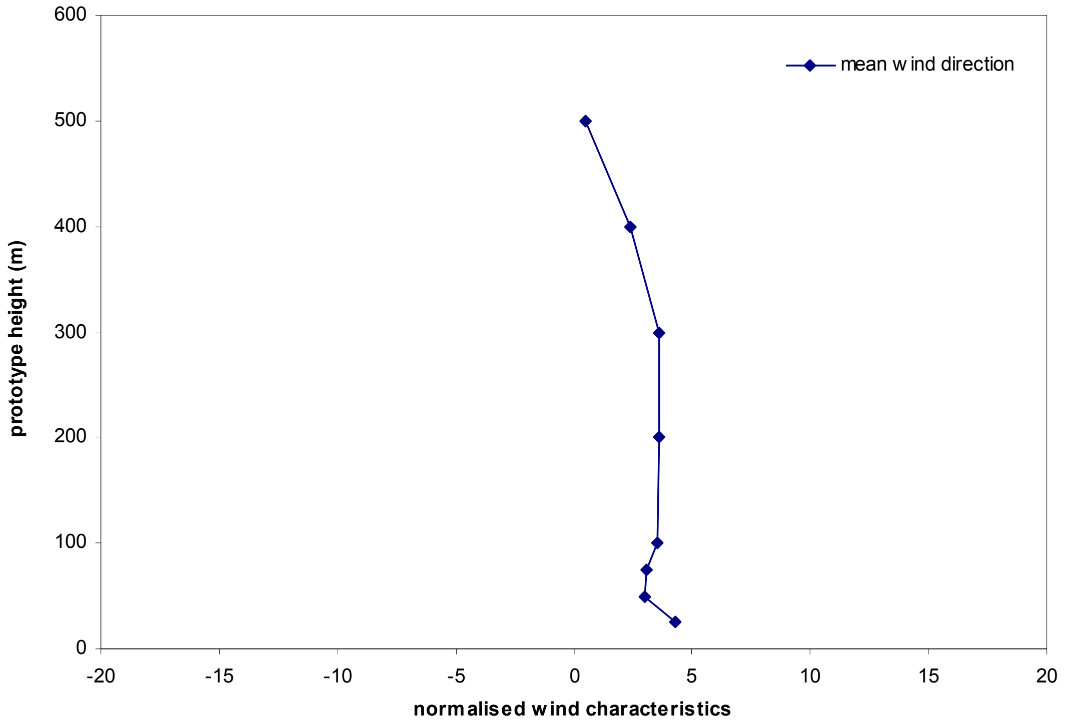

Figure 23b: Mean wind direction, Position 1, 360°

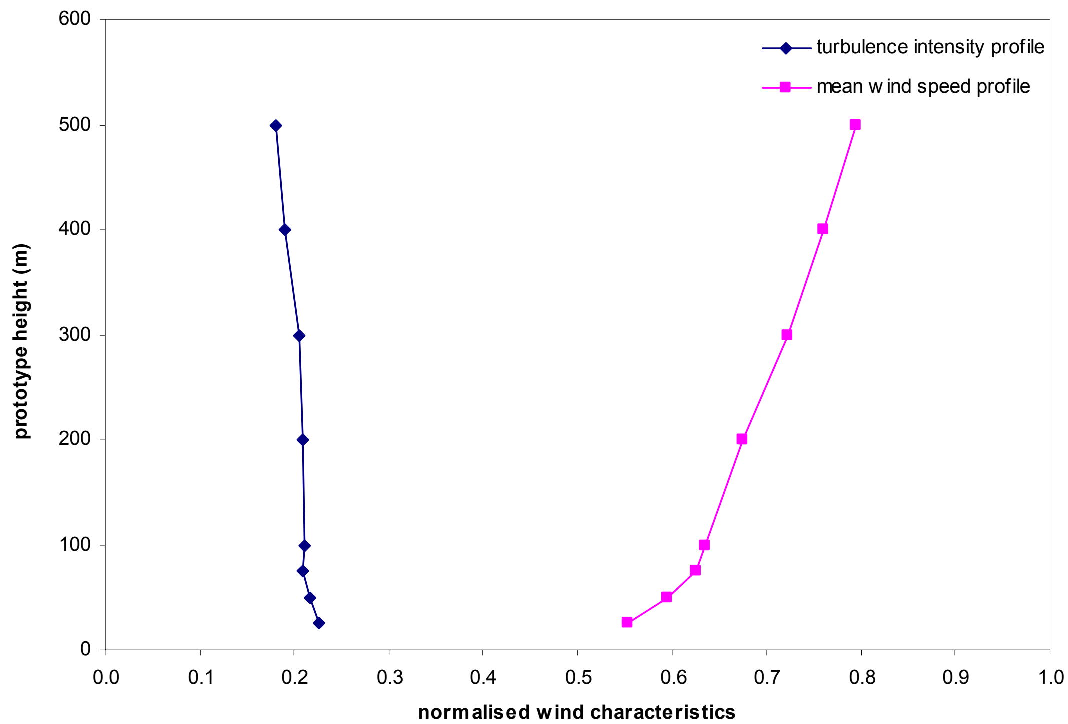

Figure 24a: Wind characteristics, Position 2, 22.5°

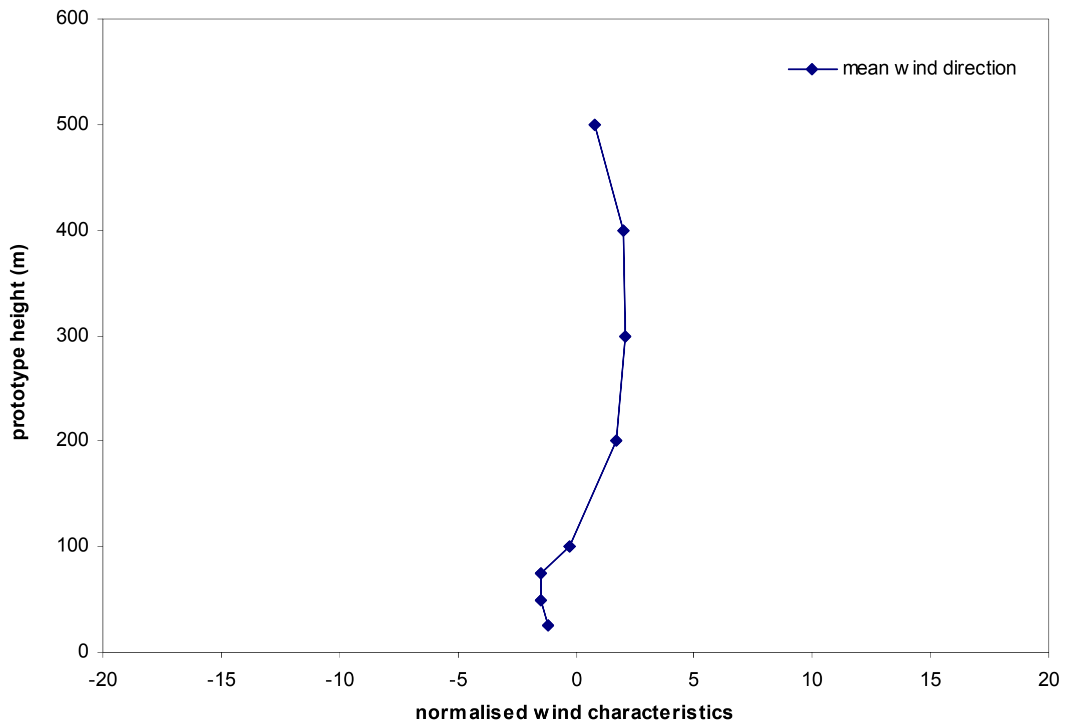

Figure 24b: Mean wind direction, Position 2, 22.5°

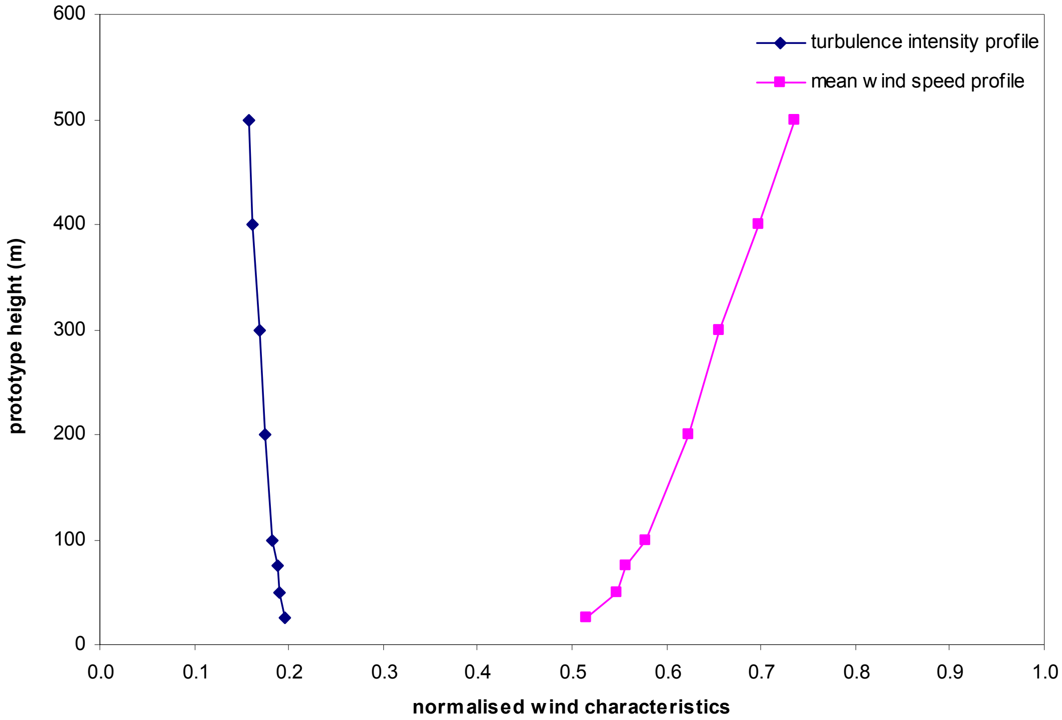

Figure 25a: Wind characteristics, Position 2, 45°

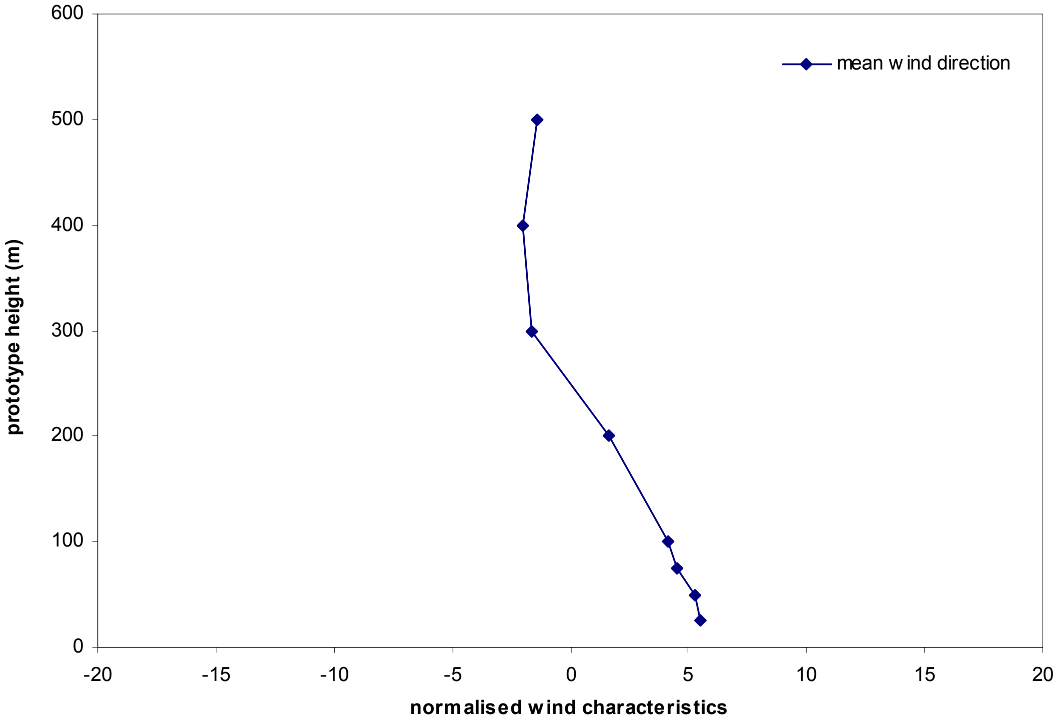

Figure 25b: Mean wind direction, Position 2, 45°

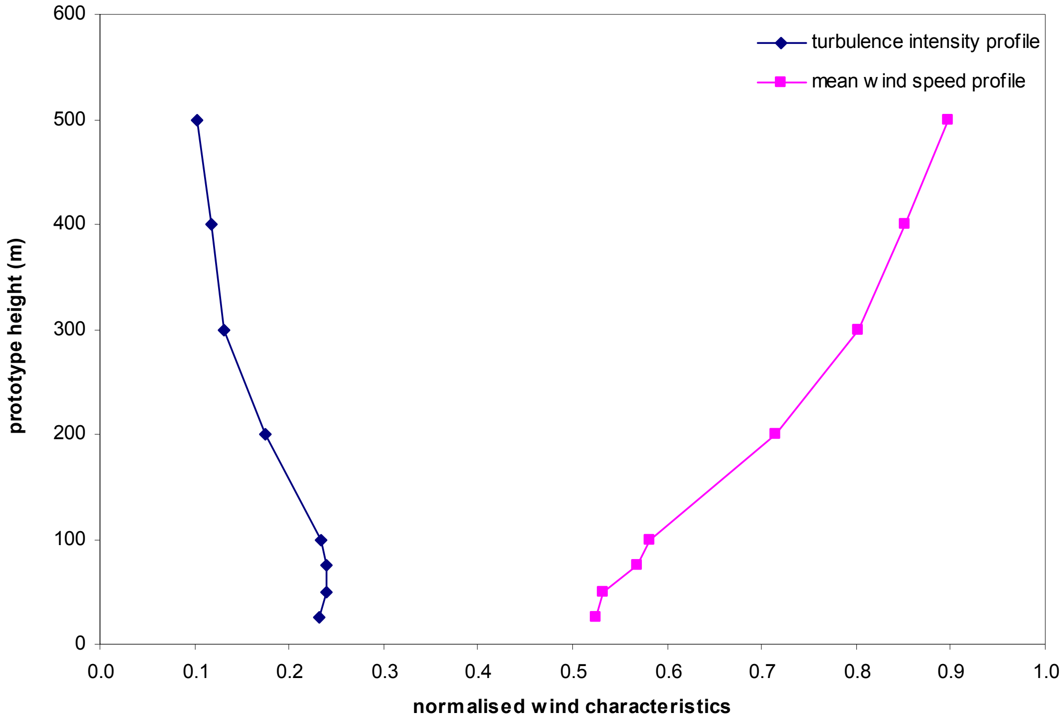

Figure 26a: Wind characteristics, Position 2, 67.5°

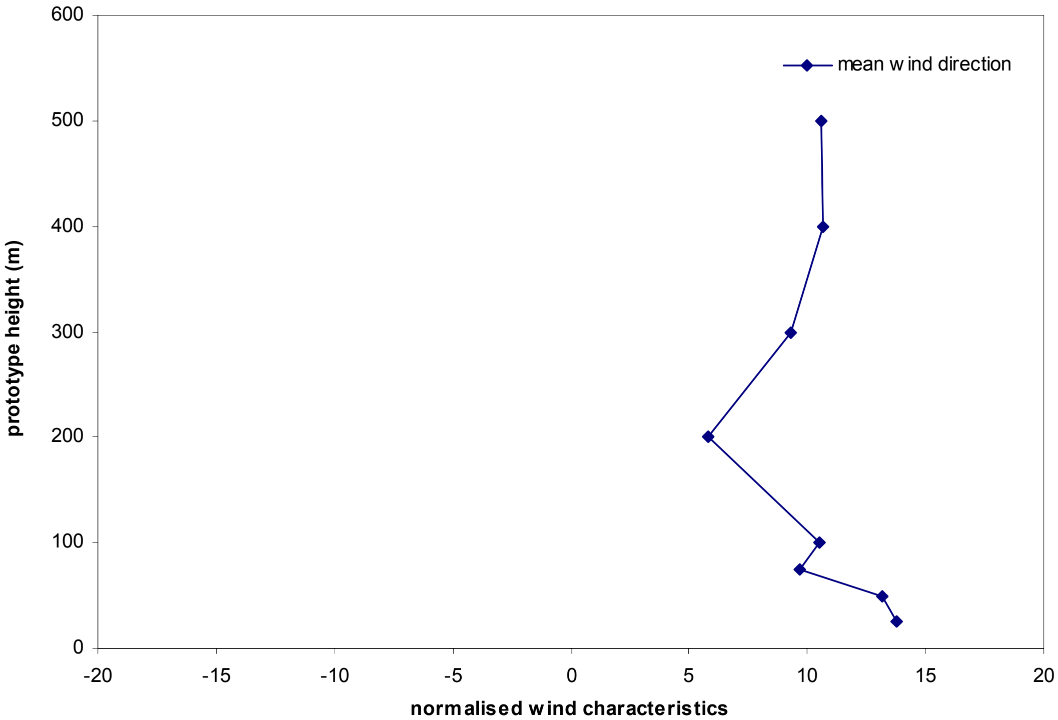

Figure 26b: Mean wind direction, Position 2, 67.5°

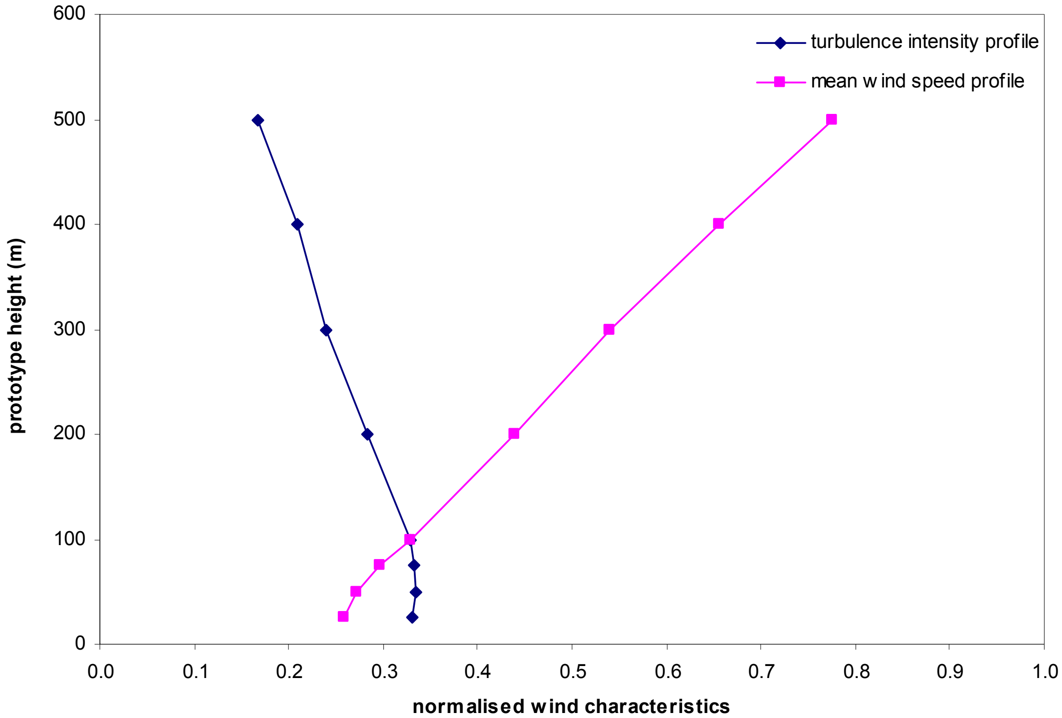

Figure 27a: Wind characteristics, Position 2, 90°

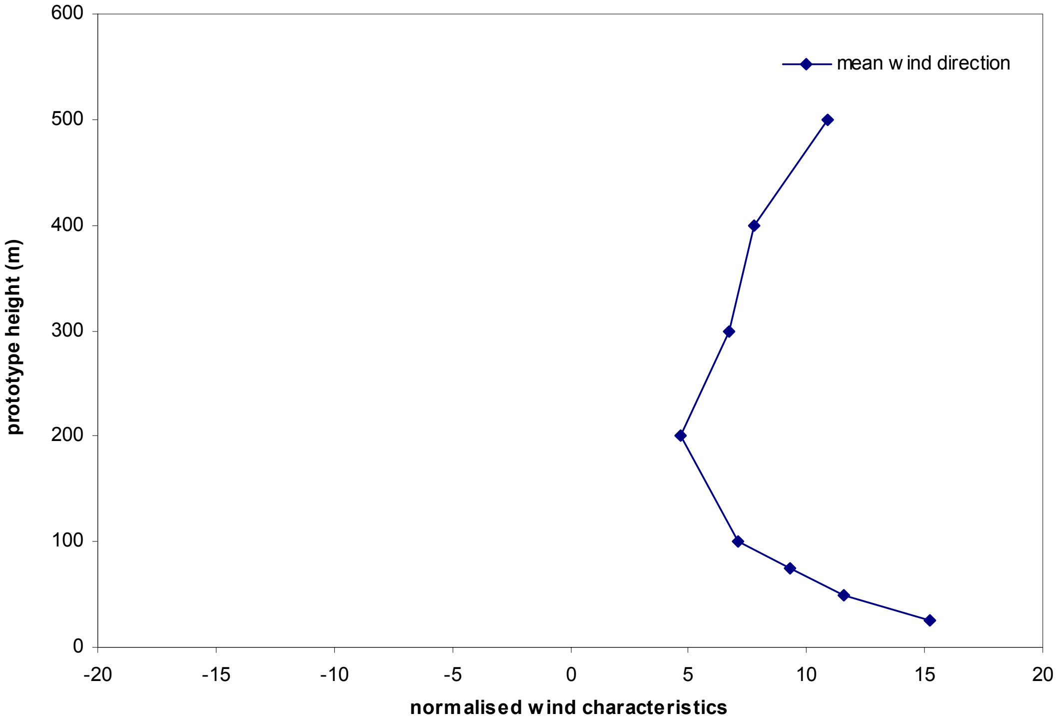

Figure 27b: Mean wind direction, Position 2, 90°

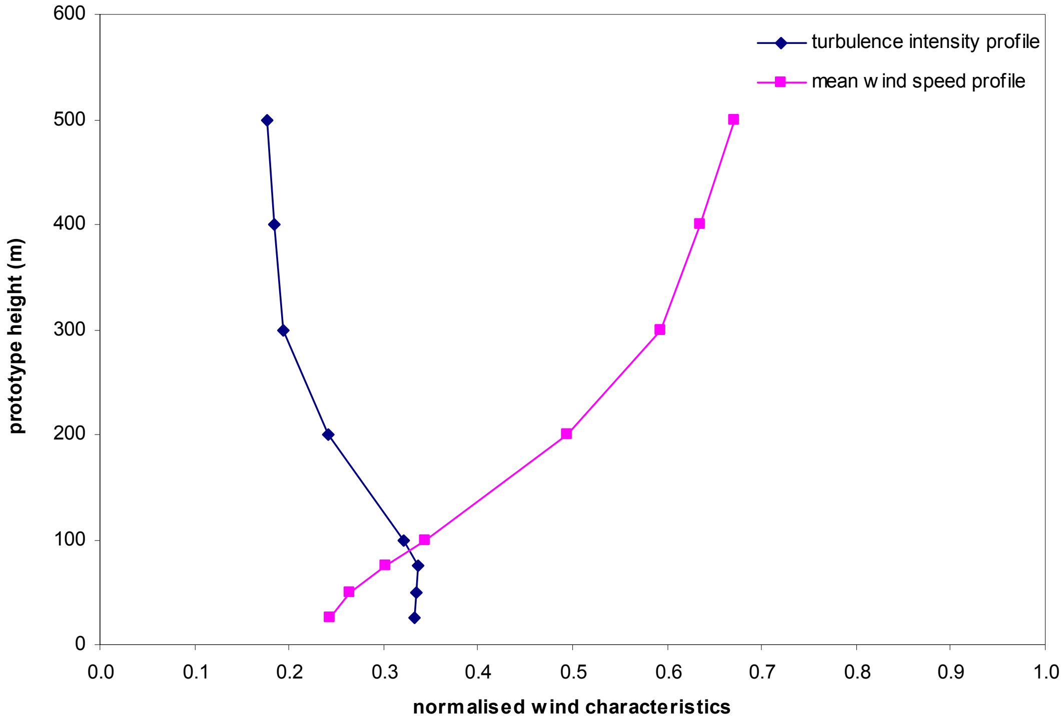

Figure 28a: Wind characteristics, Position 2, 112.5°

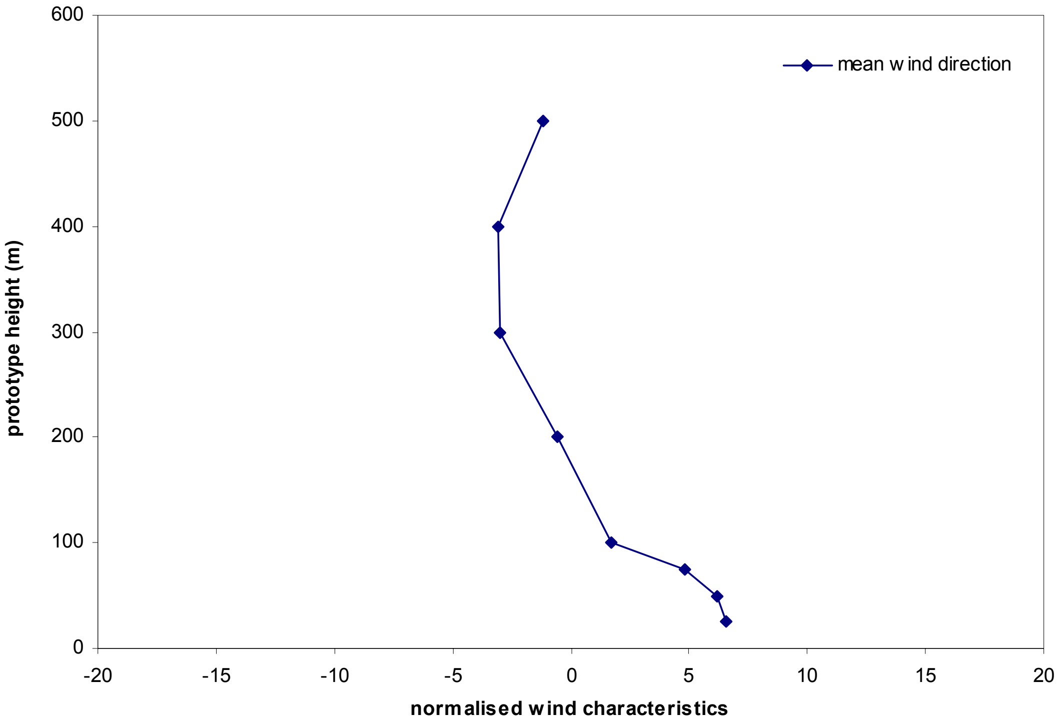

Figure 28b: Mean wind direction, Position 2, 112.5°

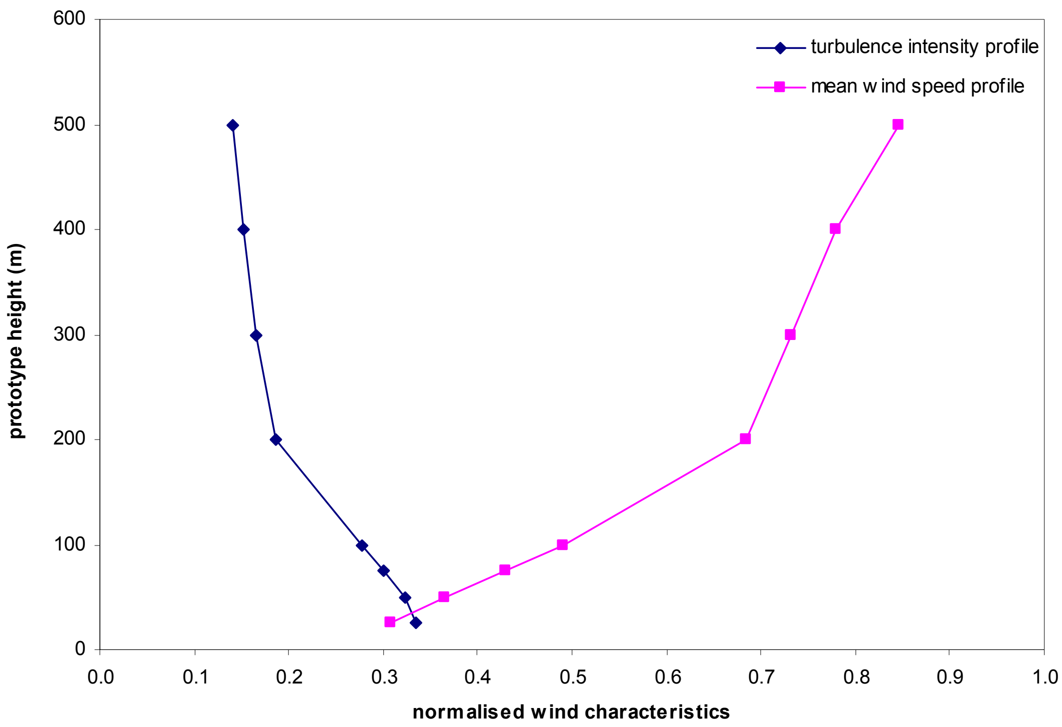

Figure 29a: Wind characteristics, Position 2, 135°

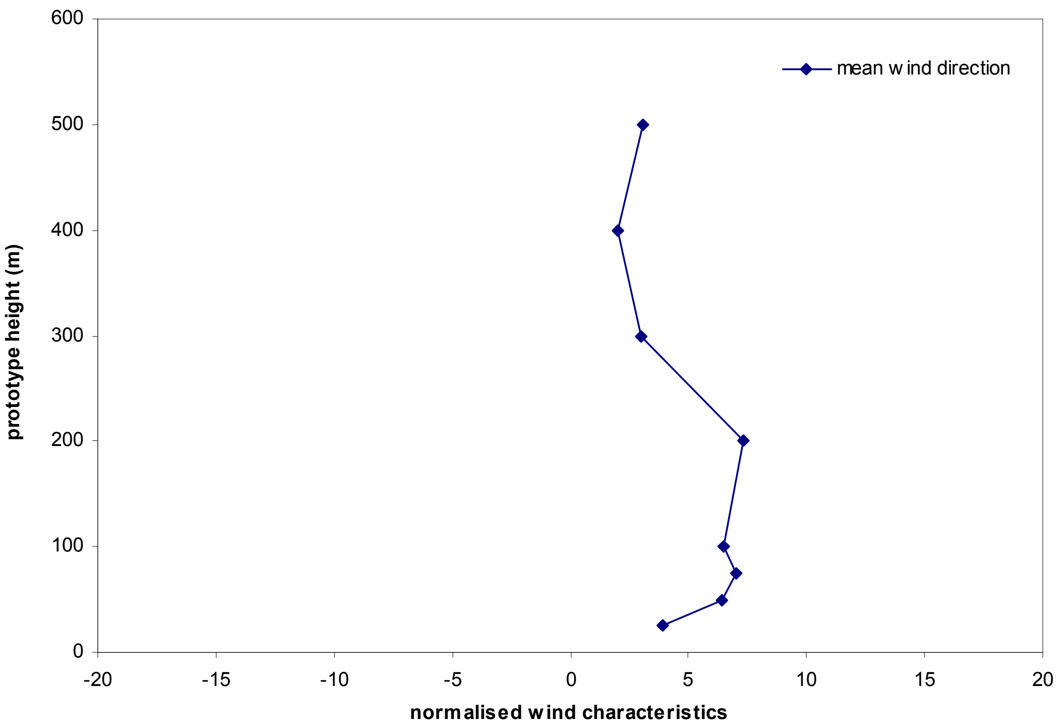

Figure 29b: Mean wind direction, Position 2, 135°

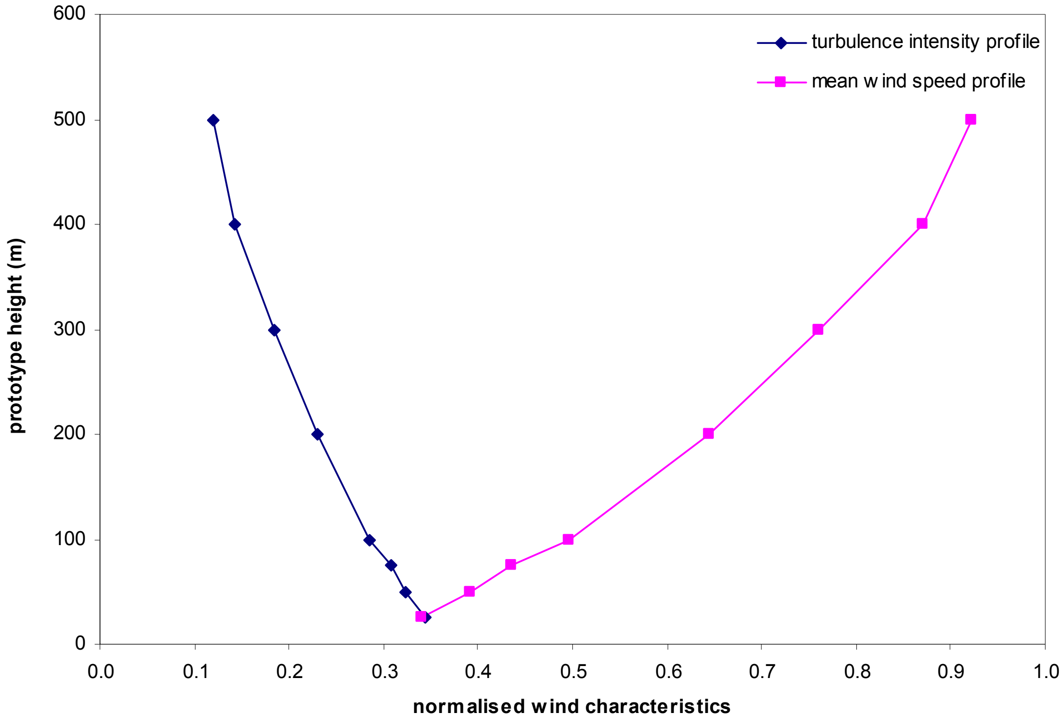

Figure 30a: Wind characteristics, Position 2, 157.5°

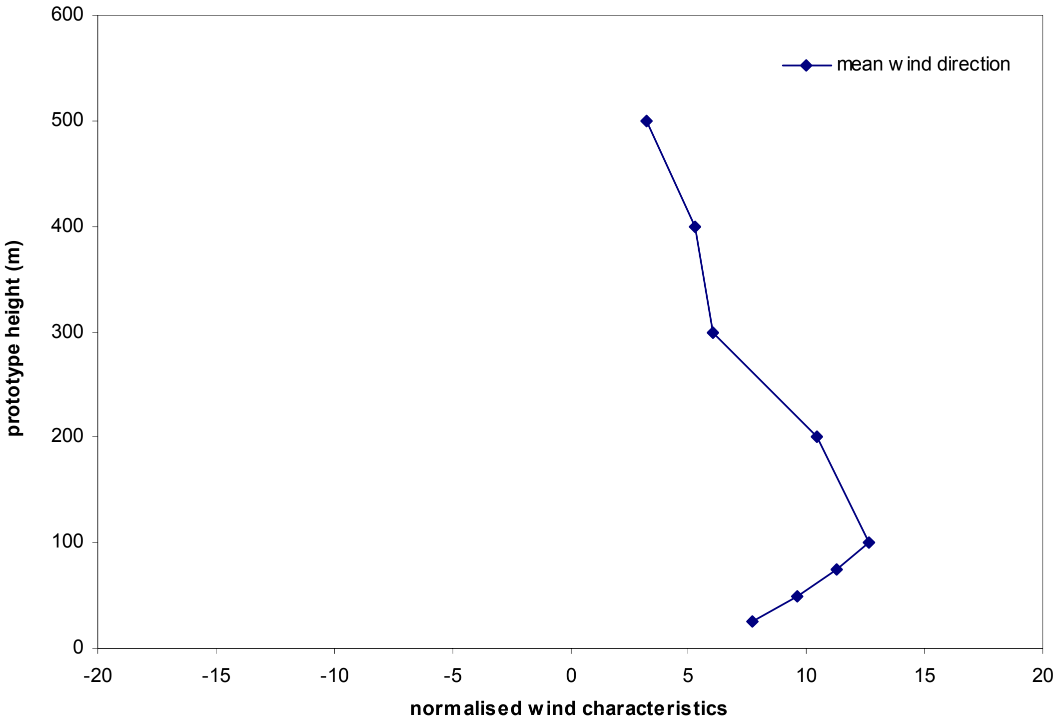

Figure 30b: Mean wind direction, Position 2, 157.5°

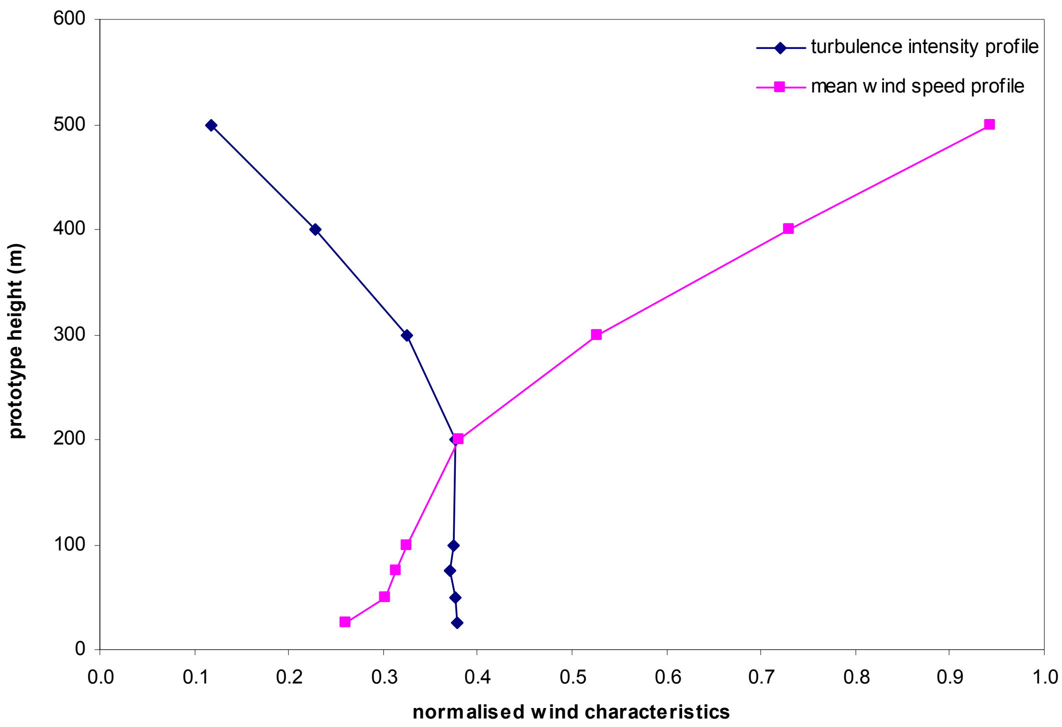

