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Summer-2017

The Performance Analysis of Single and Dual Axis Sun Tracking System: A Comparative Study

A Thesis submitted to the
Dept. of Electrical & Electronic Engineering
BRAC University
In partial fulfillment of the requirements for the
Bachelor of Science degree in Electrical & Electronic Engineering

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Declaration

We do hereby declare that the thesis titled "The Comparative Performance Analysis of Single and Dual Axis Sun Tracking System: A Comparative Study" submitted to the Department of Electrical and Electronic Engineering of BRAC University in the partial fulfillment of the Bachelor of Science in Electrical and Electronic Engineering, is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

Date: 20/08/2017

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Acknowledgement

We would like to extend our profound gratitude to our thesis advisor Dr. Md. Mosaddequr Rahman, Professor, BRAC University, who has kindly assisted us with his involvement in every step throughout the accomplishment of this paper. We are thankful to him for his cooperation, professionalism, valuable guidance and encouragement throughout the course of this work. Moreover, we would like to thank our parents and friends for inspiring us.

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Chapter 1: Introduction

1.1 Introduction to Solar Energy:

Solar Energy is touted to be the 3rd most renewable power source with the help of photo voltaic technology. Industrially advanced countries e.g. Germany, Italy, China and the USA are ranked to be the top countries with highest installed capacity of solar PV power. According to the studies of International Energy Agency in 2010, ostensibly, global solar PV capacity could reach 3000 GW or in other words, 11% of total projected global energy production by the year 2050. Therefore, it can be safely presumed that to combat the acute shortage of power as well as to meet with the ever increasing demand of energy solar energy, in near future, will emerge as a fitting and applicable substitute to other power sources. But what exactly is Solar power? And how the “ball of fire” glaring at us every day from the sky will produce energy?
Let's delve into it for a better understanding.

1.1.1 Solar Power:

In simpler words, solar energy is the energy created by the properties i.e. light and heat of the Sun. The radiation of the Sun can be used to create electricity by photo voltaic technologies. Photo voltaic literally means “light” and “electric.” A photo voltaic system generally employs solar panels comprising solar cells. The function of photovoltaic system has been described in details with figures in the next chapter.

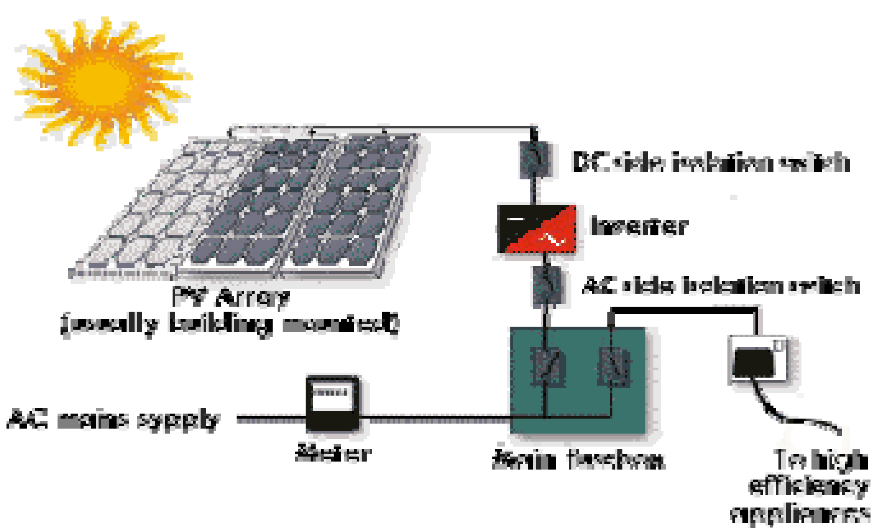


Figure:1.1 General set up of a solar panel.

1.2 Photovoltaic System:

Photovoltaic system is the most integral part in the history of solar energy and its discovery. The PV system gets its name from its function of converting photons to voltage. To elaborate, photovoltaic system converts direct sunlight to electricity via an electronic process by the means of certain types of materials called the semiconductors namely silicon. These materials manifest a unique property which causes them to absorb photons from light resulting in heating of the atoms and therefore creating free flow of electrons.

This magnificent natural phenomenon was first noted by the French physicist Edmund Bequerel, who came across the fundamental property of photoelectric effect in 1839. He noticed that exposure to sunlight could facilitate some materials to produce a small amount of electrical current. The first photovoltaic module was created almost a century later in 1954 by Bell Laboratories, which only served the purpose of curbing his curiosity as the expense was unimaginable back then to spark widespread use of this sophisticated procedure of generating electricity. During the 1970s, due to an acute shortage of power worldwide, the photovoltaic power generation system gained momentum and was being used as an additional source of power besides the mainstream electricity generation by fossil fuel.

1.2.1 How PV technology works:

Fundamentally, when photons from sunlight hit the cell, the semiconductor material gets ionized and consequently the atoms of the outermost layers break-free. Owing to the structure of the semiconductor, when the electrons pass the pn-junction situated near the upper surface of the panel, they cannot return easily and hence the upper side of the panel facing the sun forms negative voltage and the ‘holes’ or the positive charges of the pn-junction stick to the rear surface of the panel creating a positive voltage. The rear and upper sides can be connected via a circuit to extract electricity and voltage. A number of solar cells could be electrically connected and mounted on a structure to be called a photovoltaic module.

