Chapter 2 – Malaysia's Weather Data

Building Energy Efficiency Technical Guideline for Passive Design (Draft 1)

CK Tang

Foreword

This document is produced as part of Component 4, Building Sector Energy Efficiency Program (BSEEP) by CK Tang (ck@gbeet.com) and Nic Chin (nc.environmentology@gmail.com).

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CK Tang
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2.1 Introduction

A clear understanding of Malaysia's weather data enables designer to design building that response to the climate instead of against it. The climate in Malaysia is fairly consistent daily for the entire year; therefore it is useful to get an overview of an average day performance and the maximum and minimum hourly weather data for a full year. This chapter provides information on dry bulb temperature, wet bulb temperature, relative humidity, humidity ratio (moisture content), dew point temperature, global radiation, direct radiation, diffuse radiation, cloud cover and wind speed & direction, effective sky temperature and ground temperature. Charts are provided for ease of understanding the data and table of raw cross tabulation data made using pivot table function in Excel is also provided for users who wish to make use of these data for more in-depth analysis on their own.

2.2 Source of weather data

The hourly weather data of Kuala Lumpur used in this chapter was based on a Test Reference Year (TRY)[1] weather data developed in University Teknologi Malaysia (UiTM) under DANCED (Danish International Assistant) project for Energy Simulations for Buildings in Malaysia. The TRY is based on 21 years (1975 to 1995) of weather data from the Malaysian Meteorological Station in Subang, Klang Valley, Selangor. The hourly weather data that were obtained from this station is as shown in Table below.

Table 2.1: Weather data collected in Subang

Subang Meteorological Station (Klang Valley, Selangor, Malaysia) *Longitude*: 101deg 33' *Latitude*: 3deg 7'	
Parameters (hourly[2])	Units
Cloud cover	[oktas]
Dry bulb temperature	[°C]
Wet bulb temperature	[°C]
Relative humidity	[%]
Global solar radiation	[100*MJ/m²]
Sunshine hours	[hours]
Wind direction	[deg.]
Wind speed	[m/s]

A Test Reference year (TRY) consists of weather data for a given location. In order for the TRY to be representative of the climate it was constructed on the basis of at least 10 years weather data. The TRY is made up from actual monthly data (not average values) that are picked after having been subjected to different types of analysis.

It should be noted that typical energy simulation program require 2 extra data that were not collected by the Malaysian Meteorological Service, namely the direct and diffuse radiation. The

[1] Reimann, G. (2000) Energy Simulations for Buildings in Malaysia, *Test Reference Year*, 18-25.

[2] The values are integrated over a period of one hour, but the exact time interval has not been specified.

missing radiation data was calculated for the TRY via Erbs' Estimation Model from the horizontal global solar radiation.

Although not perfect, the TRY is currently the only known set of weather data for energy simulation that was compiled based on statistical analysis and it has been used in many energy simulations of various buildings in Malaysia with satisfactory results. This weather data was also used for the development of the constants in the Overall Thermal Transmission Value (OTTV) equation found in the Malaysia Standard (MS) 1525 (2007), Energy Efficiency in Non-Residential Building.

2.3 Location and Sun-Path

The global position and solar noon of six (6) cities in Malaysia provided in Table 2.2.

Table 2.2: Global Positioning and Solar Noon of 6 Cities in Malaysia

Locations	**Latitude (°N)**	**Longitude (°E)**	**Solar Noon**
1. Kuala Lumpur (Subang)	3.12	101.55	13:11
2. Penang	5.30	100.27	13:16
3. Johor Bharu	1.48	103.73	13:02
4. Kota Bharu	6.17	102.28	13:08
5. Kuching	1.48	110.33	12:36
6. Kota Kinabalu	5.93	116.05	12:13

Sun-Path diagram for 6 locations above is presented in this section and showed that the sun position is almost the same for all six (6) locations, except for the hour of the solar noon. Solar noon (when the sun is at its highest point) is 13:11 in Kuala Lumpur, while in Kota Kinabalu it is 1 hour earlier at 12:13.

The sun path is generally east-west with the sun approximately 25° to the north during summer solstice and 25° to the south during winter solstice for all locations in Malaysia.

The sun-path diagram is a useful tool to help in the design of external shading devices. The sun-path diagram is used to estimate sun angle at various time of day and year, allowing architects to design shading devices to block or allow direct sunlight at whatever time or day.

Chart 2.1: Sun-path of Kuala Lumpur

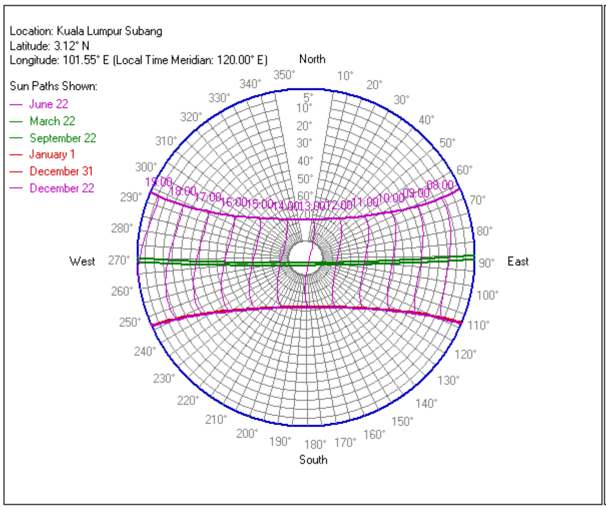


Chart 2.2: Sun-path of Penang

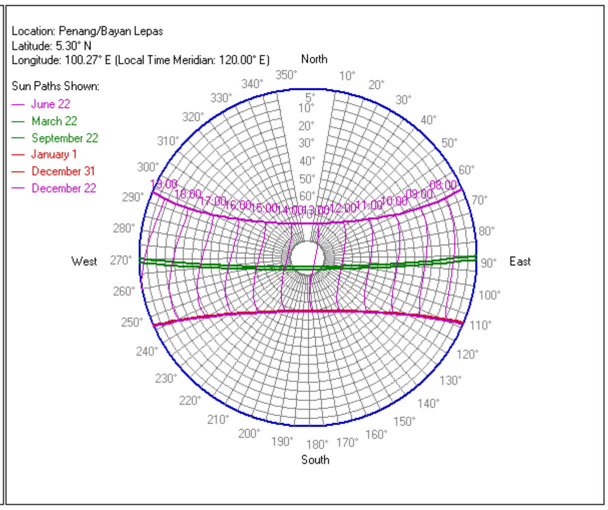


Chart 2.3: Sun-path of Johor Bharu

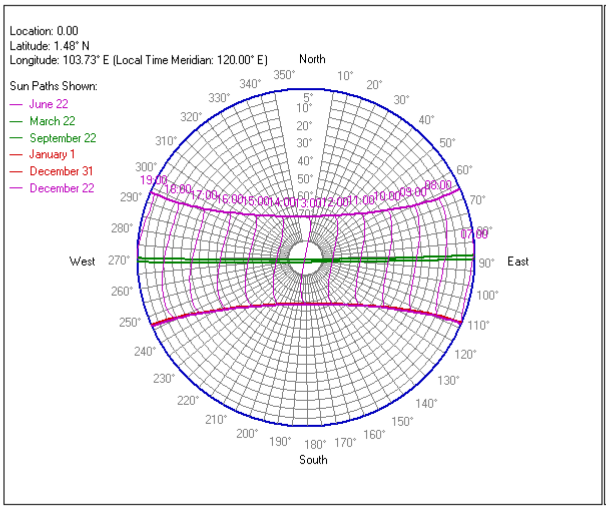


Chart 2.4: Sun-path of Kota Bharu

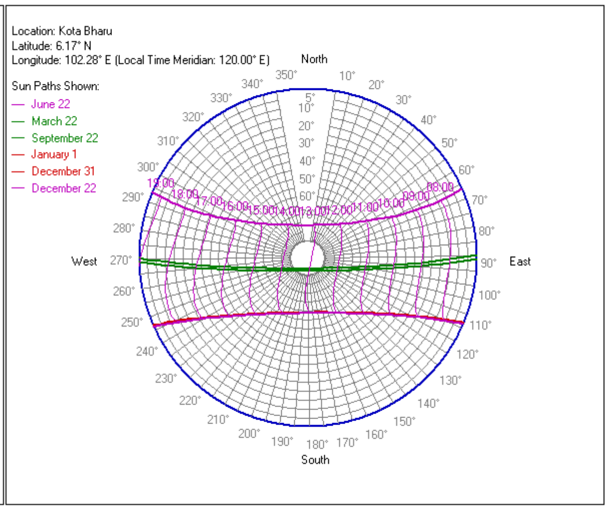


Chart 2.5: Sun-path of Kuching

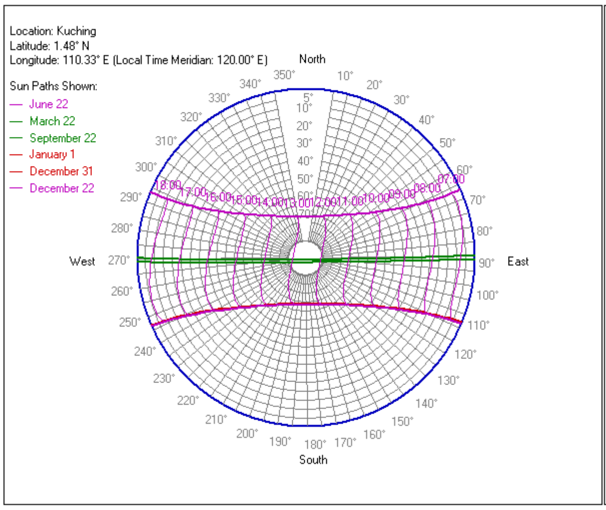


Chart 2.6: Sun-path of Kota Kinabalu

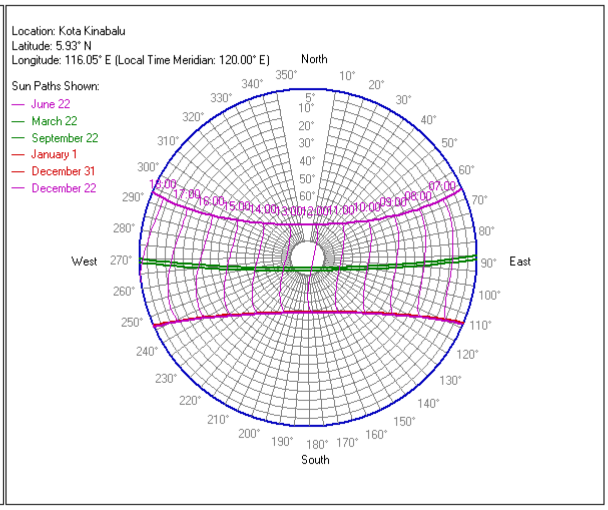
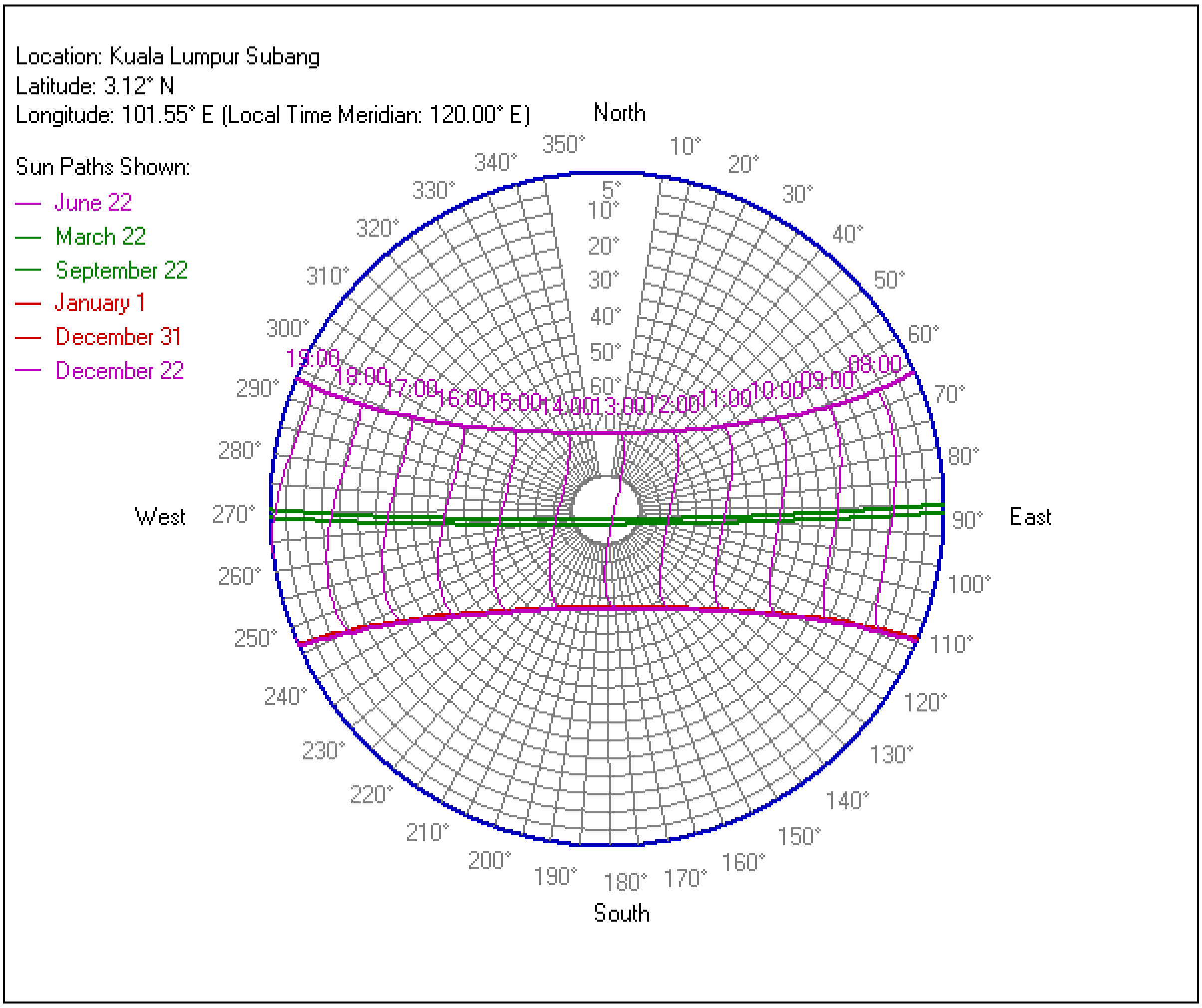