Figure 31a: Wind characteristics, Position 2, 180°

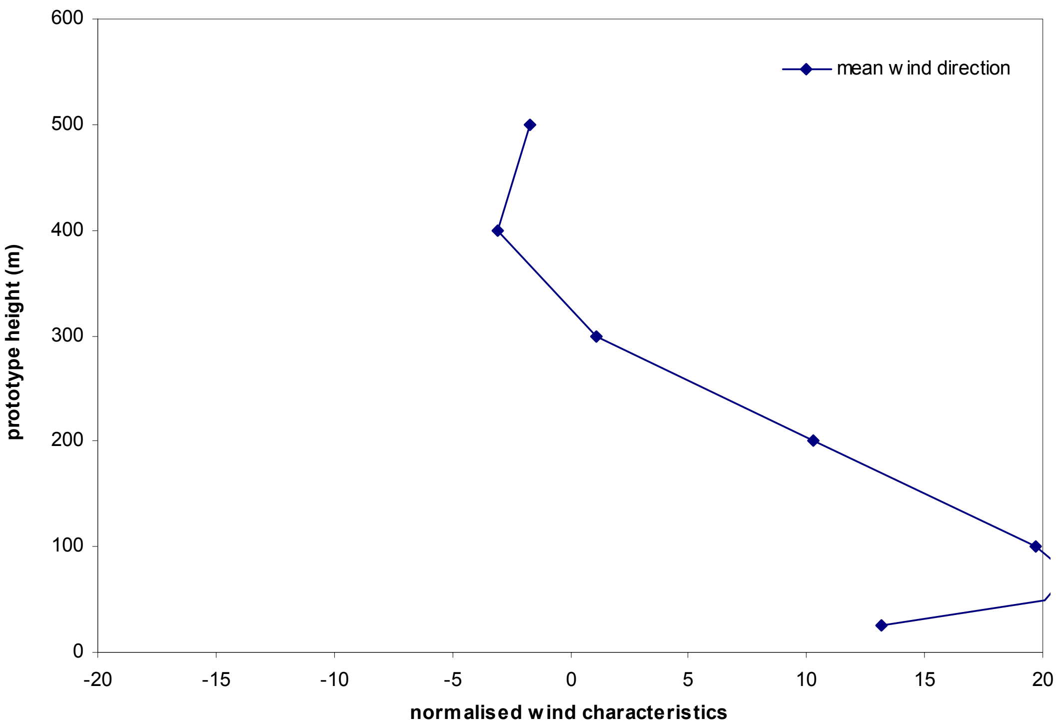

Figure 31b: Mean wind direction, Position 2, 180°

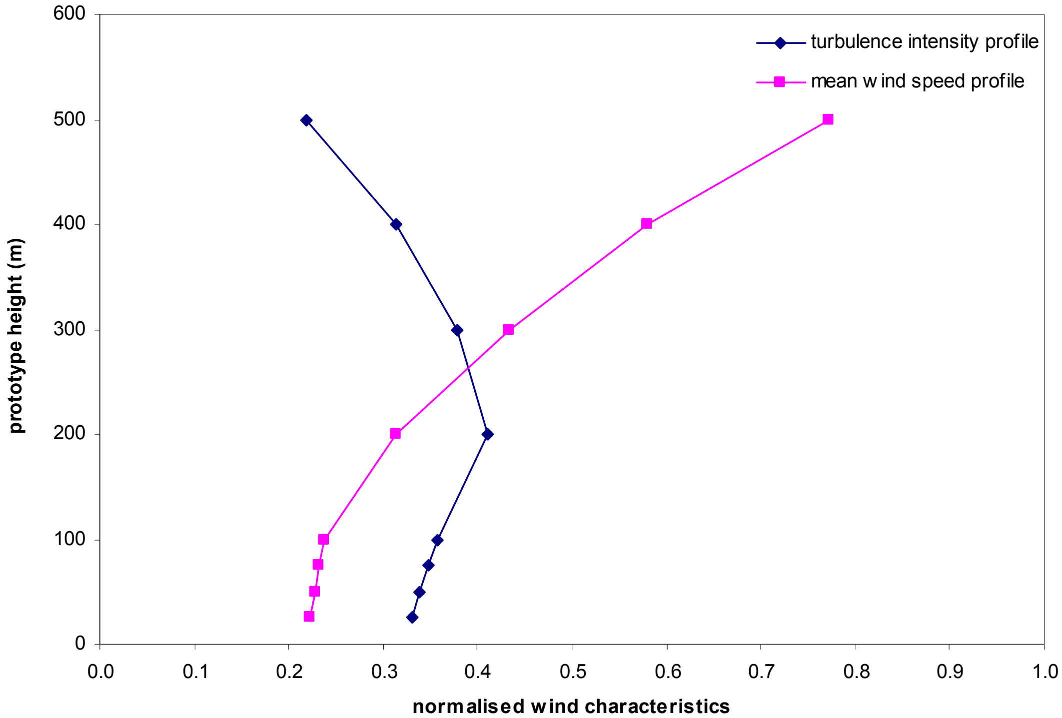

Figure 32a: Wind characteristics, Position 2, 202.5°

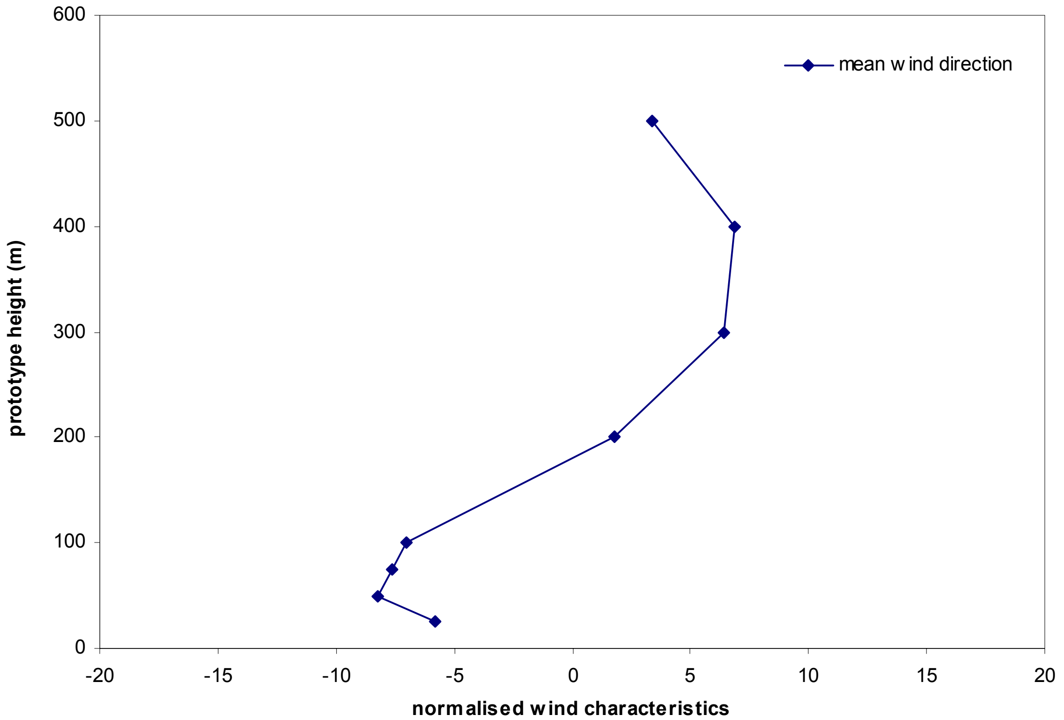

Figure 32b: Mean wind direction, Position 2, 202.5°

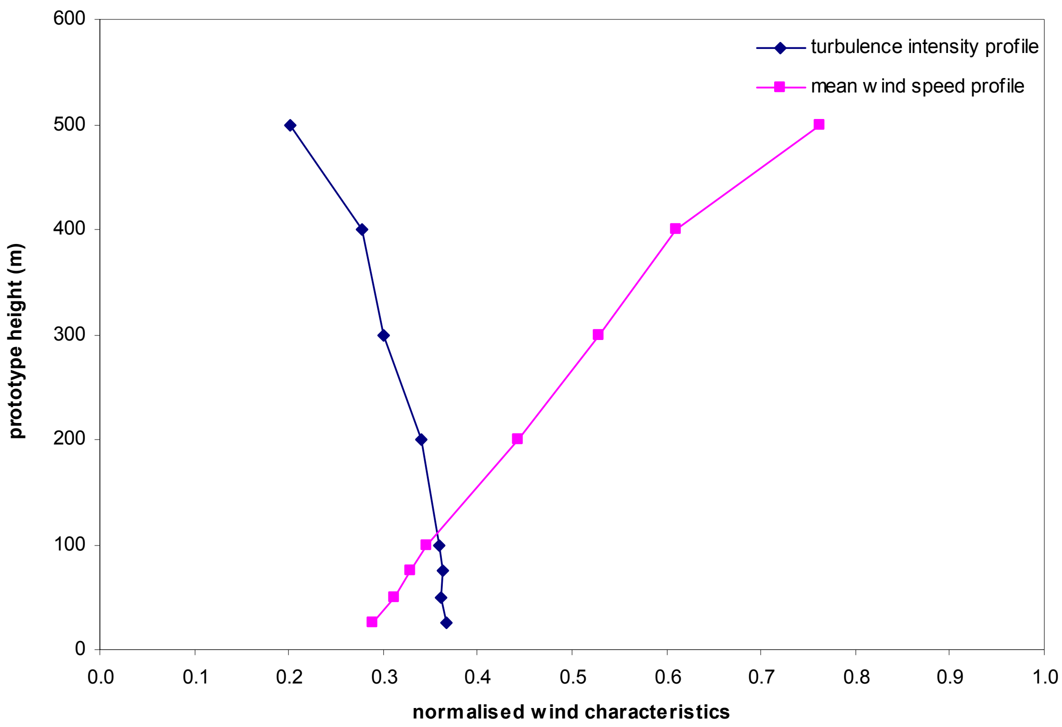

Figure 33a: Wind characteristics, Position 2, 225°

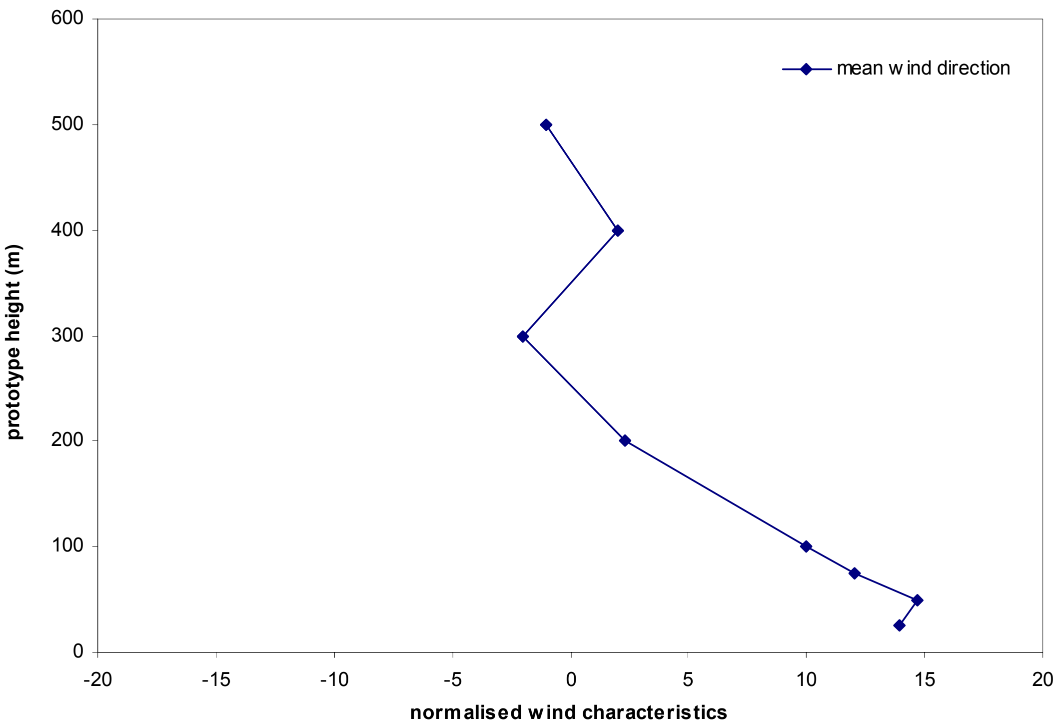

Figure 33b: Mean wind direction, Position 2, 225°

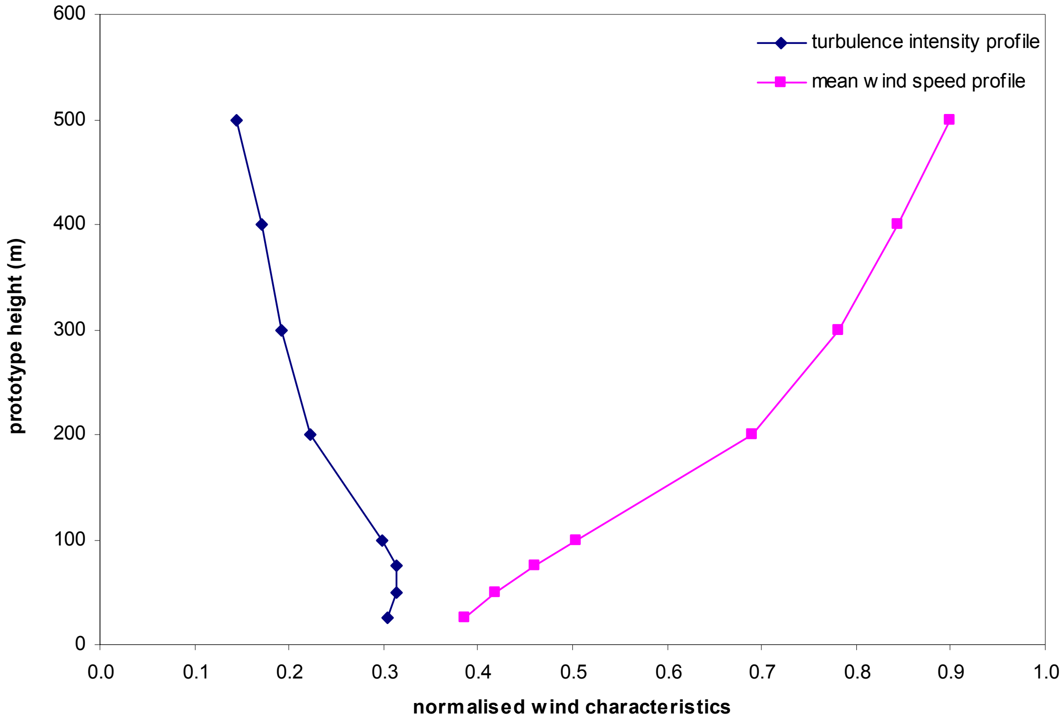

Figure 34a: Wind characteristics, Position 2, 247.5°

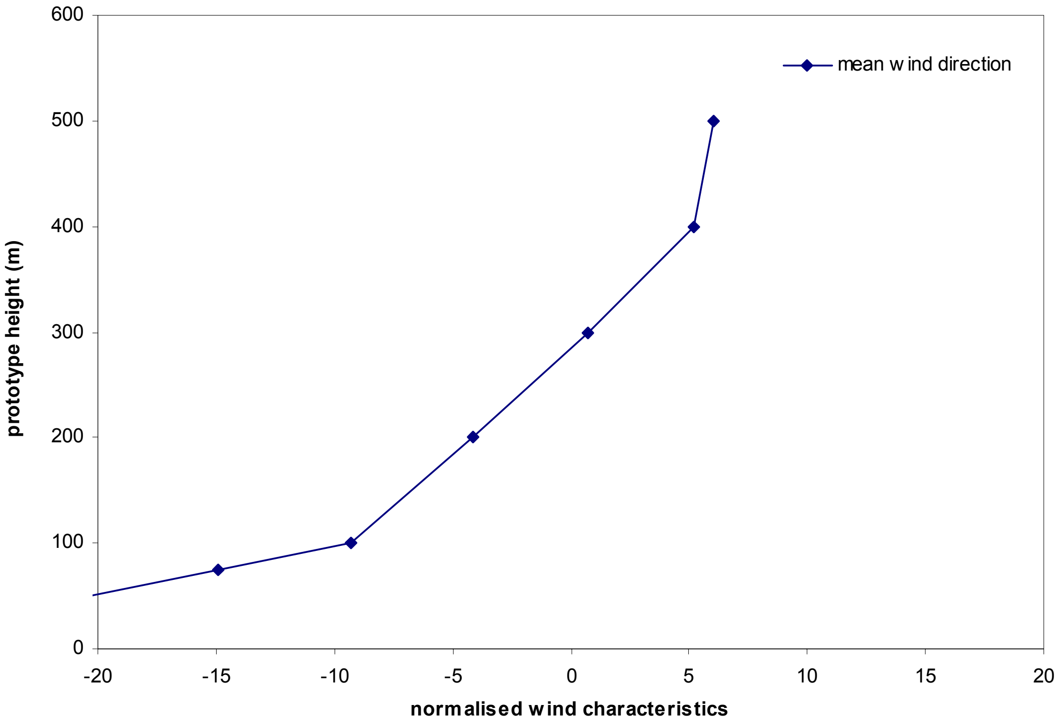

Figure 34b: Mean wind direction, Position 2, 247.5°

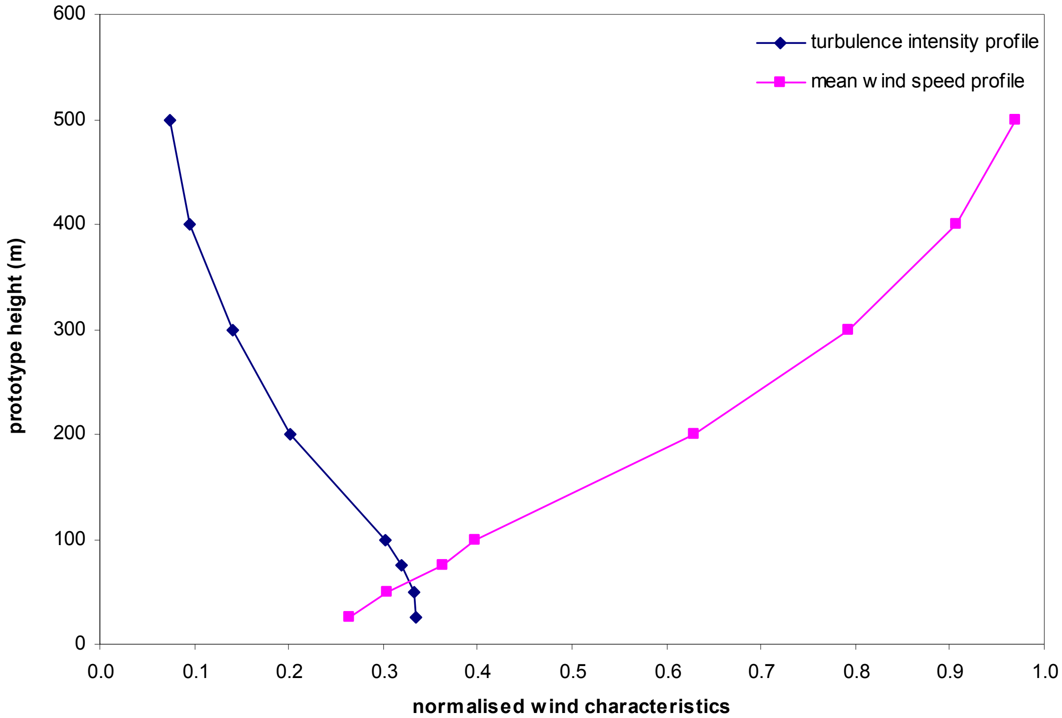

Figure 35a: Wind characteristics, Position 2, 270°

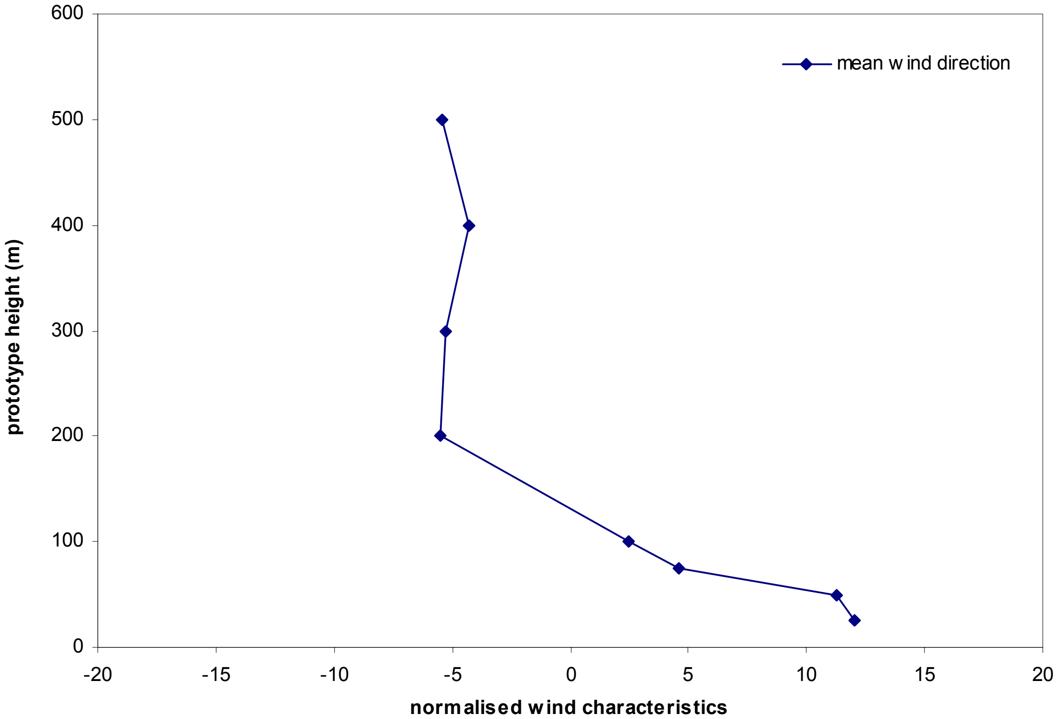

Figure 35b: Mean wind direction, Position 2, 270°

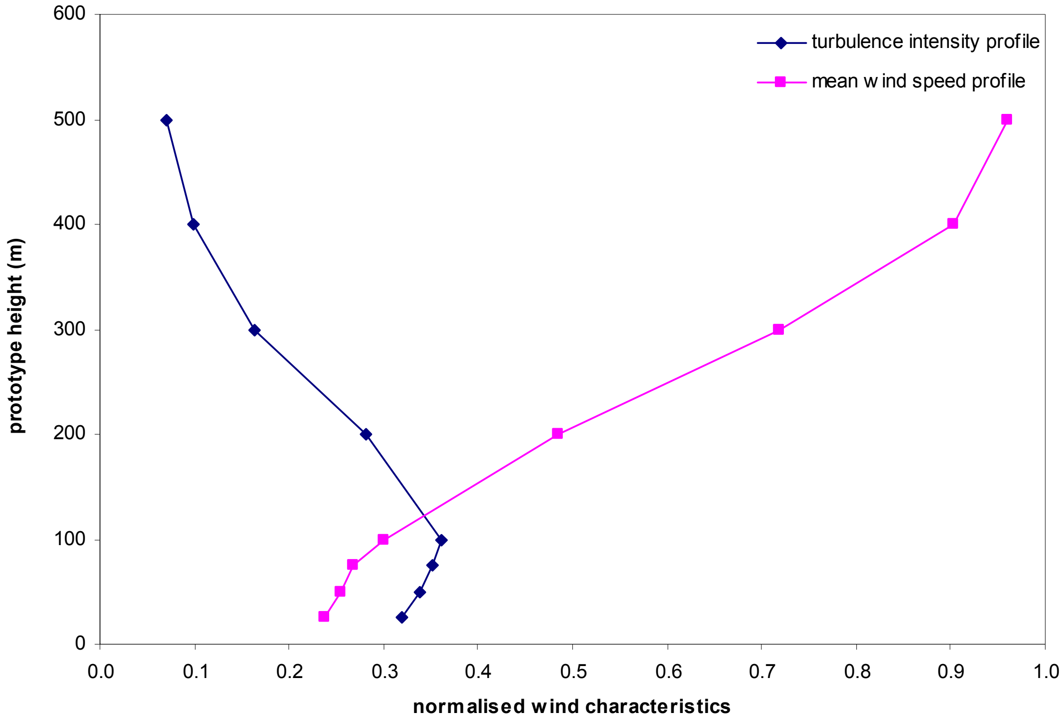

Figure 36a: Wind characteristics, Position 2, 292.5°

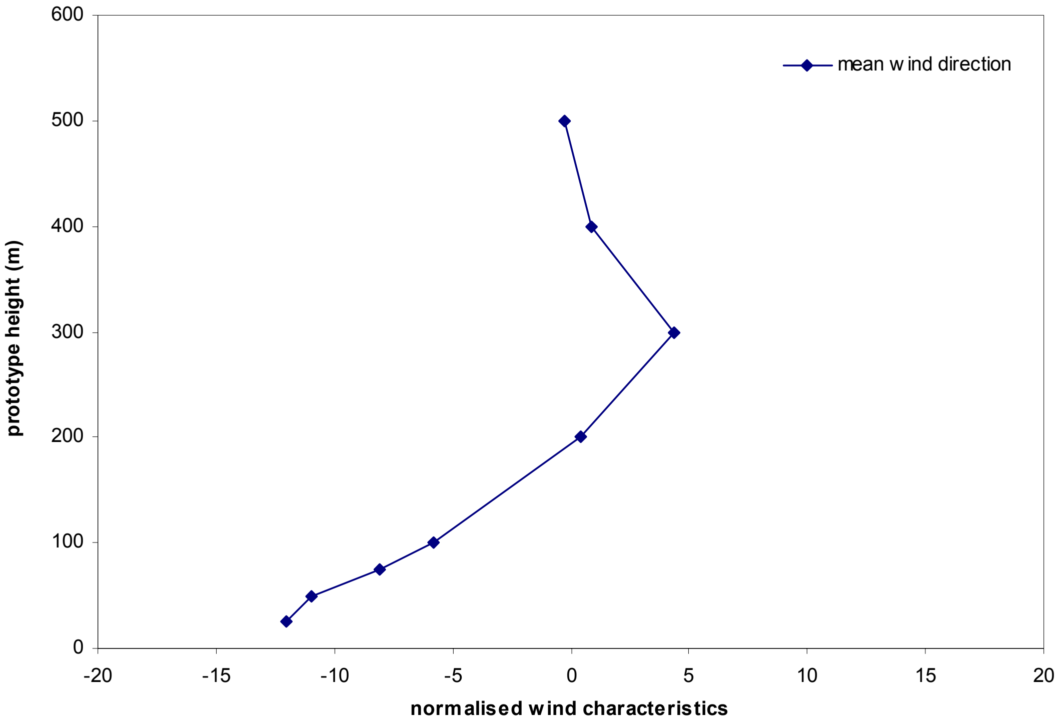

Figure 36b: Mean wind direction, Position 2, 292.5°

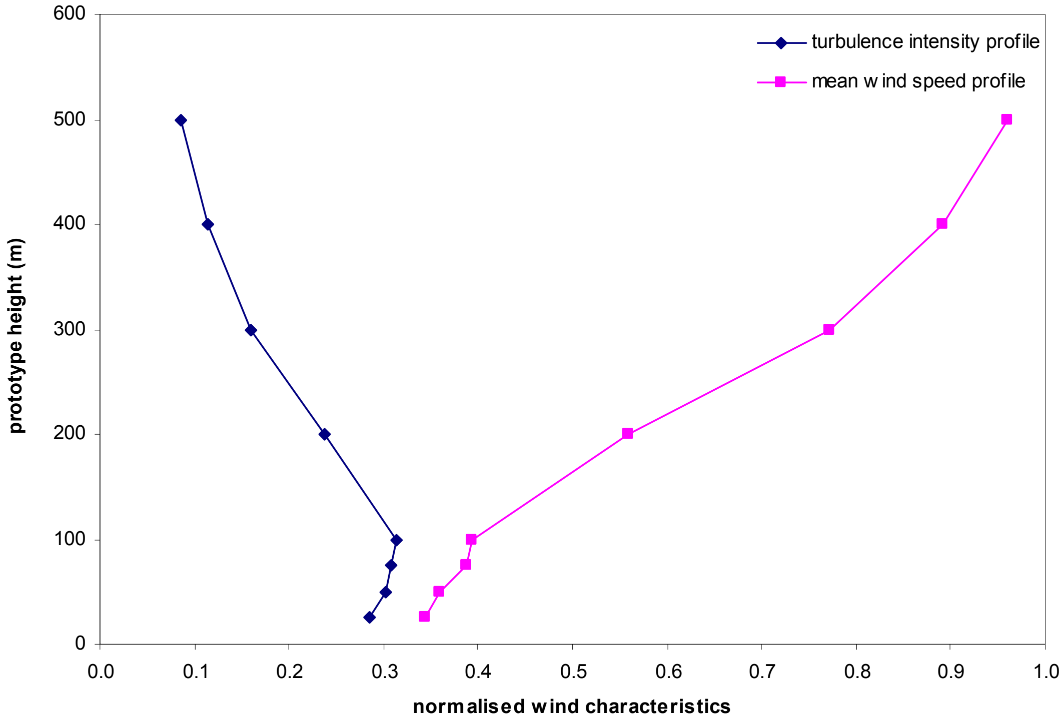

Figure 37a: Wind characteristics, Position 2, 315°

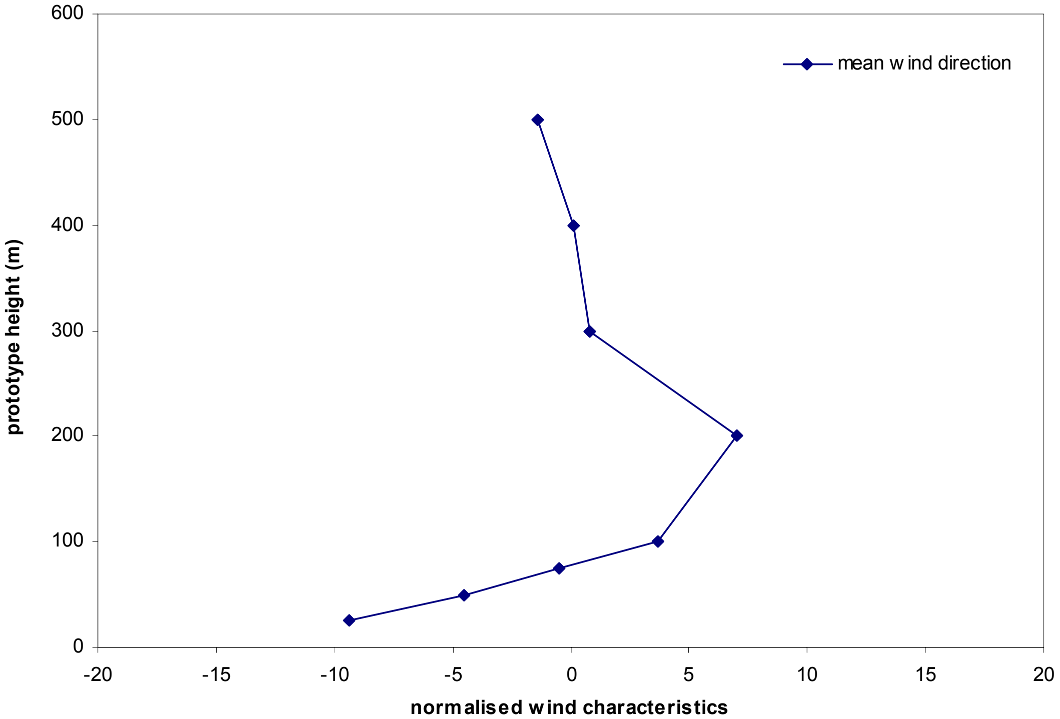

Figure 37b: Mean wind direction, Position 2, 315°

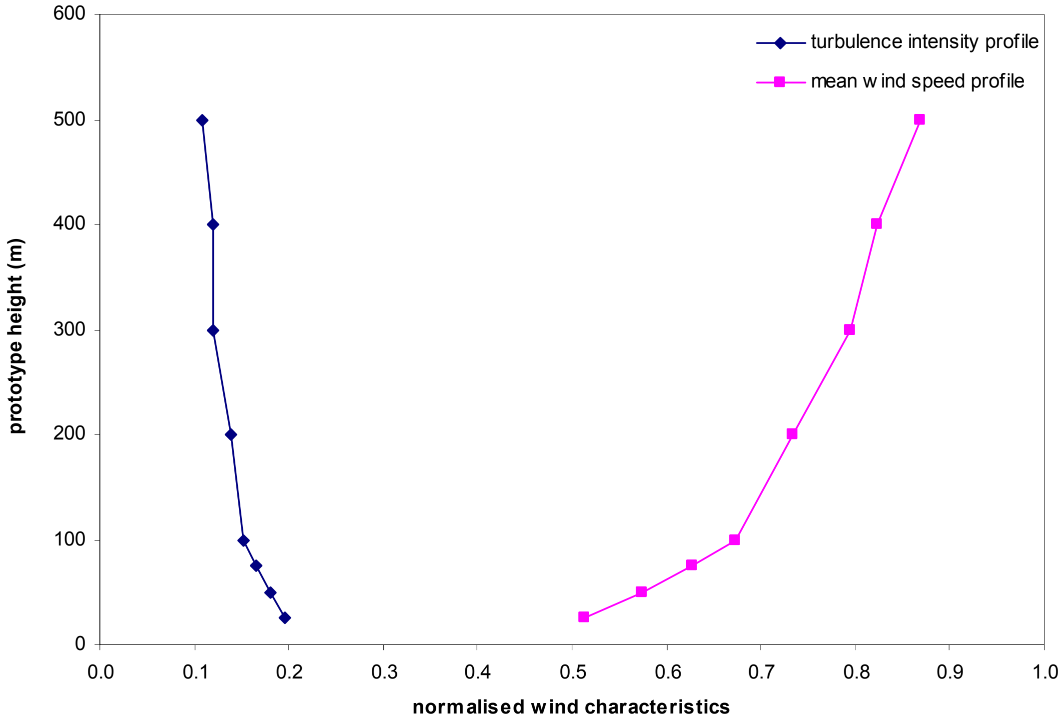

Figure 38a: Wind characteristics, Position 2, 337.5°

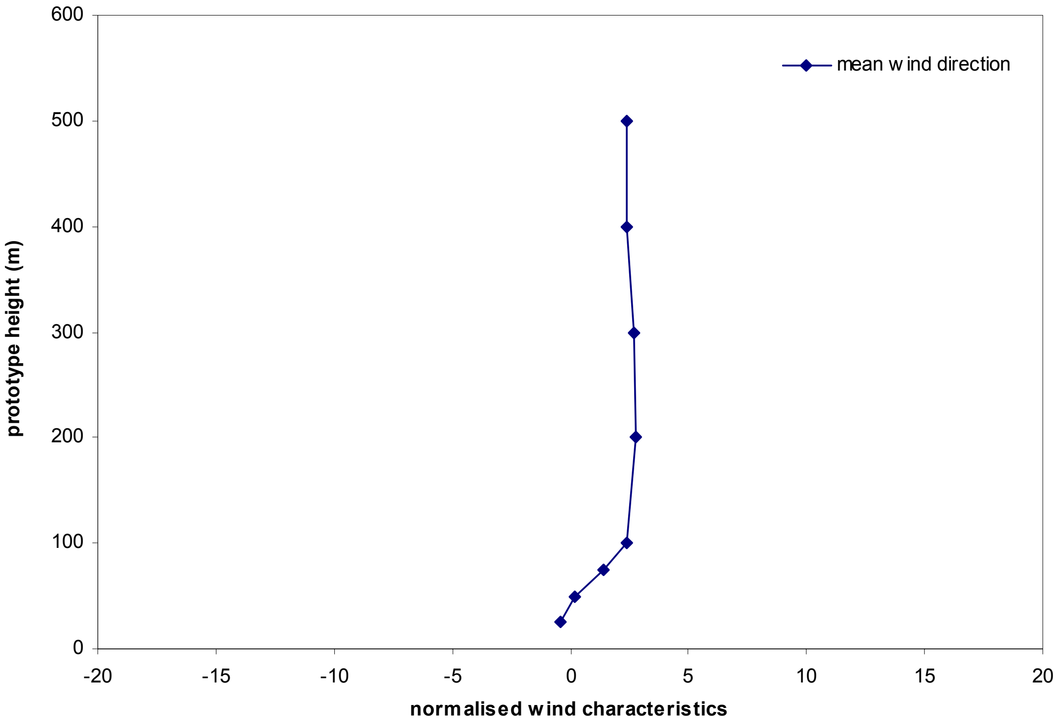

