A STUDY TO INVESTIGATE THE CAUSE OF FAILURE AND COLLAPSE OF UMNO TOWER PENANG

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A STUDY TO INVESTIGATE THE CAUSE OF FAILURE AND COLLAPSE OF UMNO TOWER PENANG

DEBBIE CYNTHIA CLARENCE BOTITI

Thesis submitted in fulfilment of the requirements
for the award of the degree of
B.Eng (Hons) Civil Engineering

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JUNE 2015

SUPERVISOR'S DECLARATION

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Dedicated to both of my parents,
for their love and devotion
making me be who I am today

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ABSTRACT

Wind-related disaster had become significant impacts in our society which responsible for the tremendous physical destruction, loss of life, injury and economic damage. On June 13th 2013, a severe thunderstorm hits Penang which lasted for about an hour. In this tragedy, the lightning arrestor pole together with several accompanying structure, the fin-shaped wall attached to a 21-storey UMNO Tower Penang came crashing down during a thunderstorm, crushing vehicles, killing two and five were severely wounded. Therefore this study was carried out to investigate the effect of wind speed to the building tower. Computational Fluid Dynamic has been used in order to examine the effect of wind to the tower. Variations of directions are tested to the tower model. From the result it clearly shows that wind load may increase up 2.71 times from North West Direction from the normal wind act to tower. Additionally historical wind speed data at the nearest meteorological station after the building was also examined. From that it was observed historical wind speed is greater compare to the design wind speed. It may also seem that this value is not the worst that can cause the structure to collapse. Historical wind speed also showed foremost wind blow come from North West Direction. It can be concluded that the possibility of the collapse are highly foreseeable due to repeatable wind speed. The effect of the geometrical shape of the tower may also increase the wind load effect to the tower. Based on the result it can be conclude the repeatable load acting to structural component of the tower may weaken the structural component. Therefore consideration of wind load direction is highly recommended during the design stage.

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ABSTRAK

Bencana yang melibatkan angin telah menjadi impak yang besar dalam masyarakat kita. Berdasarkan data yang direkod ia melibatkan kemusnahan fizikal yang besar, kehilangan nyawa, kecederaan dan kerosakan ekonomi. Pada 13 Jun 2013, Pulau Pinang di landa ribut petir yang teruk yang berlangsung selama satu jam. Dalam tragedi ini, tiang penebat kilat bersama-sama dengan beberapa struktur dinding berbentuk sirip terletak di tingkat 21 Menara UMNO Pulau Pinang telah runtuh semasa angin ribut, menghancurkan kenderaan, membunuh dua orang dan lima yang lain telah cedera teruk. Oleh itu kajian ini dijalankan untuk mengkaji kesan angin ke menara bangunan. *Computational Fluid Dynamics* (CFD) telah digunakan untuk mengkaji kesan angin ke menara. Variasi arah angin diuji terhadap model menara tersebut. Dari keputusan itu jelas menunjukkan bahawa beban angin boleh meningkat sehingga 2.71 kali dari arah Barat Laut. Selain itu rekod data kelajuan angin di stesen meteorologi yang terdekat selepas bangunan itu juga telah di siasat. Hasilnya mendapati , rekod kelajuan angin adalah lebih tinggi berbanding dengan kelajuan angin rekabentuk. Nilai rekod halaju angin ketika kejadian tidaklah luarbiasa sehingga boleh menyebabkan struktur runtuh. Kelajuan angin direkod juga menunjukkan arah tiupan angin utama datang dari arah Barat Laut . Dapat disimpulkan disini bahawa kebarangkalian struktur untuk runtuh adalah disebabkan kelajuan angin yang berulang. Kesan bentuk geometri menara juga boleh meningkatkan kesan beban angin ke menara tersebut. Dari kajian ini, boleh disimpulkan bahawa beban berulang yang bertindak terhadap komponen struktur menara itu boleh melemahkan komponen struktur. Oleh itu pertimbangan terhadap arah beban angin adalah patut dititikberatkan pada peringkat awal reka bentuk.

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LIST OF SYMBOLS

%	Percentage
m/s	Meter per second
kN/m^2	Kilonewton per meter square
km/h	Kilometers per hour
°	Degree
Md	Wind Directional Multiplier
Mz,cat	Terrain/ Height Multiplier
Ms	Shielding Multiplier
Mh	Hill Shape Multiplier
Pa	Pascal
Vs	Basic Wind Speed
Vdes	Design Wind Speed
I	Wind Importance Factor
Cfiq	Aerodynamic Shape Factor
Cdyn	Dynamic Factor

LIST OF ABBREVIATIONS

MS	Malaysia Standard
MET	Malaysian Meteorological Department
BS	British Standard
CP	Code of Practice
EN	European Standards
AS/NZS	Australia Standards/ New Zealand Standards
3D	3-Dimensional
CFD	Computational Fluid Dynamics
N	North
NW	North West
NE	North East
S	South
SE	South-East
SW	South-West
W	West
E	East
AS	American Standard

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Wind-related disaster had become significant impacts in our society which responsible for the tremendous physical destruction, loss of life, injury and economic damage. The severity and increased frequency of wind-related disaster events over the past few years in Malaysia has shifted the attention from several researchers towards to investigate the effect of wind effect on building structure in Malaysia. On June 13th 2013, a severe thunderstorm hits Penang which lasted for about an hour. In this tragedy, the lightning arrestor pole together with several accompanying structure, the fin-shaped wall attached to a 21-storey UMNO Tower Penang came crashing down during a thunderstorm, crushing vehicles, killing two and five were severely injured. Therefore this study was carried out to investigate the effect of wind speed and direction to the building tower.

Wind occurs due to the existence of different level of atmospheric pressure. When a difference in atmospheric pressure exists, air under high pressure will moves towards area of lower pressure, which in turn resulting in wind of various speeds. The greater the difference in pressure, the faster the air flows. Liu, (1991) stated that, building or structures deflect winds causing a change in wind speed and direction around the buildings or structures Wind has a very dynamic, unsteady flow pattern in the environment (Vasan & Stathopoulos, 2012). Due to this point, not every point on a building or structure in the path of flow has the same velocity. These characteristics can be reflected in the velocity distributions on the building surface in the path of flow.

Frictional effects play an important role for wind near the ground surface. Stathopoulos (2007) reported that ground obstructions slow down the movement of air close to the ground surface causing reduction in wind speed. Thus, the mean wind speed may change in direction slightly with height, as well as magnitude (Holmes, 2001). Recently, Computational Fluid Dynamics (CFD) has become a powerful tool for the study of airflow through and around structures in built-up areas. CFD enables to see results almost immediately and allows exploring the effect of different wind speed and direction. CFD techniques may be used for determination of wind effects where Standards are sometimes not directly or as easily applicable, for instance when designing tall buildings and non-conventional structures. (Mendis et al. ,2007).

High-rise buildings are particularly influential to wind effects. Therefore, information regarding the wind flow pattern can be important for architects and engineers. However, with the advent of computational analysis using advanced modeling techniques like CFD, it is made possible to simulate the same condition in a virtual environment. CFD allows designers to analyze a full domain of the model and presents the results of analysis in an easy to understand graphical way.

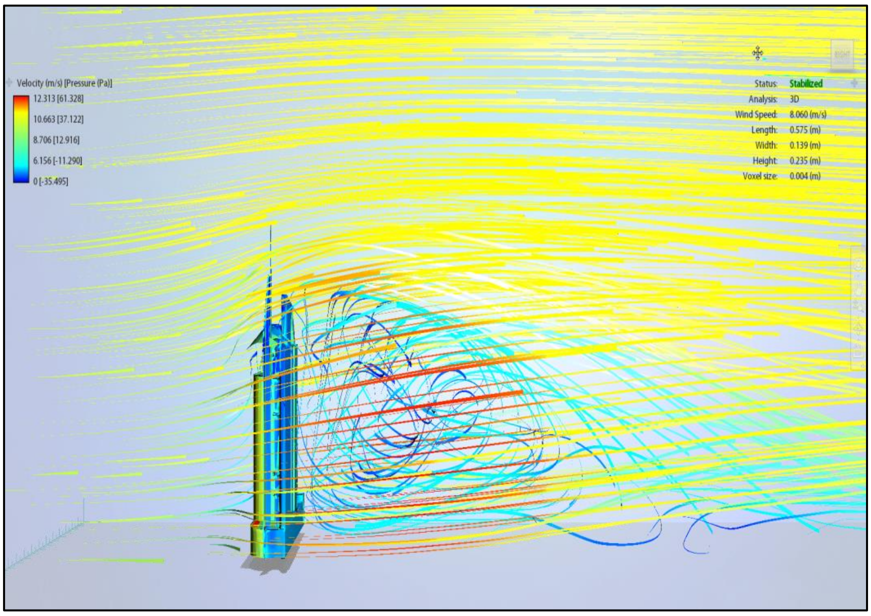


Figure 1.1 Example of result obtained from CFD analysis

Matsui et al. (2003) has examined the effects of directional wind characteristics and the orientations of structures on wind loads on the basis of the Holmes method. It is important to decide the directional characteristics of strong winds at a construction site in order to achieve a resilient wind-resistant design. Wind load in structural engineering can be defined as the natural horizontal load produced by air and it is the most important element because wind load has a great deal of influence on building design and the design of other kinds of civil engineering structures. Structural member fails because of inadequate consideration given to wind action at the design stage. In practice, it has been found useful to start with a reference wind speed based on statistical analysis of wind speed records obtained at meteorological stations throughout the country or near to the area of study.

1.2 PROBLEM STATEMENT

Design and orientation of building or structure did not consider the repeatable load effect to the building which at some point could contribute to the structural damage or failure. All of the standards provide the value of coefficients specifically for orthogonal wind directions and regular-shaped buildings. The standards do not apply to buildings or structures that are of unusual shape or location. Furthermore, the scope of MS 1553:2002 is limited to a small range of geometries and structures for which the wind loading does not control the design.

1.3 OBJECTIVES OF STUDY

In any research, there are some objectives to be achieved. In this research, the objectives are:

i. To investigate the effect of building orientation and shape to the wind characteristics.

ii. To simulate the building against variation of wind speed and direction by using Computational Fluid Dynamics

1.4 SCOPE OF STUDY

The UMNO Tower building is located in Macalister Road, Georgetown Penang. Therefore, the area of study is in the State of Penang only. Weather data were obtained from Malaysian Meteorological Department (MET) specifically for the year 2013 and 2014 in Penang. Additional weather data for nearby meteorological stations which are Butterworth, Bayan Lepas, Alor Setar and Langkawi specifically on 13 June 2013 were also collected. Computational Fluid Dynamics is used for simulation purpose in order to investigate the wind flow pattern and wind loading acting to the building tower. UMNO Tower building was drawn in Sketch-up software in accordance to the full-scale size of the UMNO Tower building.

In this research, only the effects due to wind and direction are investigated. The impact due to rain was negligible. The obstruction of other existing tall building such as KOMTAR Tower or other buildings was not considered in this research.

1.5 SIGNIFICANT OF STUDY

The research provides a clearer study and analysis by using Computational Fluid Dynamics to visualize graphically the airflow pattern and its behavior around the building or structures. Hence, it is a reliable method chosen by many researchers to conduct their experiments without harming the environment, as opposed to relying on expensive and time consuming usually in the case with using a physical wind tunnel modeling.

1.6 THESIS STRUCTURE

The thesis is divided into five main chapters:

i) Chapter 1 : Introduction

   This chapter includes the overview of the studies, problem statement, objectives, scope of study and significant of study.

ii) Chapter 2 : Literature Review

This chapter reviews about the previous study material which related to the objectives.

iii) Chapter 3 : Methodology

This chapter illustrates the flow of thesis in a flow chart, from data collection until the production of the result.

iv) Chapter 4 : Result and Discussion

This chapter displays the results and discussion based on the case study.

v) Chapter 5 : Conclusion and Recommendation

This chapter discuss about the concluding remarks of the study based on the results and discussion and future suggestion about the studies.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Wind is a phenomenon of great complexity because of the many flow situations arising from the interaction between wind and structures. Currently, a multitude of studies had been conducted in studying this interaction.

An incident at Macalister Road on 13 June 2013 that caused lighting arrestor at the top of UMNO Tower dropped off and crashed down to Macalister Road are highlighted for this research. Two triggering factors were studied in the forensic investigation, namely lighting and wind. However, in this research only the factor due to wind characters will be discussed.

2.1 WIND SPEED

Wind speed or wind flow velocity measured in meters per second or knots, is a fundamental atmospheric rate. Wind speed is caused by air moving from high pressure to low pressure area which is usually due to changes in temperature. Mendis (2007) summarized that the air movements are driven by pressure gradients in the atmosphere, which in turn are the thermodynamic consequences of variable solar heating of the earth. This upper level of wind speed is known as the gradient wind velocity.

The neutral data about the wind speeds is usually defined in terms of averaging period, return period, height above the ground, topography and ground roughness (Tony Gibbs, 2000).

2.1.1 Basic Wind Speed

The basic wind speed, Vs is the 3-second gust speed estimated to be exceeded on the average only once in 50 years at a height of 10 m (33 ft.) above the ground in an open situation. Basic wind speed is used to determine the design wind pressure acting onto a structure. It will then be adjusted for specific cases using various parameters including the averaging period, return period, ground roughness, height, topography and size of structure in order to obtain the design wind speeds for the particular cases. Basically, this wind speed is obtained by a statistical analysis of measurements at meteorological stations. Basic design wind speeds for different directions and different return periods can be derived using a rigorous analysis incorporating probability distributions for wind speed and direction.

According to Faridah et al. (2004), there exist a multitude of national wind loading codes and standards with a range of defined averaging periods and return periods that can be used for structural design purposes. However, to date, there is no single document that provides world-wide data on extreme wind speeds at present. Various studies were conducted to determine the basic wind speeds with a range of defined averaging periods and return period. Holmes (2001) summarized briefly the sources of basic design wind speed for 56 countries, and classified these countries or territories into five levels, with respect to the magnitude of their extreme wind speeds. Design wind speeds for the Asia-Pacific Region have been summarized by Holmes and Weller (2002) based on national codes and standards and a five-level zoning system. Eurocode 1: Wind actions on Structure (1991) provides a harmonized code for winds but the basic wind speeds is provided by the national application documents of respective European member countries.

Before the establishment of the Malaysian Standard, MS1552 (2002), the common practice of determining the basic wind speed was based on either the following step:

i. Obtaining wind speed data of the nearest meteorological station from Malaysian Meteorological Department (MET).

ii. Adopting any Code of Practice such as British Standard, CP3 or BS6399

In practice, establishing a reference wind speed based on statistical analysis of wind speed records obtained at meteorological stations throughout the country are proven to be useful in early stage. This is due to the fact the definition of reference wind speed may varies from one country to another.

Table 2.1 shows the typical value of the basic wind speed for 50 years return and 100 years return in 2013 for major towns in Peninsular Malaysia which is based on 3-sec gust. UMNO Tower located at George Town Penang. Therefore, Butterworth and Bayan Lepas station are referred to estimate the basic wind speed.

Table 2.1: Basic Wind Speed for major towns in Peninsular Malaysia

Stations	50 Year Return Period (ms^{-1})	100 Year Return Period (ms^{-1})	Period
Chuping	25.0	26.5	1979 – 2012
Alor Star	29.2	31.1	1939 – 2012
Butterworth	24.5	25.5	1985 – 2012
Bayan Lepas	27.2	28.6	1939 – 2012
Ipoh	30.8	32.9	1939 – 2012
Sitiawan	25.3	26.8	1939 – 2012
Batu Embun	26.8	28.7	1983 – 2012
Cameron Highlands	28.7	30.3	1983 – 2012
Subang	31.0	33.1	1966 – 2012
Petaling Jaya	31.0	33.0	1971 – 2012
KLIA Sepang	21.9	22.8	1998 – 2012
Malacca	28.5	30.4	1941 – 2012
Kluang	31.3	33.9	1974 – 2012
Senai	29.1	31.0	1974 – 2012
Mersing	31.6	33.5	1939 – 2012
Muadzam Shah	24.4	26.0	1983 – 2012
Temerloh	27.0	28.9	1978 – 2012
Kuantan	30.0	31.9	1950 – 2012
Kuala Terengganu	29.8	31.9	1985 – 2012
Kota Bahru	32.4	34.5	1939 – 2012
Kuala Krai	27.6	29.1	1985 – 2012

Source: Malaysian Meteorological Station (MET), 2013

According to the map given in MS 1335:2002, UMNO Tower situated in Zone 1 with basic wind speed=33.5 m/s at 10m height. Although **Table 2.1** has given the wind speed for various return period (Butterworth and Bayan Lepas station is the nearest to the tower) but the wind speed in 100 years is only 27.7 m/s. Therefore, basic wind speed, for that particular location is chosen as 33.5 m/s. **Figure 2.1** shows the mapping of basic wind speed in Peninsular Malaysia according to 50 years return period.