Chart 2.7: Large Sun-path of Kuala Lumpur



2.4 Dry Bulb Temperature

The daily average, maximum and minimum dry bulb temperature is provided by the chart in this section. The standard deviation is more than 2°C from 2pm to 6pm indicating that the afternoon hours have a higher change of temperature from day to day; while in the hours of midnight to 7am, the standard deviation of the dry bulb temperature is less than 1°C, indicating a fairly consistent and predictable dry bulb temperature from midnight to early morning hours.

The average dry bulb temperature of the whole year (including day and night) is 26.9°C.

The average peak dry bulb temperature is just below 32°C at the hour of 1pm to 2pm, while the maximum dry bulb temperature of the TRY is 35.6°C at 3pm.

The average low dry bulb temperature is 23.7°C at 6am in the morning; while the lowest dry bulb temperature of the TRY is 20.6° at 7am in the morning.

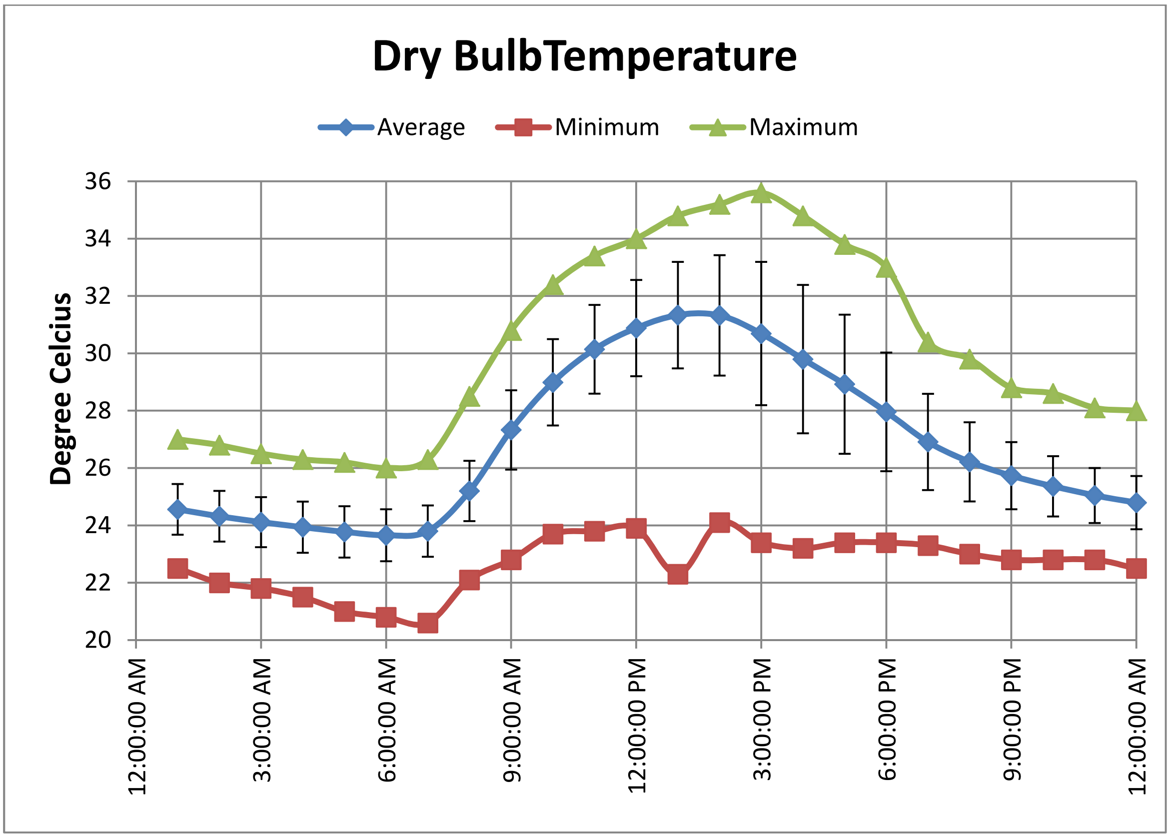
2.4.1 *Design Potential*

The understanding of the dry bulb temperature allows a clear appreciation of when natural ventilation will work and when it is not likely to work. In addition, data center designers can also make use of this knowledge to provide natural ventilation to the computer server whenever possible to save significant amount of air-conditioning energy.

2.4.2 Design Risk

The TRY is 21 years of weather data in Subang Airport from year 1975 to 1995. During these years, the Subang Airport location is fairly well surrounded by greeneries. The peak dry bulb temperature in cities is expected to be higher due to urban heat island effect.

2.4.3 Charts and Table of Raw Data



Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	24.6	22.5	27.0	0.9
2:00:00 AM	24.3	22.0	26.8	0.9
3:00:00 AM	24.1	21.8	26.5	0.9
4:00:00 AM	23.9	21.5	26.3	0.9
5:00:00 AM	23.8	21.0	26.2	0.9
6:00:00 AM	23.7	20.8	26.0	0.9
7:00:00 AM	23.8	20.6	26.3	0.9
8:00:00 AM	25.2	22.1	28.5	1.1
9:00:00 AM	27.3	22.8	30.8	1.4
10:00:00 AM	29.0	23.7	32.4	1.5
11:00:00 AM	30.1	23.8	33.4	1.5
12:00:00 PM	30.9	23.9	34.0	1.7
1:00:00 PM	31.3	22.3	34.8	1.9
2:00:00 PM	31.3	24.1	35.2	2.1
3:00:00 PM	30.7	23.4	35.6	2.5
4:00:00 PM	29.8	23.2	34.8	2.6
5:00:00 PM	28.9	23.4	33.8	2.4
6:00:00 PM	28.0	23.4	33.0	2.1
7:00:00 PM	26.9	23.3	30.4	1.7
8:00:00 PM	26.2	23.0	29.8	1.4

9:00:00 PM	25.7	22.8	28.8	1.2
10:00:00 PM	25.4	22.8	28.6	1.1
11:00:00 PM	25.0	22.8	28.1	1.0
12:00:00 AM	24.8	22.5	28.0	0.9

2.5 Wet Bulb Temperature

The wet bulb temperature is fairly consistent between day and night and throughout the year. The average peak of the wet bulb temperature is 25.4°C at 2pm, while the maximum wet bulb temperature in the TRY is 28.4°C at 2pm.

The average low of wet bulb temperature is 23.1°C at 6am, and the bottom wet bulb temperature in the TRY is 19.9°C at 7am in the morning.

2.5.1 *Design Potential*

The wet bulb temperature is a good indicator of the potential of direct evaporative cooling strategy. If the direct evaporative cooling system is 100% efficient, the lowest air temperature of a evaporative cooling system achievable is the wet bulb temperature. The efficiency of direct evaporative cooling devices depends on the system water droplet size, wetted surface area and air speed and has efficiency up to 90%[3]. During daytime, the dry bulb temperature is significantly higher than wet bulb temperature; therefore, evaporative cooler will work well. However, during night time, the dry bulb temperature is very close to the wet bulb temperature, the effectiveness of evaporative cooling is reduced significantly, i.e. the reduction of air temperature is very small with the use of evaporative cooling, even at 90% efficiency.

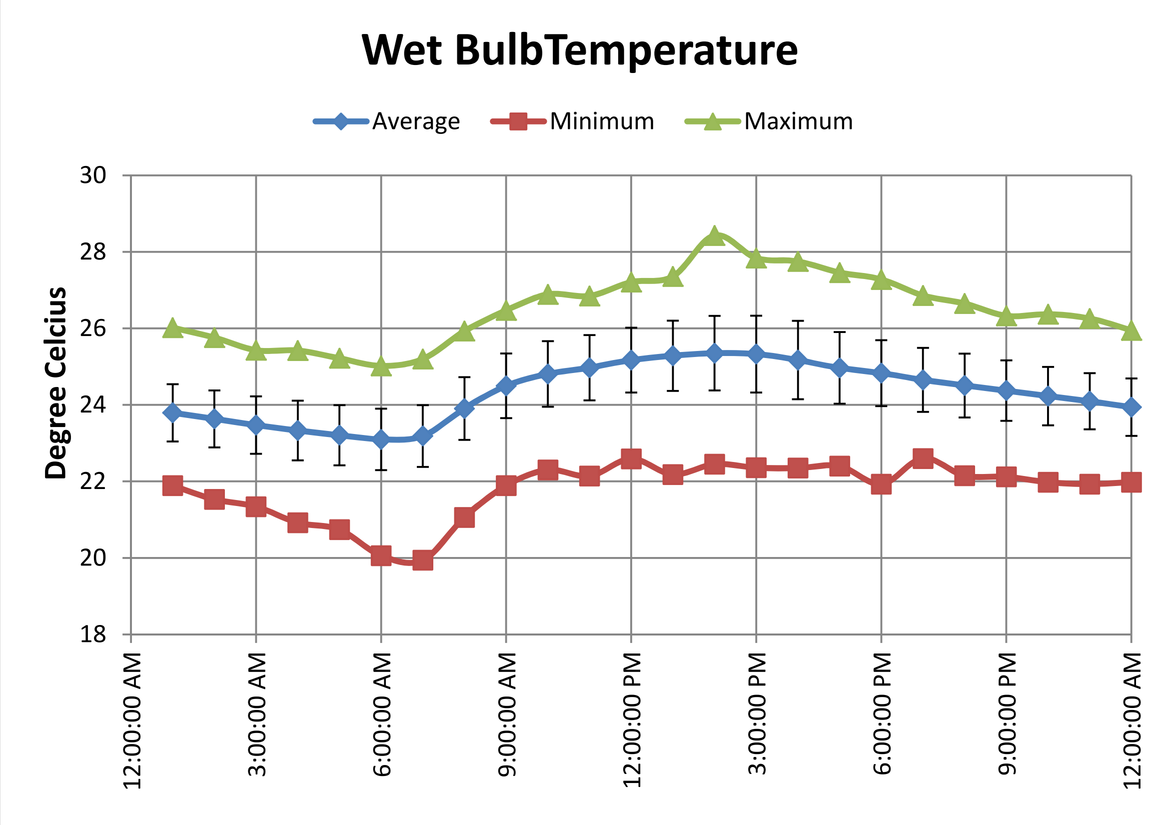
The wet bulb temperature is also a very important factor for sizing and predicting the performance of cooling tower. The lower the wet bulb temperature, the better is the performance of the cooling tower. Ashrae recommends designing an approach temperature of the cooling tower to be 5.5°C to the wet bulb temperature. The lower the condenser water temperature as it exits from the cooling tower, the more efficient it is for the performance of the chiller. Based on the TRY data, it will be best to run the chiller early in the morning, when the wet bulb temperature is lowest, to gain maximum efficiency from the chiller. Unfortunately most buildings are occupied from 8am onwards and the use of thermal storage solutions will normally introduce further inefficiencies that may negate any efficiency gained by running the chiller system in the early morning hours.