Figure 38b: Mean wind direction, Position 2, 337.5°

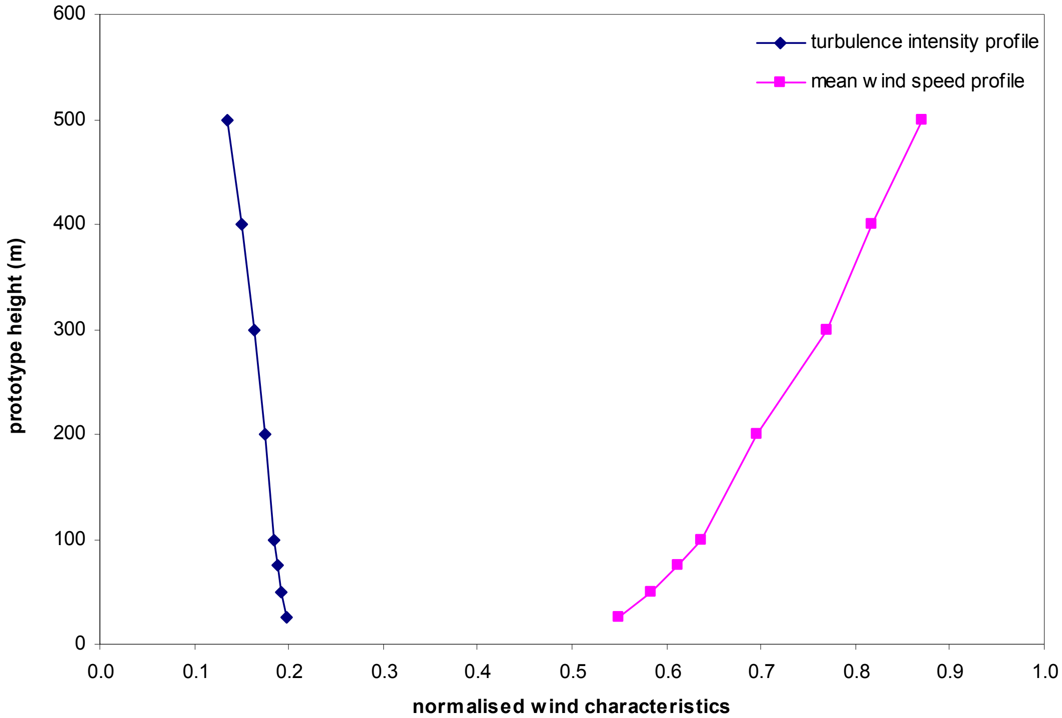

Figure 39a: Wind characteristics, Position 2, 360°

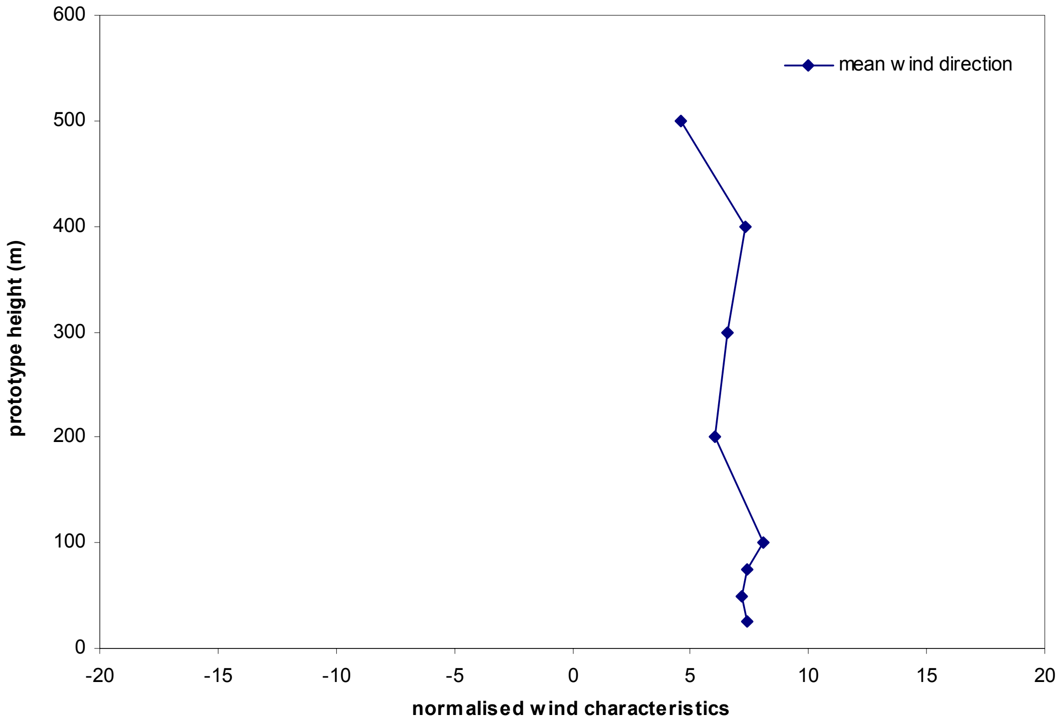

Figure 39b: Mean wind direction, Position 2, 360°

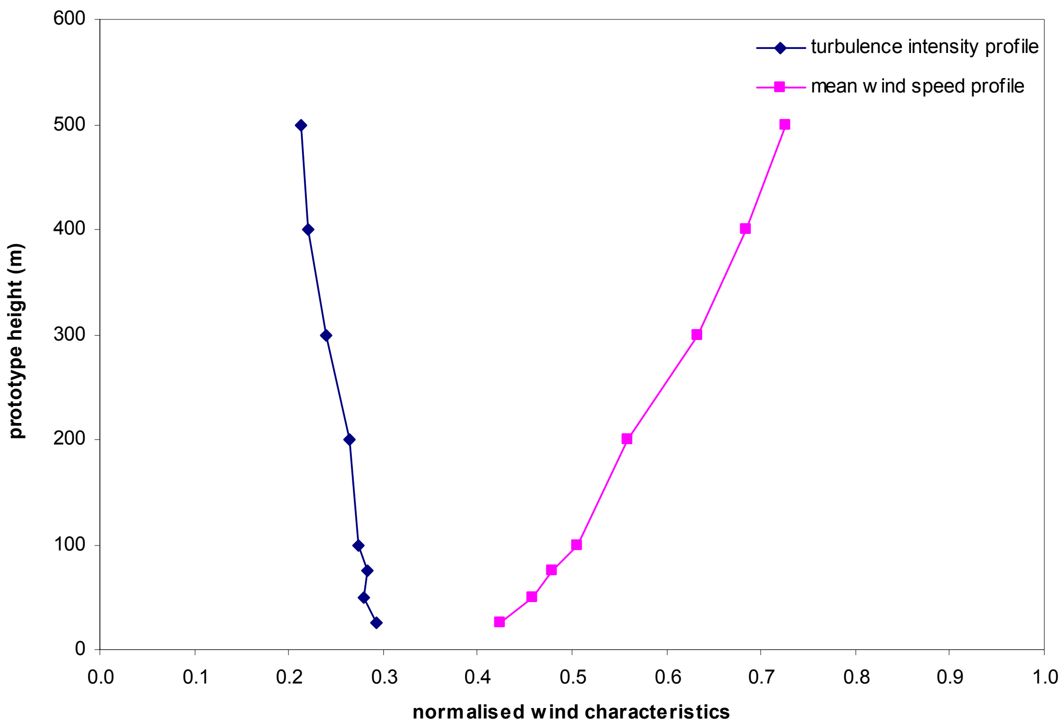

Figure 40a: Wind characteristics, Position 3, 22.5°

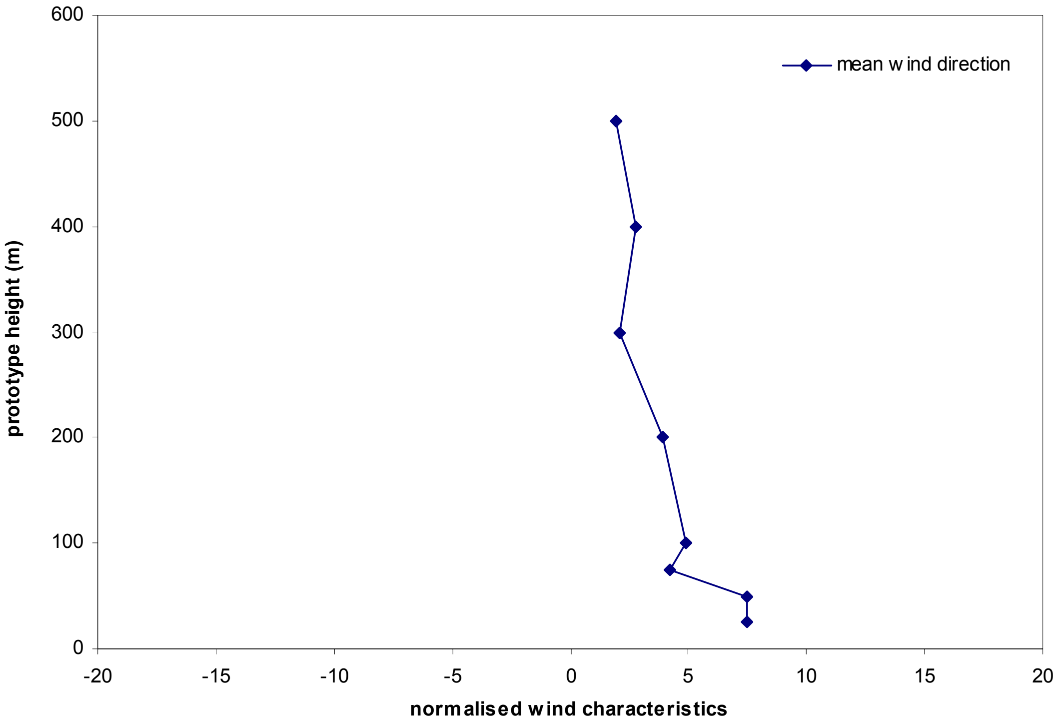

Figure 40b: Mean wind direction, Position 3, 22.5°

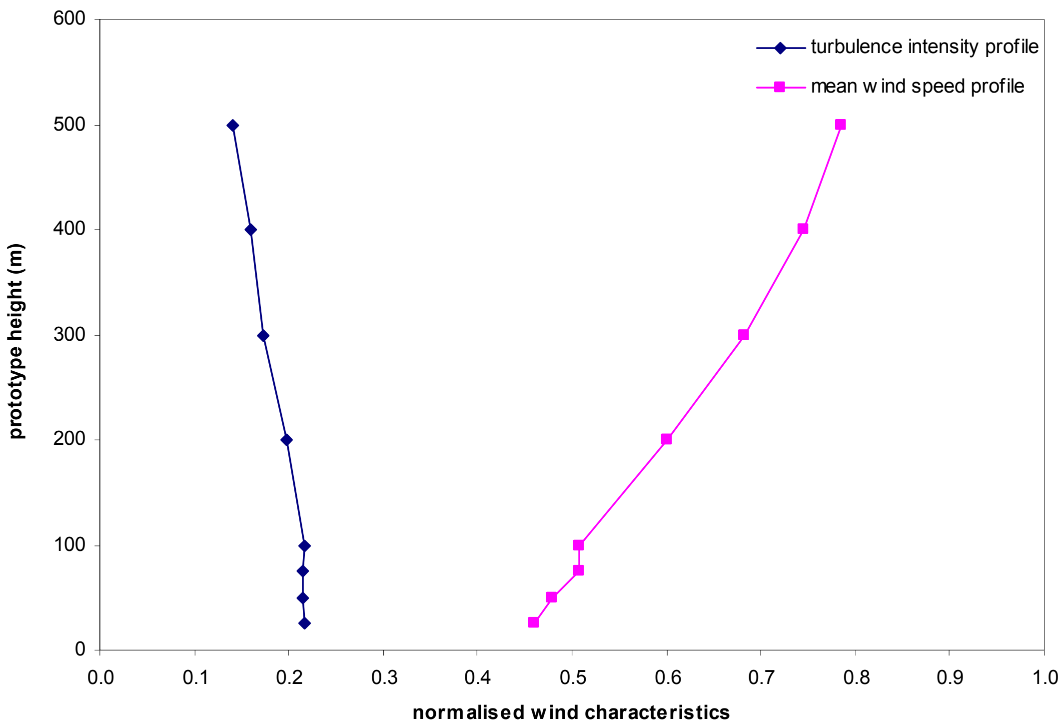

Figure 41a: Wind characteristics, Position 3, 45°

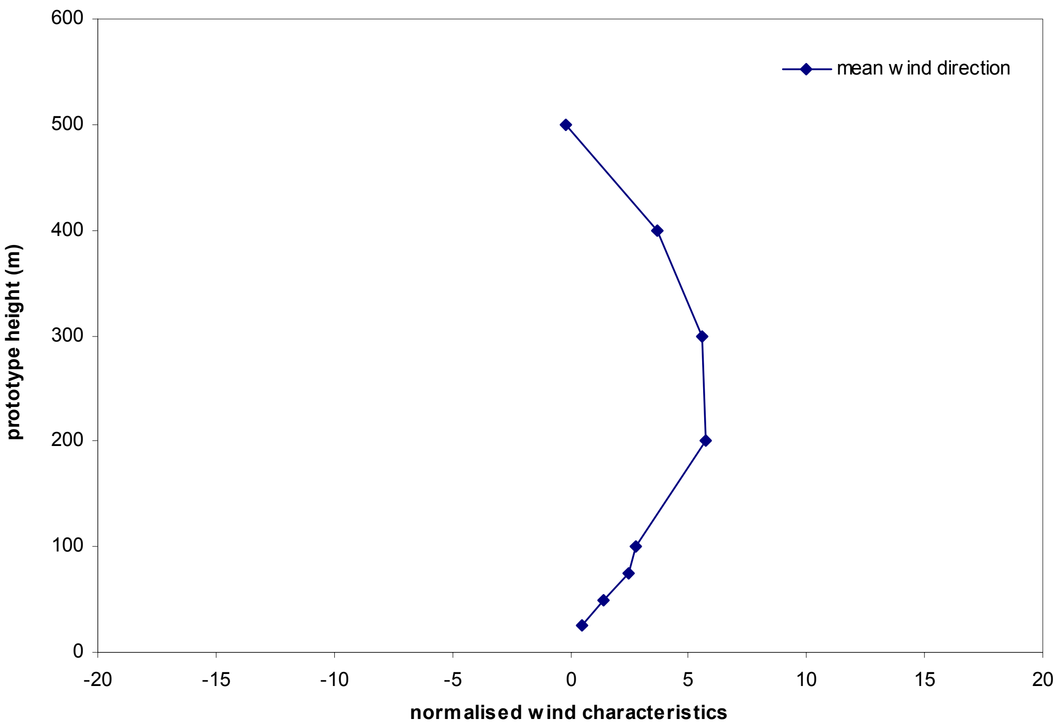

Figure 41b: Mean wind direction, Position 3, 45°

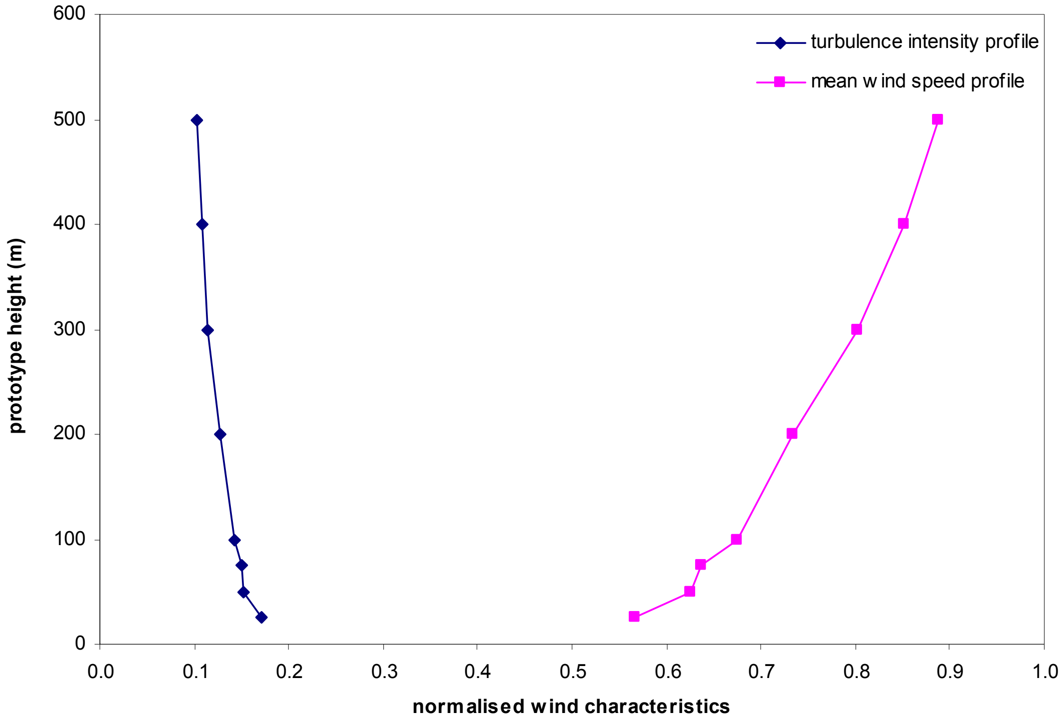

Figure 42a: Wind characteristics, Position 3, 67.5°

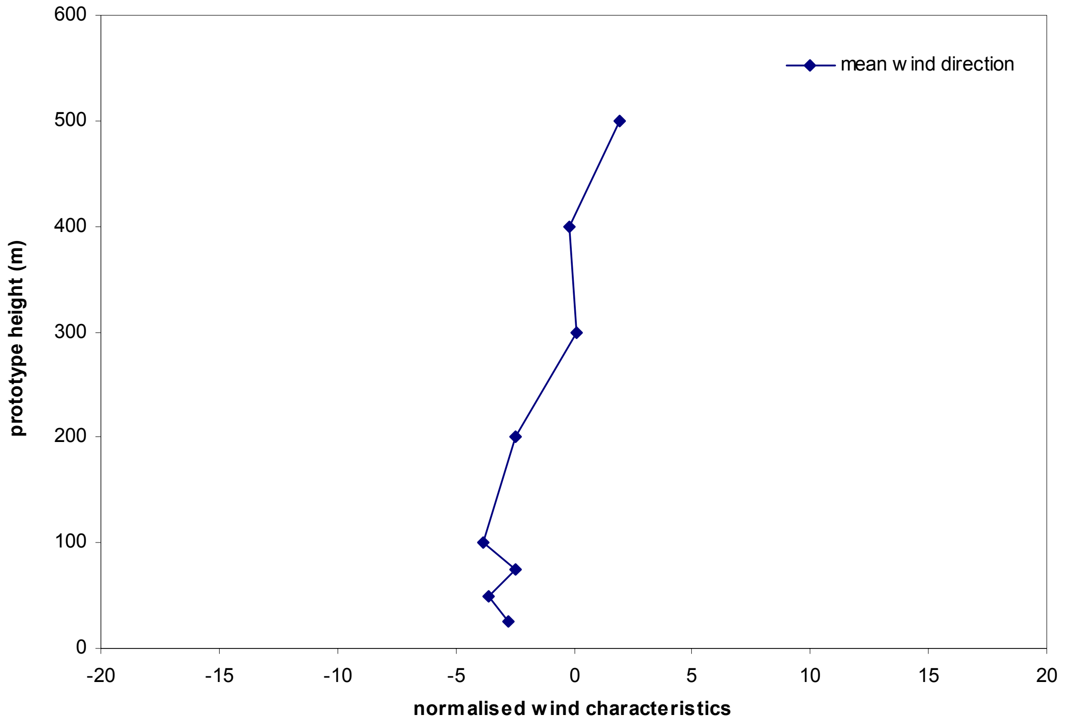

Figure 42b: Mean wind direction, Position 3, 67.5°

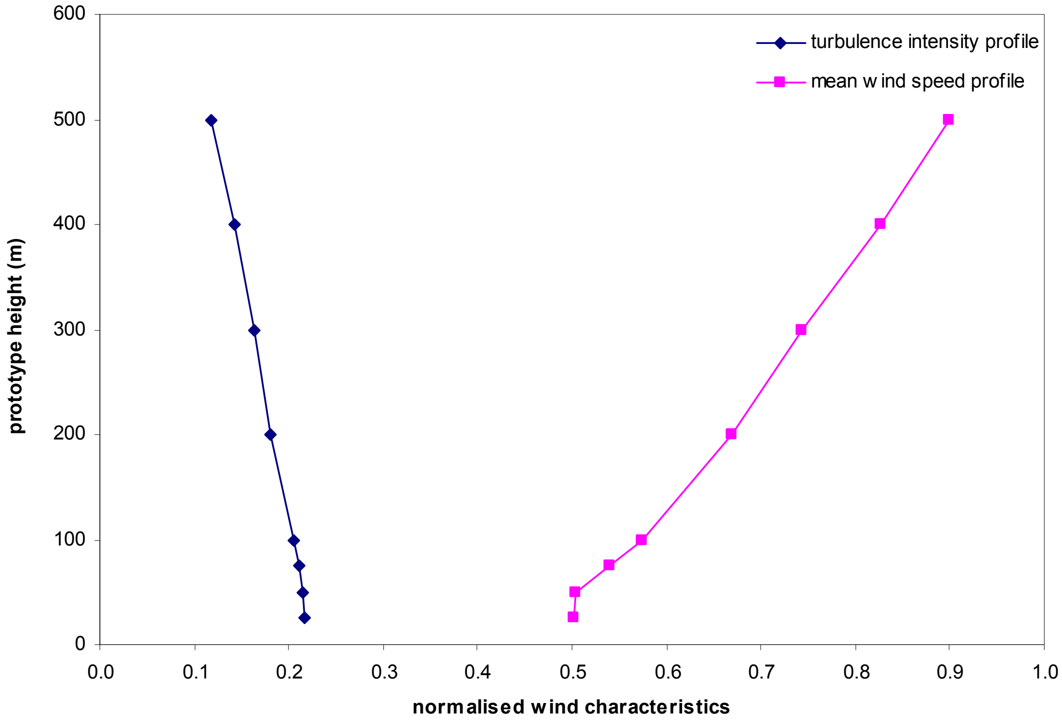

Figure 43a: Wind characteristics, Position 3, 90°

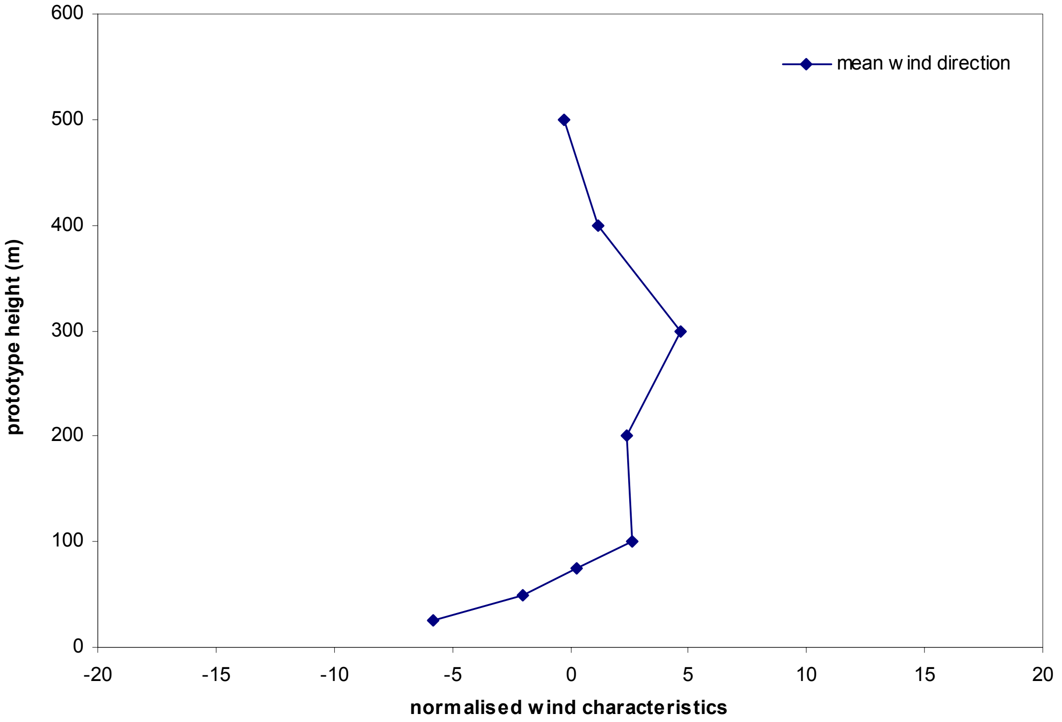

Figure 43b: Mean wind direction, Position 3, 90°

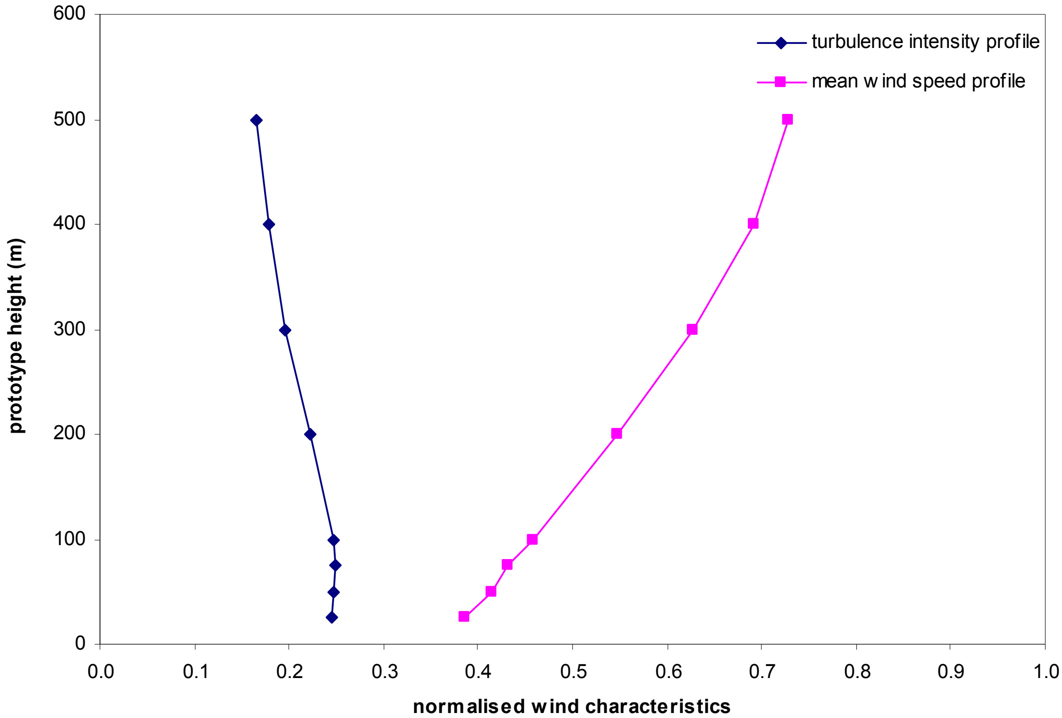

Figure 44a: Wind characteristics, Position 3, 112.5°

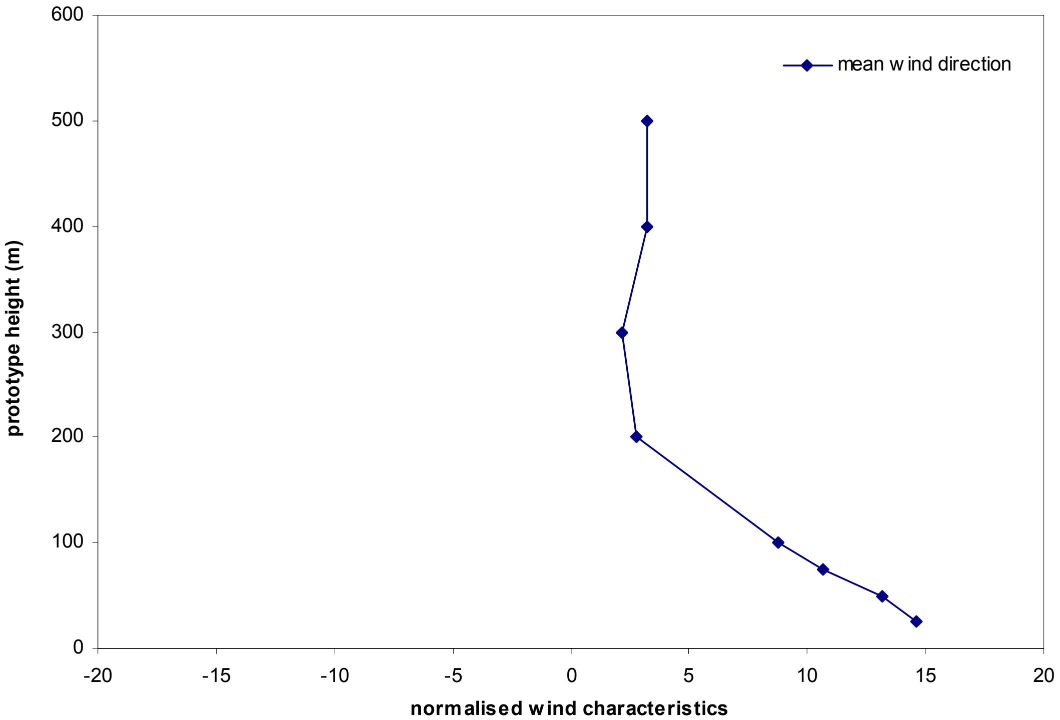

Figure 44b: Mean wind direction, Position 3, 112.5°

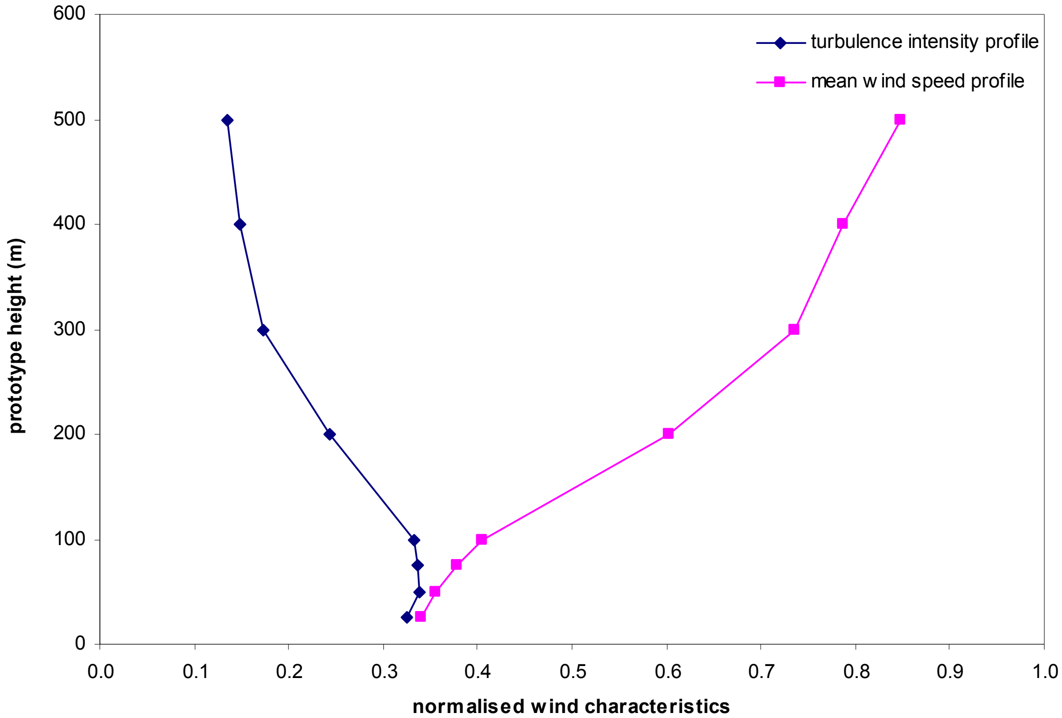

Figure 45a: Wind characteristics, Position 3, 135°

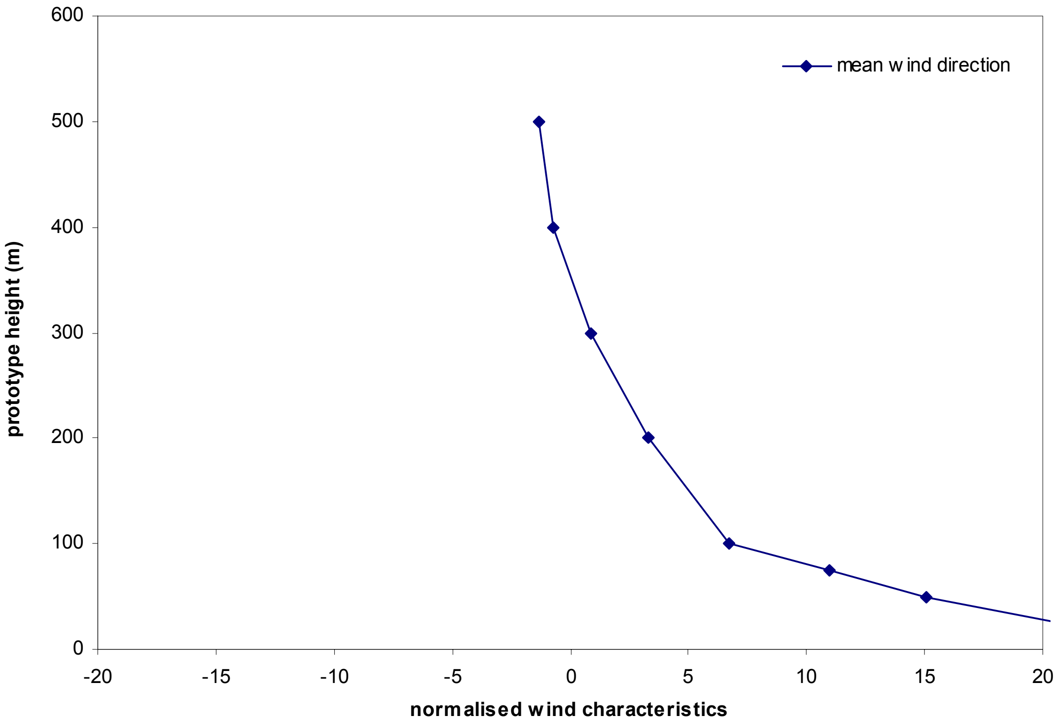

Figure 45b: Mean wind direction, Position 3, 135°

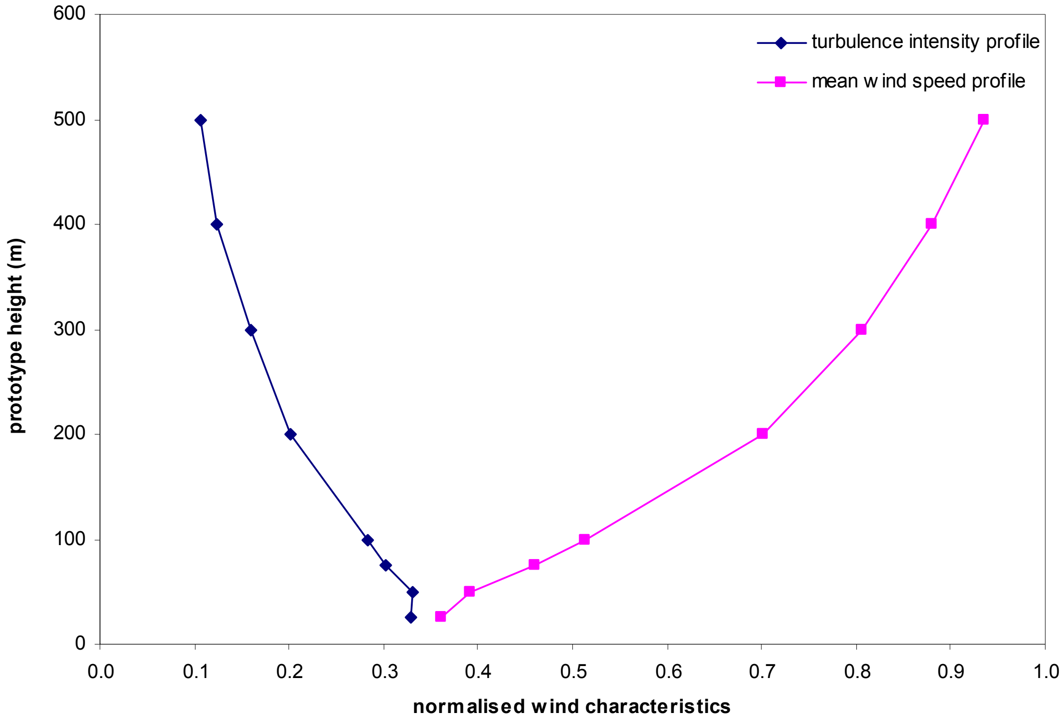

Figure 46a: Wind characteristics, Position 3, 157.5°