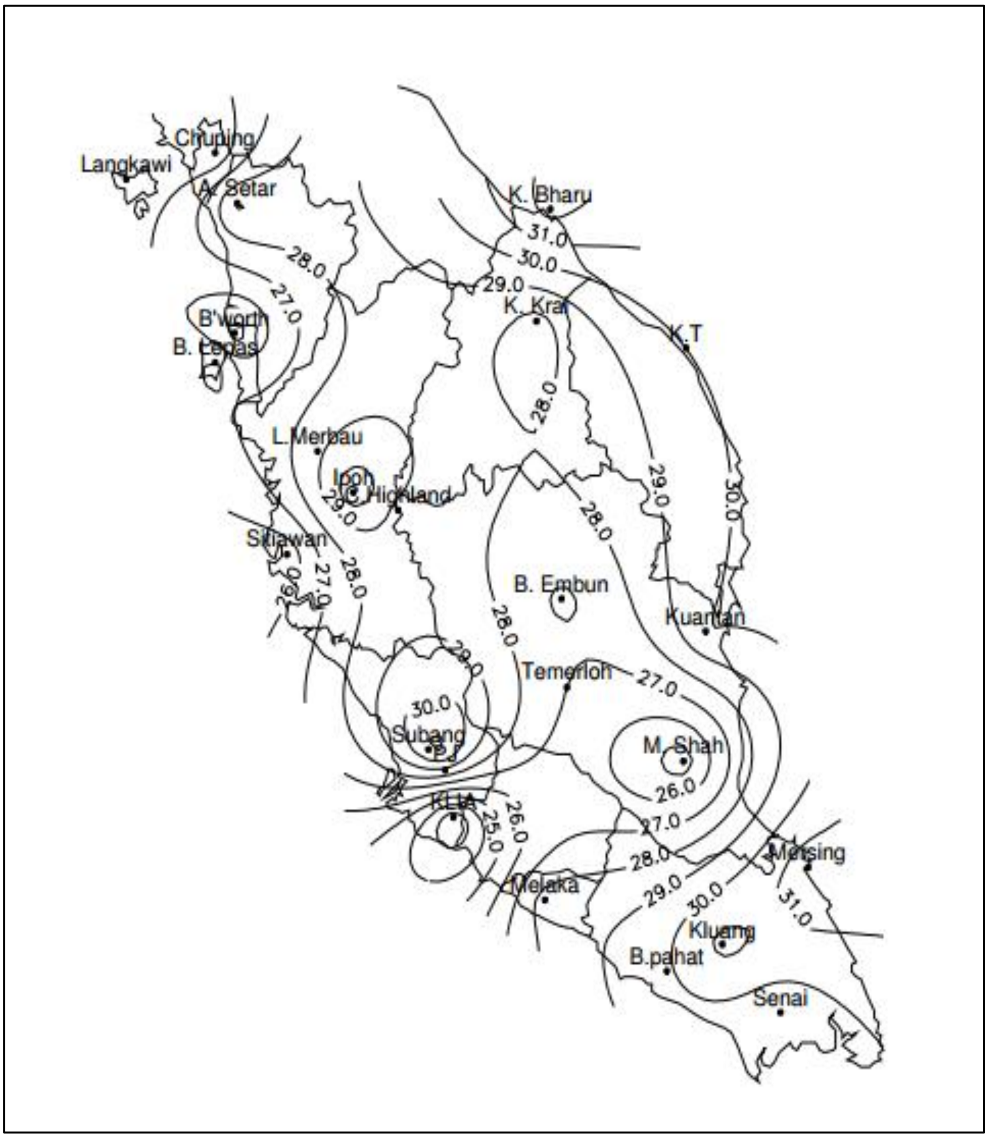


Figure 2.1 Basic Wind Speed for towns in Peninsular Malaysia
(50 Years Return Period)

Source: Malaysian Meteorological Department (MET) 2013

2.1.2 Return Period

The theoretical return period is the inverse of the probability that the event will be exceeded in any one year. Wind speeds are amenable to statistical analysis. The estimated return period are normally statistically computed from a set of data or observations. According to Tony Gibbs (2000) the shortest return period of 2 years is only recommended for temporary structures and for incomplete structures during erection. The longer the return period chosen, the lower the probability level chosen and thus the more conservative will be the design wind speed.

2.1.3 Design Wind Speed

One of the key components of any wind loading code is the design wind speed. Typical calculations of design wind are based on estimated measured data or basic wind speed information in the design codes. The variation with direction and height is determined using established techniques based on the roughness and topography of the site. Malaysia experiences low wind speed, however, this does not mean that constructed buildings or structures are free from the consequential and adversarial effects of winds.

The design wind speed shall be computed using the following equation:

$$V_{des} = V_{site}\ X\ I$$

Where,

V_{des} = Design Wind Speed

I = Wind Importance Factor

The value of site wind speed can be calculated using the following equation:

$$V_{site} = V_s(M_d)\left(M_{z,cat}\right)(M_s)(M_h)$$

Where,

V_s	=	Basic Wind Speed (m/s)
M_d	=	Wind Directional Multiplier
$M_{z,cat}$	=	Terrain /Height Multiplier
M_s	=	Shielding Multiplier
M_h	=	Hill Shape Multiplier

2.2 WIND LOADING

The estimation of wind loading for structural design in Malaysia is based on MS1553: Code of Practice on Wind Loading for Building Structures, 2002. The Code is an adaptation of the Australian/ New Zealand Standard, AS/NZS 1170.2: Structural Design General Requirements and Design Action (Faridah et al., 2004). The characteristics of wind pressures are determined based on the characteristics of the approaching wind, the geometry of structure under consideration and the geometry and proximity of the structures upwind.

Mendis et al.(2007) summarized briefly that the pressure are not steady but highly fluctuating and not uniformly distributed over the surface of the structure, partly as a result of the gustiness of the wind and also because of the local vortex shedding at the edges of the structures themselves. It is said that, under dynamic excitation, the fluctuating pressure can result in fatigue damage to structures.

Merrick and Bitsuamlak (2009) studied the shape effects on the wind-induces response of high-rise buildings and concluded that certain shapes that are prone to wind phenomena, such as vertex-shedding, which can generate high dynamic loads, governs the design of the tall buildings and the general wind loadings patterns are very useful in the building design circles.

When applying a design document, the complexities of wind loading must be constantly reminded due to many uncertainties involved. The maximum wind loads experienced by a structure during its lifetime may vary widely from those assumed in design stage.

2.2.1 Design Practices

There is wide variation between various standards when it comes to information on force and pressure coefficients. All of the standards provide the value of coefficients specifically for orthogonal wind directions and regular-shaped buildings. The Standards do not apply to buildings or structures that are of unusual shape or location. The evaluation of wind loads on buildings is carried out mainly by using codes and standards used on wind tunnel tests which performed on isolated structures in an open terrain.

The scope of MS 1553:2002 is limited to a small range of geometries and structures for which the wind loading does not control the design. The use of wind loading for mostly conventional type of building structure in the codes is perfectly adequate. However, for cases involving unusual geometry of building or structure, it is often not possible to obtain an accurate wind loading from the codes used to achieve reliable design. Current studies suggested making use of experimental wind tunnel data in replacing the coefficient given in the standard codes.

2.2.2 Design Consideration for Tall Building

As buildings become tall and complex, it becomes imperative to account for wind loads. Wind not only would effects the load distribution pattern on buildings but it also influences various design parameters.

Wind effects are an extremely important aspect in the design of tall buildings. Wind loading can often be the dominant load case, with significant increases in loading due to dynamic effects (Holmes, 2001). Model scaled tall building may be tested in commercial wind tunnels during design stage to determine the likely loads under both service-level and extreme wind events.

The simplified approach assumes a uniform lateral pressure on windward side of a building and suction on leeward wall to represent the total effect of wind. Only horizontal shear and overturning moments were calculated. For low or medium height buildings, such simple methods may have been reasonably satisfactory, but for tall buildings, the greater importance of wind loading calls for more accuracy (Pittack, 1998)

UMNO Tower is a 21-storey skyscraper located at 128 Macalister Road in George Town, Penang. The building itself is 93.5 meters tall up to the height of its roof. Design wind speed for Penang area were taken as 33.5 m/s (Zone 1) by according to 3 second gust at 10m (33 ft.) above grade for 50-year return period.

2.2.3 Wind Pressure Equation

The design wind pressure shall be computed using the following equation:

$$P = 0.613\ [Vdes]^2 C_{fig} C_{dyn} P_a$$

Where,

$Vdes$ = Design Wind Speed

C_{fig} = Aerodynamic Shape Factor

C_{dyn} = Dynamic Factor

2.4 EFFECTS OF SURROUNDINGS BUILDINGS

Several researchers indicate that wind loads on buildings in realistic environments may be considerably different from those measured on isolated buildings. Surrounding buildings or structures may either decrease or increase the flow-induced forces on a building. However, it is mainly depend on the geometry and arrangement of these structures, orientation with respect to the direction of flow and upstream terrain conditions.

Generally, the mean interference effects of tall buildings present “shielding effects” where the presence of existing nearby buildings tends to decrease the mean wind load on the principal building. Taniike (1992) found that the shielding effects could still be noticeable when the upstream building was located at a place 16 times of the building breadth away from the downstream building. Presence of a neighbouring building introduces asymmetry in wind flow pattern around the test building, leading to possible highly magnification of wind-induced torsion (Zhang et al., 1994). The parameters which cause the wind induced interference effects include shape of the buildings, wind velocity and direction, type of approach terrain, arrangements of buildings and the location of proximity of neighboring buildings (Cho et al., 2004)

UMNO Tower is 93.5 m tall (21-storey) compared to KOMTAR which is 231.7 m tall (65-storey). However, wind direction taken at Bayan Lepas and Butterworth were respectively comes from North-West Direction. It is anticipated that the KOMTAR building location was not in the wind path of UMNO Tower. There was no tall building located within 569.32 m from UMNO Tower based on site observation. Therefore, the obstruction from other buildings was not considered in the simulation.

2.5 WIND SIMULATION USING CFD

There are many situations where analytical methods cannot be used to estimate certain types of wind loads and associated structural response. CFD (Computational Fluid Dynamics) is becoming a powerful tool to predict the behavior of structures in practical engineering cases. Mendis et al. (2007) summarized that CFD techniques may be used where standards are sometimes not directly or easily applicable in determining the wind effects to the structures such as when designing tall building and non-conventional structures.

In fact, a literature survey shows that few studies have been made on the numerical simulation of wind flow conditions around building. Most of the studies carried out in this area considered only the wind flow around a single rectangular building for wind direction perpendicular to the wall of the building.

Many works using CFD to evaluate ventilation performance have been executed since it can provide detailed airflow patterns and thermal conditions. Researchers like Appupillai and Ahmed Kashef (1996) presents the application of CFD for modelling wind environmental conditions around a variety of building configurations From that reviews, it appears that they can already fill a useful role not only for research but also for generating information for early stages of design.

CFD simulations easily allow parametric studies to evaluate alternative design configurations. Most studies included a comparison of the CFD results with wind tunnel measurements for the same urban configuration such as Takakura et al. (1993) and Stathopoulos and Baskaran (1996).

Furthermore, an application of CFD for pedestrian-level wind conditions can be found in Blocken et al., (2008). While these studies did not assess wind comfort and wind safety, they have evaluated CFD as an important ingredient of such studies. To the knowledge of the author, Blocken and Persoon (2009) did a study on the wind comfort and wind safety based on CFD. Blocken (2012) reviewed that wind tunnel measurements do not provide a whole image of flow field, but CFD on the other hand provides whole-flow field data such as data at relevant parameters in all points of the computational domain. Blocken et al. (2009) performed CFD simulations of forced convective heat transfer on a 10 m tall cubic building for four reference wind speeds at building height.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

Wind are one of the factor involved based on forensic investigation. Therefore, efforts have been focused on obtaining information on wind from the Meteorological Department (MET) and conducting extensive 3D wind simulation analysis based on this data. However, wind data provided by MET so far is only sufficient to estimate the wind pressure during the incident but it is inadequate to determine the wind excitation frequency. This chapter will discuss about the methods of collecting the data and inputting the data to get the results. The main purpose of this chapter is to achieve the objectives of this study. This study is primarily consists of 4 phases, which are:

i) Data collection

   Obtaining historical weather data from 2013 to 2014 and the weather data specifically on 13 June 2013 from nearby stations (Butterworth, Bayan Lepas, Alor Setar and Langkawi meteorological station)

ii) Preparation

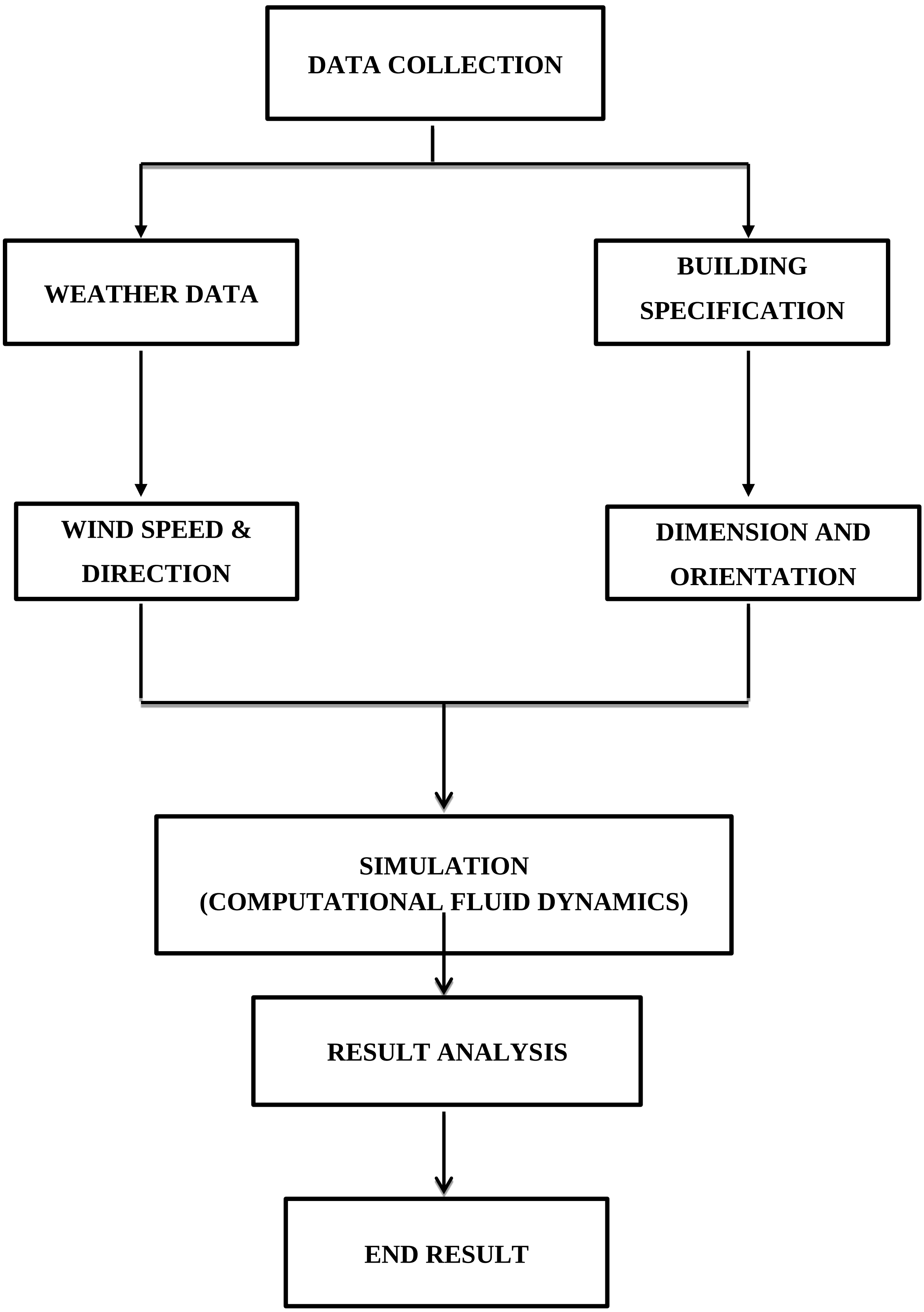
   The collected data are displayed and quantified in Microsoft Excel in the form of tables

iii) Data Processing

   Data are input into Computational Fluid Dynamics (CFD) and analyzed

iv) Results

3.2 RESEARCH FLOWCHART



3.3 DATA COLLECTION & PREPARATION OF DATA

The UMNO Tower incident happens on 13 June 2013 at about 6.45pm where severe thunderstorm hits Penang for about an hour. In this research, historical weather data were taken throughout the Year of 2013 and 2014. The main source of weather data are obtained from Malaysian Meteorological Department which focuses on Penang area and nearby meteorological stations such as Butterworth, Bayan Lepas, Alor Setar and Langkawi.

3.3.1 Historical Wind Data

In order to estimate the maximum average wind speed and which direction of wind blows foremost for that particular year, historical wind data are gathered on monthly basis starting from January 2013 until December 2014. Example information obtained from MET are as shown in **Table 3.1** and **Figure 3.1.**

Table 3.1 Daily weather data for June 2013,

Daily Weather History & Observations

2013	Temp. (°C)			Dew Point (°C)			Humidity (%)			Sea Level Press. (hPa)			Visibility (km)			Wind (km/h)			Precip. (mm)	Events
Jun	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	high	sum	
1	33	29	24	27	25	23	94	85	64	1010	1007	1004	18	10	8	11	3	-	0.00	Rain
2	32	29	25	27	25	24	94	85	68	1008	1006	1003	19	11	10	11	3	-	0.00	Rain , Thunderstorm
3	33	28	24	27	25	24	100	84	60	1009	1006	1004	19	11	8	21	5	-	0.00	Thunderstorm
4	33	29	24	26	24	23	94	86	65	1011	1008	1006	19	10	1	14	6	-	53.09	Rain , Thunderstorm
5	33	28	23	26	24	23	100	85	62	1011	1008	1006	18	10	4	21	5	-	8.89	Rain , Thunderstorm
6	32	27	23	26	24	22	100	86	66	1011	1009	1006	19	9	3	11	3	-	0.00	
7	34	29	23	27	25	23	94	84	57	1010	1008	1005	14	10	6	19	3	-	12.95	Rain , Thunderstorm
8	33	29	24	27	25	24	94	86	65	1010	1007	1004	19	11	10	8	3	-	7.87	Rain , Thunderstorm
9	32	28	24	27	26	24	95	84	64	1009	1006	1004	19	10	6	16	6	-	0.00	
10	33	29	25	27	26	24	94	84	58	1007	1006	1004	19	11	9	10	5	-	0.00	
11	33	29	25	26	24	22	100	85	56	1007	1006	1003	19	10	3	35	5	-	0.76	Rain , Thunderstorm

Source: Malaysian Meteorological Stations, 2013

Month of June, 2013

« Previous Month | Next Month »

Daily | Weekly | Monthly | Custom

	Max	Avg	Min	Sum
Temperature				
Max Temperature	36 °C	33 °C	30 °C	
Mean Temperature	30 °C	29 °C	27 °C	
Min Temperature	26 °C	24 °C	22 °C	
Degree Days				
Heating Degree Days (base 65)	0	0	0	0
Cooling Degree Days (base 65)	21	19	16	560
Growing Degree Days (base 50)	36	34	31	1012
Dew Point				
Dew Point	28 °C	25 °C	21 °C	
Precipitation				
Precipitation	53.1 mm	3.7 mm	0.0 mm	110.22 mm
Snowdepth	-	-	-	-
Wind				
Wind	35 km/h	4 km/h	0 km/h	
Gust Wind	-	-	-	
Sea Level Pressure				
Sea Level Pressure	1013 hPa	1007 hPa	1002 hPa	

Figure 3.1 Monthly weather data for June 2013

Source: Malaysian Meteorological Stations, 2013

In this research, only two main factors will be considered which are wind speed and wind direction. Therefore, not all data that was taken from MET will be used in this study. Microsoft Excel is then used to re-arrange the wind data by according to months (January until December) for both years into tabulated form. Average wind speeds for each month are calculated with respect to the wind direction. Wind direction which is measured in degree is divided into 8 azimuths namely North, North-East, East, South-East, South, South-West, West and lastly North-West. **Table 3.2** shows the range of wind direction with respect to the azimuth used.