2.5.2 *Design Risk*

The wet bulb temperature is not affected much by urban heat island effect. Therefore, the wet bulb temperature provided by the TRY is reliable to be used.

[3] http://www.wescorhvac.com/Evaporative%20cooling%20white%20paper.htm

2.5.3 CHARTS AND TABLE OF RAW DATA



Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	23.8	21.9	26.0	0.7
2:00:00 AM	23.6	21.5	25.8	0.7
3:00:00 AM	23.5	21.3	25.4	0.8
4:00:00 AM	23.3	20.9	25.4	0.8
5:00:00 AM	23.2	20.7	25.2	0.8
6:00:00 AM	23.1	20.1	25.0	0.8
7:00:00 AM	23.2	19.9	25.2	0.8
8:00:00 AM	23.9	21.1	25.9	0.8
9:00:00 AM	24.5	21.9	26.5	0.8
10:00:00 AM	24.8	22.3	26.9	0.9
11:00:00 AM	25.0	22.1	26.9	0.9
12:00:00 PM	25.2	22.6	27.2	0.8
1:00:00 PM	25.3	22.2	27.4	0.9
2:00:00 PM	25.4	22.5	28.4	1.0
3:00:00 PM	25.3	22.4	27.8	1.0
4:00:00 PM	25.2	22.4	27.8	1.0
5:00:00 PM	25.0	22.4	27.5	0.9
6:00:00 PM	24.8	21.9	27.3	0.9
7:00:00 PM	24.7	22.6	26.9	0.8
8:00:00 PM	24.5	22.2	26.7	0.8
9:00:00 PM	24.4	22.1	26.3	0.8
10:00:00 PM	24.2	22.0	26.4	0.8
11:00:00 PM	24.1	21.9	26.3	0.7
12:00:00 AM	23.9	22.0	26.0	0.8

2.6 Humidity Ratio (Moisture Content)

The humidity ratio or moisture content of the TRY weather data is fairly consistent throughout the year. The average moisture content in the TRY is 18.3 g/kg and is consistent day or night. Day to day fluctuation is highest at 2pm in the afternoon with a peak standard deviation of 1.6 g/kg.

2.6.1 Design Potential

The humidity ratio give us information about how much water is in one kilogram of air, therefore, it gives a potential water quantity that can be "squeezed" out from the air. The following known methodologies for "squeezing" water out from the air are:

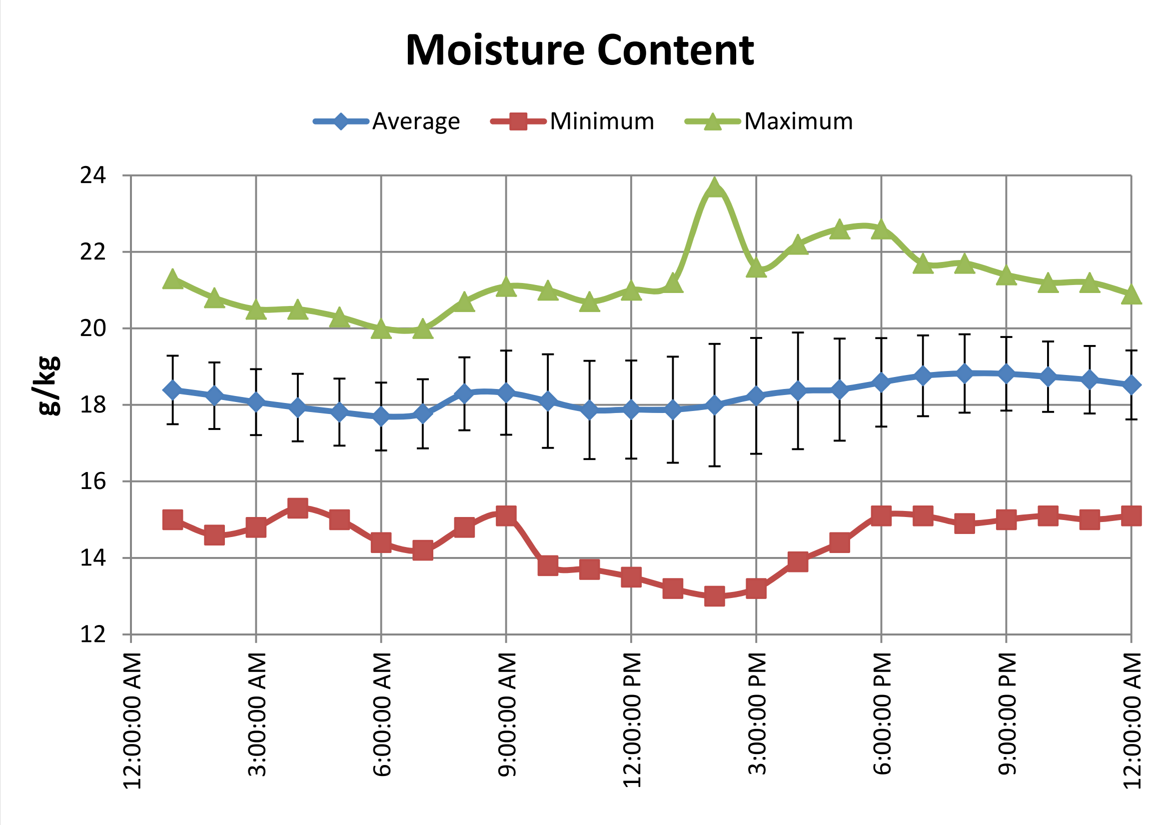
- Cold surfaces that are below the dew point temperature.
- Desiccant material that absorb moisture from the air.

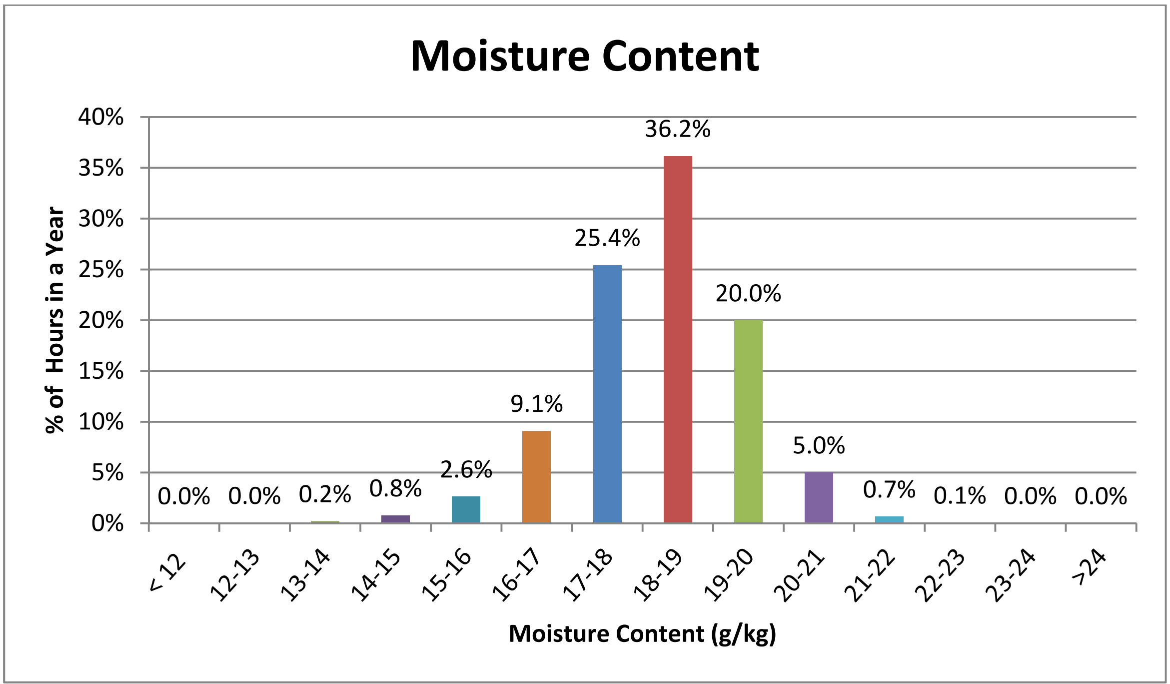
A clear understanding of humidity ratio (moisture content) provides a very useful method for engineers to estimate the amount of latent load and condensation rate that the system need to be designed for. For example, the humidity ratio provides an indication of amount of water that needs to be extracted from the outdoor air to supply air-conditioned air at 11°C and 100% relative humidity (approximately 8.2 g/kg) at the cooling coil (off-coil condition). As the average moisture content of outdoor air in Malaysia is 18.3 g/kg, an average extraction of 10.1 gram of water from each kilogram of outdoor air is required to provide a supply of air-conditioned air at 11°C and 100% relative humidity. This value provides an approximation of condensation rate of typical cooling coil in Malaysian air handling units due to intake of fresh air.

2.6.2 Design Risk

Water features and greeneries would increase the moisture content in the air. During photosynthesis process, greeneries expel moisture from leaves to provide evaporative cooling to the environment. Therefore, it is not necessary true that placing fresh air intake duct near to greeneries (to take in cooler air) will yield lower energy use because it may have higher moisture content in it.

2.6.3 CHARTS AND TABLE OF RAW DATA





Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	18.4	15.0	21.3	0.9
2:00:00 AM	18.2	14.6	20.8	0.9
3:00:00 AM	18.1	14.8	20.5	0.9
4:00:00 AM	17.9	15.3	20.5	0.9
5:00:00 AM	17.8	15.0	20.3	0.9
6:00:00 AM	17.7	14.4	20.0	0.9

7:00:00 AM	17.8	14.2	20.0	0.9
8:00:00 AM	18.3	14.8	20.7	1.0
9:00:00 AM	18.3	15.1	21.1	1.1
10:00:00 AM	18.1	13.8	21.0	1.2
11:00:00 AM	17.9	13.7	20.7	1.3
12:00:00 PM	17.9	13.5	21.0	1.3
1:00:00 PM	17.9	13.2	21.2	1.4
2:00:00 PM	18.0	13.0	23.7	1.6
3:00:00 PM	18.2	13.2	21.6	1.5
4:00:00 PM	18.4	13.9	22.2	1.5
5:00:00 PM	18.4	14.4	22.6	1.3
6:00:00 PM	18.6	15.1	22.6	1.2
7:00:00 PM	18.8	15.1	21.7	1.1
8:00:00 PM	18.8	14.9	21.7	1.0
9:00:00 PM	18.8	15.0	21.4	1.0
10:00:00 PM	18.7	15.1	21.2	0.9
11:00:00 PM	18.7	15.0	21.2	0.9
12:00:00 AM	18.5	15.1	20.9	0.9

2.7 Dew Point Temperature

The dew point temperature is directly linked to the moisture content in the air. However, the dew point temperature has the advantage of providing us information on the condensation risk due to exposure to outdoor air. Any surface temperature that is below the dew point temperature will have condensation on it. The average dew point temperature in the TRY is 23.4°C and is fairly consistent day or night and throughout the year. The peak standard deviation of the dew point temperature is 1.5°C at 2pm in the afternoon.

More than 70% of the hours, the dew point temperature is below 24°C and more than 95% of the hours the dew point temperature is below 25°C.