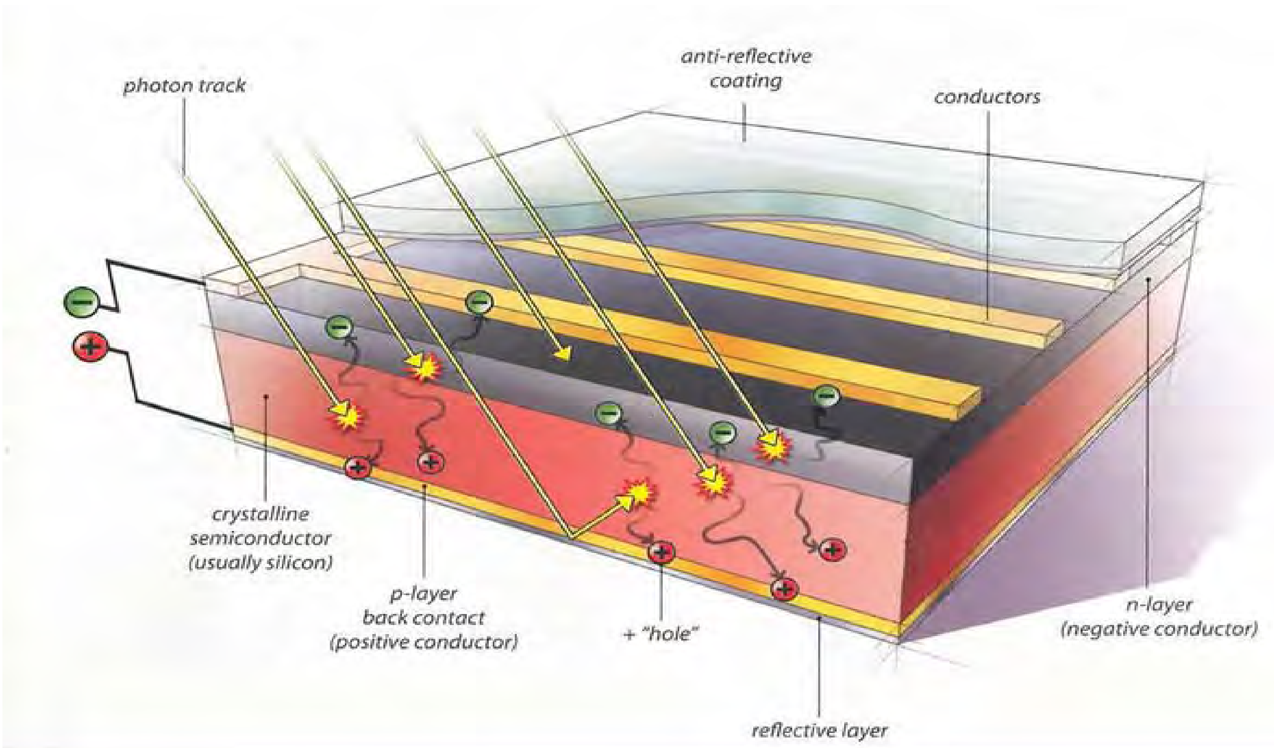


Figure:1.2 Mechanism of Photovoltaic system at molecular level

1.2.2 Modern day photovoltaic systems:

CPV: The traditional PV is more or less 15% efficient which indicates a larger chunk of the sunlight that hits the panel don't get converted into electricity. However, after the invention of photovoltaic modules in the 1950s, a lot of research and studies have gone into rendering the process more effective and beneficial. This technology has evolved a lot since the beginning of its use and scientists have come up with a number of solutions so as to modernize and revolutionize the fundamental underlying ideas of PV systems. One of it is known as concentrated photovoltaic system or CPV. Contrary to conventional PV, this one uses lenses and curved mirrors so as to concentrate sunlight and force that onto highly efficient multiple junction panels. CPV often comprises tracker system and cooling system to increase the efficiency further. Experiments showed that the efficiency of CPV can reach as much as 33% under standard test conditions and by mid 2020s, the efficiency rate is expected to hit as high as 50%.

3rd generation photovoltaic cells: 3rd generation PV systems, although much not in use, could potentially overcome the limitation in power efficiency for single band gap solar cells. Common third-generation systems include multi-layer cells made of amorphous silicon or gallium arsenide.

Other emerging photovoltaic include - Copper zinc tin sulfide solar cells, organic solar cells, polymer solar cells, perovskite solar cells etc.

1.3 Motivation:

One asset that Bangladesh is famously known for is her manpower. Bangladesh is one of the most overtly populated countries of the world and time and again it's proven to be a huge task for her to provide for her huge population. Energy is no exception to it. Bangladesh's energy infrastructure is small and insufficient. The per capita energy consumption is on the lower side compared to global standards. The huge scarcity of electricity is a raging issue that every sitting government tries to combat but not enough has been achieved to showcase considerable improvement. A large no of people of this country are deprived of electricity and that directly affect their living standards. As of 2014, only 62% of our total population has access to electricity. That indicates about one-third of the huge population is still deprived of something as fundamental as basic electricity for day to day to life necessity. The situation is seen to be a tiny bit better in major city areas like the capital after cross-border electricity trading has been ensured from the neighboring countries. However, that also hasn’t proven to be adequate to meet the huge demand of electricity of our land. Especially the rural areas continue to suffer from severe lack of supply of electricity.

Au contraire, solar energy is consistently getting more popular among people as a substitute to regularly transmitted electricity as it entirely depends on cosmic energy and there is no extra hassle of monthly utility cost and as it has been mentioned solar energy exudes next to nothing in terms of harmful waste into the environment. Keeping all such facts in mind, the authors have acquired motivation for coming up with a dual axis solar tracker which has the potential to curb the acute dearth of electrical power which engulfed the nation since forever.

1.4 Problems with traditional energy sources:

Every single thing of our world would come to a standstill if there were no energy sources. Energy sources are something namely coal, natural gas, oil, wind, solar etc. which can be used to provide power for light, heat, machines etc. Among all the energy sources, fossil fuels such as coal, oil, gas are used traditionally to produce energy and fulfill the demand of energy to run vehicles, industries, machineries and everything that needs energy. Today more than 85% energy consumed in USA is produced by fossil fuels and this reliance on fossil fuels is growing significantly. As such one day there will be scarcity of energy sources if they are over. Many problems can be observed generated by the fossil fuels and for that we need to look for alternative energy sources such as renewable energy, nuclear energy etc.

When the topic comes to regarding the environment, it is proven that extraction of oil has severe impacts on environment. There is a significant increase in vehicle traffic at oil drilling sites that creates noise pollution in wild lands. It becomes often very difficult for the wildlife migrating their routes and habitats due to noise pollution. Sometimes oil spills on land and offshore drilling sites. Consequently, animal limbs are damaged and even it causes cancer and reproduction failure to them. Poisonous chemical, vapor and dust infect the water and air as well. The discharge of methane during the extraction of oil contributes severely to climate change.