Table 3.2 Range of wind direction with respect to azimuth

AZIMUTH	RANGE IN DEGREE (˚)
North	**337.5 - 22.5**
North-East	**22.5 - 67.5**
East	**67.5 - 112.5**
South-East	**112.5 - 157.5**
South	**157.5 - 202.5**
South-West	**202.5 - 247.5**
West	**247.5 - 292.5**
North-West	**292.5 - 337.5**

Appendix A and **Appendix B** show the example of tabulated form of weather data obtained from MET for June 2013 and 2014 respectively. The monthly wind speed and wind direction data were then extracted from **Appendix A** and **B** and displayed into another set of tabulated form as shown **Appendix C** and **Appendix D**.

The average wind speed data for each month are calculated in order to estimate the maximum average wind speed with respect to the foremost wind direction for that particular year. **Table 3.3** shows the example table of calculated maximum average wind speed for Year 2013 (Refer **Appendix E** and **Appendix F** for both years).

From the **Table 3.3**, a wind rose can be constructed based on these data. **Figure 3.2** and **3.3** shows the wind rose for the year 2013 and 2014 respectively**. Appendix H & I** shows the monthly wind rose for year 2013 and 2014.

Table 3.3 Example table of calculated monthly maximum average wind speed with respect to wind direction for Year 2013

Wind Direction (Azimuth)	Range (˚) in Degree	Average wind speed by Months (km/h)											
		JAN	FEB	MARCH	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
N	337.5 - 22.5	17	18.88	19.18	17.93	15.4	19.08	18.13	17.38	15.69	17.38	17.9	17.57
NE	22.5 - 67.5	21	19.56	20	15.67	14	14.33	16	14	27	13	15.8	20.06
E	67.5 - 112.5	0	0	0	0	24	0	0	0	0	0	0	0
SE	112.5 - 157.5	0	0	0	0	0	0	0	13	0	0	0	0
S	157.5 - 202.5	0	24	0	0	24.75	0	16	21	0	0	13	0
SW	202.5 - 247.5	0	0	21	19	19	14	19.67	23.13	18	18.25	14.67	0
W	247.5 - 292.5	17	19.83	20.6	17.2	18.17	17.67	16.17	20.57	16.8	20	17.5	0
NW	292.5 - 337.5	17.4	21.25	16.7	16.83	17.25	19.67	13.5	21.25	19.71	17.29	16.89	14

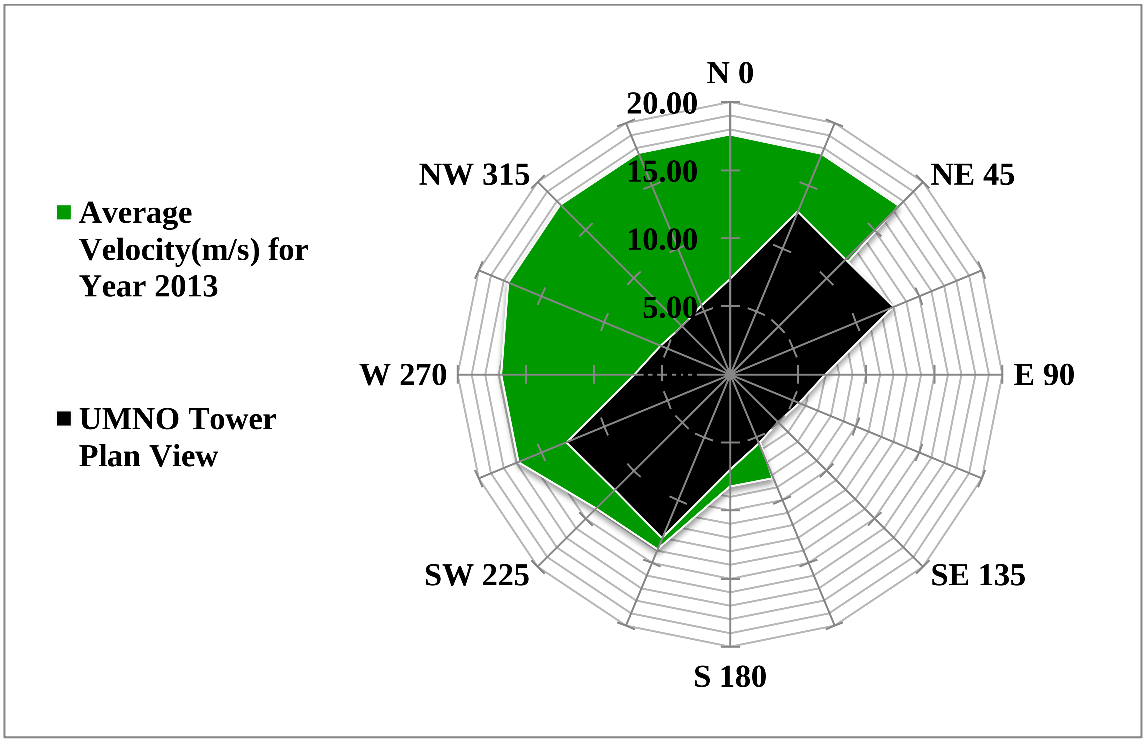


Figure 3.2 Wind Rose for Year 2013 based on MET Weather data

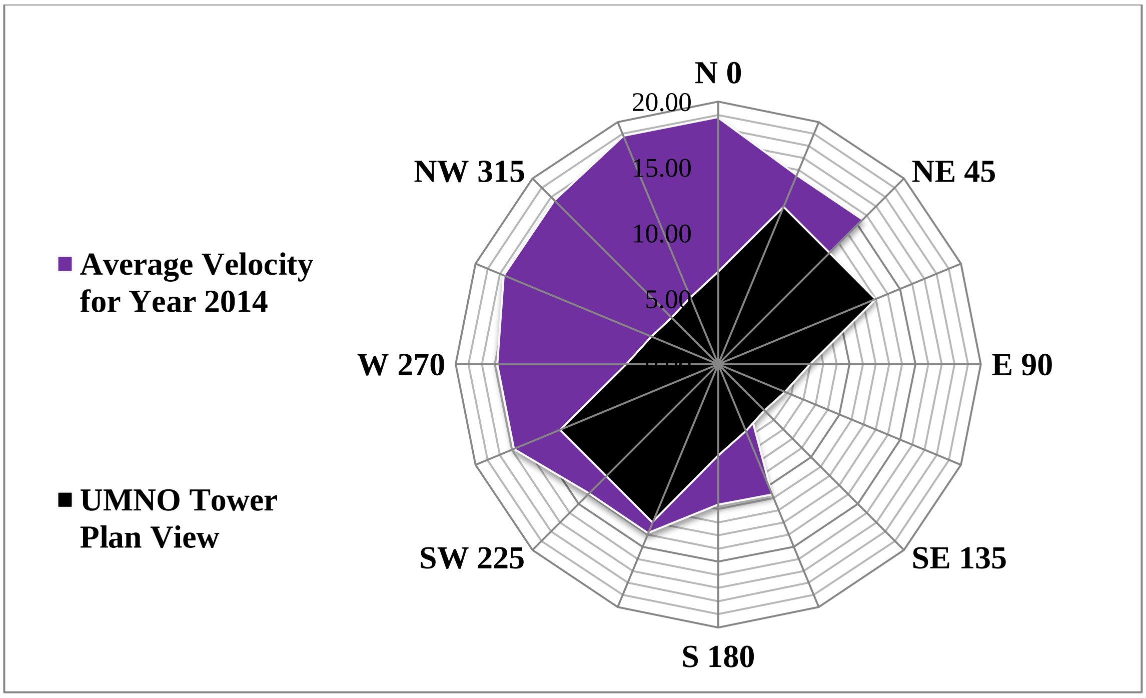


Figure 3.3 Wind Rose for Year 2014 based on MET Weather data

3.3.2 Wind Data during incident

UMNO Tower located at Macalister Road, Georgetown, Penang. However, the only available weather stations nearby are located at Bayan Lepas, Butterworth, Alor Setar and Langkawi. Therefore, an effort in gaining hourly mean surface wind data specifically for 13 June 2013 was conducted. Malaysian Meteorological Department (MET) is referred to obtain the weather data at Butterworth, Bayan Lepas, Alor Setar and Langkawi stations. Among 4 stations involved, the nearest station to the building model is the Butterworth station. **Figure 3.4** shows the location of Butterworth Station Therefore, the data obtained from Butterworth station are close enough to describe the wind speed and wind direction at that time of event. **Table 3.4** shows the summary of hourly mean surface wind speed for all 4 stations on 13 June 2013. (Refer **Appendix G**)

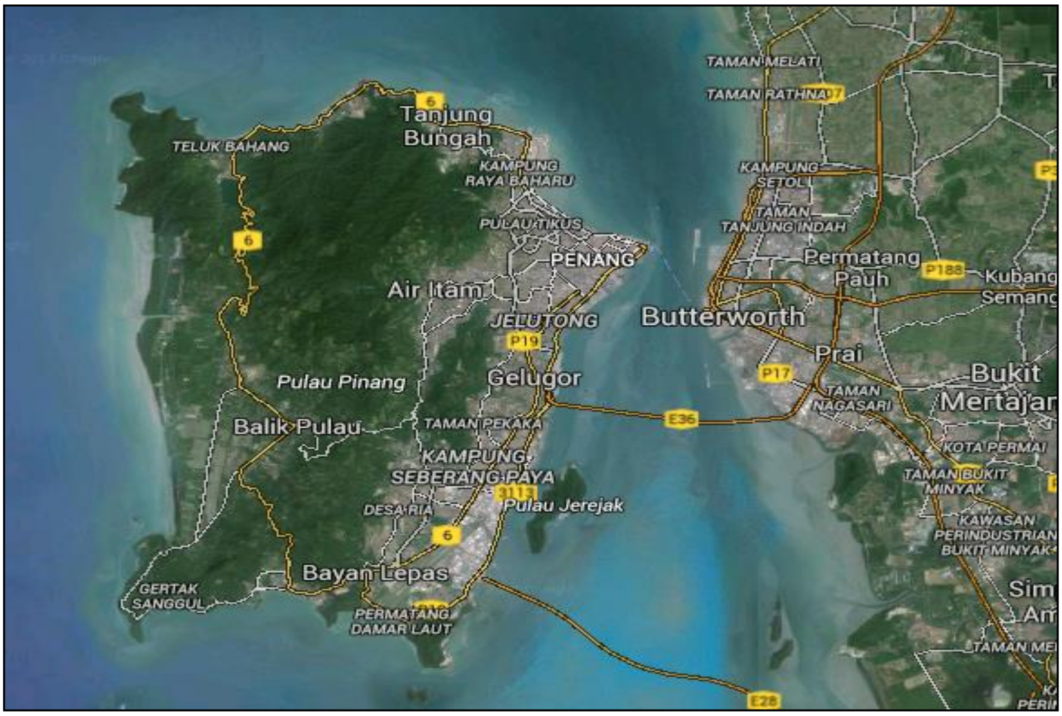


Figure 3.4 Locations of Butterworth and Bayan Lepas Station

Source: Google Earth, 2013

Table 3.4 Summary of hourly mean surface wind speed for all 4 stations on 13 June 2013

Time (24 hrs)	Wind Speed (m/s)			
	Butterworth	Bayan Lepas	P.Langkawi	Alor Setar
1:00	0.8	*CALM	0.9	1.2
2:00	0.8	0.6	0.8	0.3
3:00	0.5	*CALM	0.6	0.8
4:00	1.1	0.5	2.4	1.9
5:00	0.9	*CALM	0.7	1
6:00	0.7	*CALM	2	0.9
7:00	1.4	0.9	0.5	1.8
8:00	1.2	*CALM	1.1	2.4
9:00	3.6	1.4	1	1.9
10:00	2.1	3.6	1.3	1.7
11:00	2.7	3.8	2.4	0.9
12:00	2.2	5.2	1.2	2.2
13:00	0.4	3.7	1.6	1.1
14:00	1.9	2.8	2.9	1.5
15:00	1.5	3.1	6.7	1.4
16:00	2.4	1.8	6.7	5.6
17:00	5.1	2.3	3.8	4.9
18:00	7	2.8	5.6	1.2
19:00	11.6	8.4	3.4	3.9
20:00	7.7	6.4	4.3	2.1
21:00	2.7	3.9	2.7	3.7
22:00	4.3	0.6	1.7	3
23:00	3.6	1.3	0.5	2.3
24:00	2.2	2.4	0.4	0.8

***CALM** is measured when the wind speed is less than 0.5 meters per second or less than one knot.

Source: Malaysian Meteorological Stations (MET), 2013

3.4 DATA PROCESSING

3.4.1 CFD Simulation

The dimension of the building model used in this simulation is in accordance to the full-scale size of the UMNO Tower building (as in the architectural drawing). To simulate the actual condition of wind flow surrounding the area, the size of computational domain used for this model must satisfy the allowable range referred to Osman (2005) which has also been used by other researchers such as Gary Easom (2000) and Delaunay et al. (1995). **Figure 3.5** below shows the building model with the computational domain of 1626.23 m in length, 1158.8 m width and 569.32 m high.

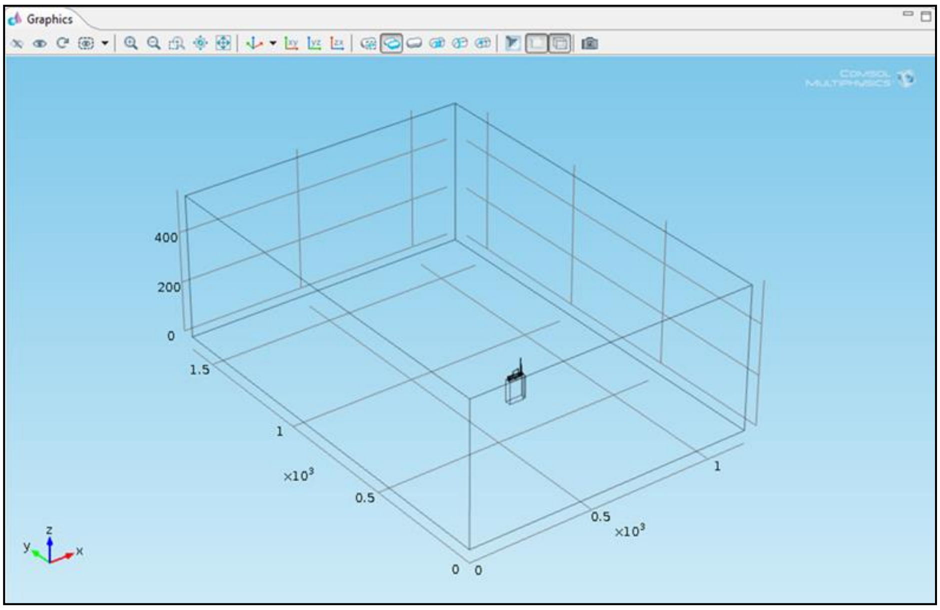


Figure 3.5 The computational domain of the building model

Source: Aminah, 2013

During the site visit observation, there was no tall building located within 569.32 m from UMNO Tower. Thus, in this simulation no other model will be included in front of the UMNO Tower model.

CFD are used to predict pressure around the building when a certain wind speed hits the building model. Therefore, in this research, CFD is used to predict wind loading of the UMNO Tower. The wind speed used is based on the maximum wind speed close to the time of incident which was obtained from the nearest meteorological station, whereby in this case, the Butterworth Station. The dimension of the building model used in this simulation is in accordance to the full-scale size of the UMNO Tower which was drawn by using Sketch Up Software. **Figure 3.6** shows the full-scale UMNO building.

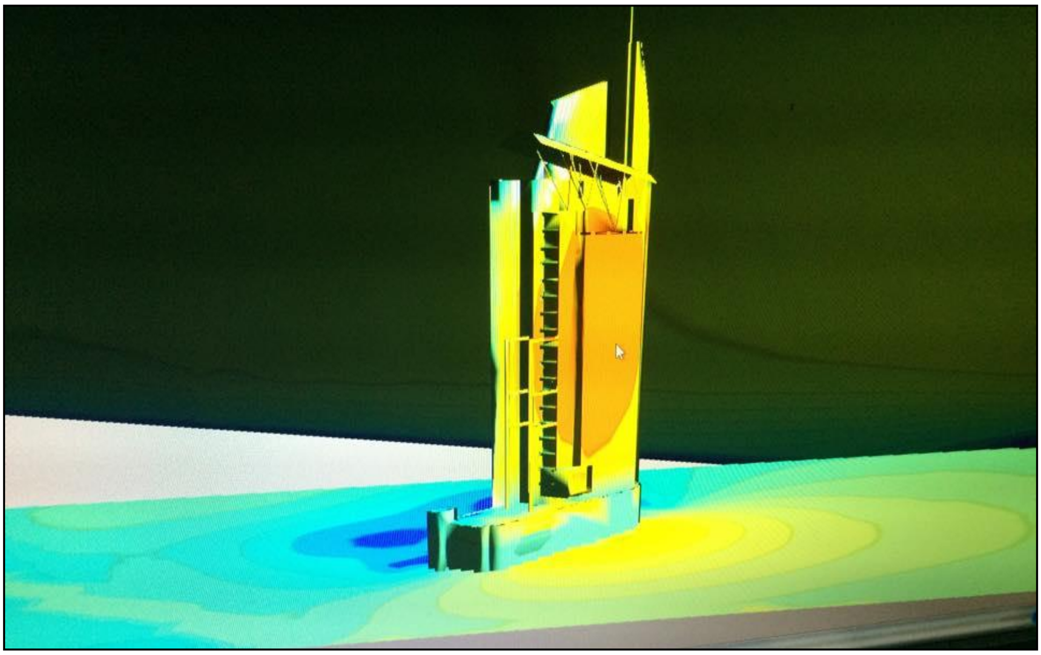


Figure 3.6 The schematic drawing of the building model

Source: Sketch-up, 2013

The wind directions during the recorded wind speed for those stations are shown in **Figure 4.3.** Based on **Table 3.4**, maximum wind speed taken for the closest time to the incident which is just before 7.00pm at Butterworth Station is 11.6 m/s from North-West Direction. During the incident, the wind direction from Butterworth station is 300˚ (NW direction). Therefore the simulation of UMNO Tower is done by using wind speed of 11.6 m/s from 300 (North-West Direction) and the summary of wind pressure of different angle using wind speed of 11.6 m/s are tabulated in **Appendix J**. **Figure 3.7** and **Figure 3.8** show the predicted wind pressure on UMNO Tower.