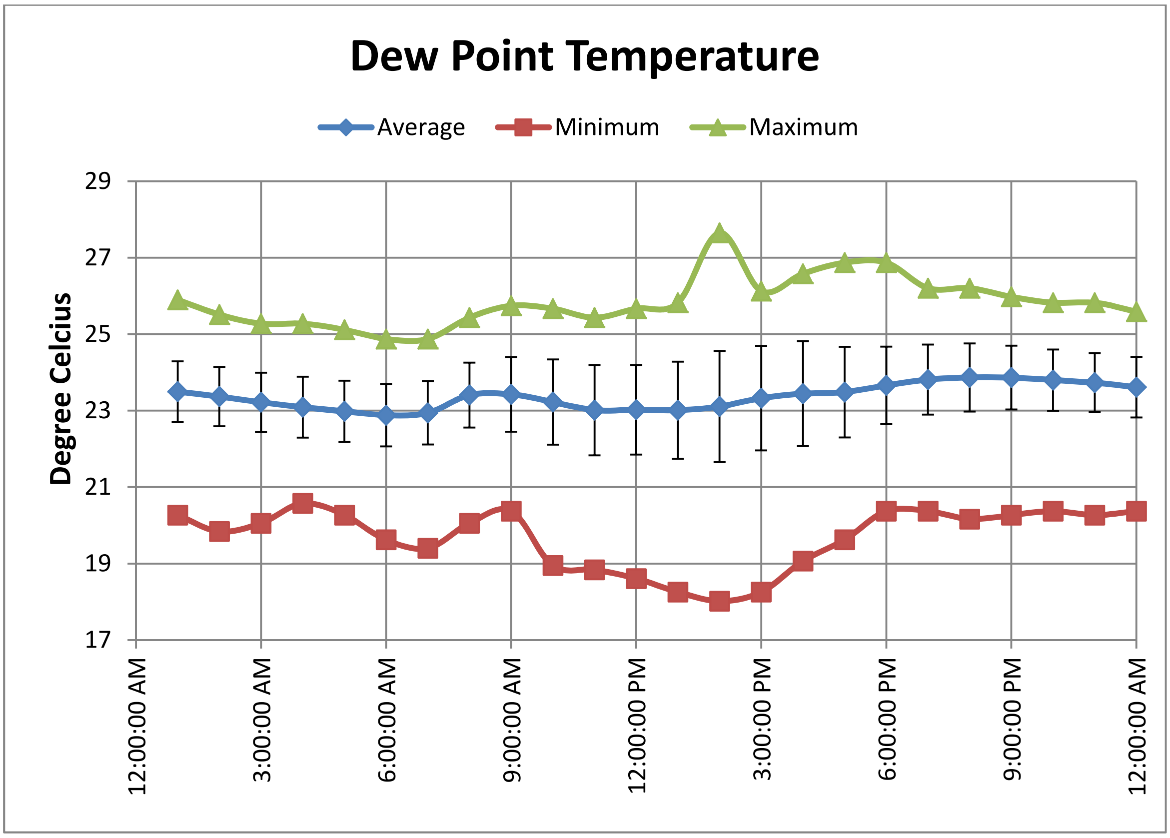
2.7.1 Design Potential

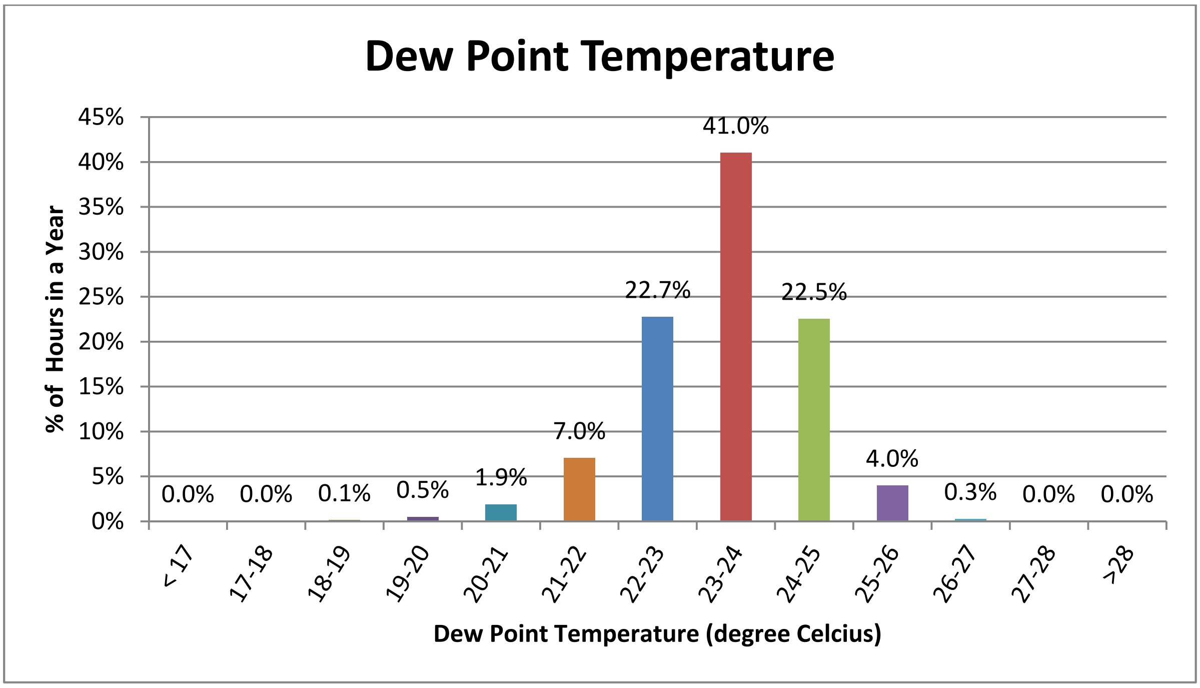
The dew point temperature provides an indication when condensation will occur. As long as surface temperature is kept above the dew point temperature, there will be no condensation. For example, if a surface temperature exposed to outdoor air is kept above 25°C, the risk of condensation is less than 5% and above 26°C, the risk of condensation is less than 0.5%. This provides a possibility to provide radiant cooling to outdoor area (e.g. al-fresco dinning, etc.) where the surface temperature can be kept above the dew point temperature to avoid condensation while minimizing energy consumption to cool occupants in an outdoor space.

2.7.2 Design Risk

If there are water features, greeneries and cooking done (evaporation of water) within the space, the moisture content in the air may increase and causes the dew point temperature to increase as well. Therefore, condensation may occur at higher surface temperature due to these micro-climatic conditions.

2.7.3 CHARTS AND TABLE OF RAW DATA





Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	23.5	20.3	25.9	0.8
2:00:00 AM	23.4	19.8	25.5	0.8
3:00:00 AM	23.2	20.1	25.3	0.8
4:00:00 AM	23.1	20.6	25.3	0.8
5:00:00 AM	23.0	20.3	25.1	0.8
6:00:00 AM	22.9	19.6	24.9	0.8

7:00:00 AM	22.9	19.4	24.9	0.8
8:00:00 AM	23.4	20.1	25.4	0.8
9:00:00 AM	23.4	20.4	25.7	1.0
10:00:00 AM	23.2	19.0	25.7	1.1
11:00:00 AM	23.0	18.8	25.4	1.2
12:00:00 PM	23.0	18.6	25.7	1.2
1:00:00 PM	23.0	18.3	25.8	1.3
2:00:00 PM	23.1	18.0	27.7	1.5
3:00:00 PM	23.3	18.3	26.1	1.4
4:00:00 PM	23.4	19.1	26.6	1.4
5:00:00 PM	23.5	19.6	26.9	1.2
6:00:00 PM	23.7	20.4	26.9	1.0
7:00:00 PM	23.8	20.4	26.2	0.9
8:00:00 PM	23.9	20.2	26.2	0.9
9:00:00 PM	23.9	20.3	26.0	0.8
10:00:00 PM	23.8	20.4	25.8	0.8
11:00:00 PM	23.7	20.3	25.8	0.8
12:00:00 AM	23.6	20.4	25.6	0.8

2.8 Relative Humidity

Relative humidity is a measure of the amount of water (moisture) in air as compared to the maximum amount of water the air can absorb, expressed in percentage. It is not a direct indicator of how much water is in the air, as provided by the humidity ratio (moisture content) or dew point temperature. The dry bulb temperature determines the maximum moisture the air can absorb; therefore, relative humidity is directly linked to both the humidity ratio (moisture content) as well as dry bulb temperature, expressed in percentage of moisture in the air.

Due to the reason that moisture content in the air is fairly constant day or night, the changes of relative humidity is strongly related to the dry bulb temperature of the air. During night time and early morning hours when the dry bulb temperature is low; the relative humidity is very high (between 90% to 100% relative humidity). However during daytime hours when the dry bulb temperature is high; the relative humidity has an average low of 62%.

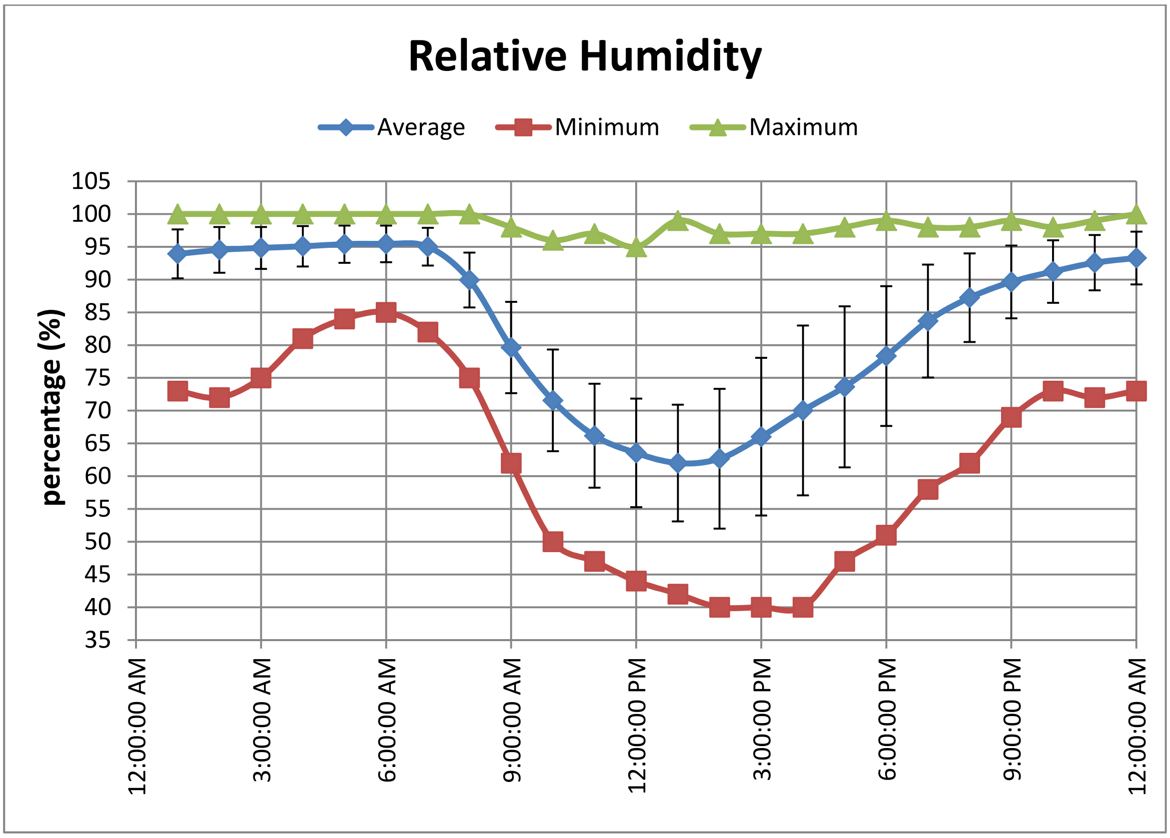
2.8.1 Design Potential

A low relative humidity is an indication of how well evaporative cooling will work. The lower the relative humidity, the easier it is for water to evaporate to reduce the dry bulb air temperature. At very high relative humidity level, 90% or more, very small amount of water will be able to be evaporated.

2.8.2 Design Risk

Relative humidity is a factor of both dry bulb temperature and moisture content. It is not possible to compute energy change when provided with relative humidity alone. For example, how much energy will it take to reduce relative humidity of 90% to 50%? It would not be possible to give an answer to such a question. However, it will be possible to compute the energy change if the question is rephrased into how much energy will it take to reduce relative humidity of 90% at 25°C to a relative humidity of 50% at 23°C. Relative humidity is useful as an indicator of moisture in the air only when provided with the dry bulb temperature.