In power plants, fired coal often pollutes air which comprises of heavy metals, sulfur dioxide, nitrogen oxide and some particular matter (PM). As a result, environmental change occurs in the form of acid rain, smog, venoms in the environment and countless cerebrovascular, respiratory, cardiovascular effects. Emission of particular matter and gases from the coal mines such as CH4(Methane), CO (Carbon Mono Oxide), SO2 (Sulphur Di oxide) pollute air. When the coal is washed, it produces the liquid coal waste named slurry. Spills or leaks jeopardize earth waters and underground as sludge of coal contains toxins. Some radioactive elements such as Uranium and Thorium are often found in coals and when the coal is burnt, ash flies up to ten times their original levels containing those elements. Mining, processing, burning and waste storage of coal pollute water and have serious impacts on health and environment. Culm known as waste coal is comprised of mixture of coal that is not used with soil and rock and occurs from previous mining operations and the supply of local water is often polluted from the runoff local waste coal.

The combustion of natural gas has influence on global warming. The main component of natural gas is methane and it leaks during the removal and drilling of natural gas from wells. In addition, methane is 34 times powerful than carbon dioxide at trapping heat over a 100-year period and 86 times stronger over a 20-year period. When the natural gas is burned, nitrogen oxides are produces which is a precursor to smog. Local and regional air quality can be affected by unconventional gas development. In some areas where people drill, there is noticeable increase in hazardous air pollutants e.g. particular matter and ozone. These components have adverse effects on human health and can often cause cancer. Those who live less than a half mile from unconventional gas well sites are at greater risk than those of living farther from well sites. Erosion of dirt, minerals and other harmful pollutants into nearby streams may occur due to construction process when the site is cleared to build a well pad, pipelines and across roads. Drinking water sources are often contaminated with hazardous chemicals used in drilling the wellbore, the refining and processing the gas, disposing of wastewater, hydraulically fracturing the well and so on and these are some adverse effects on communities imposed by unconventional gas development.

1.5 Project Overview:

The authors have worked on the performance evaluation of the three types of solar power systems: 1. Fixed Axis 2.Single Axis and 3. Dual Axis.

The fixed axis solar system is generally mounted on top of a roof or in the open space where there's no blockage from trees or buildings. As the name suggests, this particular system will be fixated in a certain position and will not be moving with the course of a day or a year. As in, the changes of solar intensity with respect to the changes of the solar position will have no effect on the positioning of the panel.

The single axis solar panel, on the other hand, will possess the capacity to track the sun as the sun careens from east to west throughout the day. It should be notable that single axis refers to the changes in the position of the tracker to be following the sun's one dimensional movement. The sun's changing position with respect to seasons, will not be taken into account by the single axis tracker. A single axis tracker should be able to generate considerably more energy than what a fixed axis does.

The dual axis tracker is essentially able to follow the sun as it changes its positioning throughout a day as well as a year. As we are all aware of, the sun doesn't only shift from east to west on a daily basis– as seasons change, the sun's position also varies moving from north to south. The dual axis tracker essentially follows the sun's two-dimensional movement to ensure the angle of incidence between the sun ray and the panel is always kept minimum. This way the system is able to absorb maximum sunlight and therefore should be capable of producing more energy than single and fixed axis trackers.

The objective of this work is to calculate the yearly energy that the three systems yield respectively and evaluate as well as compare the performances of the systems with respect to Bangladesh. Another additional study has been added which assesses the rainy season's effect on the three system's performances and whether or not the dual axis tracker truly proves to be a better solution as compared to single axis solar tracker to benefit the solar energy revolution.