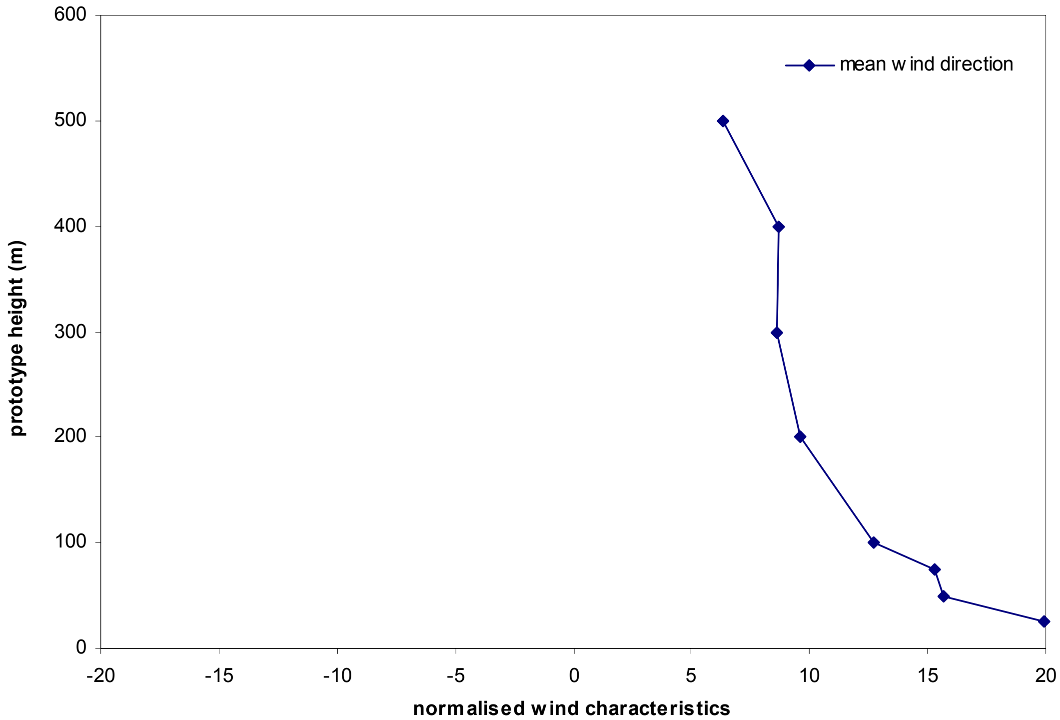

Figure 46b: Mean wind direction, Position 3, 157.5°

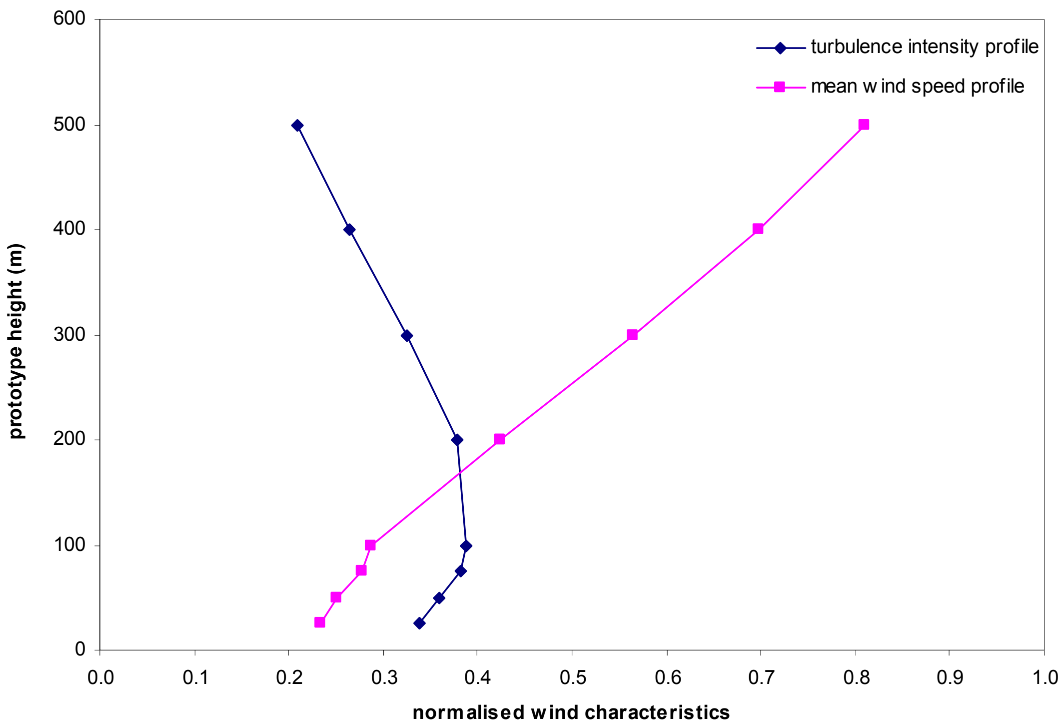

Figure 47a: Wind characteristics, Position 3, 180°

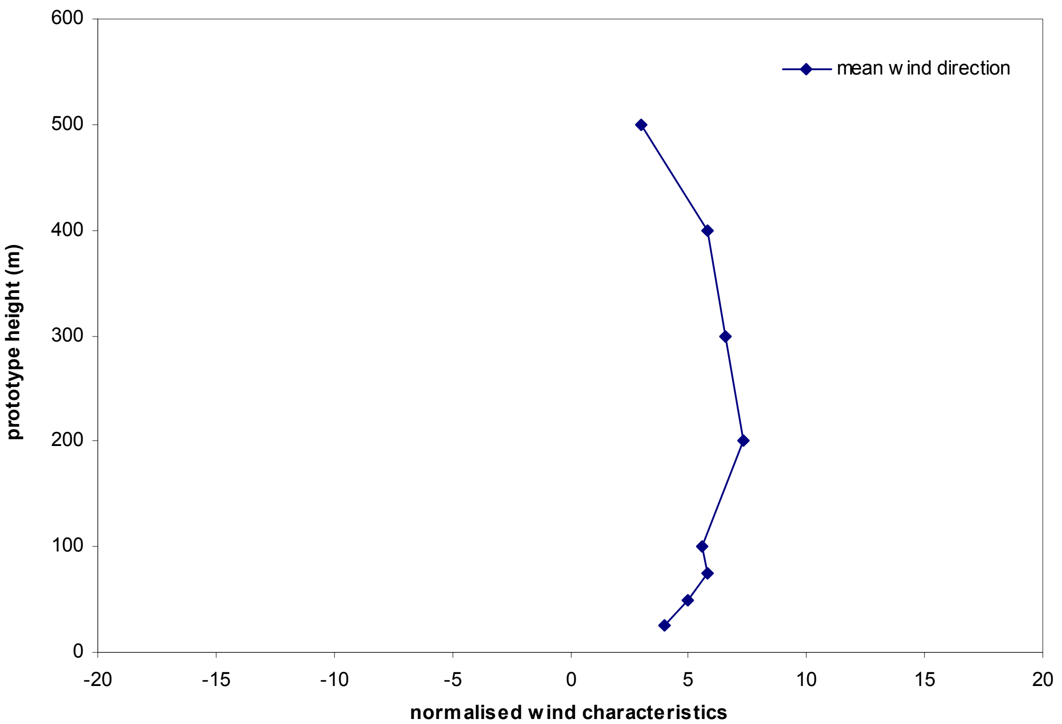

Figure 47b: Mean wind direction, Position 3, 180°

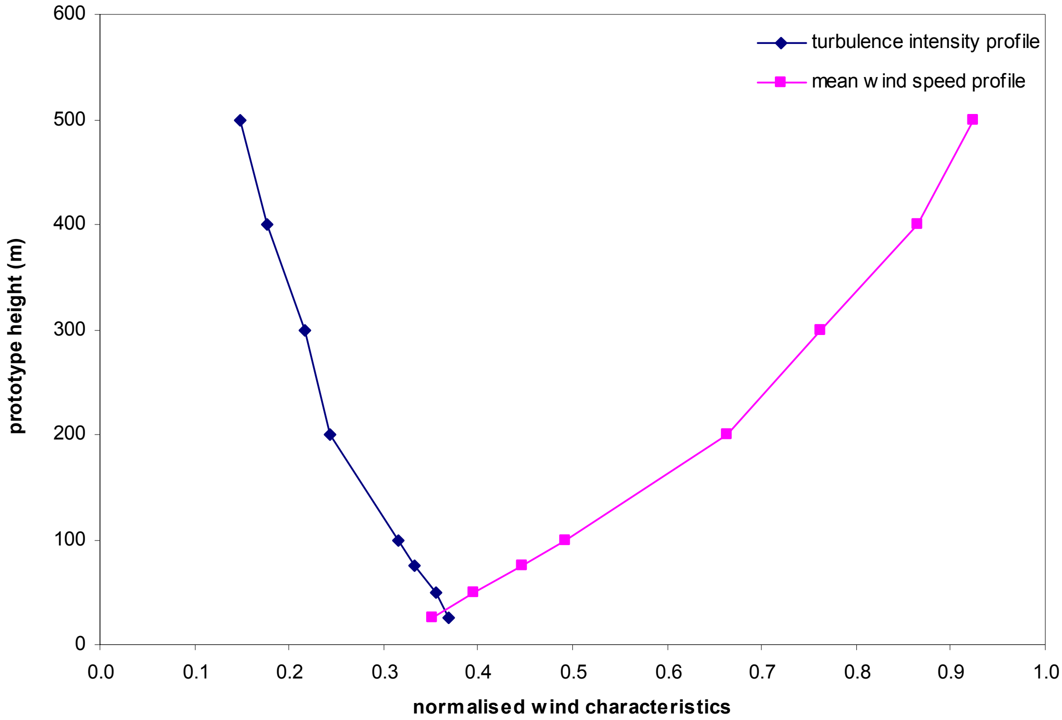

Figure 48a: Wind characteristics, Position 3, 202.5°

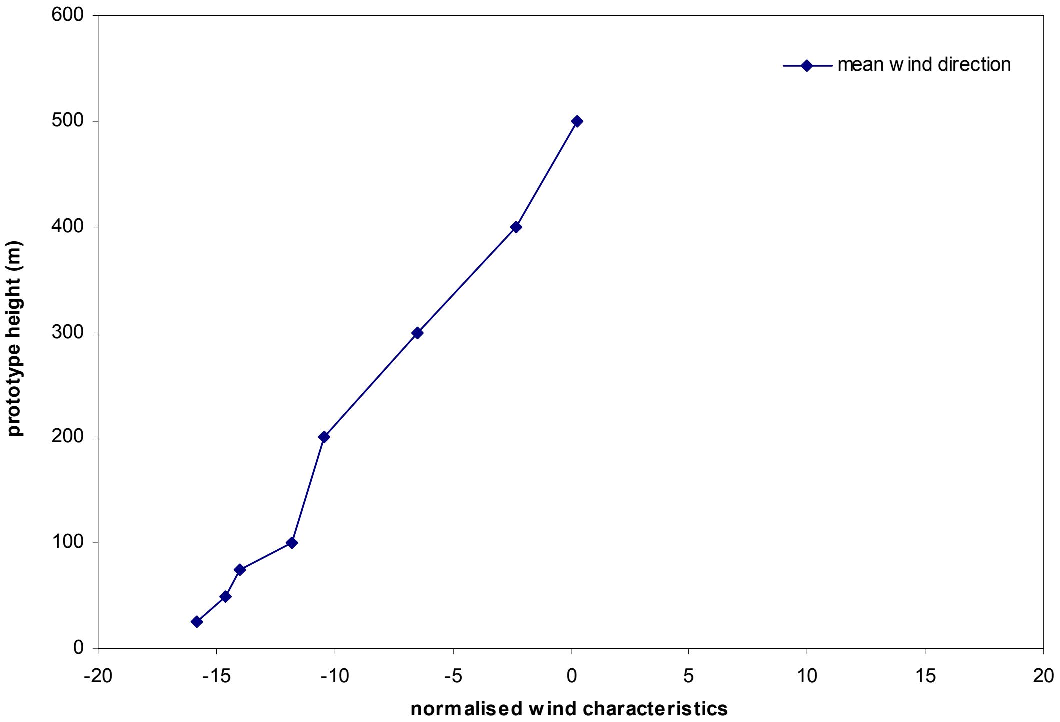

Figure 48b: Mean wind direction, Position 3, 202.5°

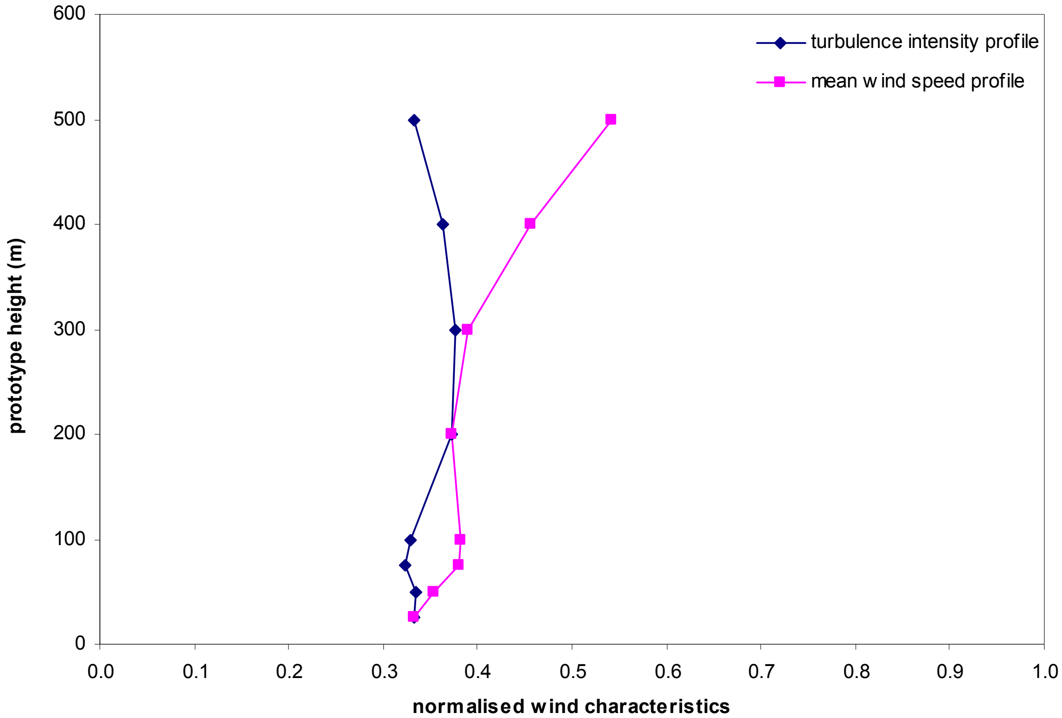

Figure 49a: Wind characteristics, Position 3, 225°

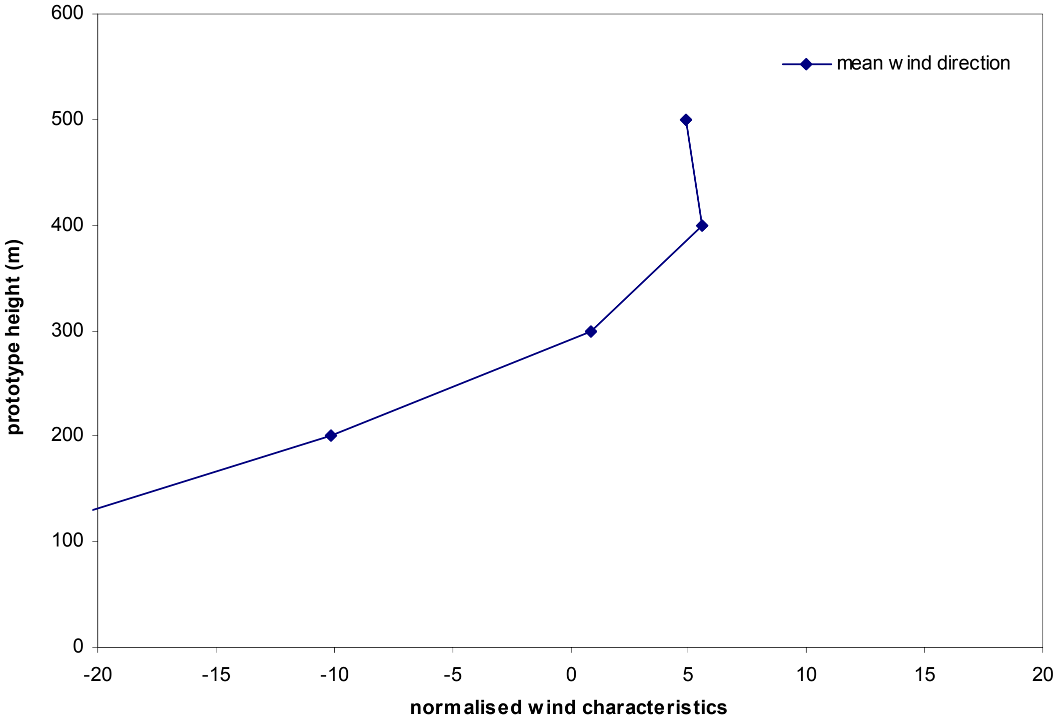

Figure 49b: Mean wind direction, Position 3, 225°

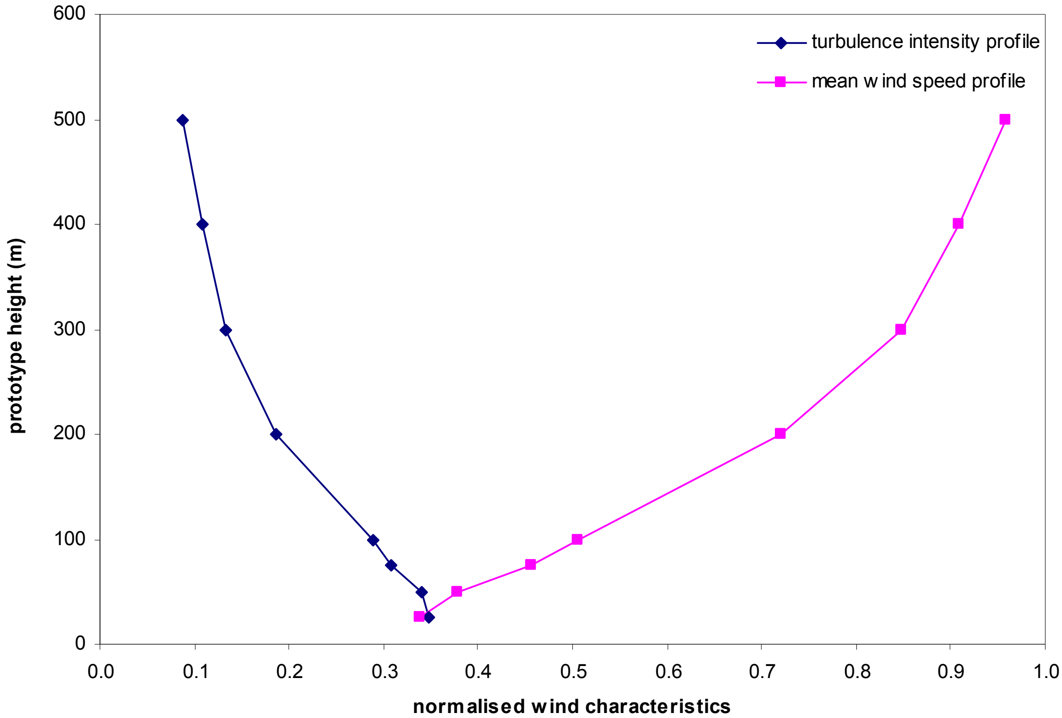

Figure 50a: Wind characteristics, Position 3, 247.5°

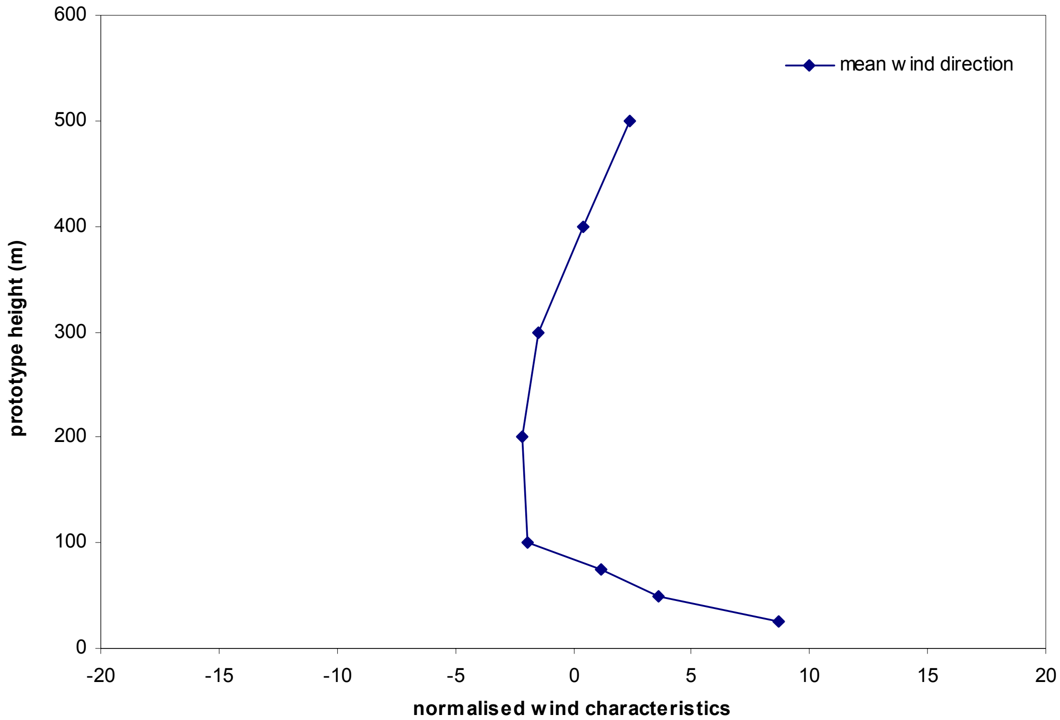

Figure 50b: Mean wind direction, Position 3, 247.5°

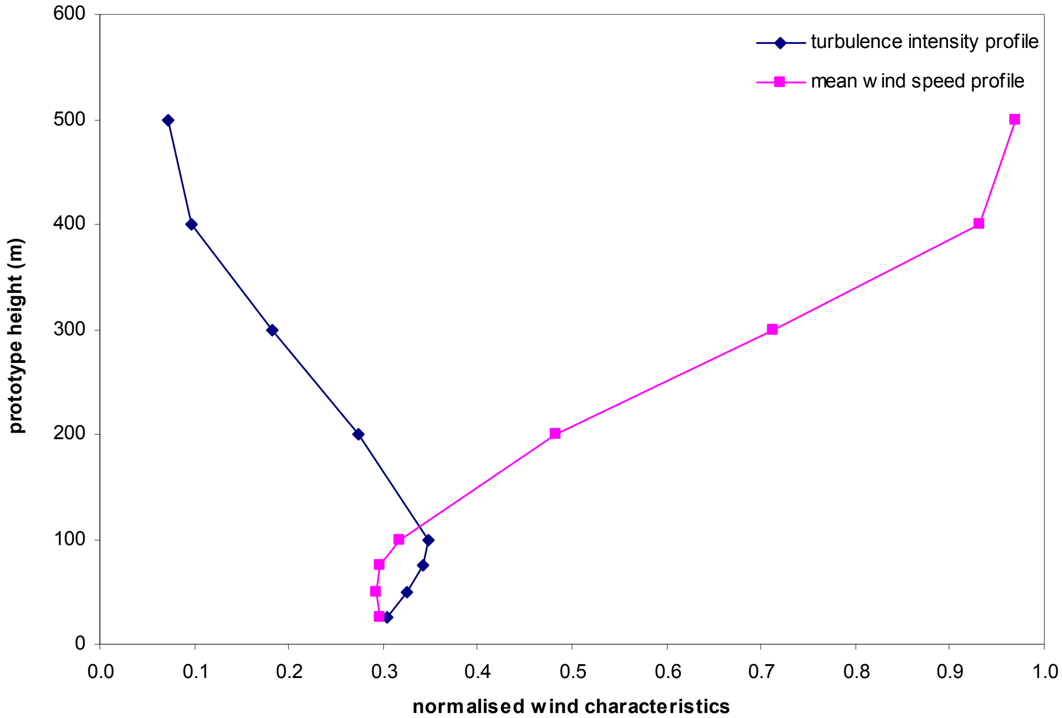

Figure 51a: Wind characteristics, Position 3, 270°

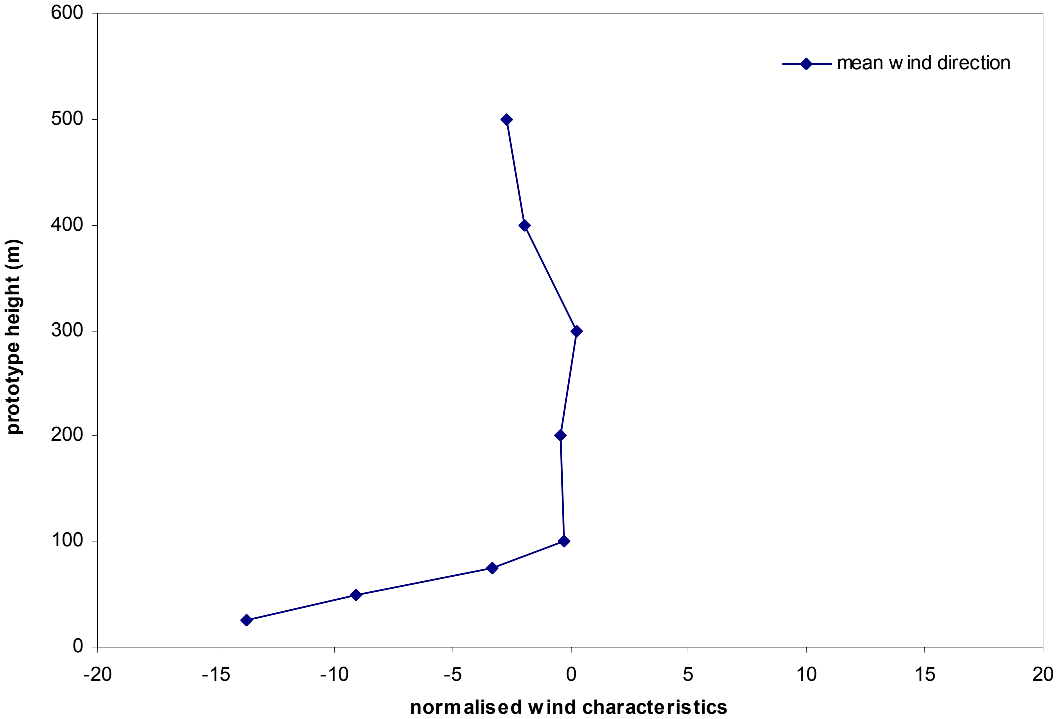

Figure 51b: Mean wind direction, Position 3, 270°

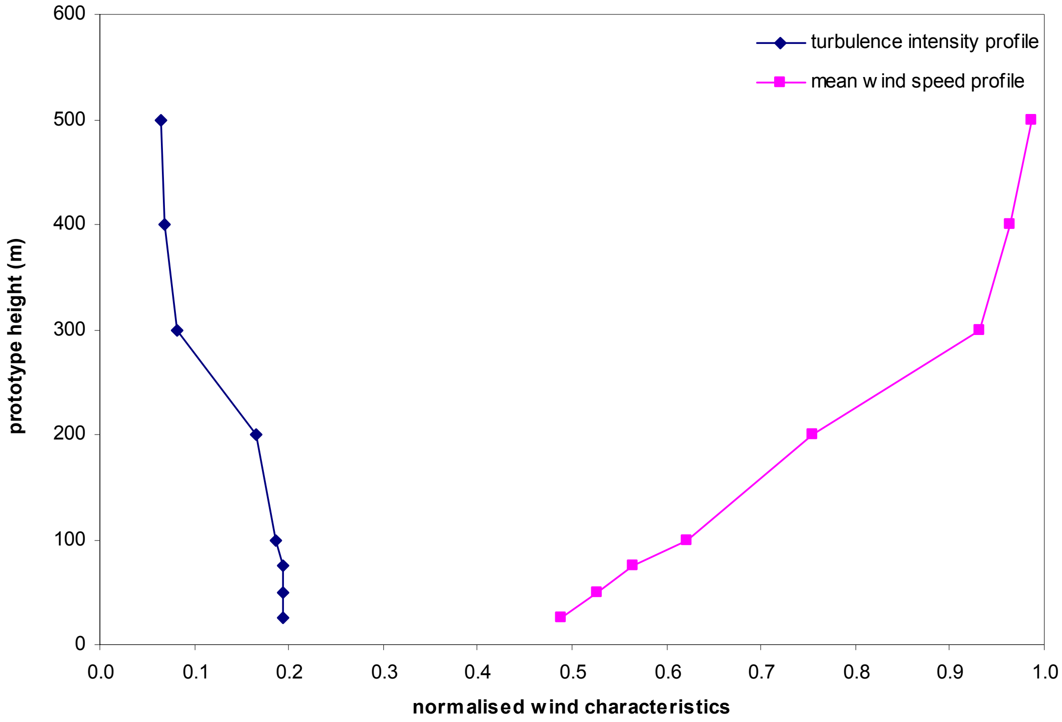

Figure 52a: Wind characteristics, Position 3, 292.5°

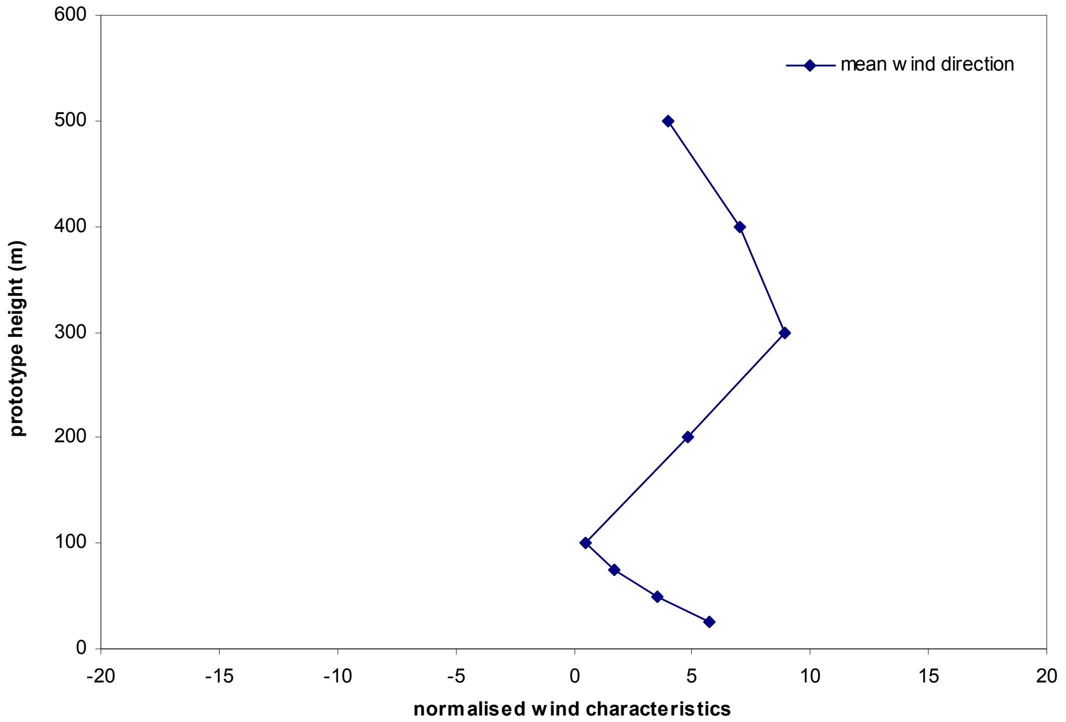

Figure 52b: Mean wind direction, Position 3, 292.5°

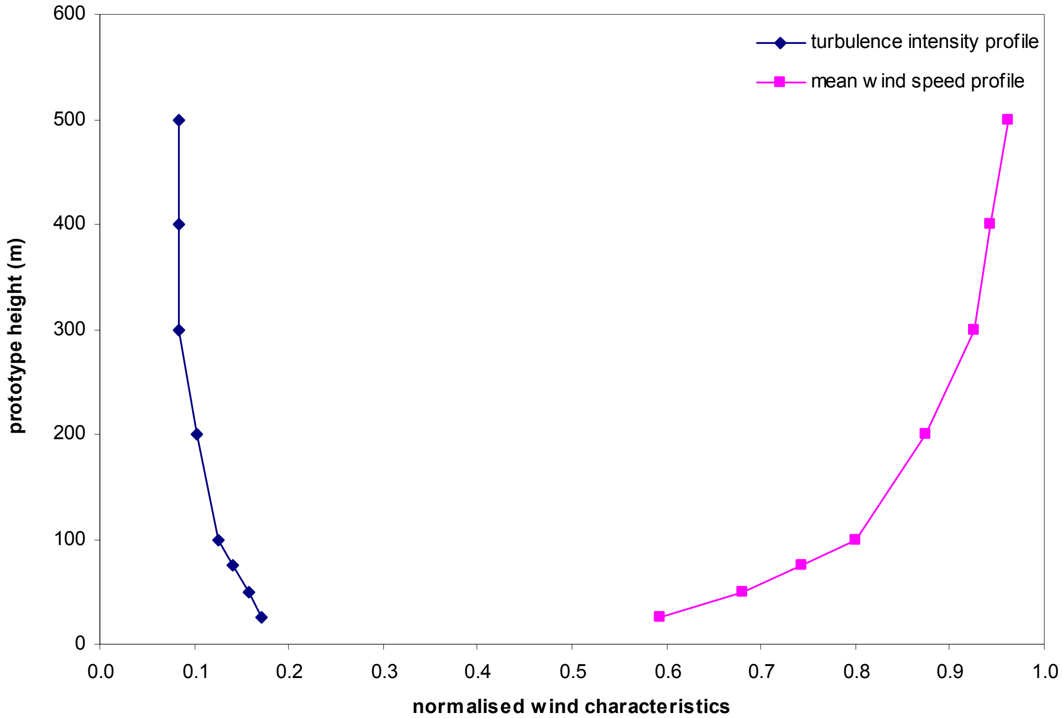

Figure 53a: Wind characteristics, Position 3, 315°

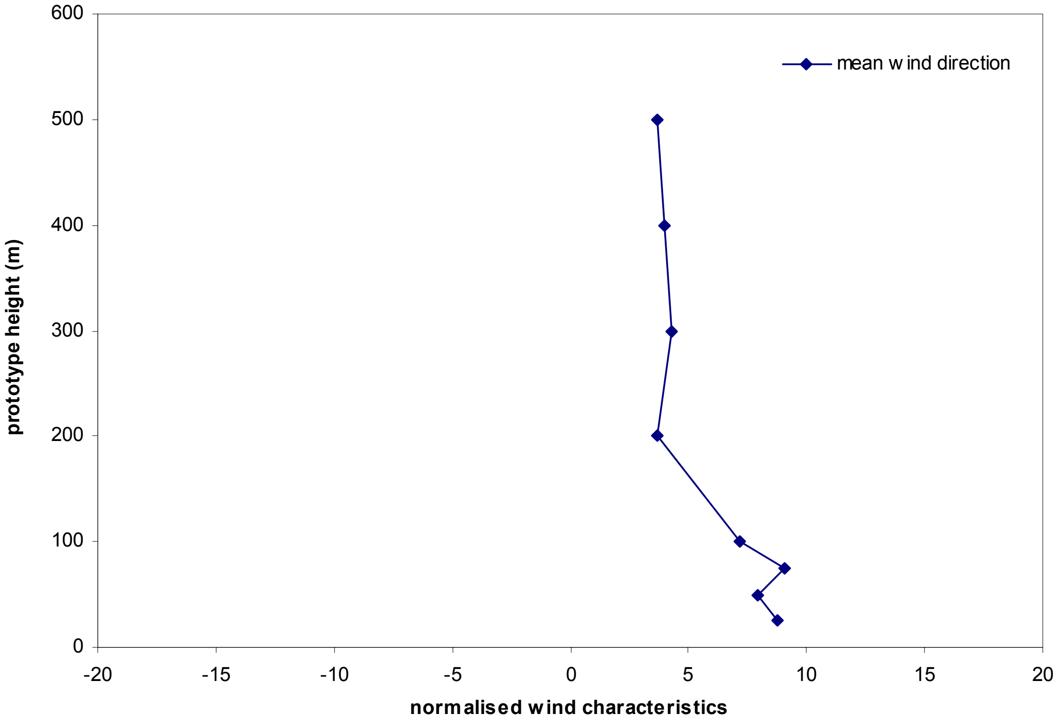

Figure 53b: Mean wind direction, Position 3, 315°

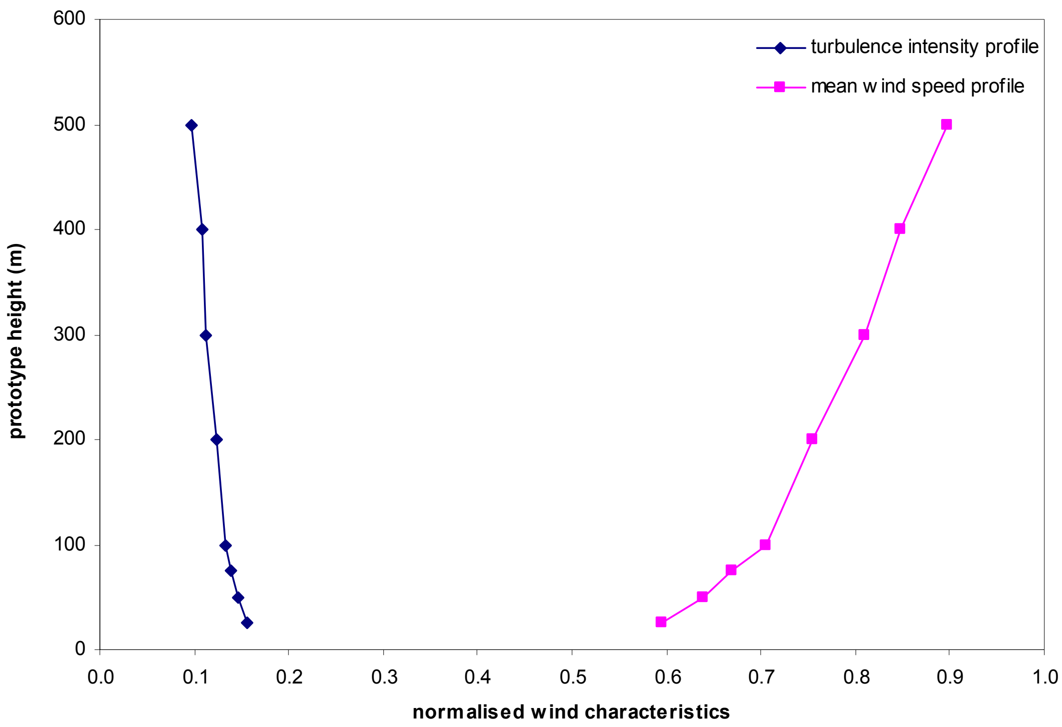

