

**OPTIMISATION OF TILT ANGLES FOR FIXED-
PV PANEL VIA COMPUTATIONAL
ALGORITHM**

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**OPTIMISATION OF TILT ANGLES FOR FIXED-PV PANEL VIA
COMPUTATIONAL ALGORITHM**

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**A project report submitted in partial fulfilment of the requirements for the
award of Bachelor of Engineering (Honours) Industrial Engineering**

Faculty of Engineering and Green Technology

Universiti Tunku Abdul Rahman

April 2022

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which has been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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Specially dedicated to
my beloved father, mother, and two brothers

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I would like to thank everyone who had contributed to the successful completion of this project. I would like to take this opportunity to express my gratitude to my research supervisor, Dr. Tan Ming Hui, for his invaluable advice, guidance, understanding, and enormous patience throughout the research development. Additionally, I appreciate his effort and time, especially since he has always been willing to spend time with me to conduct FYP meetings via Microsoft Teams every week despite being swamped with his job. I was able to gain lots of experiences, skills, and knowledge from him.

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OPTIMISATION OF TILT ANGLES FOR FIXED-PV PANEL VIA COMPUTATIONAL ALGORITHM

ABSTRACT

Solar energy is one of the clean, renewable, and unlimited energy sources which has the potential to fulfil global energy demand in the future time. To maximise the power generation, PV panels are often integrated with sun-tracking system to track the position of the sun to ensure the PV panels' surface are always perpendicular to the incoming sunray. On the other hand, it entails more maintenance and operational expenses by using a single-axis or dual-axis tracking system. Since the aim is to entice investors to invest in solar PV systems, it is advised that the fixed-PV panel, which does not include a sun tracking device, can be used to reduce the investment cost. Even though much research and analysis have been conducted and studied in relation to determining the optimal angles for fixed-PV panels, there are relatively few studies connected to Malaysia. Therefore, this Final Year Project (FYP) proposes and develops a computational algorithm to calculate the annual energy generation at different tilt angles of the PV panel and determine the optimum tilt angles of the PV panel at various locations in Malaysia under local weather conditions. Ultimately, a Graphical user interface (GUI) application was also developed to assist the user in obtaining the outcomes. The investigation was performed based on simulation using MATLAB® (R2021a), and the Weather Data files were all obtained from JRC Photovoltaic Geographical Information System (PVGIS). To present a more accessible manner for the user to evaluate, polar contour diagrams for annual energy generation and the loss percentage of annual energy generation due to location restrictions in different locations have been generated in the end. Based on the findings of the GUI application, the PV panels in all locations in Malaysia tend to be placed in the position

that faces West to achieve the highest annual energy output. Additionally, the comparisons among three cases have been performed, which are Case 1: optimum annual energy generation based on optimal tilt angles, Case 2: optimum annual energy generation based on optimal tilt angle and azimuth angle faces South, and Case 3: optimum annual energy generation based on tilt angle according to location's latitude coordinate and azimuth angle faces South. At the end, it can be concluded that the top priority to obtain the optimum annual energy generation will be Case 1, by following with Case 3 and Case 2.

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LIST OF SYMBOLS / ABBREVIATIONS

δ	Declination angle, $^{\circ}$
N	Number of the calendar dates, day
Γ	Day angle, R
t_s	Solar time, hour
LCT	Local clock time, hour
EOT	Equation of time, minute
LC	Longitude correction, hour
x	The function of the calendar dates
$\text{Long}_{\text{local}}$	Longitude of the observer, $^{\circ}$
Long_{sm}	Longitude for the standard meridian, $^{\circ}$
ω	Hour angle, $^{\circ}$
φ	Latitude of the location, $^{\circ}$
α	Solar altitude angle, $^{\circ}$
θ_z	Solar zenith angle, $^{\circ}$
A	Solar azimuth angle, $^{\circ}$
θ_i	Cosine angle, $^{\circ}$
β	Tilt angle, $^{\circ}$
γ	Aperture azimuth angle, $^{\circ}$
$I_{t,a}$	Global/total aperture irradiance, W/m^2

$I_{t,h}$	Global/total irradiance on the horizontal plane, W/m^2
$I_{b,n}$	Beam/direct irradiance on a plane always normal to sunrays, W/m^2
$I_{d,h}$	Diffuse irradiance on the horizontal plane, W/m^2
ρ	Ground albedo/solar reflectivity
H_o	Extra-terrestrial irradiation, W/m^2
G_{sc}	Solar constant, W/m^2
ω_{ss}	Sunset hour angle, $^\circ$
E_o	Correction factor of the Earth's orbit
$I_{b,a}$	Beam/direct normal irradiance, W/m^2
A_i	The ratio of beam/direct normal irradiance on the horizontal to the extra-terrestrial irradiance
R_d	The ratio of the diffuse irradiation on a tilted surface to that on a horizontal surface
R_b	The ratio of the beam irradiation on the tilted surface to that on a horizontal surface
H_D	Sky-diffuse irradiation, W/m^2
H_B	Beam/direct irradiation, W/m^2
H_R	Ground-reflected irradiation, W/m^2
H_T	Total irradiation on a tilted surface, W/m^2
B_T	Direct irradiation on a tilted surface, W/m^2
Energy	Hourly energy generated, J
$I_{o,h}$	Cosine effect, W/m^2

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

As the blueprint of the Industrial Revolution 4.0 keeps expanding and spreading continuously to the entire world nowadays, energy utilisation is highly dispensable to develop new technology and innovation. In fact, energy is one of the most popular and essential affairs on the international environment and development agenda. However, it is believed that not all kinds of energy resources are clean, renewable, and unlimited. Therefore, the environmental issues have been indirectly involved and aroused public attention.

For most of human history, fossil fuels such as natural gas, petroleum, oil, and coal have always played a dominant role in global energy systems to meet the global energy demand since they are effortless and accessible to be found in plenty but still limited on the Earth (Mamun et al., 2021). On the other hand, the electricity generation and usage of fossil fuels have made our planet depends on these energy resources (Ayara et al., 2019). On account of fossil fuels is cost-effective and super-efficient energy sources, making them the top choice among other energy resources. However, the public's environmental awareness is gradually increasing over time. Several environmental issues such as the pollution of air and water, greenhouse gases, and

acidic rainfall have been aroused, prompting the government to pay more attention and take seriously to this topic. Plus, the concentration on the consumption of fossil fuels for energy supply is a significant risk to the stability of the global climate system and our natural living conditions (El-Ghonemy, 2012). Hence, more and more people have begun promoting and encouraging the use of renewable energy in recent years.

Solar energy is one of the cleanest, most plentiful, and limitless renewable energy supplies available since the sun is a redundant resource in the Universe. It is worth mentioning that the solar power in the irradiance form trapped by the Earth is approximately 1.8×10^{11} MW (Sharma et al., 2020). This solar irradiance is far enough for the entire world to overcome any present energy crisis if utilized efficiently (Sharma et al., 2020). In fact, most countries, including Malaysia, have been encouraging their citizens to alter their mode of utilising energy from fossil fuels to solar power in daily life to maximize the country's green industry and the renewable energy potential in the near future. In line with this goal, Malaysia's government even adopted some proactive initiatives related to the green industry and introduced the Net Energy Metering (NEM) Scheme to boost and encourage Malaysia's Renewable Energy (RE) uptake. Furthermore, another alternative is self-consumption (SELCO), which occurs when energy is produced for personal use. Any surplus is not permitted to be exported to the grid to incentivise individuals to install photovoltaic (PV) panels for personal use (Sustainable Energy Development Authority Malaysia, n.d.). Therefore, solar energy is anticipated to be a future trend and a feasible alternative for the world's future energy needs.

In order to convert sunlight into electricity, it is mandatory to install the PV panel, also known as a solar panel, to accomplish the energy conversion. PV panel will generate electricity for powering household appliances and equipment once it captures the energy from the Sun. The mechanism of the PV panel is straightforward; in fact, the PV panel consists of photovoltaic (PV) cells that truly convert solar energy into electricity by using a semiconductor made of silicon (El-Ghonemy, 2012). When the sunlight hits the PV panel, its energy will be partially absorbed by PV cells into the semiconductor. After that, the energy will lose the electrons, which allow them to flow

voluntarily, and these electrons' flow will become a current for application purposes when some conductor is placed on the top and bottom of the PV panel.

Additionally, the Ministry of Energy, Science, Technology, Environment, and Climate Change has set an ambitious renewable energy target of generating 20% of the country's power by 2030 (Eusoff, 2018). Despite the fact that solar energy is gradually accepted and widely utilized by the public, it still could not reach the government's expected usage target rate in Malaysia. Therefore, some approaches need to be rendered and implemented to attract more people to participate in this project. The installation of PV panels is a type of investment to the people since it indeed needs plenty of initial investment cost in advance. Hence, it is believed that the improvement and optimisation of PV panels' energy output generation are vital to attract the investors' attention to solar energy.

Several academics from various countries had already conducted investigations on tilt angles. For instance, Getu and Alan (2019) in Canada determined that maximum annual energy generation may be achieved with an ideal tilt angle of 46° to 47° and a Surface Azimuth angle of 15° W/E due South. On the other hand, in Romania, Roxana et al. (2019) concluded that the PV panel should be mounted with the optimal tilt angles between 44° and 47° . In summary, it is fairly believed that these studies imply that it is vital to find the optimum angles and suitable configuration layout to optimise the ultimate performance of the PV power plant.

Although a lot of investigation and analysis related to determine the PV panel's optimum angles had been done and studied, very few studies were associated with Malaysia. For instance, Khatib et al. (2015) have already done the research in Malaysia. However, they only considered the tilt angle in their study, and the value of the Surface Azimuth angle was always assumed to face towards the South direction. Furthermore, Khatib et al. (2015) concluded that the optimal tilt angle is recommended based on the location's latitude.

Therefore, this Final Year Project (FYP) will conduct similar research in Malaysia by considering one more tilt angle, the Surface Azimuth angle, to determine the optimal tilt angles (tilt angle, β and azimuth angle, γ) of the PV panel under Malaysia weather conditions. Besides, the thermal effect and soiling effect that acts on the PV panel will be ignored in this study.

Nevertheless, this Final Year Project will also construct a Graphical user interface (GUI) application to assist the user in determining the ideal optimal angles for the PV panel installation position. For other information, the application can generate results according to the location, the area and efficiency of the PV panel provided by the user. It is positively believed that this application can bring convenience, time-saving, and value to researchers and engineers in the solar engineering field. In fact, it is not easy to find similar applications in the current market since this kind of application is still not common and widespread. Therefore, it is hopefully expected that more people willing to make research and contributions to this aspect of renewable energy in the end.

1.2 Problem Statement

As a matter of fact, many researchers from various countries have already performed studies to increase the power output generation of the PV panel by implementing sun tracking mechanisms such as single-axis and dual-axis tracking systems. However, it is necessary to have additional instruments such as motor and tracking drive systems inside the PV system if sun-tracking is implemented. Besides, this also incurs extra maintenance and operating costs to the system that may increase the cost of investment. Since the goal is to attract investors to invest in solar PV systems, it is suggested to utilise the fixed-PV panel that does not contain sun tracking system with a lower capital cost, maintenance, and operating costs.

Based on the literature reviews and research that other researchers have done, there is very little research conducted and analysed in Malaysia using Malaysia's weather to find out the optimum tilt angles of the PV panel. Moreover, it can be discovered that different location has different optimum tilt angles. Hence, the optimum tilt angles are location dependent.

Despite Khatib et al. (2015) having already done the research in Malaysia, they only considered a single tilt angle without viewing the Surface Azimuth angle. Therefore, this may cause the result of their research is not at the optimum power output generation of the PV panel.

On the other hand, it can be observed that the sun's direction has been changing over time. Therefore, installing a PV panel is not an effective decision if the tilt angles and configuration are not always facing the sun. The PV panel will generally be set up naturally in a fixed direction to obtain maximum energy. However, to achieve optimal energy gained, the tilt angles of the PV panel play a critical role.

In this Final Year Project (FYP), it can be done by exploring whether the Surface Azimuth angle will affect the performance of the PV panel in Malaysia. Therefore, the PV panel's tilt angle, β and azimuth angle, γ will be analysed. It is worth mentioning that these variables will permanently be altered depending on the location and weather data obtained.

On the other hand, a user-friendly GUI application will be constructed to ease the users (researchers and engineers) to determine the optimal tilt angles and optimum annual energy generation of the PV panel.

1.3 Aims and Objectives

The primary goal of this Final Year Project (FYP) is to determine the optimal tilt angle and Surface Azimuth angle for a photovoltaic (PV) panel in Malaysia. The objectives of the final year project are:

- i. To develop a computational algorithm to calculate the annual energy generation at different tilt angles of the PV panel.
- ii. To determine the optimum tilt angles of PV panel at various locations in Malaysia under local weather conditions.
- iii. To develop a Graphical user interface (GUI) application to determine maximum annual energy generation and optimal tilt angles of PV panel.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 The movement of the Sun

It is essential to consider and forecast the sun's position relative to the collection device, which is a photovoltaic panel, over time to clearly comprehend how to collect solar energy adequately. Undoubtedly, the sun's location has varied in response to the Earth's rotation. The Earth revolves around the sun every 365.25 days in a slightly elliptical orbit, which will produce variations in the Earth-sun distance, equinoxes, and solstices.

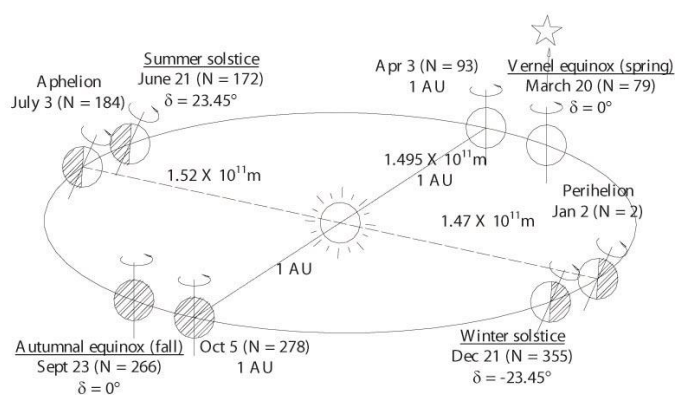


Figure 2.1: The Earth's rotation around the Sun (William and Michael, 2001)

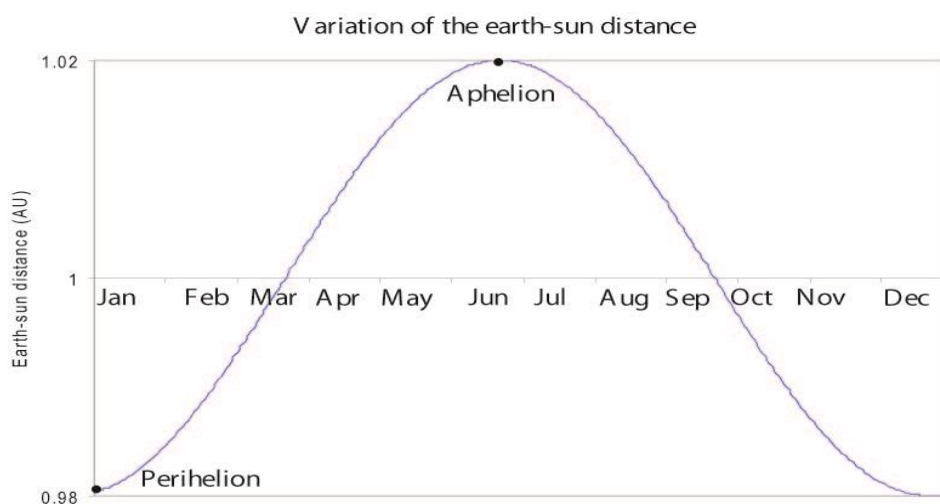


Figure 2.2: The Variation of the Earth-sun distance (William and Michael, 2001)

On the other hand, the Earth generally rotates 24 hours about its polar axis, with a 23.45° inclination to the ecliptic. This Earth's rotation produces days and nights.

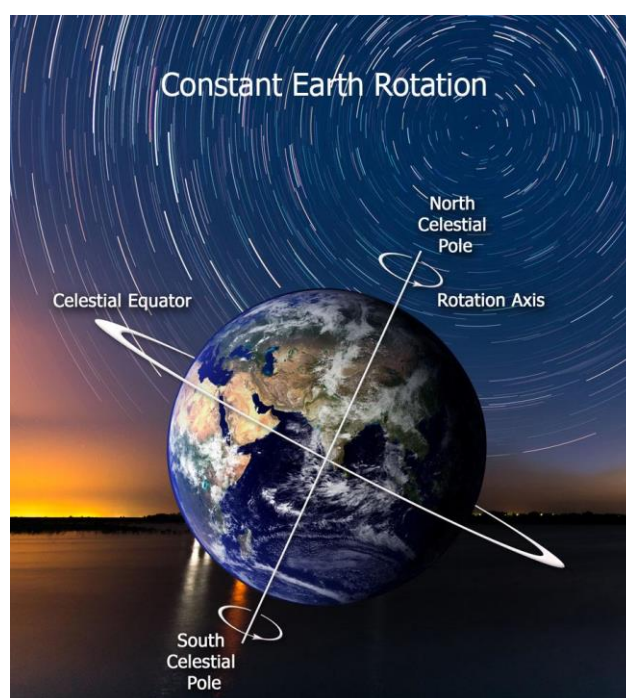


Figure 2.3: Earth Rotation (UM Photo Gallery, n.d.)

In order to determine the sun's position from the Earth, the declination angle, δ , is required. It is the angle formed between the horizontal line to the sun and the Earth's equatorial plane.

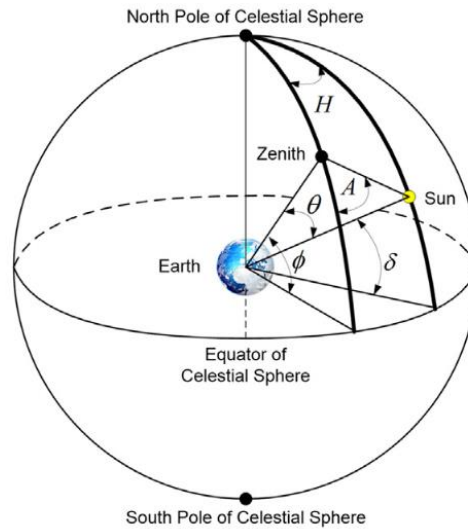


Figure 2.4: Different incident angles between the sunlight and the PV panel (Kuo et al., 2018)

According to William and Michael (2001) and Khatib et al. (2015), the declination angle can be obtained by applying the formula below:

$$\delta = \sin^{-1}\{0.39795 \cos [0.98563(N - 173)]\} \quad (2.1)$$

On the other hand, according to Getu and Alan (2019), Kaldellis and Zafirakis (2012), Bakirci (2012) and Oprea et al. (2019), the declination angle can also be obtained by applying the formula below:

$$\delta = (23.45) \sin \frac{360(284 + N)}{365} \quad (2.2)$$

Moreover, there is a declination angle formula proposed by Khalil and Shaffie (2013) in Cairo, Egypt:

$$\delta = (0.006918 - 0.399912 \cos \Gamma + 0.070257 \sin \Gamma - 0.006758 \cos 2\Gamma + 0.000907 \sin 2\Gamma - 0.002697 \cos 3\Gamma + 0.00148 \sin 3\Gamma) \left(\frac{180}{\pi} \right) \quad (2.3)$$

$$\Gamma = \frac{2\pi(N - 1)}{365} \quad (2.4)$$

Besides, Yan et al. (2013) in Brisbane, Australia, suggested another formula to calculate declination angle. It is shown below:

$$\delta = 23.45 \times \left[\frac{360}{365} \times (284 + N) \right] \quad (2.5)$$

According to Bahrami et al. (2016), who performed the research in Europe and Africa, they recommended that the formula to calculate declination angle will be:

$$\delta = -23.45 \cos \left[\frac{360(N + 10)}{365.25} \right] \quad (2.6)$$

Beside that, Benghanem (2011) conducted the study in Madinah, Saudi Arabia, and the researcher used the formula below to calculate the declination angle:

$$\delta = \frac{23.45\pi}{180} \sin \frac{2\pi(284 + N)}{365} \quad (2.7)$$

Where δ = declination angle ($^{\circ}$); N = number of the calendar dates (day); Γ = day angle (R). For instance, N = 31 when it is on January 31 whereas February 17 would be N = 31 + 17 = 48. The range of declination angle is between -23.45° and 23.45° . The Winter solstice (about December 22) occurs when $\delta = -23.45^{\circ}$, Summer solstice (about June 21) occurs when $\delta = 23.45^{\circ}$, Vernal equinox (about March 20) and Autumnal equinox (about September 23) occurs when $\delta = 0^{\circ}$.

2.2 The Solar time and Hour angle

Solar time's basic notion is to forecast the position of the sun's energies concerning a fixed place on the Earth. In fact, it is ordinarily different from the local clock time (LCT). For instance, the LCT of Kuala Lumpur, Malaysia (UTC+8) is 8.30 PM (expressed as 20.50 hours), whereas it is 8.30 AM (defined as 8.50 hours) in New York, United States (UTC-4) at the same time but different time zones. Therefore, solar time is crucial to define interchangeable time to avoid confusion and puzzlement to the people scattered around the world. It is worth mentioning that solar time is longitudinal dependent on the 24-hour clock system. Solar time (t_s) can be determined as (William and Michael, 2001):

$$t_s = LCT + \frac{EOT}{60} - LC \quad (2.8)$$

Where t_s = solar time (hour); LCT = local clock time (hour); EOT = Equation of time (minute), LC = longitude correction (hour) and they are given by (William and Michael, 2001):

$$EOT = 0.258 \cos x - 7.416 \sin x - 3.648 \cos 2x - 9.228 \sin 2x \quad (2.9)$$

$$x = \frac{360(N - 1)}{365.242} \quad (2.10)$$

Where x = the function of the calendar dates. EOT is the year-to-year difference between mean solar time (as represented by clocks) and apparent solar time (as indicated by sundials). It is worth mentioning that the rotation of the Earth is not always revolving at the same speed constantly. It sometimes will rotate at a slower or faster rate than usual. Hence, EOT will be applied to consider this factor to make the calculation more accurate and precise. Additionally, longitude correction can be obtained by using the formula below (William and Michael, 2001):

$$LC = \frac{(\text{Long}_{\text{local}} - \text{Long}_{\text{sm}})}{15} \quad (2.11)$$

Where $\text{Long}_{\text{local}}$ = longitude of the observer ($^{\circ}$); Long_{sm} = longitude for the standard meridian ($^{\circ}$) = 120° in Malaysia (UTC+8), which is located East of Greenwich time (positive standard time zones, UTC+ve) is designed as negative, whereas in West of Greenwich (negative standard time zone, UTC-ve) as positive value when it is applied in the equation. The Prime Meridian is located in Greenwich with the standard time zone 0 (UTC). In fact, The time changes in 1-hour decrements (towards West) or increments (towards East) with respect to every 15° from the Prime Meridian.

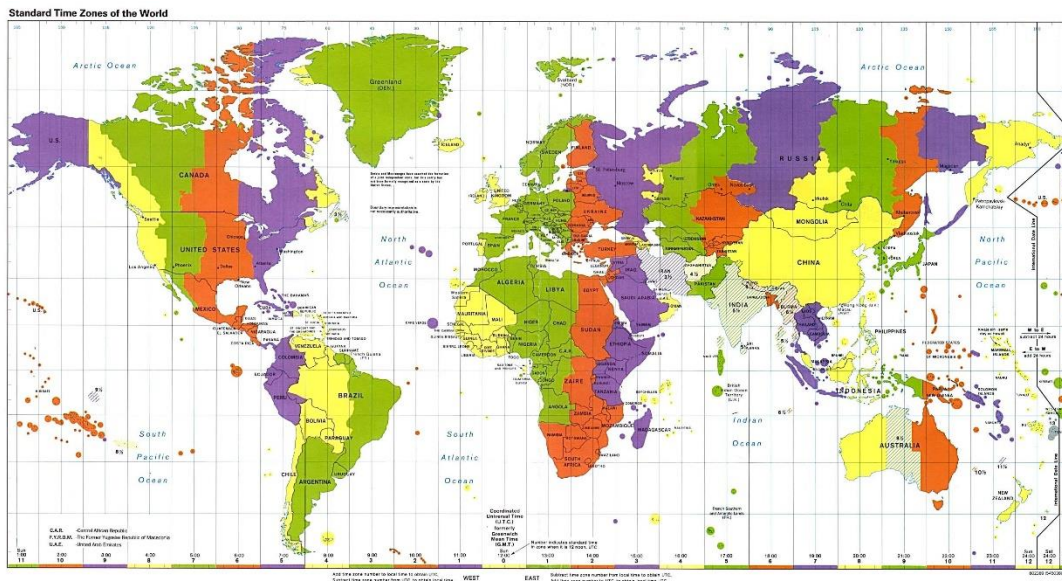


Figure 2.5: Standard Time Zone of the World

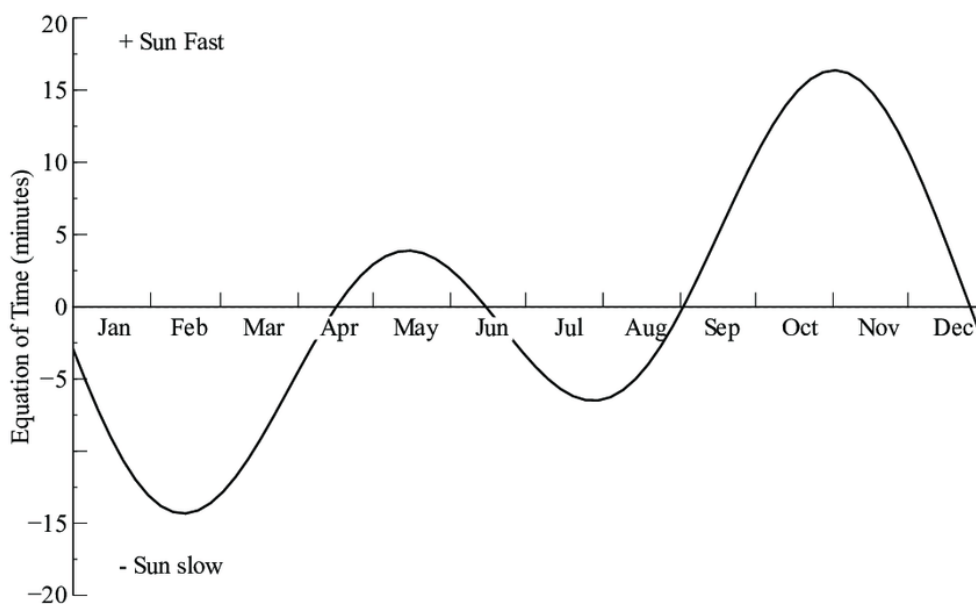


Figure 2.6: Equation of Time (William and Michael, 2001)

However, according to Benghanem (2011), the researcher proposed that the Equation of Time (EOT) can be separated into four parts for different calendar days. The formulas are shown below:

For $1 \leq N \leq 106$,

$$EOT = -14.2 \sin \frac{\pi(N + 7)}{111} \quad (2.12)$$

For $107 \leq N \leq 166$,

$$EOT = 4.0 \sin \frac{\pi(N - 106)}{59} \quad (2.13)$$

For $167 \leq N \leq 246$,

$$EOT = -6.5 \sin \frac{\pi(N - 166)}{80} \quad (2.14)$$

For $247 \leq N \leq 365$,

$$EOT = 16.4 \sin \frac{\pi(N - 247)}{113} \quad (2.15)$$

On the other hand, solar time (t_s) is given as follows (Benghanem, 2011):

$$t_s = LCT + \frac{EOT}{60} + \frac{\text{Long}_{\text{local}} - \text{Long}_{\text{sm}}}{15} \quad (2.16)$$

The hour angle (ω) expresses the time of the day relative to the solar noon. It is the East to West angular displacement of the sun around the polar axis. Apart from that, it is also an angle between the meridian plane (between the Earth's axis and zenith) containing observer and meridian that touches the Earth-Sun line (between the Earth's axis and given sun point).

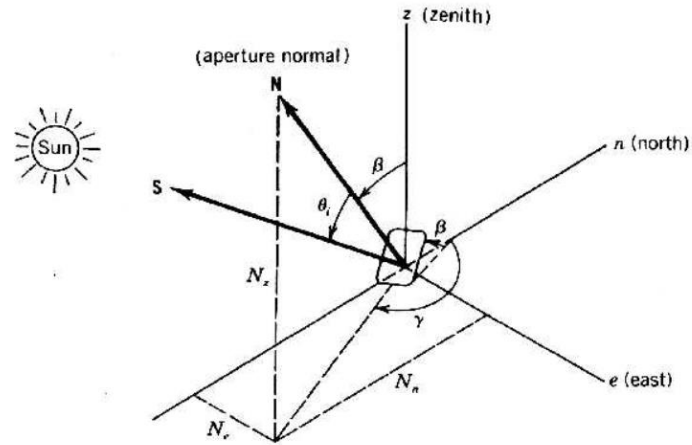


Figure 2.7: A Fixed Aperture whose orientation is defined by the tilt angle and the Azimuth Angle of the Aperture (William and Michael, 2001)

According to William and Michael (2001) and Noorian et al. (2008), Kaldellis (2012) and Oprea et al. (2019), the formula to calculate the hour angle is shown below:

$$\omega = 15(t_s - 12) \quad (2.17)$$

On the other hand, Benghanem (2011) proposed another formula, which is shown below:

$$\omega = \pi \frac{(12 - t_s)}{12} \quad (2.18)$$

Besides, according to Khalil and Shaffie (2013), they suggested that the hour angle formula will be:

$$\omega = \cos^{-1}(-\tan \phi \tan \delta) \quad (2.19)$$

Where ω = hour angle ($^\circ$); φ = latitude of the location ($^\circ$). The range of hour angle is between -180° and 180° . The angle is negative East of the meridian plane and positive West of the meridian plane. Apart from that, the value of the hour angle is 0° at noon, negative in the morning and positive in the afternoon, as well as it is increased by 15° per hour. Therefore, every 1° indicates 4 minutes theoretically.

2.3 The Sun angles of the observer

Since the photovoltaic (PV) panel is placed on the Earth, it acts spontaneously like an observer of the sun. Furthermore, the previous equations are based on an observation point at the Earth's centre, which is not as precise and accurate when the observer is positioned on the Earth's surface. Therefore, it is considered the point of location on the Earth's surface as the centre of the world. A three-dimensional Earth surface coordinate system would determine the angles to the sun's position.

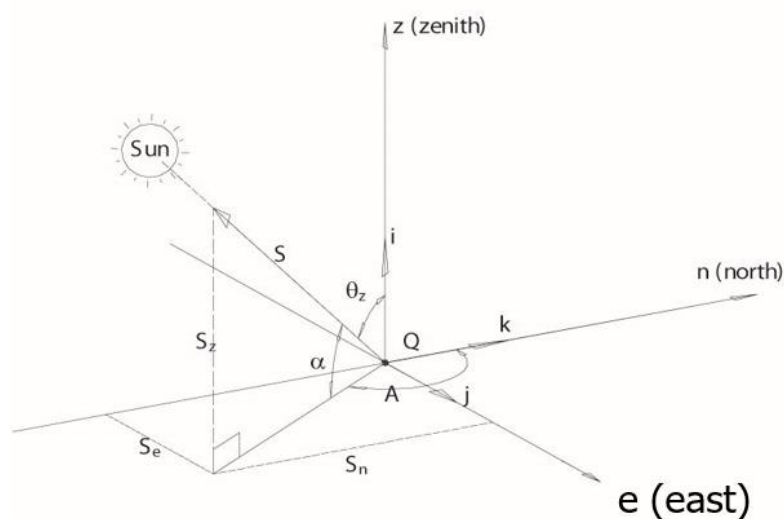


Figure 2.8: Angles of the Sun's observer (William and Michael, 2001)

Solar Altitude angle (α) is the angle between the central sunray and the horizontal plane of the observer's point. According to William and Michael (2001) and Kuo et al. (2018), it can be calculated as:

$$\alpha = \sin^{-1}(\sin \delta \sin \varphi + \cos \delta \cos \omega \cos \varphi) \quad (2.20)$$

Where α = solar altitude angle ($^{\circ}$). The range of Solar Altitude angles is between 0° and 90° .