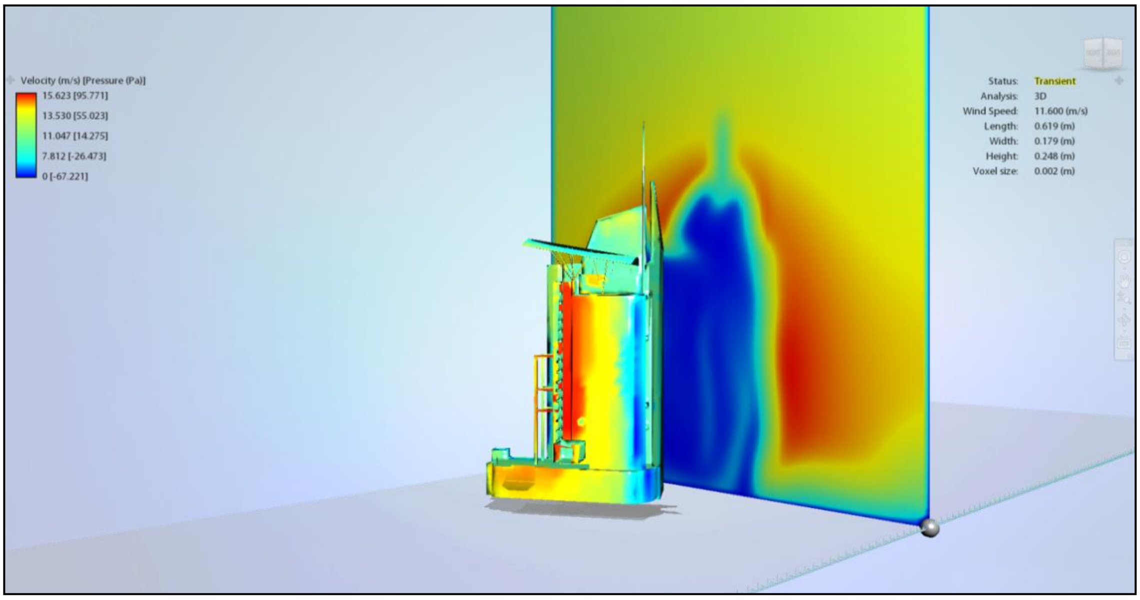


Figure 3.7 The predicted wind pressure on UMNO Tower at 11.6 m/s from NW direction, (CFD Software, 2015)

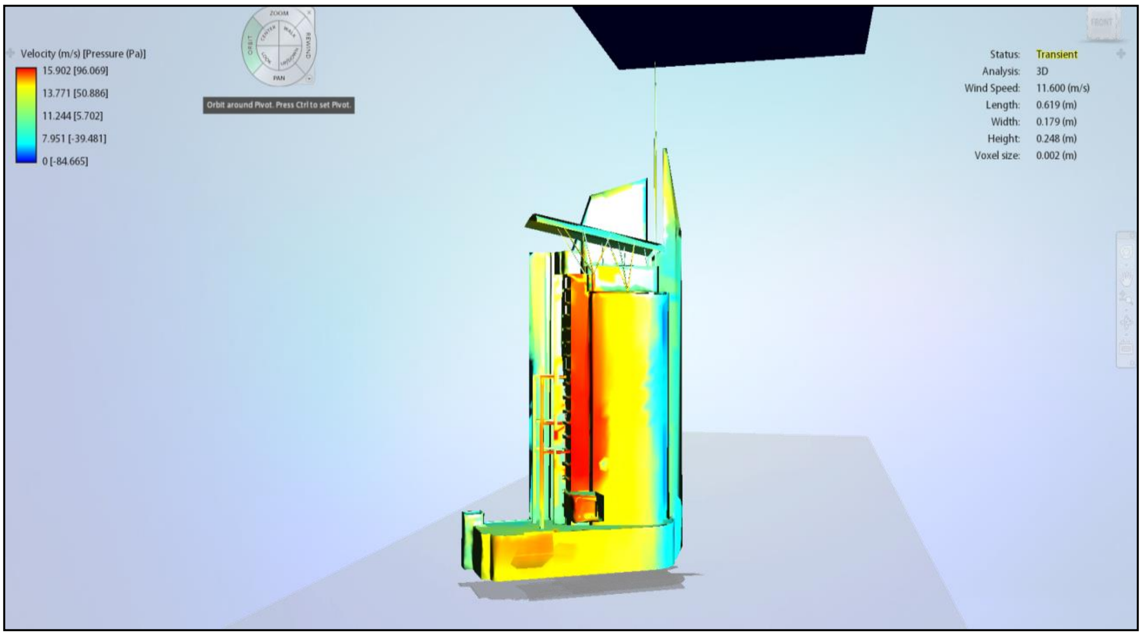


Figure 3.8 The predicted wind pressure on UMNO Tower at 11.6 m/s from NW direction, (CFD Software, 2015)

Simulations on different wind speeds with different angles have also been carried out and the summary of wind pressure on the tower is tabulated in **Appendix K**. **Table 3.5** shows the range of wind direction with respect to the azimuth used in CFD simulation only. Some adjustment on the range of wind direction used in CFD is made in order to display the correct orientation of the tower based on real situation.

Table 3.5 Range of wind direction with respect to azimuth used in CFD

AZIMUTH	RANGE IN DEGREE (˚)
South	**337.5 - 22.5**
South-West	**22.5 - 67.5**
West	**67.5 - 112.5**
North-West	**112.5 - 157.5**
North	**157.5 - 202.5**
North-East	**202.5 - 247.5**
East	**247.5 - 292.5**
South-East	**292.5 - 337.5**

3.5 RESULTS

By using Computational Fluid Dynamics software, the predicted wind pressure on UMNO Tower is produced as shown in **Figure 3.7** and **3.8.** From these data, analysis and discussion can be concluded.

3.6 SUMMARY

The whole progress of this research project has been mapped based on the simplified research flowchart. The main software used for this research is Computational Fluid Dynamic (CFD). This chapter also shows the sequences of steps in doing the research.

CHAPTER 4

RESULT & DISCUSSION

4.1 INTRODUCTION

All of the information from previous **Chapter 3** was analyzed and the result of the research will be presented in this chapter. This chapter shows the result and the establishment made. Objectives of the study were carried out successfully. After collection of weather data from weather stations, data were tabulated and graphs were plotted to be analysed.

As mentioned in **Chapter 3**, only two main factors are considered in this research which are wind speed and wind direction. Microsoft Excel is then used to re-arrange the wind data by according to months (January until December) for both years into tabulated form. From there, the average wind speeds for each month are calculated with respect to the wind direction. **(Appendix C & D).**

4.2 HISTORICAL WIND SPEED

Table 4.1 Calculated monthly maximum average wind speed with respect to wind direction for Year 2013

Wind Direction (Azimuth)	Range (°) in degree	Max Average Wind Speed km/h	Max Average Wind Speed m/s
N	337.5 - 22.5	17.63	4.90
NE	22.5 - 67.5	17.54	4.87
E	67.5 - 112.5	2	0.56
SE	112.5 - 157.5	1.08	0.30
S	157.5 - 202.5	8.23	2.29
SW	202.5 - 247.5	13.89	3.86
W	247.5 - 292.5	16.79	4.66
NW	292.5 - 337.5	17.65	4.90

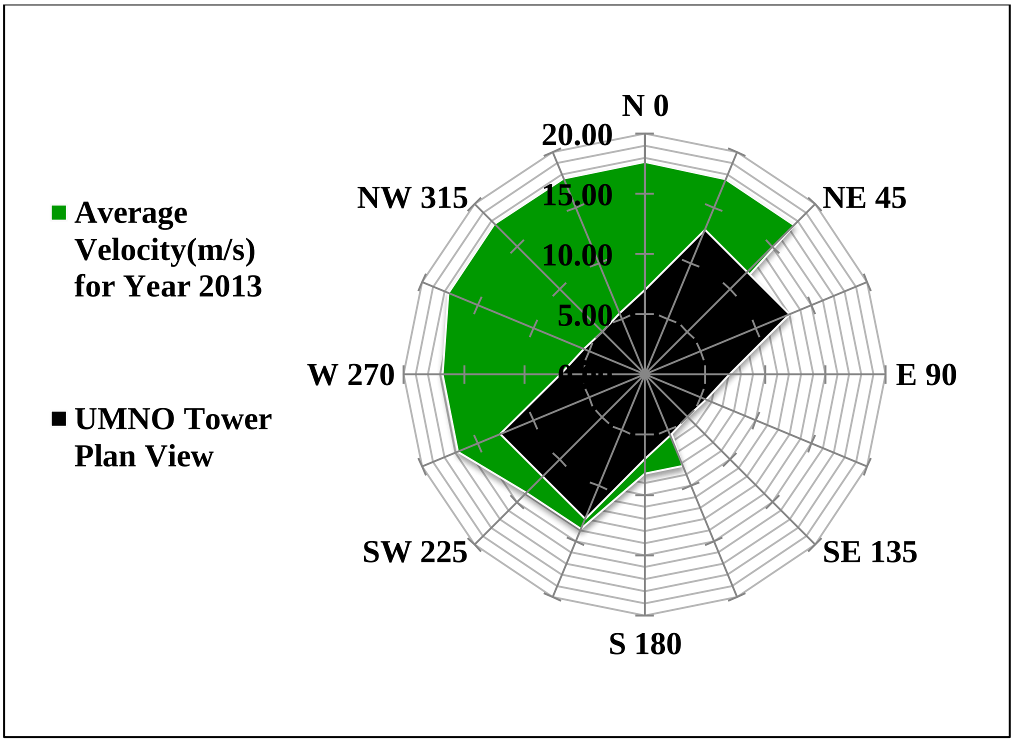


Figure 4.1 Wind Rose for Year 2013 based on MET Weather data

Table 4.2 Calculated monthly maximum average wind speed with respect to wind direction for Year 2014

Wind Direction (Azimuth)	Range (°) in degree	Max Average Wind Speed km/h	Max Average Wind Speed m/s
N	**337.5 - 22.5**	18.82	5.23
NE	**22.5 - 67.5**	13.25	3.68
E	**67.5 - 112.5**	0.00	0.00
SE	**112.5 - 157.5**	2.83	0.79
S	**157.5 - 202.5**	8.20	2.28
SW	**202.5 - 247.5**	14.75	4.10
W	**247.5 - 292.5**	16.00	4.44
NW	**292.5 - 337.5**	18.21	5.06

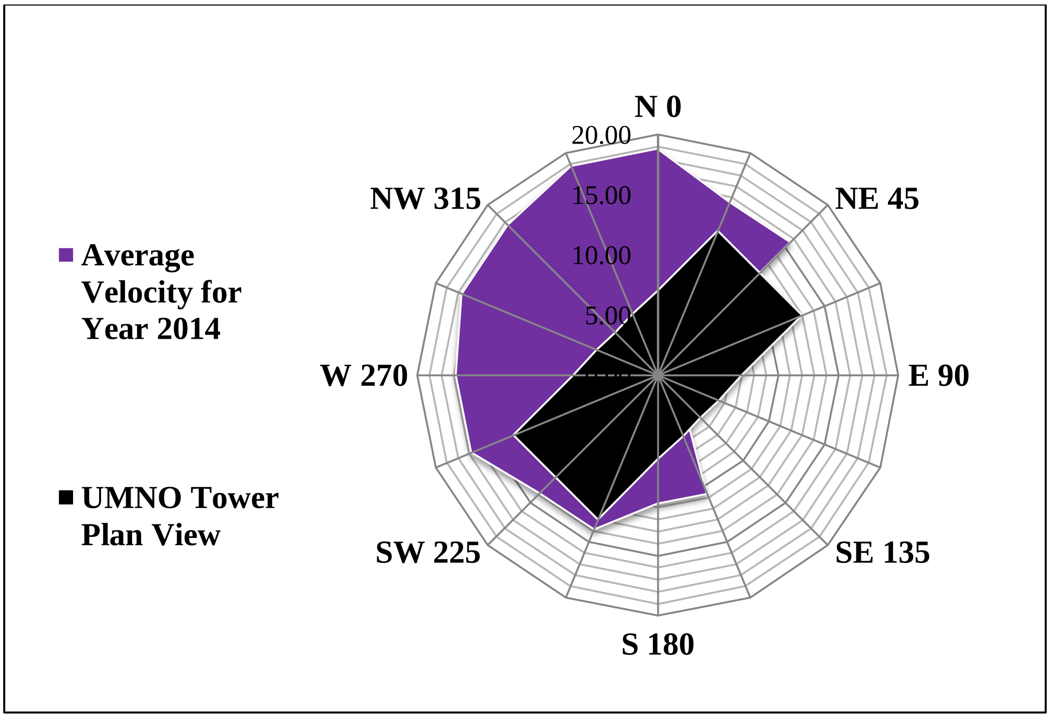


Figure 4.2 Wind Rose for Year 2014 based on MET Weather data

The average wind speed data for each month are calculated in order to estimate the maximum average wind speed with respect to the foremost wind direction for that particular year**. (Appendix E & F).**

From **Table 4.1**, shown that the wind direction comes from North Direction have the maximum average wind speed of 17.65 km/h. As seen from **Figure 4.1**, it can be concluded that the foremost direction wind blows comes from North West Direction for the Year 2013 which is almost perpendicular to the largest exposed surface of the fin shaped wall which had fell and crashed down to Macalister Road. However, from **Table 4.2,** for the Year 2014, foremost wind blows came from North Direction with a maximum average wind speed of 18.82 km/h. **Figure 4.2** shows the foremost wind blows is from North Direction of the building.

It may also seem that this value is not the worst that can cause the structure to collapse. Historical wind speed also had shown foremost wind blow come from North West Direction. From that it can determined, at which direction of wind that can affect the failure of building structure.

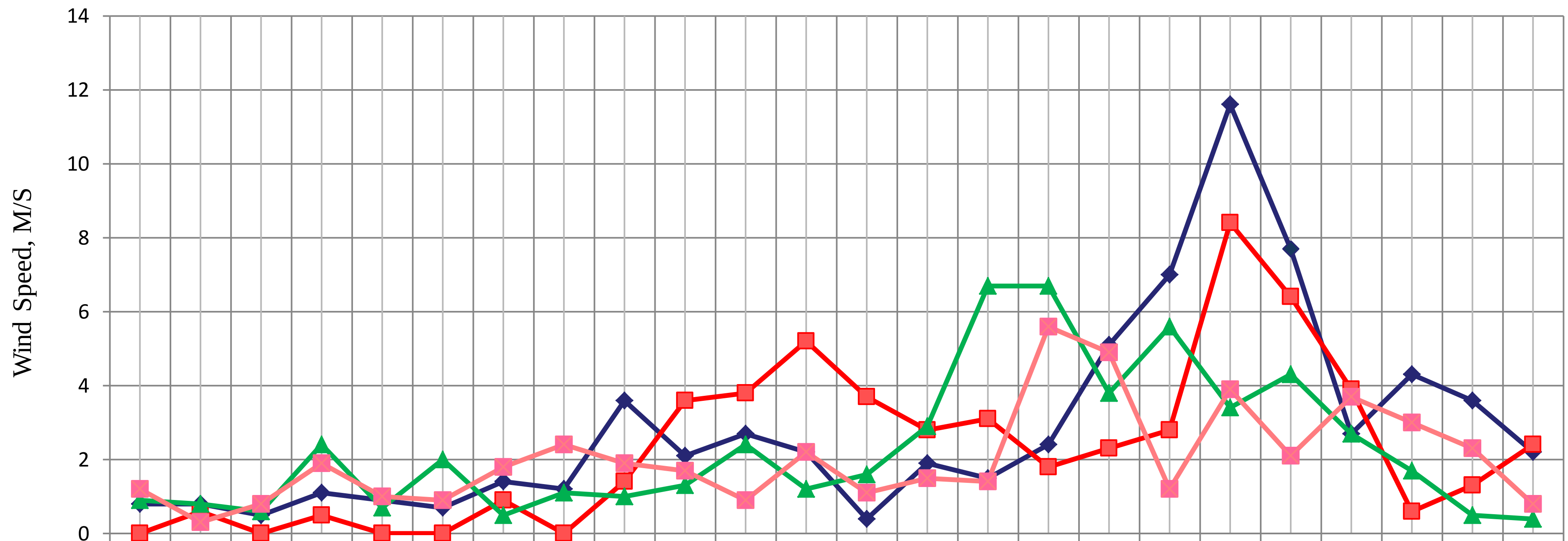
4.3 WIND DATA ESTIMATION DURING INCIDENT

Table 4.3 Summary of Wind Speed Data for 13th June 2013 (MET)

Station	Wind Direction (^{o})	Hourly Surface Wind (m/s)	Maximum Surface Wind (m/s)
Butterworth	300	11.6	19.1 (time:1853/300^{o})
Bayan Lepas	320	8.4	15.9 (time:2002/300^{o})
Alor Setar	210	3.9	14.0 (time:1909/270^{o})
Langkawi	270	3.4	14.9 (time:1537/270^{o})

Table 4.4 Summary of Wind Speed Data for 13th June 2013 at Butterworth Station

Time (24 hrs)	Velocity (m/s)	Wind Direction (degree)
1:00	0.8	120 SE
2:00	0.8	160 S
3:00	0.5	100 E
4:00	1.1	60 NE
5:00	0.9	60 NE
6:00	0.7	80 E
7:00	1.4	60 NE
8:00	1.2	50 NE
9:00	3.6	360 N
10:00	2.1	10 N
11:00	2.7	80 E
12:00	2.2	20 N
13:00	0.4	90 E
14:00	1.9	300 NW
15:00	1.5	80 E
16:00	2.4	340 N
17:00	5.1	330 NW
18:00	7	340 N
19:00	11.6	300 NW
20:00	7.7	290 W
21:00	2.7	220 SW
22:00	4.3	80 E
23:00	3.6	100 E
24:00	2.2	50 NE



	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM
Butterworth	0.8	0.8	0.5	1.1	0.9	0.7	1.4	1.2	3.6	2.1	2.7	2.2	0.4	1.9	1.5	2.4	5.1	7	11.6	7.7	2.7	4.3	3.6	2.2
Bayan Lepas	0	0.6	0	0.5	0	0	0.9	0	1.4	3.6	3.8	5.2	3.7	2.8	3.1	1.8	2.3	2.8	8.4	6.4	3.9	0.6	1.3	2.4
P.Langkawi	0.9	0.8	0.6	2.4	0.7	2	0.5	1.1	1	1.3	2.4	1.2	1.6	2.9	6.7	6.7	3.8	5.6	3.4	4.3	2.7	1.7	0.5	0.4
Alor Setar	1.2	0.3	0.8	1.9	1	0.9	1.8	2.4	1.9	1.7	0.9	2.2	1.1	1.5	1.4	5.6	4.9	1.2	3.9	2.1	3.7	3	2.3	0.8

Time

Figure 4.3 Wind speed for 13th June 2013 (data included in **Appendix G**) for all 4 stations.