Figure 54a: Wind characteristics, Position 3, 337.5°

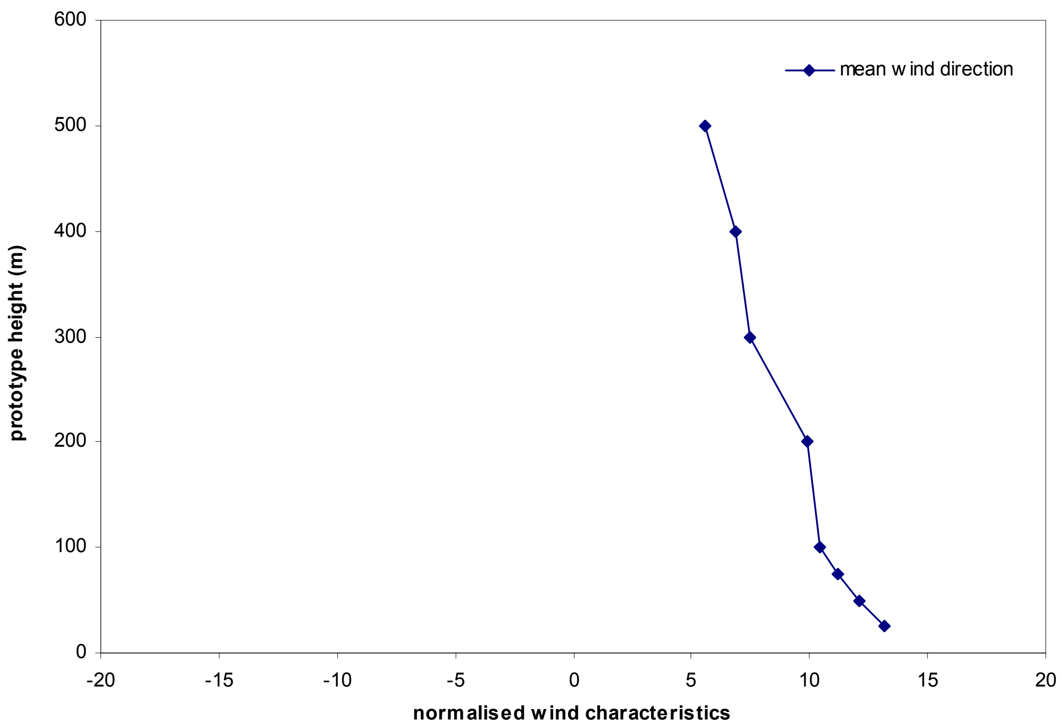

Figure 54b: Mean wind direction, Position 3, 337.5°

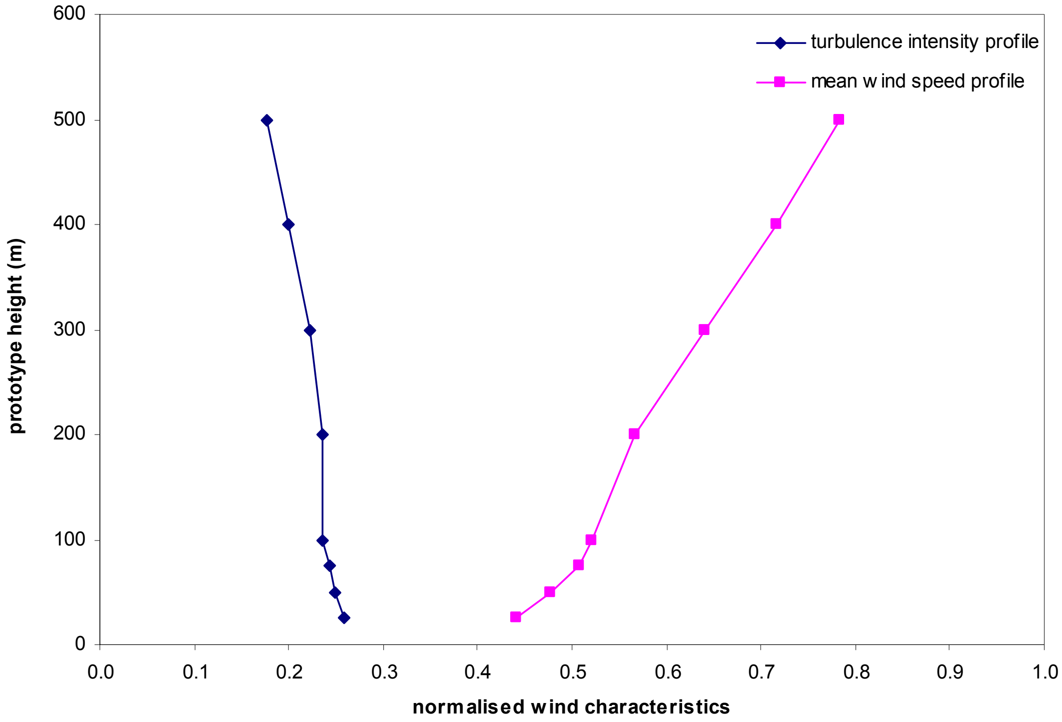

Figure 55a: Wind characteristics, Position 3, 360°

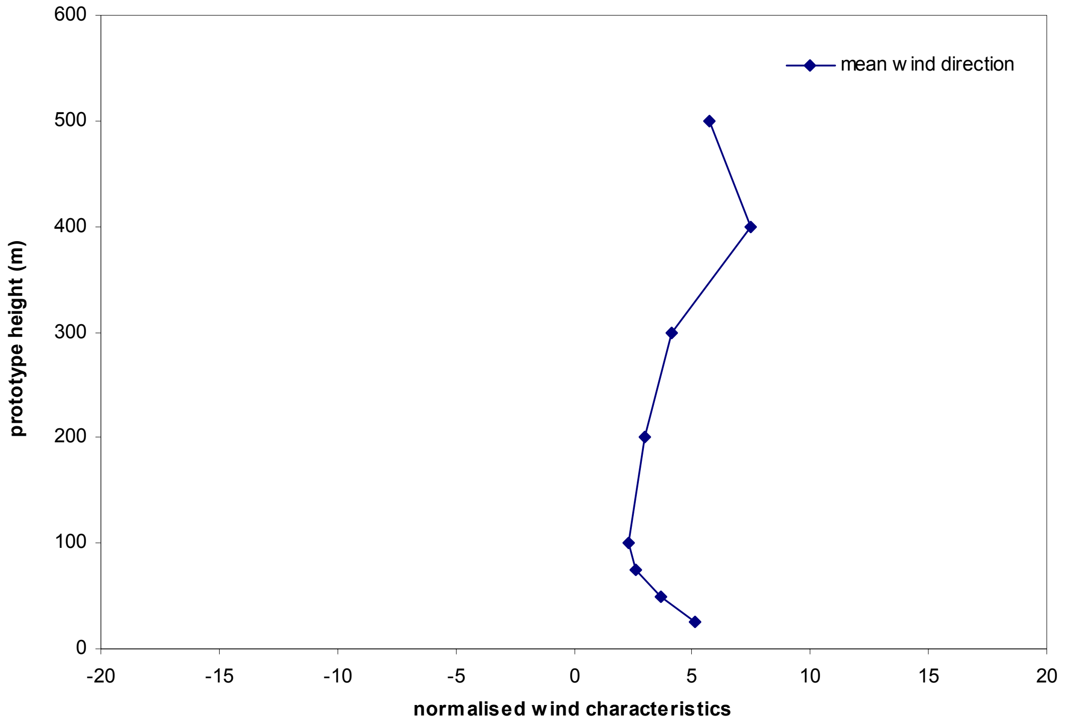

Figure 55b: Mean wind direction, Position 3, 360°

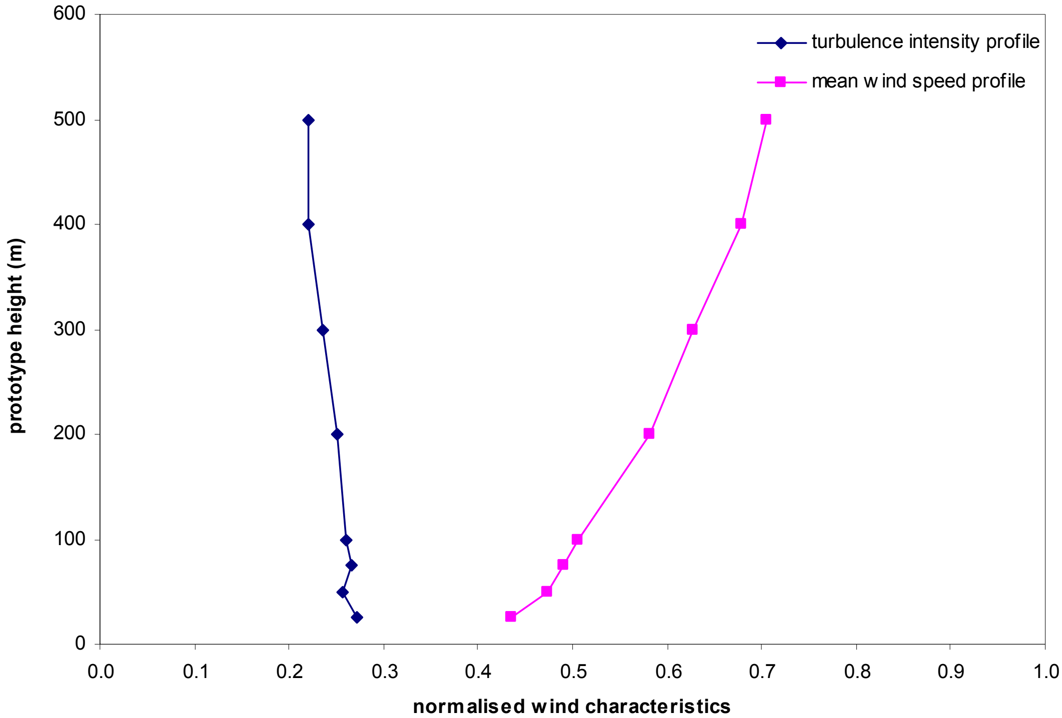

Figure 56a: Wind characteristics, Position 4, 22.5°

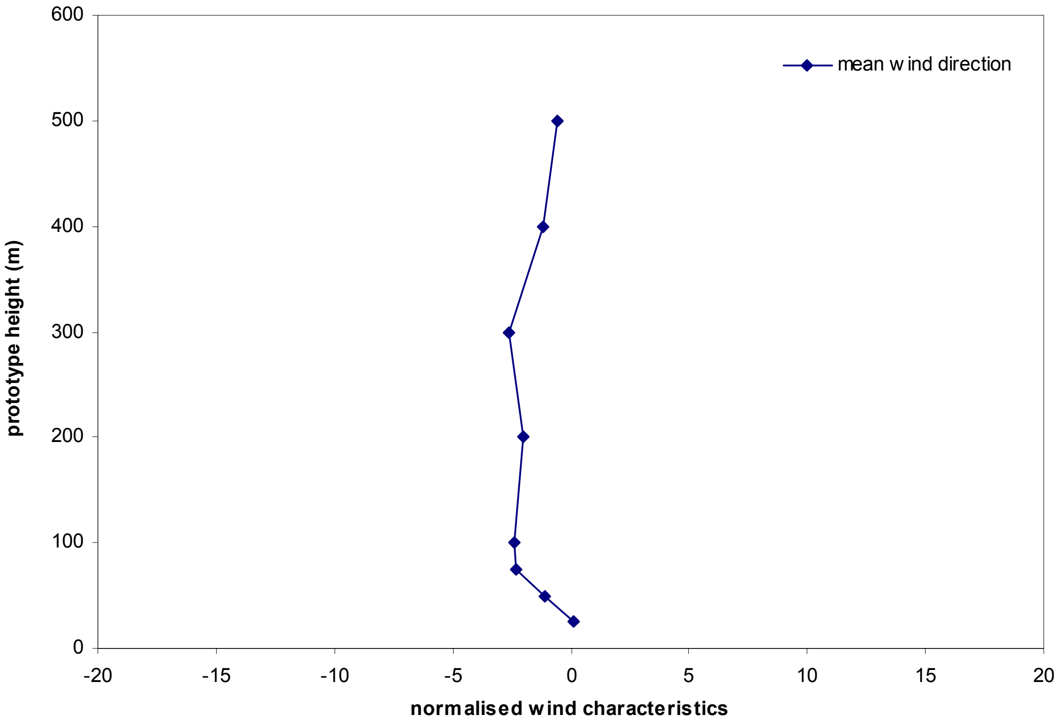

Figure 56b: Mean wind direction, Position 4, 22.5°

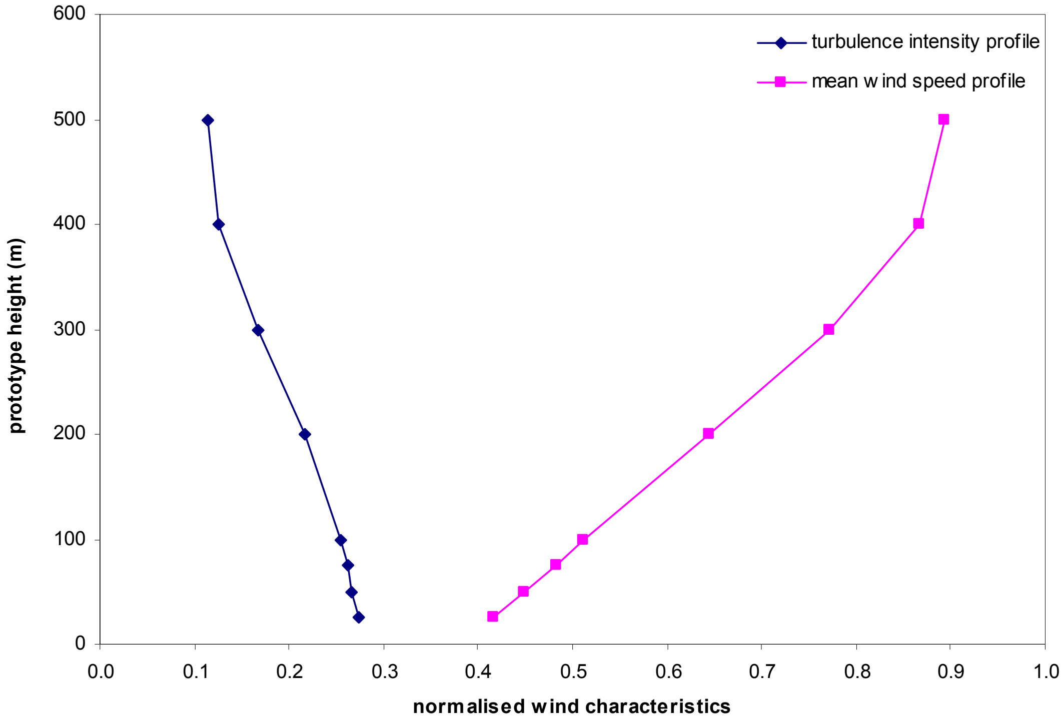

Figure 57a: Wind characteristics, Position 4, 45°

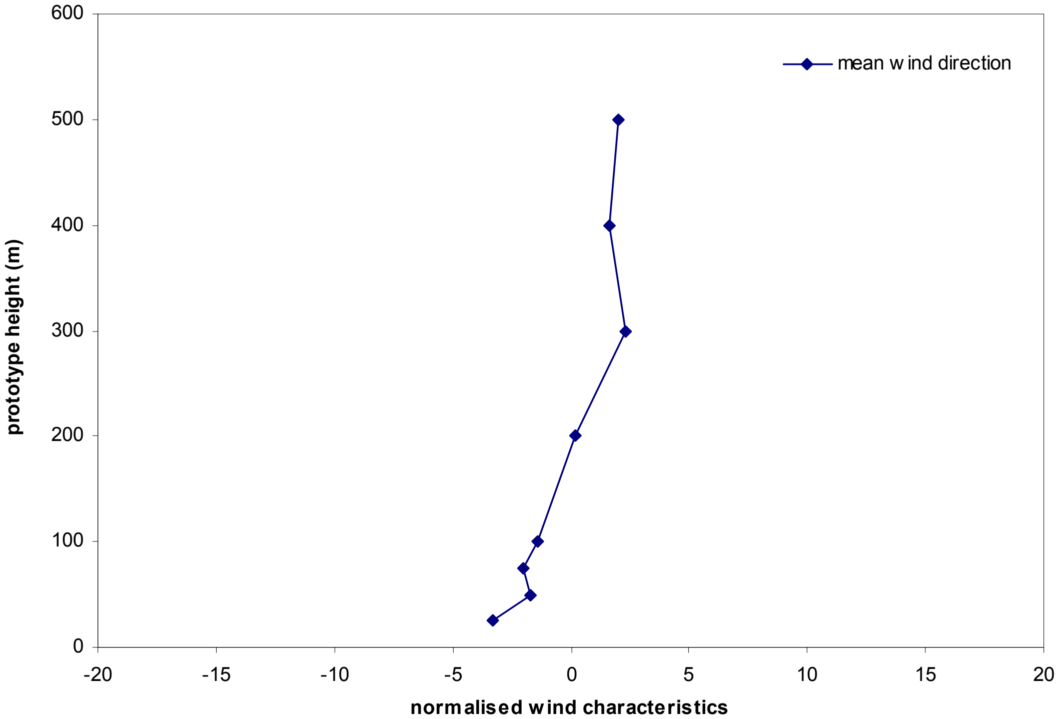

Figure 57b: Mean wind direction, Position 4, 45°

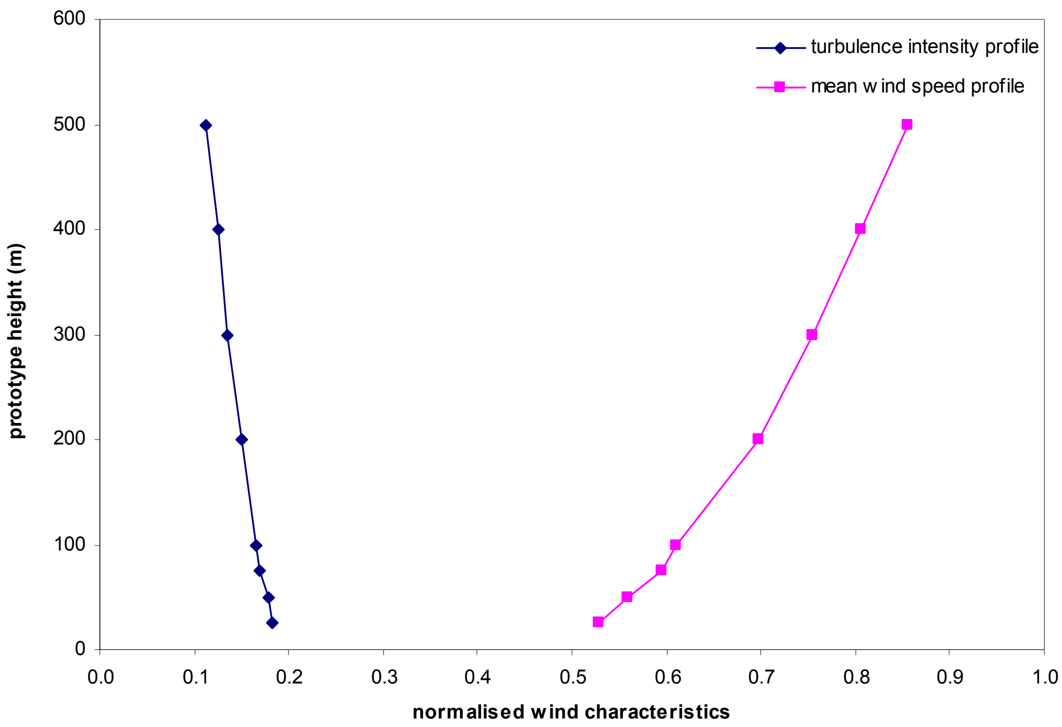

Figure 58a: Wind characteristics, Position 4, 67.5°

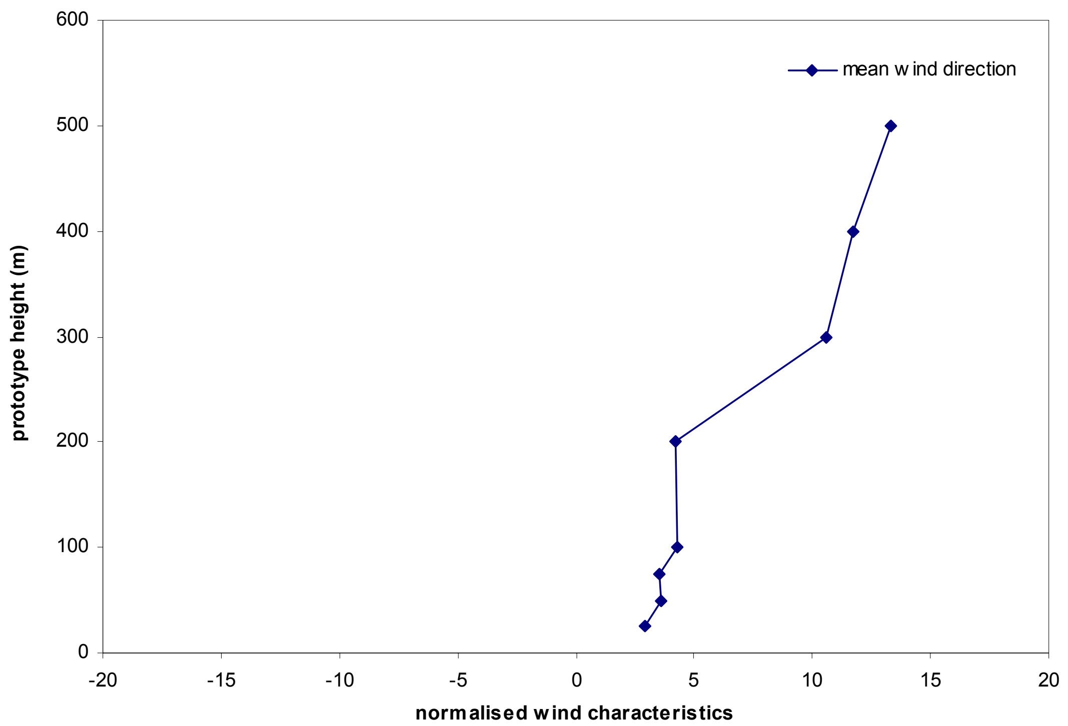

Figure 58b: Mean wind direction, Position 4, 67.5°

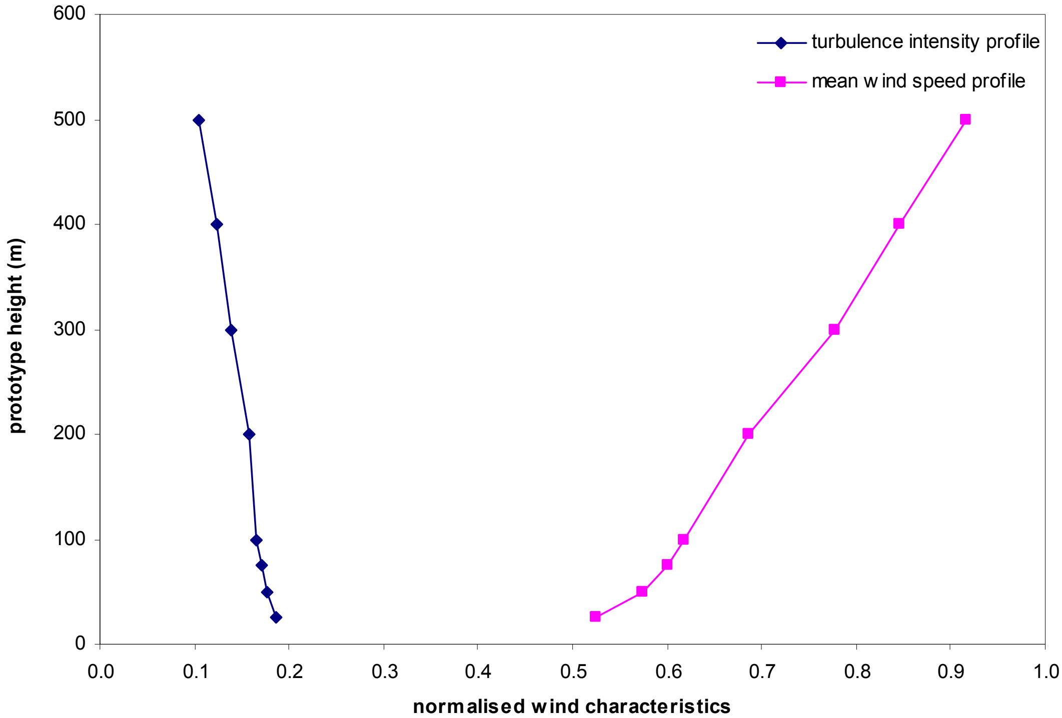

Figure 59a: Wind characteristics, Position 4, 90°

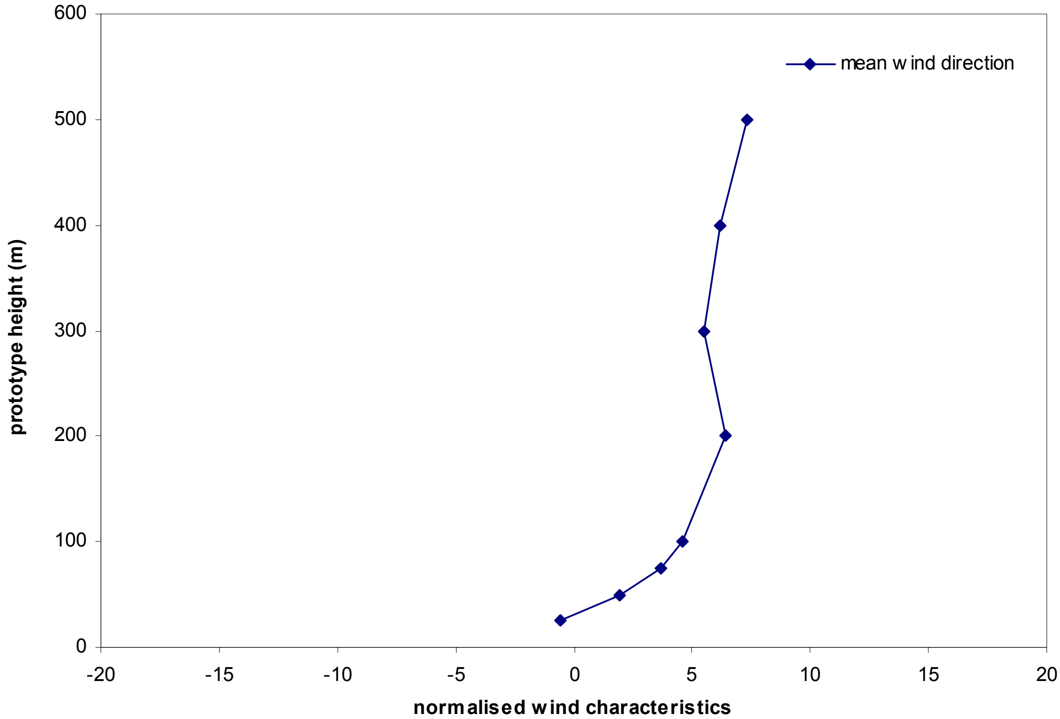

Figure 59b: Mean wind direction, Position 4, 90°

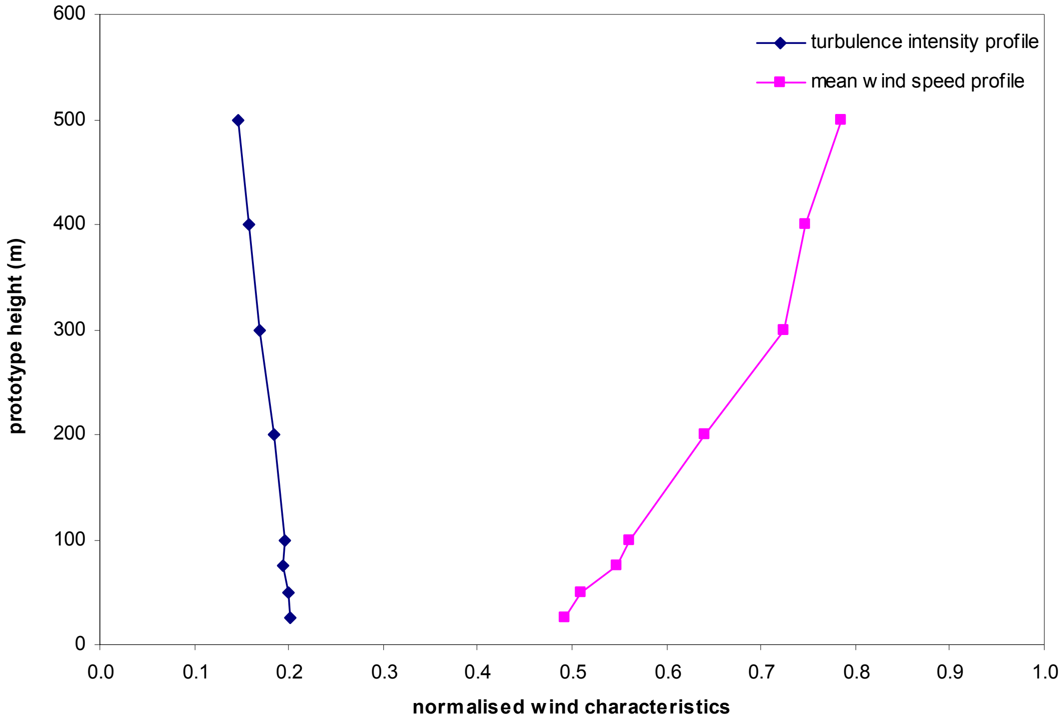

Figure 60a: Wind characteristics, Position 4, 112.5°

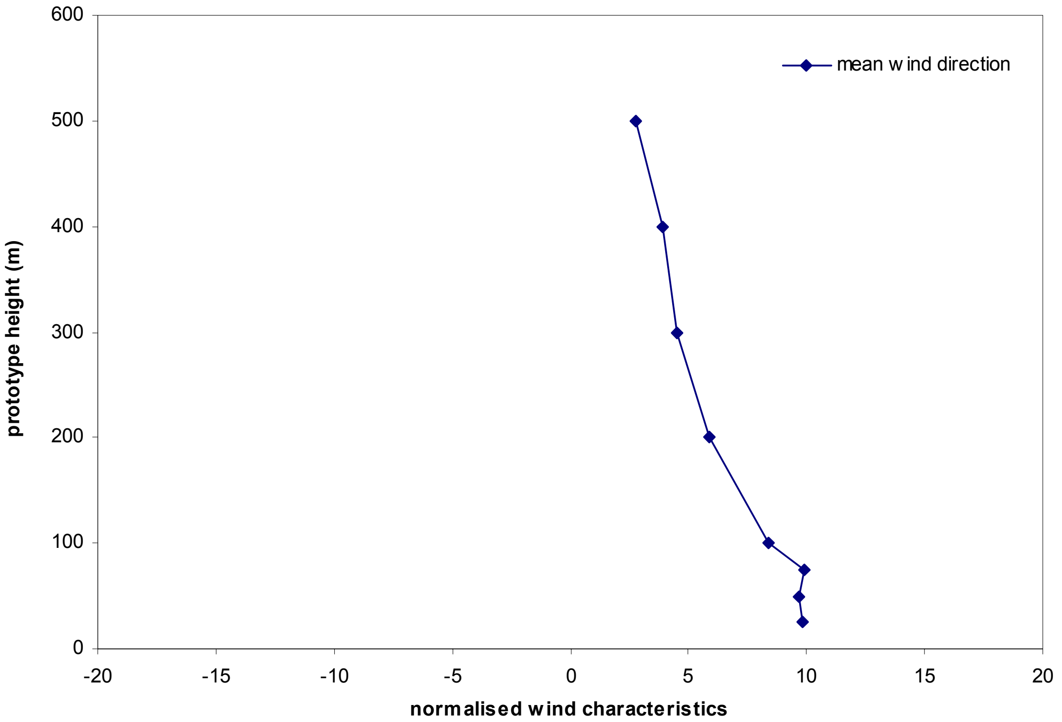

Figure 60b: Mean wind direction, Position 4, 112.5°

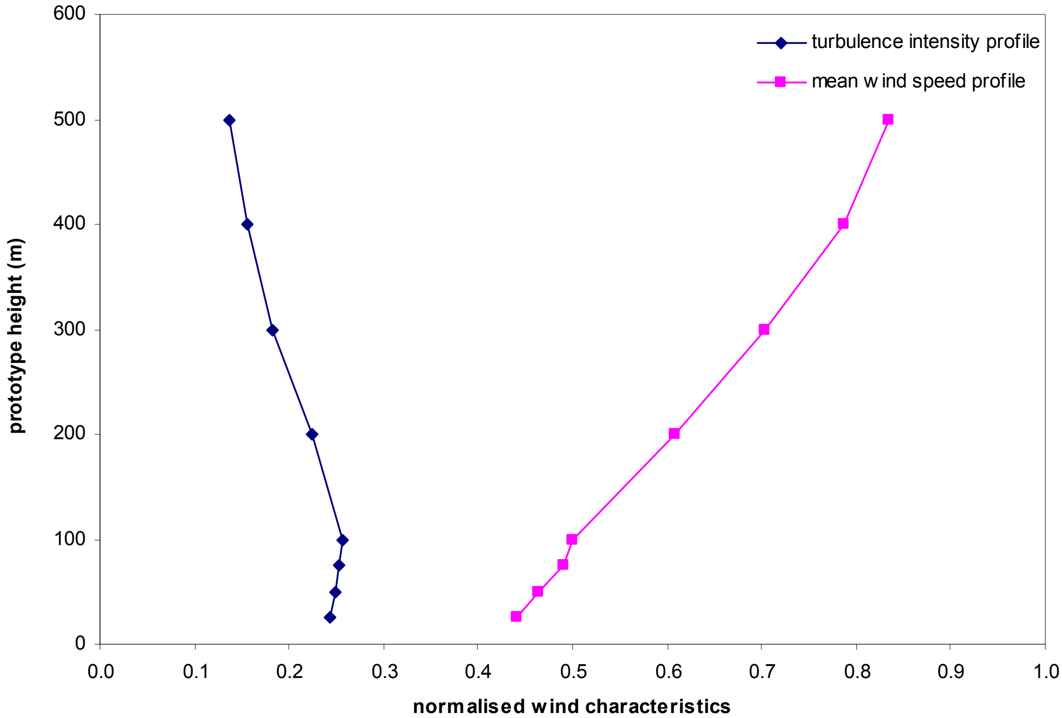

Figure 61a: Wind characteristics, Position 4, 135°

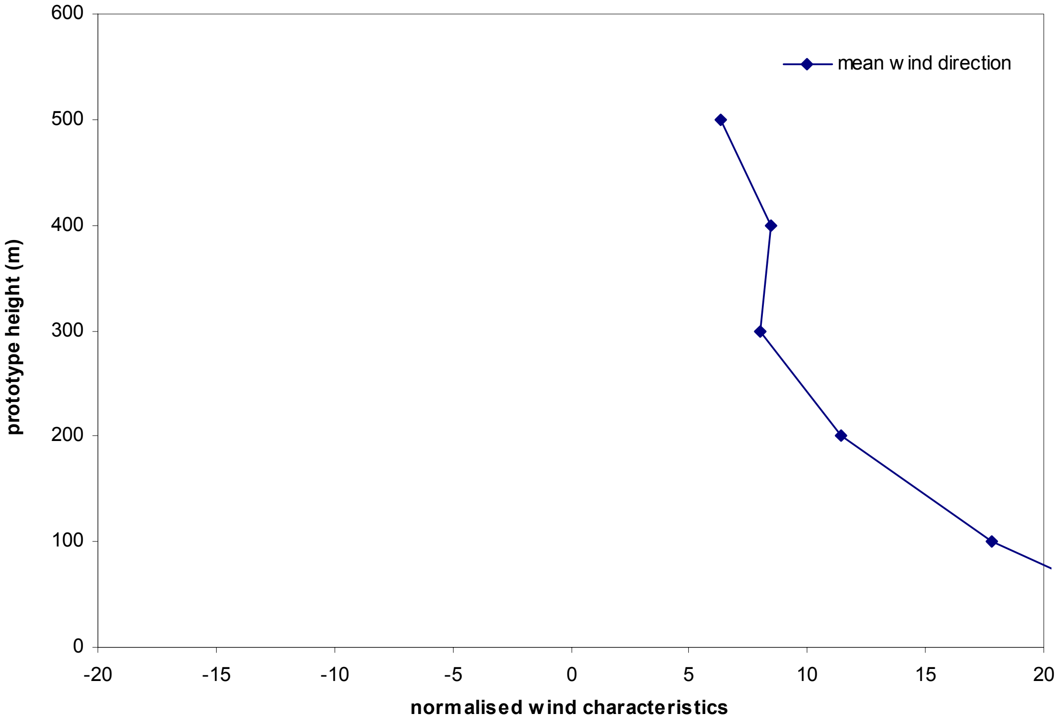

Figure 61b: Mean wind direction, Position 4, 135°