Solar Zenith angle (θ_z), also known as the sun's elevation, is the angle between the central sunray and the vertical line called zenith (Z), which is orthogonal with the horizontal of the observer's point. It can be determined as (William and Michael, 2001):

$$\theta_z = 90^{\circ} - \alpha \quad (2.21)$$

Besides, according to Noorian (2008) and Benghanem (2011), the Solar Zenith angle can also be calculated as:

$$\theta_z = \cos^{-1}(\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos \omega) \quad (2.22)$$

Moreover, Mehleri et al. (2010) and Khalil and Shaffie (2013) proposed another formula that can calculate the Solar Zenith angle:

$$\theta_z = \cos^{-1}(\sin \varphi \sin \delta \cos \varphi \cos \delta \cos \omega) \quad (2.23)$$

Where θ_z = solar zenith angle ($^{\circ}$). It has a range between 0° and 180° . The direction of θ_z will be considered positive if it is in the counterclockwise direction.

It is worth mentioning that the Solar Azimuth angle (A) is the angle measured on the horizontal plane. It can be separated into two cases:

Case 1: $\sin \omega < 0$,

$$A = \cos^{-1} \left(\frac{\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi}{\cos \alpha} \right) \quad (2.24)$$

Case 2: $\sin \omega > 0$,

$$A = 360^\circ - \cos^{-1} \left(\frac{\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi}{\cos \alpha} \right) \quad (2.25)$$

Where A = solar azimuth angle ($^\circ$), with a range of 0° to 360° . It is regarded as a positive value if it begins with the north-pointing coordinate axis and proceeds clockwise to the projection of the centre sunray onto the horizontal plane. The value of the Solar Azimuth angle is 0° or 360° in the North, 90° in the East, 180° in the South, and 270° in the West (William and Michael, 2001).

2.4 Irradiance on a Collector Aperture

The weather and solar irradiance data of specific locations can be obtained from Photovoltaic Geographical Information System (PVGIS), which European Commission owns. Therefore, the data of global/total irradiance on the horizontal plane ($I_{t,h}$), beam/direct irradiance on a plane is always normal to sunrays ($I_{b,n}$), and diffuse irradiance on the horizontal plane ($I_{d,h}$) could be obtained from the website.

It is worth mentioning that the sunlight is not just a central parallel line from the sun; in fact, it will be dispersed into three ray components which are beam/direct, diffuse, and reflected when it reaches the surface of the Earth.

In this Final Year Project, tilt angle (β) and Surface Azimuth angle (γ) will be investigated and analysed to determine the maximum energy generated by the photovoltaic (PV) panel. The value of the Surface Azimuth angle is 0° or 360° in the North, 90° in the East, 180° in the South, and 270° in the West.

Therefore, the cosine angle of the incidence for a fixed aperture between a sunray and the aperture normal (θ_i) will be used when the angle is due to North, and it is given by (William and Michael, 2001):

$$\theta_i = \cos^{-1} \left[\begin{array}{l} \cos \beta (\sin \delta \sin \varphi + \cos \delta \cos \varphi \cos \omega) - \\ \cos \delta \sin \omega \sin \beta \sin \gamma + \\ \sin \beta \cos \gamma (\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi) \end{array} \right] \quad (2.26)$$

On the other hand, when the angle is due to South, the angle of incidence of beam irradiation (θ_i) with degree unit is given by (Kuo et al., 2018):

$$\begin{aligned} \theta_i = \cos^{-1} & (\sin \delta \sin \varphi \cos \beta - \sin \delta \cos \varphi \sin \beta \cos \gamma \\ & + \cos \delta \cos \varphi \cos \beta \cos \omega \\ & + \cos \delta \sin \varphi \sin \beta \cos \gamma \cos \omega \\ & + \cos \delta \sin \beta \sin \gamma \sin \omega) \end{aligned} \quad (2.27)$$

Where θ_i = cosine angle/the angle of incidence of beam irradiation ($^\circ$); β = tilt angle ($^\circ$); γ = aperture azimuth angle ($^\circ$).

Hence, global/total aperture irradiance ($I_{t,a}$) could be calculated as follows (William and Michael, 2001):

$$I_{t,a} = I_{b,n} \cos \theta_i + [I_{d,h} \left(\frac{1 + \cos \beta}{2} \right) + \rho I_{t,h} \left(\frac{1 - \cos \beta}{2} \right)] \quad (2.28)$$

Where $I_{t,a}$ = global/total aperture irradiance (W/m^2); $I_{t,h}$ = global/total irradiance on the horizontal plane (W/m^2); $I_{b,n}$ = beam/direct irradiance on a plane always normal to sunrays (W/m^2); $I_{d,h}$ = diffuse irradiance on the horizontal plane (W/m^2); ρ is ground albedo/solar reflectivity and it is supposed to be 0.3 for assuming the condition of the location is grassland (WeiXiang, 2008).

Apart from that, according to Getu and Alan (2019), extra-terrestrial irradiation (H_o) is determined as:

$$H_o = \left(\frac{G_{sc}}{\pi}\right) \left(1 + 0.033 \cos\left(2\pi \frac{N}{365}\right)\right) \left(\cos \varphi \cos \delta \sin \omega_{ss} + \frac{\pi}{180} \omega_{ss} \sin \varphi \sin \delta\right) \quad (2.29)$$

Besides, according to Khalil and Shaffie (2013), they suggested another formula will be:

$$H_o = \left(\frac{24}{\pi}\right) \times I_{sc} \times E_o \left[\cos \varphi \cos \delta \sin \omega + \left(\frac{\pi \omega}{180}\right) \sin \varphi \sin \delta\right] \quad (2.30)$$

Where H_o = extra-terrestrial irradiation (W/m^2); G_{sc} = solar constant, and it is supposed to be $1367 W/m^2$ (Khalil and Shaffie, 2013); ω_{ss} = sunset hour angle ($^\circ$), and it is given by Getu and Alan (2019) and Khatib et al. (2018):

$$\omega_{ss} = \cos^{-1}(-\tan \varphi \tan \delta) \quad (2.31)$$

Besides, E_o = correction factor of the Earth's orbit, and it is given by (Khalil and Shaffie, 2013):

$$E_o = 1 + 0.033 \cos\left(\frac{2\pi N}{365}\right) \quad (2.32)$$

Moreover, according to William and Michael (2001), the beam/direct normal irradiance ($I_{b,a}$) with W/m^2 unit can also be determined as follows:

$$I_{b,a} = I_{b,n} \cos \theta_i \quad (2.33)$$

2.5 Sky-diffuse irradiation

2.5.1 Isotropic Solar Energy Model

Isotropic solar models are premised on the basis that isotropic radiation has the same amplitude regardless of measurement direction and that anisotropic field has the same effect regardless of the orientation of the test particle. It comes from a point source known as an isotropic radiator and radiates evenly in all directions. In general, there are a lot of isotropic models that can be applied to calculate the ratio of the diffuse irradiation on a tilted surface to that on a horizontal surface (R_d).

According to Liu and Jordan (1962), Liu and Jordan isotropic model will be:

$$R_d = \frac{1 + \cos \beta}{2} \quad (2.34)$$

Besides, according to Badescu (2002), Badescu isotropic model will be:

$$R_d = \frac{3 + \cos 2\beta}{4} \quad (2.35)$$

Furthermore, according to Tian et al. (2001), Tian et al. isotropic model will be:

$$R_d = 1 - \frac{\beta}{180} \quad (2.36)$$

Moreover, according to Koronakis (1986), Koronakis isotropic model will be:

$$R_d = \frac{1}{3}(2 + \cos \beta) \quad (2.37)$$

2.5.2 Anisotropic Solar Energy Model

On account the sunlight, in reality, is not utterly symmetric on the sides of the photovoltaic (PV) panel practically, the anisotropic model is advantageous to simulate a more precise situation. It is believed that this decision will help us increase the model's accuracy.

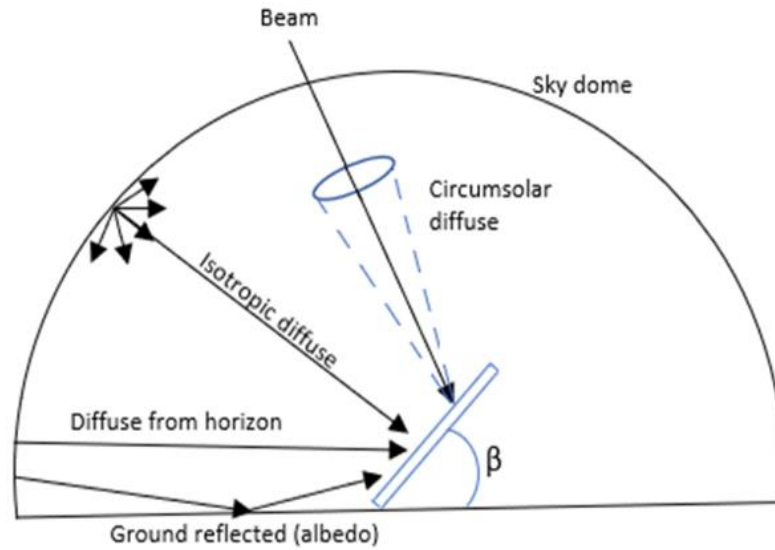


Figure 2.9: Diffuse Irradiance Components (da Silva, 2019)

Hay & Davies diffuse model (Hay, 1979) is generally based on the isotropic model. It only divides the sky diffuse irradiation isotropic and circumsolar components. Additionally, the horizon brightening was not considered on it. To each of these components, an anisotropic factor (A_i) is applied (da Silva, 2019):

$$A_i = \frac{I_{b,n}}{H_o} \quad (2.38)$$

After obtaining the required variables from the previous formula, the ratio of the diffuse irradiation on a tilted surface to that on a horizontal surface (R_d) can be determined as (da Silva, 2019):

$$R_d = I_{d,h} \left[A_i R_b + (1 - A_i) \left(\frac{1 + \cos \beta}{2} \right) \right] \quad (2.39)$$

On the other hand, another anisotropic model which is Reindl et al. model will be (Reindl et al., 1990):

$$R_d = \frac{H_b}{H_0} R_b + \left(1 - \frac{H_b}{H_0}\right) \left(\frac{1 + \cos \beta}{2}\right) \left[1 + \sqrt{\frac{H_b}{H_0}} \left(\sin \frac{\beta}{2}\right)^3\right] \quad (2.40)$$

Besides, according to Skartveit and Olseth (1986), Skartveit and Olseth anisotropic model will be:

$$R_d = \frac{H_b}{H_0} R_b + \Omega \cos \beta + \left(1 - \frac{H_b}{H_0} - \Omega\right) \left(\frac{1 + \cos \beta}{2}\right) \quad (2.41)$$

Where

$$\Omega = \text{Max}\left[0, \left(0.3 - 2 \frac{H_b}{H_0}\right)\right] \quad (2.42)$$

On the other hand, according to Steven and Unsworth (1980), Steven and Unsworth anisotropic model will be:

$$R_d = 0.51R_b + \frac{1+\cos\beta}{2} - \frac{1.74}{1.26\pi} \left[\sin\beta - \left(\beta \frac{\pi}{180}\right) \cos\beta - \pi \left(\sin\frac{\beta}{2}\right)^2 \right] \quad (2.43)$$

The ratio of the average diffuse irradiation on a tilted surface to that on a horizontal surface (R_d) is determined as (Getu and Alan, 2019):

$$R_d = R_b \frac{I_{b,n}}{H_o} + \left(1 - \frac{I_{b,n}}{H_o}\right) \left(\frac{1 + \cos \beta}{2}\right) \quad (2.44)$$

Where R_d = the ratio of the diffuse irradiation on a tilted surface to that on a horizontal surface; R_b = the ratio of the beam irradiation on the tilted surface to that on a horizontal surface.

On the other hand, according to Getu and Alan (2019) and Benghanem (2011), the sky-diffuse irradiation (H_D) with W/m^2 unit could be obtained by:

$$H_D = R_d I_{d,h} \quad (2.45)$$

2.6 Beam/direct irradiation

The ratio of the beam irradiation on the tilted surface to that on a horizontal surface (R_b) can be used to estimate slope irradiation, it is proposed by da Silva (2019) and Mehleri et al. (2010):

$$R_b = \frac{\cos \theta_i}{\cos \theta_z} \quad (2.46)$$

On the other hand, according to Benghanem (2011), to calculate R_b , it can be separated into two cases: the surface in the Northern and Southern hemispheres.

For the Northern hemisphere, the formula will be:

$$R_b = \frac{\cos(\varphi - \beta) \cos \delta \sin \omega_{ss} + \omega_{ss} \sin(\varphi - \beta) \sin \delta}{\cos \varphi \cos \delta \sin \omega_{ss} + \omega_{ss} \sin \varphi \sin \delta} \quad (2.47)$$

Whereas for the Southern hemisphere, the formula will be:

$$R_b = \frac{\cos(\varphi + \beta) \cos \delta \sin \omega_{ss} + \omega_{ss} \sin(\varphi + \beta) \sin \delta}{\cos \varphi \cos \delta \sin \omega_{ss} + \omega_{ss} \sin \varphi \sin \delta} \quad (2.48)$$

According to Getu and Alan (2019) and Benghanem (2011), beam/direct irradiation received on a tilted surface (H_B) with W/m^2 unit is calculated as:

$$H_B = (I_{t,h} - I_{d,h})R_b \quad (2.49)$$

2.7 Ground-reflected irradiation

The ground-reflected irradiation (H_R) with W/m^2 unit is determined as proposed by Getu and Alan (2019) and Benghanem (2011):

$$H_R = I_{t,h}\rho\left(\frac{1 - \cos \beta}{2}\right) \quad (2.50)$$

2.8 Total irradiation on a tilted surface

The formula to calculate the total irradiation on a tilted surface (H_T) is proposed by Getu and Alan (2019), Noorian (2008), Mehleri et al. (2010) and Benghanem (2011):

$$H_T = H_B + H_D + H_R \quad (2.51)$$

On the other hand, according to Noorian (2008), the formula can be written again as follows:

$$H_T = B_T \frac{\cos \theta_i}{\cos \theta_z} + R_d I_{d,h} + I_{t,h} \rho \left(\frac{1 - \cos \beta}{2} \right) \quad (2.52)$$

Where H_T = total irradiation on a tilted surface (W/m^2); B_T = direct irradiation on a tilted surface (W/m^2).

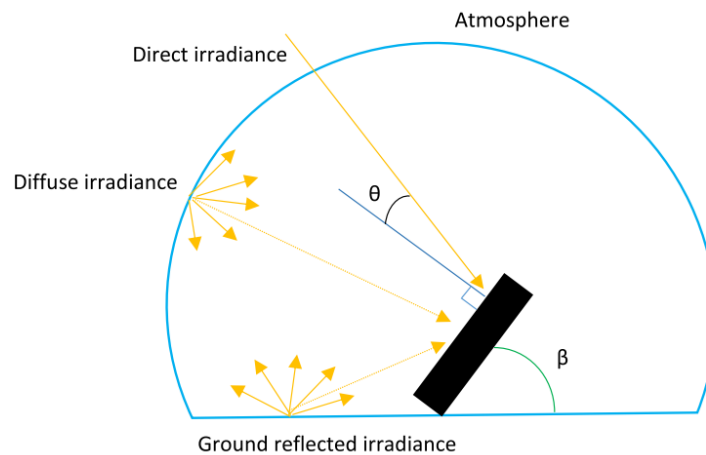


Figure 2.10: Irradiance components scheme (Conceição et al., 2019)

2.9 Hourly Energy generation

In this case, an LG brand with the photovoltaic panel model LG365Q1C-A5 will be utilised to find the hourly generation of energy. The dimensions per PV cell of the PV panel are 161.7 mm x 161.7 mm, and it consists of a total of 60 solar cells, which have an overall 21.1% module efficiency.

Therefore, in order to calculate the hourly energy generated with a unit of W/m^2 by using the LG365Q1C-A5 PV panel, the formulas are given:

$$Energy (J) = H_T \times 60 \times A \times efficiency \times 3600 \text{ second} \quad (2.53)$$

2.10 Cosine Effect

Solar energy falling on a horizontal surface outside the Earth's atmosphere is reduced by the cosine of the angle between the sun and a line normal to the surface. Hence, it is described by the formula below for the extra-terrestrial horizontal surface (William and Michael, 2001).

$$I_{o,h} = H_o \cos \theta_z \quad (2.54)$$

Where $I_{o,h}$ = cosine effect (W/m^2). Its value will generally be smaller than extra-terrestrial irradiation (H_o).

2.11 Result outcomes from other research

According to the result obtained from Khatib et al. (2015), the Liu and Jordan model for solar energy incident on a tilted surface was utilised to optimise PV module tilt angle for the five locations in Malaysia. According to the findings, the tilt angle of the PV module must be adjusted seasonally. For East Malaysia, which includes the states of Sabah and Sarawak, a monthly optimal tilt angle modification is advised. PV module collected yields in Kuala Lumpur, Johor Bahru, Ipoh, Kuching, and Alor Setar increased by 5.03%, 5.02%, 5.65%, 7.96%, and 6.13% respectively, when the optimum tilt angle was changed monthly. When the optimum tilt angle was adjusted seasonally, the collected yields increased by 4.54%, 4.58%, 5.70%, 4.11%, and 5.85% respectively.

Getu and Alan (2019) reported that the seasonal optimal tilt angles achieved using anisotropic models are more consistent, implying that anisotropic model forecasts are more accurate than isotropic model predictions. For improved performance, both models suggested that the panels be modified seasonally. Isotropic models had optimal tilt angles ranging from 37° to 44° , whereas the four anisotropic models had optimum tilt angles ranging from 46° to 47° . The total solar energy received by a solar panel placed 15° West or East of due South is unaffected (less than 1%). With increasing West or East of due South direction, the amount of solar energy received decreases. This finding also suggests that a single-axis tracking device might be built to acquire the monthly optimal angle.

By referring to Roxana et al. (2019), the optimal tilt angle for fixed PV panels was explored using four distinct models. As a result, values for the fixed tilt angles were calculated on a monthly, seasonal, biennial, and annual basis. After that, the total irradiation throughout the year was computed using the tilt angles that had previously been established. A 4.76% increase in total irradiation is projected when utilising a monthly optimal tilt angle compared to the number observed when using a yearly tilt angle. Seasonal angles are not suggested since they only give a marginal increase in total irradiation (0.5%) compared to biennial tilt angles. While using monthly or biannual optimal tilt angles may not seem to be very encouraging at first, it may be beneficial in the long run. As a result, depending on the total installed power of a solar power plant, the increase in energy production throughout the lifetime of the PV panels may be pretty constant, surpassing the expenses of the upgraded mechanical structure and other operating costs. As a result, each unique PV power plant project must be evaluated to determine the cost-benefit ratio of adopting an optimal tilt angle system across the project's life cycle.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

The computational algorithm's flow chart (Figure 3.1) is presented below to calculate the annual energy generation of the PV panel at different tilt angles and find the optimum tilt angles by identifying the highest energy generation. All calculations were done using MATLAB® (R2021a) based program.

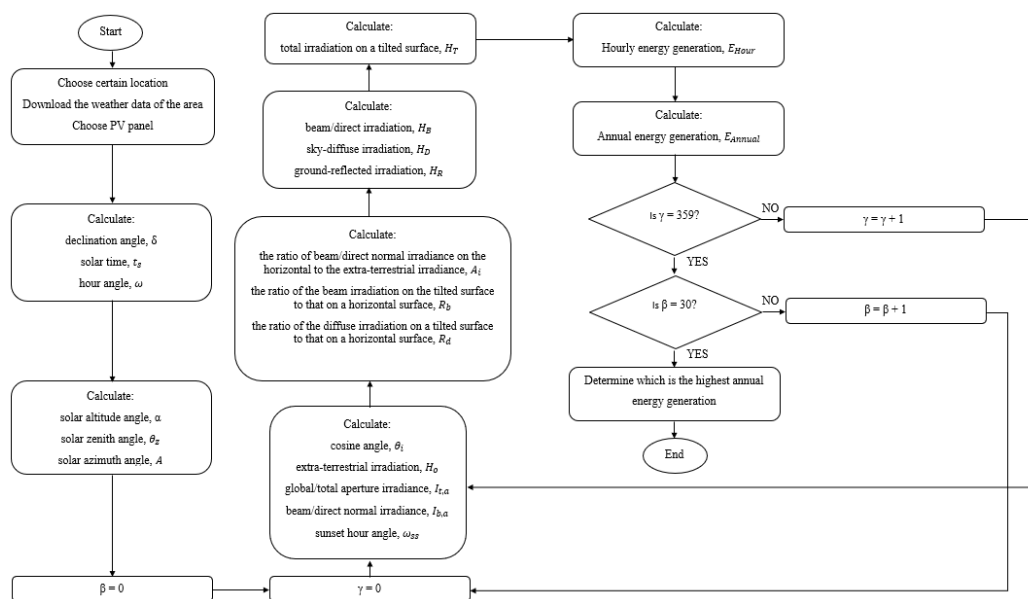


Figure 3.1: Flow Chart of the computational algorithm

3.2 Calculations

3.2.1 Declination angle, solar time, and hour angle

According to William and Michael (2001), the declination angle can be obtained by applying the formula below:

$$\delta = \sin^{-1}\{0.39795 \cos [0.98563(N - 173)]\} \quad (3.1)$$

Solar time (t_s) can be determined as (William and Michael, 2001):

$$t_s = \text{LCT} + \frac{\text{EOT}}{60} - \text{LC} \quad (3.2)$$

Besides, according to William and Michael (2001), the hour angle (ω) expresses the time of the day relative to the solar noon.

$$\omega = 15(t_s - 12) \quad (3.3)$$

3.2.2 Solar Altitude angle, Solar Zenith angle, and Solar Azimuth angle

Solar Altitude Angle (α) is the angle between the central sunray and the horizontal plane of the observer's point. It can be calculated as (William and Michael, 2001):

$$\alpha = \sin^{-1}(\sin \delta \sin \varphi + \cos \delta \cos \omega \cos \varphi) \quad (3.4)$$

Moreover, the Solar Zenith angle (θ_z) can be determined as (William and Michael, 2001):

$$\theta_z = 90^\circ - \alpha \quad (3.5)$$

Solar Azimuth angle (A) is the angle measured on the horizontal plane. It can be separated into two cases:

Case 1: $\sin \omega < 0$,

$$A = \cos^{-1} \left(\frac{\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi}{\cos \alpha} \right) \quad (3.6)$$

Case 2: $\sin \omega > 0$,

$$A = 360^\circ - \cos^{-1} \left(\frac{\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi}{\cos \alpha} \right) \quad (3.7)$$

3.2.3 Cosine angle, extra-terrestrial irradiance, global/total aperture irradiance, beam/direct normal irradiance, and sunset hour angle

The cosine angle of the incidence for a fixed aperture between a sunray and the aperture normal (θ_i) will be used, and it is given by (William and Michael, 2001):

$$\theta_i = \cos^{-1} \left[\frac{\cos \beta (\sin \delta \sin \varphi + \cos \delta \cos \varphi \cos \omega) - \cos \delta \sin \omega \sin \beta \sin \gamma + \sin \beta \cos \gamma (\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi)}{\cos \alpha} \right] \quad (3.8)$$

Apart from that, according to Getu and Alan (2019), extra-terrestrial irradiation (H_o) is determined as:

$$H_o = \left(\frac{G_{sc}}{\pi}\right) \left(1 + 0.033 \cos\left(2\pi \frac{N}{365}\right)\right) \left(\cos \varphi \cos \delta \sin w_{ss} + \frac{\pi}{180} w_{ss} \sin \varphi \sin \delta\right) \quad (3.9)$$

Hence, global/total aperture irradiance ($I_{t,a}$) could be calculated as follows (William and Michael, 2001):

$$I_{t,a} = I_{b,n} \cos \theta_i + \left[I_{d,h} \left(\frac{1 + \cos \beta}{2}\right) + \rho I_{t,h} \left(\frac{1 - \cos \beta}{2}\right) \right] \quad (3.10)$$

Besides, according to William and Michael (2001), the beam/direct normal irradiance ($I_{b,a}$) can also be determined as follows:

$$I_{b,a} = I_{b,n} \cos \theta_i \quad (3.11)$$

The sunset hour angle is given by (Getu and Alan, 2019):

$$\omega_{ss} = \cos^{-1}(-\tan \varphi \tan \delta) \quad (3.12)$$

3.2.4 Ratios due to different irradiances

An anisotropic model, Hay & Davies, will be applied to calculate diffuse irradiation. Hay & Davies diffuse model is generally based on the isotropic model. It only divides the sky diffuse irradiation isotropic and circumsolar components. Additionally, the

horizon brightening was not considered on it. To each of these components, an anisotropic factor (A_i) is applied (da Silva, 2019).

$$A_i = \frac{I_{b,n}}{H_o} \quad (3.13)$$

The ratio of the beam irradiation on the tilted surface to that on a horizontal surface (R_b) can be used to estimate slope irradiation, it is given by (da Silva, 2019):

$$R_b = \frac{\cos \theta_i}{\cos \theta_z} \quad (3.14)$$

After obtaining the required variables from the previous formula, the ratio of the diffuse irradiation on a tilted surface to that on a horizontal surface (E_d) can be determined as (da Silva, 2019):

$$R_d = I_{d,h} [A_i R_b + (1 - A_i) \left(\frac{1 + \cos \beta}{2} \right)] \quad (3.15)$$

3.2.5 Beam/direct irradiance, sky-diffuse irradiance, ground-reflected irradiance, and total irradiation on a tilted surface

According to Getu and Alan (2019), beam/direct irradiation received on a tilted surface (H_B) is calculated as:

$$H_B = (I_{t,h} - I_{d,h}) R_b \quad (3.16)$$

On the other hand, the sky-diffuse irradiation (H_D) could be obtained by (Getu and Alan, 2019):

$$H_D = R_d I_{d,h} \quad (3.17)$$

The ground-reflected irradiation (H_R) is determined as (Getu and Alan, 2019):

$$H_R = I_{t,h} \rho \left(\frac{1 - \cos \beta}{2} \right) \quad (3.18)$$

Total irradiation on a tilted surface (H_T) is calculated by (Getu and Alan, 2019):

$$H_T = H_B + H_D + H_R \quad (3.19)$$

3.2.6 Hourly energy generated

In order to calculate the hourly energy generated by the LG365Q1C-A5 PV panel, the formula is given:

$$\text{Energy (J)} = H_T \times 60 \times A \times \text{efficiency} \times 3600 \text{ second} \quad (3.20)$$

3.3 Verification

The verification objective is to ensure that the software meets the design standards in terms of accuracy and validity. This section is divided into two parts: the final result using formulae and the MATLAB® (R2021a) based software. For other information, annual energy generation will only be computed using MATLAB® since manual calculation using formulae has limitations. However, the value of hourly energy generation can still be obtained at the end.

Furthermore, in order to have a valid comparison between both calculations, the default data obtained from the Weather Data Sheet will be shown in the table below:

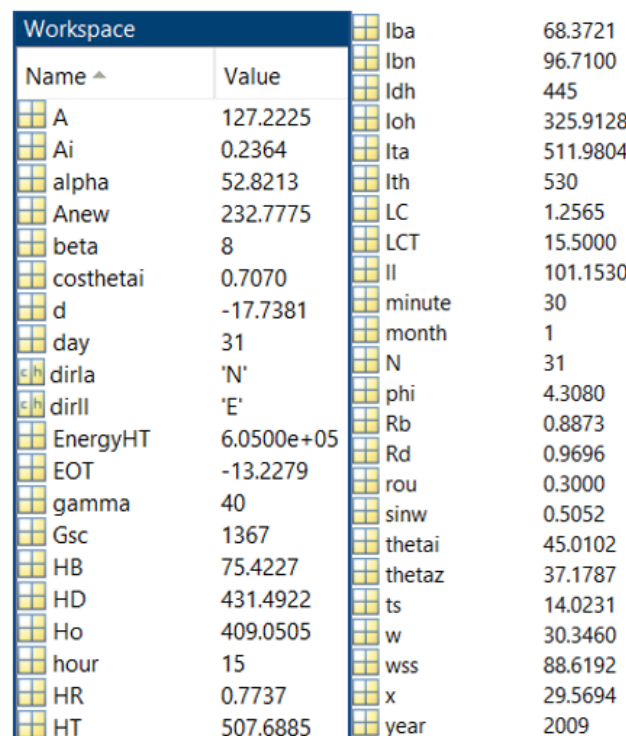
Table 3.1: Default Data for Verification Purposes

Latitude coordinate	4.308° N
Longitude coordinate	101.153° E
Tilt angle, β	8°
Aperture Azimuth angle, γ	40°
Date (YYYY-MM-DD)	2009-01-31
Time (HH:MM)	15:30
Direct irradiance on a plane always normal to sunrays, $I_{b,n}$	96.71 W/m ²
Diffuse irradiance on the horizontal plane, $I_{d,h}$	445 W/m ²
Global/total irradiance on the horizontal plane, $I_{t,h}$	530 W/m ²
Ground albedo/solar reflectivity, ρ	0.3
Area of PV panel	1.5688 m ²
Efficiency of PV panel	21.1%

3.3.1 MATLAB® (R2021a) based software Calculation

MATLAB® enables users to do mathematical computations such as matrix manipulations, function and data visualisation, algorithm implementation, user interface creation and connecting with other language-based programmes. Therefore, it can process massive data by constructing programming to enable the function and calculation.

Here are the variable values that are computed with pre-written programming. The results were shown in the panel of the workspace. On the other hand, the hourly energy generation was also shown in the name of HT, which is 507.6885 J in the list.