The historical wind speed data at the nearest meteorological station after the building was also examined as shown in **Table 4.3** and **Table 4.4.** From that it was observed historical wind speeds are greater compare to the design wind speed.

Wind speed and wind direction from nearby meteorological station are used to estimate the maximum wind speed taken for the closest time to the incident which is just before 7.00pm. From there, the data are used to estimate the wind pressure of the building by using CFD software.

Malaysian Meteorological Department (MET) is referred to obtain the weather data at Butterworth, Bayan Lepas, Alor Setar and Langkawi stations. Based on **Table 4.3**, Butterworth and Bayan Lepas stations recorded maximum surface wind speed of 19.1 m/s and 15.9 m/s, respectively but at different time. Among 4 stations involved, the nearest station to the building model is the Butterworth station. Therefore, the data obtained from Butterworth station are close enough to describe the wind speed and wind direction at that time of event.

Furthermore, it is noted that the wind direction on the day of incident is almost perpendicular to the largest exposed surface of the fin shaped wall, which may produce the maximum force on the wall as shown.

Figure 4.3 shows the wind speed for 13th June 2013 for all 4 stations. It shows that a sudden increase in wind speed happen within the duration of 6-7pm recorded at Butterworth Station on that day which increases from 7.0 m/s up to 11.6 m/s. It is at about 7pm is where it was reported that the fin-shaped wall along with the lighting arrestor pole fell off from the UMNO Tower. Bayan Lepas station also recorded the same increment of wind speed within 6-7 pm on that particular day.

It may also seem that this value is not the worst that can cause the structure to collapse but highly foreseeable that the collapse was due to repeatable wind speed.

4.4 CFD SIMULATION RESULTS

The wind speed used for simulation is based on the maximum wind speed close to the time of incident which was obtained from the nearest meteorological station, whereby in this case, the Butterworth Station. Based on the **Table 3.4**, hourly surface wind speed taken for the closest time to the incident which is just before 7.00pm at Butterworth Station is 11.6 m/s from North-West Direction.

Based on historical data in **Appendix E**, the maximum average wind speed also shown that foremost wind blow comes from North West Direction.

From Butterworth station, at 7pm on 13 June 2013, the highest recorded wind speed of 11.6 m/s also came from 300˚ (NW direction). Furthermore, it is noted that the wind direction on the day of incident is almost perpendicular to the largest exposed surface of the fin shaped wall, which may produce the maximum force on the wall as shown in **Figure 4.4.**

Therefore, wind speed of 11.6 m/s from 300 (North-West Direction) are chosen to for the simulation. The summaries of wind pressure of different angle using wind speed of 11.6 m/s are tabulated in **Appendix J**.

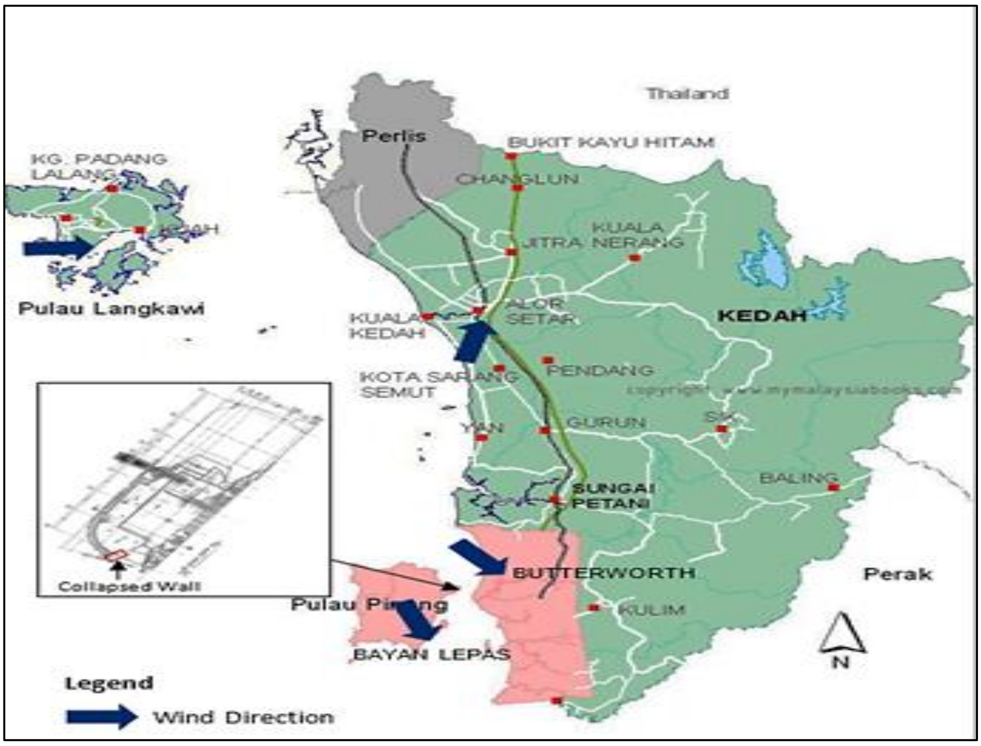


Figure 4.4 Wind Directions at 7:00 PM on 13th June 2013, (Majid 2013)

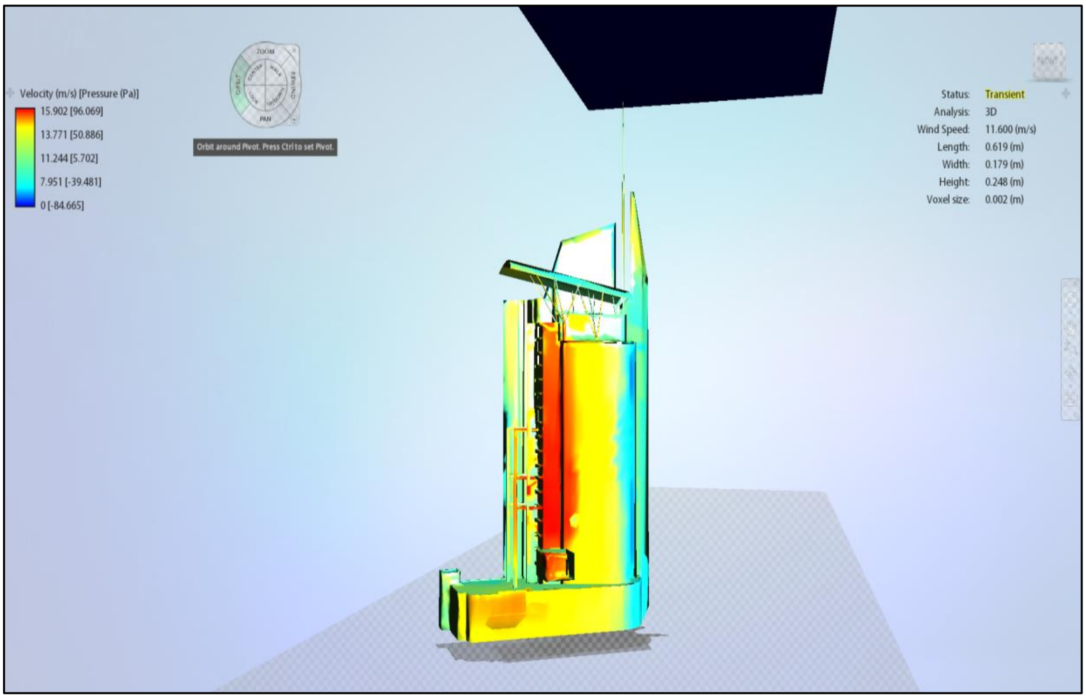


Figure 4.5 The predicted wind pressure on UMNO Tower at 11.6 m/s from NW direction

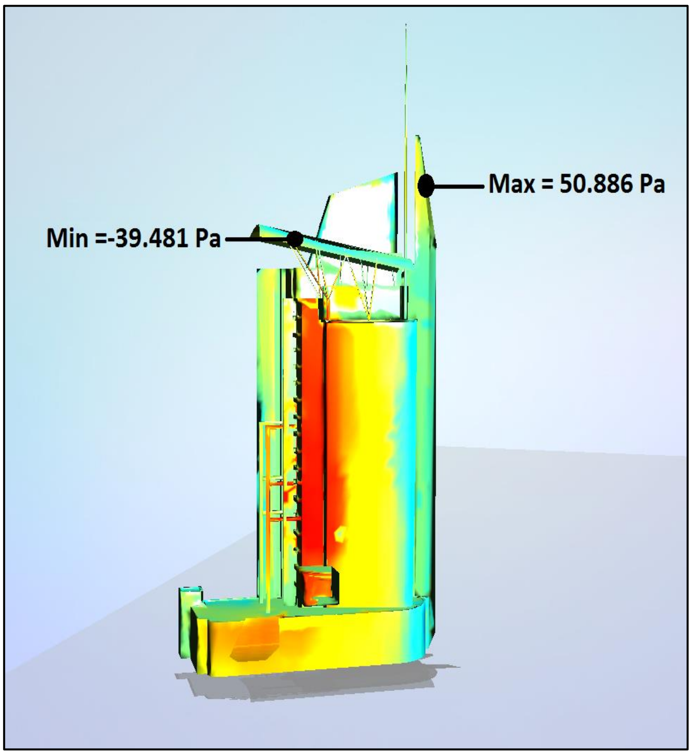


Figure 4.6 The predicted wind pressure on UMNO Tower (enlarged mode)

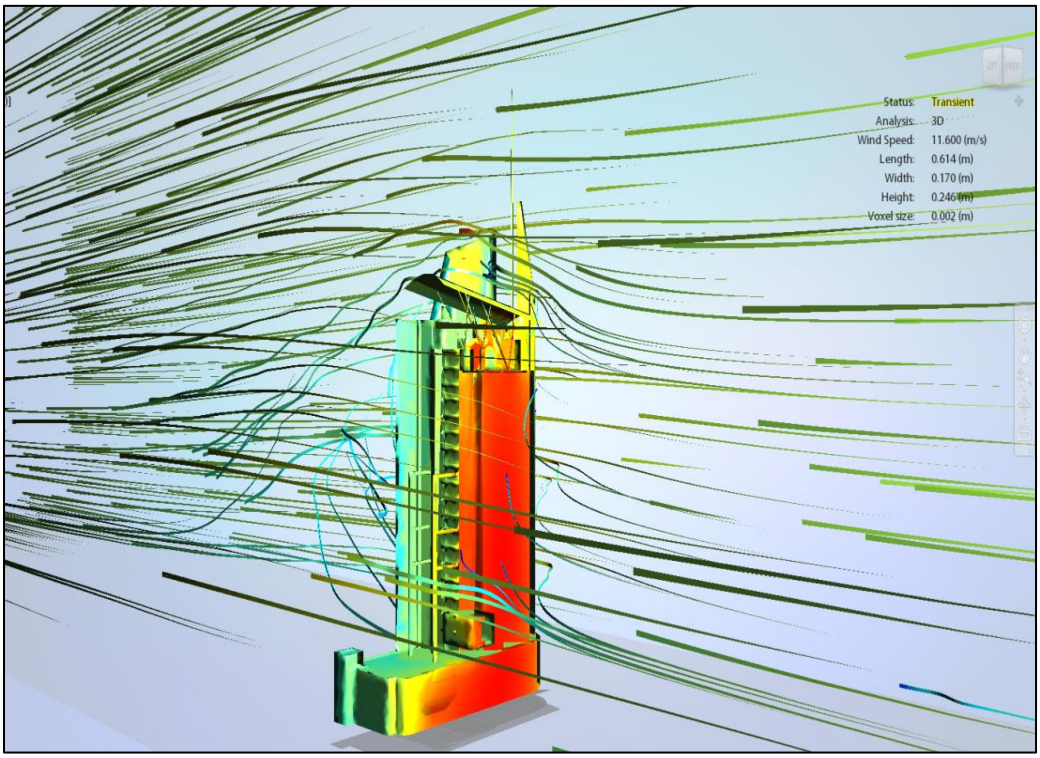


Figure 4.7 The enlarged mode of the building with wind streamlines

Table 4.4 Summary of wind pressure of different angle using wind speed of 11.6 m/s.

No.	Initial Velocity (m/s)	Direction (deg)	Coefficient
1	11.6	0 S	0.285
2	11.6	22.5 S	1.042
3	11.6	45 SW	1.349
4	11.6	67.5 SW	1.202
5	11.6	90 W	1.472
6	11.6	112.5 W	1.516
7	11.6	135 NW	1.674
8	11.6	157.5 NW	1.710
9	11.6	180 N	1.468
10	11.6	202.5 N	1.173
11	11.6	225 NE	1.222
12	11.6	247.5 NE	1.605
13	11.6	270 E	0.758
14	11.6	292.5 E	1.492
15	11.6	315 SE	1.210
16	11.6	337.5 SE	1.545

The results of predicted pressure around the building shown in **Figure 4.5** are based on wind speed of 11.6 m/s at 300 degrees. The enlarged mode of the building model in **Figure 4.6** shows the positive pressure at the windward face and negative pressure (suction) at the leeward face.

The figure also shows the maximum pressure of 50.886 Pa (0.051 kN/m^2) was developed at the tip of the collapsed fin-shaped wall and the minimum pressure of -39.481 Pa (-0.04 kN/m^2) is formed at the roof. **Figure 4.7** shows the enlarged mode of predicted wind streamlines surrounding the building in green colour.

From **Table 4.4,** it shows that with a wind speed of 11.6 m/s flows towards the building, the possibility of wind load may increase are up to 2.71 times from North West Direction from the normal wind act to the tower. However, it may also seem that this value is not the worst that can cause the structure to collapse but it can be conclude that the possibility of the collapse are highly foreseeable due to repeatable wind speed.

Simulations on different wind speeds with different angles have also been carried out and the summaries of wind pressures on the tower are tabulated in **Appendix K**. The range of wind direction with respect to the azimuth used in CFD simulation is shown in **Table 3.6**. Some adjustment on the range of wind direction used in CFD is made in order to display the correct orientation of the tower based on real situation.

4.5 SUMMARY

It is noted that based on the data obtained, the wind direction on the day of incident is almost perpendicular to the largest exposed surface of the fin shaped wall, which may produce the maximum force on the wall.

In short, the possibility of wind load may increase are up to 2.71 times from North West Direction from the normal wind act to the tower. However, it may also seem that this value is not the worst that can cause the structure to collapse but it can be conclude that the possibility of the collapse are highly foreseeable due to repeatable wind speed.

Based on the result it can be conclude the repeatable load acting to structural component of the tower may weaken the structural component. Therefore consideration of wind load direction is highly recommended during the design stage

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 INTRODUCTION

This chapter will discuss about the conclusion for each of the objectives outline for this study. For future study, there are several recommendations also included at the end of the chapter to improve the study for this research.

5.2 CONCLUSION

Wind-related disaster had become significant impacts in our society which responsible for the tremendous physical destruction, loss of life, injury and economic damage. The severity and increased frequency of wind-related disaster events over the past few years in Malaysia has shifted the attention from several researchers towards to investigate the effect of wind effect on building structure in Malaysia. There are two objectives in this study. The concluding remarks for each objective are discussed below.

5.2.1 Objective 1: To investigate the effect of building orientation and shape to the wind characteristics

The first objective is to investigate the effect of building orientation and shape to the wind characteristics. It was mentioned in previous chapters, in this research, only two factors are considered, wind speed and wind direction. In order to determine the effect of building orientation to the tower, the value of wind speed and wind direction were determined based on the historical weather data obtained from Malaysian Meteorological Station. This was done in order to estimate in which direction of wind that can affect the failure of building structure. Based on these data, the effect of the geometrical shape of the tower may increase the wind load effect to the tower and different orientation of tower may influence the changes in velocity acting to the tower. Therefore, the objective has been achieved by concluding that the shape and building orientation did influence the strength of the structure which may result in fatigue of structure under dynamic excitation.

5.2.2 Objective 2: To simulate the building against variation of wind speed and direction by using Computational Fluid Dynamics.

The second objective is to simulate the building against variation of wind speed and direction by using Computational Fluid Dynamics. CFD was used to predict the behavior of structures. This simulation technique allows the wind flows around or through the building or structure to be analysed in a great detail.

In order to simulate the building, a constant wind speed and a range of wind direction has been decided. Based on those results, a dynamic 2D and 3D of flow line animations are generated and the wind load acting on the surface of the building had been determined. The objective is achieved by determining the wind loading acting on the surface of the building tower from which direction of the wind blows. From the results, it may also seem that this value obtained is not the worst that can cause the structure to collapse but highly foreseeable that the collapse was due to repeatable wind speed. The repeatable load acting to structural component of the tower may weaken the structural component. Therefore consideration of wind load direction is highly recommended during the design stage.

5.3 RECOMMENDATION

For future studies, there are a few recommendations can be made to investigate in-depth the cause of failure of the UMNO Tower.

The first recommendation is to broaden the scope of study by considering the effect of wind speed against topography factors and structural strength of the Tower in which could contribute to the failure or collapse of UMNO Tower. This can be done by collecting the topographical data of the location and conduct few test to determine the concrete strength of the wall itself.

The final recommendation is to refer different codes or standards in these studies such as American Standard ASCE 7-02. If the use of a different code during initial design leads to significantly different results to the local code then this can have a significant impact on the design process. This is because of the scope of MS 1553:2002 is only limited to a small range of geometries and structures for which the wind loading does not control the design.