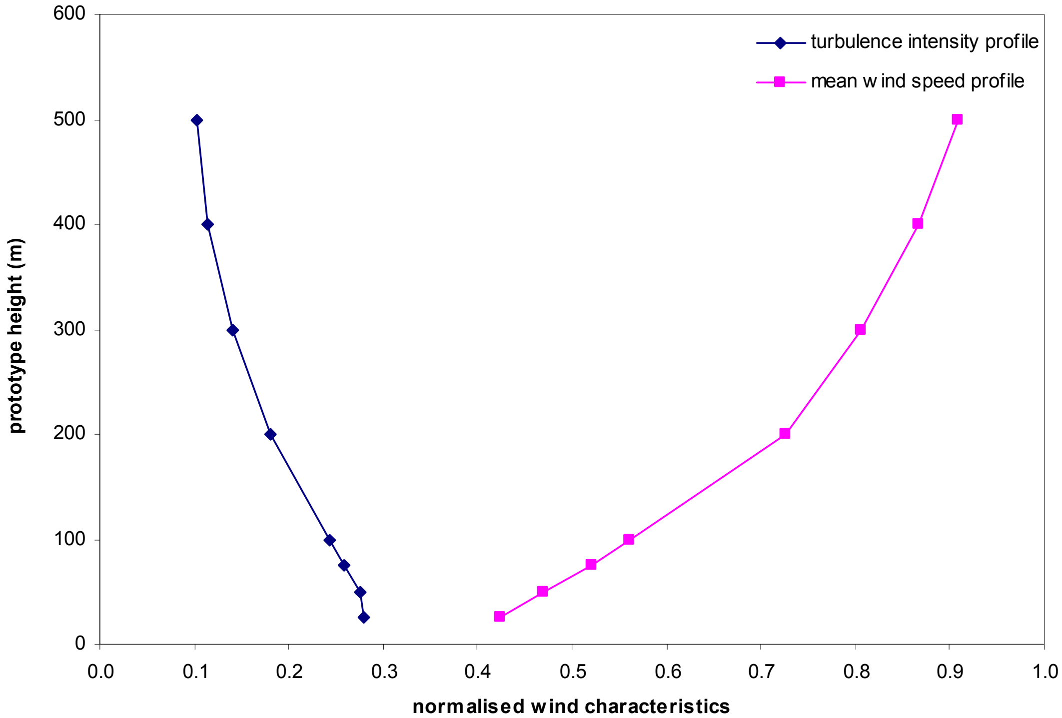

Figure 62a: Wind characteristics, Position 4, 157.5°

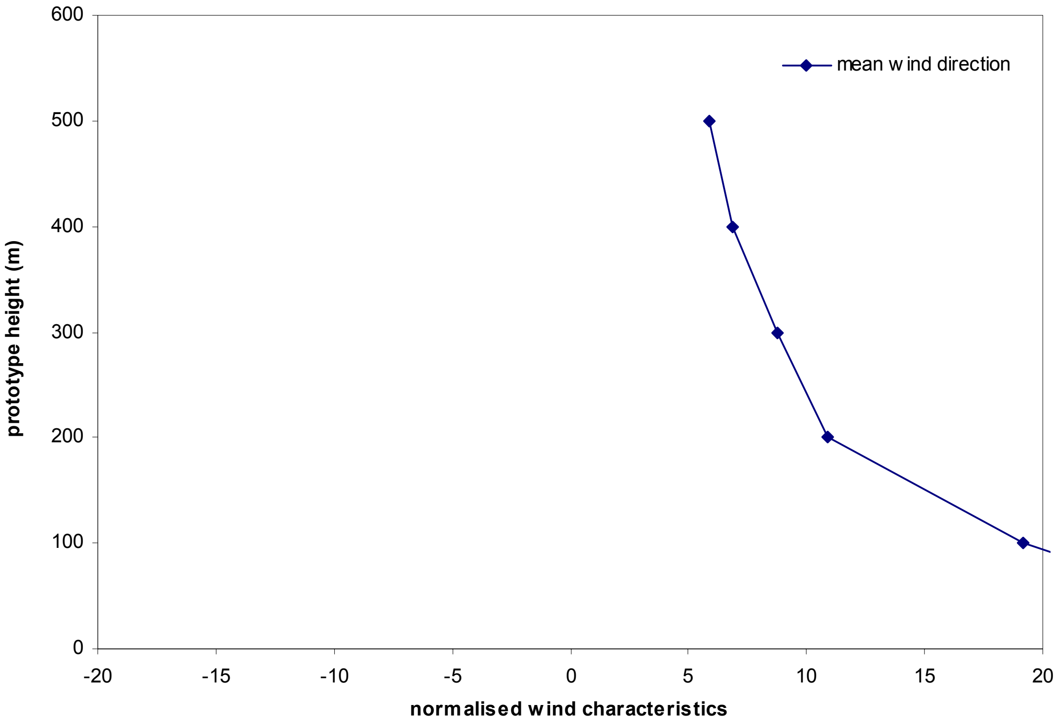

Figure 62b: Mean wind direction, Position 4, 157.5°

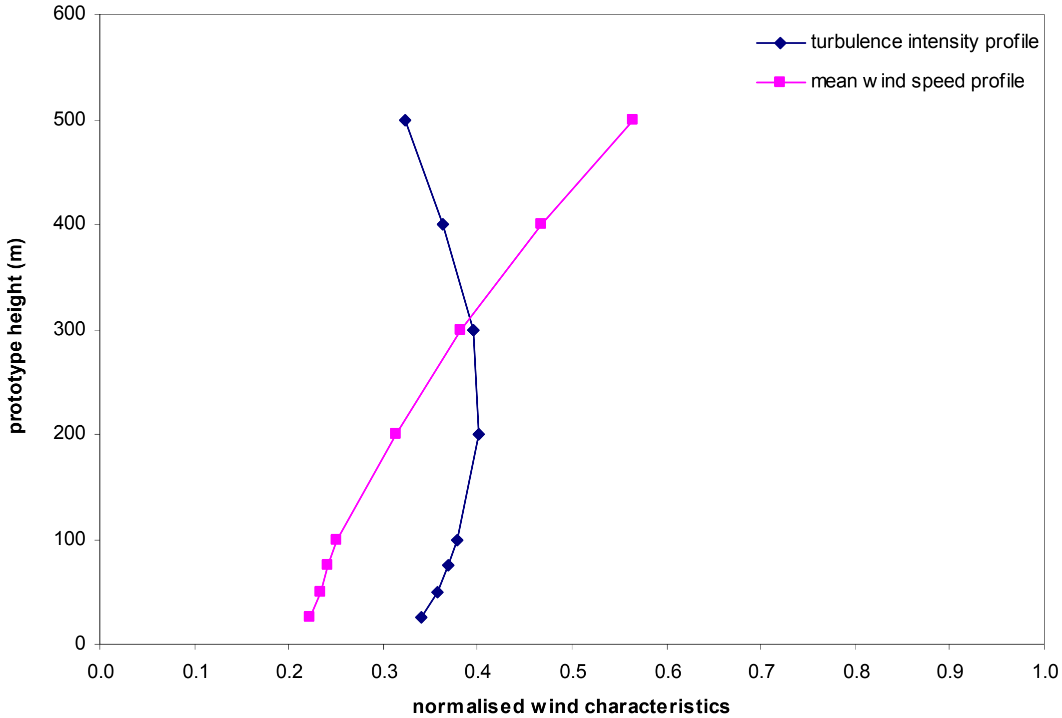

Figure 63a: Wind characteristics, Position 4, 180°

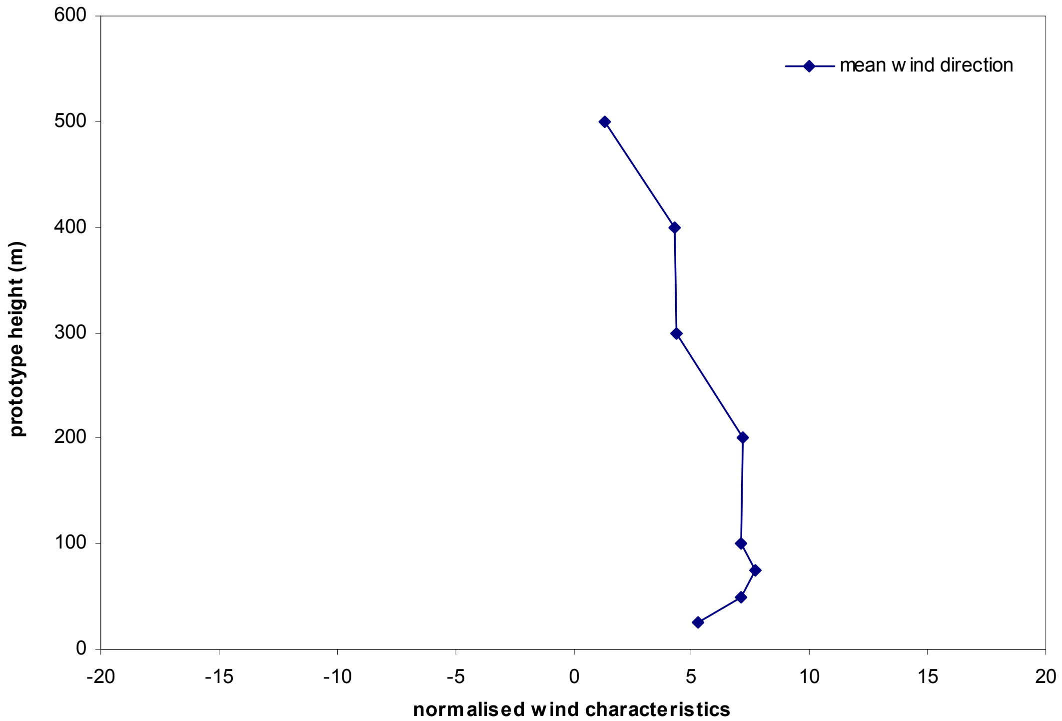

Figure 63b: Mean wind direction, Position 4, 180°

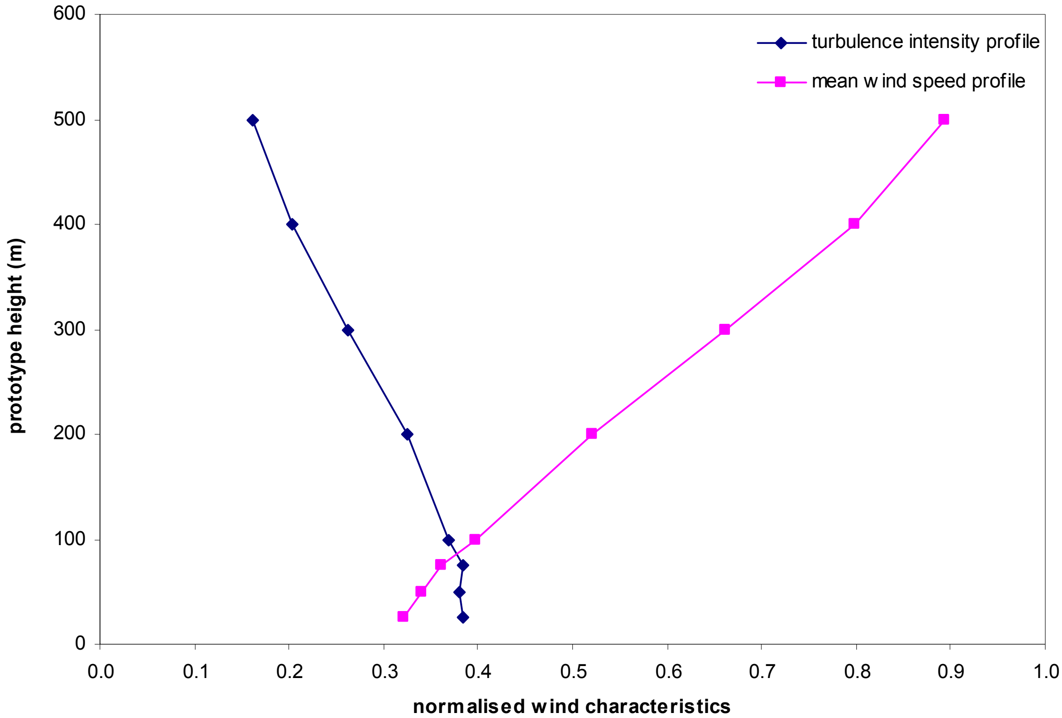

Figure 64a: Wind characteristics, Position 4, 202.5°

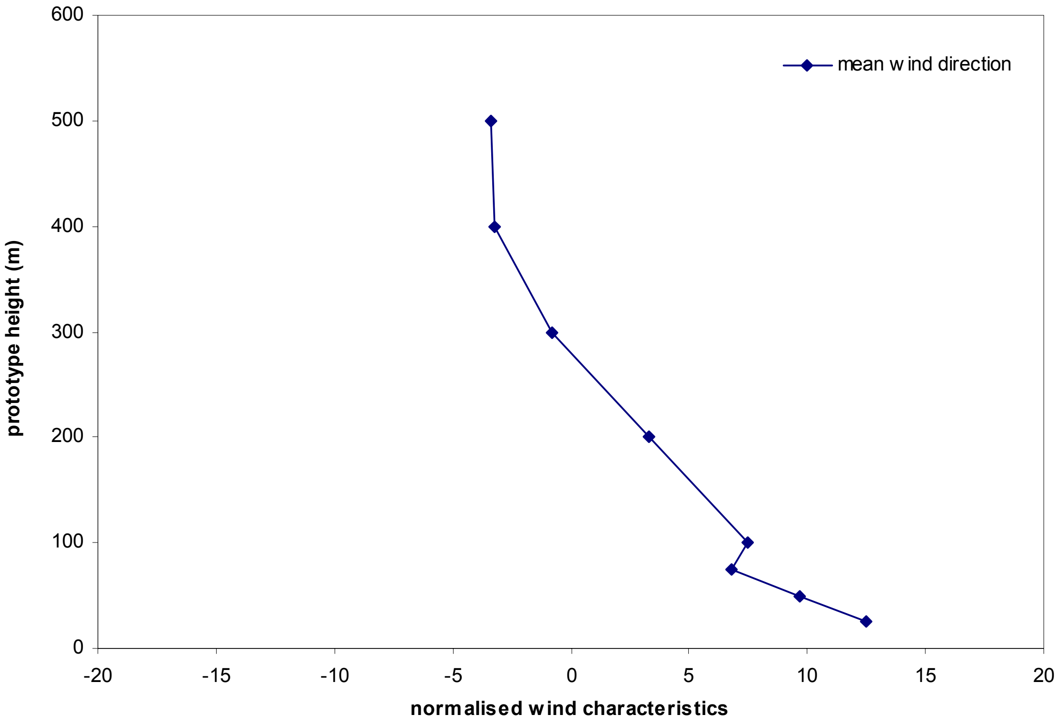

Figure 64b: Mean wind direction, Position 4, 202.5°

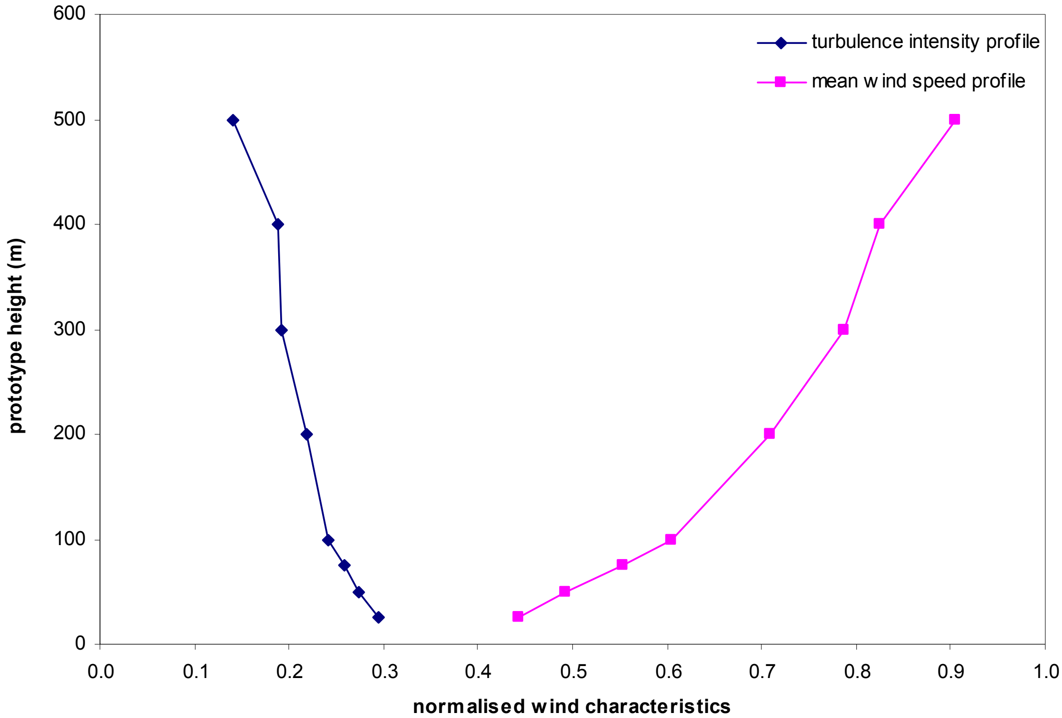

Figure 65a: Wind characteristics, Position 4, 225°

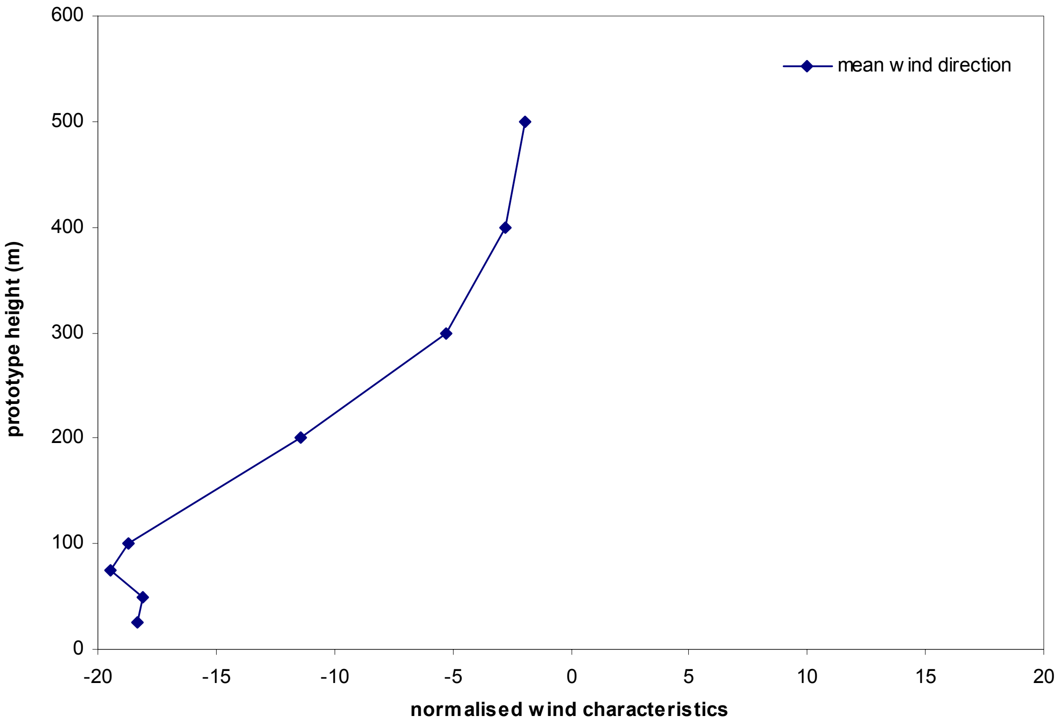

Figure 65b: Mean wind direction, Position 4, 225°

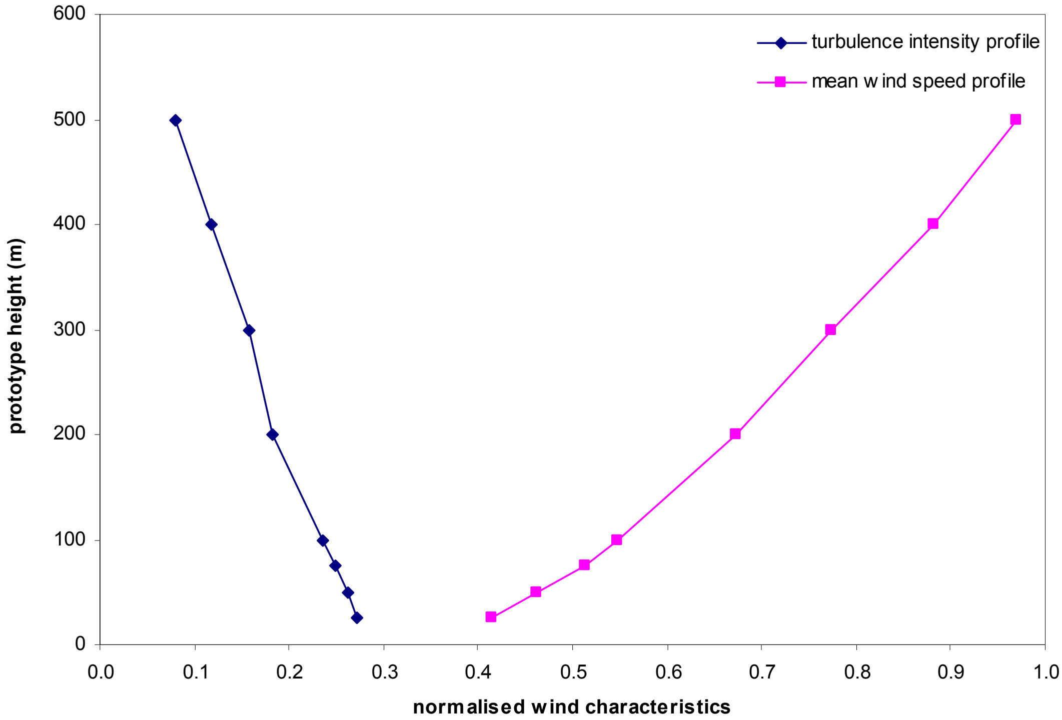

Figure 66a: Wind characteristics, Position 4, 247.5°

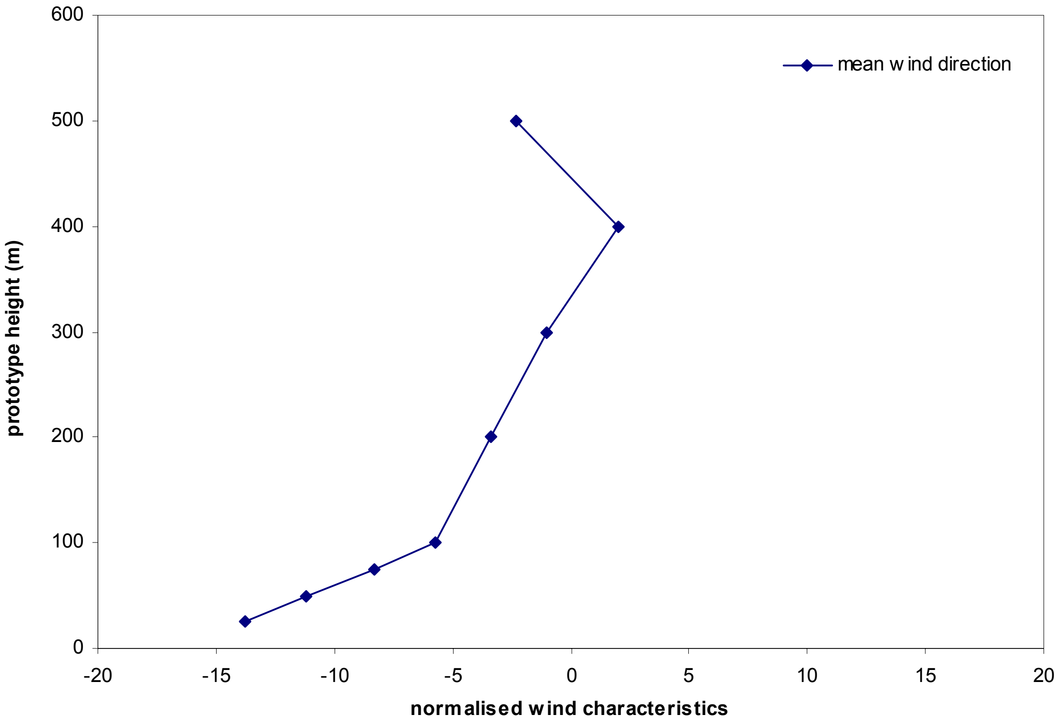

Figure 66b: Mean wind direction, Position 4, 247.5°

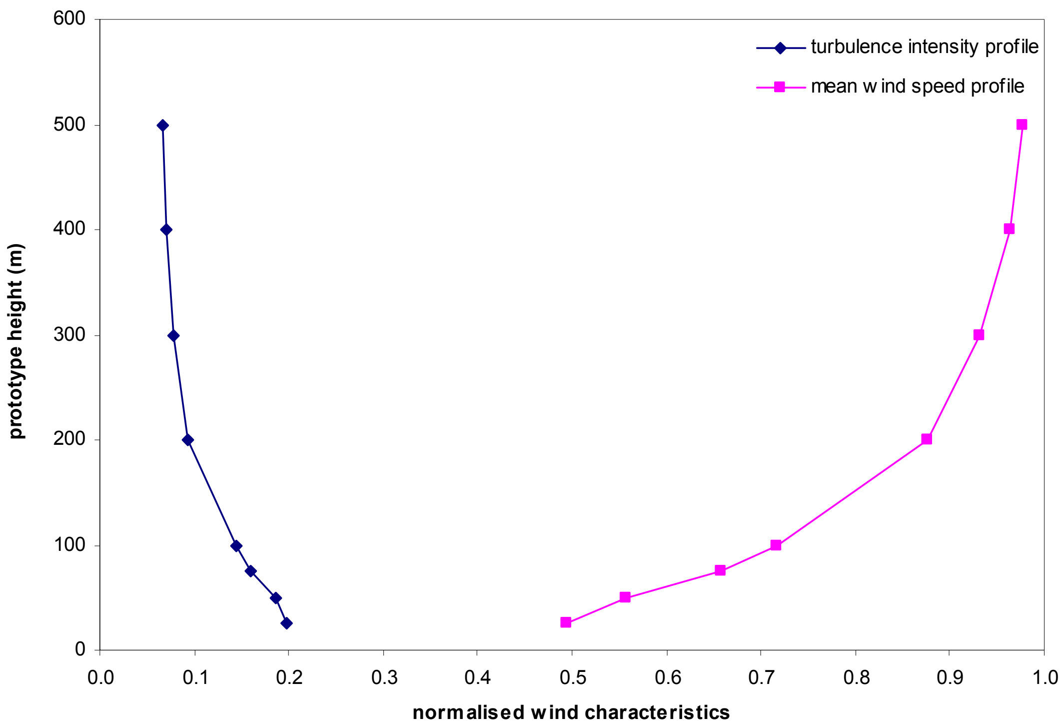

Figure 67a: Wind characteristics, Position 4, 270°

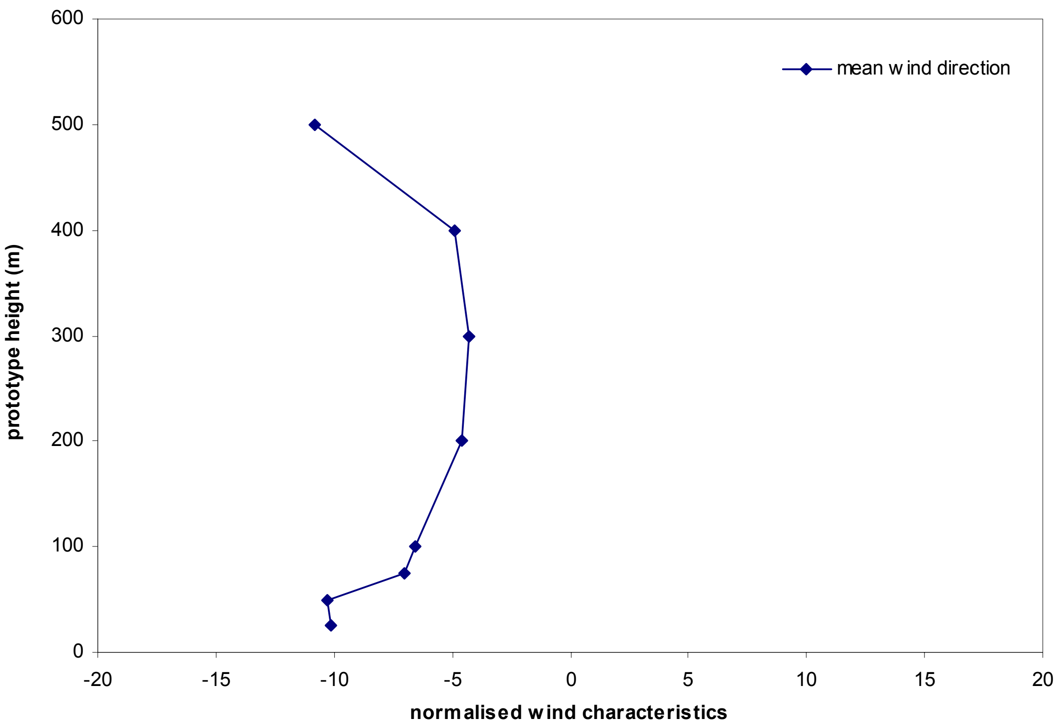

Figure 67b: Mean wind direction, Position 4, 270°

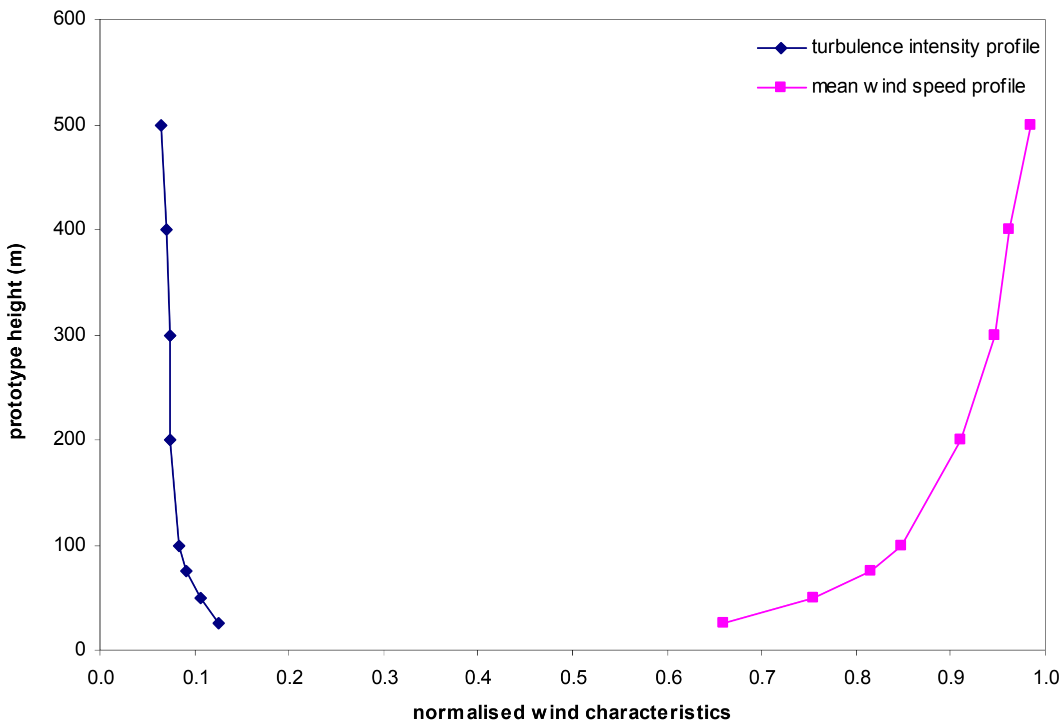

Figure 68a: Wind characteristics, Position 4, 292.5°

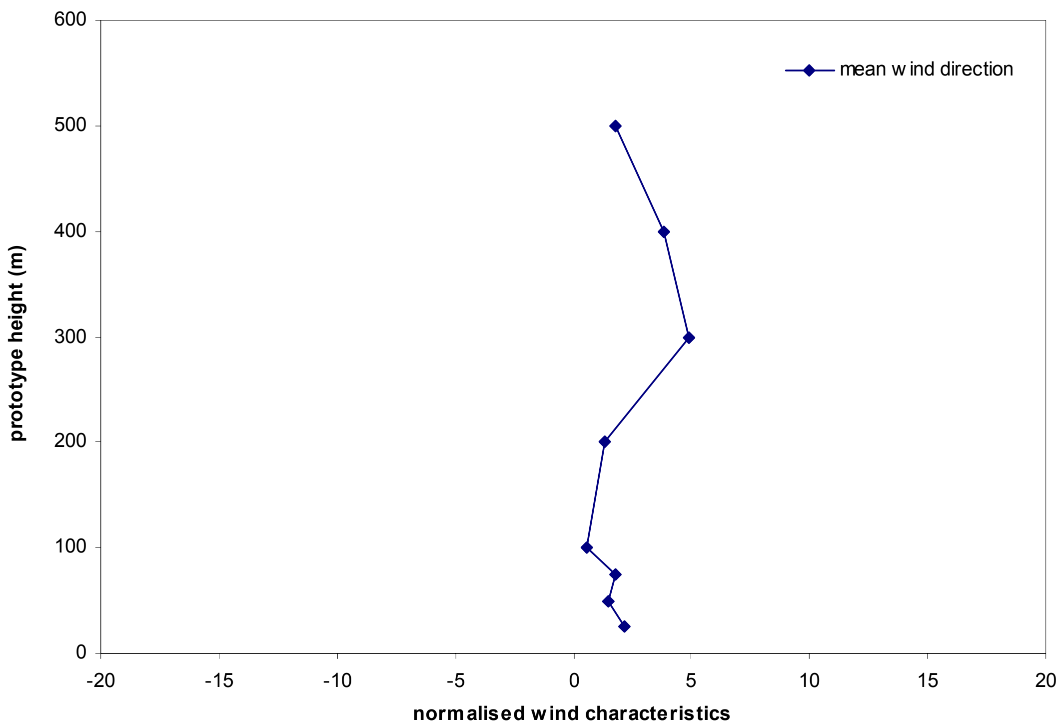

Figure 68b: Mean wind direction, Position 4, 292.5°

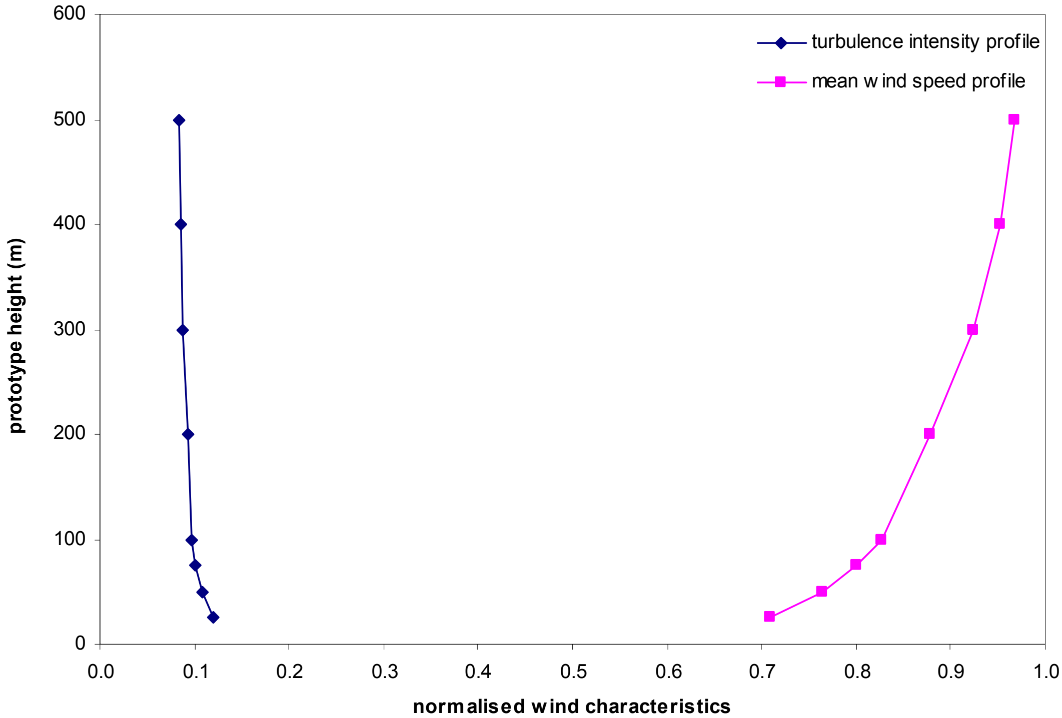

Figure 69a: Wind characteristics, Position 4, 315°