Workspace			
Name ^	Value		
A	127.2225	lba	68.3721
Ai	0.2364	lbn	96.7100
alpha	52.8213	ldh	445
Anew	232.7775	loh	325.9128
beta	8	lta	511.9804
costhetai	0.7070	lth	530
d	-17.7381	LC	1.2565
day	31	LCT	15.5000
dirla	'N'	ll	101.1530
dirll	'E'	minute	30
EnergyHT	6.0500e+05	month	1
EOT	-13.2279	N	31
gamma	40	phi	4.3080
Gsc	1367	Rb	0.8873
HB	75.4227	Rd	0.9696
HD	431.4922	rou	0.3000
Ho	409.0505	sinw	0.5052
hour	15	thetai	45.0102
HR	0.7737	thetaz	37.1787
HT	507.6885	ts	14.0231
		w	30.3460
		wss	88.6192
		x	29.5694
		year	2009

Figure 3.2: Results are shown in MATLAB® Workspace

3.3.2 Manual calculation

Declination angle

$$\begin{aligned}\delta &= \sin^{-1}\{0.39795 \cos [0.98563(N - 173)]\} \\ &= \sin^{-1}\{0.39795 \cos [0.98563(31 - 173)]\} \\ &= -17.7381 \text{ (}^\circ\text{)}\end{aligned}$$

Local clock time

$$\begin{aligned}LCT &= Hour + \frac{Minute}{60} \\ &= 15 + \frac{30}{60} \\ &= 15.5 \text{ (hours)}\end{aligned}$$

The function of the calendar dates

$$\begin{aligned}x &= \frac{360(N - 1)}{365.242} \\ &= \frac{360(31 - 1)}{365.242} \\ &= 29.5694 \text{ (}^\circ\text{)}\end{aligned}$$

Equation of time

$$\begin{aligned}EOT &= 0.258 \cos x - 7.416 \sin x - 3.648 \cos 2x - 9.228 \sin 2x \\ &= 0.258 \cos 29.5694 - 7.416 \sin 29.5694 - 3.648 \cos (2 \times 29.5694) - 9.228 \sin (2 \times 29.5694) \\ &= -13.2279 \text{ (minutes)}\end{aligned}$$

Longitude correction

$$\begin{aligned}LC &= \frac{(\text{Long}_{\text{local}} - \text{Long}_{\text{sm}})}{15} \\ &= \frac{-101.153 - (-120)}{15} \\ &= 1.2565 \text{ (hours)}\end{aligned}$$

Solar time

$$\begin{aligned}
 t_s &= \text{LCT} + \frac{\text{EOT}}{60} - \text{LC} \\
 &= 15.5 + \left(\frac{-13.2279}{60}\right) - 1.2565 \\
 &= 14.0231 \text{ (hours)}
 \end{aligned}$$

Hour angle

$$\begin{aligned}
 \omega &= 15(t_s - 12) \\
 &= 15(14.0230 - 12) \\
 &= 30.346 \text{ (}^\circ\text{)}
 \end{aligned}$$

Solar altitude angle

$$\begin{aligned}
 \alpha &= \sin^{-1}(\sin \delta \sin \phi + \cos \delta \cos \omega \cos \phi) \\
 &= \sin^{-1}(\sin(-17.7381) \sin 4.308 + \cos(-17.7381) \cos 30.346 \cos 4.308) \\
 &= 52.8213 \text{ (}^\circ\text{)}
 \end{aligned}$$

Solar zenith angle

$$\begin{aligned}
 \theta_z &= 90^\circ - \alpha \\
 &= 90^\circ - 52.8213 \\
 &= 37.1787 \text{ (}^\circ\text{)}
 \end{aligned}$$

Solar azimuth angle

$$\begin{aligned}
 \because \sin \omega &= \sin 30.346 \\
 &= 0.5052 > 0 \\
 \therefore A &= 360^\circ - \cos^{-1} \left(\frac{\sin \delta \cos \phi - \cos \delta \cos \omega \sin \phi}{\cos \alpha} \right) \\
 &= 360^\circ - \cos^{-1} \left(\frac{\sin(-17.7381) \cos 4.308 - \cos(-17.7381) \cos 30.346 \sin 4.308}{\cos 52.8213} \right) \\
 &= 232.7775 \text{ (}^\circ\text{)}
 \end{aligned}$$

Cosine angle

$$\begin{aligned}\theta_i &= \cos^{-1} \left[\frac{\cos \beta (\sin \delta \sin \varphi + \cos \delta \cos \varphi \cos \omega) - \cos \delta \sin \omega \sin \beta \sin \gamma + \sin \beta \cos \gamma (\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi)}{\sin \beta \cos \gamma (\sin \delta \cos \varphi - \cos \delta \cos \omega \sin \varphi)} \right] \\ &= \cos^{-1} \left[\frac{\cos 8 (\sin(-17.7381) \sin 4.308 + \cos(-17.7381) \cos 4.308 \cos 30.346) - \cos(-17.7381) \sin 30.346 \sin 8 \sin 40 + \sin 8 \cos 40 (\sin(-17.7381) \cos 4.308 - \cos(-17.7381) \cos 30.346 \sin 4.308)}{\sin 8 \cos 40 (\sin(-17.7381) \cos 4.308 - \cos(-17.7381) \cos 30.346 \sin 4.308)} \right] \\ &= \cos^{-1} [0.9903(-0.0229 + 0.8196) - 0.0430 + 0.1066(-0.3038 - 0.0617)] \\ &= 45.0102 (^\circ)\end{aligned}$$

Global/total aperture irradiance

$$\begin{aligned}I_{t,a} &= I_{b,n} \cos \theta_i + [I_{d,h} \left(\frac{1 + \cos \beta}{2} \right) + \rho I_{t,h} \left(\frac{1 - \cos \beta}{2} \right)] \\ &= 96.71 \cos 45.0102 + [445 \left(\frac{1 + \cos 8}{2} \right) + 0.3 \times 530 \times \left(\frac{1 - \cos 8}{2} \right)] \\ &= 511.9804 \text{ (W/m}^2\text{)}\end{aligned}$$

Sunset hour angle

$$\begin{aligned}\omega_{ss} &= \cos^{-1}(-\tan \varphi \tan \delta) \\ &= \cos^{-1}(-\tan 4.308 \tan(-17.7381)) \\ &= 88.6192 (^\circ)\end{aligned}$$

Extra-terrestrial irradiation

$$\begin{aligned}H_o &= \left(\frac{G_{sc}}{\pi} \right) \left(1 + 0.033 \cos \left(2\pi \frac{N}{365} \right) \right) \left(\cos \varphi \cos \delta \sin w_{ss} + \frac{\pi}{180} w_{ss} \sin \varphi \sin \delta \right) \\ &= \left(\frac{1367}{\pi} \right) \left(1 + 0.033 \cos \left(2\pi \frac{31}{365} \right) \right) \left(\cos 4.308 \cos(-17.7381) \sin 88.6192 + \frac{\pi}{180} \times 88.6192 \times \sin 4.308 \sin(-17.7381) \right) \\ &= 409.0505 \text{ (W/m}^2\text{)}\end{aligned}$$

Beam/direct normal irradiance

$$\begin{aligned} I_{b,a} &= I_{b,n} \cos \theta_i \\ &= 96.71 \times \cos 45.0102 \\ &= 68.3721 \text{ (W/m}^2\text{)} \end{aligned}$$

Beam/direct normal irradiance on the horizontal to the extra-terrestrial irradiance

$$\begin{aligned} A_I &= \frac{I_{b,n}}{H_o} \\ &= \frac{96.71}{409.0505} \\ &= 0.2364 \text{ (W/m}^2\text{)} \end{aligned}$$

The ratio of the beam irradiation on the tilted surface to that on a horizontal surface

$$\begin{aligned} R_b &= \frac{\cos \theta_i}{\cos \theta_z} \\ &= \frac{\cos 45.0102}{\cos 37.1787} \\ &= 0.8873 \end{aligned}$$

Beam/direct irradiation

$$\begin{aligned} H_B &= (I_{t,h} - I_{d,h})R_b \\ &= (530 - 445)0.8873 \\ &= 75.4227 \text{ (W/m}^2\text{)} \end{aligned}$$

The ratio of the diffuse irradiation on a tilted surface to that on a horizontal surface

$$\begin{aligned} R_d &= R_b \frac{I_{b,n}}{H_o} + \left(1 - \frac{I_{b,n}}{H_o}\right) \left(\frac{1 + \cos \beta}{2}\right) \\ &= 0.8873 \times \frac{96.71}{409.0505} + \left(1 - \frac{96.71}{409.0505}\right) \left(\frac{1 + \cos 8}{2}\right) \\ &= 0.9696 \end{aligned}$$

Sky-diffuse irradiation

$$\begin{aligned} H_D &= R_d I_{d,h} \\ &= 0.9696 \times 445 \\ &= 431.4895 \text{ (W/m}^2\text{)} \end{aligned}$$

Ground-reflected irradiation

$$\begin{aligned} H_R &= I_{t,h} \rho \left(\frac{1 - \cos \beta}{2} \right) \\ &= 530 \times 0.3 \left(\frac{1 - \cos 8}{2} \right) \\ &= 0.7737 \text{ (W/m}^2\text{)} \end{aligned}$$

Total irradiation on a tilted surface

$$\begin{aligned} H_T &= H_B + H_D + H_R \\ &= 75.4227 + 431.4895 + 0.7737 \\ &= 507.6859 \text{ (W/m}^2\text{)} \end{aligned}$$

Hourly energy generated

$$\begin{aligned} \text{Energy (J)} &= H_T \times 60 \times A \times \text{efficiency} \times 3600 \text{ second} \\ &= 507.6859 \times 60 \times (0.1617 \times 0.1617) \times 0.211 \times 3600 \text{ second} \\ &= 604994.3908 \text{ (J)} \end{aligned}$$

3.3.3 Comparison of both calculations

In this section, the result of both calculation methods will be compared, and the percentage differences will also be calculated by using the equation

$$\left| \frac{\text{MATLAB}^\circledast \text{ calculation} - \text{Manual calculation}}{\text{Manual calculation}} \right| \times 100\% \text{ in the table below.}$$

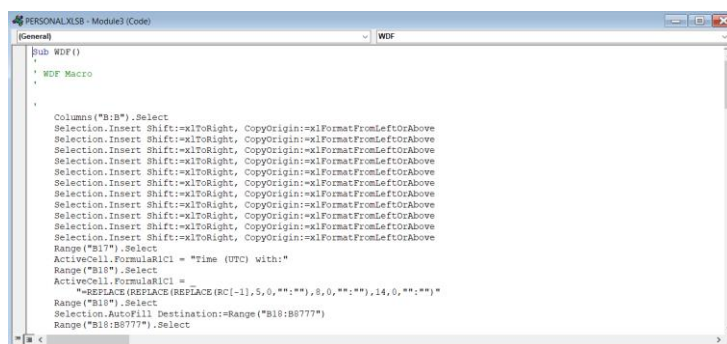
Table 3.2: Result Comparison by using Two Different Methods

Variable	MATLAB® calculation	Manual calculation	Percentage difference (%)
δ	-17.7381°	-17.7381°	0
LCT	15.5 hours	15.5 hours	0
x	29.5694°	29.5694°	0
EOT	-13.2279 minutes	-13.2279 minutes	0
LC	1.2565 hours	1.2565 hours	0
t_s	14.0231 hours	14.0231 hours	0
ω	30.3460°	30.3460°	0
α	52.8213°	52.8213°	0
θ_z	37.1787°	37.1787°	0
A	232.7775°	232.7775°	0
θ_i	45.0102°	45.0102°	0
I_{t,a}	511.9804 W/m ²	511.9804 W/m ²	0
ω_{ss}	88.6192°	88.6192°	0
H_o	409.0505 W/m ²	409.0505 W/m ²	0
I_{b,a}	68.3721 W/m ²	68.3721 W/m ²	0
A_i	0.2364 W/m ²	0.2364 W/m ²	0
R_b	0.8873	0.8873	0
H_B	75.4227 W/m ²	75.4227 W/m ²	0
R_d	0.9696	0.9696	0
H_D	431.4922 W/m ²	431.4895 W/m ²	Less than 0.0001
H_R	0.7737 W/m ²	0.7737 W/m ²	0
H_T	507.6885 W/m ²	507.6859 W/m ²	Less than 0.0001
Energy	6049975.1048 J	604994.3908 J	Less than 0.0001

By referring to the table above, it can be observed that almost all of the variables have a zero-percentage difference except the values of H_D, H_T, and Energy which are less than 0.0001%. Therefore, these differences can be accepted since the percentage value are extremely small, and it can be concluded that the results of MATLAB® (R2021a) based software calculation and Manual calculation are valid.

3.4 Microsoft Excel Macro Design

The function of Macro is versatile and useful. It helps people complete repetitive tasks automatically and rapidly once the user has recorded specific Macros before. When the user constructs a Macro, the system will record every step that the mouse click and keystrokes. Once the Macro is finished recording, the user is allowed to run it as many times as they intend, as well as edit it to make some minor changes to the way it is supposed to work. Therefore, a Macro that helps the user manage and abstract the required data was created to lighten up the burden of data automation.



```

PERSONAL.XLSB - Module1 (Code)
[General]
Sub WDF ()
    ' WDF Macro
    '
    Columns("B:B").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftAbove
    Range("B17").Select
    ActiveCell.FormulaR1C1 = "time (UTC) with:"
    Range("B18").Select
    ActiveCell.FormulaR1C1 =
        "=REPLACE(REPLACE(REPLACE(RC[-1],5,0,""":""),8,0,""":""),14,0,""":"")"
    Range("B18").Select
    Selection.AutoFill Destination:=Range("B18:B8777")
    Range("B18:B8777").Select

```

Figure 3.3: Overview of Macro

3.4.1 Macro Design

With respect to obtaining the data required, here are the steps that Macro implements in the Microsoft Excel file.

1. The Macro will insert a total of 11 columns in advance.
2. It will perform the **REPLACE** function in column B to separate the time data, which are initially attached in the form of YYYYMMDD:HHMM.

3. The functions of **LEFT**, **MID**, and **RIGHT** will be initiated between columns C and G. This step will separate the time data effectively by the system detecting the position of the data.
4. From columns H to L, they will be labelled with the name of Year, Month, Day, Hour, and Minute respectively. On the other hand, all data will be moved forwardly to 8 hours earlier for standard time zone correction from UTC to UTC+8. Besides, the data will also be moved forwardly to 30 minutes earlier in order to obtain the average result.
5. In order to give a better understanding to the user, Cell O16, P16 and Q16 will be labelled to the name of Global irradiance on the horizontal plane ($I_{t,h}$), Beam/direct irradiance on a plane always normal to sun rays ($I_{b,n}$) and Diffuse irradiance on the horizontal plane ($I_{d,h}$) respectively.
6. After it, the second tab in the file named “Sheet2” will be created, and the purpose is to neatly organise and integrate the data required from “Sheet1”.
7. In Cell B1 and B2 of the “Sheet2” tab, the functions of **MID**, **FIND**, and **LEN** will be utilized to show the coordinates of the location’s latitude and longitude in the end.

3.4.2 Flow Chart of Macro

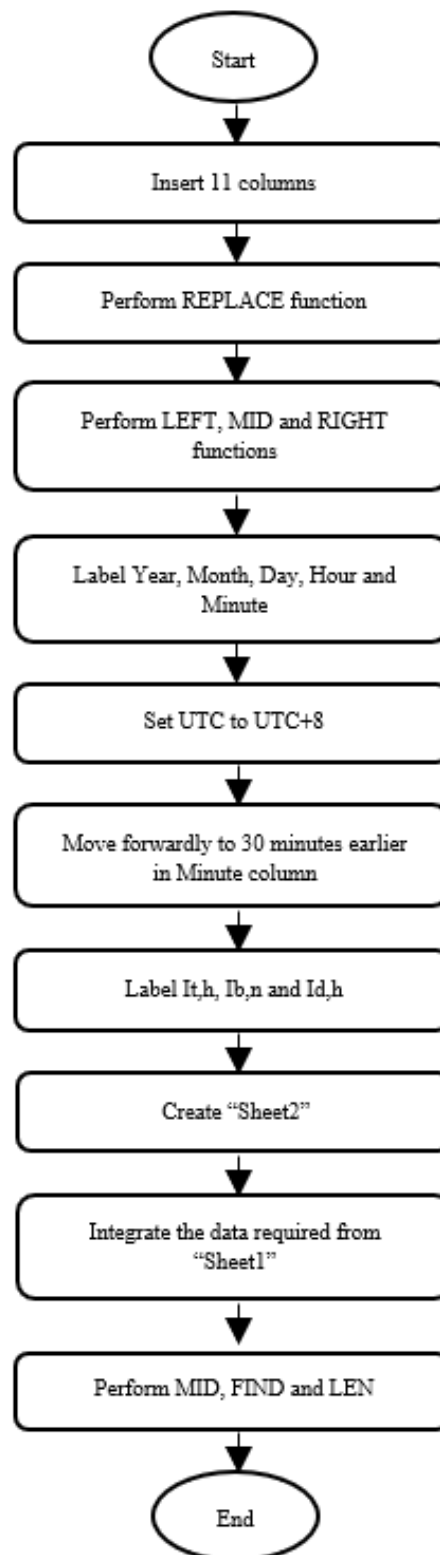


Figure 3.4: Flow Chart of Microsoft Excel Macro

3.4.3 Procedures for using Macro

Nevertheless, the purpose of constructing Macro is to lighten up the burden and increase work efficiency. Here are the procedures for initiating Macro to give the user a clear and better understanding of it:

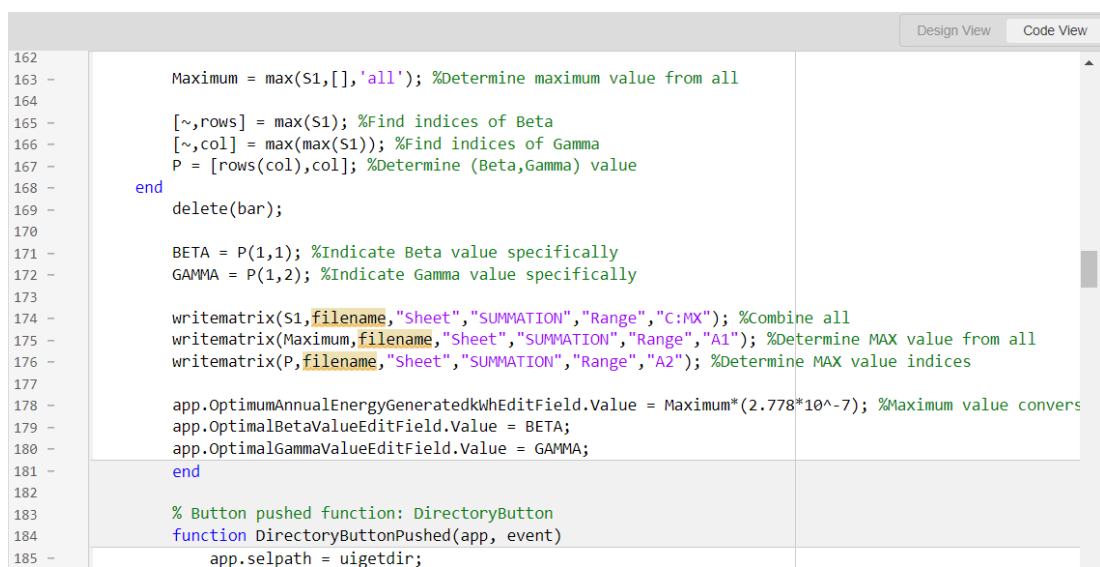
1. When the user downloaded the Weather Data file from JRC Photovoltaic Geographical Information System (PVGIS) – European Commission website, it will be in the file type of Microsoft Excel Comma Separated Values File (.csv).
2. The user must use the “**Save as**” function to create another same file but a different type with Microsoft Excel Worksheet (.xlsx).
3. Before using Macro to initiate the data automation, the user needs to rename the Tab Name to “**Sheet1**”. The user must do such things because the Macro has the limitation, and it can only detect the same name during the programming.
4. After that, the user must go to the **Developer** tab, click **Macros** and select the Macro that wants to initiate in the Microsoft Excel File. It is worth mentioning that the data required will appear in Tab 2, which is named “Sheet2”, after activating.
5. The user is required to save the file again for future operation.

3.5 MATLAB System Design

The title of the system is “Optimum Tilt Angle (β) and Azimuth Angle (γ) of Fixed-PV panel.” It can provide the final result values of optimum energy generation, optimal tilt angle, and azimuth angle in a particular location for the fixed-PV panel after undergoing a computational algorithm under Malaysia weather conditions.

3.5.1 Graphical Modelling Language

App Designer, which is included with MATLAB (MATrix LABoratory), enables system developers to easily create graphical user interfaces by dragging and dropping visual components. On the other side, the actions and processes are implemented using the well-known MATLAB programming language. Not to mention that MATLAB Runtime can later be used to create apps that can be run on any computer.



```

162
163 -     Maximum = max(S1,[], 'all'); %Determine maximum value from all
164
165 -     [~,rows] = max(S1); %Find indices of Beta
166 -     [~,col] = max(max(S1)); %Find indices of Gamma
167 -     P = [rows(col),col]; %Determine (Beta,Gamma) value
168 - end
169 -     delete(bar);
170
171 -     BETA = P(1,1); %Indicate Beta value specifically
172 -     GAMMA = P(1,2); %Indicate Gamma value specifically
173
174 -     writematrix(S1,filename,"Sheet","SUMMATION","Range","C:MX"); %Combine all
175 -     writematrix(Maximum,filename,"Sheet","SUMMATION","Range","A1"); %Determine MAX value from all
176 -     writematrix(P,filename,"Sheet","SUMMATION","Range","A2"); %Determine MAX value indices
177
178 -     app.OptimumAnnualEnergyGeneratedkWhEditField.Value = Maximum*(2.778*10^-7); %Maximum value convers
179 -     app.OptimalBetaValueEditField.Value = BETA;
180 -     app.OptimalGammaValueEditField.Value = GAMMA;
181 - end
182
183 % Button pushed function: DirectoryButton
184 function DirectoryButtonPushed(app, event)
185 -     app.selpath = uigetdir;

```

Figure 3.5 (a)

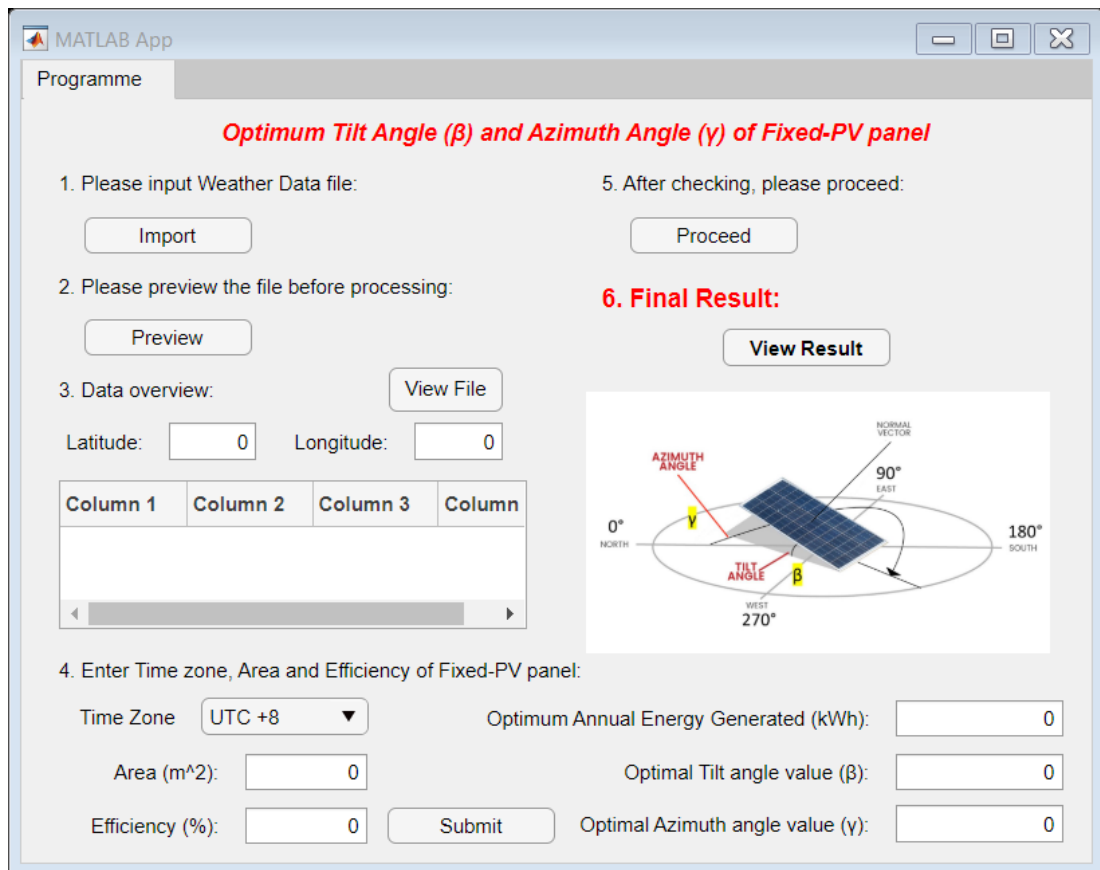


Figure 3.5 (b)

Figure 3.5: Application in (a) Code view and (b) GUI view

3.5.2 Module Description

This section explains how the module works and how it shows to the user in the Graphical user interface (GUI) application.

3.5.2.1 File input module

This class is to let users submit the Weather Data file after completing data automation in Microsoft Excel.

Code View

```
[app.file,app.path,app.indx] = uigetfile('*.xlsx');
app.filename = strcat(app.path,app.file);
```

By referring to the coding above, *uigetfile()* function will be used to allow the system to open a file selection dialog box. Additionally, **.xlsx* is the filter index selection that only allows the user selects a certain type of file. *app.file,app.path,app.indx* abstracts the file location that user selected. For instance, system will return a file name *C:\Users\User\iCloudDrive\FYP\tmy_1.492_103.741_(Johor Bahru)* when the user selects the Weather Data file. Besides, *strcat()* function is to concatenate strings horizontally. For instance, after applying *strcat()* function, 'Have a' and 'good day ahead!' will be concatenated into 'Have a good day ahead!', same goes with the file name. In fact, the file name that *app.file,app.path,app.indx* abstracted is separated into three parts. Therefore, it is necessary to use *strcat()* function to ensure that the file name is combined perfectly and can be used in other modules. In the end, the file name will be stored in *app.filename* for further operation.

```
bar = waitbar(0,'Please wait . . . ','CreateCancelBtn','setappdata(gcf,'canceling',1));
    pause(1);

    setappdata(bar,'canceling',0);
```

The codes are related to the visualization of the wait bar. It is worth mentioning that the wait bar is ubiquitous in GUI applications to indicate progress. Otherwise, the user will never know when the process will end. By applying the codes above, *0* and *'Please wait . . . '* implied that the wait bar would output the message of *'Please wait*

. . . .' once it starts. On the other hand, *CreateCancelBtn* callback and *setappdata()* function will be used to create a “**Cancel**” button to provide an option when the user intends to terminate the process halfway.

```

steps = 100;
    for step = 1:steps
        if getappdata(bar,'canceling')
            break
        end

        if step >= 33 && step <50
            waitbar(step/steps,bar,'Still importing . . . . .');
            pause(0.1);
        elseif step >= 50 && step <67
            waitbar(step/steps,bar,'Keep trying . . . . .');
            pause(0.1);
        elseif step >= 67 && step <100
            waitbar(step/steps,bar,'Almost done . . . . .');
            pause(0.1);
        elseif step == 100
            waitbar(step/steps,bar,'Done! Please proceed to next step!');
            pause(1.2);
        else
            waitbar(step/steps,bar,'Submitting the data . . .');
            pause(0.1);
        end
    end
    delete(bar);

```

According to the codes above, the wait bar is separated into 100 parts. *If* function will be used to allow the wait bar outputs the designed message in certain progress. For example, when the progress is between 33% and 49%, the wait bar dialog box will show “*Still importing*” whereas the “*Almost done*” message will be revealed when the progress is between 67% and 99%. Furthermore,

`getappdata()` and `For` function will be used when the user hits the “**Cancel**” button, and the process will immediately be broken and end the looping. The function of `delete()` is to let the system delete the wait bar once the process ends; otherwise, the wait bar dialog box will remain in the user interface.

GUI View

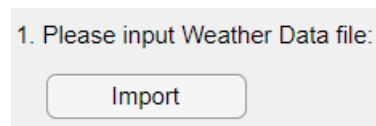


Figure 3.6: File input module

When the user clicks the “**Import**” button, a “Select file to Open” window will be popped out, and the user needs to select a Weather Data File with the file type of Microsoft Excel Worksheet (.xlsx) only.

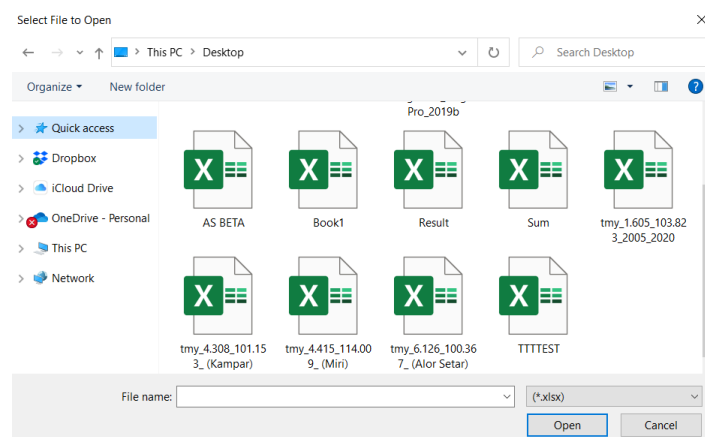


Figure 3.7: “Select file to Open” window

Once the user clicks “**Open**”, a message box will pop out to indicate the input progress. There are a total of 6 types of message boxes that will be expected to show, which are “*Please wait*” in the beginning, “*Submitting the data . . .*” when the progress is between 1% and 32%, from 33% to 50% for “*Still importing*”,

“*Keep trying*” indicates the progress is from 51% to 67%, from 68% to 99% for “*Almost done*” and “*Done! Please proceed to next step!*” once the process is completed.

Nevertheless, there is a “**Cancel**” button on the right bottom of the box in order to allow the user to stop the process halfway through inserting the file.

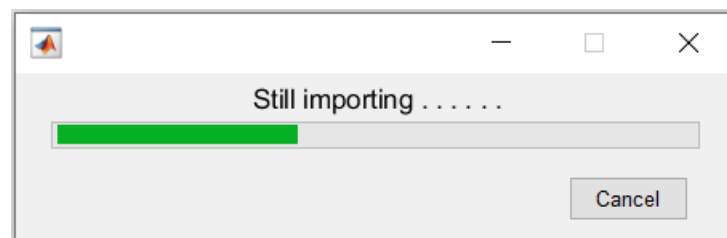


Figure 3.8: One of the message boxes to indicate the progress with “Cancel” button

3.5.2.2 Preview module

This class is to let the user checks the data details of the file chosen previously, which are Year, Month, Day, Hour, Minute, as well as the value of $I_{t,h}$, $I_{b,n}$ and $I_{d,h}$ to ensure that it was the correct file that user wants to compute the computational algorithm.

Code View

```
app.t = readtable(app.filename,"sheet",2,"Range","C6:K8758");
```

readtable() function is used to allow the system to abstract the Microsoft Excel data and show them in the table in the GUI application. For other information, *app.filename* is the stored variable from the File input module. Besides, “*sheet*”, 2,

"Range" and "C6:K8758" indicate that the data location is in the range of Cell C6 to K8758 in tab 2 of the file.

```
app.phi = readmatrix(app.filename,"sheet",2,"Range","B1:B1");
app.ll = readmatrix(app.filename,"sheet",2,"Range","B2:B2");
```

On the other hand, *readmatrix()* assigns a certain range of data to the variable. For instance, *app.phi* will return the data by abstracting the value of Cell B1 in tab 2 of the file.

```
app.LatitudeEditField.Value = app.phi;
app.LongitudeEditField.Value = app.ll;
```

The value of *app.LatitudeEditField.Value* will return the value obtained from *app.phi* and it can be used in other modules afterwards.

```
app.UITable.Data = app.t;
app.t.Properties.VariableNames{1} = 'Year';
app.t.Properties.VariableNames{2} = 'Month';
app.t.Properties.VariableNames{3} = 'Day';
app.t.Properties.VariableNames{4} = 'Hour';
app.t.Properties.VariableNames{5} = 'Minute';
app.t.Properties.VariableNames{6} = '-Space-';
app.t.Properties.VariableNames{7} = 'G(h)';
app.t.Properties.VariableNames{8} = 'Gb(n)';
app.t.Properties.VariableNames{9} = 'Gd(h)';
app.UITable.ColumnName = app.t.Properties.VariableNames;
```

After the system obtains the data, *app.UITable.Data* create a table and *app.t.Properties.VariableNames{}* indicates the name of the column heading. For

instance, `app.t.Properties.VariableNames{1} = 'Year'` will rename the first column heading to Year. After that, `app.UITable.ColumnName` will help to output all of the heading names to the user interface of the application.

GUI View

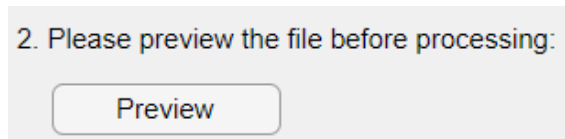


Figure 3.9: Preview module

When the user clicks the “**Preview**” button, the abstracted data in the Weather Data file will be shown in the table on the top right of the system interface in around 5 seconds. Not to mention that the coordinates of latitude and longitude of the location will also be automatically shown above the table. After checking that there is no mistake, the user may proceed to the following steps, which involve the Data input module.

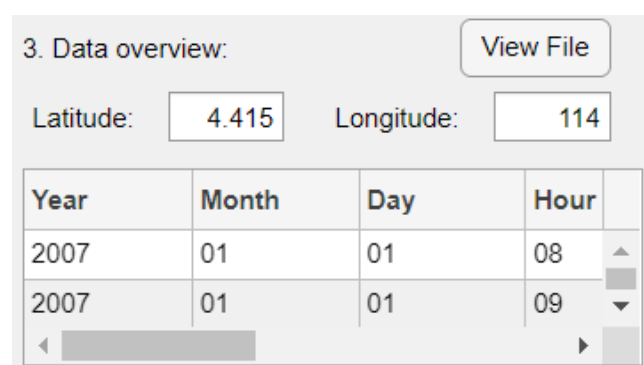


Figure 3.10: Data overview in tableau

3.5.2.3 Data input module

This class is to let the user choose an option from a time zone dropdown list and enter the value of the characteristics of their Solar PV panel, such as the area and efficiency. Not to mention that the annual energy generation result will be depended on these values since there are various PV panels in the vast market. It is believed that the system left the option to the user by requesting them to insert their PV panel values in order to obtain a more accurate result in the end.