2.8.3 CHARTS AND TABLE OF RAW DATA

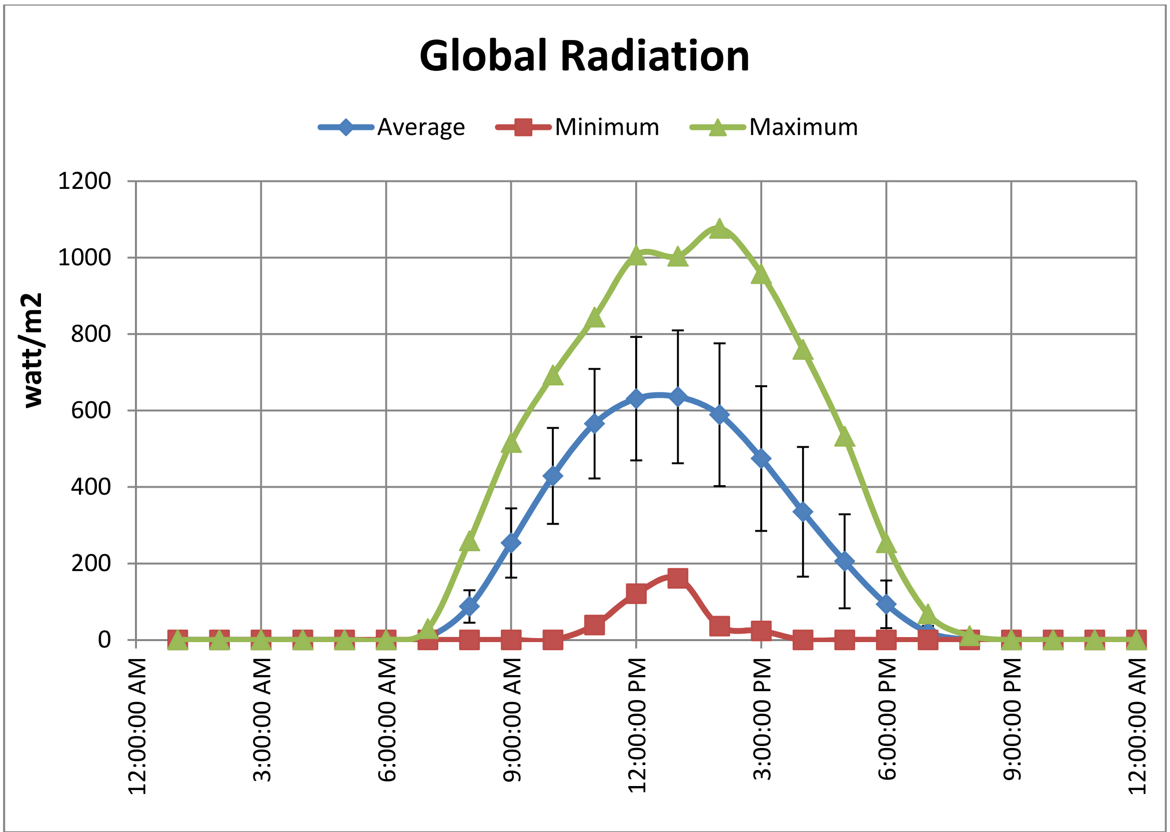


Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	93.9	73	100	3.7
2:00:00 AM	94.5	72	100	3.5
3:00:00 AM	94.8	75	100	3.2
4:00:00 AM	95.1	81	100	3.1
5:00:00 AM	95.4	84	100	2.8
6:00:00 AM	95.4	85	100	2.8
7:00:00 AM	95.0	82	100	2.9
8:00:00 AM	89.9	75	100	4.2
9:00:00 AM	79.6	62	98	7.0
10:00:00 AM	71.6	50	96	7.8
11:00:00 AM	66.2	47	97	7.9
12:00:00 PM	63.6	44	95	8.3
1:00:00 PM	62.0	42	99	8.9
2:00:00 PM	62.7	40	97	10.7
3:00:00 PM	66.0	40	97	12.0
4:00:00 PM	70.0	40	97	13.0
5:00:00 PM	73.6	47	98	12.3
6:00:00 PM	78.3	51	99	10.7
7:00:00 PM	83.7	58	98	8.6
8:00:00 PM	87.2	62	98	6.8
9:00:00 PM	89.6	69	99	5.5
10:00:00 PM	91.2	73	98	4.8
11:00:00 PM	92.6	72	99	4.2
12:00:00 AM	93.3	73	100	4.0

2.9 Horizontal Global Radiation

The average global radiation is almost a perfect symmetry between the morning hours and afternoon hours with peak close to solar noon. The average peak is 636 W/m² at 1pm while the absolute peak in the TRY is 1077 W/m² at 2pm, western sun. The absolute peak of solar radiation is almost double of the average peak. This indicates that there are days where the clouds cover are low, allowing direct solar radiation to cause high solar gain in buildings. However on average, the cloud cover in tropical climate provides good protection to reduce the impact of direct solar radiation. The TRY data also showed that it is possible at any time of day for the solar radiation to be reduced close to zero, most likely caused by heavy rain cloud covers.

2.9.1 *Charts and Table of Raw Data*



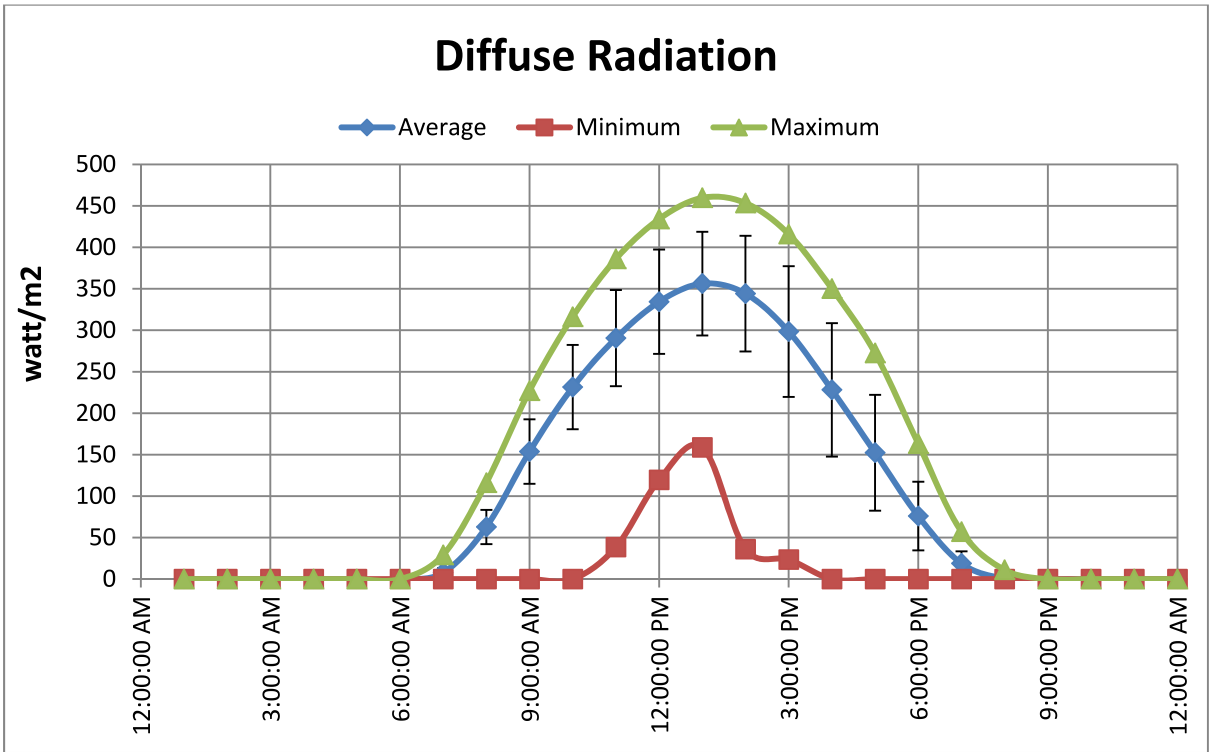
Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.0	0.0	0.0	0.0
2:00:00 AM	0.0	0.0	0.0	0.0
3:00:00 AM	0.0	0.0	0.0	0.0
4:00:00 AM	0.0	0.0	0.0	0.0
5:00:00 AM	0.0	0.0	0.0	0.0
6:00:00 AM	0.0	0.0	0.0	0.0
7:00:00 AM	7.7	0.0	29.2	5.7
8:00:00 AM	87.5	0.0	259.1	42.4
9:00:00 AM	253.6	0.0	516.2	90.7
10:00:00 AM	429.0	0.0	692.8	125.4
11:00:00 AM	565.7	38.9	844.3	143.2
12:00:00 PM	631.0	120.8	1006.4	161.3
1:00:00 PM	635.9	161.1	1003.7	173.8
2:00:00 PM	589.2	36.1	1076.5	186.7

3:00:00 PM	474.6	23.7	958.0	189.3
4:00:00 PM	335.2	0.0	759.7	169.7
5:00:00 PM	205.7	0.0	532.7	122.8
6:00:00 PM	93.2	0.0	254.1	62.4
7:00:00 PM	20.0	0.0	67.7	16.7
8:00:00 PM	0.7	0.0	11.1	1.7
9:00:00 PM	0.0	0.0	0.0	0.0
10:00:00 PM	0.0	0.0	0.0	0.0
11:00:00 PM	0.0	0.0	0.0	0.0
12:00:00 AM	0.0	0.0	0.0	0.0

2.10 Diffuse Solar Radiation

The average peak diffuse radiation is 356 W/m² at 1pm, while the absolute peak diffuse radiation is 460 W/m² also at 1pm. The standard deviation is generally low, with the highest at 80 W/m² at 4pm in the afternoon.

2.10.1 Charts and Table of Raw Data



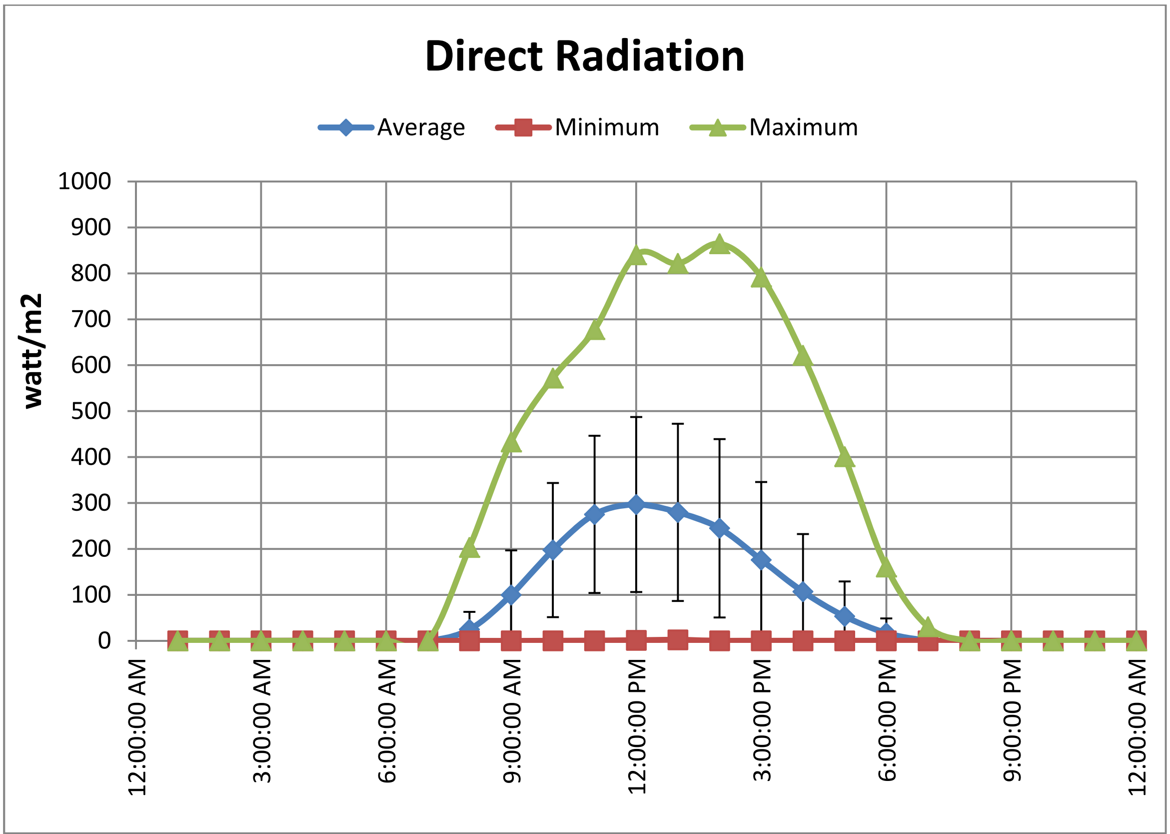
Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.0	0.0	0.0	0.0
2:00:00 AM	0.0	0.0	0.0	0.0
3:00:00 AM	0.0	0.0	0.0	0.0
4:00:00 AM	0.0	0.0	0.0	0.0
5:00:00 AM	0.0	0.0	0.0	0.0
6:00:00 AM	0.0	0.0	0.0	0.0
7:00:00 AM	7.7	0.0	29.2	5.7
8:00:00 AM	62.8	0.0	116.1	20.7
9:00:00 AM	153.8	0.0	227.1	38.8
10:00:00 AM	231.4	0.0	316.2	50.8
11:00:00 AM	290.4	38.7	386.1	58.0
12:00:00 PM	334.4	119.7	434.0	62.9

1:00:00 PM	356.2	158.9	459.7	62.5
2:00:00 PM	344.1	36.0	453.3	69.8
3:00:00 PM	298.4	23.6	415.9	78.8
4:00:00 PM	228.1	0.0	350.1	80.4
5:00:00 PM	152.3	0.0	272.5	69.8
6:00:00 PM	76.1	0.0	163.3	41.4
7:00:00 PM	18.8	0.0	57.1	14.6
8:00:00 PM	0.7	0.0	11.1	1.7
9:00:00 PM	0.0	0.0	0.0	0.0
10:00:00 PM	0.0	0.0	0.0	0.0
11:00:00 PM	0.0	0.0	0.0	0.0
12:00:00 AM	0.0	0.0	0.0	0.0

2.11 Direct Solar Radiation

The average peak direct radiation is 297 W/m² at 12noon, while the absolute peak direct radiation is 865 W/m² at 2pm in the afternoon. The absolute peak direct solar radiation is almost 3 higher than the average peak direct solar radiation. The standard deviation is rather high, with the highest at 194 W/m² at 2pm in the afternoon. All these data indicates that there is a significant difference between the average and the absolute peak direct radiation in the TRY. It is also quite clear from the direct radiation chart that the average direct radiation is higher in the morning hours than the afternoon hours. However, the absolute peak direct solar radiation occurs in the afternoon hour.