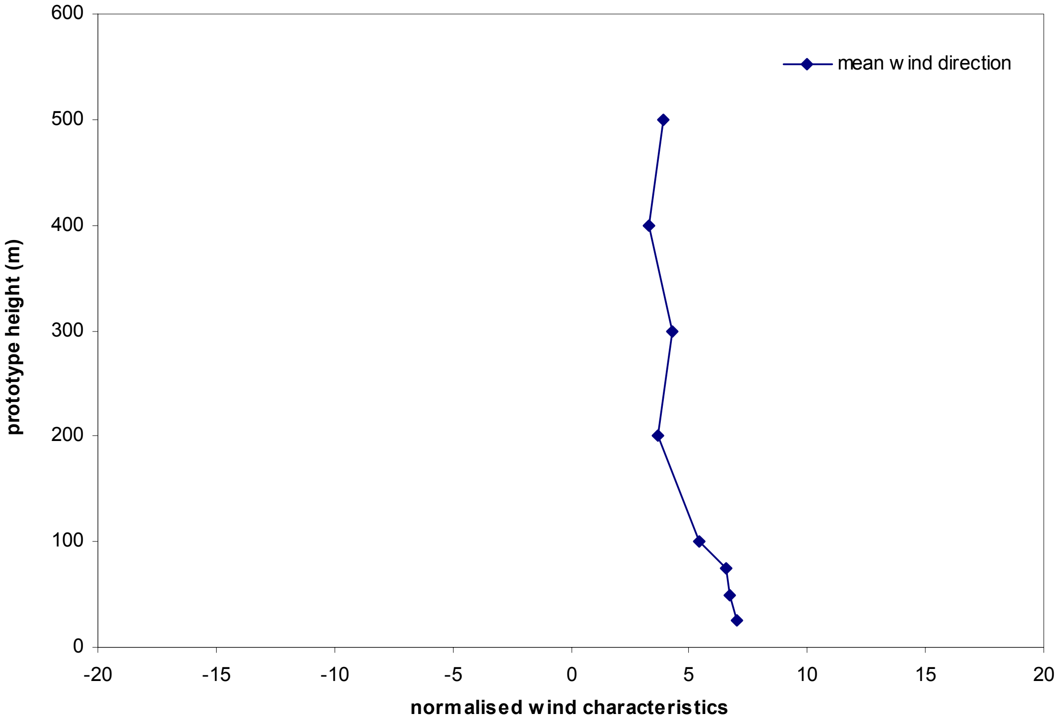

Figure 69b: Mean wind direction, Position 4, 315°

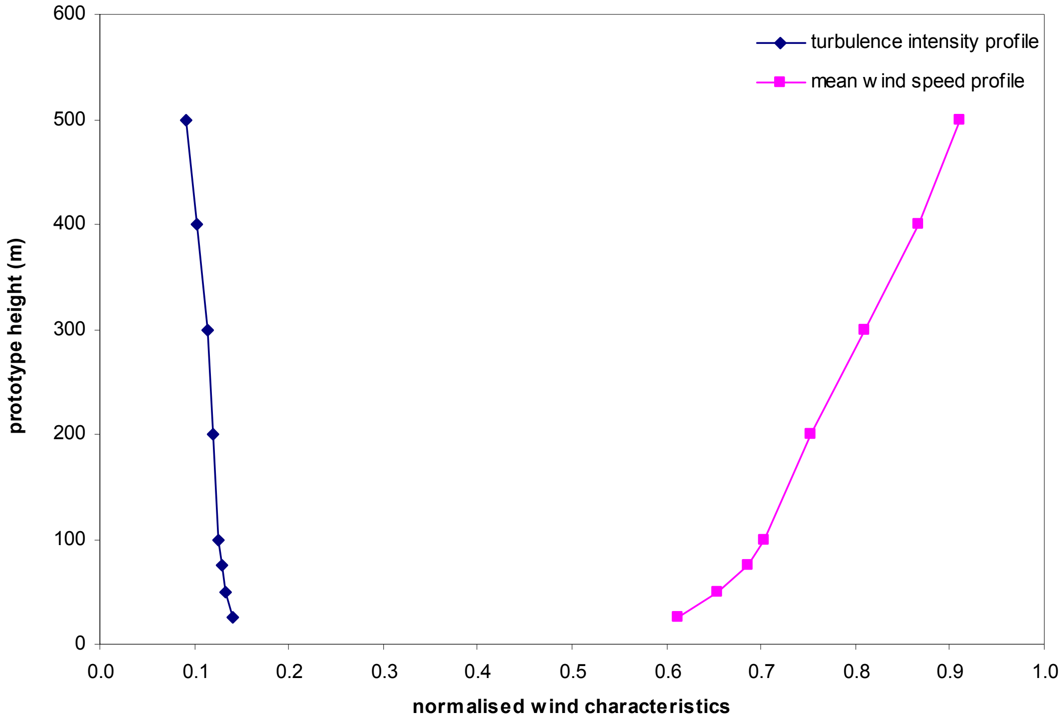

Figure 70a: Wind characteristics, Position 4, 337.5°

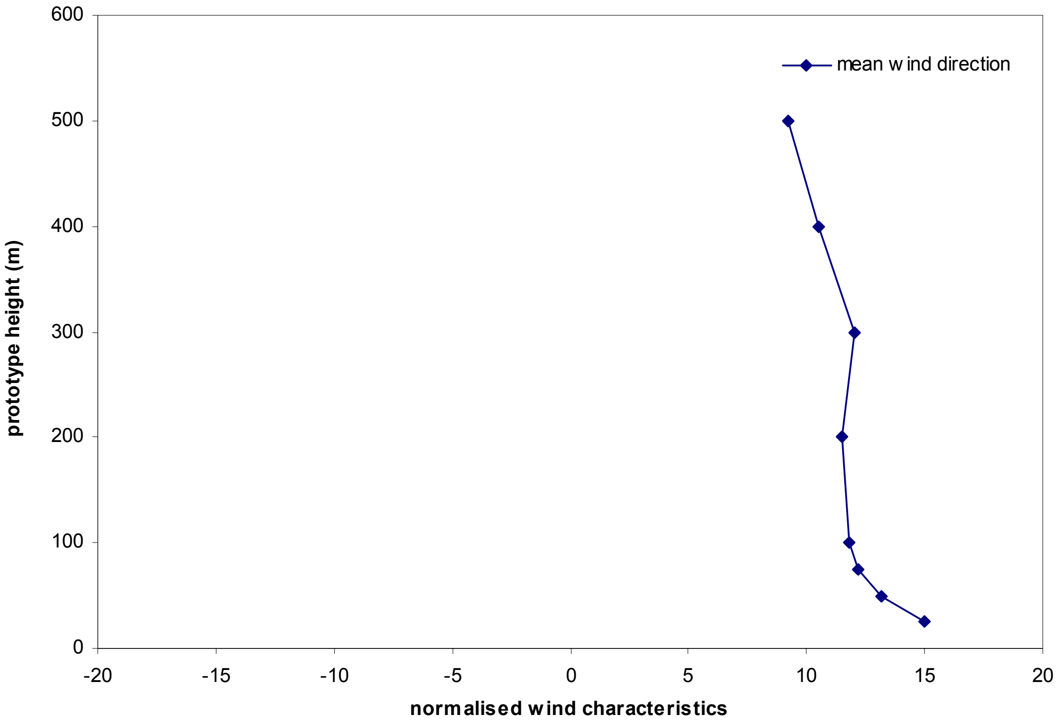

Figure 70b: Mean wind direction, Position 4, 337.5°

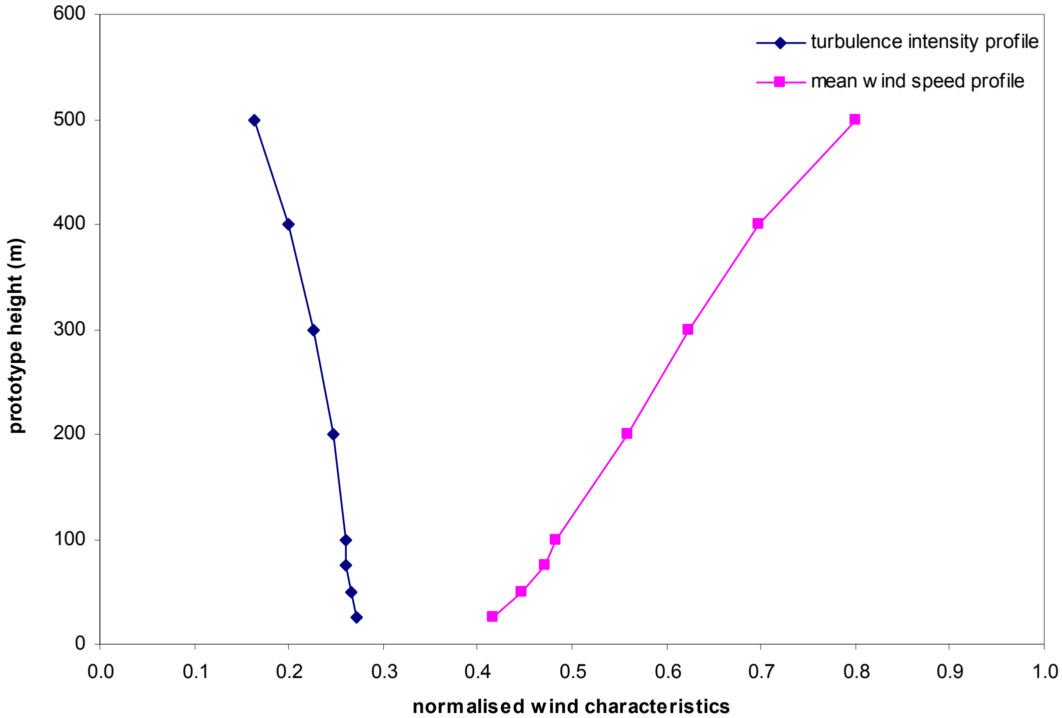

Figure 71a: Wind characteristics, Position 4, 360°

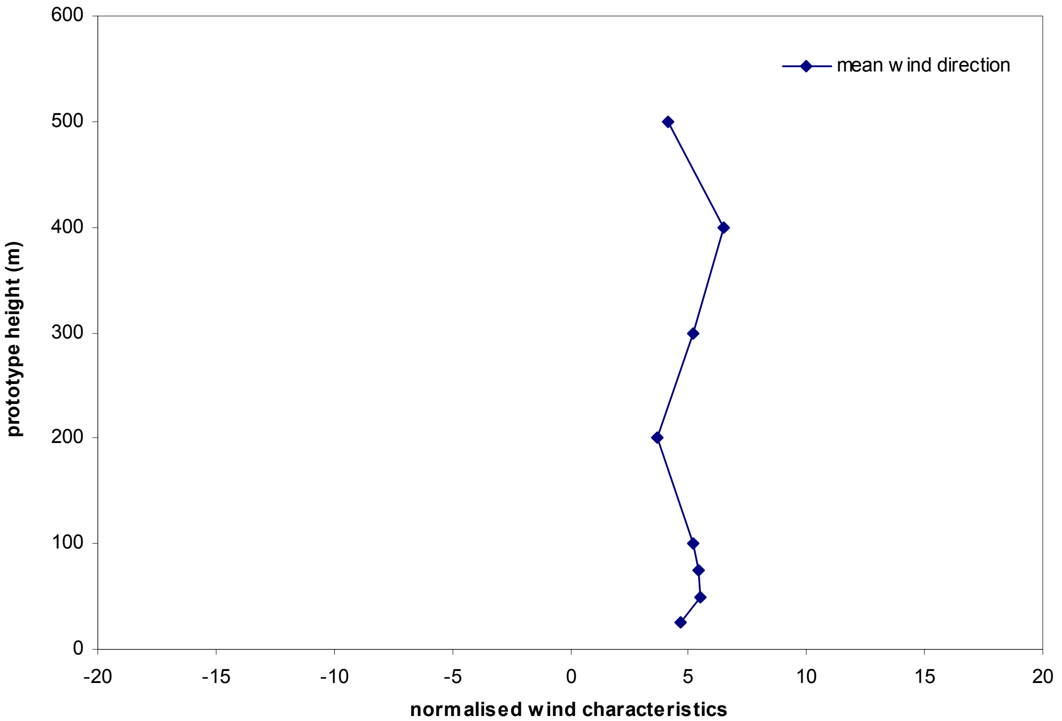

Figure 71b: Mean wind direction, Position 4, 360°

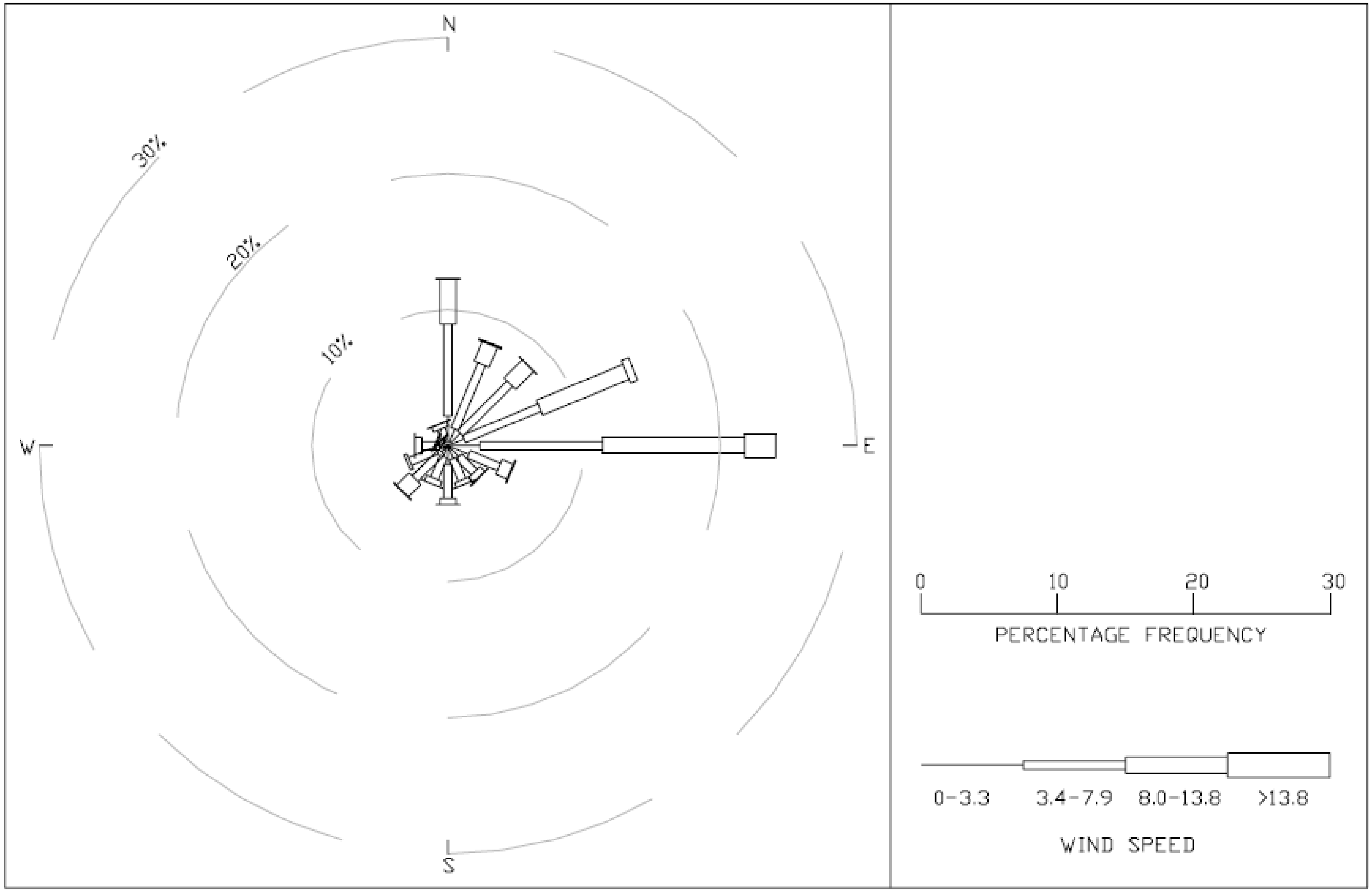

Figure 72: Wind rose for annual, non-typhoon winds for Position 1, corrected to 500m

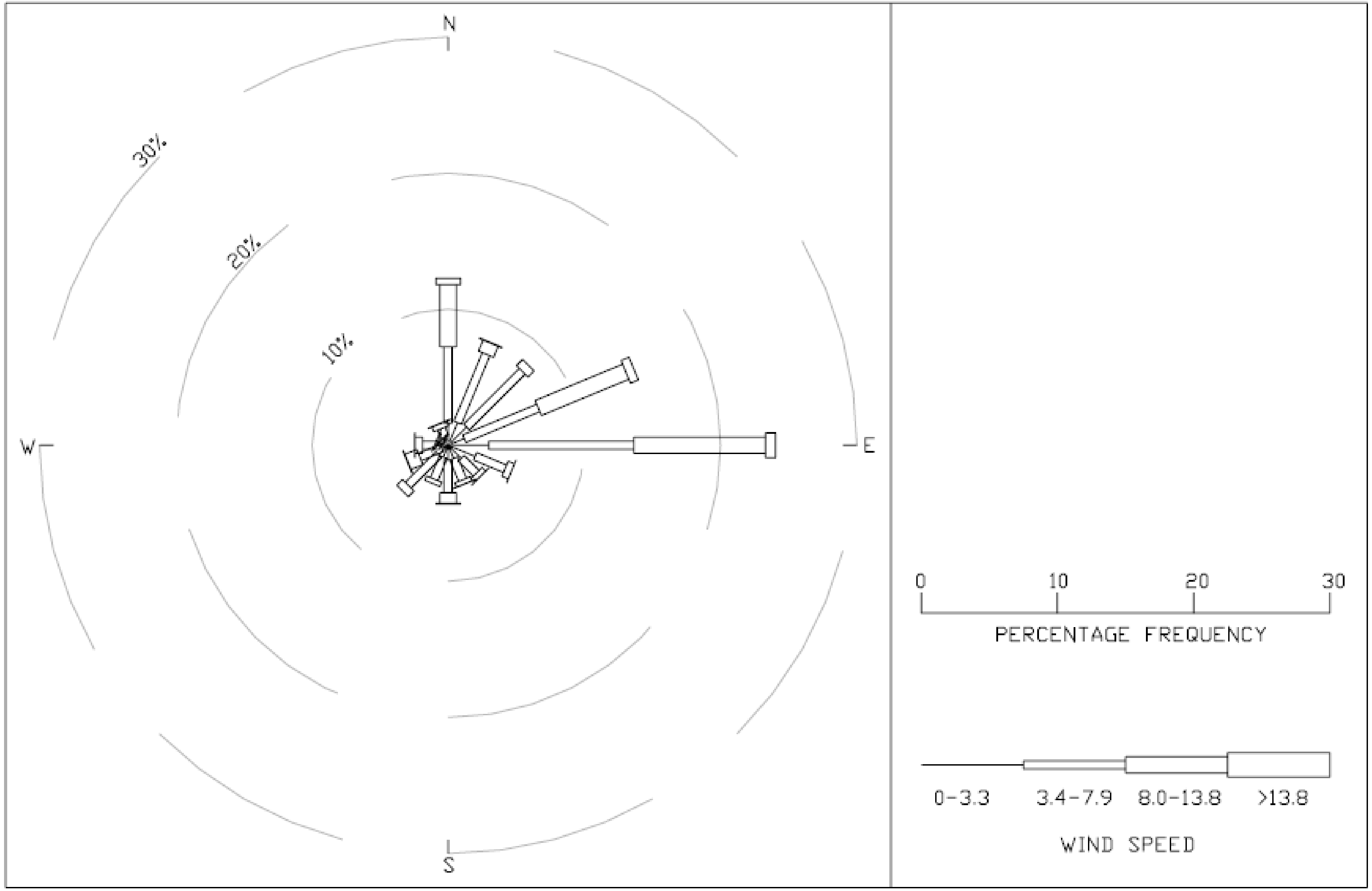

Figure 73: Wind rose for annual, non-typhoon winds for Position 2, corrected to 500m

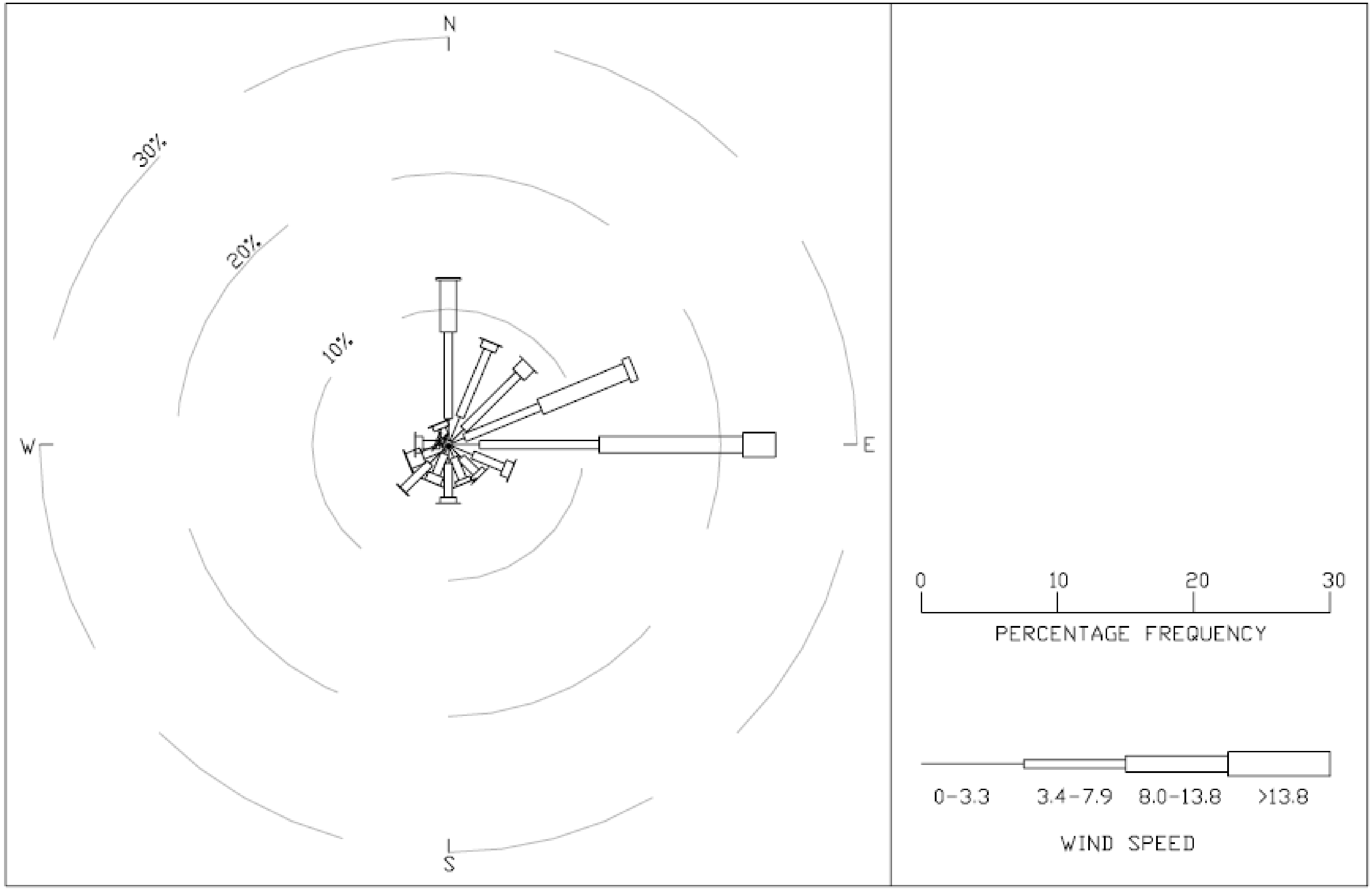

Figure 74: Wind rose for annual, non-typhoon winds for Position 3, corrected to 500m

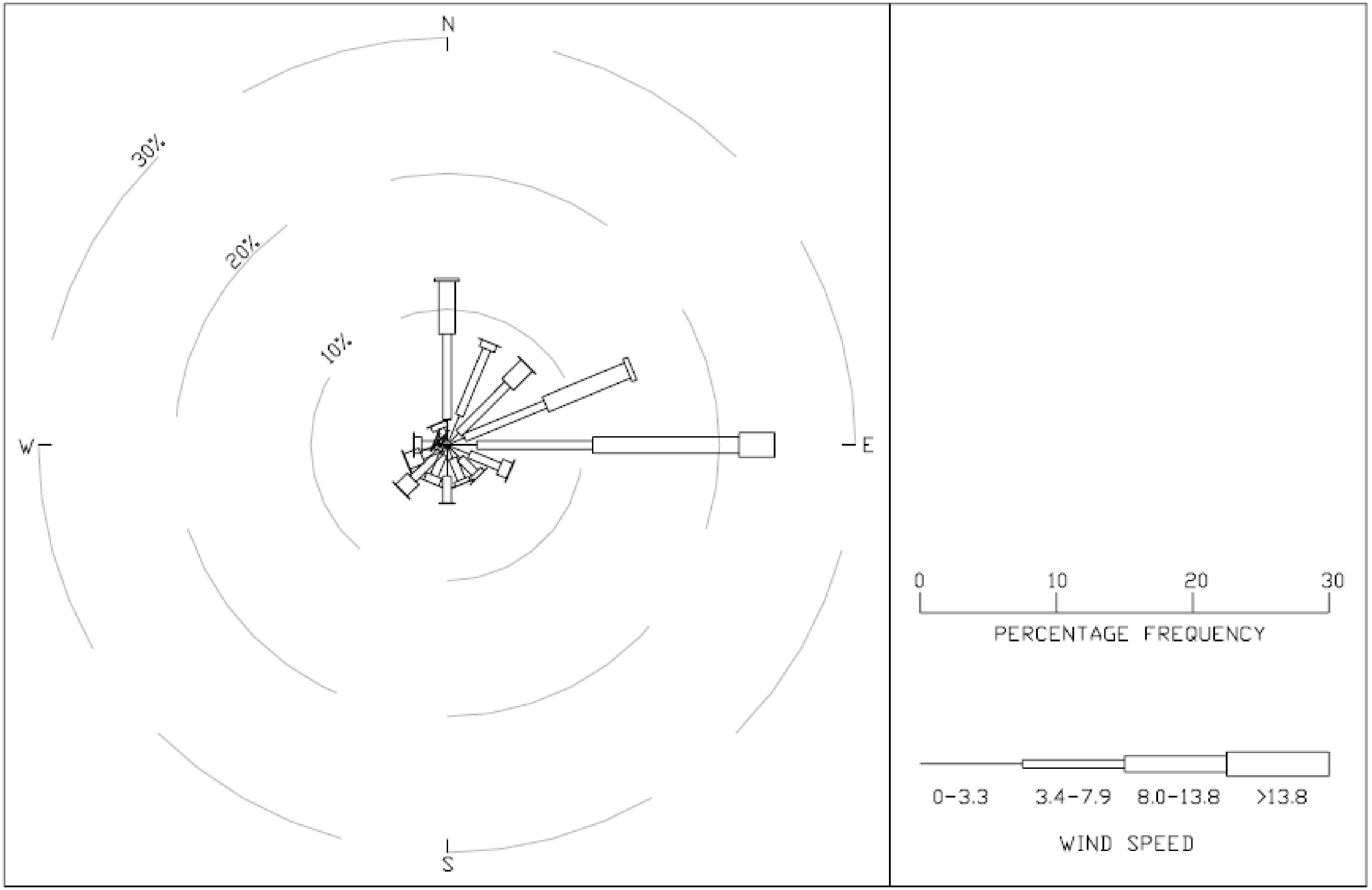

Figure 75: Wind rose for annual, non-typhoon winds for Position 4, corrected to 500m

APPENDIX A

MEAN WIND DIRECTION SIGN CONVENTION

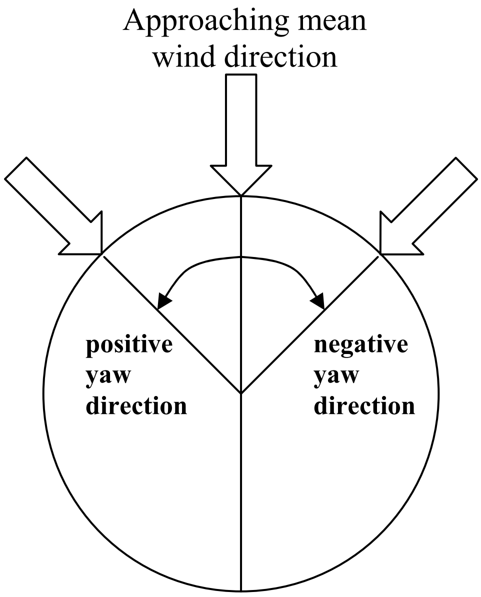

Figure A1: Mean wind direction sign convention

APPENDIX B

EXAMPLE APPLICATION OF STUDY RESULTS

B.1 Wind characteristics at Waglan Island

Hong Kong Observatory's (HKO) Waglan Island wind data, corrected to a height of 500 m, are used as the basis of all analyses of wind characteristics in this study and those data are considered to be representative of winds approaching Hong Kong.