Code View

```
app.area = app.Aream2EditField.Value;  
app. efficiency = app.EfficiencyEditField.Value;
```

app.area returns the value of *app.Aream2EditField.Value* which is the area of fixed PV-panel value entered by the user whereas *app. efficiency* returns the value of *app.EfficiencyEditField.Value* which is the value of efficiency.

```
switch app.TimeZoneDropDown.Value  
    case 'UTC'  
        app.timezone = 0;  
    case 'UTC +1'  
        app.timezone = 15;  
    case 'UTC +2'  
        app.timezone = 30;  
    case 'UTC +3'  
        app.timezone = 45;  
    case 'UTC +4'  
        app.timezone = 60;  
    case 'UTC +5'  
        app.timezone = 75;  
    case 'UTC +6'  
        app.timezone = 90;
```

```

case 'UTC +7'
    app.timezone = 105;
case 'UTC +8'
    app.timezone = 120;
case 'UTC +9'
    app.timezone = 135;
case 'UTC +10'
    app.timezone = 150;
case 'UTC +11'
    app.timezone = 165;
otherwise
    app.timezone = 180;
end

```

On the other hand, in order to let the system able to determine the time zone of the country, *switch*, *case*, *otherwise* function has been used to allow the system returns a certain value for the option which the user has chosen. For instance, the time zone of Malaysia is UTC +8, therefore, *app.TimeZoneDropDown.Value* returns *120* to the *app.timezone* for further calculation.

```

bar = waitbar(0,'Please wait . . . ','CreateCancelBtn','setappdata(gcf,"canceling",1)');

    pause(0.8);

    setappdata(bar,'canceling',0);

```

The code shown above is a typical wait bar function. Not to mention that the wait bar dialog box comes with a “**Cancel**” button.

```

steps = 10;
for step = 1:steps
    if getappdata(bar,'canceling')
        break
    end
end

```

```

end

if step == 10
    waitbar(1,bar,'Done! Please proceed to next step!');
    pause(1.2);
else
    waitbar(step/steps,bar,'Submitting the data . . .');
    pause(0.1);
end
end
delete(bar);

```

According to the codes above, the wait bar is separated into 10 parts. *If* function is used to allow the wait bar outputs the designed message in certain progress. Furthermore, *getappdata()* and *For* function are used when the user hits the “**Cancel**” button, the process will be immediately broken and end the looping. *Delete ()* function is to let the system delete the wait bar once the process ends; otherwise, the wait bar dialog box will remain in the user interface.

GUI View

Figure 3.11: Data input module

When the user clicks the “**Submit**” button, a message box will be popped out to indicate the progress. The same goes with the File input module; different message boxes are expected to show which are “*Please wait*” to kick start the process,

“*Submitting the data . . .*” during the process and “*Done! Please proceed to next step!*” once the process is completed. Besides, a “**Cancel**” button will also be attached to allow the users whether they want to terminate the process halfway of the process or not.

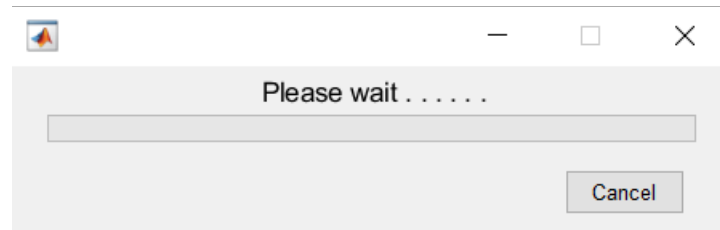


Figure 3.12: One of the message boxes to indicate the process with “Cancel” button

3.5.2.4 Annual energy generation module

This module is to let the user obtain the “Result.xlsx” file after the process completion.

Code View

```
WeatherData = readmatrix(app.filename,"sheet",2,"Range","C7:K8758");
```

Firstly, *readmatrix()* is used to assign a certain range of data to the variable, the concept is the same as the previous explanation.

```
filename = 'Result.xlsx';
```

Secondly, the system will assign the name of '*Result.xlsx*' for the filename variable to generate the result file with this name after calculating the range of tilt angle

starting from 0° to 45° and the values of surface azimuth angle from 0° to 359° for annual energy generation

```
phi = app.phi;
ll = app.ll;
```

phi returns the value of *app.phi* which is the coordinate of latitude whereas *ll* returns the value of *app.ll* which is the coordinate of longitude.

```
writematrix(Energy,filename,"Sheet",beta,"Range","C7:K8758");
writematrix(Summation,filename,"Sheet",beta,"Range","C1:MX1");
writematrix(Maximum,filename,"Sheet",beta,"Range","A1");
```

Lastly, *writematrix()* function will be used to allow the system to generate and store the data after performing a series of calculations to the Microsoft Excel file.

GUI View

5. After checking, please proceed:

Proceed

Figure 3.13: Annual energy generation module

When the user clicks the “**Proceed**” button, a series of calculations that had been programmed beforehand will be performed immediately. It is worth mentioning that the computational algorithm will calculate the range of tilt angle starting from 0° to 45° and the values of Surface Azimuth angle from 0° to 359° for annual energy generation to obtain the final optimum result in the next module. Nevertheless, there is no “**Cancel**” button in this module due to this module needs to process the

overwhelming algorithm. For other information, a cycle of the algorithm may cost at least 4 hours, therefore, it is believed that the elimination of the “**Cancel**” button can somehow prevent the user clicks the button accidentally. Otherwise, the user needs to compute another calculation cycle again, which is extremely time-consuming.

After the computational algorithm functioning ends, a file named “Result.xlsx” will be generated, and the user can refer to and read the calculated data in the file.

3.5.2.5 Result module

This module is to let the user obtain the final value of the optimum annual generation, optimal tilt angle and surface azimuth angle. On the other hand, the user will get the “Sum.xlsx” file after completing the process.

Code View

```
filename = 'Sum.xlsx';
```

Firstly, the program will assign the name '*Sum.xlsx*' for the filename variable to generate the final result file with this name. This file is different from the '*Result.xlsx*' since the algorithm will compare the results in the “Result.xlsx” file tab by tab to get the final result. In other words, the algorithm will keep updating the data until the last tab, which is the 46th tab, finish processing.

```
bar = waitbar(1,'In progress, please wait a moment . . .');
```

waitbar() function that will output '*In progress, please wait a moment . . .*' during the process is used.

```

for beta = 1:1:46
    waitbar(beta/46,bar,'In progress, please wait a moment . . .');
    pause(0.01);

S =
readmatrix("C:\Users\User\Desktop\Result.xlsx","sheet",beta,"Range","C1:MX1");

S1 = [S1;S];

Maximum = max(S1,[],'all');

[~,rows] = max(S1);
[~,col] = max(max(S1));
P = [rows(col),col];
    end
    delete(bar);

```

According to the codes above, *For* function is used for looping, *waitbar()* function will be used for the dialog box and output message. On the other hand, *readmatrix()* will also allow the system to read the data from a Microsoft Excel file. Besides, as usual, *delete()* function will also be used to prevent any wait bar dialog box from being retained in the user interface.

Furthermore, it is worth mentioning that $S1 = [S1;S]$ is one of the essential codes since it can let the system compute the data comparison tab by tab. Nevertheless, the *max()* function allows the system to determine the optimal tilt angles and optimum annual energy generation. In order to find the indices of tilt angle (β), $[\sim,rows] = \max(S1)$ will be applied whereas $[\sim,col] = \max(\max(S1))$ is the code to find the indices of surface azimuth angle (γ). In the end, $P = [rows(col),col]$ is used to determine the optimal tilt angles value in the form of (β,γ) .

```

BETA = P(1,1);
GAMMA = P(1,2);

```

By applying these two lines codes above, the value of tilt angle and surface azimuth angle will be separated into two since they are originally combined as a vector. Therefore, $P(1,1)$ and $P(1,2)$ abstract the tilt angle and Surface Azimuth angle respectively.

```
writematrix(S1,filename,"Sheet","SUMMATION","Range","C:MX");
writematrix(Maximum,filename,"Sheet","SUMMATION","Range","A1");
writematrix(P,filename,"Sheet","SUMMATION","Range","A2");
```

writematrix() function is used to allow the system to generate and store the data after performing a computational algorithm to the Microsoft Excel file.

```
app.OptimumAnnualEnergyGeneratedkWhEditField.Value =
Maximum*(2.778*10^-7);
app.OptimalTiltanglevalueEditField.Value = BETA;
app.OptimalAzimuthanglevalueEditField.Value = GAMMA;
```

At the end, the results will be shown on the right bottom of the system interface by returning the variable values.

GUI View

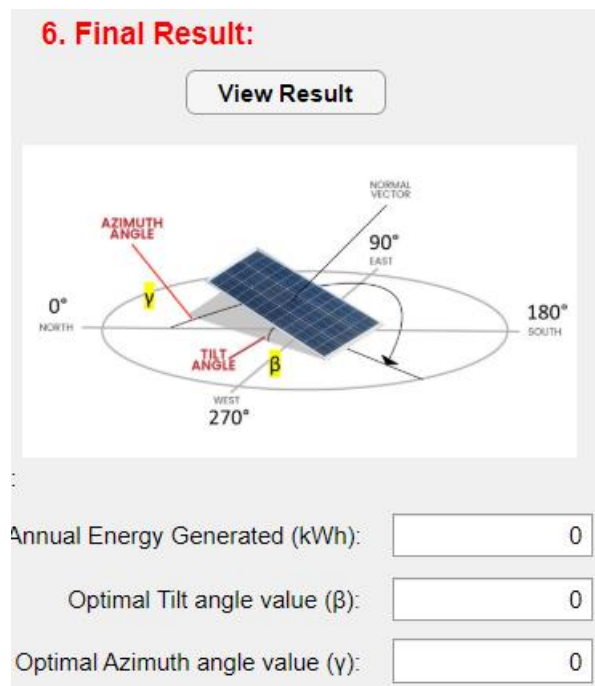


Figure 3.14: Result module

When the user clicks the “**View Result**” button, it will stimulate another computational algorithm to obtain the most suitable position of the Fixed-PV panel in a particular location and show the most effective annual energy generation.

It is worth mentioning that the algorithm will compare the results in the “Result.xlsx” file tab by tab to get the final result. In other words, the algorithm will keep updating the data until the last tab which is the 46th tab finish processing. In the end, the results will be shown on the right bottom of the system interface which is shown above.

On the other hand, a wait bar window will have also appeared during the process. Same with the Annual energy generation module, there is no “**Cancel**” button attached for the same reason.

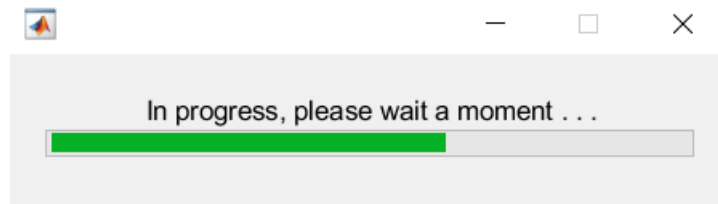


Figure 3.15: Message box to indicate the process

3.5.2.6 View File module

This module is simple, it locates above the Preview module and gives the user a quick glance to ensure that files are generated by the system smoothly and successful.

Code View

```
app.selpath = uigetdir;
```

uigetdir() function will be used to allow the system to open a folder selection dialog box to the user.

GUI View

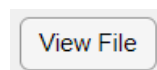


Figure 3.16: View File module

When the user clicks this “**View File**” button, a “Select Folder to Open” window will be popped out, the user can simply browse and take a look to ensure that

the files required whether have been generated or not. If not, it is suggested to close the user interface and rerun it.

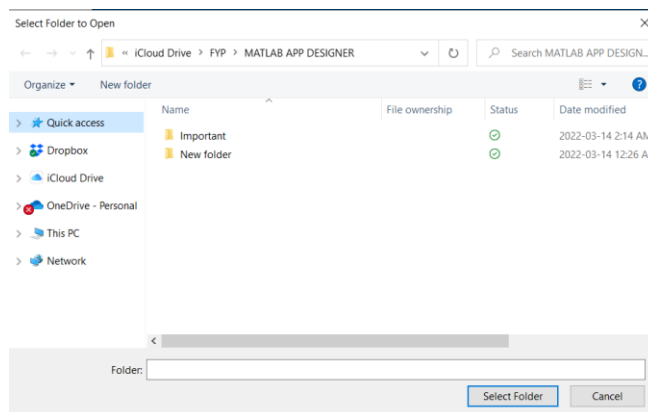


Figure 3.17: “Select Folder to Open” window

3.6 User Manual

This section describes how to use the tools to assist the user in getting the final result. In other words, it is also a user guide to possibly eliminate some confusion and avoid mistakes when the user is using the tools provided. For other information, the user will receive two programmed tools from the author. Here are the procedures:

1. Go to https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html to download the Weather Data file from JRC Photovoltaic Geographical Information System (PVGIS) – European Commission website.
2. On the website, the user will see a world map on the left screen and a table that can let the user input the information on the right screen. Go to the bottom of the world map, enter the address or Lat/Lon of location, and click “Go!” button.
3. Point the cursor to the middle part of the screen, and select the TMY ribbon. For other information, TMY is defined as Typical Meteorological Year.
4. In the TMY ribbon, select the period. It is recommended to choose the latest timeframe, which is usually the last option.

5. After selecting, click the “**csv**” download button, which is located at the bottom. For other information, the file will be in the file type of Microsoft Excel Comma Separated Values File (.csv) in File Explorer.
6. Open the downloaded Weather Data file, go to **File** tools, and select “**Save as**” to create another same file but a different type with Microsoft Excel Worksheet (.xlsx). Please note that the user must choose “Excel Workbook” in the **Save as type** box.
7. After that, please proceed with the Microsoft Excel Macro in the same file.
8. Before using Macro to initiate the data automation, rename the Tab Name to “**Sheet1**”.
9. Go to the **Developer** tab, click **Macros** in the **Code** group and select the Macro that wants to initiate in the file.
10. The process will be expected to complete in a few seconds. For other information, the data required will appear in Tab 2, which is named “**Sheet2**” after initiating.
11. Click “**Save**” to keep the data. After that, please proceed to another application titled “Optimum Tilt Angle (β) and Azimuth Angle (γ) of Fixed-PV panel”.
12. In the GUI application, click “**Import**” button, a “Select file to Open” window will be popped out. Select a Weather Data file with the file type of Microsoft Excel Worksheet (.xlsx) only.
13. Click “**Preview**” button, the abstracted data in the Weather Data file will be shown in the table on the top right of the system interface in around 5 seconds.
14. Input the value of Area and Efficiency to the two boxes provided. After that, click “**Submit**” button, a message box will be popped out to indicate the progress.
15. Click “**Proceed**” button, a series of calculations that had been programmed beforehand will be performed immediately. After the computational algorithm functioning ends, a file named “**Result.xlsx**” will be generated and the user can refer to and read the calculated data in File Explorer.
16. Click “**View Result**” button, the final result of the value of the optimum annual generation, optimal tilt angle and surface azimuth angle will be shown in the boxes at the end. Besides, a file named “**Sum.xlsx**” will be generated after completing the process.

17. All of the procedures have been completed. For other information, click “**View File**” button if the user needs to check and view the files halfway through the process.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results

A total of 11 locations were selected to perform the computational algorithm using the Graphical user interface (GUI) application. Therefore, the final results of their optimal tilt angles (β and γ) and optimum annual energy generation were obtained and shown in Table 4.1. The value of the azimuth angle is 0° or 360° in the North, 90° in the East, 180° in the South, and 270° in the West.

Table 4.1: Results generated by using GUI application (Case 1)

No.	Location	Coordinate	Optimal Tilt Angle (β)	Optimal Azimuth Angle (γ)	Optimum Annual Energy Generation
1	Miri	4.415 °N, 114.009 °E	32°	259°	702 kWh
2	Alor Setar	6.126 °N, 100.367°E	14°	245°	684 kWh
3	Kuantan	3.763 °N, 103.220 °E	24°	266°	647 kWh

4	Kuala Terengganu	5.329 °N, 103.137 °E	25°	261°	669 kWh
5	Kuala Lumpur	3.139 °N, 101.687 °E	8°	256°	569 kWh
6	Johor Bahru	1.492 °N, 103.741 °E	12°	266°	552 kWh
7	Kota Kinabalu	5.980 °N, 116.073 °E	23°	261°	662 kWh
8	Kuching	1.553 °N, 110.345 °E	31°	273°	612 kWh
9	Kota Bahru	6.125 °N, 102.254 °E	21°	254°	683 kWh
10	Kampar	4.308 °N, 101.153 °E	8°	230°	594 kWh
11	Kangar	6.437 °N, 100.193 °E	18°	259°	680 kWh

On the other hand, the Malaysia map shown in Figure 4.1 is the selected locations which performed by the computational algorithm using the GUI application. In general, 8 locations are located in the Peninsular Malaysia, whereas 3 locations are located in the East Malaysia.



Figure 4.1: A total of 11 pinned locations on the Malaysia map

Besides, the polar contour diagrams shown in Figure 4.2 for the 11 locations were also generated to provide an easier and better understanding to the user. For instance, by observing Figure 4.2 (a), the polar contour diagram of Miri, it is believed that the optimum energy generation, which is 702 kWh, can be obtained when the tilt angle and azimuth angle are 32° and 259° respectively. In other words, it is preferable to let the fixed-PV panel face to 259° S bearing to gain the maximum annual energy generation for the generation of electricity.

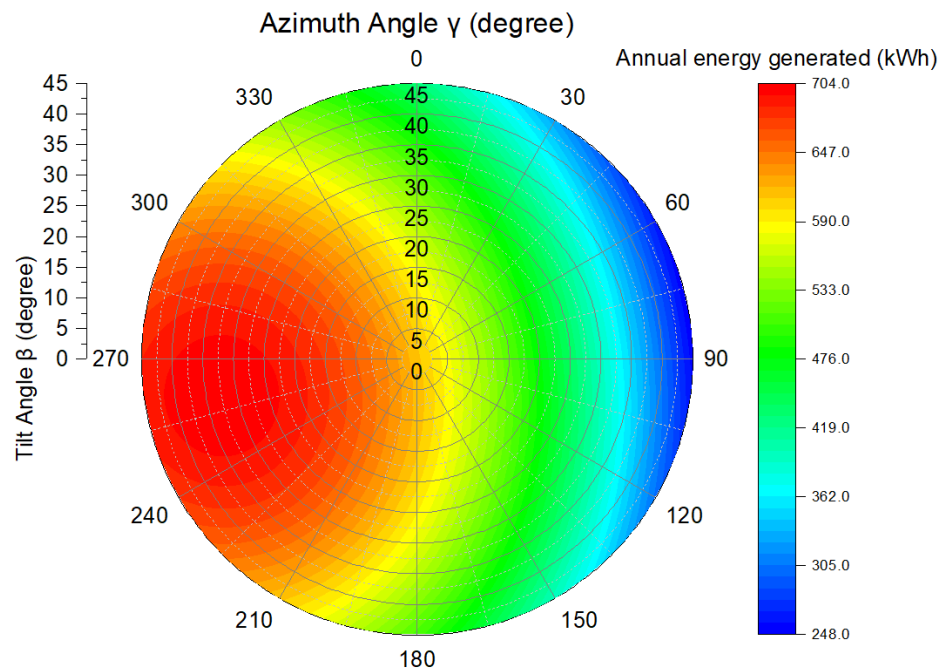


Figure 4.2 (a)

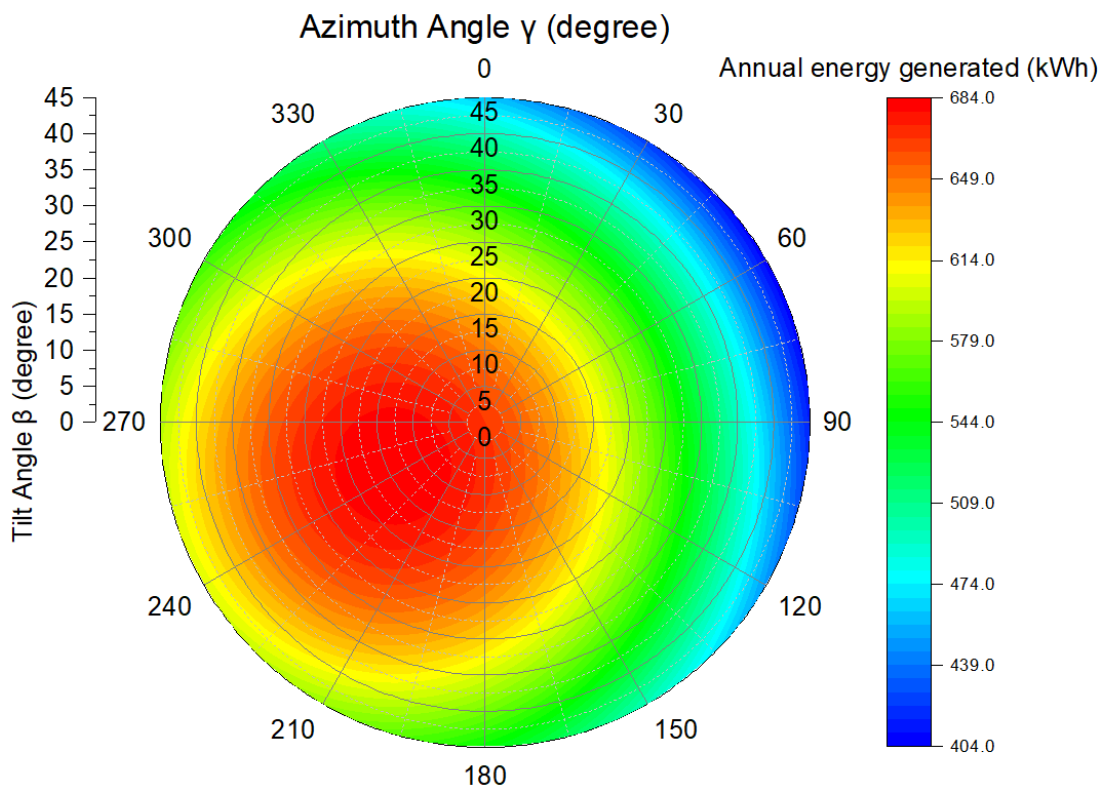


Figure 4.2 (b)

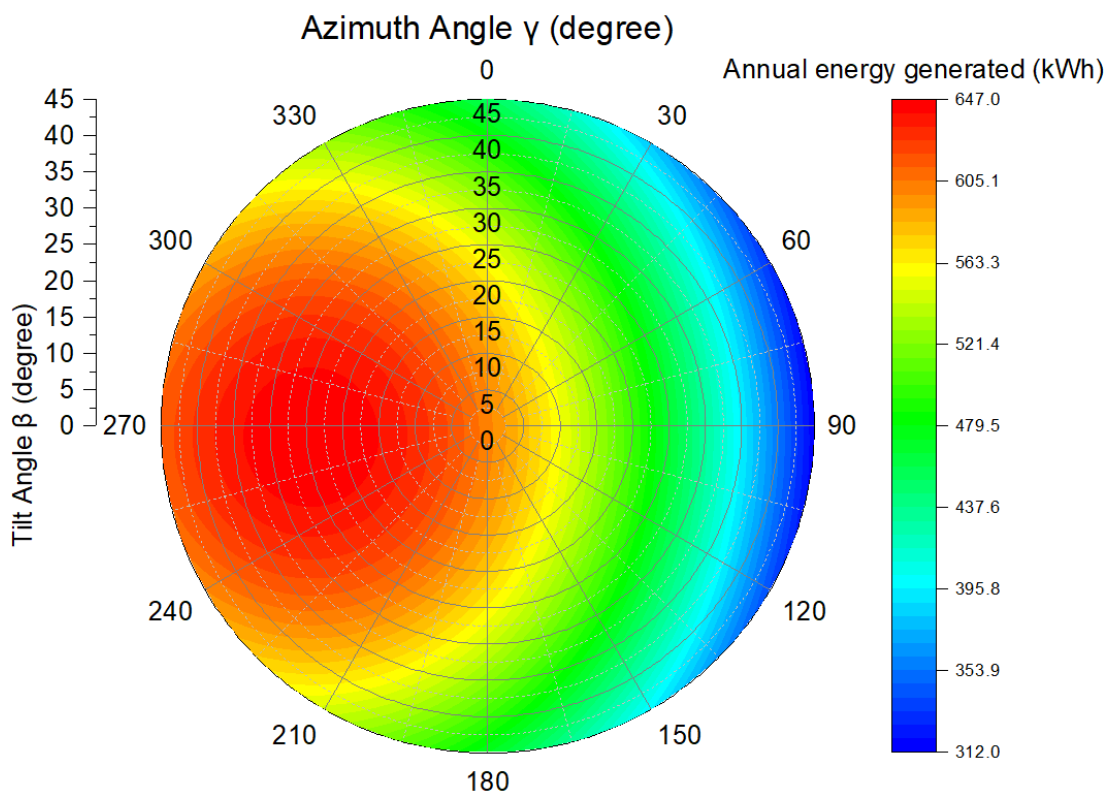


Figure 4.2 (c)

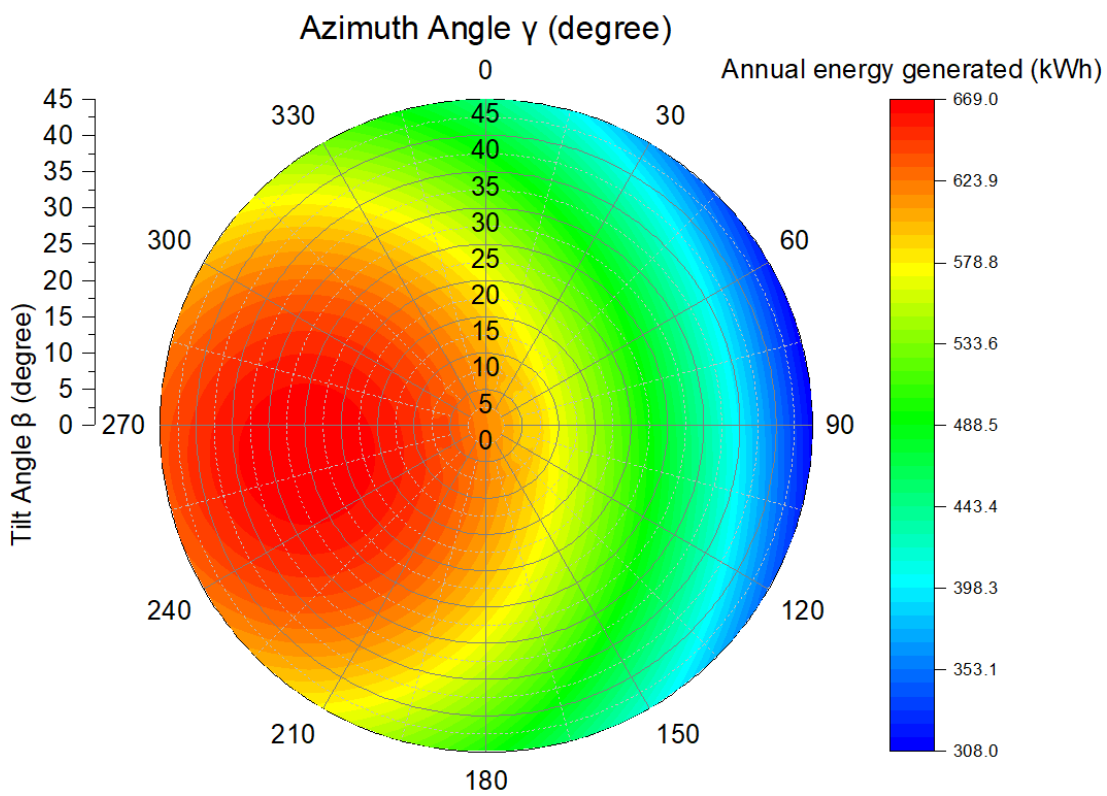


Figure 4.2 (d)

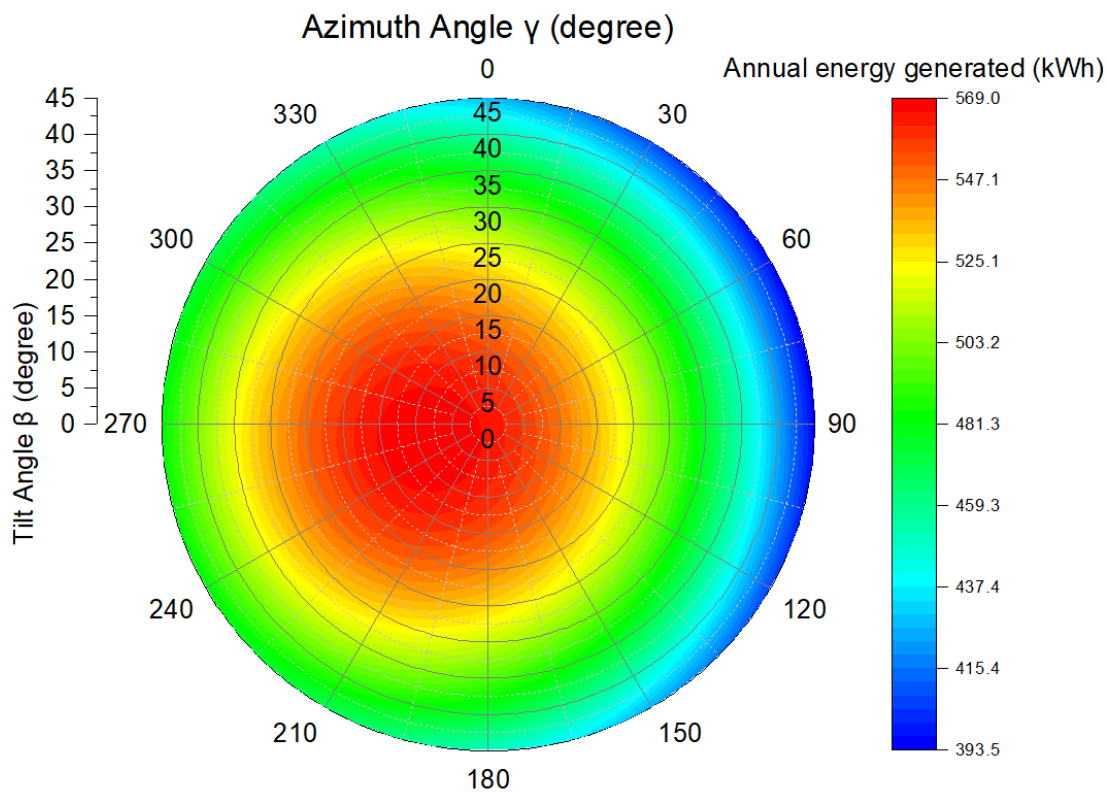


Figure 4.2 (e)

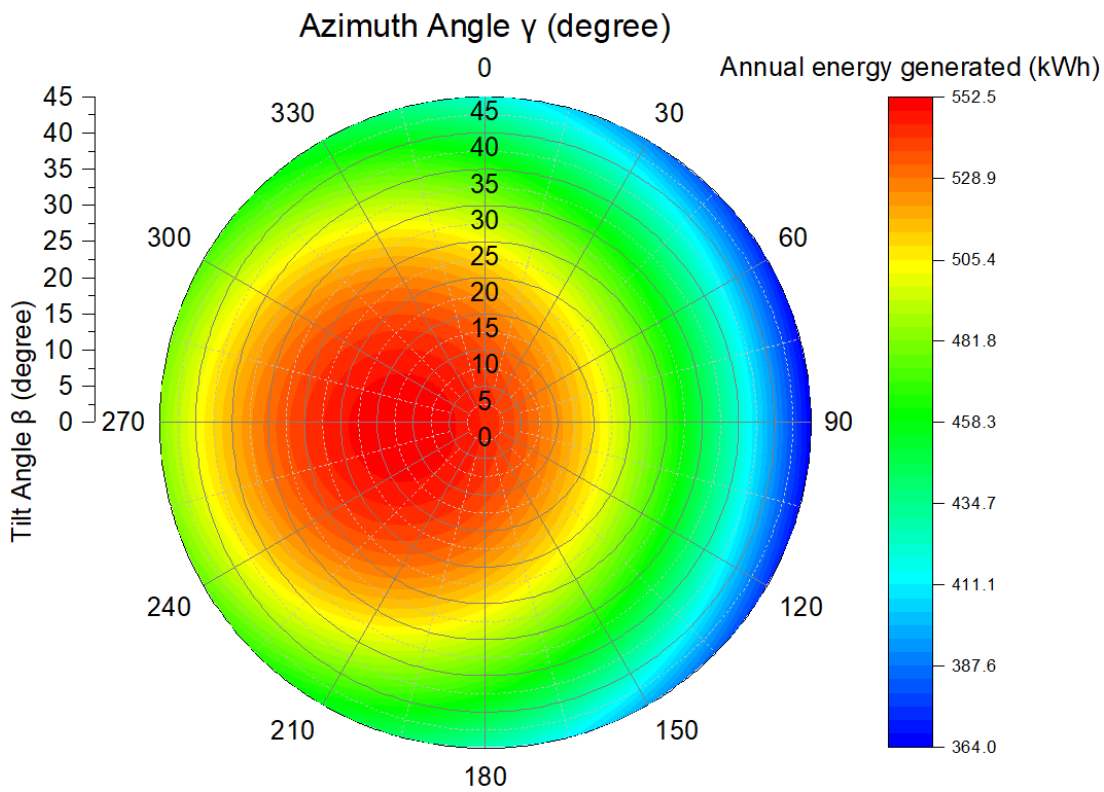


Figure 4.2 (f)