2.11.1 Charts and Table of Raw Data



Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.0	0.0	0.0	0.0
2:00:00 AM	0.0	0.0	0.0	0.0

3:00:00 AM	0.0	0.0	0.0	0.0
4:00:00 AM	0.0	0.0	0.0	0.0
5:00:00 AM	0.0	0.0	0.0	0.0
6:00:00 AM	0.0	0.0	0.0	0.0
7:00:00 AM	0.0	0.0	0.0	0.0
8:00:00 AM	24.7	0.0	203.2	38.2
9:00:00 AM	99.8	0.0	433.1	97.1
10:00:00 AM	197.6	0.0	572.2	146.1
11:00:00 AM	275.2	0.2	677.7	171.1
12:00:00 PM	296.7	1.2	840.6	190.6
1:00:00 PM	279.7	2.3	821.7	193.0
2:00:00 PM	245.1	0.1	864.5	194.2
3:00:00 PM	176.2	0.0	792.2	169.6
4:00:00 PM	107.0	0.0	621.7	125.4
5:00:00 PM	53.4	0.0	401.0	76.0
6:00:00 PM	17.2	0.0	160.8	31.4
7:00:00 PM	1.2	0.0	30.6	4.0
8:00:00 PM	0.0	0.0	0.0	0.0
9:00:00 PM	0.0	0.0	0.0	0.0
10:00:00 PM	0.0	0.0	0.0	0.0
11:00:00 PM	0.0	0.0	0.0	0.0
12:00:00 AM	0.0	0.0	0.0	0.0

2.12 Comparison of Global, Direct and Diffuse Radiation

Placing the average global, direct and diffuse radiation in the same chart provides a distinct understanding that the average direct solar radiation is more intense in the morning while the average diffuse radiation is more intense in the afternoon hours.

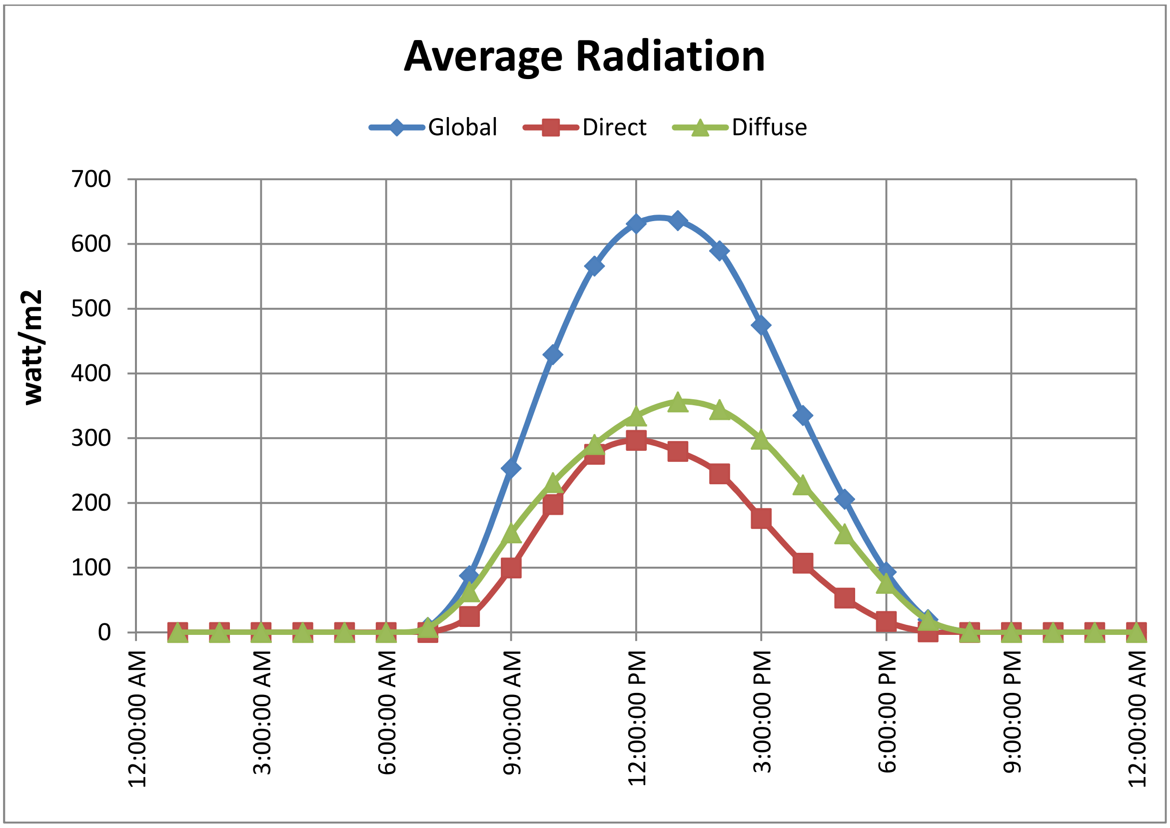
2.12.1 Design Potential

It is important to shade the western façade from direct solar radiation to reduce peak cooling load in buildings. The peak cooling load in building determines the size of air-conditioning equipment to be provided. However for energy efficiency, the plot of average solar radiations showed that it is more important to shade the eastern façade from direct solar radiation to reduce annual energy consumption in building.

2.12.2 Design Risk

The direct and diffuse radiation in the TRY is not a measured value but computed from the measured horizontal global radiation using via Erbs' Estimation Model. However, the result generally agrees with daily observation of solar radiation in this climate. The tropical climate that it rains more often in the afternoon than in the morning provided the skies with an averagely heavier cloud covers in the afternoon than in the morning.

2.12.3 Charts and Table of Raw Data



2.13 Cloud Cover (Oktas)

The cloud cover in the TRY is measured in Oktas unit. Oktas is defined by the World Meteorological Organization as provided by the table below[4].

Oktas	Definition	Category
0	Sky clear	Fine
1	1/8 of sky covered or less, but not zero	Fine
2	2/8 of sky covered	Fine
3	3/8 of sky covered	Partly Cloudy
4	4/8 of sky covered	Partly Cloudy
5	5/8 of sky covered	Partly Cloudy
6	6/8 of sky covered	Cloudy
7	7/8 of sky covered or more, but not 8/8	Cloudy
8	8/8 of sky completely covered, no breaks	Overcast

The cloud cover is generally high in the TRY and is reflective of a tropical climate. The average cloud cover has an Oktas of 6.8 in Malaysia and is fairly consistent day and night and throughout the year. The maximum cloud cover has the maximum Oktas of 8 and can occurs at any time of day. However the minimum Oktas 0 is recorded by the TRY happening at 6am and 7am in the early morning and the minimum cloud cover in the afternoon is at least 1 Oktas higher than in the morning, indicating that minimum cloud cover is heavier in the afternoon than in the morning.

[4] http://worldweather.wmo.int/oktas.htm

The standard deviation is higher in the morning as compared to the afternoon, indicating that there is a larger day to day variation of cloud cover in the morning as compared to the afternoon. In other words, in the afternoon, the sky is consistently heavy with cloud where else, in the morning; the cloud cover may sometimes be low.

2.13.1 Design Potential

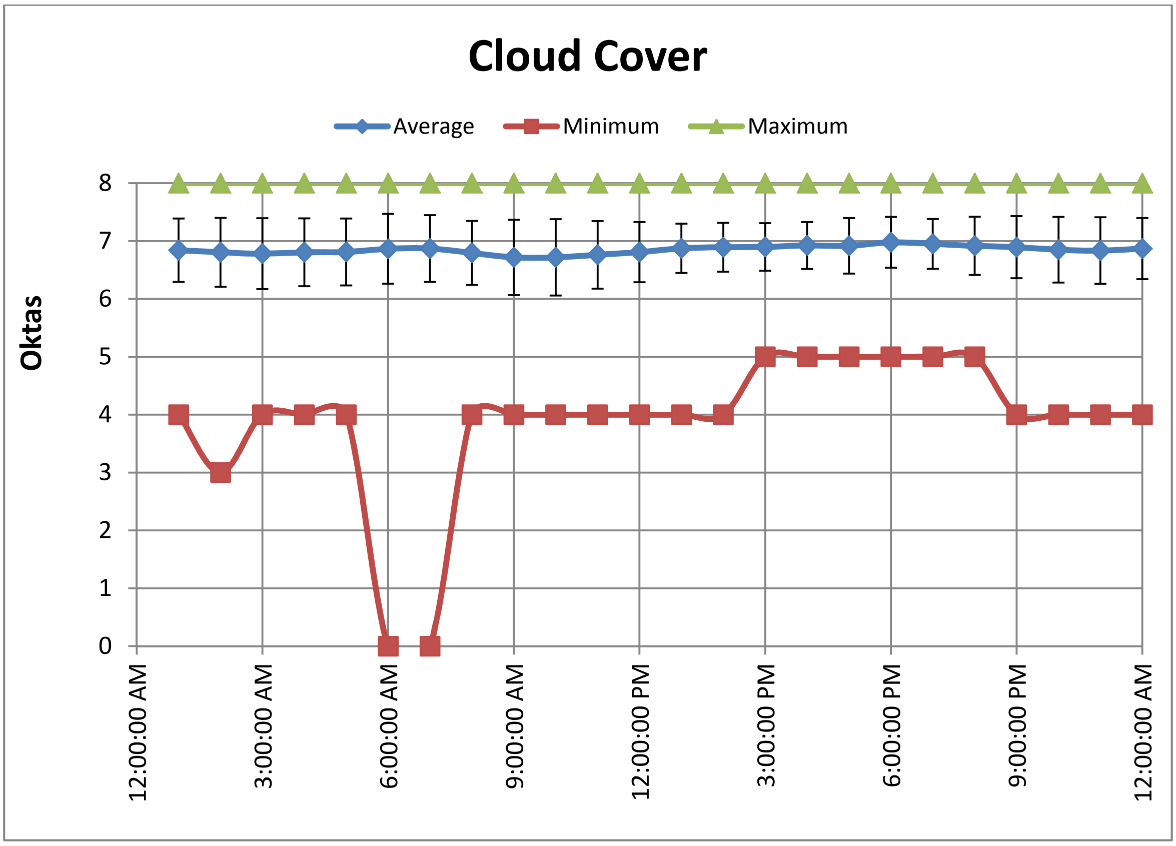
High Oktas numbers indicate heavy cloud cover in Malaysia's climate. It also means that during daytime, Malaysian sky is normally bright because the sky will be illuminated by the clouds as opposed to clear blue skies.

Heavy clouds cover also hinders radiation heat transfer between objects on the ground with the sky. In general the lower the Oktas number, the better it is for the sky to cool objects on the ground surface.

2.13.2 Design Risk

Oktas measurement is done manually by meteorologists. They would take a look at the sky and decide how many eight of the sky is covered by clouds.

2.13.3 Charts and Table of Raw Data



Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	6.8	4.0	8.0	0.5
2:00:00 AM	6.8	3.0	8.0	0.6
3:00:00 AM	6.8	4.0	8.0	0.6
4:00:00 AM	6.8	4.0	8.0	0.6
5:00:00 AM	6.8	4.0	8.0	0.6
6:00:00 AM	6.9	0.0	8.0	0.6

7:00:00 AM	6.9	0.0	8.0	0.6
8:00:00 AM	6.8	4.0	8.0	0.6
9:00:00 AM	6.7	4.0	8.0	0.7
10:00:00 AM	6.7	4.0	8.0	0.7
11:00:00 AM	6.8	4.0	8.0	0.6
12:00:00 PM	6.8	4.0	8.0	0.5
1:00:00 PM	6.9	4.0	8.0	0.4
2:00:00 PM	6.9	4.0	8.0	0.4
3:00:00 PM	6.9	5.0	8.0	0.4
4:00:00 PM	6.9	5.0	8.0	0.4
5:00:00 PM	6.9	5.0	8.0	0.5
6:00:00 PM	7.0	5.0	8.0	0.4
7:00:00 PM	7.0	5.0	8.0	0.4
8:00:00 PM	6.9	5.0	8.0	0.5
9:00:00 PM	6.9	4.0	8.0	0.5
10:00:00 PM	6.8	4.0	8.0	0.6
11:00:00 PM	6.8	4.0	8.0	0.6
12:00:00 AM	6.9	4.0	8.0	0.5

2.14 Effective Sky Temperature

It is useful to provide the effective sky temperature in this chapter because it provides an indication of the possibility of using the sky to cool building passively. The effectiveness of radiation heat exchange between objects on the ground surface with the sky is defined by the effective sky temperature. The effective sky temperature is not provided by the TRY but is estimated from the dry bulb temperature, dew point temperature and cloud cover using equations provided by Clark and Blanplied[5].