Based on the corrected Waglan Island data, the average annual percentage occurrence of upper level winds, $\overline{V}_{500,\mathrm{approach}}(\theta)$, approaching Hong Kong from a particular wind direction are presented in Table B1. For example, from Table B1 it can be seen that in any given year, on average, winds approach Hong Kong from the east approximately 24.1% of the time.

Table B1: Percentage occurrence of directional winds for Hong Kong based on Waglan Island wind record

Wind Direction	Wind Angle (°)	Percentage Occurrence (%)
north	0 or 360	12.3
north-north-east	22.5	8.2
north-east	45	8.3
east-north-east	67.5	14.7
east	90	24.1
east-south-east	112.5	5.0
south-east	135	3.3
south-south-east	157.5	3.1
south	180	4.3
south-south-west	202.5	3.0
south-west	225	4.8
west-south-west	247.5	3.2
west	270	2.5
west-north-west	292.5	0.9
north-west	315	0.6
north-north-west	337.5	1.7

B.2 Wind Characteristics at the proposed Tamar Development site (Position 2)

For each wind direction tested in the 1:2000 scale topographical study, mean wind speed, turbulence intensity and yaw angles were measured at eight heights above each measurement position. Equations defining normalised mean wind speed and turbulence intensity, as discussed in Section 4 of this report, are reproduced in Equations (B1) and (B2) below.

$$\text{normalised wind velocity} = \frac{\overline{V}_z(\theta)}{\overline{V}_{500,\text{approach}}(\theta)} \qquad \text{(B1)}$$

$$\text{turbulence intensity} = \frac{\sigma_{V,z}(\theta)}{\overline{V}_z(\theta)} \qquad \text{(B2)}$$

where:

$\overline{V}_z(\theta)$ = mean wind speed at a height z (z = 25, 50, 75, 100, 200, 300, 400 or 500 m in prototype scale) for an approaching wind direction θ (θ = 22.5º, 45º, 67.5º, 90º, 112.5º, 135º, 157.5º, 180º, 202.5º, 225º, 247.5º, 270º, 292.5º, 315º, 337.5º or 360º);

$\overline{V}_{500,\text{approach}}(\theta)$ = mean wind speed of the approaching wind at a height equivalent to 500 m in prototype scale, for an approaching wind direction θ, that is determined from the Waglan Island wind characteristics;

$\sigma_{V,z}(\theta)$ = the standard deviation of the fluctuating wind speed V_z for an approaching wind direction θ.

The vertical profiles of mean wind speed, turbulence intensity and mean wind direction are expected to be used as input boundary conditions for more detailed site studies to be conducted later and at larger scales, typically of the order of 1:400. For example, for east winds at Position 2, profiles of mean wind speed and turbulence intensity are presented in Table B2 below and are also presented graphically in Figure 26a.

Table B2: Mean wind speed and turbulence intensity profiles, for east winds at Position 2

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.259	33.1	15.2
50	0.272	33.4	11.6
75	0.296	33.3	9.3
100	0.329	32.8	7.1
200	0.438	28.4	4.7
300	0.540	23.9	6.7
400	0.656	20.9	7.8
500	**0.776**	16.8	10.9

The value of the normalised mean wind speed at 500 m (0.776) in Table B2 is used in Equation (B3) to determine the upper level wind speed for east winds for the proposed Tamar site, corresponding to $V_\infty(90^o)$ in the parlance adopted in Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005).

$$V_{\infty,\text{Position 2}}\left(90^o\right) = 0.776 \times \overline{V}_{500,\text{approach}}\left(90^o\right) \quad \text{(B3)}$$

It is important to note that the value of 0.776 is specifically for east winds. Normalised mean wind speeds at 500 m for each of the measured wind directions for Position 2 are presented in Table B3 and the appropriate values should be used when determining V_∞ for each wind direction.

Table B3: Normalised mean wind speeds at 500 m for Position 2

Wind Direction	Wind Angle (°)	Normalised mean wind speed at 500 m
north	0 or 360	0.871
north-north-east	22.5	0.794
north-east	45	0.735
east-north-east	67.5	0.897
east	90	**0.776**
east-south-east	112.5	0.671
south-east	135	0.846
south-south-east	157.5	0.922
south	180	0.943
south-south-west	202.5	0.773
south-west	225	0.763
west-south-west	247.5	0.900
west	270	0.969
west-north-west	292.5	0.960
north-west	315	0.961
north-north-west	337.5	0.868

As the yaw angle at 500 m in Table B2 is only 10.9º no significant mean directional change is expected for east winds at a height of 500 m. Similar results were also found for the other measured wind directions. Therefore, the wind rose for winds at 500 m at Position 2 exhibited similar overall directional characteristics to the wind rose for Waglan Island (i.e. east winds at Position 2 will occur approximately 24.1% of the time, on average, in any given year). However, the values of the normalised mean wind speed in Table B3 indicates that the magnitudes of the directional mean wind speeds at Position 2 will differ from those at Waglan Island.

B.3 Pedestrian Level Wind Speed for Air Ventilation Assessment (AVA)

AVA for a particular site will be based on wind velocity ratios (VR). It is expected that VR's will be measured directly at a number of locations in and around a selected site during a more detailed wind tunnel model study conducted at a later stage. Where required, the magnitude of the pedestrian level wind speed at a particular location may be estimated from Equation (B4).

$$V_p(\theta) = VR(\theta) \times V_\infty(\theta) \qquad \text{(B4)}$$

where:

$V_p(\theta)$ = the pedestrian level wind speed for a wind direction θ;

$VR(\theta)$ = the wind velocity ratio measured in a wind tunnel model study at a particular measurement location for a wind direction θ;

$V_\infty(\theta)$ = the upper level (i.e. 500 m for this study) wind speed for a wind direction θ, as determined from Equation (B3).

APPENDIX C

TABULATED RESULTS FOR WAGLAN ISLAND

Table C1: Percentage occurrence of directional winds for at 500 m, Waglan Island

Wind Angle (°)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
0 or 360	1.2%	3.8%	5.4%	1.9%	12.3%
22.5	0.9%	4.4%	2.5%	0.3%	8.2%
45	0.8%	3.8%	3.5%	0.2%	8.3%
67.5	0.9%	4.2%	7.4%	2.3%	14.7%
90	1.6%	6.2%	10.0%	6.3%	24.1%
112.5	1.1%	2.2%	1.3%	0.4%	5.0%
135	1.0%	1.6%	0.6%	0.1%	3.3%
157.5	0.8%	1.7%	0.5%	0.1%	3.1%
180	0.9%	2.2%	1.2%	0.1%	4.3%
202.5	0.6%	1.4%	1.0%	0.1%	3.0%
225	0.5%	2.2%	1.9%	0.2%	4.8%
247.5	0.4%	1.3%	1.4%	0.2%	3.2%
270	0.5%	1.1%	0.7%	0.1%	2.5%
292.5	0.3%	0.4%	0.2%	0.0%	0.9%
315	0.3%	0.2%	0.1%	0.0%	0.6%
337.5	0.5%	0.6%	0.5%	0.1%	1.7%

APPENDIX D

TABULATED RESULTS FOR POSITION 1

Table D1: Percentage occurrence of directional winds at 500 m, Position 1

Wind Angle (°)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
0 or 360	2.2%	6.7%	3.3%	0.1%	12.3%
22.5	1.3%	5.2%	1.6%	0.1%	8.2%
45	1.3%	5.2%	1.9%	0.0%	8.3%
67.5	1.3%	6.0%	6.9%	0.6%	14.7%
90	2.4%	9.0%	10.5%	2.2%	24.1%
112.5	1.7%	2.4%	0.9%	0.1%	5.0%
135	1.1%	1.6%	0.5%	0.0%	3.3%
157.5	1.0%	1.7%	0.4%	0.0%	3.1%
180	1.4%	2.5%	0.4%	0.0%	4.3%
202.5	0.9%	1.7%	0.4%	0.0%	3.0%
225	0.7%	2.8%	1.3%	0.0%	4.8%
247.5	0.9%	2.1%	0.2%	0.0%	3.2%
270	0.6%	1.3%	0.5%	0.0%	2.5%
292.5	0.4%	0.4%	0.1%	0.0%	0.9%
315	0.4%	0.2%	0.1%	0.0%	0.6%
337.5	0.7%	0.7%	0.4%	0.0%	1.7%

Table D2: Wind characteristics at Position 1, 22.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.542	21.9	1.1
50	0.573	20.9	0.9
75	0.628	19.6	0.0
100	0.643	19.2	-0.7
200	0.734	17.4	-0.7
300	0.817	15.4	-1.1
400	0.875	13.4	-0.9
500	0.924	11.9	-1.0

Table D3: Wind characteristics at Position 1, 45°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.605	16.7	0.9
50	0.642	16.0	0.1
75	0.676	14.9	0.4
100	0.700	14.1	-0.5
200	0.757	13.2	0.0
300	0.803	12.6	-0.9
400	0.831	12.6	-0.1
500	0.880	11.4	-0.4

Table D4: Wind characteristics at Position 1, 67.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.533	19.6	-0.1
50	0.577	18.7	1.3
75	0.591	19.2	2.7
100	0.627	18.2	3.0
200	0.731	15.0	2.0
300	0.801	12.8	2.5
400	0.847	11.3	3.5
500	0.889	10.4	2.1

Table D5: Wind characteristics at Position 1, 90°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.411	26.3	8.4
50	0.435	26.2	6.7
75	0.466	25.6	6.1
100	0.496	25.4	6.4
200	0.580	23.4	2.7
300	0.705	19.6	3.6
400	0.778	16.9	4.3
500	0.886	12.9	3.8

Table D6: Wind characteristics at Position 1, 112.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.355	31.8	13.9
50	0.392	31.7	8.4
75	0.442	29.9	3.2
100	0.492	28.4	1.4
200	0.677	19.6	0.3
300	0.763	15.8	2.0
400	0.809	14.8	3.4
500	0.825	14.9	3.3

Table D7: Wind characteristics at Position 1, 135°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.319	33.7	16.7
50	0.350	33.1	10.7
75	0.389	32.2	4.9
100	0.440	30.0	0.9
200	0.623	21.7	-6.0
300	0.735	18.6	-2.4
400	0.879	14.3	-4.5
500	0.965	10.7	-2.3

Table D8: Wind characteristics at Position 1, 157.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.401	35.4	15.6
50	0.477	32.2	13.3
75	0.557	28.0	10.7
100	0.667	23.0	8.6
200	0.795	16.0	6.7
300	0.818	15.5	2.2
400	0.888	13.1	-0.3
500	0.946	10.6	1.9

Table D9: Wind characteristics at Position 1, 180°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.326	38.4	7.4
50	0.343	37.1	12.5
75	0.360	37.4	13.8
100	0.409	35.7	13.3
200	0.501	32.9	11.7
300	0.589	29.3	7.7
400	0.677	25.5	6.9
500	0.802	19.5	6.0

Table D10: Wind characteristics at Position 1, 202.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.317	35.9	16
50	0.324	37.2	11
75	0.354	36.2	11.1
100	0.351	37.0	9.6
200	0.442	35.4	2.0
300	0.544	31.4	-2.7
400	0.668	25.2	-3.2
500	0.824	17.1	-7.9

Table D11: Wind characteristics at Position 1, 225°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.378	30	-22.9
50	0.399	30.1	-20.2
75	0.406	30.9	-13.7
100	0.429	30.3	-7.6
200	0.550	25.1	-0.4
300	0.715	18.4	-0.5
400	0.851	12.1	1.4
500	0.928	8.7	2.0

Table D12: Wind characteristics at Position 1, 247.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.485	26.8	-13.3
50	0.531	25.2	-13.2
75	0.559	24.7	-10.6
100	0.579	24.3	-10.8
200	0.620	24.2	-4.1
300	0.610	25.9	1.1
400	0.640	25.6	7.2
500	0.643	25.7	8.0

Table D13: Wind characteristics at Position 1, 270º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.314	31.1	5.4
50	0.361	30.3	3.3
75	0.387	30.1	1.0
100	0.422	29.5	0.3
200	0.561	24.3	-1.6
300	0.741	17.4	-1.5
400	0.869	11.4	-4.1
500	0.954	7.8	-4.3

Table D14: Wind characteristics at Position 1, 292.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.583	15.5	-0.3
50	0.674	12.7	-1.7
75	0.727	11.6	-2
100	0.765	10.2	-1.9
200	0.854	8.5	-1.0
300	0.892	8.1	-2.1
400	0.917	7.6	-1.5
500	0.946	6.7	-2.3

Table D15: Wind characteristics at Position 1, 315º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.597	16.7	2.1
50	0.671	14.5	3.4
75	0.711	13.5	3.7
100	0.733	12.8	3.3
200	0.813	10.6	2.4
300	0.863	9.5	1.9
400	0.900	8.9	0.5
500	0.932	8.2	0.6

Table D16: Wind characteristics at Position 1, 337.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.443	22.6	1.8
50	0.477	21.5	2.6
75	0.507	21.1	1.8
100	0.541	20.6	1.3
200	0.644	18.4	-0.9
300	0.749	15.3	-0.7
400	0.818	13.1	-0.5
500	0.867	11.5	-1.5

Table D17: Wind characteristics at Position 1, 360º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.450	24.1	4.3
50	0.476	23.9	3.0
75	0.514	23.0	3.1
100	0.525	23.0	3.5
200	0.589	21.4	3.6
300	0.645	20.2	3.6
400	0.692	18.6	2.4
500	0.724	18.1	0.5

APPENDIX E

TABULATED RESULTS FOR POSITION 2

Table E3: Percentage occurrence of directional winds at 500 m, Position 2

Wind Angle (°)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
0 or 360	1.6%	5.6%	4.6%	0.5%	12.3%
22.5	1.8%	5.4%	0.9%	0.1%	8.2%
45	1.9%	5.8%	0.6%	0.0%	8.3%
67.5	1.3%	5.9%	6.9%	0.6%	14.7%
90	3.0%	10.7%	9.7%	0.7%	24.1%
112.5	2.1%	2.4%	0.5%	0.0%	5.0%
135	1.4%	1.5%	0.4%	0.0%	3.3%
157.5	1.1%	1.7%	0.3%	0.0%	3.1%
180	1.1%	2.4%	0.8%	0.0%	4.3%
202.5	0.9%	1.8%	0.3%	0.0%	3.0%
225	1.0%	3.2%	0.6%	0.0%	4.8%
247.5	0.5%	1.7%	0.9%	0.0%	3.2%
270	0.6%	1.3%	0.6%	0.0%	2.5%
292.5	0.4%	0.4%	0.1%	0.0%	0.9%
315	0.4%	0.2%	0.1%	0.0%	0.6%
337.5	0.7%	0.7%	0.4%	0.0%	1.7%

Table E2: Wind characteristics at Position 2, 22.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.553	22.7	-1.2
50	0.596	21.7	-1.5
75	0.625	20.9	-1.5
100	0.635	21.1	-0.3
200	0.675	20.9	1.7
300	0.722	20.5	2.1
400	0.760	19.1	2.0
500	0.794	18.1	0.8

Table E3: Wind characteristics at Position 2, 45°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.515	19.6	5.5
50	0.547	19.0	5.3
75	0.556	18.9	4.5
100	0.578	18.2	4.1
200	0.624	17.5	1.6
300	0.656	16.9	-1.6
400	0.699	16.1	-2.0
500	0.735	15.8	-1.4

Table E4: Wind characteristics at Position 2, 67.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.525	23.2	13.8
50	0.533	24.0	13.2
75	0.569	24.0	9.7
100	0.582	23.3	10.5
200	0.716	17.4	5.8
300	0.803	13.1	9.3
400	0.851	11.7	10.7
500	0.897	10.2	10.6

Table E5: Wind characteristics at Position 2, 90°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.259	33.1	15.2
50	0.272	33.4	11.6
75	0.296	33.3	9.3
100	0.329	32.8	7.1
200	0.438	28.4	4.7
300	0.540	23.9	6.7
400	0.656	20.9	7.8
500	0.776	16.8	10.9

Table E6: Wind characteristics at Position 2, 112.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.243	33.3	6.6
50	0.265	33.5	6.2
75	0.302	33.7	4.8
100	0.344	32.2	1.7
200	0.495	24.2	-0.6
300	0.593	19.3	-3.0
400	0.635	18.4	-3.1
500	0.671	17.7	-1.2

Table E7: Wind characteristics at Position 2, 135°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.308	33.4	3.9
50	0.364	32.3	6.4
75	0.430	30.1	7.0
100	0.490	27.8	6.5
200	0.684	18.7	7.3
300	0.731	16.6	3.0
400	0.780	15.3	2.0
500	0.846	14.1	3.1

Table E8: Wind characteristics at Position 2, 157.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.341	34.4	7.7
50	0.392	32.3	9.6
75	0.435	30.8	11.3
100	0.496	28.5	12.6
200	0.645	23.0	10.4
300	0.761	18.5	6.0
400	0.871	14.3	5.3
500	0.922	12.0	3.2

Table E9: Wind characteristics at Position 2, 180°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.260	37.9	13.2
50	0.302	37.7	20.1
75	0.314	37.0	21.1
100	0.325	37.4	19.7
200	0.380	37.7	10.3
300	0.527	32.6	1.1
400	0.730	22.8	-3.1
500	0.943	11.7	-1.7

Table E10: Wind characteristics at Position 2, 202.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.223	33.1	-5.8
50	0.227	33.9	-8.2
75	0.232	34.7	-7.6
100	0.238	35.7	-7.0
200	0.313	41.1	1.8
300	0.433	37.8	6.4
400	0.580	31.4	6.9
500	0.773	21.8	3.4

Table E11: Wind characteristics at Position 2, 225°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.289	36.7	13.9
50	0.312	36.2	14.7
75	0.328	36.3	12.0
100	0.346	35.9	10.0
200	0.444	34.1	2.3
300	0.529	30.1	-2.0
400	0.610	27.8	2.0
500	0.763	20.2	-1.0

Table E12: Wind characteristics at Position 2, 247.5^{o}

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (^{o})
25	0.386	30.4	-25.9
50	0.418	31.3	-20.5
75	0.460	31.3	-14.9
100	0.503	29.9	-9.3
200	0.691	22.3	-4.1
300	0.781	19.2	0.7
400	0.844	17.2	5.2
500	0.900	14.4	6.0

Table E13: Wind characteristics at Position 2, 270^{o}

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (^{o})
25	0.265	33.4	12.0
50	0.304	33.3	11.3
75	0.364	31.9	4.6
100	0.398	30.2	2.5
200	0.629	20.2	-5.5
300	0.792	14.0	-5.3
400	0.908	9.5	-4.3
500	0.969	7.5	-5.4

TableE14: Wind characteristics at Position 2, 292.5^{o}

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (^{o})
25	0.237	31.9	-12.0
50	0.255	33.9	-11.0
75	0.269	35.2	-8.1
100	0.301	36.1	-5.8
200	0.485	28.2	0.4
300	0.718	16.4	4.4
400	0.902	9.9	0.9
500	0.960	7.1	-0.3

Table E15: Wind characteristics at Position 2, 315^{o}

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (^{o})
25	0.345	28.6	-9.4
50	0.359	30.2	-4.5
75	0.387	30.8	-0.5
100	0.393	31.4	3.7
200	0.559	23.8	7.0
300	0.771	16.0	0.8
400	0.892	11.4	0.1
500	0.961	8.48	-1.4

Table E16: Wind characteristics at Position 2, 337.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.514	19.5	-0.4
50	0.575	18.1	0.2
75	0.628	16.6	1.4
100	0.673	15.3	2.4
200	0.734	13.9	2.8
300	0.795	12.0	2.7
400	0.824	11.9	2.4
500	0.868	10.9	2.4

Table E17: Wind characteristics at Position 2, 360º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.550	19.8	7.4
50	0.583	19.2	7.2
75	0.612	18.9	7.4
100	0.637	18.4	8.1
200	0.695	17.5	6.0
300	0.770	16.3	6.6
400	0.817	15.0	7.3
500	0.871	13.5	4.6

APPENDIX F

TABULATED RESULTS FOR POSITION 3

Table F4: Percentage occurrence of directional winds at 500 m, Position 3

Wind Angle (°)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
0 or 360	1.9%	6.4%	3.8%	0.2%	12.3%
22.5	2.2%	5.3%	0.6%	0.0%	8.2%
45	1.6%	5.7%	1.0%	0.0%	8.3%
67.5	1.3%	6.0%	6.8%	0.6%	14.7%
90	2.3%	8.8%	10.6%	2.4%	24.1%
112.5	2.0%	2.4%	0.6%	0.0%	5.0%
135	1.4%	1.5%	0.4%	0.0%	3.3%
157.5	1.0%	1.7%	0.3%	0.0%	3.1%
180	1.4%	2.5%	0.4%	0.0%	4.3%
202.5	0.7%	1.7%	0.6%	0.0%	3.0%
225	1.9%	2.8%	0.1%	0.0%	4.8%
247.5	0.4%	1.6%	1.1%	0.1%	3.2%
270	0.6%	1.3%	0.6%	0.0%	2.5%
292.5	0.4%	0.4%	0.1%	0.0%	0.9%
315	0.4%	0.2%	0.1%	0.0%	0.6%
337.5	0.6%	0.6%	0.4%	0.0%	1.7%

Table F2: Wind characteristics at Position 3, 22.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.423	29.3	7.5
50	0.459	27.9	7.5
75	0.478	28.3	4.2
100	0.506	27.3	4.9
200	0.558	26.4	3.9
300	0.633	24.0	2.1
400	0.685	22.1	2.8
500	0.726	21.2	1.9

Table F3: Wind characteristics at Position 3, 45°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.460	21.7	0.5
50	0.479	21.5	1.4
75	0.507	21.5	2.5
100	0.507	21.6	2.8
200	0.601	19.8	5.7
300	0.683	17.3	5.6
400	0.746	15.9	3.7
500	0.785	14.0	-0.2

Table F4: Wind characteristics at Position 3, 67.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.566	17.1	-2.8
50	0.625	15.3	-3.6
75	0.636	15.1	-2.5
100	0.675	14.3	-3.8
200	0.734	12.8	-2.5
300	0.801	11.5	0.1
400	0.851	10.8	-0.2
500	0.887	10.3	1.9

Table F5: Wind characteristics at Position 3, 90º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.502	21.7	-5.8
50	0.503	21.5	-2
75	0.540	21.1	0.3
100	0.574	20.6	2.6
200	0.668	18.1	2.4
300	0.743	16.4	4.7
400	0.827	14.2	1.2
500	0.900	11.8	-0.3

Table F6: Wind characteristics at Position 3, 112.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.386	24.5	14.6
50	0.414	24.7	13.2
75	0.431	24.9	10.7
100	0.458	24.7	8.8
200	0.548	22.3	2.8
300	0.627	19.6	2.2
400	0.693	17.8	3.2
500	0.728	16.5	3.2

Table F7: Wind characteristics at Position 3, 135º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.341	32.6	20.6
50	0.356	33.8	15.1
75	0.378	33.7	11
100	0.405	33.2	6.7
200	0.603	24.4	3.3
300	0.736	17.3	0.9
400	0.786	14.9	-0.7
500	0.848	13.5	-1.3

Table F8: Wind characteristics at Position 3, 157.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.361	32.8	19.9
50	0.392	33.0	15.7
75	0.460	30.3	15.3
100	0.514	28.3	12.7
200	0.702	20.2	9.6
300	0.806	15.9	8.6
400	0.880	12.4	8.7
500	0.935	10.6	6.3

Table F9: Wind characteristics at Position 3, 180°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.234	33.9	4.0
50	0.251	36.0	5.0
75	0.277	38.3	5.8
100	0.288	38.7	5.6
200	0.424	37.8	7.3
300	0.565	32.6	6.6
400	0.698	26.4	5.8
500	0.810	20.9	3.0

Table F10: Wind characteristics at Position 3, 202.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.353	36.9	-15.8
50	0.395	35.6	-14.6
75	0.447	33.2	-14.0
100	0.492	31.6	-11.8
200	0.663	24.4	-10.4
300	0.763	21.6	-6.5
400	0.865	17.6	-2.3
500	0.925	14.8	0.3

Table F11: Wind characteristics at Position 3, 225°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.333	33.2	-26.6
50	0.354	33.4	-26.0
75	0.381	32.3	-27.7
100	0.382	32.8	-24.5
200	0.373	37.3	-10.1
300	0.390	37.7	0.9
400	0.457	36.4	5.6
500	0.543	33.2	4.9

Table F12: Wind characteristics at Position 3, 247.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.338	34.8	8.7
50	0.378	34.0	3.6
75	0.457	30.8	1.2
100	0.506	28.9	-1.9
200	0.720	18.6	-2.2
300	0.847	13.3	-1.5
400	0.909	10.8	0.4
500	0.959	8.82	2.4

Table F13: Wind characteristics at Position 3, 270°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.297	30.4	-13.7
50	0.293	32.5	-9.1
75	0.296	34.3	-3.3
100	0.317	34.8	-0.3
200	0.482	27.3	-0.4
300	0.714	18.3	0.3
400	0.931	9.72	-1.9
500	0.969	7.15	-2.7

Table F14: Wind characteristics at Position 3, 292.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.488	19.3	5.7
50	0.526	19.4	3.5
75	0.565	19.3	1.7
100	0.623	18.6	0.5
200	0.756	16.5	4.8
300	0.931	8.1	8.9
400	0.964	6.9	7.0
500	0.987	6.5	4.0

Table F15: Wind characteristics at Position 3, 315°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.592	17.2	8.8
50	0.680	15.7	7.9
75	0.743	14.0	9.1
100	0.801	12.6	7.2
200	0.874	10.3	3.7
300	0.926	8.4	4.3
400	0.943	8.4	4.0
500	0.962	8.4	3.7

Table F16: Wind characteristics at Position 3, 337.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.595	15.5	13.2
50	0.639	14.6	12.1
75	0.670	13.9	11.2
100	0.705	13.3	10.4
200	0.755	12.3	9.9
300	0.810	11.3	7.5
400	0.848	10.9	6.9
500	0.897	9.7	5.6

Table F17: Wind characteristics at Position 3, 360º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.441	25.9	5.1
50	0.477	24.9	3.7
75	0.507	24.3	2.6
100	0.522	23.5	2.3
200	0.567	23.5	3.0
300	0.640	22.2	4.1
400	0.716	19.9	7.5
500	0.784	17.7	5.7

APPENDIX G

TABULATED RESULTS FOR POSITION 4

Table G1: Percentage occurrence of directional winds at 500 m, Position 4

Wind Angle (°)	Percentage Occurrence (%) for wind speed ranges:				
	0-3.3 m/s	3.4–7.9 m/s	8.0–13.8 m/s	>13.8 m/s	Total
0 or 360	1.9%	6.3%	3.9%	0.2%	12.3%
22.5	2.4%	5.3%	0.5%	0.0%	8.2%
45	1.2%	5.1%	2.0%	0.0%	8.3%
67.5	1.4%	6.4%	6.5%	0.4%	14.7%
90	2.3%	8.5%	10.7%	2.6%	24.1%
112.5	1.8%	2.4%	0.8%	0.1%	5.0%
135	1.4%	1.5%	0.4%	0.0%	3.3%
157.5	1.1%	1.7%	0.3%	0.0%	3.1%
180	2.3%	2.0%	0.1%	0.0%	4.3%
202.5	0.8%	1.7%	0.6%	0.0%	3.0%
225	0.7%	2.8%	1.2%	0.0%	4.8%
247.5	0.4%	1.6%	1.2%	0.1%	3.2%
270	0.6%	1.2%	0.6%	0.0%	2.5%
292.5	0.4%	0.4%	0.1%	0.0%	0.9%
315	0.4%	0.2%	0.1%	0.0%	0.6%
337.5	0.6%	0.6%	0.4%	0.0%	1.7%

Table G2: Wind characteristics at Position 4, 22.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.434	27.1	0.1
50	0.474	25.7	-1.1
75	0.490	26.6	-2.3
100	0.506	26.0	-2.4
200	0.583	25.1	-2.0
300	0.626	23.5	-2.6
400	0.679	22.0	-1.2
500	0.705	22.1	-0.6

Table G3: Wind characteristics at Position 4, 45°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.417	27.3	-3.3
50	0.449	26.6	-1.7
75	0.482	26.2	-2.0
100	0.512	25.4	-1.4
200	0.645	21.7	0.2
300	0.771	16.8	2.3
400	0.868	12.5	1.6
500	0.894	11.5	2.0

Table G4: Wind characteristics at Position 4, 67.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.529	18.3	2.9
50	0.560	17.9	3.6
75	0.596	16.9	3.5
100	0.611	16.6	4.3
200	0.699	15.0	4.2
300	0.755	13.5	10.6
400	0.806	12.6	11.7
500	0.856	11.3	13.3

Table G5: Wind characteristics at Position 4, 90º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.525	18.7	-0.6
50	0.574	17.6	1.9
75	0.601	17.2	3.7
100	0.617	16.6	4.6
200	0.687	15.7	6.4
300	0.778	13.9	5.5
400	0.846	12.4	6.2
500	0.917	10.4	7.3

Table G6: Wind characteristics at Position 4, 112.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.492	20.1	9.8
50	0.509	19.9	9.7
75	0.548	19.4	9.9
100	0.560	19.6	8.4
200	0.640	18.5	5.9
300	0.724	16.9	4.5
400	0.747	15.8	3.9
500	0.785	14.7	2.8

Table G7: Wind characteristics at Position 4, 135º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.441	24.3	27.5
50	0.465	24.9	24.8
75	0.490	25.2	20.3
100	0.499	25.6	17.8
200	0.607	22.4	11.4
300	0.703	18.3	8.0
400	0.786	15.6	8.5
500	0.835	13.7	6.3

Table G8: Wind characteristics at Position 4, 157.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.425	28.0	28.2
50	0.469	27.5	24.7
75	0.520	25.9	22.6
100	0.560	24.3	19.2
200	0.726	18.1	10.9
300	0.806	14.1	8.8
400	0.868	11.5	6.9
500	0.909	10.2	5.9

Table G9: Wind characteristics at Position 4, 180°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.222	34.0	5.3
50	0.234	35.7	7.1
75	0.242	36.8	7.7
100	0.251	37.9	7.1
200	0.314	40.2	7.2
300	0.381	39.5	4.4
400	0.467	36.4	4.3
500	0.565	32.3	1.3

Table G10: Wind characteristics at Position 4, 202.5°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.321	38.4	12.5
50	0.340	38.1	9.7
75	0.362	38.4	6.8
100	0.398	36.9	7.5
200	0.520	32.6	3.3
300	0.661	26.2	-0.8
400	0.798	20.3	-3.2
500	0.893	16.2	-3.4

Table G11: Wind characteristics at Position 4, 225°

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (°)
25	0.442	29.5	-18.3
50	0.493	27.4	-18.1
75	0.553	25.8	-19.5
100	0.604	24.1	-18.7
200	0.709	21.9	-11.4
300	0.787	19.2	-5.3
400	0.826	18.9	-2.8
500	0.905	14.0	-1.9

Table G12: Wind characteristics at Position 4, 247.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.414	27.1	-13.8
50	0.462	26.3	-11.2
75	0.514	24.9	-8.3
100	0.548	23.5	-5.7
200	0.674	18.3	-3.4
300	0.774	15.8	-1.0
400	0.883	11.8	2.0
500	0.970	8.0	-2.3

Table G13: Wind characteristics at Position 4, 270º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.495	19.7	-10.1
50	0.558	18.7	-10.3
75	0.658	16.0	-7.0
100	0.717	14.5	-6.6
200	0.877	9.2	-4.6
300	0.932	7.7	-4.3
400	0.965	7.0	-4.9
500	0.977	6.6	-10.8

Table G14: Wind characteristics at Position 4, 292.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.660	12.6	2.2
50	0.754	10.6	1.5
75	0.816	9.2	1.8
100	0.848	8.4	0.6
200	0.911	7.5	1.3
300	0.948	7.4	4.9
400	0.963	7.0	3.8
500	0.985	6.5	1.8

Table G15: Wind characteristics at Position 4, 315º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.710	12.0	7.0
50	0.765	10.8	6.7
75	0.801	10.0	6.6
100	0.827	9.7	5.4
200	0.878	9.3	3.7
300	0.925	8.8	4.3
400	0.953	8.5	3.3
500	0.967	8.5	3.9

Table G16: Wind characteristics at Position 4, 337.5º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.611	14.1	15.0
50	0.654	13.4	13.2
75	0.686	12.9	12.2
100	0.703	12.6	11.8
200	0.752	12.0	11.5
300	0.810	11.5	12.0
400	0.867	10.3	10.5
500	0.911	9.1	9.2

Table G17: Wind characteristics at Position 4, 360º

Prototype scale height (m)	Normalised mean wind speed	Turbulence intensity (%)	Yaw angle (º)
25	0.417	27.2	4.7
50	0.447	26.7	5.5
75	0.471	26.1	5.4
100	0.482	26.1	5.2
200	0.559	24.8	3.7
300	0.623	22.6	5.2
400	0.697	20.0	6.5
500	0.800	16.4	4.1