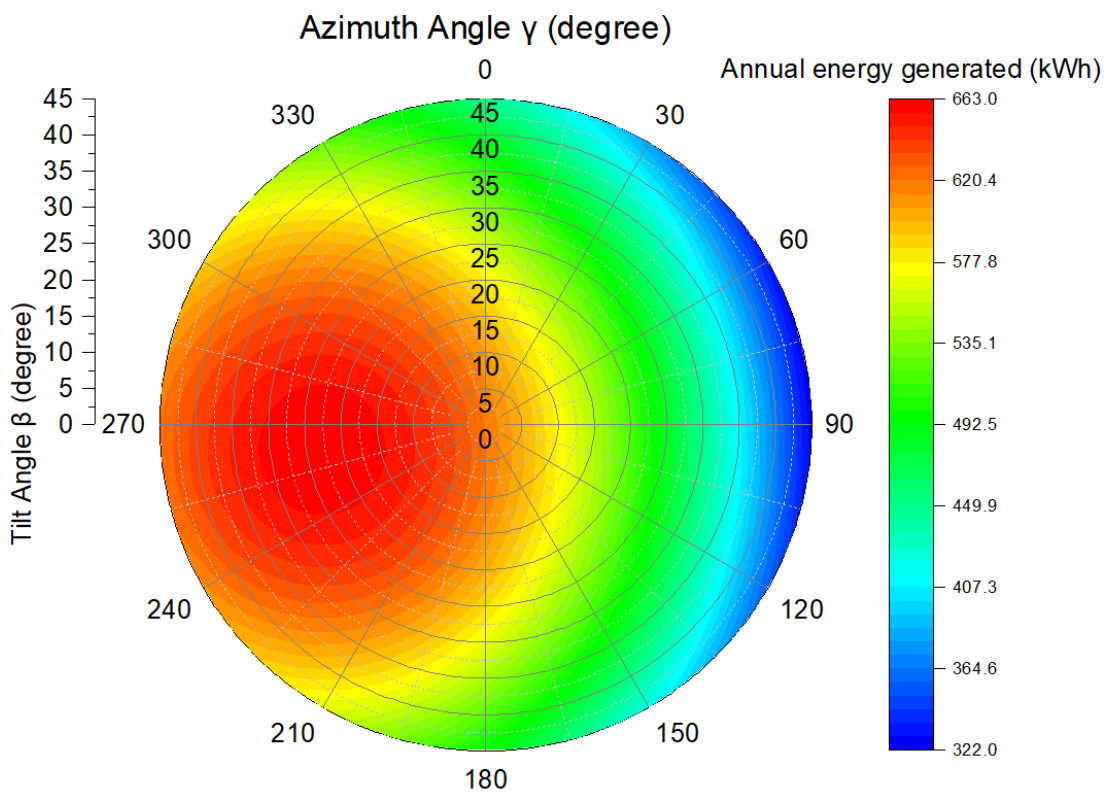


Figure 4.2 (g)

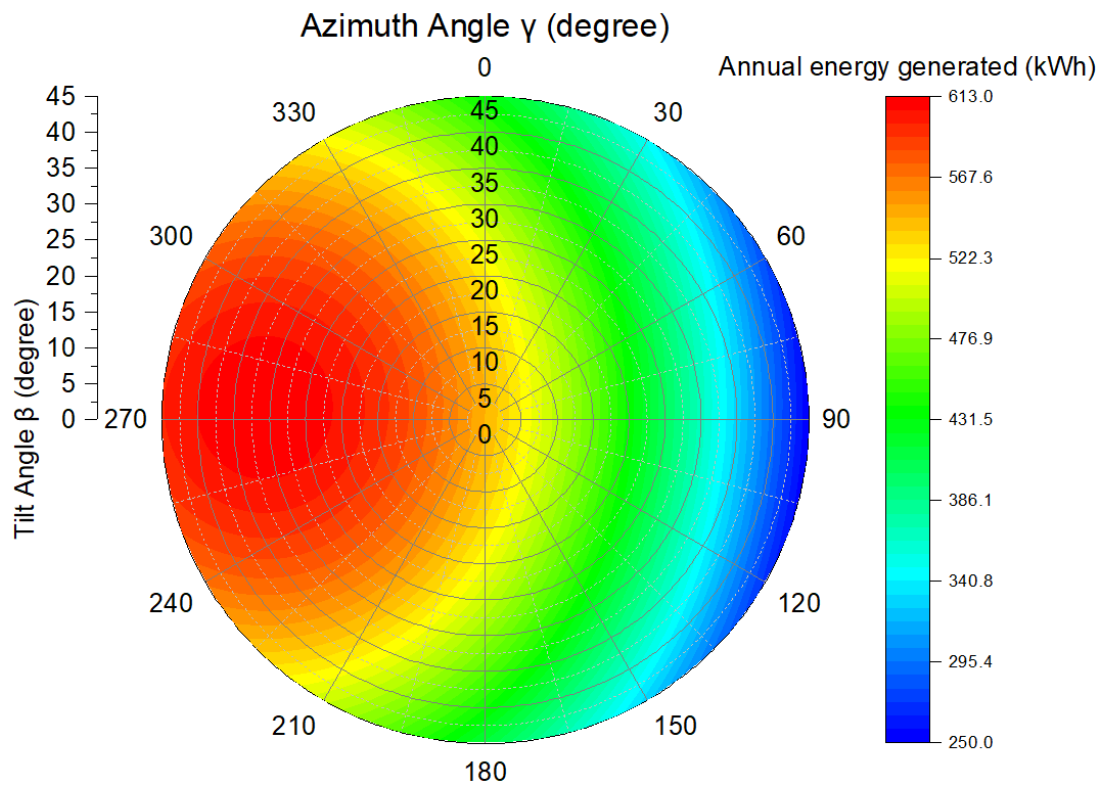


Figure 4.2 (h)

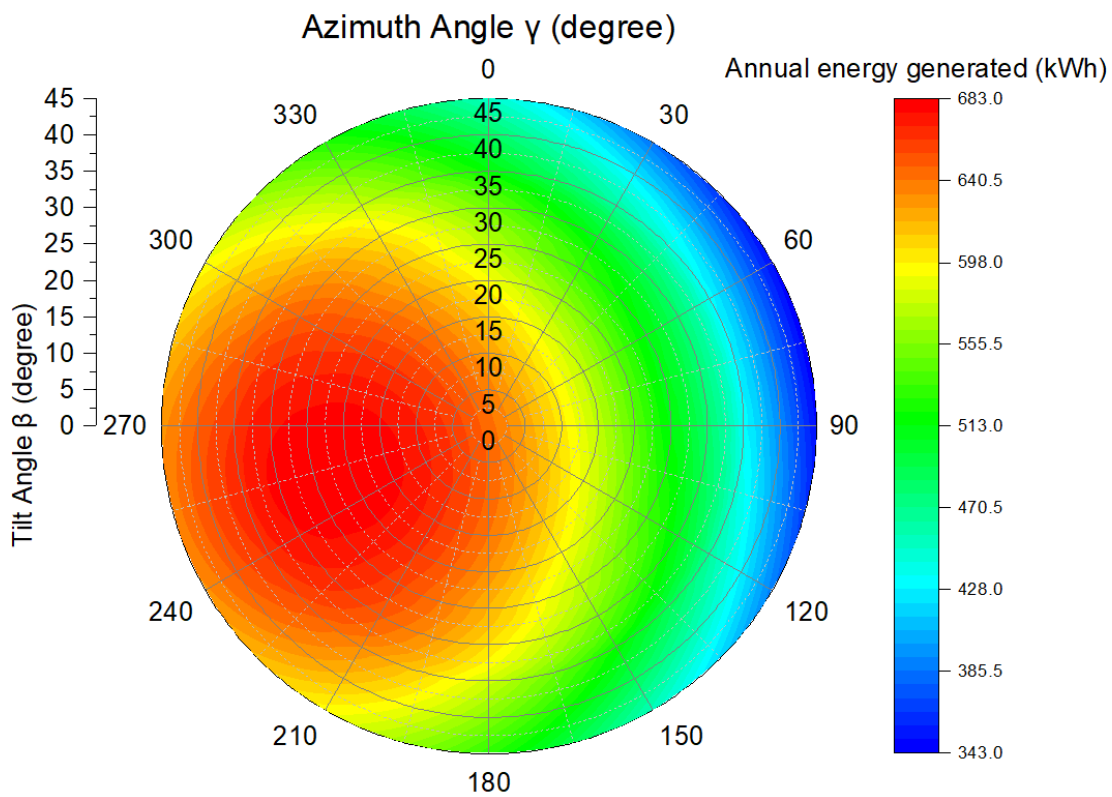


Figure 4.2 (i)

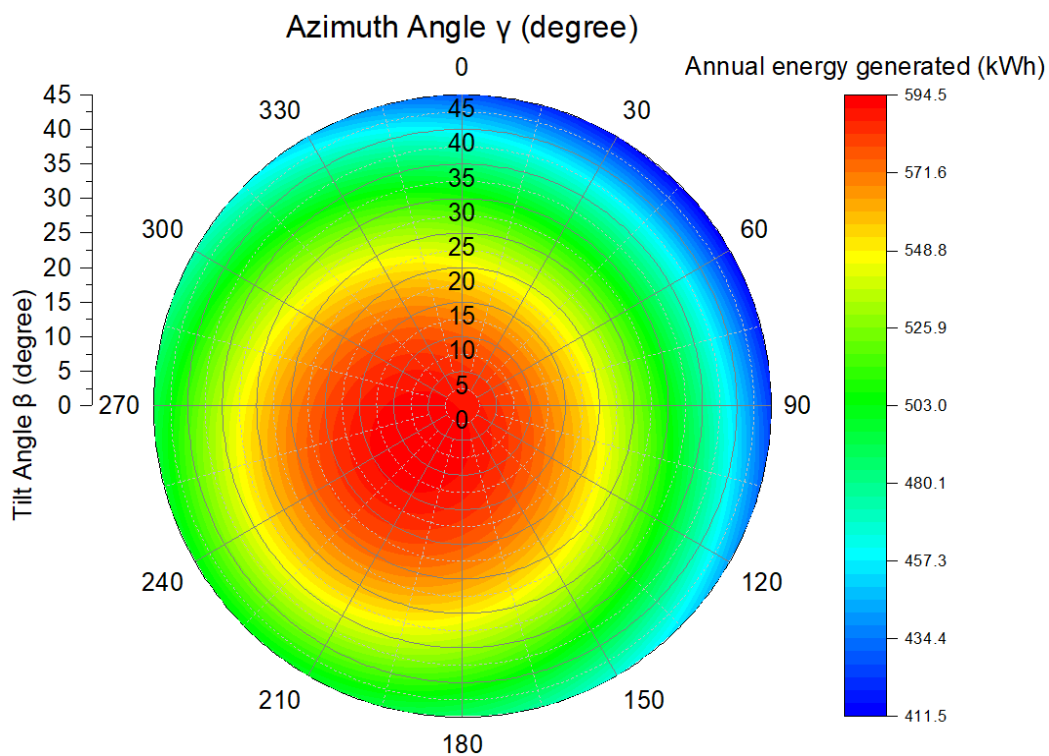


Figure 4.2 (j)

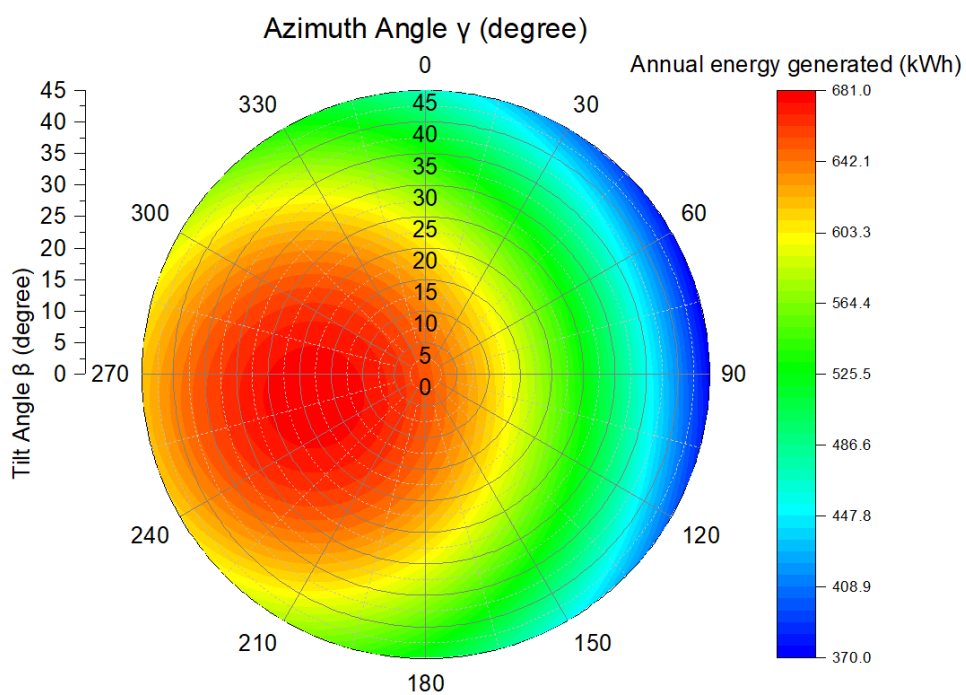


Figure 4.2 (k)

Figure 4.2: Polar Contour diagram of (a) Miri, (b) Alor Setar, (c) Kuantan, (d) Kuala Terengganu, (e) Kuala Lumpur, (f) Johor Bahru, (g) Kota Kinabalu, (h) Kuching, (i) Kota Bahru, (j) Kampar, and (k) Kangar

4.2 Analysis

4.2.1 Result by considering tilt angle and azimuth angle

By reviewing the value of optimal azimuth angle of different locations in Table 4.2, it can be discovered that the fixed-PV panel tends to face to the West. For instance, in Miri, Alor Setar, Kuantan, Kuala Terengganu, Kuala Lumpur, Johor Bahru, Kota Kinabalu, Kuching, Kota Bahru, Kampar, and Kangar, the bearings are all in the direction of 259° S, 245° S, 266° S, 261° S, 256° S, 266° S, 261° S, 273° S, 254° S, 230° S, and 259° S respectively. Furthermore, by studying the monthly solar isolation of these locations in Figure 4.3, it can be explored that all of the locations indeed have a more significant solar isolation value in the afternoon session compared to the morning session every month. For instance, in Figure 4.4 (a), the fixed-PV panel in Miri will receive 72 kWh/m² of solar isolation in the morning and 186 kWh/m² of solar isolation in the afternoon in January. In other words, the reason to cause the smaller solar isolation in the morning session may be the cloudy weather, rain, and so on since these uncertain factors can result in lower solar isolation received by the fixed-PV panel. Same goes with other locations; by referring to Figure 4.4, it can be seen that Miri, Alor Setar, Kuantan, Kuala Terengganu, Kuala Lumpur, Johor Bahru, Kota Kinabalu, Kuching, Kota Bahru, Kampar, and Kangar have an immense solar isolation value in the afternoon session compared to the morning session every month.

In order to have an easier way to observe the changes, it is recommended to refer back to Figure 4.3 since this chart disclosed the information for the solar isolation in both morning and afternoon sessions in a one-year timeframe. For Miri and Kuching, which are located in East Malaysia, it is evident that their solar isolation in the afternoon is 2.26 times and 2.55 times larger than the sunray isolation in morning throughout the entire year respectively. On the other hand, for other locations such as Alor Setar, Kuantan, Kuala Terengganu, Kota Kinabalu, Kota Bahru, and Kangar, the solar isolation value ratio between the afternoon and morning sessions is around 1.7.

Moreover, according to the chart, Kuala Lumpur, Johor Bahru, and Kampar have the lesser ratio with 1.47, 1.33, and 1.56 respectively.

Nevertheless, by referring back to Table 4.1, it can be seen that both Miri and Kuching have the more significant optimal tilt angle, which is 32° and 31° , respectively. Moreover, for Kuala Lumpur, Johor Bahru, and Kampar, their optimal tilt angle is 8° , 12° , and 8° respectively, which are considered small compared to others. For the rest of the locations, their optimal tilt angle range is from 14° to 25° . Hence, it is reasonable to conclude that larger ratio of the solar isolation between morning and afternoon sessions will result in a bigger optimal tilt angle and vice-versa.

Besides, by referring back to Figure 4.3, it is obvious to discover that majority of solar isolation has been received by the fixed-PV panel in the afternoon throughout the entire year when the direction of the sun is in the West. Therefore, the results obtained can be considered valid.

Table 4.2: Bearing in a different location

No.	Location	Optimal Azimuth Angle (γ)	Bearing
1	Miri	259°	259° S
2	Alor Setar	245°	245° S
3	Kuantan	266°	266° S
4	Kuala Terengganu	261°	261° S
5	Kuala Lumpur	256°	256° S
6	Johor Bahru	266°	266° S
7	Kota Kinabalu	261°	261° S
8	Kuching	273°	273° S
9	Kota Bahru	254°	254° S
10	Kampar	230°	230° S
11	Kangar	259°	259° S

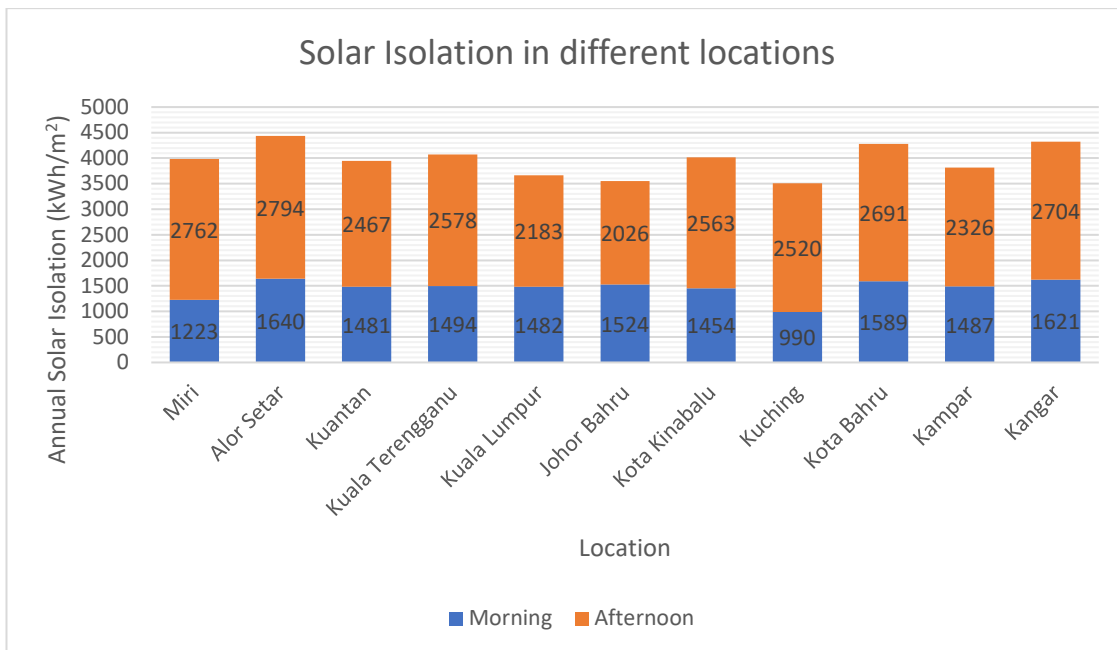


Figure 4.3: Annual Solar Isolation in different locations

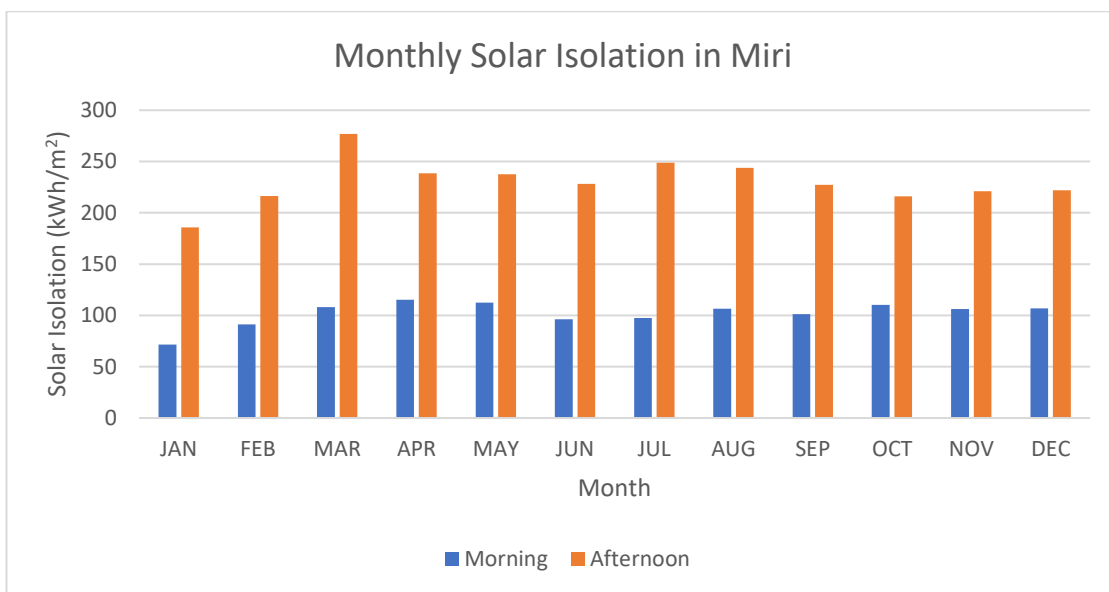


Figure 4.4 (a)

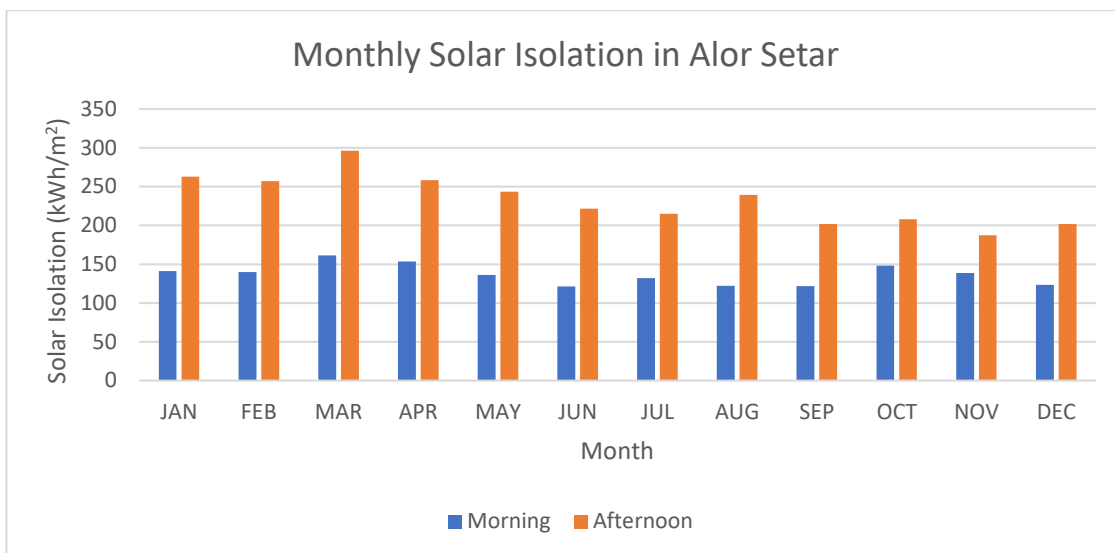


Figure 4.4 (b)

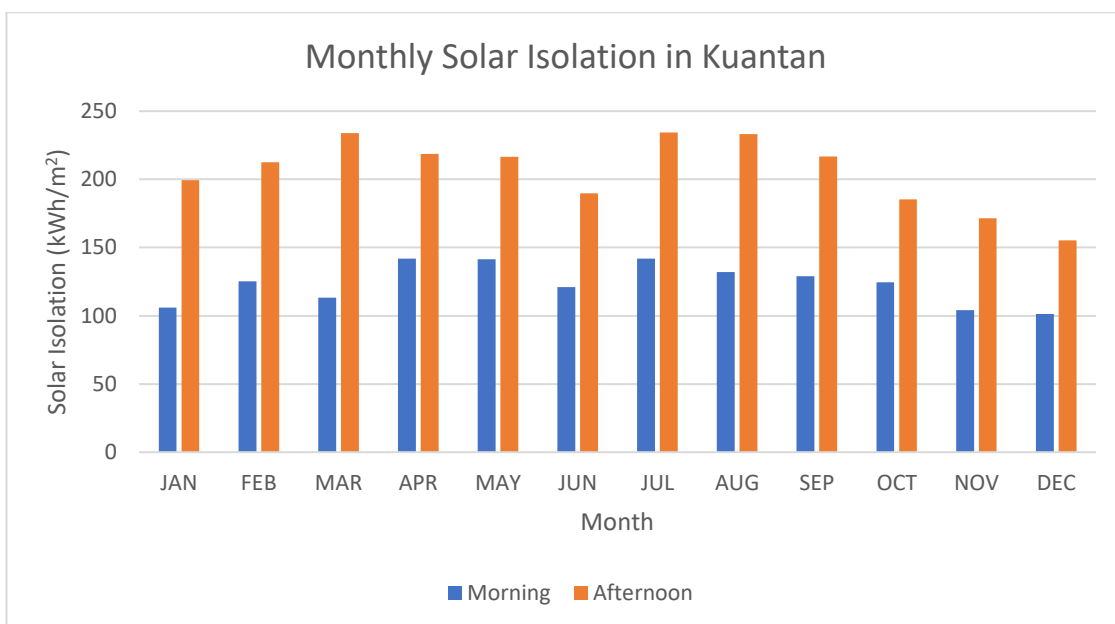


Figure 4.4 (c)

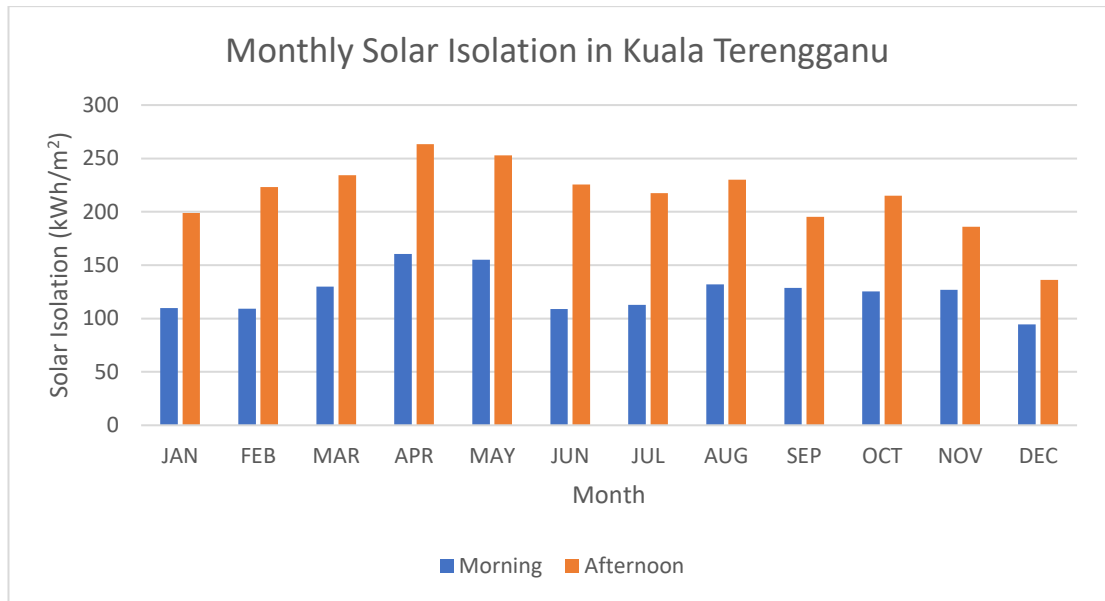


Figure 4.4 (d)

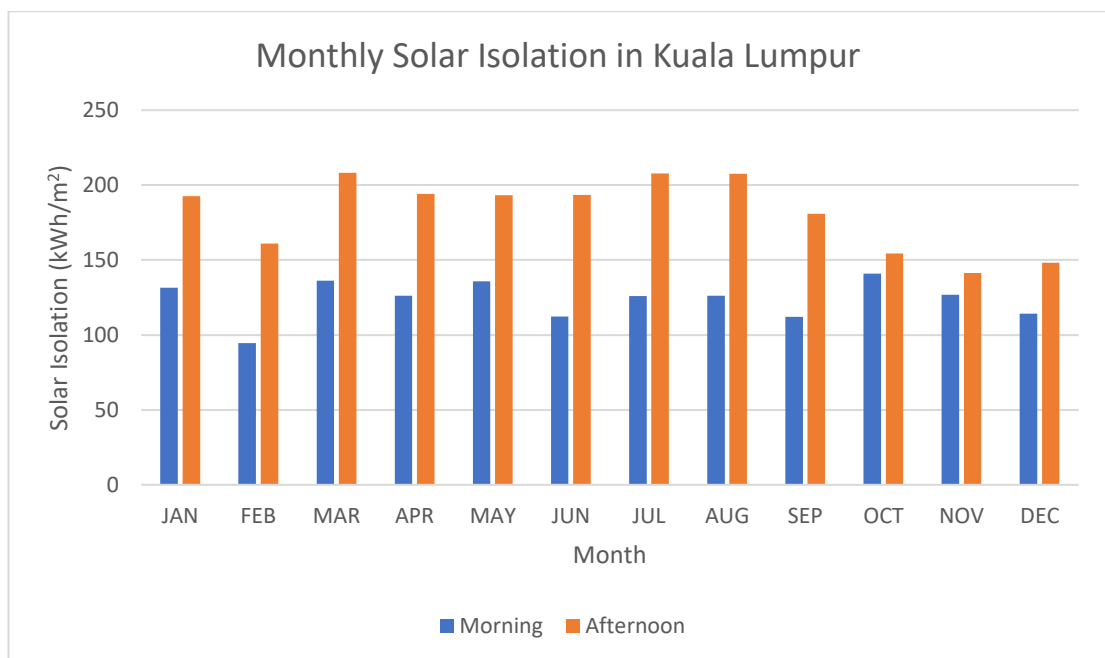


Figure 4.4 (e)

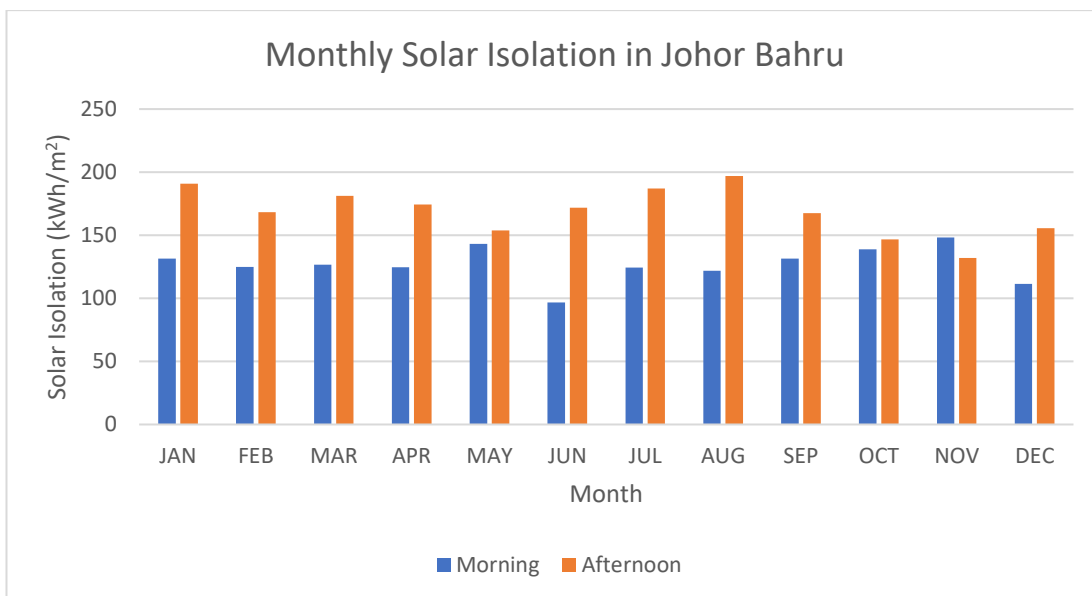


Figure 4.4 (f)