The estimated average effective sky temperature in TRY is 18°C. It is higher during daytime and is lower during night time. The average lowest effective sky temperature is 14.6°C at 7am in the morning. While the absolute lowest effective sky temperature was estimated to be 9.5°C at 8am in the morning. Although the daytime average effective sky temperature is in the low 20s°C, the direct and diffuse solar radiation during daytime is providing much more heat than the sky is removing.

On average, the effective sky temperature is below 20°C from the hours of 6pm to 11am. The average lowest effective sky temperature is approximately 15°C at 6am in the morning.

2.14.1 Design Potential

The lower the effective sky temperature is, the better it is for the sky to absorb heat (cooling) from objects on the ground. Therefore, as long as a surface is shielded from direct radiation or does not absorb solar radiation (as in products with very high solar reflectivity) or during night time (no solar radiation), the sky can be used as a mean of heat rejection or cooling source.

Roof system that can block heat gain during day time and rejects heat during night time will potentially be effective means of cooling a building. Buildings that are primary used during night time such as residential homes will benefit significantly from such roof design. Movable roof

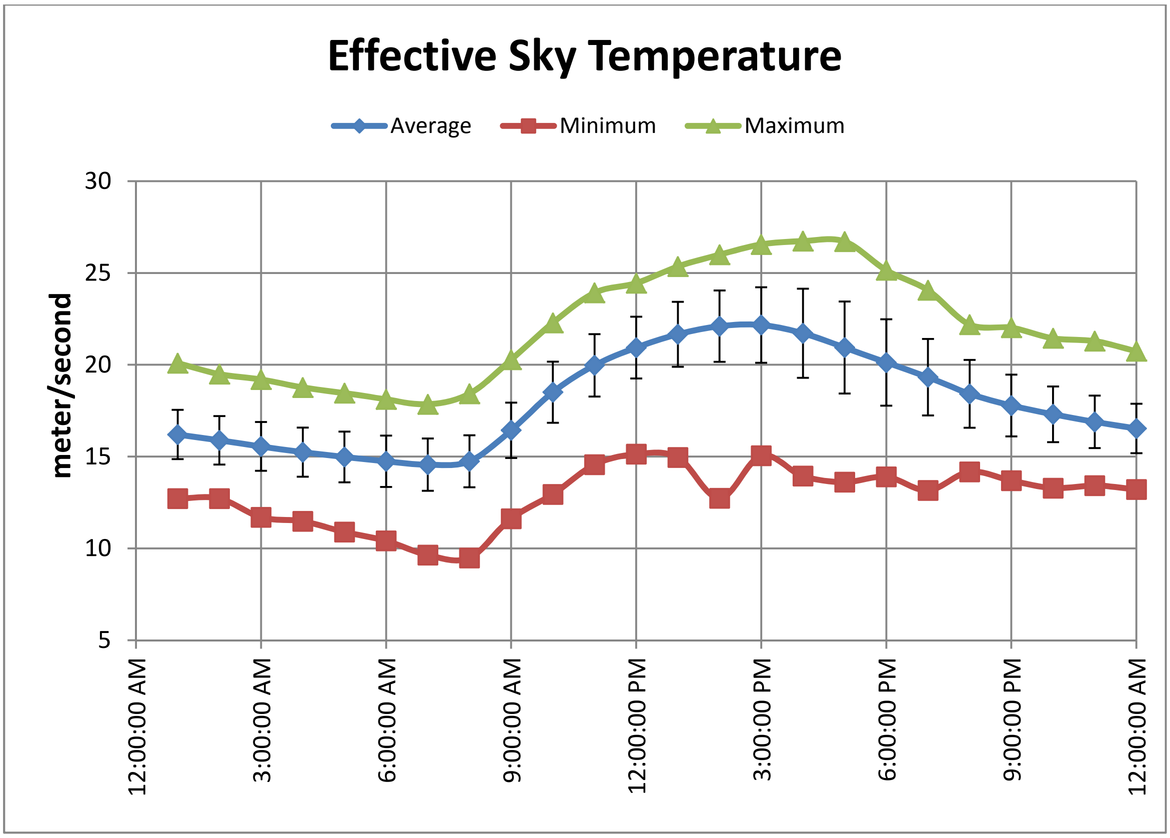
[5] Gene Clark and M. Blanpied, 1979. "The Effect of IR Transparent Windscreens on Net Nocturnal Cooling from Horizontal Surfaces," Proceedings of the 4th National Passive Solar Conference, Kansas City, MO.

insulation, cool roof paints that rejects solar radiation during daytime while having high emissivity to reject heat and etc. may be interesting solutions for residential homes.

2.14.2 Design Risk

An average effective sky temperature above 20°C during daytime is not considered to be efficient to cool objects on the ground. Therefore, using the sky to cool objects on the ground will only be useful during nighttime when the effective sky temperature is reduced below 20°C. In countries where the cloud cover is low and ambient air temperature is moderate, it is possible for the sky to provide consistent effective sky temperature below 10°C (in some places, even below 0°C, making it possible to make ice with the night sky[6]). The high effective sky temperature found in this climate is largely due to the high moisture content in the air and the heavy cloud cover.

2.14.3 Charts and Table of Raw Data



Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	16.20	12.7	20.1	1.3
2:00:00 AM	15.89	12.7	19.5	1.3
3:00:00 AM	15.55	11.7	19.2	1.3
4:00:00 AM	15.24	11.5	18.8	1.3
5:00:00 AM	14.98	10.9	18.5	1.4
6:00:00 AM	14.74	10.4	18.1	1.4
7:00:00 AM	14.56	9.6	17.9	1.4
8:00:00 AM	14.75	9.5	18.4	1.4
9:00:00 AM	16.43	11.6	20.3	1.5
10:00:00 AM	18.51	12.9	22.3	1.7

[6] "Lesson 1: History Of Refrigeration, Version 1 ME". Indian Institute of Technology Kharagpur. Archived from the original on 2011-11-06.

11:00:00 AM	19.97	14.6	23.9	1.7
12:00:00 PM	20.93	15.1	24.4	1.7
1:00:00 PM	21.66	15.0	25.4	1.8
2:00:00 PM	22.10	12.7	26.0	1.9
3:00:00 PM	22.17	15.0	26.6	2.1
4:00:00 PM	21.72	13.9	26.7	2.4
5:00:00 PM	20.94	13.6	26.7	2.5
6:00:00 PM	20.12	13.9	25.1	2.4
7:00:00 PM	19.33	13.2	24.1	2.1
8:00:00 PM	18.42	14.2	22.2	1.8
9:00:00 PM	17.78	13.7	22.0	1.7
10:00:00 PM	17.31	13.3	21.4	1.5
11:00:00 PM	16.89	13.4	21.3	1.4
12:00:00 AM	16.53	13.2	20.7	1.3

2.15 Ground Temperature

The ground temperature was computed from the TRY using Kasuda's equation[7] at 1 meter depth. It was computed that the soil temperature is constant at 26.9°C for the entire year. Further investigation using Kasuda's equation showed that at any depths greater 0.5 meter, the ground temperature will be constant at 26.9°C.

It is also important to note that groundwater temperature will also be at the same temperature as the ground (soil) temperature.

2.15.1 Design Potential

There exist designs that channel air intake into building through an underground chamber to pre-cool the air before entering the building. However, this strategy will work well in this climate during daytime when the outdoor air temperature is higher than the soil temperature. However, during night time, the outdoor air temperature is lower than the soil temperature; channeling night air into the underground chamber will heat up the air instead of cooling it down. In short, this strategy will work well with office type of building where the building is occupied during daytime; however, it will not work well for residential homes because the homes are normally occupied during night time.

The TRY has an average wet bulb temperature of 24.3°C and typical design of cooling tower calls for an approach temperature of 5.5°C higher than the wet bulb temperature, providing an average of 29.8°C return water temperature to the chiller. The groundwater temperature is estimated to be 26.9°C; therefore it is approximately 3°C colder than the water from the cooling tower. Colder water for the condensing side of the chiller will improve the efficiency of chiller significantly. Water from deep lakes would also be good potential for such opportunity to improve efficiency of the chiller because the temperature of water in deep lakes will also follows the ground temperature.

2.15.2 Design Risk

The Kasuda's equation does not account for rainfall on the soil, as water from the soil will evaporate at the wet bulb temperature, the surface of the soil may be cooler on average for climate such as Malaysia where it rains fairly often and consistently throughout the year. The effect of rainfall is

[7] Kasuda, T., and Archenbach, P.R. 1965. Earth Temperature and Thermal Diffusivity at Selected Stations in the United States, ASHRAE Transactions, Vol. 71, Part 1.

expected to be minimal on the ground temperature. However, actual measurement of on-site ground temperature is highly recommended.

In addition, further studies are recommended to ensure that the colder daytime air achieved via an underground chamber can be achieved without increasing the moisture content of the air. An increase in moisture content will increase energy consumption of the air-conditioning system.

Excessive groundwater harvesting without adequate recharge will cause soil properties to deteriorate and may cause ground to sink. Moreover, pumping water over long distances will also increase the water temperature due to frictional losses and conduction gain through the pipes, which may cause the predicted 3°C colder water temperature not to be achieved.

2.16 Wind Speed

The average wind speed in the TRY showed that wind speed is low (less than 0.5 m/s) from the hours of 8pm to 8am. The wind speed starts to increase at 8am and has an average peak of 3.5 m/s at 3pm in the afternoon. The hourly maximum wind speed showed that it is possible to have high wind speed any time of the day, with the lowest chance of high wind speed is 8 am in the morning. The data also showed that it is also possible to zero wind speed at any time of the day.

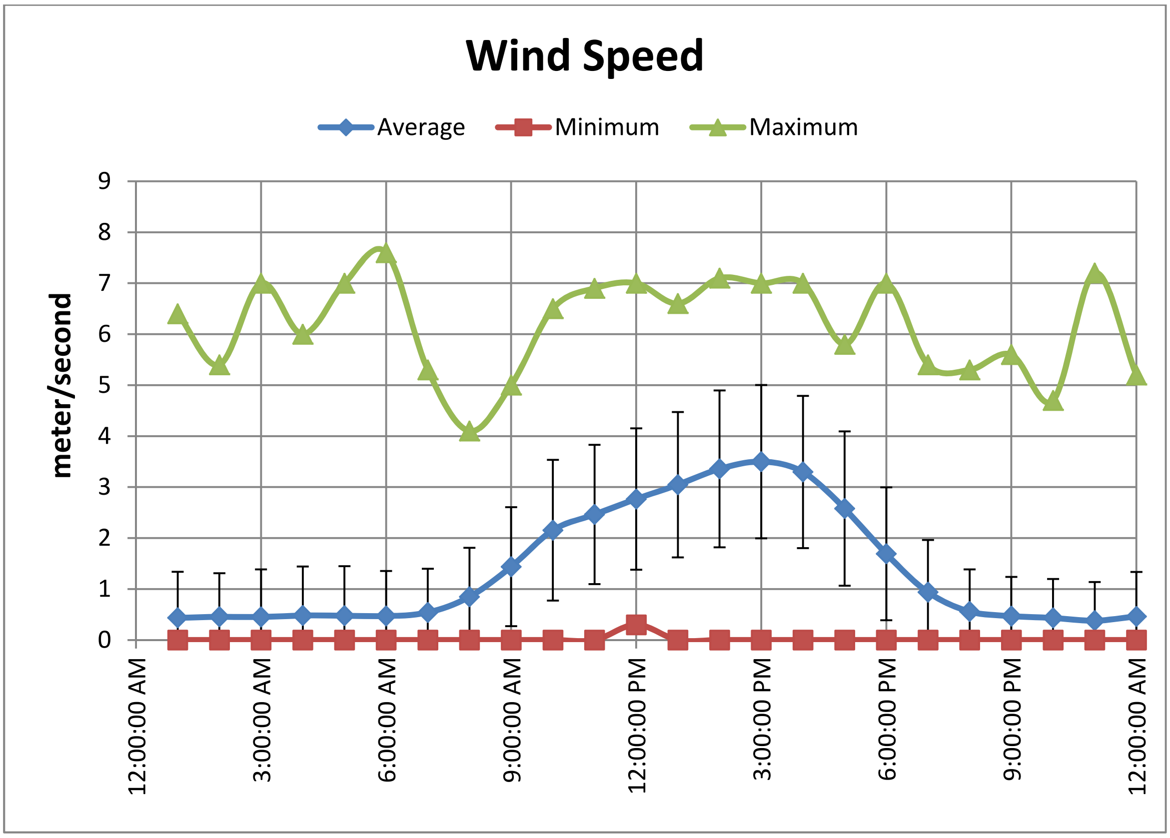
2.16.1 Design Potential

It is important to note that the peak average wind speed occurs at the same time of high dry bulb temperature. In addition, when the dry bulb temperature is low, the average wind speed is also low. This indicates that building designed with cross-ventilation at all hours will on average bring more hot air than cool air into the building. As the wind speed data showed that high wind speed can occur at any time, it is also possible for cross ventilation to bring cool air to benefit the building occupants, therefore, cross-ventilation design need to consider the hours occupant make use of the space and also the possibility to divert hot wind away from occupants during certain hours/condition of the day and divert cool air towards occupant during certain hours/condition of the day. Operable window, where the building occupant has control over when cross ventilation is used is highly recommended.