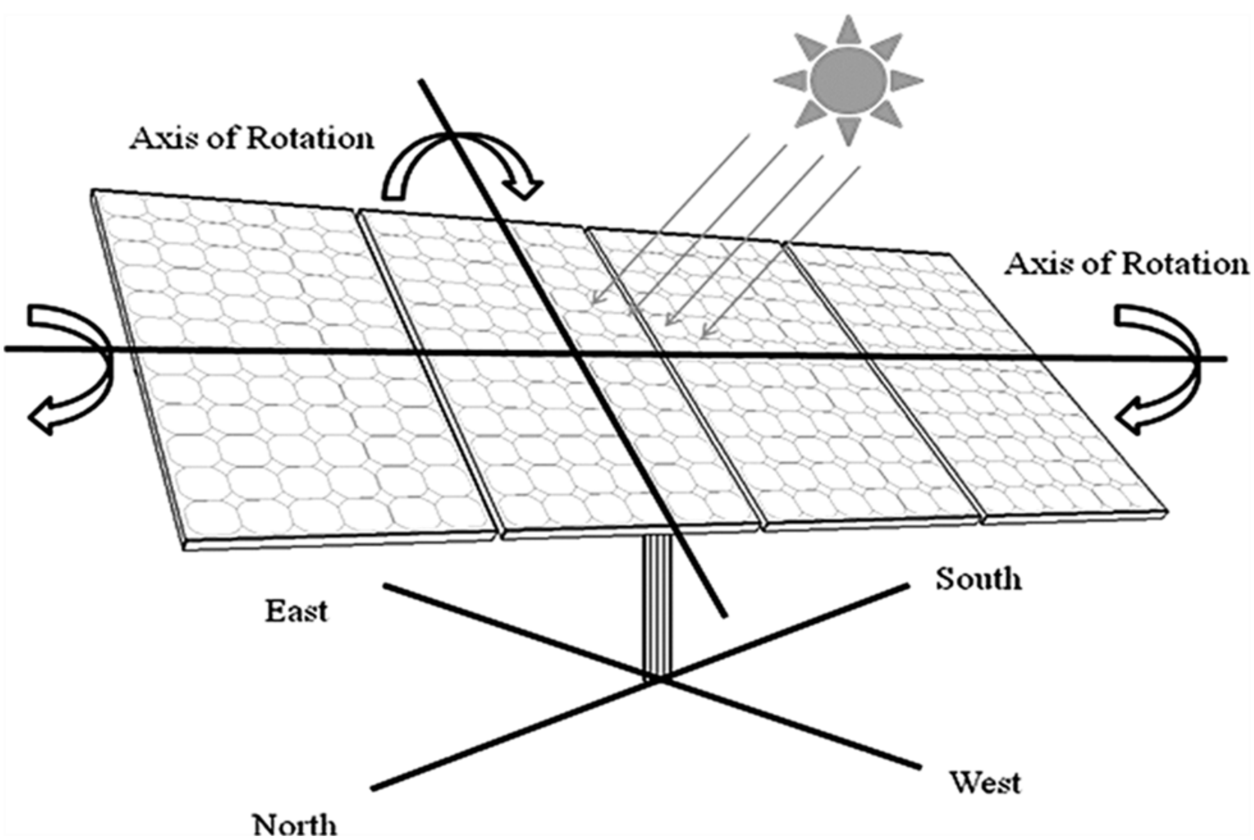


Figure:1.3 Dual axis solar tracker system.

1.6 Summary of the following chapters:

The introduction to solar energy, the motivating factors and the project overview have been jotted down in the previous chapters. In the following chapters theoretical overview on the project has been provided. In the chapter 2, an elaborate idea of solar radiation has been presented and in addition to that all the necessary terms in the context of solar intensity have been explained with illustrations. Various sun angles like solar altitude, zenith angle, solar declination angle, hour angle have been explained and later air mass, solar irradiance and cumulative incident energy have been defined too.

Moving on to the 3rd chapter, monthly solar irradiance and cumulative solar incident and energy have been calculated for a particular day, month and year, in that order and comparative plots and bar charts pertaining to the calculations have been attached for a clearer understanding of each of fixed, single and dual axis solar panels. Furthermore, a comparison between efficiency of single and dual axis trackers has been shown to assess and evaluate the difference between them. Following that, solar energy has been calculated by taking into account the cloud effect and consequent results have been demonstrated through graphs and tables. And lastly, the cost calculation of the two systems in question have been attached so as to evaluate the cost effectiveness of the systems.

Chapter:2 Theoretical Overview

2.1: Features of Solar Radiation:

The solar irradiance is the output of light energy from the entire disk of the Sun, measured at the Earth. The solar spectral irradiance is a measure of the brightness of the entire Sun at a wavelength of light. It is also known as short-wave radiation. Solar radiation comes in many forms, such as visible light, radio waves, heat (infrared), x-rays, and ultraviolet rays. Usually, when we are calculating solar energy we opt to find out the amount of irradiance from the direct sun light that is observed by the PV panels and in order to do so we also need to define its features like azimuth angle, solar altitude, latitude, declination angle, observer's location. A brief description about all these features and their respective figures defining the same are displayed in this section.

2.2 Defining Different Angles and Their Respective Equations:

2.2.1 Solar Altitude:

Solar altitude refers to the angle of the sun relative to the Earth's horizon. Solar altitude is measured in degrees. The value of the solar altitude varies based on the time of day, the time of year and the latitude on Earth. Solar altitude is defined as (α) in figure below,

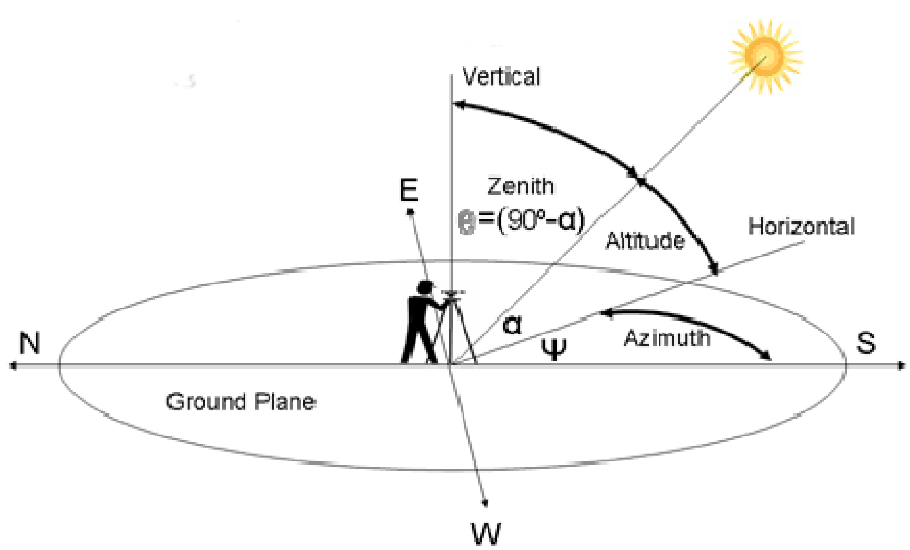


Figure: 2.2.1, Solar Altitude (α)

Solar Altitude can be calculated through the equation below,

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

2.2.2 Zenith Angle:

The solar zenith angle is the angle between the Zenith and the center of the sun's disc. The solar elevation angle is the altitude of the Sun, the angle between the horizon and the center of the Sun's disc. Since these two angles are complementary, the cosine of either one of them equals the sine of the other. Zenith Angle is shown in **Figure2.2.1** whereθ_z, is known as Zenith Angle. The equation of Zenith angle is given below,

$$\theta_z = 90° - \alpha$$

2.2.3 Declination Angle:

The declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°.

$$\delta = 23.45° \sin\left[\frac{360(n-80)}{365}\right]$$

Here, n defines number of a particular day

2.2.4 Latitude Angle:

Latitude is defined with respect to an equatorial reference plane. This plane passes through the center O of the sphere, and also contains the great circle representing the equator. The latitude of a point P on the surface is defined as the angle that a straight line, passing through both P and O, subtends with respect to the equatorial plane. If P is above the reference plane, the latitude is positive (or northerly); if P is below the reference plane, the latitude is negative (or southerly). Latitude angles can range up to +90 degrees (or 90 degrees north), and down to -90 degrees (or 90 degrees south). Latitudes of +90 and -90 degrees correspond to the north and south geographic poles on the earth.