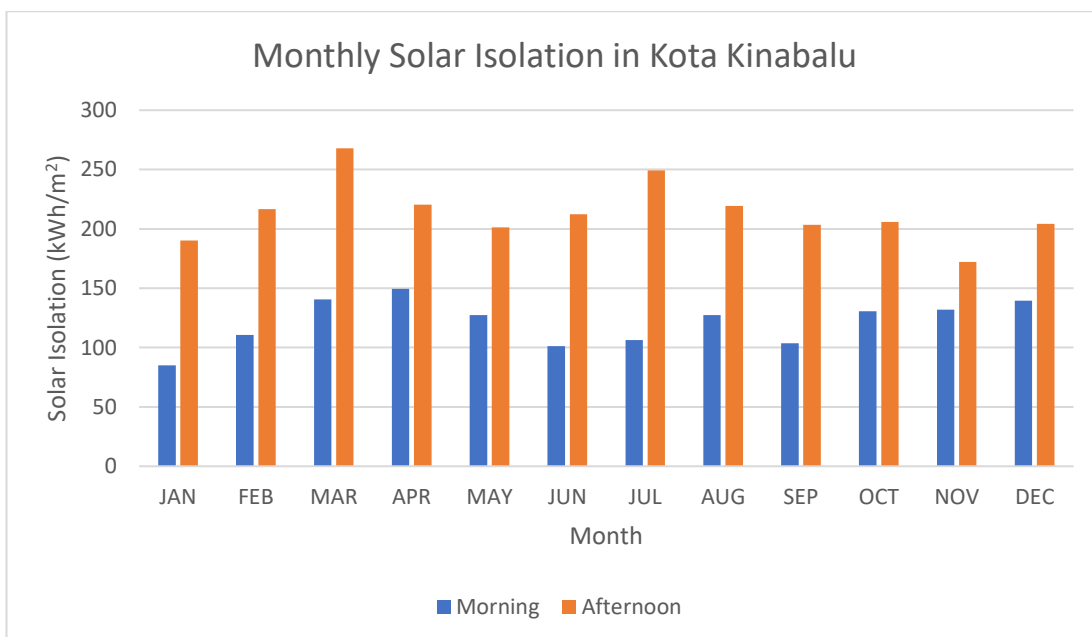


Figure 4.4 (g)

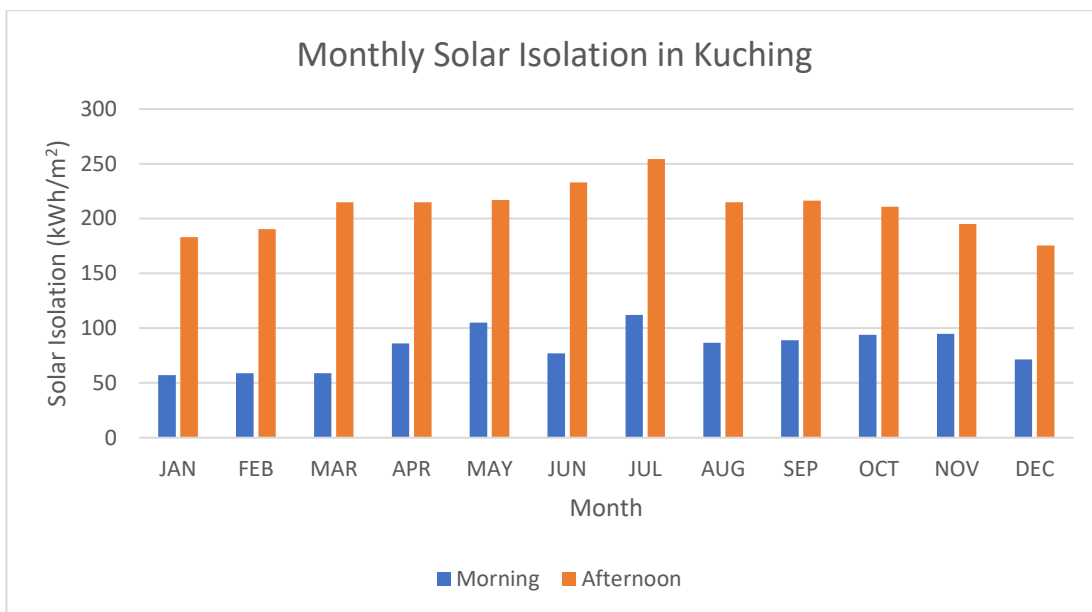


Figure 4.4 (h)

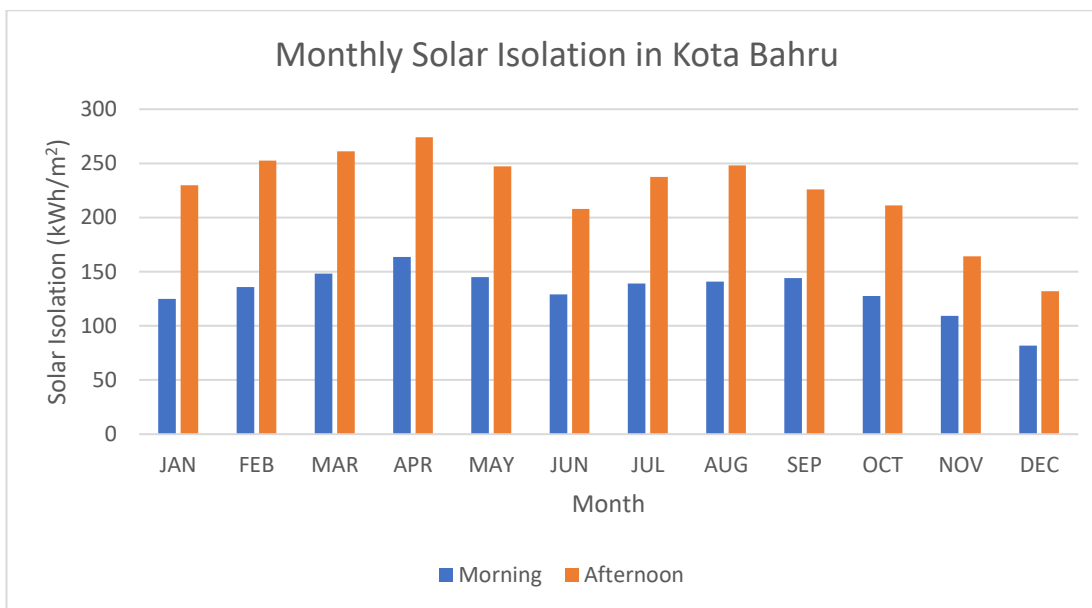


Figure 4.4 (i)

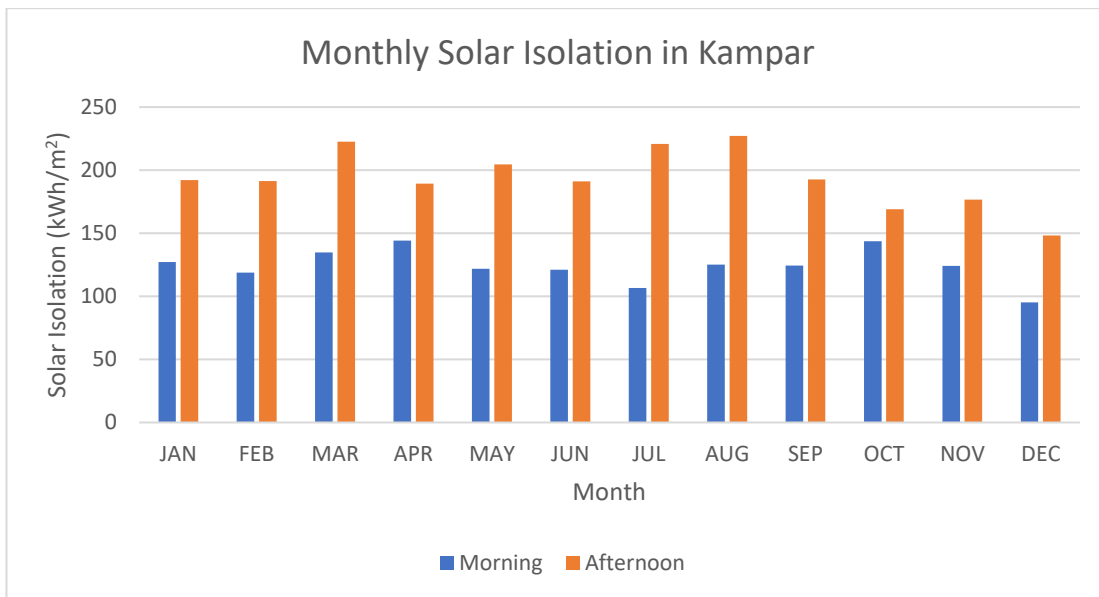


Figure 4.4 (j)

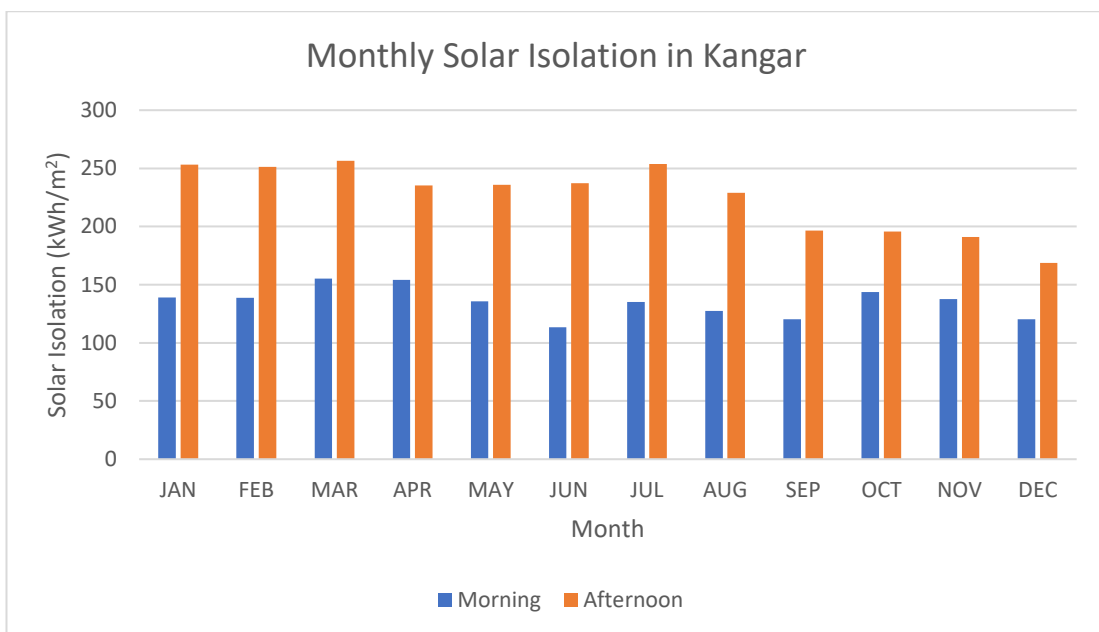


Figure 4.4 (k)

Figure 4.4: Monthly Solar Isolation in (a) Miri, (b) Alor Setar, (c) Kuantan, (d) Kuala Terengganu, (e) Kuala Lumpur, (f) Johor Bahru, (g) Kota Kinabalu, (h) Kuching, (i) Kota Bahru, (j) Kampar, and (k) Kangar

4.2.2 Comparison under three situations

On the other hand, the comparisons among Case 1: annual energy generation based on optimal tilt angles, Case 2: annual energy generation based on optimal tilt angle and azimuth angle faces South, and Case 3: annual energy generation based on tilt angle according to location's latitude coordinate and azimuth angle faces South have been performed, and the gain percentage of annual energy generation will also be evaluated in the end. Hence, the result for these 3 cases will be shown in Table 4.1, Table 4.3, and Table 4.4 respectively. Moreover, the overview of these 3 cases will be compiled and shown in Table 4.5.

Table 4.3: Results generated by using GUI application (Case 2)

Location	Optimal Tilt Angle (β)	Optimal Azimuth Angle (γ)	Optimum Annual Energy Generation
Miri	32°	180°	568 kWh
Alor Setar	14°	180°	665 kWh
Kuantan	24°	180°	566 kWh
Kuala Terengganu	25°	180°	586 kWh
Kuala Lumpur	8°	180°	562 kWh
Johor Bahru	12°	180°	536 kWh
Kota Kinabalu	23°	180°	592 kWh
Kuching	31°	180°	479 kWh
Kota Bahru	21°	180°	629 kWh
Kampar	8°	180°	591 kWh
Kangar	18°	180°	636 kWh

Table 4.4: Results generated by using GUI application (Case 3)

Location	Optimal Tilt Angle (β)	Optimal Azimuth Angle (γ)	Optimum Annual Energy Generation
Miri	4°	180°	615 kWh

Alor Setar	6°	180°	670 kWh
Kuantan	4°	180°	601 kWh
Kuala Terengganu	5°	180°	619 kWh
Kuala Lumpur	3°	180°	564 kWh
Johor Bahru	1°	180°	544 kWh
Kota Kinabalu	5°	180°	620 kWh
Kuching	2°	180°	544 kWh
Kota Bahru	6°	180°	647 kWh
Kampar	4°	180°	592 kWh
Kangar	6°	180°	653 kWh

By referring to Table 4.5, it can be discovered that the most prominent annual energy generation can always be obtained by involving both tilt angle and azimuth angle. On the other hand, for the comparison between Case 2 and 3 which both azimuth angle remains 180° (facing South direction), it may be determined that greater annual energy generation can be achieved by applying the tilt angle in accordance with the location's latitude coordinates. For instance, in Johor Bahru, 544 kWh of annual energy generation can be obtained by using the tilt angle according to the latitude is larger than 536 kWh when the optimal tilt angle is according to the result generated by the GUI application, same goes with other locations. Therefore, the top priority to obtain the optimum annual energy generation will be Case 1, following by Case 3 and Case 2.

Table 4.5: Annual energy generation comparison among Case 1, 2, and 3

Location	Case 1	Case 2	Case 3
Miri	702 kWh	568 kWh	615 kWh
Alor Setar	684 kWh	665 kWh	670 kWh
Kuantan	647 kWh	566 kWh	601 kWh
Kuala Terengganu	669 kWh	586 kWh	619 kWh

Kuala Lumpur	569 kWh	562 kWh	564 kWh
Johor Bahru	552 kWh	536 kWh	544 kWh
Kota Kinabalu	662 kWh	592 kWh	620 kWh
Kuching	611 kWh	479 kWh	544 kWh
Kota Bahru	683 kWh	629 kWh	647 kWh
Kampar	594 kWh	591 kWh	592 kWh
Kangar	680 kWh	636 kWh	653 kWh

Moreover, Table 4.6 is a comparison table that has been created to examine the energy gained when the azimuth angle is not considered and set to be 180° (facing South direction). In contrast, the tilt angle is under two situations according to the result generated by the GUI application (Case 2) and the latitude coordinate of the location (Case 3). For instance, in the location of Kuching, 27.86% and 12.53% of energy gained will be expected when the user decides to place the fixed-PV panel under Case 2 and 3. On the other hand, similar outcome for Miri existed, 23.69% and 14.25% of energy gained will be expected when the user choose to install the fixed-PV panel under Case 2 and 3. As a result, it is still advised to use both tilt angle and azimuth angle to determine the optimal annual energy generation for the fixed-PV panel to work optimally.

Table 4.6: Gain percentage of energy generation compared to the Case 1 result

Location	Case 2	Case 3
Miri	23.69%	14.25%
Alor Setar	2.91%	2.10%
Kuantan	14.35%	7.69%
Kuala Terengganu	14.07%	8.13%
Kuala Lumpur	1.19%	0.78%
Johor Bahru	3.04%	1.54%
Kota Kinabalu	11.87%	6.76%

Kuching	27.86%	12.53%
Kota Bahru	8.59%	5.58%
Kampar	0.53%	0.46%
Kangar	6.85%	4.18%

4.2.3 Energy loss of fixed-PV panel by placing undesired location

It is reasonable to consider that the fixed-PV panel will not always be placed in the ideal and desired location due to its restrictions, such as the blockage of the vital component of the building, rooftop with limited space, and so on. Therefore, the polar contour diagrams in different locations regarding the loss percentage of annual energy generation have been generated and shown in Figure 4.5 to guide the users when they placed the fixed-PV panel in the other location.

By referring to Figure 4.5, it is believed that these polar contour diagrams can provide a guideline to the user so that they can get some understanding and expectation if they choose to place the fixed-PV panel in the other place and direction.

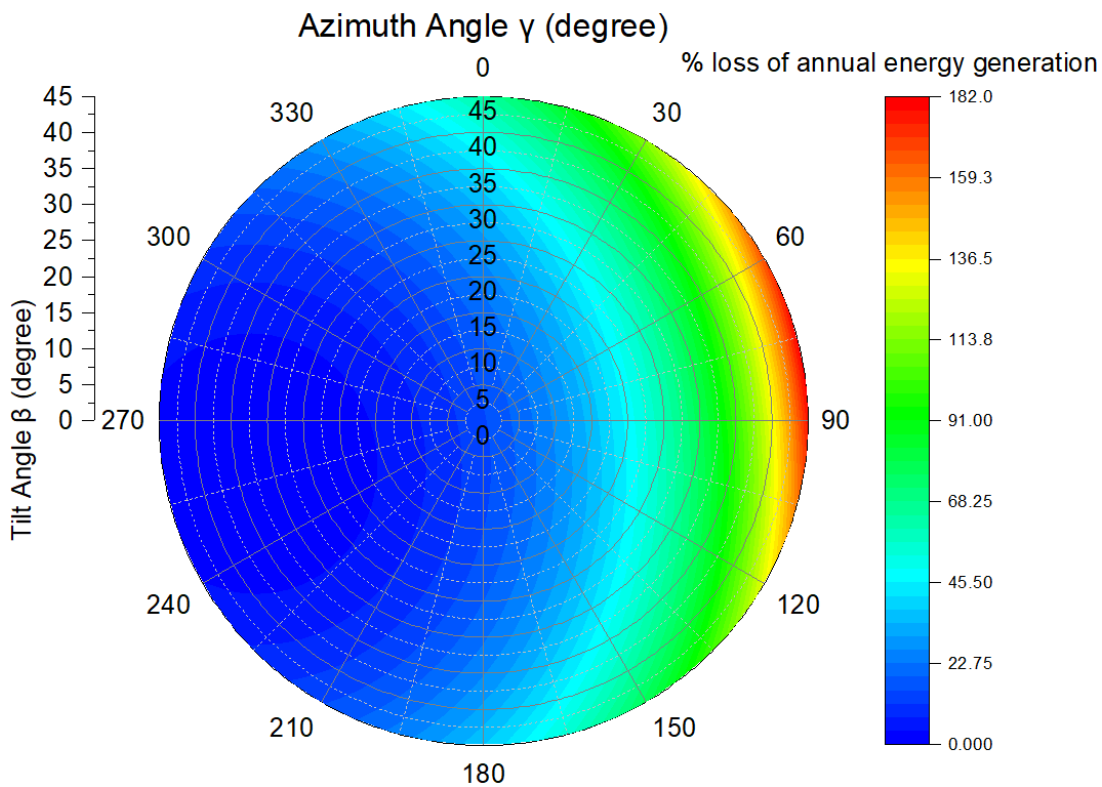


Figure 4.5 (a)

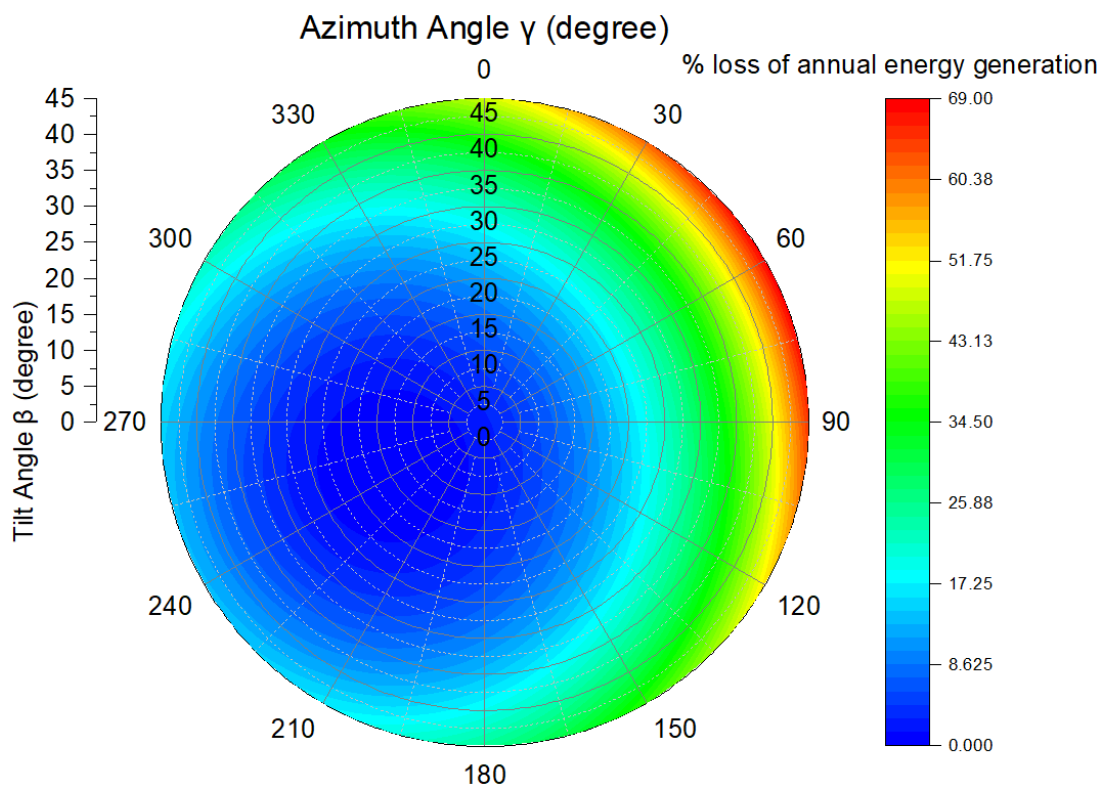


Figure 4.5 (b)

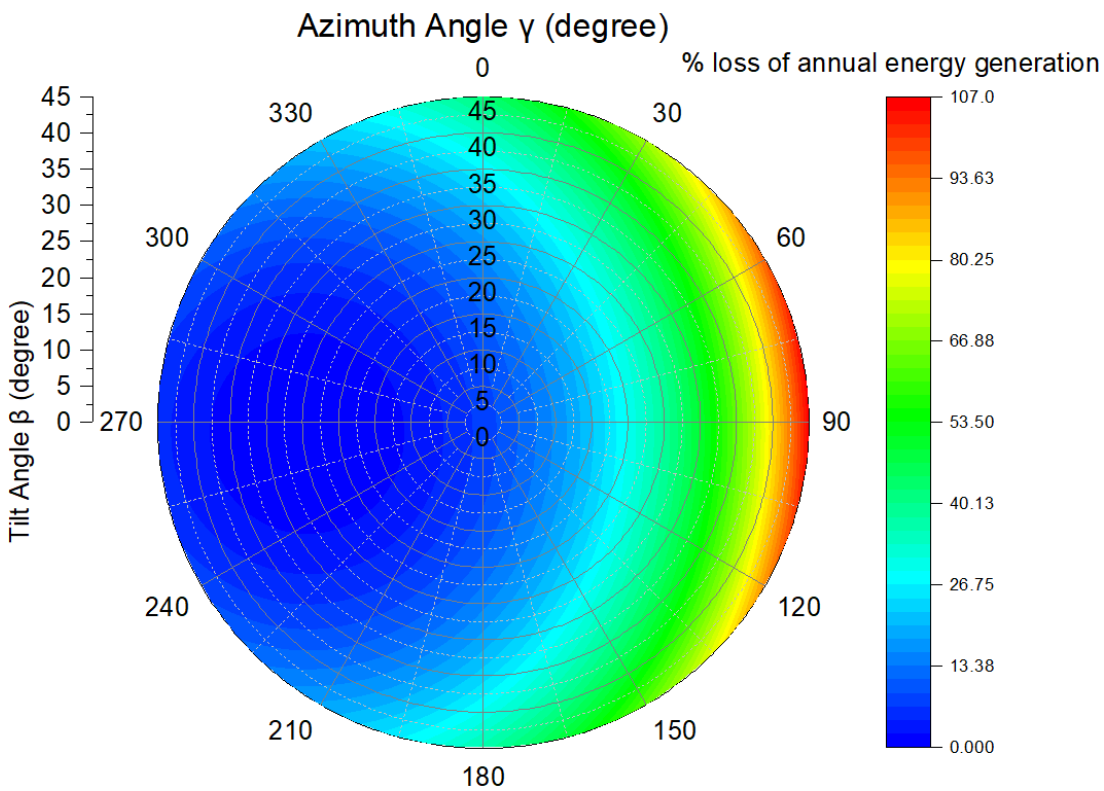


Figure 4.5 (c)

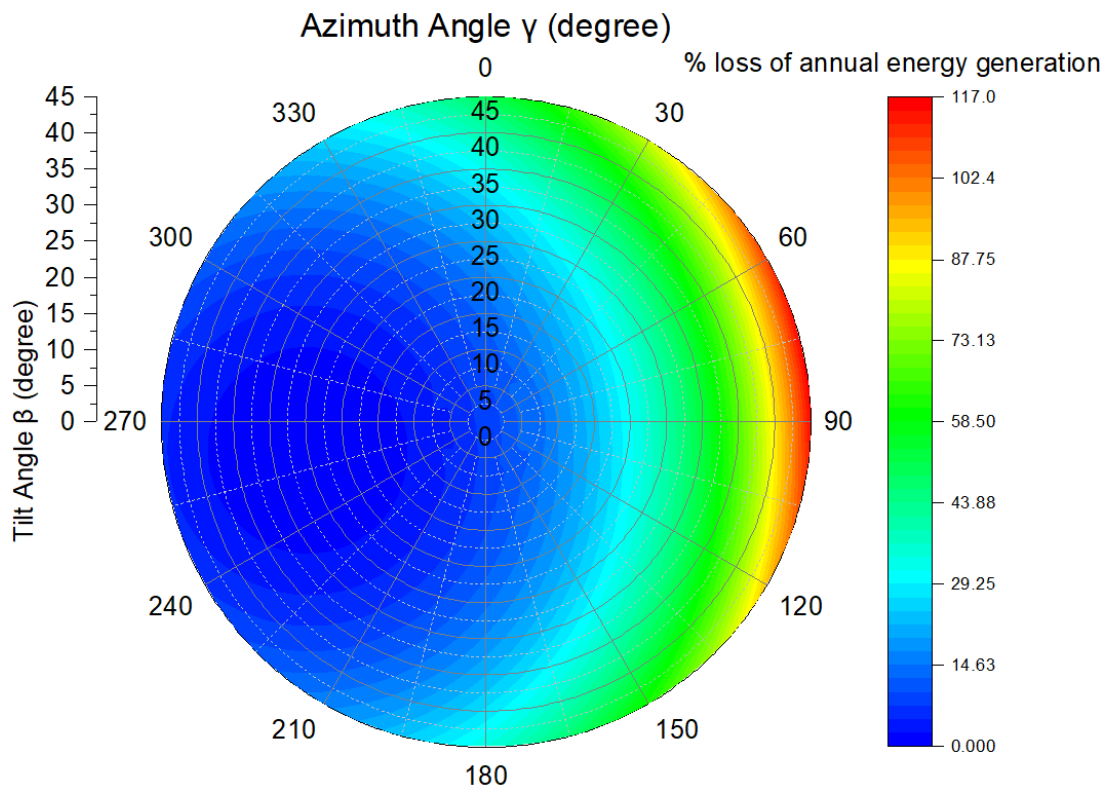


Figure 4.5 (d)

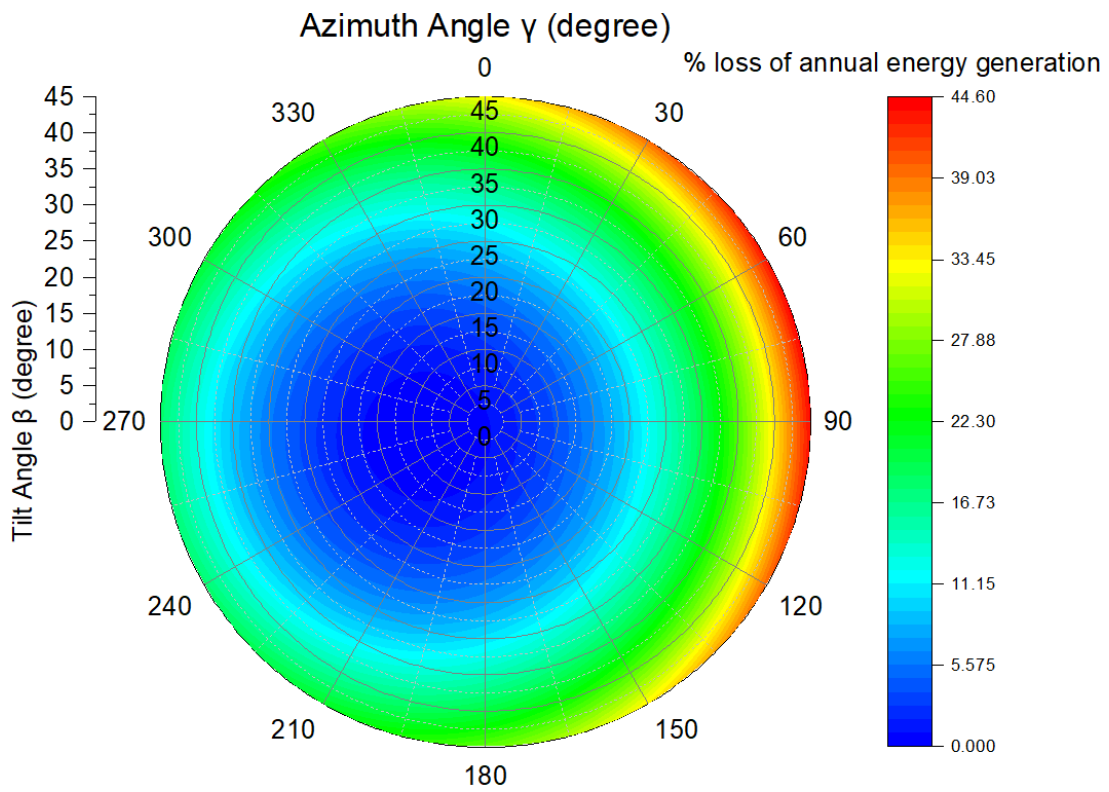


Figure 4.5 (e)

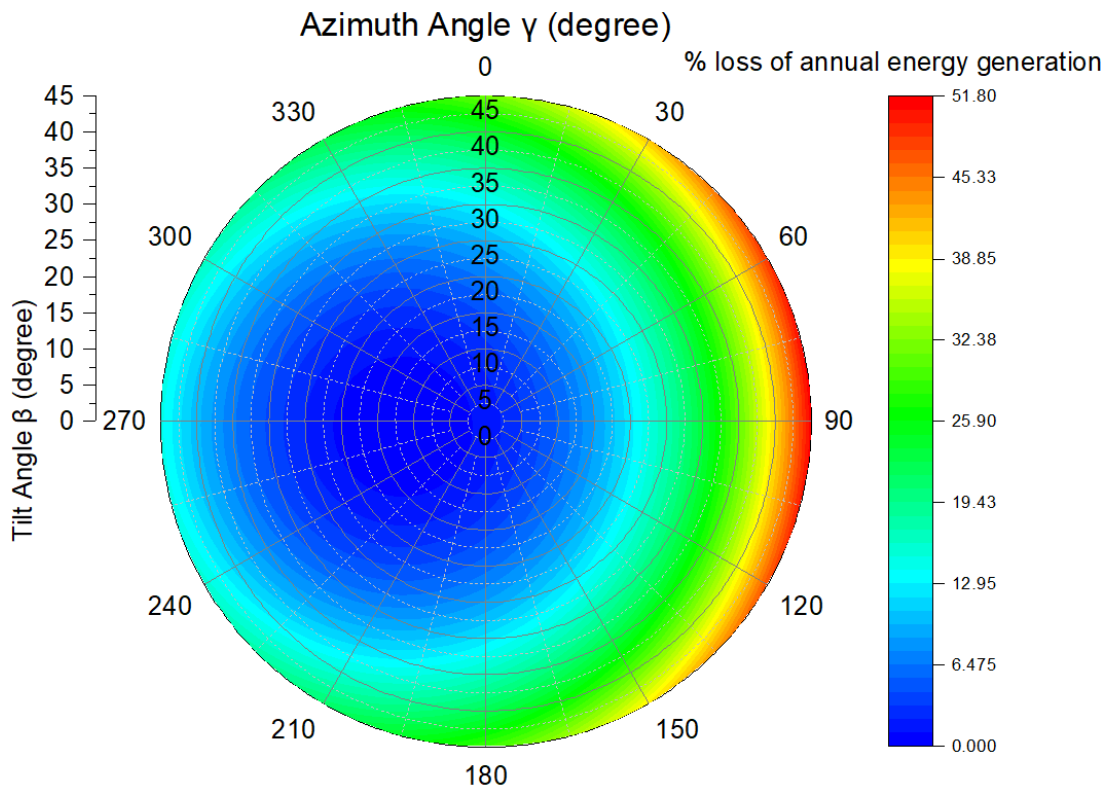


Figure 4.5 (f)