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Appendix A: Weather data obtained from Malaysian Meteorological Station (MET) for June 2013

MYT	Temperature, C			Dew Point, C			Humidity			Sea Level Pressure, Pa			Visibility, km			Wind Speed km/h		Gust Speed km/h	Events	Wind Direction Degrees
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Max		
1/6/2013	34	31	27	26	25	23	89	74	52	1010	1007	1004	10	9	9	16	5	34		355
2/6/2013	29	27	25	26	24	23	95	87	72	1009	1007	1004	10	9	3	21	6	37	Rain	18
3/6/2013	33	28	24	26	24	23	94	78	58	1008	1007	1005	10	9	9	13	3			356
4/6/2013	32	29	26	26	25	24	89	79	63	1010	1008	1006	10	9	6	13	3		Rain	52
5/6/2013	33	30	26	27	26	24	89	79	57	1011	1008	1005	10	9	9	19	6		Rain	11
6/6/2013	33	29	26	27	24	22	89	76	59	1010	1008	1006	10	9	8	23	10		Thunderstorm	12
7/6/2013	34	30	26	27	26	24	94	78	55	1010	1008	1005	11	9	7	14	5	27		318
8/6/2013	34	30	27	27	26	24	89	76	56	1009	1007	1004	10	9	8	13	6			344
9/6/2013	30	28	25	27	25	23	100	87	73	1009	1007	1006	10	8	2	27	6	52	Rain-Thunderstorm	327
10/6/2013	33	29	24	27	26	24	94	81	59	1008	1006	1004	10	9	8	23	8	39	Rain-Thunderstorm	3
11/6/2013	31	28	25	27	26	23	95	86	75	1008	1006	1004	10	9	6	16	3		Rain-Thunderstorm	5
12/6/2013	31	28	24	26	24	23	100	83	62	1008	1006	1004	11	9	6	11	6		Rain-Thunderstorm	28
13/6/2013	31	28	24	26	24	22	94	82	64	1008	1006	1004	10	8	3	29	5	55	Rain	14
14/6/2013	32	28	24	27	24	23	94	80	57	1007	1005	1004	10	9	8	14	5			350
15/6/2013	32	28	24	26	25	23	94	79	62	1007	1005	1003	10	9	8	14	3			220
16/6/2013	32	29	26	27	26	22	94	81	65	1008	1006	1004	10	7	6	23	3	52		252

17/6/2013	32	28	23	26	24	23	94	80	58	1008	1006	1003	10	8	5	24	6	47	Rain-Thunderstorm	329
18/6/2013	33	28	24	26	24	24	94	77	56	1007	1005	1003	10	9	6	14	3			225
19/6/2013	33	29	26	26	25	24	89	76	52	1008	1006	1004	10	9	8	16	3		Thunderstorm	276
20/6/2013	32	29	27	27	26	25	94	81	63	1010	1007	1005	10	8	6	21	3		Rain-Thunderstorm	294
21/6/2013	33	29	26	26	26	25	94	78	57	1009	1008	1006	8	7	6	14	3			246
22/6/2013	33	29	26	27	25	24	94	78	59	1009	1007	1005	8	7	6	14	5			246
23/6/2013	33	29	25	27	25	23	89	77	59	1009	1007	1005	8	7	6	14	3			240
24/6/2013	33	29	26	27	26	23	89	77	59	1011	1009	1006	7	4	2	14	3			253
25/6/2013	33	29	26	27	26	23	89	77	55	1012	1010	1008	8	5	1	19	5		Rain	340
26/6/2013	31	28	26	26	24	22	89	80	66	1013	1011	1010	10	8	6	29	6		Rain	355
27/6/2013	30	28	25	25	24	23	94	82	66	1013	1011	1009	10	9	6	19	5		Rain	23
28/6/2013	31	28	24	26	24	22	91	82	67	1011	1010	1008	10	8	7	19	3		Rain-Thunderstorm	321
29/6/2013	33	29	25	26	24	23	94	77	52	1011	1010	1008	10	8	6	13	3			334
30/6/2013	33	29	26	26	24	23	89	76	53	1012	1009	1006	10	9	1	13	3		Rain	344

Appendix B: Weather data obtained from Malaysian Meteorological Station (MET) for June 2014

MYT	Temperature, C			Dew Point, C			Humidity			Sea Level Pressure, Pa			Visibility, km			Wind Speed km/h		Gust Speed km/h	Events	Wind Direction Degrees
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Max		
1/6/2014	32	29	26	27	26	25	100	87	70	1010	1008	1006	10	9	8	14	5		Rain-Thunderstorm	336
2/6/2014	32	29	26	27	26	25	94	83	68	1009	1007	1006	10	9	6	23	6		Rain	211
3/6/2014	32	29	27	27	26	25	94	83	66	1008	1006	1004	10	9	8	21	6			254
4/6/2014	29	28	25	27	26	24	100	87	73	1009	1007	1005	10	8	3	13	5		Rain-Thunderstorm	329
5/6/2014	31	28	25	27	25	23	100	84	66	1008	1006	1004	11	9	3	14	8		Rain-Thunderstorm	198
6/6/2014	32	29	25	28	27	25	94	81	69	1008	1006	1004	10	9	8	23	10	37		165
7/6/2014	33	30	28	28	27	26	94	81	66	1007	1005	1003	10	9	8	24	8			185
8/6/2014	33	31	28	28	27	25	89	80	67	1007	1005	1003	10	9	6	24	10			188
9/6/2014	33	30	27	28	27	26	94	85	64	1008	1005	1004	10	8	6	19	6		Rain	240
10/6/2014	33	30	27	28	27	26	94	80	63	1008	1006	1004	10	8	6	19	5			272
11/6/2014	33	30	28	28	27	26	94	82	66	1008	1006	1004	10	8	6	19	5		Rain-Thunderstorm	244
12/6/2014	31	28	26	27	26	24	94	86	70	1008	1006	1005	10	8	6	19	5		Rain-Thunderstorm	17
13/6/2014	34	30	26	27	26	25	94	79	58	1008	1005	1004	10	9	6	14	5			359
14/6/2014	33	30	27	27	26	25	94	79	66	1009	1007	1005	10	9	8	16	5			244
15/6/2014	33	30	28	28	27	26	94	82	66	1009	1007	1005	10	8	6	16	5			229
16/6/2014	33	31	28	27	26	24	86	75	63	1009	1007	1005	10	9	8	24	10			195

17/6/2014	32	30	28	27	26	26	94	81	67	1009	1007	1006	8	7	6	14	3			224
18/6/2014	32	29	26	27	26	25	94	82	64	1010	1008	1007	10	8	6	21	6			213
19/6/2014	34	30	26	28	26	25	89	78	57	1010	1008	1006	8	7	6	13	5			348
20/6/2014	33	30	27	27	27	25	94	82	59	1011	1009	1007	8	7	5	16	6			260
21/6/2014	33	30	27	27	27	26	94	81	63	1012	1010	1008	8	6	5	19	5			238
22/6/2014	33	30	27	28	27	25	89	81	66	1012	1010	1008	8	6	5	19	5		Thunderstorm	247
23/6/2014	33	30	27	28	26	25	94	79	59	1011	1009	1006	10	8	6	21	3			330
24/6/2014	33	30	27	27	26	24	89	77	63	1010	1008	1005	10	8	6	16	5			284
25/6/2014	33	30	27	27	26	24	94	80	61	1010	1008	1007	7	5	2	19	6			244
26/6/2014	33	30	27	27	26	25	94	79	58	1012	1010	1008	6	5	3	14	5			311
27/6/2014	32	28	25	27	26	25	100	89	68	1012	1011	1009	7	5	3	13	3		Rain-Thunderstorm	317
28/6/2014	33	29	24	27	26	25	100	87	69	1012	1010	1007	9	6	2	19	3		Rain-Thunderstorm	296
29/6/2014	29	27	24	26	24	23	100	90	79	1013	1010	1007	10	8	2	19	6	32	Rain-Thunderstorm	2
30/6/2014	31	28	24	26	24	23	100	89	75	1013	1010	1008	10	9	6	19	6	24	Rain	11

Appendix C: Monthly wind speed and wind direction data for Year 2013

DAY	JAN		FEB		MAC		APRIL		MAY		JUNE		JULY		AUG		SEPT		OCT		NOV		DEC	
	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)
1	N 31	16	N 16	21	NE 35	19	SW 243	19	W 283	16	N 355	16	N 1	19	N 338	11	N 342	21	N 8	11	NW 323	16	NE 32	21
2	N 355	13	N 356	21	NE 30	21	NW 331	16	W 280	19	N 18	21	NE 46	16	N 7	19	N 340	16	N 347	16	N 339	19	NE 27	19
3	NE 25	23	N 14	19	NE 24	19	W 292	21	N 338	23	N 356	13	N 3	21	N 14	21	NW 312	19	N 345	16	N 4	23	NE 27	14
4	N 16	21	NE 28	19	N 5	16	W 272	14	NW 321	19	NE 52	13	N 354	21	SW 221	19	NW 298	24	N 346	21	NW 332	16	NE 33	13
5	W 270	16	W 275	23	N 20	21	N 350	14	W 282	21	N 11	19	N 348	10	S 193	21	N 345	13	N 21	19	N 21	16	N 16	16
6	N 346	14	W 285	21	N 2	19	N 354	16	N 9	13	N 12	23	S 190	16	N 350	16	NW 318	23	SW 210	24	NE 33	16	N 16	14
7	N 18	10	W 274	19	N 13	26	NW 336	13	N 15	13	NW 318	14	W 277	14	N 344	16	N 8	16	NW 319	16	NW 326	14	NE 35	21
8	N 7	29	W 289	19	N 357	19	N 341	19	S 193	19	N 344	13	W 268	19	N 349	16	N 358	14	NE 26	13	NW 293	16	NE 33	23
9	N 11	14	W 269	16	NW 311	19	NE 24	14	N 357	19	NW 327	27	W 271	19	SW 232	26	N 356	16	NE 40	13	W 277	19	N 359	13
10	N 8	13	N 16	21	W 270	21	N 12	19	S 172	24	N 3	23	S 194	16	NE 26	14	N 348	16	N 5	23	SW 211	14	NE 27	16
11	W 250	16	NW 314	19	W 285	19	N 343	23	S 165	32	N 5	16	W 258	16	SE 117	13	N 6	11	N 348	14	W 263	16	NE 29	16
12	NW 311	14	NE 34	21	NW 301	16	N 343	19	S 181	24	NE 28	11	NW 327	14	NW 294	16	NW 319	19	N 349	13	NW 306	19	NW 316	14
13	N	19	W	21	N	19	NW	16	SW	19	N	29	N 347	21	SE	13	W	19	N	16	N	13	NE	16

	341		279		349		295		240		14				114		273		6		346		31	
14	N 342	19	NW 336	19	N 344	14	NE 28	14	W 263	16	N 350	14	NW 330	13	SW 218	16	NW 305	23	NE 35	13	NW 325	19	N 6	14
15	N 19	16	NW 334	21	NE 32	21	N 2	16	NW 337	11	SW 220	14	SW 234	29	W 284	27	SW 227	13	NW 304	24	NW 298	19	N 13	19
16	NE 30	19	NE 59	16	N 349	26	W 276	16	W 258	16	W 252	23	N 353	21	W 289	14	W 261	16	W 285	27	N 350	19	N 352	16
17	NE 29	23	S 161	24	NW 336	19	NE 28	19	E 92	24	NW 329	24	N 8	18	W 259	21	NW 334	14	W 285	16	NE 59	14	N 358	16
18	NE 33	24	NW 296	26	N 351	14	N 354	14	NW 296	24	SW 225	14	W 252	14	N 340	14	N 346	11	N 349	19	NW 336	19	N 17	19
19	N 356	16	N 5	21	NW 332	16	NW 325	16	NW 330	16	W 276	16	SW 224	19	SW 245	21	NW 328	16	NW 307	19	N 13	21	N 21	21
20	N 351	19	N 351	19	NW 344	16	W 270	16	N 11	16	NW 294	21	SW 247	14	W 249	16	W 269	14	N 353	19	N 18	19	NE 28	23
21	N 351	16	N 20	19	SW 235	21	N 338	11	N 342	14	SW 246	14	N 343	14	SW 240	21	W 251	19	N 345	26	N 360	11	N 12	21
22	NE 50	16	N 356	10	NW 321	19	N 339	14	NW 305	14	SW 246	14	W 268	14	W 257	16	SW 237	16	N 345	13	S 192	13	NE 27	23
23	N 347	14	NE 25	26	N 2	23	N 19	19	W 271	21	SW 240	14	W 277	16	SW 223	34	SW 238	24	NW 336	19	SW 230	14	N 6	16
24	N 2	19	NE 29	21	W 283	23	NW 296	24	N 338	16	W 253	14	W 284	13	SW 240	24	SW 243	19	SW 224	16	NE 35	16	NE 28	21
25	N 6	19	NE 38	19	W 292	21	N 17	19	NE 34	14	N 340	19	W 249	16	W 272	16	W 284	16	W 288	21	N 17	24	N 21	19
26	NW 297	19	NE 36	19	NW 298	16	N 10	14	NW 326	19	N 355	29	SW 241	21	W 291	34	N 352	14	SW 230	14	SW 207	16	NE 34	26
27	NW 316	14	NE 41	16	W 268	19	N 1	26	NW 334	14	NE 23	19	SW 240	19	SW 244	24	NE 31	27	NW 318	13	N 5	14	N 21	23
28	W 285	19	NE 57	19	NW 324	16	NW 320	16	NW 296	21	NW 321	19	W 271	13	NW 316	40	N 358	13	SW 241	19	NE 26	19	NE 29	24
29	NW 337	19			NW 332	16	W 251	19	N 341	13	NW 334	13	W 249	19	NW 299	13	N 9	24	NW 337	16	NW 337	14	NE 25	29
30	NW 316	21			NW 324	14	N 352	26	N 357	13	N 344	13	W 289	21	NW 310	16	N 13	19	NW 332	14	NE 32	14	NE 38	16
31	N 339	19			N 343	14			N 360	14			SW 245	16	N 339	26			W 286	16			N 12	19

Appendix D: Monthly wind speed and wind direction data for Year 2014

DAY	JAN		FEB		MAC		APRIL		MAY		JUNE		JULY		AUG		SEPT		OCT		NOV		DEC	
	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)	WIND DIRECTION (DEG)	SPEED (M/S)
1	N 357	21	N 14	19	NW 314	19	NW 303	23	W 274	16	NW 336	14	N 1	19	W 248	14	W 248	24	N 5	21	NW 301	16	N 358	19
2	N 21	14	N 19	23	W 271	19	W 269	16	W 280	19	SW 211	23	NW 293	16	SW 244	23	NW 294	26	W 273	23	N 360	14	NW 302	16
3	NE 33	16	NW 329	23	NW 294	23	NW 313	19	N 338	21	W 254	21	W 255	19	NW 332	23	SW 245	21	NW 334	19	W 261	24	NW 314	16
4	N 10	19	NW 313	19	NW 311	21	NW 300	23	NE 52	19	NW 329	13	SW 235	16	SW 239	16	NW 323	24	N 350	23	N 9	16	NW 299	21
5	NE 41	16	NW 300	16	W 274	23	N 5	29	N 360	19	S 198	14	W 280	16	SW 243	16	NW 330	11	N 22	16	N 21	14	N 14	19
6	SE 120	21	NW 320	19	W 267	21	N 349	19	N 16	19	S 165	23	W 259	21	NW 320	24	W 275	19	NW 305	16	N 15	16	W 292	24
7	NW 326	19	NW 314	19	NW 324	24	NW 301	21	N 354	21	S 185	24	N 356	14	SW 207	42	N 15	16	SW 217	23	N 359	23	N 22	19
8	NE 32	23	N 9	21	NW 303	23	NW 309	24	N 17	16	S 188	24	NW 322	16	S 192	34	N 19	11	S 201	23	N 1	19	NE 64	26
9	NE 24	19	N 358	16	N 359	21	N 354	16	N 344	16	SW 240	19	SW 241	16	W 258	26	NE 31	16	NW 336	13	S 197	19	NW 297	21
10	NW 294	16	NW 319	19	N 8	21	N 340	13	N 347	24	W 272	19	W 279	13	N 5	21	N 4	14	NW 295	16	NW 335	16	NW 299	16
11	N 22	23	NW 335	21	NW 324	21	NW 314	13	W 288	16	SW 244	19	W 271	19	SW 226	42	NW 324	14	N 2	23	NW 331	14	N 22	21
12	NE 29	24	NW 308	23	NW 313	24	NW 316	16	W 266	19	N 17	19	W 261	16	W 279	16	W 267	23	NE 37	21	NW 310	27	NE 23	19
13	NE	16	NW	21	NW	19	N	19	NW	16	N	14	SW	13	W	19	N 357	16	N	19	N	19	N	19

	24		323		294		5		330		359		237		277				19		11		21	
14	NW 333	21	NW 313	23	NW 333	19	N 338	14	SE 123	13	SW 244	16	W 258	19	NW 324	14	S 169	16	N 359	16	NE 38	21	N 10	13
15	N 342	19	NW 296	24	N 10	26	N 343	19	N 354	16	SW 229	16	N 3	27	NW 312	24	NW 319	39	N 13	16	N 359	19	N 13	16
16	NE 30	21	W 250	21	NE 25	19	NW 314	19	NW 335	13	S 195	24	N 6	14	S 202	24	NW 306	14	N 13	16	N 342	19	NE 34	16
17	NE 24	24	NW 301	21	S 173	24	N 17	19	SW 244	16	SW 224	14	N 351	14	W 250	23	SW 205	21	N 14	19	NE 28	32	NE 38	19
18	NE 29	26	NW 309	16	SW 209	21	W 264	21	N 351	21	SW 213	21	SW 236	23	W 276	26	SW 217	19	N 343	24	NE 35	13	N 21	19
19	N 3	23	NW 303	19	W 273	23	SW 223	21	NW 306	13	N 348	13	W 251	19	NW 312	16	N 348	29	W 255	19	NE 36	16	NE 30	26
20	N 12	21	NE 58	34	N 357	16	W 267	19	W 257	29	W 260	16	W 266	14	NW 313	16	N 4	14	SW 230	27	NE 30	16	NE 30	16
21	N 18	27	SW 241	23	NW 325	14	NW 327	23	W 256	16	SW 238	19	SW 242	14	SW 243	16	NW 317	21	N 341	16	N 6	19	NE 33	16
22	N 17	27	N 358	24	NW 300	21	NE 31	16	W 249	14	SW 247	19	NW 312	16	W 255	21	W 269	14	NW 332	19	N 5	27	NE 27	13
23	N 19	23	NW 307	21	N 358	23	NW 300	21	SW 237	16	NW 330	21	SW 236	14	NW 320	14	W 282	16	NW 330	14	N 5	16	NE 32	13
24	N 13	16	NW 301	23	NW 328	23	SW 211	21	SW 213	21	W 284	16	SW 213	21	NW 319	14	N 347	26	N 359	23	NW 312	13	NE 26	14
25	N 12	19	N 342	23	W 265	21	NW 315	27	NW 304	21	SW 244	19	SW 229	21	W 259	32	NW 304	19	SW 244	19	NW 310	16	NE 31	13
26	NE 25	19	NW 332	16	W 268	19	N 351	14	NW 302	13	NW 311	14	W 254	13	S 200	16	W 281	19	NW 295	16	NE 24	27	NE 63	24
27	N 15	19	NW 307	24	W 277	23	NW 301	21	SW 226	14	NW 317	13	N 340	23	N 14	16	NW 333	16	NW 319	16	N 15	23	W 287	14
28	NE 42	19	W 280	21	W 266	21	W 288	21	W 252	19	NW 296	19	NW 325	14	N 16	16	W 272	19	NW 298	23	N 354	21	NE 25	19
29	N 344	21			NE 27	24	NW 325	16	N 342	11	N 2	19	N 17	10	W 265	11	N 20	14	N 351	21	N 341	13	NE 40	27
30	N 8	19			W 251	19	NW 310	16	NW 304	19	N 11	19	W 248	19	SW 233	16	N 2	24	N 9	14	SW 222	19	N 22	24
31	N 13	16			NW 324	24			NW 305	21			W 287	14	SW 231	23			N 345	19			N 8	21