2.16.2 Design Risk

Wind speed and wind direction data should be further checked against other year data to ensure that the data in TRY is reflective of the actual situation. The selected months of TRY data was predominantly selected based on the dry bulb temperature, global horizontal solar radiation and humidity ratio. Therefore, it is recommended for academicians and researchers to investigate the wind data further to confirm the behavior of wind speed and wind direction according to the hour of day and day of the year.

2.16.3 CHARTS AND TABLE OF RAW DATA



Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.44	0.0	6.4	0.9
2:00:00 AM	0.46	0.0	5.4	0.9
3:00:00 AM	0.45	0.0	7.0	0.9
4:00:00 AM	0.48	0.0	6.0	1.0
5:00:00 AM	0.48	0.0	7.0	1.0
6:00:00 AM	0.47	0.0	7.6	0.9
7:00:00 AM	0.54	0.0	5.3	0.9
8:00:00 AM	0.85	0.0	4.1	1.0
9:00:00 AM	1.44	0.0	5.0	1.2
10:00:00 AM	2.15	0.0	6.5	1.4
11:00:00 AM	2.46	0.0	6.9	1.4
12:00:00 PM	2.77	0.3	7.0	1.4
1:00:00 PM	3.05	0.0	6.6	1.4
2:00:00 PM	3.36	0.0	7.1	1.5
3:00:00 PM	3.50	0.0	7.0	1.5
4:00:00 PM	3.30	0.0	7.0	1.5
5:00:00 PM	2.58	0.0	5.8	1.5
6:00:00 PM	1.69	0.0	7.0	1.3
7:00:00 PM	0.94	0.0	5.4	1.0
8:00:00 PM	0.56	0.0	5.3	0.8
9:00:00 PM	0.47	0.0	5.6	0.8
10:00:00 PM	0.43	0.0	4.7	0.8
11:00:00 PM	0.38	0.0	7.2	0.8
12:00:00 AM	0.46	0.0	5.2	0.9

2.17 Wind Direction & Hours of Air Temperature below 29°C

Base on Ashrae 55, thermal adaptive comfort model for natural ventilation, an operative temperature of 29°C in Malaysia's climate will provide 80% population satisfaction rate[8]. Harvesting natural ventilation with air temperature above 29°C will only heat up the environment providing uncomfortable setting to the building occupants; therefore, natural ventilation should aim to harvest the cold wind that is below 29°C. This section provides information on which direction wind below 29°C is normally coming from and what is the right hour in a day to harvest cold wind in Malaysia.

Detailed analysis of the TRY of its wind direction and dry bulb air temperature yields that a significant 37.5% of the hours in the whole year, the dry bulb (wind) temperature is below 29°C. The occurrence of cold wind is largely during the hours of late evening to mid-morning. Charts provided in this section showed that colder wind comes from the North (946 hours, 29%), North-West (593 hours, 18%), East (430 hours, 13%), South (326 hours, 10%), South-East (297 hours, 9%), South-West (249 hours, 8%), North-East (248 hours, 8%) and lastly West (196 hours, 6%). In short, colder wind is primary from north and north-west (combined to provide 47% of total cold wind available), then followed by east and south.

Cold wind from the north and north-west normally occurs during late afternoon (~5pm) until late morning (~9am). While cold wind from the east mainly occurs in the morning hours of 8am to 9am. Cold wind from the south is low but is consistent throughout the day.

2.17.1 Design Potential

Capturing wind from the north and north-west should be the primary objective to use natural ventilation to cool the environment. Cool wind is primary available from the hours of 5pm to 9am. When the air temperature is high during noon time, it will not be comfortable to harvest natural ventilation. Ideally the building occupants should have control over the natural ventilation by providing ability to the building occupants to close windows or doors, to divert wind away from occupied space when the wind is hot and to allow wind towards occupied space when the wind is cold. Motorized louvers with temperature sensors may also be used to provide this diversion of natural ventilation without requiring manual intervention.

2.17.2 Design Risk

Wind speed and wind direction data should be further checked against other year data to ensure that the data in TRY is a true reflection of the actual situation. The selected months of TRY were predominantly selected based on the dry bulb temperature, global horizontal solar radiation and humidity ratio. Therefore, it is recommended for academicians and researchers to investigate the wind data further to confirm the behavior of wind speed and wind direction according to the hour of day and day of the year.

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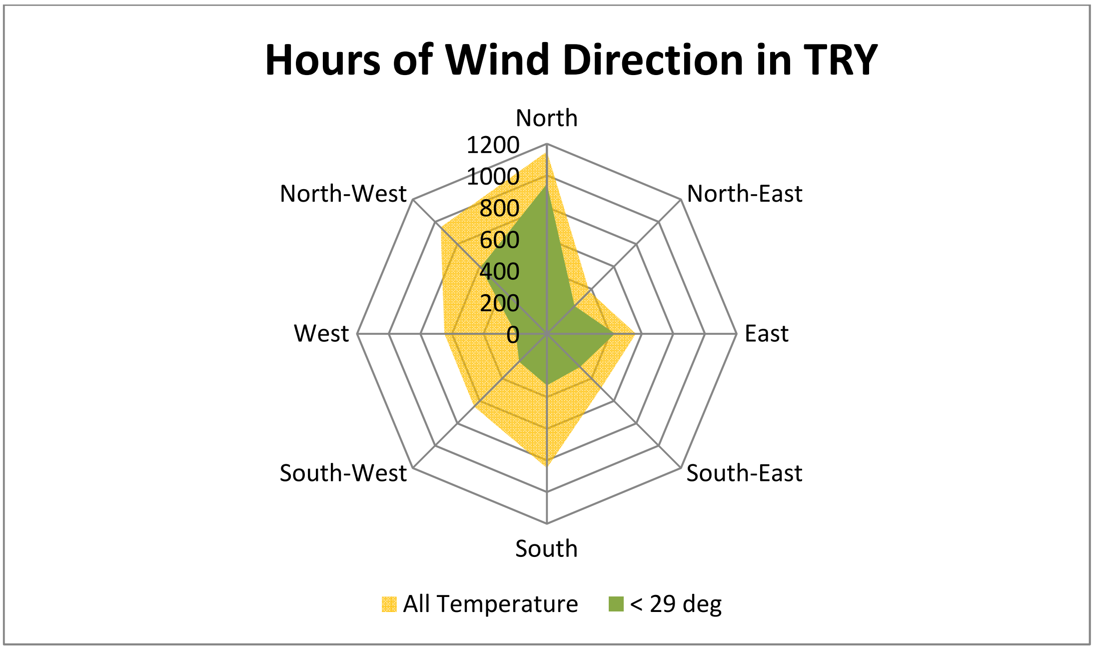
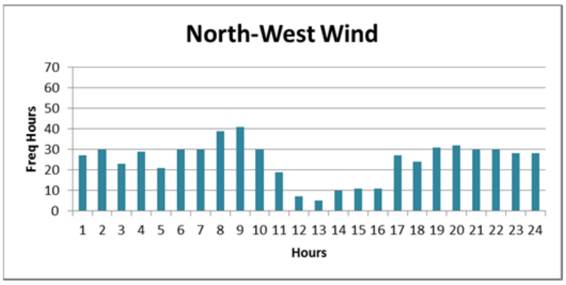
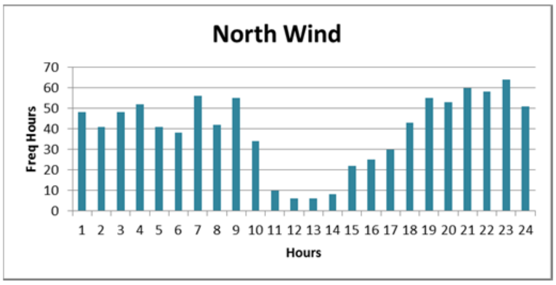
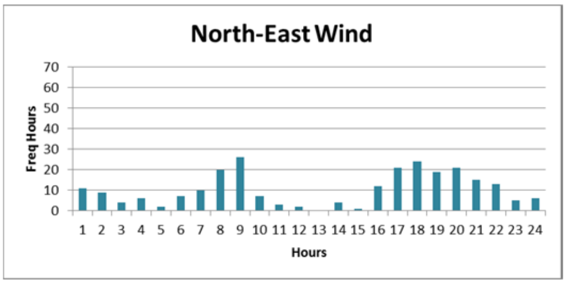
[8] Ashrae 55

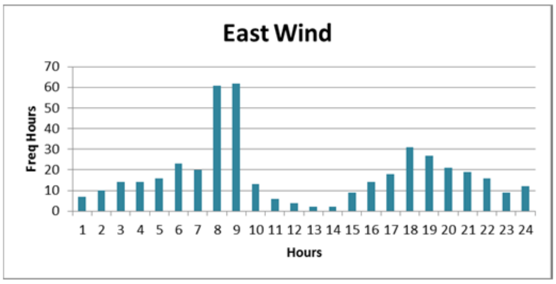
2.17.3 Wind Charts of Air Temperature Below 29°C

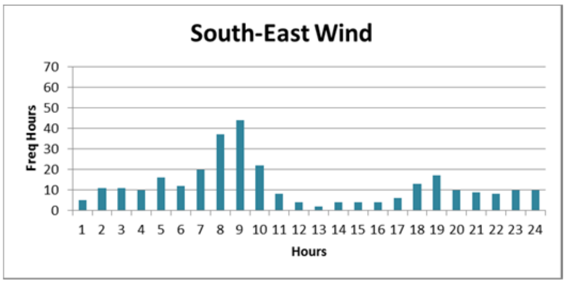


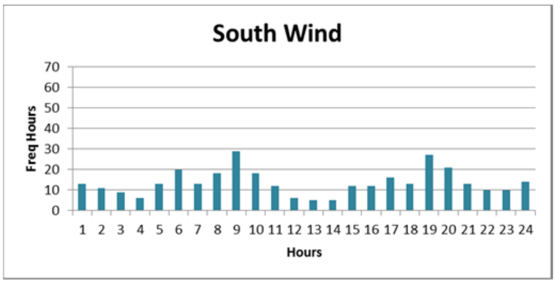


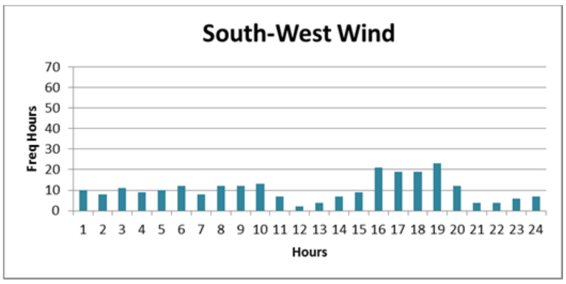


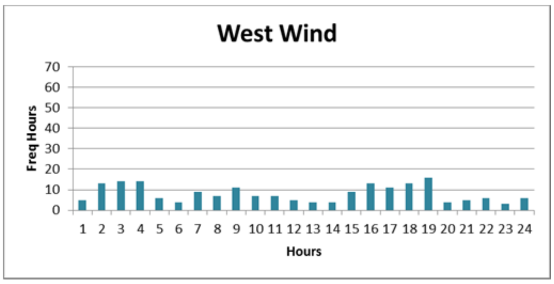












End of Chapter 2