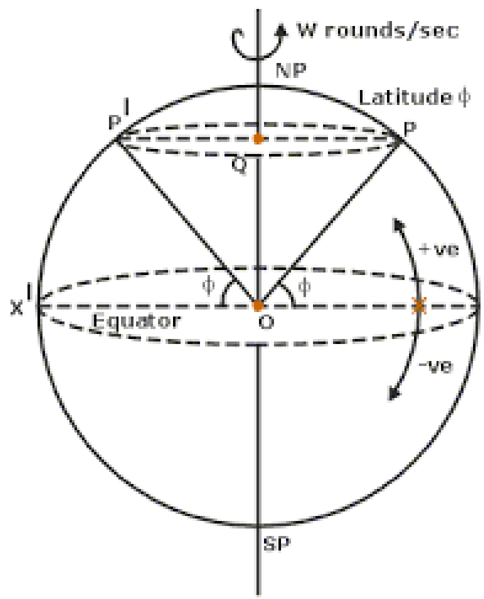


Figure 2.2.4, Latitude Angle, φ

2.2.5 Sunrise Angle:

Sunrise angle can be considered as the angle when the sun is positioned exactly on the horizon at dawn. Normally sunrise angle is calculated in degrees and express as ωs and the equation is given below,

$$\omega_s = \cos^{-1}(-\tan\delta \tan\varphi)$$

2.2.6 Hour Angle:

Observing the sun from earth, the solar hour angle is an expression of time, expressed in angular measurement, usually degrees, from solar noon. At solar noon the hour angle is 0.000 degree, with the time before solar noon expressed as negative degrees, and the local time after solar noon expressed as positive degrees. For example, at 10:30 AM local apparent time the hour angle is -22.5°. The Equation expressing hour angle is jotted here,

$$\omega = -\omega_s + \left(\left(2 * \frac{\omega_s}{t}\right) * (T - S_r)\right)$$

Where, T is particular time of a day

t is total day hour available

Sr is sun rise time of the day.

2.2.7 Sunrise and Sunset Time:

In order to find out total hours of sunlight available on a particular day we need to calculate the sun rise and sun set time of that particular day. By subtracting sunrise time from sunset we will be able to gain the value of total day hour, *t* of a day. The equations needed to do so is as follows,

$$S_r = 12 - \left(\frac{1}{15}\right) * \left(\cos^{-1}(-\tan\delta * \tan\varphi)\right)$$

Sunset time can also be found in the similar fashion. Finally, we can find the value of total day hours available by subtracting these two which is,

$$t = S_s - S_r$$

2.3 Defining Factors for Finding Solar Energy:

2.3.1 Air Mass:

Air Mass is a measure of how much atmosphere the sun's rays have to pass through on their way to the surface of the earth. Since particles in the atmosphere absorb and scatter light rays, the more atmosphere solar radiation passes through on its way to us, the less solar energy we can expect to get. The equation is given bellow:

$$AM = \csc \alpha$$

2.3.2 Solar Irradiance:

Solar irradiance is the power per unit area received from the sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument irradiance may be measured in space or at the Earth’s surface after atmospheric absorption and scattering. It is measured perpendicular to the incoming sunlight. Total solar irradiance (TSI), is a measure of the solar power over all wavelength per unit area incident on the earth’s upper atmosphere.

Units: the SI unit of irradiance is watt per square meter (W/m^2).

The equation is given bellow:

For Dual Axis:

$$I = I_0 * (0.7)^{AM^{0.678}}$$

For Single Axis:

$$I = I_0 * \cos \delta * \cos \theta$$

Where, δ will change with season but θ will remain 0 regardless of time for a particular day.

For Fixed Axis the equation is same, but θ and δ will change with time and season.

2.3.3 Cumulative Incident Energy:

Cumulative Incident energy is total of all intensity values calculated over a given time period. We can calculate total energy generation for particular time period such as for a day, for a month or even for a year. For a particular day we can use numerical integration of Intensity for a given time period like total number of hours available from dawn to dusk. In terms of months we multiply the value with the total number of days available for that particular month and for year we add up all the values for 12 months.

Cumulative Incident Energy: $A \cos \delta \int_{Sun\ Rise}^{Sun\ Set} I \cos \theta \, dt$

For Dual Axis δ , θ both are zero.

For Single Axis δ, will Change with seasons but θ, will remain unchanged.

For Fixed Axis both will change with different time and season.

Chapter:3 Calculations of Direct Beam Incident Energy

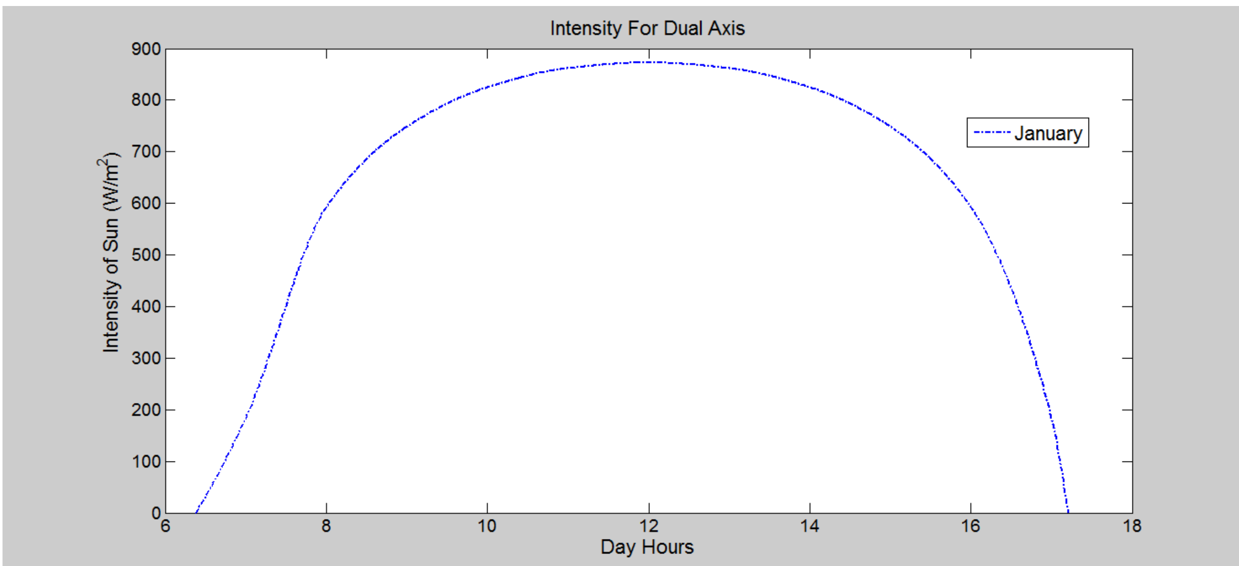
3.1Dual Axis:

In this part we will see the calculations of solar irradiance and incident energy for Dual axis solar tracker

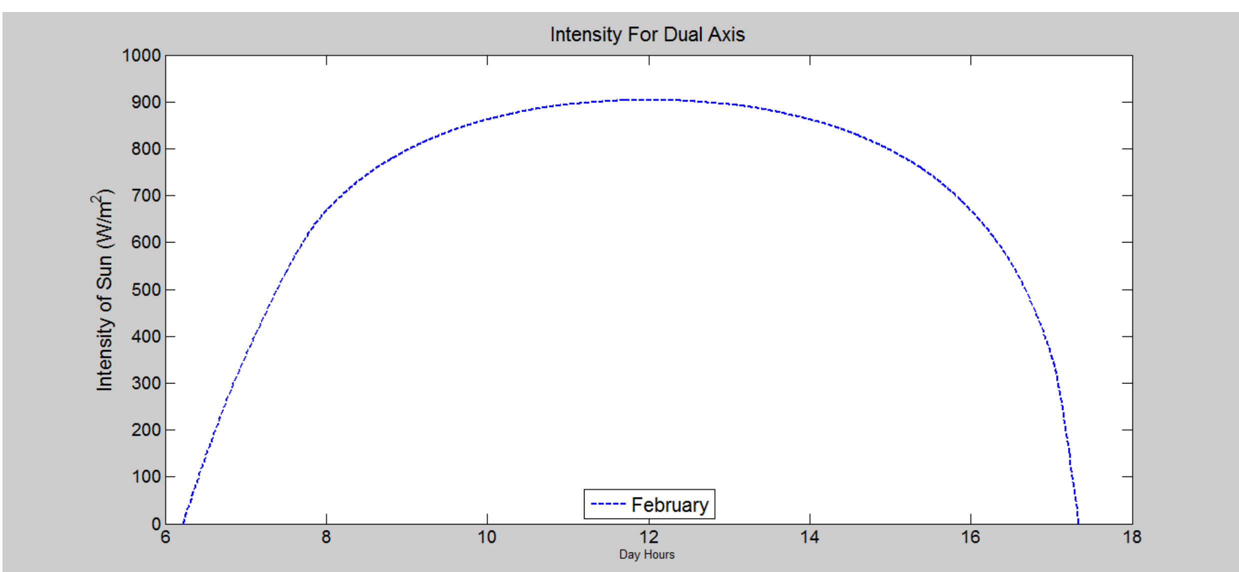
3.1.1 Monthly Solar Irradiance:

The value of solar irradiance for a day of every single month is given below by using plots:

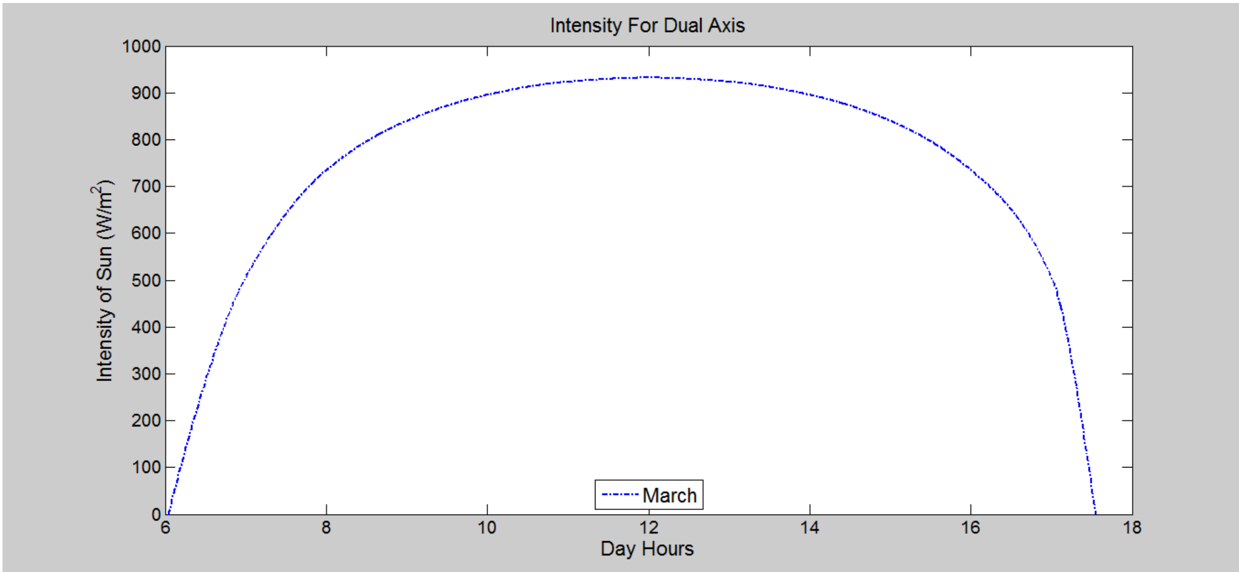
January:



February:



March:


Intensity For Dual Axis
Intensity of Sun (W/m^2)
1000
900
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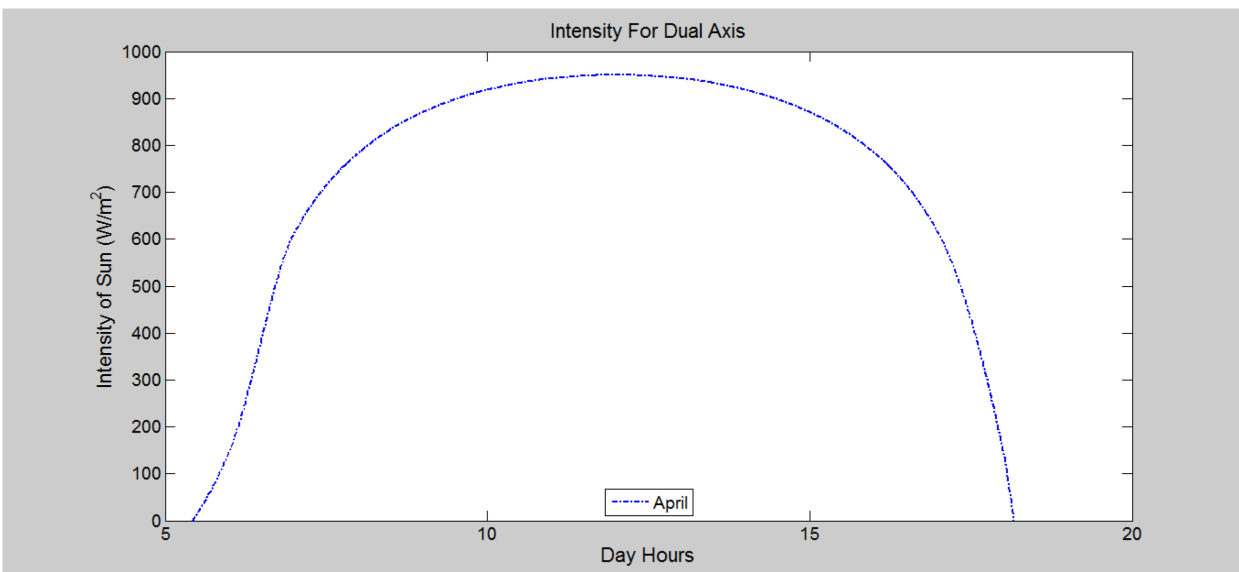
700
600
500
400
300
200
100
0
6
8
10
12
14
16
18
Day Hours
March

April:


Intensity For Dual Axis
Intensity of Sun (W/m^2)
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200
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0
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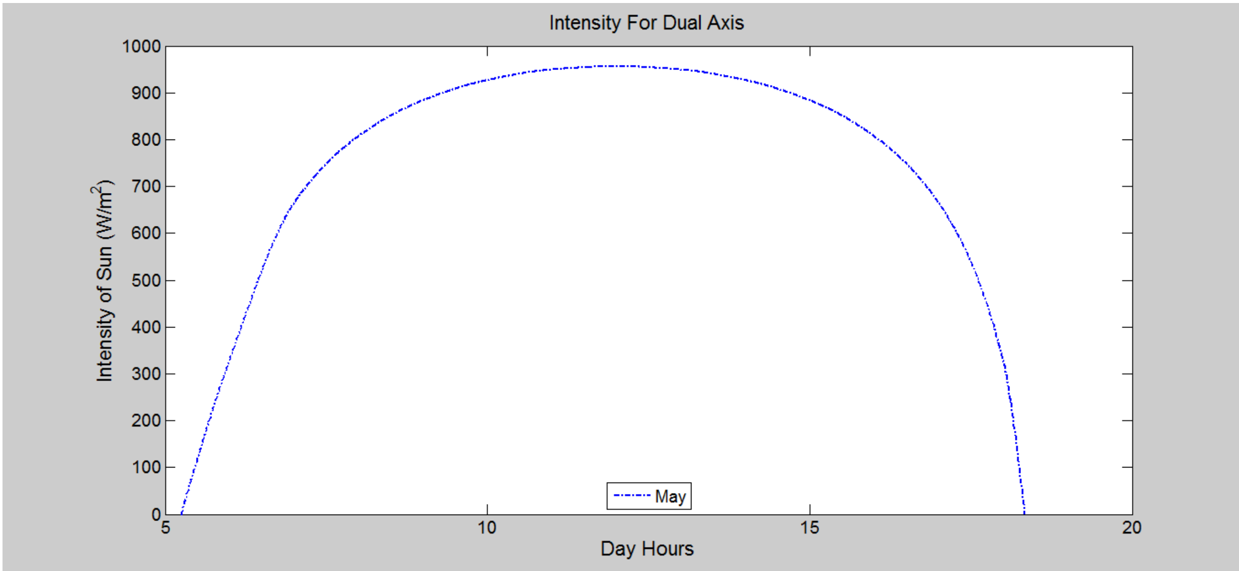
15
20
Day Hours
April

May:


Intensity For Dual Axis
Intensity of Sun (W/m2)
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200
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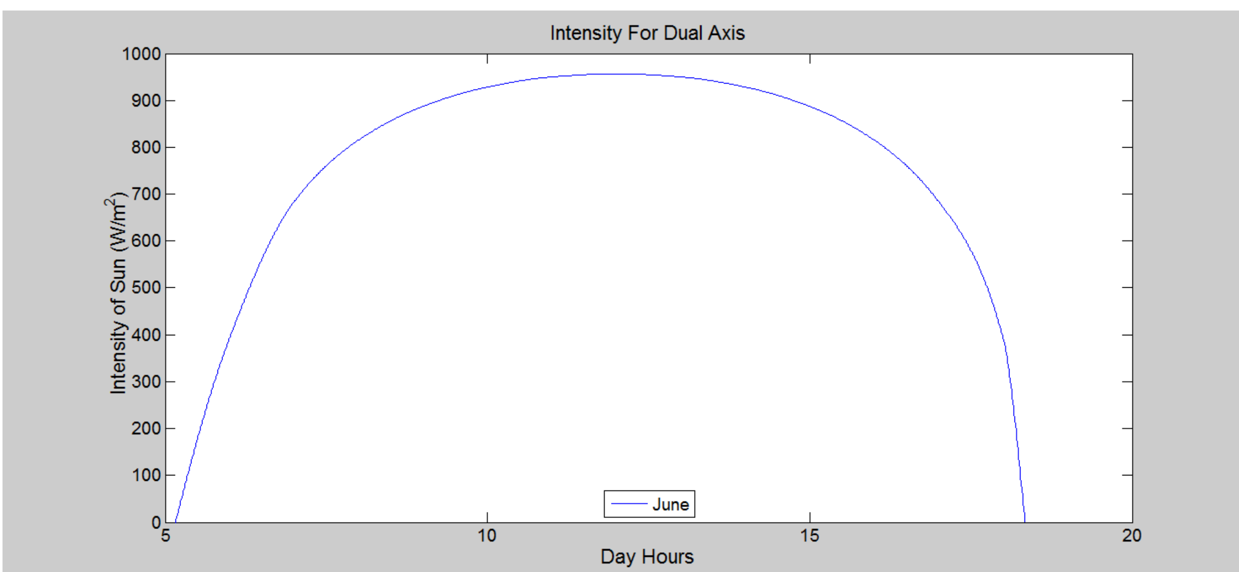
15
20
Day Hours
May