Appendix E: Calculated monthly maximum average wind speed with respect to wind direction for Year 2013

Wind Direction (Azimuth)	Range (°) in degree	Average wind speed according to months (km/h)												Max Average Wind Speed km/h	Max Average Wind Speed m/s
		JAN	FEB	MARCH	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC		
N	**337.5 - 22.5**	17	18.88	19.18	17.93	15.4	19.08	18.13	17.38	15.69	17.38	17.9	17.57	17.63	4.90
NE	**22.5 - 67.5**	21	19.56	20	15.67	14	14.33	16	14	27	13	15.8	20.06	17.54	4.87
E	**67.5 - 112.5**	0	0	0	0	24	0	0	0	0	0	0	0	2	0.56
SE	**112.5 - 157.5**	0	0	0	0	0	0	0	13	0	0	0	0	1.08	0.30
S	**157.5 - 202.5**	0	24	0	0	24.75	0	16	21	0	0	13	0	8.23	2.29
SW	**202.5 - 247.5**	0	0	21	19	19	14	19.67	23.13	18	18.25	14.67	0	13.89	3.86
W	**247.5 - 292.5**	17	19.83	20.6	17.2	18.17	17.67	16.17	20.57	16.8	20	17.5	0	16.79	4.66
NW	**292.5 - 337.5**	17.4	21.25	16.7	16.83	17.25	19.67	13.5	21.25	19.71	17.29	16.89	14	17.65	4.90

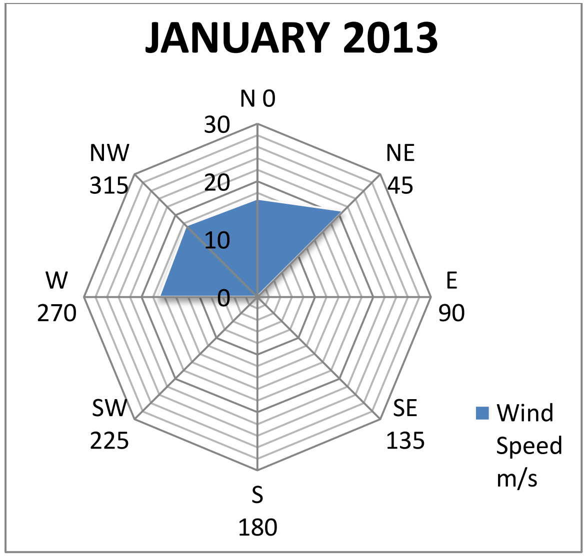
Appendix F: Calculated monthly maximum average wind speed with respect to wind direction for Year 2014

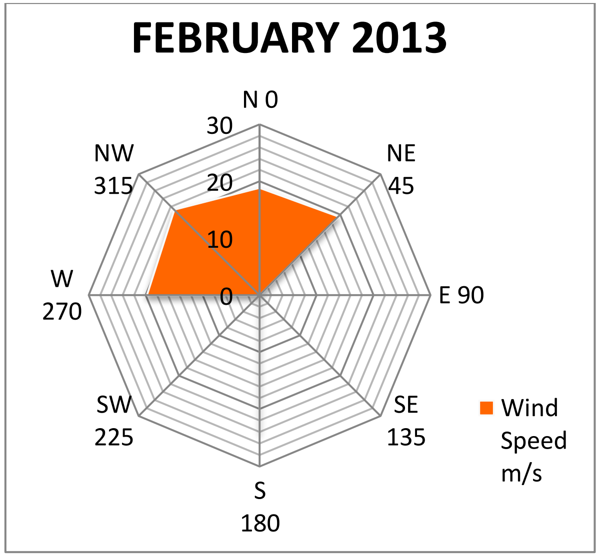
Wind Direction (Azimuth)	Range (˚) in degree	Average wind speed according to months (km/h)												Max Average Wind Speed km/h	Max Average Wind Speed m/s
		JAN	FEB	MARCH	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC		
N	**337.5 - 22.5**	20.44	21.00	21.40	18.00	18.40	16.80	17.29	17.67	18.22	19.07	18.53	19.00	18.82	5.23
NE	**22.5 - 67.5**	20.27	34.00	21.50	16.00	19.00	0.00	0.00	0.00	16.00	21.00	20.83	18.64	13.25	3.68
E	**67.5 - 112.5**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE	**112.5 - 157.5**	21.00	0.00	0.00	0.00	13.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.83	0.79
S	**157.5 - 202.5**	0.00	0.00	24.00	0.00	0.00	21.80	0.00	24.67	16.00	23.00	19.00	0.00	8.20	2.28
SW	**202.5 - 247.5**	0.00	23.00	21.00	21.00	16.75	18.50	17.25	24.25	20.33	23.00	19.00	0.00	14.75	4.10
W	**247.5 - 292.5**	0.00	21.00	21.00	19.25	18.50	18.00	16.83	20.89	19.14	21.00	24.00	19.00	16.00	4.44
NW	**292.5 - 337.5**	18.67	20.39	21.15	20.14	16.57	15.67	15.50	18.13	20.44	16.89	17.00	18.00	18.21	5.06

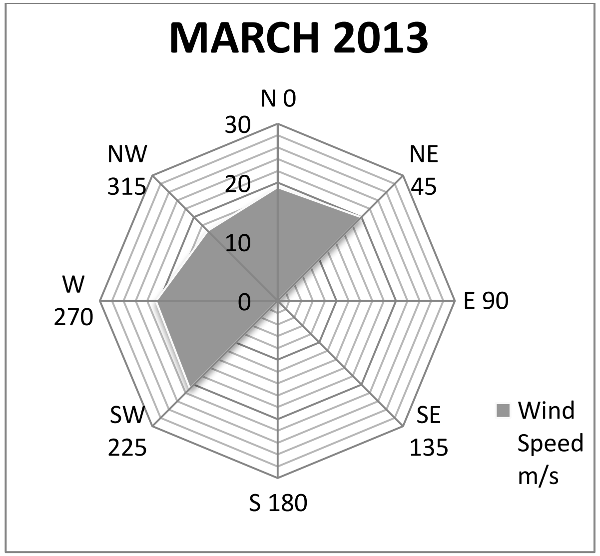
Appendix G: Summary of hourly mean surface wind speed and wind direction for all 4 stations on 13 June 2013.

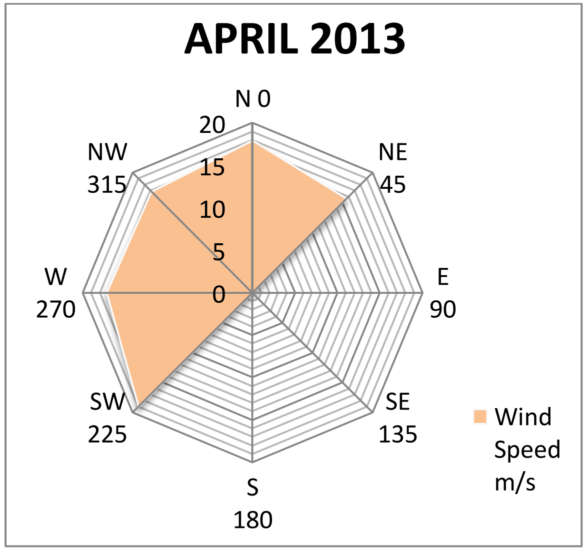
Stations	Butterworth		Bayan Lepas		P.Langkawi		Alor Setar	
Time (24 hrs)	**Speed (m/ s)**	**Direction**	**Speed (m/ s)**	**Direction**	**Speed (m/ s)**	**Direction**	**Speed (m/ s)**	**Direction**
1:00	0.8	120	CALM		0.9	110	1.2	190
2:00	0.8	160	0.6	340	0.8	350	0.3	120
3:00	0.5	100	CALM		0.6	310	0.8	100
4:00	1.1	60	0.5	320	2.4	260	1.9	130
5:00	0.9	60	CALM		0.7	30	1	110
6:00	0.7	80	CALM		2	210	0.9	50
7:00	1.4	60	0.9	330	0.5	270	1.8	310
8:00	1.2	50	CALM		1.1	50	2.4	250
9:00	3.6	360	1.4	10	1	20	1.9	170
10:00	2.1	10	3.6	30	1.3	250	1.7	140
11:00	2.7	80	3.8	50	2.4	60	0.9	140
12:00	2.2	20	5.2	60	1.2	120	2.2	290
13:00	0.4	90	3.7	70	1.6	280	1.1	260
14:00	1.9	300	2.8	60	2.9	230	1.5	170
15:00	1.5	80	3.1	70	6.7	230	1.4	210
16:00	2.4	340	1.8	40	6.7	290	5.6	290
17:00	5.1	330	2.3	350	3.8	290	4.9	290
18:00	7	340	2.8	40	5.6	260	1.2	340
19:00	11.6	300	8.4	320	3.4	270	3.9	210
20:00	7.7	290	6.4	300	4.3	250	2.1	230
21:00	2.7	220	3.9	250	2.7	290	3.7	190
22:00	4.3	80	0.6	40	1.7	290	3	170
23:00	3.6	100	1.3	30	0.5	70	2.3	140
24:00	2.2	50	2.4	20	0.4	100	0.8	80

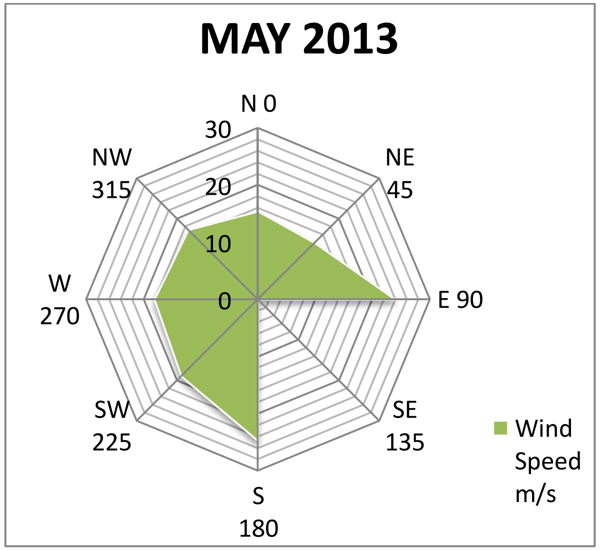
Appendix H: Monthly Wind Rose for Year 2013 (January to December)

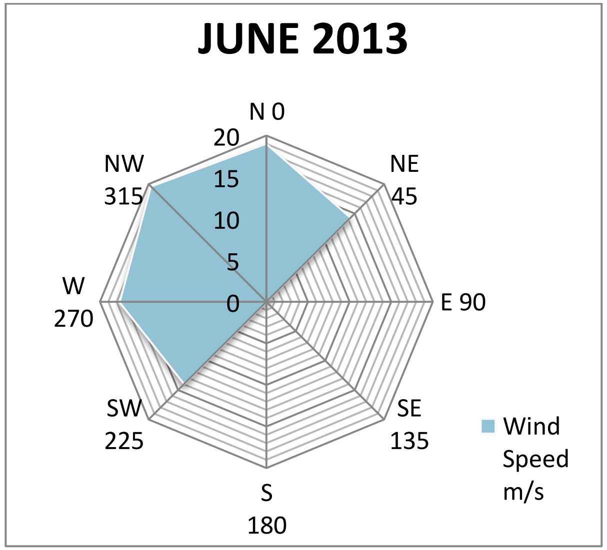


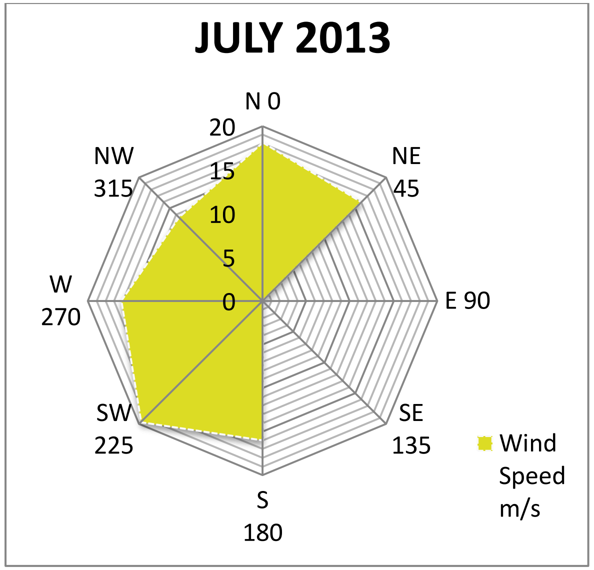


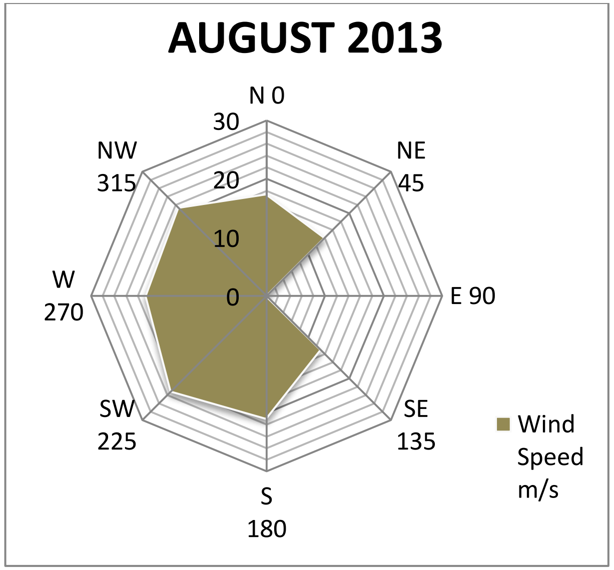


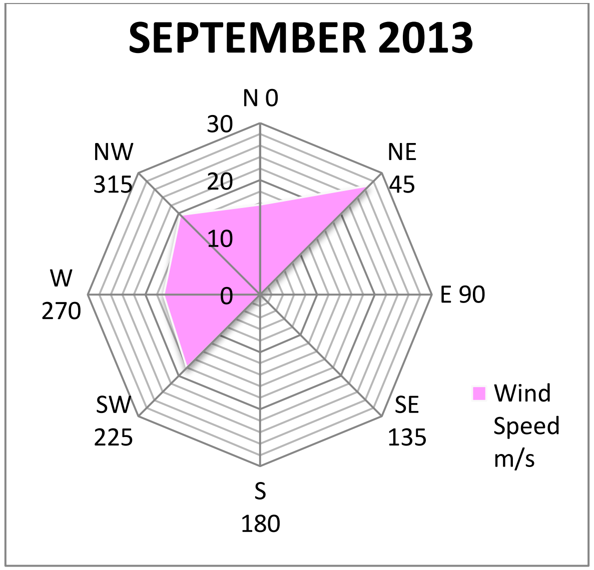


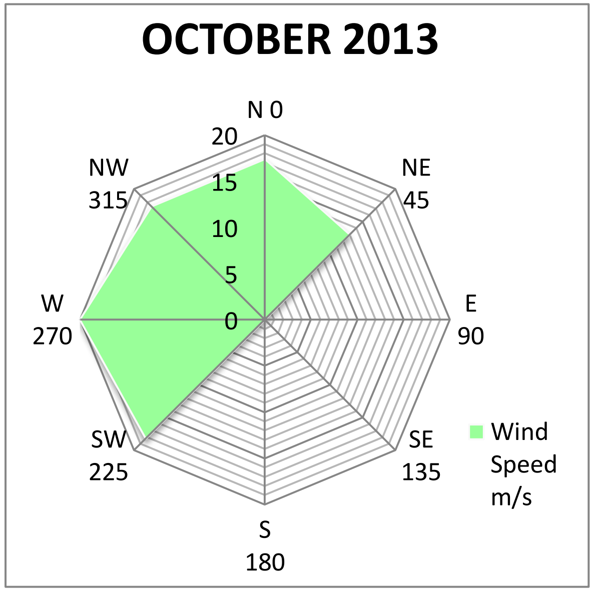


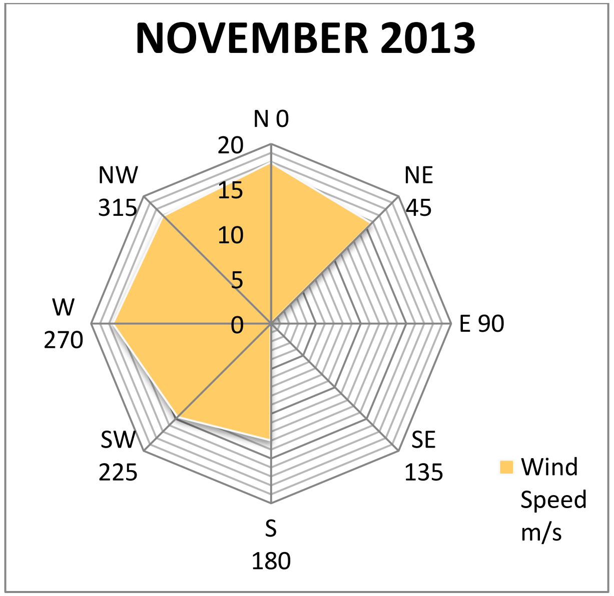


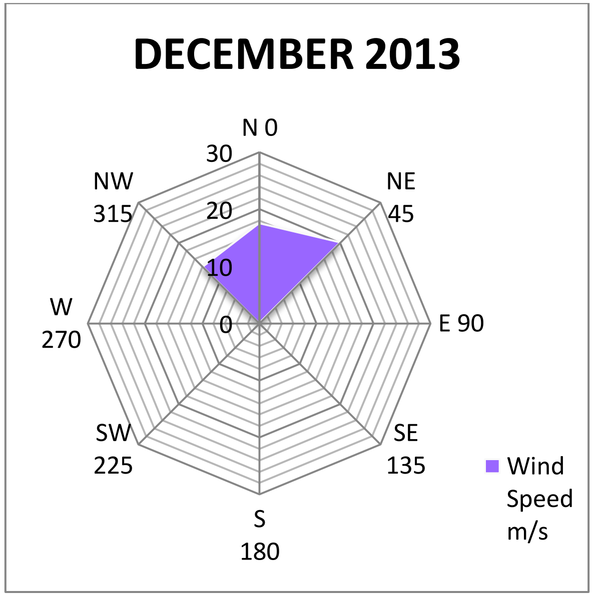

JULY 2013
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
0
5
10
15
20
Wind Speed m/s


AUGUST 2013
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
0
10
20
30
Wind Speed m/s