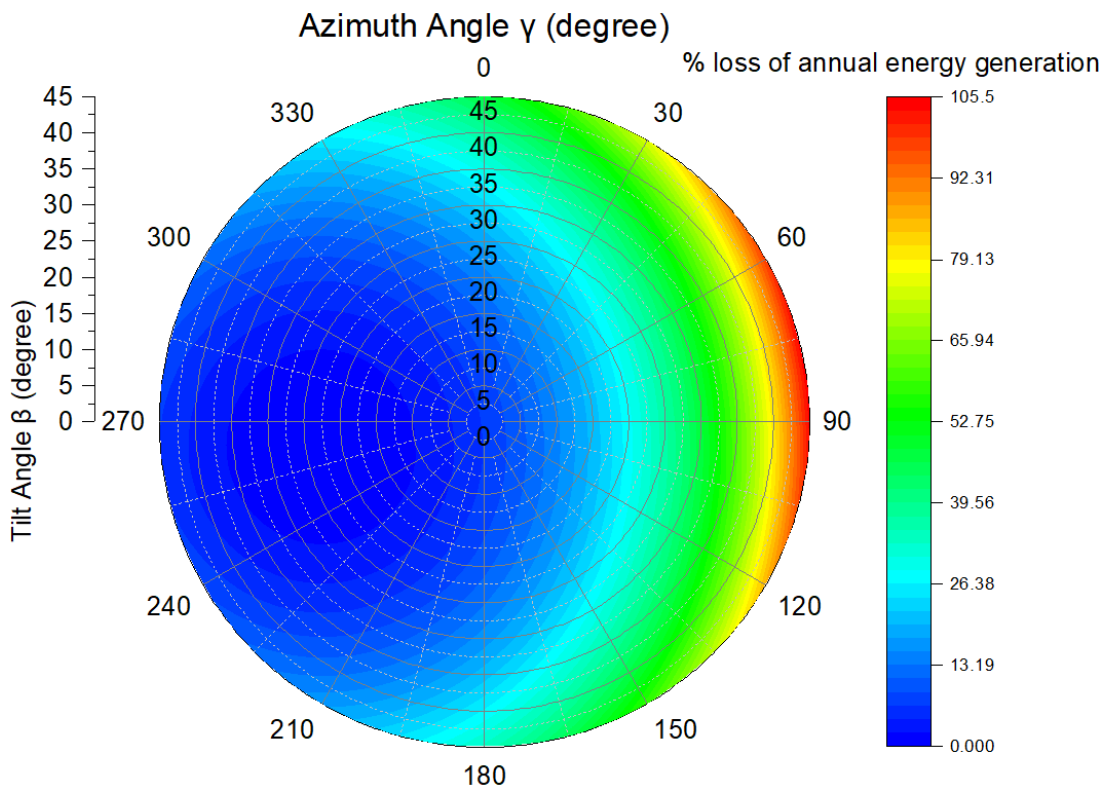


Figure 4.5 (g)

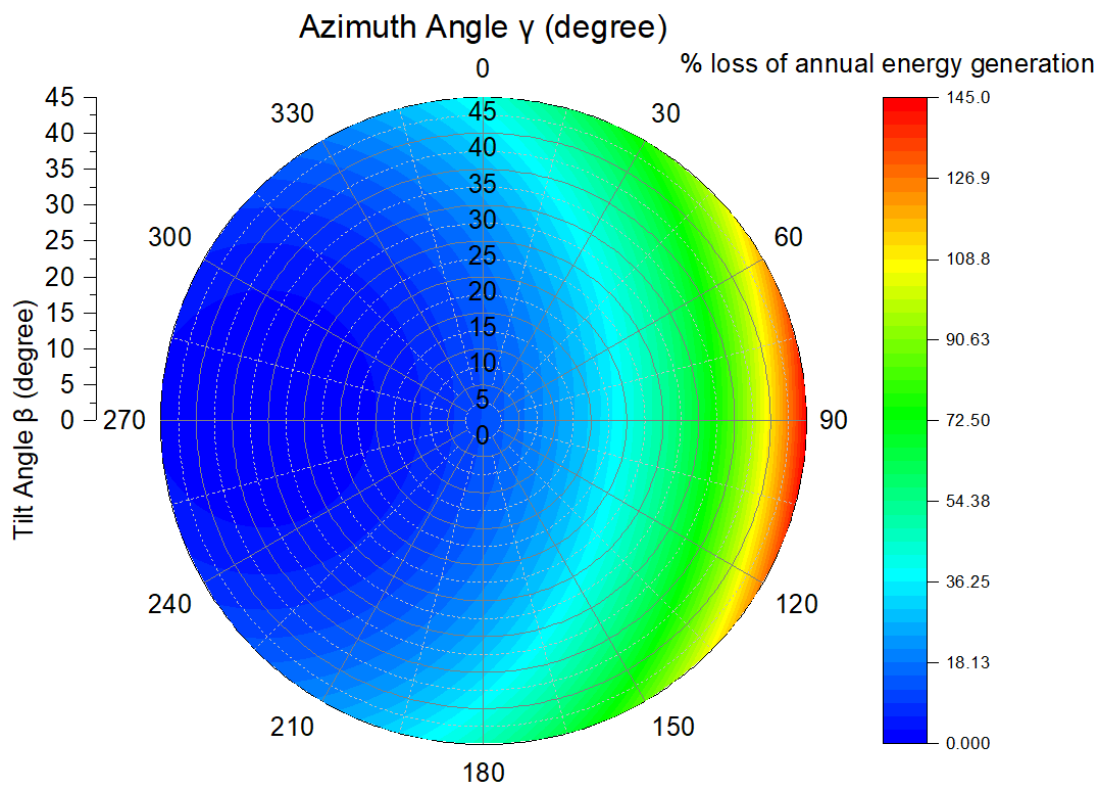


Figure 4.5 (h)

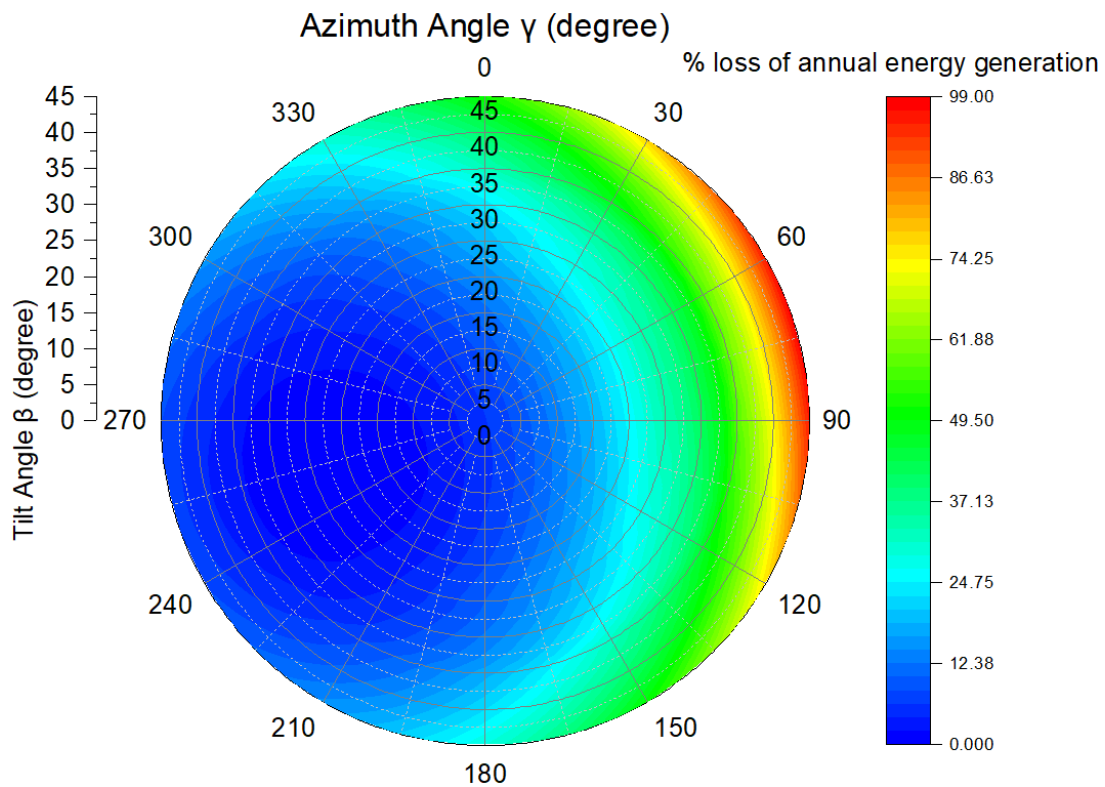


Figure 4.5 (i)

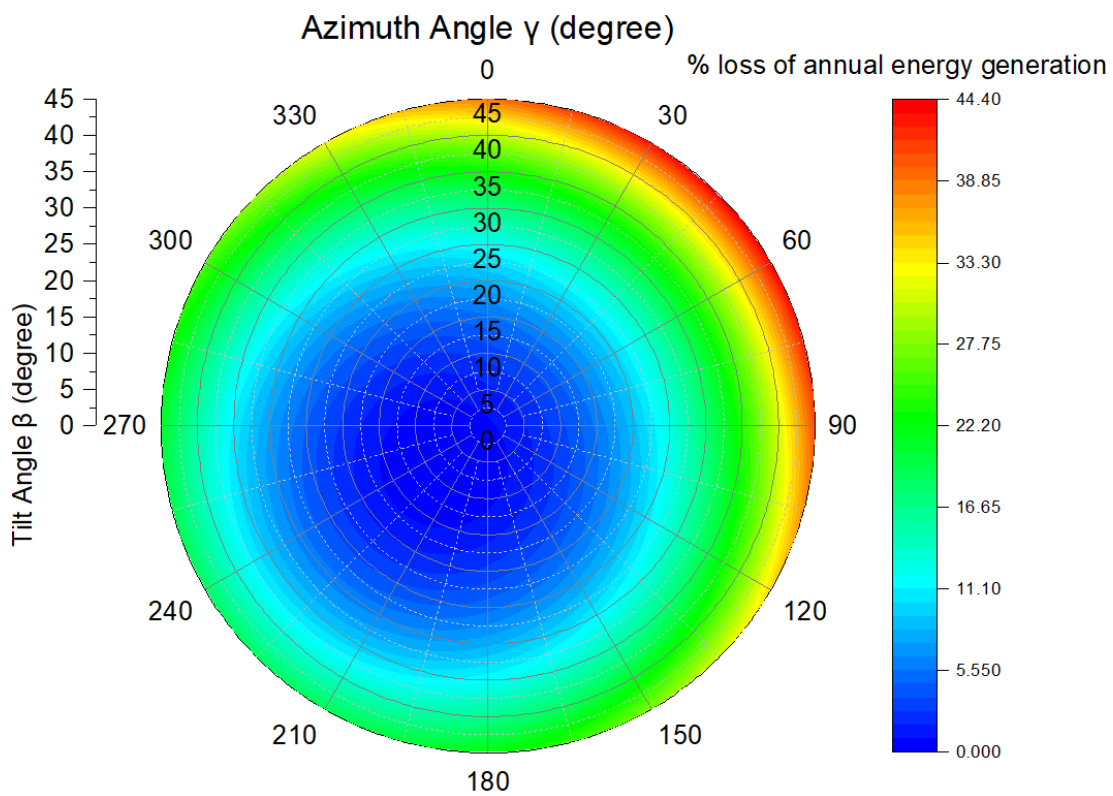


Figure 4.5 (j)

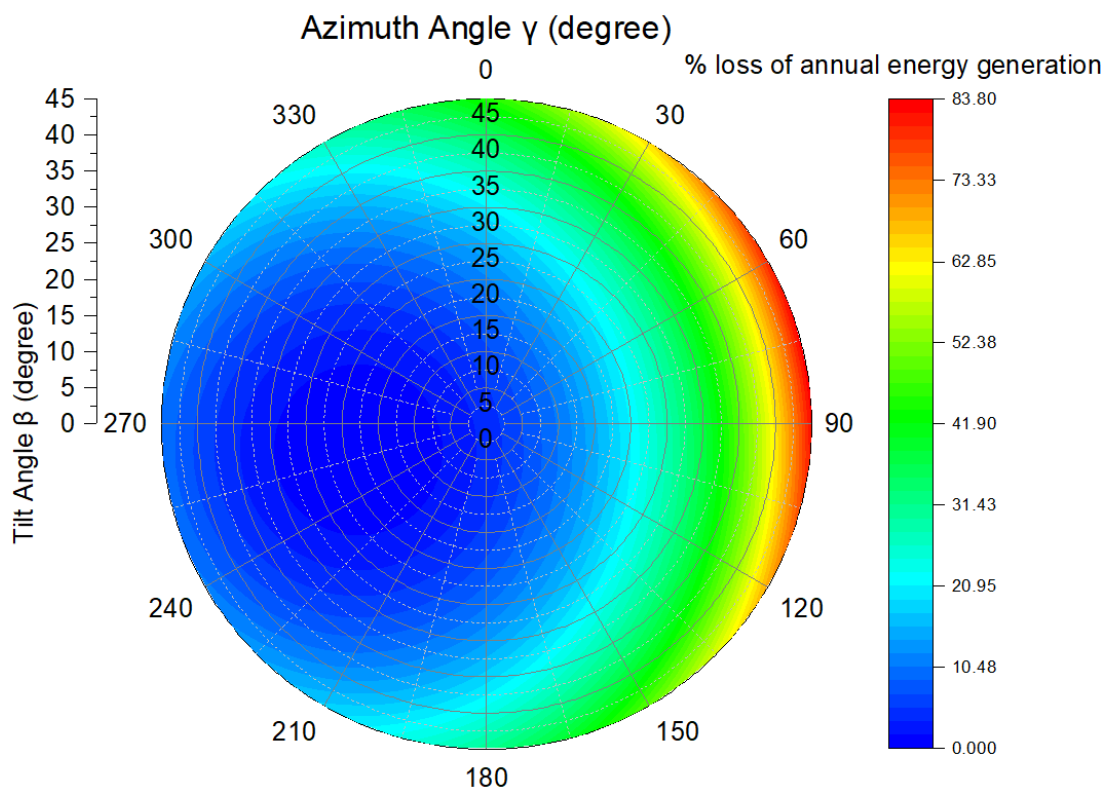


Figure 4.5 (k)

Figure 4.5: Loss percentage of annual energy generation in (a) Miri, (b) Alor Setar, (c) Kuantan, (d) Kuala Terengganu, (e) Kuala Lumpur, (f) Johor Bahru, (g) Kota Kinabalu, (h) Kuching, (i) Kota Bahru, (j) Kampar, and (k) Kangar

4.2.4 Application in real life

In order to make the public able to understand the polar contour diagram practically and realistically, Figure 4.6 discloses the application in real life. Here is the common scenario: Henry plans to install PV panels on his house roof in Johor Bahru; however, he does not know which position PV panels are supposed to place since his goal is to obtain the highest annual energy generation to maximise his investment profit. Unfortunately, the direction of his house is not ideal to fulfil the conditions of achieving optimum annual energy generation with a tilt angle of 12° and azimuth angle of 266° due to the space restriction. Therefore, after referring to Figure 4.7, he knows that there are three alternatives: roof sides A, B, and C could be chosen according to his roof side's direction. For roof side A, the PV panels must be placed at a tilt angle of 20° and an azimuth angle of 210° . However, it is expected to have an energy loss of 3.26% compared to the optimum energy generation with optimal tilt angles. For roof side B, the annual energy generation will be lowest for his house by placing the PV panels at a tilt angle of 20° and an azimuth angle of 120° . Lastly, for roof side C, with a 20° tilt angle and 30° azimuth angle, the energy loss of PV panels will be 8.88%. Comparing these three options makes it reasonable to choose roof side A to install PV panels since it can achieve the highest annual energy generation for Henry's house.

On the other hand, it is reasonable to focus on the energy loss from the user's perspective. However, the position of the property is fixed, and it cannot be amended easily, the feasible approach could be finding and performing further analysis for the most suitable tilt angles of the PV panel without compromising much energy loss as far as possible by using GUI application after going to the site for inspection. However, it is ideal if the property can conform to the optimum tilt angles shown in the GUI application. Please be noted that when the user is using the GUI application, a total of 2 files will be generated; therefore, there is a file named "Sum.xlsx", which consists of all annual energy generation values of the tilt angle from 0° to 45° , as well as the azimuth angle from 0° to 359° . Hence, the user can easily refer to the file for decision making due to the concern of installing the PV panel.

To sum up, it is suggested that this kind of application and concept can be applied to different PV panel users' real estate by providing more understanding pictures to fulfil their requirements case by case since it frequently appears in our daily lives.

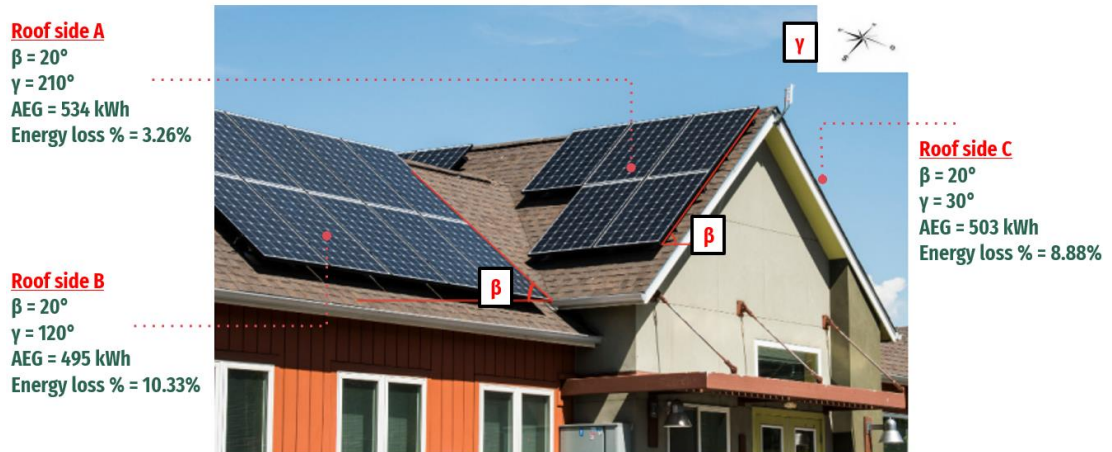


Figure 4.6: Rooftop's PV Panel Installation for Normal House (Johor Bahru)

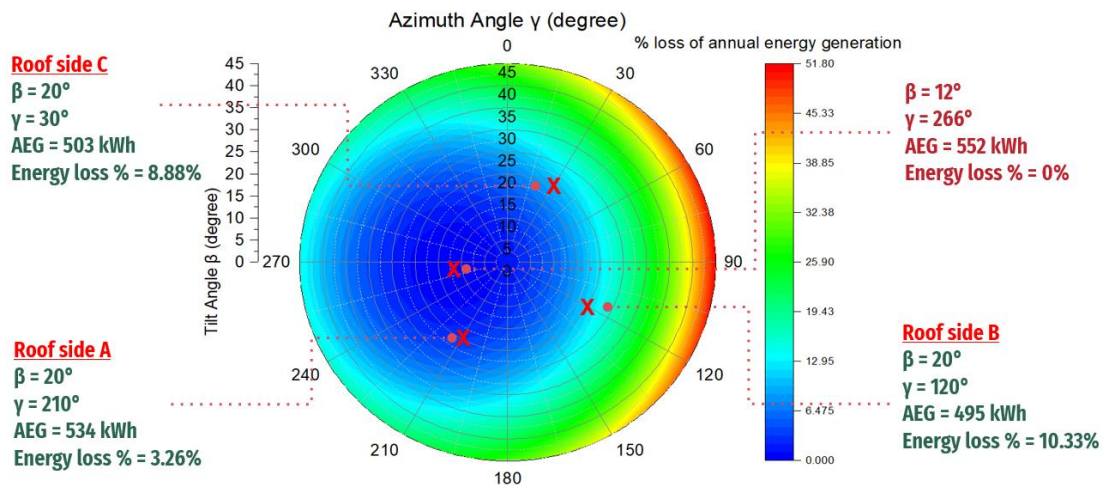


Figure 4.7: Polar Contour Diagram for loss percentage of annual energy generation in Johor Bahru

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this Final Year Project (FYP), the computational algorithm has been developed using MATLAB® (R2021a) to calculate the annual energy generation at different tilt angle and azimuth angle of the PV panel in Malaysia. For Peninsular Malaysia, 8 locations have been selected: Alor Setar, Kuantan, Kuala Terengganu, Kuala Lumpur, Johor Bahru, Kota Bahru, Kampar, and Kangar, whereas 3 locations in East Malaysia have been selected: Miri, Kota Kinabalu, and Kuching are studied and evaluated in this FYP. Moreover, the polar contour diagrams for annual energy generation in different locations have been generated to provide an easier way for evaluation.

On the other hand, optimum tilt angles of PV panel at these 11 locations under the local weather conditions have also been determined. As mentioned in the previous chapter, the PV panel of all locations tends to place in the position facing the West to obtain the optimum annual energy generation. Besides, by evaluating the solar isolation in these 11 locations, it can be discovered that larger solar isolation can be obtained in the afternoon session. In order words, lower solar isolation received by a PV panel in the morning session may be due to some uncertain factors that block the incident sunray which affect the performance of the PV panel, such as cloudy weather, rain, haze, and so on throughout the entire year. To sum up, local weather and location were also the factors to affect the annual energy generation and tilt angles.

Furthermore, the comparisons among three situations have been performed which are Case 1: annual energy generation based on optimal tilt angles, Case 2: annual energy generation based on optimal tilt angle and azimuth angle faces South, and Case 3: annual energy generation based on tilt angle according to location's latitude coordinate and azimuth angle faces South. It is worth mentioning that the most prominent annual energy generation can always be obtained by involving both tilt angle and azimuth angle. Besides, between the situation Case 2 and 3, when the azimuth angle remains to be 180° , it can be concluded that larger annual energy generation can be obtained by applying the tilt angle according to the latitude coordinate of location compared to the result when the tilt angle is according to the result generated by the GUI application. Moreover, another comparison has been conducted to examine the energy gained when the azimuth angle is not considered and set to be 180° (facing South direction). According to the result, to maximise the fixed-PV panel's performance, it is recommended to use both tilt and azimuth angles to find the optimum annual energy generation. Therefore, it can be concluded that the top priority to obtain the optimum annual energy generation will be Case 1, following by Case 3 and Case 2. Furthermore, for the 11 locations that selected in Malaysia, annual energy generation of Case 2 and Case 3 are compared with respect to Case 1 will be expected to have the average of 8.93% and 5.34% energy loss respectively.

Moreover, in this FYP, the condition that the PV panel cannot be placed in the ideal and desired location according to the result generated by the computational algorithm due to the location's restrictions has also been considered. Therefore, the polar contour diagrams in different locations regarding the loss percentage of annual energy generation have been created to guide the user to expect the annual energy generation outcome if they choose to place the fixed-PV panel in the other direction.

Last but not least, a Microsoft Excel Macro for data automation and a Graphical user interface (GUI) application has been created in MATLAB® App Designer to determine the maximum annual energy generation and optimal tilt angles of PV panel by omitting a series of overwhelming calculation. It is believed that these two algorithms can increase the efficiency of work for the user such as the researchers and

engineers to analyse new proposed sites by following the user manuals, which can be found in the previous chapter.

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APPENDICES

APPENDIX A: Computational Algorithm

```

WeatherData =
readmatrix("C:\Users\User\iCloudDrive\FYP\Weather
Data\dong ma\tmy_5.980_116.073_ (Kota
Kinabalu).xlsx", "sheet", "Sheet1", "Range", "C7:K8758");

filename = 'KotaKinabaluTestResult.xlsx';
%%
Energy = zeros(8752,360);

Summation = zeros(8752,360);
Maximum = zeros(8752,360);
Result = zeros(8752,360);

mN = zeros(8752,1);
md = zeros(8752,1);
mLCT = zeros(8752,1);
mEOT = zeros(8752,1);
mts = zeros(8752,1);
mw = zeros(8752,1);
malpha = zeros(8752,1);
mthetaz = zeros(8752,1);
mA = zeros(8752,1);
mAnew = zeros(8752,1);
mthetai = zeros(8752,1);
mEd = zeros(8752,1);

mRd = zeros(8752,1);
mHB = zeros(8752,1);
mHD = zeros(8752,1);
mHR = zeros(8752,1);
mHT = zeros(8752,1);
mIba = zeros(8752,1);

```

```

mEnergyHT = zeros(8752,1);
%%
for beta = 1:1:46 %spreadsheet number
    for gamma = 1:1:360 %column (heng) in each
spreadsheet
        for j = 1:8752 %row (zhi) in each spreadsheet

            phi = 5.980;
            dirla = 'N'; %This is Latitude
            ll = 116.073;
            dirll = 'E'; %This is Longitude

            rou = 0.3;

            year = WeatherData(j,1);
            month = WeatherData(j,2);
            day = WeatherData(j,3);

            days = day;

            hour = WeatherData(j,4);
            minute = WeatherData(j,5);

            Ibn = WeatherData(j,8); %Gb(n), Direct irradiance on
a plane always normal to sun rays, W/m^2
            Idh = WeatherData(j,9); %Gd(h), Diffuse irradiance on
the horizontal plane, W/m^2
            Ith = WeatherData(j,7); %G(h), Global irradiance on
the horizontal plane, W/m^2

            if (rem(year,100)==0 && rem(year,400)~=0) ||
rem(year,4)~=0
                ly = 0;
            else
                ly = 1;
            end

            for i=1:month-1
                switch(i)
                    case {1,3,5,7,8,10,12}
                        days = days+31;
                    case {4,6,9,11}
                        days = days+30;
                    case 2
                        days = days+28+ly;
                end
            end
        end

        N = days; %Number of day, days

```

```

d = asind(0.39795*cosd(0.98563*(N-173))); %Declination
angle, degrees

LCT = hour+(minute/60); %Local Clock Time, hours

x = (360*(N-1))/365.242; %degrees
EOT = (0.258*cosd(x))-(7.416*sind(x))-(3.648*cosd(2*x))-
(9.228*sind(2*x)); %Equation of Time, minutes

if dirll=='E'
    ll = -ll;
    LC = (ll-(-120))/15; %hours
    ts = (EOT/60)+LCT-LC; %Solar Time, hours
else
    LC = (ll-(-120))/15; %hours
    ts = (EOT/60)+LCT-LC; %Solar Time, hours
end

w = 15*(ts-12); %Hour angle, degrees

if dirla=='S'
    phi = -phi;
    alpha =
asind((sind(d)*sind(phi))+((cosd(d)*cosd(w)*cosd(phi))));
%Solar Altitude Angle, degrees
else
    alpha =
asind((sind(d)*sind(phi))+((cosd(d)*cosd(w)*cosd(phi))));
%Solar Altitude Angle, degrees
end

thetaz = 90-alpha; %Zenith Angle, degrees

if dirla=='S'
    phi = -phi;
    A = acosd(((sind(d)*cosd(phi))-
(cosd(d)*cosd(w)*sind(phi)))/(cosd(alpha))); %Solar
Azimuth Angle, degrees
else
    A = acosd(((sind(d)*cosd(phi))-
(cosd(d)*cosd(w)*sind(phi)))/(cosd(alpha))); %Solar
Azimuth Angle, degrees
end

sinw = sind(w); %The value of sin(w)

if sinw > 0
    %disp('The sin(w) is > 0');
    Anew = 360-A; %Solar Azimuth Angle, degrees
elseif sinw < 0
    %disp('The sin(w) is < 0');

```

```

    Anew = A; %Solar Azimuth Angle, degrees
else
    %disp('The sin(w) is = 0');
    Anew = A; %Solar Azimuth Angle, degrees
end

thetai = acosd((cosd(beta-
1)*((sind(d)*sind(phi))+(cosd(d)*cosd(phi)*cosd(w))) ...
    - (cosd(d)*sind(w)*sind(beta-1)*sind(gamma)) ...
    + ((sind(beta-1)*cosd(gamma))*((sind(d)*cosd(phi))-
(cosd(d)*cosd(w)*sind(phi))))); %degrees

costhetai = cosd(thetai); %The value of cos(thetai)

Ita = (Ibn*cosd(thetai))+((Idh*((1+cosd(beta-
1))/2))+ (rou*Ith*((1-cosd(beta-1))/2))); %W/m^2 Global
Aperture Irradiance

Gsc = 1367; %Solar constant, W/m^2
wss = acosd((-tand(phi))*tand(d)); %Sunset hour angle
Ho =
(Gsc/pi)*(1+(0.033*cosd(360*N/365)))*((cosd(phi)*cosd(d)*
sind(wss))+(pi/180*wss*sind(phi)*sind(d))); %Extraterrest
rial irradiance
Ai = Ibn/Ho; %Direct normal irradiance on the horizontal
to the extraterrestrial irradiance
Rb = (cosd(thetai)/cosd(thetaz)); %The ratio of the beam
radiation on the tilted surface to that on a horizontal
surface
Ed = Idh*((Ai*Rb)+((1-Ai)*((1+cosd(beta-
1))/2))); %Anisotropic model: Hay&Davies

Rd = ((Ibn/Ho)*(Rb))+((1-(Ibn/Ho))*((1+cosd(beta-1))/2));

HB = (Ith-Idh)*Rb; %Direct beam
HD = Rd*Idh; %Diffuse beam
HR = (Ith)*(rou)*((1-cosd(beta-1))/2); %Reflected
components
HT = HB+HD+HR; %Total radiation on a tilted surface

Iba = Ibn*cosd(thetai); %Beam normal irradiance

%Energy (J) = Ita or HT * LG365Q1C-A5 cell total area *
LG365Q1C-A5 module efficiency * 3600second
EnergyHT = HT*(60*161.7/1000*161.7/1000)*0.211*3600;
%%
mN(j,1) = N;
md(j,1) = d;
mLCT(j,1) = LCT;
mEOT(j,1) = EOT;
mts(j,1) = ts;

```



```

mw(j,1) = w;
malpha(j,1) = alpha;
mthetaz(j,1) = thetaz;
mA(j,1) = A;
mAnew(j,1) = Anew;
mthetai(j,1) = thetai;
mEd(j,1) = Ed;
mRd(j,1) = Rd;
mHB(j,1) = HB;
mHD(j,1) = HD;
mHR(j,1) = HR;
mHT(j,1) = HT;
mIba(j,1) = Iba;
%%
mEnergyHT(j,1) = EnergyHT;

Energy(:,gamma) = mEnergyHT;
Summation = sum(Energy);
    end
end

Maximum = max(Energy,[],'all');

writematrix(Energy,filename,"Sheet",beta,"Range","C7:MX87
58"); %Write Result

writematrix(Summation,filename,"Sheet",beta,"Range","C1:M
X1"); %Write Result after summation%
writematrix(Maximum,filename,"Sheet",beta,"Range","A1");
%Determine MAX value
end

filename = 'Sum.xlsx';

Maximum = zeros(45,360);
S1 = [];

for beta = 1:1:45

    S =
readmatrix("C:\Users\User\Desktop\Result.xlsx","sheet",be
ta,"Range","C1:MX1");

    S1 = [S1;S]; %Row by row

    Maximum = max(S1,[],'all'); %Determine maximum value
from all

    [~,rows] = max(S1); %Find indices of Beta
    [~,col] = max(max(S1)); %Find indices of Gamma

```

```
P = [rows(col),col]; %Determine (Beta,Gamma) value

BETA = P(1,1); %Indicate Beta value specifically
GAMMA = P(1,2); %Indicate Gamma value specifically

writematrix(S1,filename,"Sheet","SUMMATION","Range","C:MX
"); %Combine all

writematrix(Maximum,filename,"Sheet","SUMMATION","Range",
"A1"); %Determine MAX value from all

writematrix(P,filename,"Sheet","SUMMATION","Range","A47")
; %Determine MAX value indices
end
```