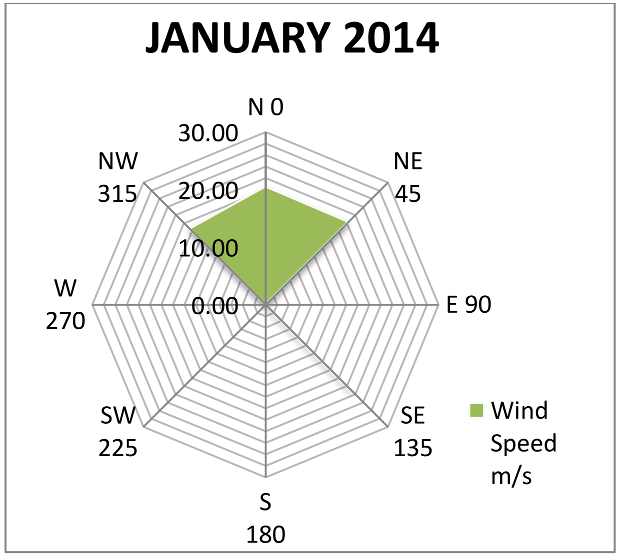

SEPTEMBER 2013
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
0
10
20
30
Wind Speed m/s

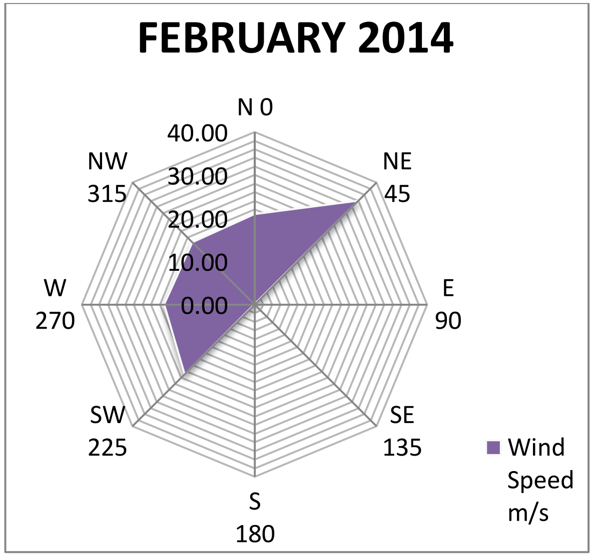

OCTOBER 2013
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
0
5
10
15
20
Wind Speed m/s

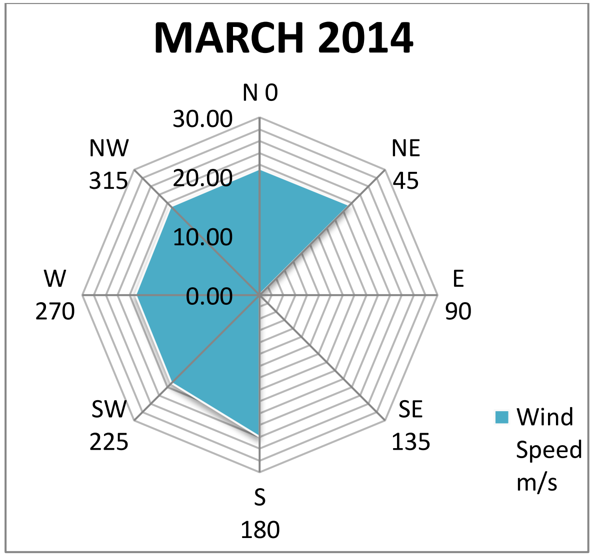

NOVEMBER 2013
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
0
5
10
15
20
Wind Speed m/s

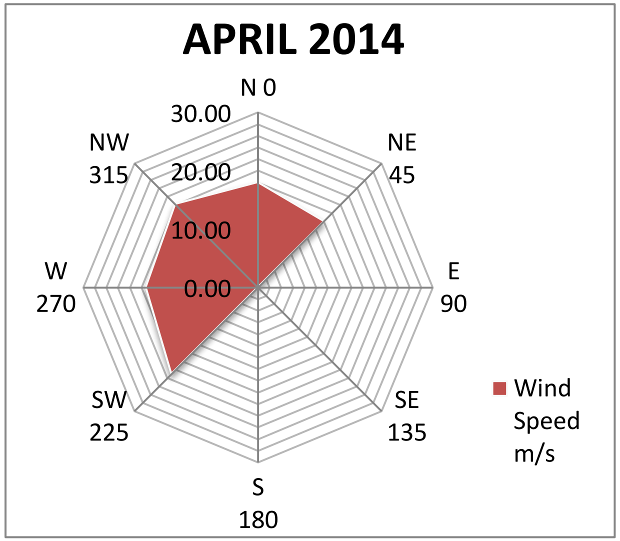

DECEMBER 2013
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
0
10
20
30
Wind Speed m/s

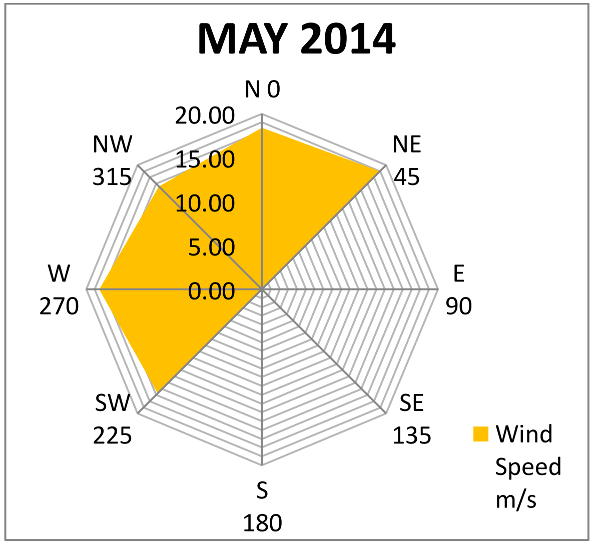
Appendix I: Monthly Wind Rose for Year 2014 (January to December)

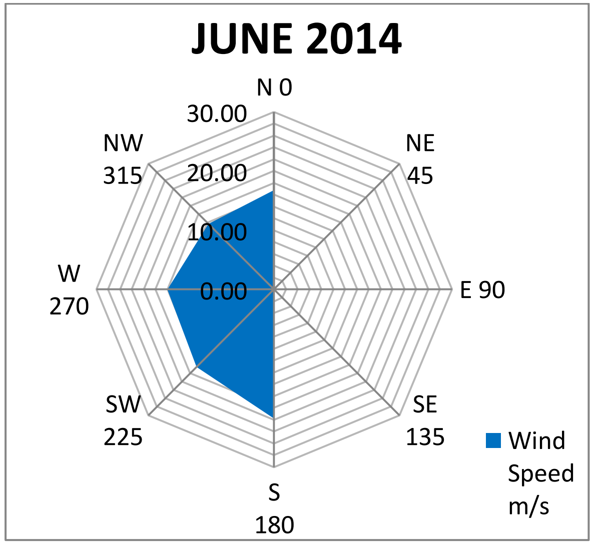


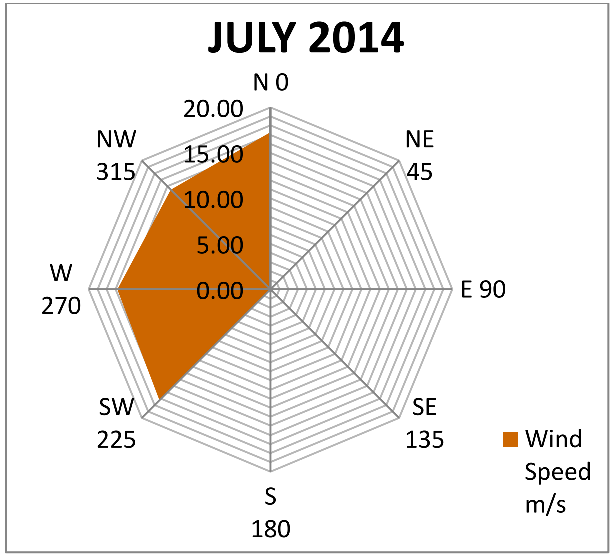


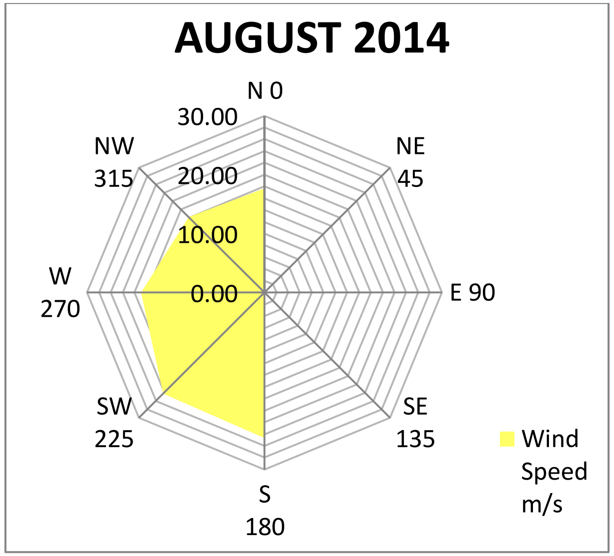


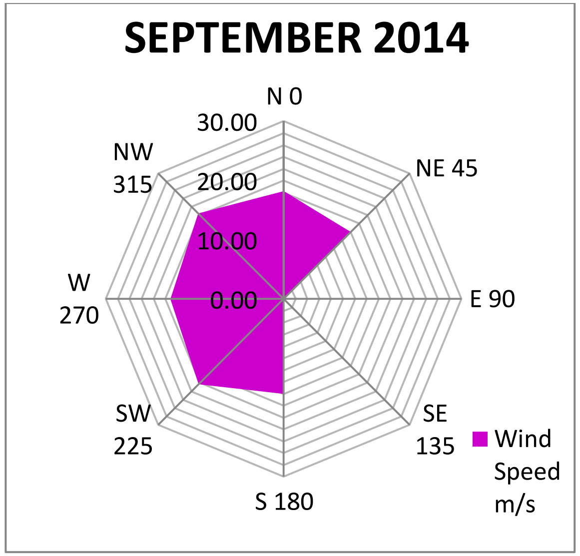


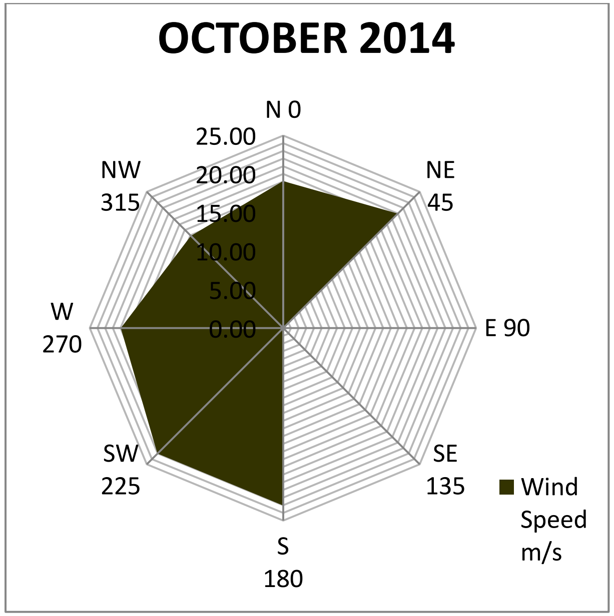


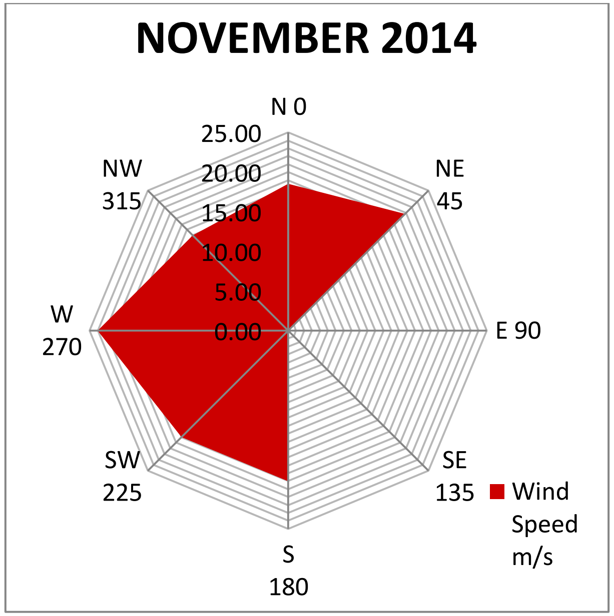


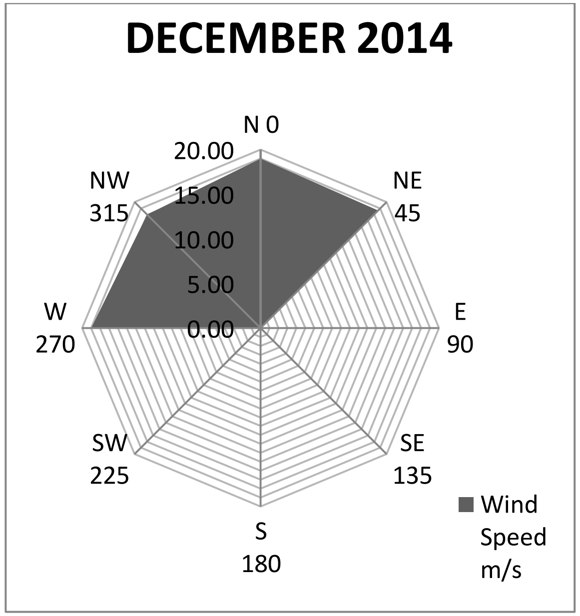

JULY 2014
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
20.00
15.00
10.00
5.00
0.00
Wind Speed m/s


AUGUST 2014
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
30.00
20.00
10.00
0.00
Wind Speed m/s


SEPTEMBER 2014
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
30.00
20.00
10.00
0.00
Wind Speed m/s


OCTOBER 2014
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
25.00
20.00
15.00
10.00
5.00
0.00
Wind Speed m/s


NOVEMBER 2014
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
25.00
20.00
15.00
10.00
5.00
0.00
Wind Speed m/s


DECEMBER 2014
N 0
NE 45
E 90
SE 135
S 180
SW 225
W 270
NW 315
20.00
15.00
10.00
5.00
0.00
Wind Speed m/s

Appendix J: Summary of wind pressure of different angle using wind speed of 11.6 m/s.

No.	Initial Velocity (m/s)	Direction (deg)	Changes in Velocity (m/s)	Pressure (Pa)	Difference in velocity (m/s)	Percentage difference of velocity (%)	Coefficient
1	11.6	0 S	14.910	87.004	3.310	28.534	0.285
2	11.6	22.5 S	23.684	48.471	12.084	104.172	1.042
3	11.6	45 SW	27.245	46.549	15.645	134.871	1.349
4	11.6	67.5 SW	25.547	47.054	13.947	120.233	1.202
5	11.6	90 W	28.679	53.559	17.079	147.233	1.472
6	11.6	112.5 W	29.186	75.951	17.586	151.603	1.516
7	11.6	135 NW	31.019	57.655	19.419	167.405	1.674
8	11.6	157.5 NW	30.216	57.492	18.616	160.483	1.710
9	11.6	180 N	28.631	36.131	17.031	146.819	1.468
10	11.6	202.5 N	25.205	28.508	13.605	117.284	1.173
11	11.6	225 NE	25.779	45.009	14.179	122.233	1.222
12	11.6	247.5 NE	31.432	67.418	19.832	170.966	1.605
13	11.6	270 E	20.391	104.405	8.791	75.784	0.758
14	11.6	292.5 E	28.911	68.373	17.311	149.233	1.492
15	11.6	315 SE	25.640	52.507	14.040	121.034	1.210
16	11.6	337.5 SE	29.522	65.407	17.922	154.500	1.545

Appendix K: Summary of wind pressure of different angle using different wind speeds (10m/s and 30 m/s)

No.	Initial Velocity (m/s)	Direction (deg)	Changes in Velocity (m/s)	Pressure (Pa)	Difference in velocity (m/s)	Percentage difference of velocity (%)	Coefficient
1	10	0 S	14.085	52.409	4.085	40.850	0.409
2	10	22.5 S	17.165	53.948	7.165	71.650	0.717
3	10	45 SW	16.324	60.228	6.324	63.240	0.632
4	10	67.5 SW	18.444	67.922	8.444	84.440	0.844
5	10	90 W	17.624	76.403	7.624	76.240	0.762
6	10	112.5 W	20.200	69.415	10.200	102.000	1.020
7	10	135 NW	24.250	51.504	14.250	142.500	1.425
8	10	157.5 NW	24.039	35.355	14.039	140.390	1.404
9	10	180 N	19.969	30.542	9.969	99.690	0.997
10	10	202.5 N	20.646	33.950	10.646	106.460	1.065
11	10	225 NE	21.598	36.670	11.598	115.980	1.160
12	10	247.5 NE	21.688	47.916	11.688	116.880	1.169
13	10	270 E	22.508	53.164	12.508	125.080	1.251
14	10	292.5 E	22.031	77.048	12.031	120.310	1.203
15	10	315 SE	21.110	71.141	11.110	111.100	1.111
16	10	337.5 SE	22.449	43.211	12.449	124.490	1.245

No.	Initial Velocity (m/s)	Direction (deg)	Changes in Velocity (m/s)	Pressure (Pa)	Difference in velocity (m/s)	Percentage difference of velocity (%)	Coefficient
1	30	0 S	39.622	553.965	9.622	32.073	0.321
2	30	22.5 S	44.250	588.889	14.250	47.500	0.475
3	30	45 SW	44.390	566.154	14.390	47.967	0.480
4	30	67.5 SW	46.168	633.420	16.168	53.893	0.539
5	30	90 W	44.492	666.520	14.492	48.307	0.483
6	30	112.5 W	46.806	680.886	16.806	56.020	0.560
7	30	135 NW	68.937	497.740	38.937	129.790	1.298
8	30	157.5 NW	67.657	326.919	37.657	125.523	1.255
9	30	180 N	41.873	449.581	11.873	39.577	0.396
10	30	202.5 N	62.875	307.702	32.875	109.583	1.096
11	30	225 NE	52.092	526.347	22.092	73.640	0.736
12	30	247.5 NE	50.160	649.721	20.160	67.200	0.672
13	30	270 E	49.703	588.134	19.703	65.677	0.657
14	30	292.5 E	66.630	654.941	36.630	122.100	1.221
15	30	315 SE	48.620	501.393	18.620	62.067	0.621
16	30	337.5 SE	66.742	370.045	36.742	122.473	1.225