APPENDIX B: Microsoft Excel Macro

```

Sub WDF()
'
' WDF Macro
'
'
Columns("B:B").Select
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Range("B17").Select
ActiveCell.FormulaR1C1 = "Time (UTC) with:"
Range("B18").Select
ActiveCell.FormulaR1C1 = _
    "=REPLACE(REPLACE(REPLACE(RC[-1],5,0,"":":""),8,0,"":":""),14,0,"":"")"
Range("B18").Select

```

```
Selection.AutoFill Destination:=Range("B18:B8777")
Range("B18:B8777").Select
Range("C18").Select
ActiveCell.FormulaR1C1 = "=LEFT(RC[-1],4)"
Range("C18").Select
Selection.AutoFill Destination:=Range("C18:C8777")
Range("C18:C8777").Select
Range("D18").Select
ActiveCell.FormulaR1C1 = "=MID(RC[-2],6,2)"
Range("D18").Select
Selection.AutoFill Destination:=Range("D18:D8777")
Range("D18:D8777").Select
Range("E18").Select
ActiveCell.FormulaR1C1 = "=MID(RC[-3],9,2)"
Range("E18").Select
Selection.AutoFill Destination:=Range("E18:E8777")
Range("E18:E8777").Select
Range("F18").Select
ActiveCell.FormulaR1C1 = "=MID(RC[-4],12,2)"
Range("F18").Select
Selection.AutoFill Destination:=Range("F18:F8777")
Range("F18:F8777").Select
Range("G18").Select
ActiveCell.FormulaR1C1 = "=RIGHT(RC[-5],2)"
Selection.AutoFill Destination:=Range("G18:G8777")
Range("G18:G8777").Select
Range("H17").Select
ActiveCell.FormulaR1C1 = "Year"
Range("I17").Select
ActiveCell.FormulaR1C1 = "Month"
```

```
Range("J17").Select
ActiveCell.FormulaR1C1 = "Day"
Range("K17").Select
ActiveCell.FormulaR1C1 = "Hour"
Range("L17").Select
ActiveCell.FormulaR1C1 = "Minute"
Range("H18").Select
ActiveCell.FormulaR1C1 = "=R[8]C[-5]"
Range("H18").Select
Selection.AutoFill Destination:=Range("H18:H8777")
Range("H18:H8777").Select
Range("I18").Select
ActiveCell.FormulaR1C1 = "=R[8]C[-5]"
Range("I18").Select
Selection.AutoFill Destination:=Range("I18:I8777")
Range("I18:I8777").Select
Range("J18").Select
ActiveCell.FormulaR1C1 = "=R[8]C[-5]"
Range("J18").Select
Selection.AutoFill Destination:=Range("J18:J8777")
Range("J18:J8777").Select
Range("K18").Select
ActiveCell.FormulaR1C1 = "=R[8]C[-5]"
Range("K18").Select
Selection.AutoFill Destination:=Range("K18:K8777")
Range("K18:K8777").Select
Range("L18").Select
ActiveCell.FormulaR1C1 = "30"
Range("L18").Select
Selection.AutoFill Destination:=Range("L18:L8777")
```

```
Range("L18:L8777").Select
Range("O16").Select
ActiveCell.FormulaR1C1 = "Ith"
Range("P16").Select
ActiveCell.FormulaR1C1 = "Ibn"
Range("Q16").Select
ActiveCell.FormulaR1C1 = "Idh"
Range("O16:Q17").Select
With Selection.Interior
    .Pattern = xlSolid
    .PatternColorIndex = xlAutomatic
    .ThemeColor = xlThemeColorAccent5
    .TintAndShade = 0.799981688894314
    .PatternTintAndShade = 0
End With
Range("H17:L17").Select
With Selection.Interior
    .Pattern = xlSolid
    .PatternColorIndex = xlAutomatic
    .ThemeColor = xlThemeColorAccent5
    .TintAndShade = 0.799981688894314
    .PatternTintAndShade = 0
End With
Range("B1").Select
ActiveCell.FormulaR1C1 = "=MID(RC[-1],FIND("":",RC[-1])+1,LEN(RC[-1]))"
Range("B1").Select
Selection.AutoFill Destination:=Range("B1:B2"), Type:=xlFillDefault
Range("B1:B2").Select
Sheets.Add After:=ActiveSheet
ActiveWindow.SmallScroll Down:=-18
```

```
Sheets("Sheet1").Select
Range( _
"B17:B1048576,H17:H1048576,I17:I1048576,J17:J1048576,K17:K1048576,L17:L1
048576" _
).Select
Range("L17").Activate
ActiveWindow.SmallScroll Down:=-12
Selection.Copy
Sheets("Sheet2").Select
Range("B6").Select
ActiveSheet.Paste
Sheets("Sheet1").Select
Range("O16:O1048576,P16:P1048576,Q16:Q1048576").Select
Range("Q16").Activate
Application.CutCopyMode = False
Selection.Copy
Sheets("Sheet2").Select
Range("I5").Select
ActiveSheet.Paste
Sheets("Sheet1").Select
Range("A1:B3").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("Sheet2").Select
Range("A1").Select
ActiveSheet.Paste
ActiveWindow.SmallScroll Down:=9
End Sub
```

APPENDIX C: Graphical user interface (GUI) Application

```

classdef GUI < matlab.apps.AppBase

% Properties that correspond to app components
properties (Access = public)
    UIFigure matlab.ui.Figure
    TabGroup matlab.ui.container.TabGroup
    ProgrammeTab matlab.ui.container.Tab
    Image matlab.ui.control.Image
    TimeZoneDropDown matlab.ui.control.DropDown
    TimeZoneDropDownLabel matlab.ui.control.Label
    EnterTimezoneAreaandEfficiencyofFixedPVpanelLabel
    matlab.ui.control.Label
    EfficiencyEditField matlab.ui.control.NumericEditField
    EfficiencyLabel matlab.ui.control.Label
    Aream2EditField matlab.ui.control.NumericEditField
    Aream2Label matlab.ui.control.Label
    SubmitButton matlab.ui.control.Button
    ProceedButton matlab.ui.control.Button
    Label matlab.ui.control.Label
    ViewFileButton matlab.ui.control.Button
    ViewResultButton matlab.ui.control.Button
    AftercheckingpleaseproceedLabel matlab.ui.control.Label
    OptimalAzimuthanglevalueEditField matlab.ui.control.NumericEditField
    OptimalAzimuthanglevalueEditFieldLabel matlab.ui.control.Label
    OptimalTiltanglevalueEditField matlab.ui.control.NumericEditField
    OptimalTiltanglevalueEditFieldLabel matlab.ui.control.Label
    OptimumAnnualEnergyGeneratedkWhEditField
    matlab.ui.control.NumericEditField
    OptimumAnnualEnergyGeneratedkWhEditFieldLabel matlab.ui.control.Label
    FinalResultLabel matlab.ui.control.Label
    LongitudeEditField matlab.ui.control.NumericEditField
    LongitudeEditFieldLabel matlab.ui.control.Label
    LatitudeEditField matlab.ui.control.NumericEditField
    LatitudeEditFieldLabel matlab.ui.control.Label
    UITable matlab.ui.control.Table
    DataoverviewLabel matlab.ui.control.Label
    PreviewButton matlab.ui.control.Button
    PleasepreviewthefilebeforeprocessingLabel matlab.ui.control.Label
    ImportButton matlab.ui.control.Button
    PleaseinputWeatherDatafileLabel matlab.ui.control.Label
end

```



```

properties (Access = private)
file % Description
path
indx
filename
t

selpath
phi
ll
area
efficiency
timezone
end

% Callbacks that handle component events
methods (Access = private)

% Button pushed function: ImportButton
function ImportButtonPushed(app, event)
[app.file,app.path,app.indx] = uigetfile('*.xlsx');
app.filename = strcat(app.path,app.file);
bar = waitbar(0,'Please wait . . . . .');
setappdata(bar,'canceling','canceling',1);
pause(1);
setappdata(bar,'canceling',0);
steps = 100;
for step = 1:steps
if getappdata(bar,'canceling')
break
end
if step >= 33 && step <50
waitbar(step/steps,bar,'Still importing . . . . .');
pause(0.1);
elseif step >= 50 && step <67
waitbar(step/steps,bar,'Keep trying . . . . .');
pause(0.1);
elseif step >= 67 && step <100
waitbar(step/steps,bar,'Almost done . . . . .');
pause(0.1);
elseif step == 100
waitbar(step/steps,bar,'Done! Please proceed to next step!');
pause(1.2);
else
waitbar(step/steps,bar,'Submitting the data . . .');
pause(0.1);
end
end
delete(bar);

```

end

% Button pushed function: PreviewButton

```
function PreviewButtonPushed(app, event)
app.t = readtable(app.filename, "sheet", 2, "Range", "C6:K8758");
app.phi = readmatrix(app.filename, "sheet", 2, "Range", "B1:B1");
app.ll = readmatrix(app.filename, "sheet", 2, "Range", "B2:B2");
app.LatitudeEditField.Value = app.phi;
app.LongitudeEditField.Value = app.ll;
app.UITable.Data = app.t;
app.t.Properties.VariableNames{1} = 'Year'; %1st Header that you want
to show
app.t.Properties.VariableNames{2} = 'Month'; %2nd Header that you want
to show
app.t.Properties.VariableNames{3} = 'Day';
app.t.Properties.VariableNames{4} = 'Hour';
app.t.Properties.VariableNames{5} = 'Minute';
app.t.Properties.VariableNames{6} = '-Space-';
app.t.Properties.VariableNames{7} = 'G(h)';
app.t.Properties.VariableNames{8} = 'Gb(n)';
app.t.Properties.VariableNames{9} = 'Gd(h)';
app.UITable.ColumnName = app.t.Properties.VariableNames;
end
```

% Button pushed function: SubmitButton

```
function SubmitButtonPushed(app, event)
app.area = app.Aream2EditField.Value;
app.efficiency = app.EfficiencyEditField.Value;
switch app.TimeZoneDropDown.Value
case 'UTC'
app.timezone = 0;
case 'UTC +1'
app.timezone = 15;
case 'UTC +2'
app.timezone = 30;
case 'UTC +3'
app.timezone = 45;
case 'UTC +4'
app.timezone = 60;
case 'UTC +5'
app.timezone = 75;
case 'UTC +6'
app.timezone = 90;
case 'UTC +7'
app.timezone = 105;
case 'UTC +8'
app.timezone = 120;
case 'UTC +9'
app.timezone = 135;
case 'UTC +10'
app.timezone = 150;
case 'UTC +11'
```

```

app.timezone = 165;
otherwise
app.timezone = 180;
end
bar = waitbar(0,'Please wait . . . . .
.', 'CreateCancelBtn', 'setappdata(gcf,'canceling',1)');
pause(0.8);
setappdata(bar, 'canceling',0);
steps = 10;
for step = 1:steps
if getappdata(bar, 'canceling')
break
end
if step == 10
waitbar(1,bar, 'Done! Please proceed to next step!');
pause(1.2);
else
waitbar(step/steps,bar, 'Submitting the data . . .');
pause(0.1);
end
end
delete(bar);
end

% Button pushed function: ViewResultButton
function ViewResultButtonPushed(app, event)
filename = 'Sum.xlsx';
Maximum = zeros(46,360);
S1 = [];
bar = waitbar(1,'In progress, please wait a moment . . .');
for beta = 1:1:46
waitbar(beta/46,bar, 'In progress, please wait a moment . . .');
pause(0.01);
S =
readmatrix('C:\Users\User\Desktop\Result.xlsx', "sheet", beta, "Range", "C1
:MX1");

S1 = [S1;S]; %Row by row

Maximum = max(S1,[], 'all'); %Determine maximum value from all

[~,rows] = max(S1); %Find indices of Beta
[~,col] = max(max(S1)); %Find indices of Gamma
P = [rows(col),col]; %Determine (Beta,Gamma) value
end
delete(bar);
BETA = P(1,1); %Indicate Beta value specifically
GAMMA = P(1,2); %Indicate Gamma value specifically
writematrix(S1,filename, "Sheet", "SUMMATION", "Range", "C:MX"); %Combine
all

```

```
writematrix(Maximum,filename,"Sheet","SUMMATION","Range","A1");
%Determine MAX value from all
writematrix(P,filename,"Sheet","SUMMATION","Range","A2"); %Determine
MAX value indices
app.OptimumAnnualEnergyGeneratedkWhEditField.Value =
Maximum*(2.778*10^-7); %Maximum value conversion (J to kWh)
app.OptimalTiltanglevalueEditField.Value = BETA;
app.OptimalAzimuthanglevalueEditField.Value = GAMMA;
end
```

```
% Button pushed function: ViewFileButton
function ViewFileButtonPushed(app, event)
app.selpath = uigetdir;
end
```

```
% Button pushed function: ProceedButton
function ProceedButtonPushed(app, event)
WeatherData = readmatrix(app.filename,"sheet",2,"Range","C7:K8758");
bar = waitbar(1,'In progress . . .');
filename = 'Result.xlsx';
%% Location coordinates
phi = app.phi;
dirla = 'N'; %Latitude N/W
ll = app.ll;
dirll = 'E'; %Longitude E/S
%% Storage
Energy = zeros(8752,360);
```

```
Summation = zeros(8752,360);
Maximum = zeros(8752,360);
Result = zeros(8752,360);
```

```
mN = zeros(8752,1);
md = zeros(8752,1);
mLCT = zeros(8752,1);
mEOT = zeros(8752,1);
mts = zeros(8752,1);
mw = zeros(8752,1);
malpha = zeros(8752,1);
mthetaz = zeros(8752,1);
mA = zeros(8752,1);
mAnew = zeros(8752,1);
%miOh = zeros(8752,1);
mthetai = zeros(8752,1);
mIta = zeros(8752,1);
mEd = zeros(8752,1);
```

```
mRd = zeros(8752,1);
mHB = zeros(8752,1);
```

```

mHD = zeros(8752,1);
mHR = zeros(8752,1);
mHT = zeros(8752,1);
mIba = zeros(8752,1);

mEnergyHT = zeros(8752,1);
%% ALL
for beta = 1:1:46 %spreadsheet number
waitbar(beta/46,bar,'In progress, please wait a moment . . .');
for gamma = 1:1:360 %column
for j = 1:8752 %row

%% Obtain data from Excel
rou = 0.3;

year = WeatherData(j,1);
month = WeatherData(j,2);
day = WeatherData(j,3);
days = day;
hour = WeatherData(j,4);
minute = WeatherData(j,5);
Ibn = WeatherData(j,8); %Gb(n), Direct irradiance on a plane always
normal to sun rays, W/m^2
Idh = WeatherData(j,9); %Gd(h), Diffuse irradiance on the horizontal
plane, W/m^2
Ith = WeatherData(j,7); %G(h), Global irradiance on the horizontal
plane, W/m^2
%% Febraury days calculation
if (rem(year,100)==0 && rem(year,400)~=0) || rem(year,4)~=0
ly = 0;
else
ly = 1;
end
%% Days for month calculation
for i=1:month-1
switch(i)
case {1,3,5,7,8,10,12}
days = days+31;
case {4,6,9,11}
days = days+30;
case 2
days = days+28+ly;
end
end
%% Equations Part 1
N = days; %Number of day, days
d = asind(0.39795*cosd(0.98563*(N-173))); %Declination angle, degrees
LCT = hour+(minute/60); %Local Clock Time, hours
x = (360*(N-1))/365.242; %degrees
EOT = (0.258*cosd(x))-(7.416*sind(x))-(3.648*cosd(2*x))-
(9.228*sind(2*x)); %Equation of Time, minutes

```

```

%% Location coordinates calculation (E/S)
if dirll=='E'
ll = -ll;
LC = (ll-(-app.timezone))/15; %hours
ts = (EOT/60)+LCT-LC; %Solar Time, hours
else
LC = (ll-(-app.timezone))/15; %hours
ts = (EOT/60)+LCT-LC; %Solar Time, hours
end
%% Equation Part 2
w = 15*(ts-12); %Hour angle, degrees
%% Location coordinates calculation (E/S)
if dirla=='S'
phi = -phi;
alpha = asind((sind(d)*sind(phi)))+((cosd(d)*cosd(w)*cosd(phi)));
%Solar Altitude Angle, degrees
else
alpha = asind((sind(d)*sind(phi)))+((cosd(d)*cosd(w)*cosd(phi)));
%Solar Altitude Angle, degrees
end
%% Equation Part 3
thetaz = 90-alpha; %Zenith Angle, degrees
%% Location coordinates calculation (E/S)
if dirla=='S'
phi = -phi;
A = acosd(((sind(d)*cosd(phi))-
(cosd(d)*cosd(w)*sind(phi)))/(cosd(alpha))); %Solar Azimuth Angle,
degrees
else
A = acosd(((sind(d)*cosd(phi))-
(cosd(d)*cosd(w)*sind(phi)))/(cosd(alpha))); %Solar Azimuth Angle,
degrees
end
%% Equation Part 4
sinw = sind(w); %The value of sin(w)
%% sinw calculation for Anew
if sinw > 0
%disp('The sin(w) is > 0');
Anew = 360-A; %Solar Azimuth Angle, degrees
elseif sinw < 0
%disp('The sin(w) is < 0');
Anew = A; %Solar Azimuth Angle, degrees
else
%disp('The sin(w) is = 0');
Anew = A; %Solar Azimuth Angle, degrees
end
%% Equations Part 5
thetai = acosd((cosd(beta-
1)*((sind(d)*sind(phi))+(cosd(d)*cosd(phi)*cosd(w))) ...
-(cosd(d)*sind(w)*sind(beta-1)*sind(gamma)) ...
+((sind(beta-1)*cosd(gamma))*((sind(d)*cosd(phi))-
(cosd(d)*cosd(w)*sind(phi))))); %degrees
costhetai = cosd(thetai); %The value of cos(thetai)

```

```

Ita = (Ibn*cosd(thetai))+((Idh*((1+cosd(beta-1))/2))+rou*Ith*((1-
cosd(beta-1))/2))); %W/m^2 Global Aperture Irradiance
Gsc = 1367; %Solar constant, W/m^2
wss = acosd((-tand(phi))*tand(d)); %Sunset hour angle
Ho =
(Gsc/pi)*(1+(0.033*cosd(360*N/365)))*((cosd(phi)*cosd(d)*sind(wss))+
(pi/180*wss*sind(phi)*sind(d))); %Extraterrestrial irradiance
Ai = Ibn/Ho; %Direct normal irradiance on the horizontal to the
extraterrestrial irradiance
Rb = (cosd(thetai)/cosd(thetaz)); %The ratio of the beam radiation on
the tilted surface to that on a horizontal surface
Ed = Idh*(Ai*Rb)+((1-Ai)*((1+cosd(beta-1))/2))); %Anisotropic model:
Hay&Davies
Rd = ((Ibn/Ho)*(Rb))+((1-(Ibn/Ho))*((1+cosd(beta-1))/2)));
HB = (Ith-Idh)*Rb; %Direct beam
HD = Rd*Idh; %Diffuse beam
HR = (Ith)*rou*((1-cosd(beta-1))/2); %Reflected components
HT = HB+HD+HR; %Total radiation on a tilted surface
Iba = Ibn*cosd(thetai); %Beam normal irradiance
%Energy (J) = Ita or HT * LG365Q1C-A5 cell total area * LG365Q1C-A5
module efficiency * 3600second
EnergyHT = HT*app.area*(app. efficiency/100)*3600;
%% Store variables
mN(j,1) = N;
md(j,1) = d;
mLCT(j,1) = LCT;
mEOT(j,1) = EOT;
mts(j,1) = ts;
mw(j,1) = w;
malpha(j,1) = alpha;
mthetaz(j,1) = thetaz;
mA(j,1) = A;
mAnew(j,1) = Anew;
mthetai(j,1) = thetai;
mIta(j,1) = Ita;
mEd(j,1) = Ed;
mRd(j,1) = Rd;
mHB(j,1) = HB;
mHD(j,1) = HD;
mHR(j,1) = HR;
mHT(j,1) = HT;
mIba(j,1) = Iba;
mEnergyHT(j,1) = EnergyHT;
%% Store Energy
Energy(:,gamma) = mEnergyHT;
%% Store Annual Energy Generated
Summation = sum(Energy);
end
end
%% Store Maximum
Maximum = max(Energy,[], 'all');
%% Writematrix for Energy, Annual Energy Generated, Maximum
writematrix(Energy,filename, "Sheet",beta, "Range", "C7:K8758"); %Write
Result

```

```

writematrix(Summation,filename,"Sheet",beta,"Range","C1:MX1"); %Write
Result after summation
writematrix(Maximum,filename,"Sheet",beta,"Range","A1"); %Determine MAX
value
end
delete(bar);
end

% Value changed function: LatitudeEditField
function LatitudeEditFieldValueChanged(app, event)
value = app.LatitudeEditField.Value;
end

% Value changed function:
% OptimumAnnualEnergyGeneratedkWhEditField
function OptimumAnnualEnergyGeneratedkWhEditFieldValueChanged(app,
event)
value = app.OptimumAnnualEnergyGeneratedkWhEditField.Value;
end

% Value changed function: TimeZoneDropDown
function TimeZoneDropDownValueChanged(app, event)
value = app.TimeZoneDropDown.Value;
end
end

% Component initialization
methods (Access = private)

% Create UIFigure and components
function createComponents(app)

% Create UIFigure and hide until all components are created
app.UIFigure = uifigure('Visible', 'off');
app.UIFigure.Position = [100 100 640 480];
app.UIFigure.Name = 'MATLAB App';

% Create TabGroup
app.TabGroup = uitabgroup(app.UIFigure);
app.TabGroup.Position = [1 1 640 480];

% Create ProgrammeTab
app.ProgrammeTab = uitab(app.TabGroup);
app.ProgrammeTab.Title = 'Programme';

```



```

% Create PleaseinputWeatherDatafileLabel
app.PleaseinputWeatherDatafileLabel = uilabel(app.ProgrammeTab);
app.PleaseinputWeatherDatafileLabel.Position = [23 395 184 22];
app.PleaseinputWeatherDatafileLabel.Text = '1. Please input Weather
Data file: ';

% Create ImportButton
app.ImportButton = uibutton(app.ProgrammeTab, 'push');
app.ImportButton.ButtonPushedFcn = createCallbackFcn(app,
@ImportButtonPushed, true);
app.ImportButton.Position = [38 364 100 22];
app.ImportButton.Text = 'Import';

% Create PleasepreviewthefilebeforeprocessingLabel
app.PleasepreviewthefilebeforeprocessingLabel =
uilabel(app.ProgrammeTab);
app.PleasepreviewthefilebeforeprocessingLabel.Position = [23 334 243
22];
app.PleasepreviewthefilebeforeprocessingLabel.Text = '2. Please preview
the file before processing: ';

% Create PreviewButton
app.PreviewButton = uibutton(app.ProgrammeTab, 'push');
app.PreviewButton.ButtonPushedFcn = createCallbackFcn(app,
@PreviewButtonPushed, true);
app.PreviewButton.Position = [38 303 100 22];
app.PreviewButton.Text = 'Preview';

% Create DataoverviewLabel
app.DataoverviewLabel = uilabel(app.ProgrammeTab);
app.DataoverviewLabel.Position = [23 272 98 22];
app.DataoverviewLabel.Text = '3. Data overview: ';

% Create UITable
app.UITable = uitable(app.ProgrammeTab);
app.UITable.ColumnName = {'Column 1'; 'Column 2'; 'Column 3'; 'Column
4'};
app.UITable.RowName = {};
app.UITable.Position = [23 140 279 89];

% Create LatitudeEditFieldLabel
app.LatitudeEditFieldLabel = uilabel(app.ProgrammeTab);
app.LatitudeEditFieldLabel.HorizontalAlignment = 'right';
app.LatitudeEditFieldLabel.Position = [23 241 51 22];
app.LatitudeEditFieldLabel.Text = 'Latitude: ';

% Create LatitudeEditField

```

```

app.LatitudeEditField = uicontrol(app.ProgrammeTab, 'numeric');
app.LatitudeEditField.ValueChangedFcn = createCallbackFcn(app,
@LatitudeEditFieldValueChanged, true);
app.LatitudeEditField.Position = [89 241 52 22];

% Create LongitudeEditFieldLabel
app.LongitudeEditFieldLabel = uicontrol(app.ProgrammeTab);
app.LongitudeEditFieldLabel.HorizontalAlignment = 'right';
app.LongitudeEditFieldLabel.Position = [158 241 62 22];
app.LongitudeEditFieldLabel.Text = 'Longitude: ';

% Create LongitudeEditField
app.LongitudeEditField = uicontrol(app.ProgrammeTab, 'numeric');
app.LongitudeEditField.Position = [235 241 53 22];

% Create FinalResultLabel
app.FinalResultLabel = uicontrol(app.ProgrammeTab);
app.FinalResultLabel.FontSize = 15;
app.FinalResultLabel.FontWeight = 'bold';
app.FinalResultLabel.FontColor = [1 0 0];
app.FinalResultLabel.Position = [347 326 112 22];
app.FinalResultLabel.Text = '6. Final Result: ';

% Create OptimumAnnualEnergyGeneratedkWhEditFieldLabel
app.OptimumAnnualEnergyGeneratedkWhEditFieldLabel =
uicontrol(app.ProgrammeTab);
app.OptimumAnnualEnergyGeneratedkWhEditFieldLabel.HorizontalAlignment =
'right';
app.OptimumAnnualEnergyGeneratedkWhEditFieldLabel.Position = [271 76
236 22];
app.OptimumAnnualEnergyGeneratedkWhEditFieldLabel.Text = 'Optimum
Annual Energy Generated (kWh): ';

% Create OptimumAnnualEnergyGeneratedkWhEditField
app.OptimumAnnualEnergyGeneratedkWhEditField =
uicontrol(app.ProgrammeTab, 'numeric');
app.OptimumAnnualEnergyGeneratedkWhEditField.ValueChangedFcn =
createCallbackFcn(app,
@OptimumAnnualEnergyGeneratedkWhEditFieldValueChanged, true);
app.OptimumAnnualEnergyGeneratedkWhEditField.Position = [522 76 100
22];

% Create OptimalTiltanglevalueEditFieldLabel
app.OptimalTiltanglevalueEditFieldLabel = uicontrol(app.ProgrammeTab);
app.OptimalTiltanglevalueEditFieldLabel.HorizontalAlignment = 'right';
app.OptimalTiltanglevalueEditFieldLabel.Position = [356 44 151 22];
app.OptimalTiltanglevalueEditFieldLabel.Text = 'Optimal Tilt angle
value ( $\beta$ ): ';

```

```

% Create OptimalTiltanglevalueEditField
app.OptimalTiltanglevalueEditField = uicontrol(app.ProgrammeTab,
'numeric');
app.OptimalTiltanglevalueEditField.Position = [522 44 100 22];

% Create OptimalAzimuthanglevalueEditFieldLabel
app.OptimalAzimuthanglevalueEditFieldLabel = uicontrol(app.ProgrammeTab);
app.OptimalAzimuthanglevalueEditFieldLabel.HorizontalAlignment =
'right';
app.OptimalAzimuthanglevalueEditFieldLabel.Position = [329 13 178 22];
app.OptimalAzimuthanglevalueEditFieldLabel.Text = 'Optimal Azimuth
angle value (γ)';

% Create OptimalAzimuthanglevalueEditField
app.OptimalAzimuthanglevalueEditField = uicontrol(app.ProgrammeTab,
'numeric');
app.OptimalAzimuthanglevalueEditField.Position = [522 13 100 22];

% Create AftercheckingpleaseproceedLabel
app.AftercheckingpleaseproceedLabel = uicontrol(app.ProgrammeTab);
app.AftercheckingpleaseproceedLabel.Position = [347 395 186 22];
app.AftercheckingpleaseproceedLabel.Text = '5. After checking, please
proceed: ';

% Create ViewResultButton
app.ViewResultButton = uicontrol(app.ProgrammeTab, 'push');
app.ViewResultButton.ButtonPushedFcn = createCallbackFcn(app,
@ViewResultButtonPushed, true);
app.ViewResultButton.FontWeight = 'bold';
app.ViewResultButton.Position = [419 297 100 22];
app.ViewResultButton.Text = 'View Result';

% Create ViewFileButton
app.ViewFileButton = uicontrol(app.ProgrammeTab, 'push');
app.ViewFileButton.ButtonPushedFcn = createCallbackFcn(app,
@ViewFileButtonPushed, true);
app.ViewFileButton.Position = [220 270 68 26];
app.ViewFileButton.Text = 'View File';

% Create Label
app.Label = uicontrol(app.ProgrammeTab);
app.Label.FontSize = 14;
app.Label.FontWeight = 'bold';
app.Label.FontAngle = 'italic';
app.Label.FontColor = [1 0 0];
app.Label.Position = [120 411 436 49];

```

```

app.Label.Text = 'Optimum Tilt Angle ( $\beta$ ) and Azimuth Angle ( $\gamma$ ) of
Fixed-PV panel';

% Create ProceedButton
app.ProceedButton = uibutton(app.ProgrammeTab, 'push');
app.ProceedButton.ButtonPushedFcn = createCallbackFcn(app,
@ProceedButtonPushed, true);
app.ProceedButton.Position = [364 364 100 22];
app.ProceedButton.Text = 'Proceed';

% Create SubmitButton
app.SubmitButton = uibutton(app.ProgrammeTab, 'push');
app.SubmitButton.ButtonPushedFcn = createCallbackFcn(app,
@SubmitButtonPushed, true);
app.SubmitButton.Position = [219 12 100 22];
app.SubmitButton.Text = 'Submit';

% Create Aream2Label
app.Aream2Label = uilabel(app.ProgrammeTab);
app.Aream2Label.HorizontalAlignment = 'right';
app.Aream2Label.Position = [52 44 67 22];
app.Aream2Label.Text = 'Area (m2):';

% Create Aream2EditField
app.Aream2EditField = uieditfield(app.ProgrammeTab,
'numeric');
app.Aream2EditField.Position = [134 44 73 22];

% Create EfficiencyLabel
app.EfficiencyLabel = uilabel(app.ProgrammeTab);
app.EfficiencyLabel.HorizontalAlignment = 'right';
app.EfficiencyLabel.Position = [37 12 82 22];
app.EfficiencyLabel.Text = 'Efficiency (%):';

% Create EfficiencyEditField
app.EfficiencyEditField = uieditfield(app.ProgrammeTab,
'numeric');
app.EfficiencyEditField.Position = [134 12 73 22];

% Create EnterTimezoneAreaandEfficiencyofFixedPVpanelLabel
app.EnterTimezoneAreaandEfficiencyofFixedPVpanelLabel =
uilabel(app.ProgrammeTab);

app.EnterTimezoneAreaandEfficiencyofFixedPVpanelLabel.Position = [23
105 321 22];
app.EnterTimezoneAreaandEfficiencyofFixedPVpanelLabel.Text
= '4. Enter Time zone, Area and Efficiency of Fixed-PV panel:';

```

```

% Create TimeZoneDropDownLabel
app.TimeZoneDropDownLabel = uilabel(app.ProgrammeTab);
app.TimeZoneDropDownLabel.HorizontalAlignment = 'right';
app.TimeZoneDropDownLabel.Position = [30 77 63 22];
app.TimeZoneDropDownLabel.Text = 'Time Zone';

% Create TimeZoneDropDown
app.TimeZoneDropDown = uidropdown(app.ProgrammeTab);
app.TimeZoneDropDown.Items = {'UTC', 'UTC +1', 'UTC +2',
'UTC +3', 'UTC +4', 'UTC +5', 'UTC +6', 'UTC +7', 'UTC +8', 'UTC +9',
'UTC +10', 'UTC +11', 'UTC +12'};
app.TimeZoneDropDown.ValueChangedFcn =
createCallbackFcn(app, @TimeZoneDropDownValueChanged, true);
app.TimeZoneDropDown.Position = [108 77 100 22];
app.TimeZoneDropDown.Value = 'UTC +8';

% Create Image
app.Image = uiimage(app.ProgrammeTab);
app.Image.Position = [318 126 312 157];
app.Image.ImageSource = 'IMG_1556.jpg';

% Show the figure after all components are created
app.UIFigure.Visible = 'on';
end
end

% App creation and deletion
methods (Access = public)

% Construct app
function app = GUI

% Create UIFigure and components
createComponents(app)

% Register the app with App Designer
registerApp(app, app.UIFigure)

if nargin == 0
    clear app
end
end
end

```

```
% Code that executes before app deletion
function delete(app)

    % Delete UIFigure when app is deleted
    delete(app.UIFigure)
end
end
end
```