June:


Intensity For Dual Axis
Intensity of Sun (W/m2)
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200
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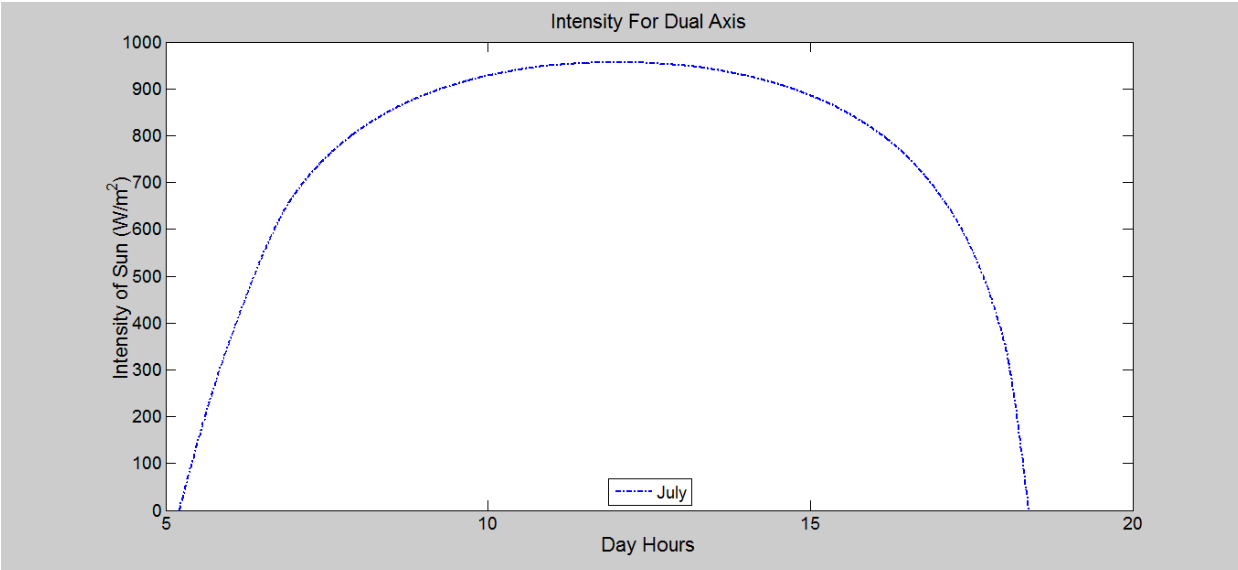
15
20
Day Hours
June

July:


Intensity For Dual Axis
Intensity of Sun (W/m2)
Day Hours
July
1000
900
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700
600
500
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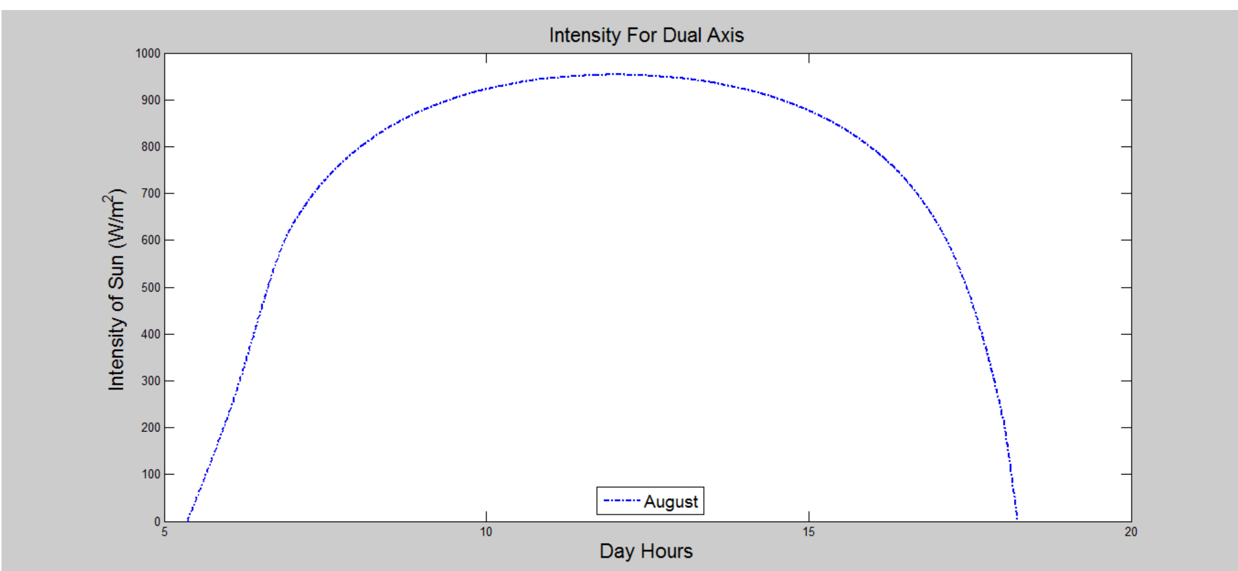
300
200
100
0
5
10
15
20

August:


Intensity For Dual Axis
Intensity of Sun (W/m2)
Day Hours
August
1000
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600
500
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200
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5
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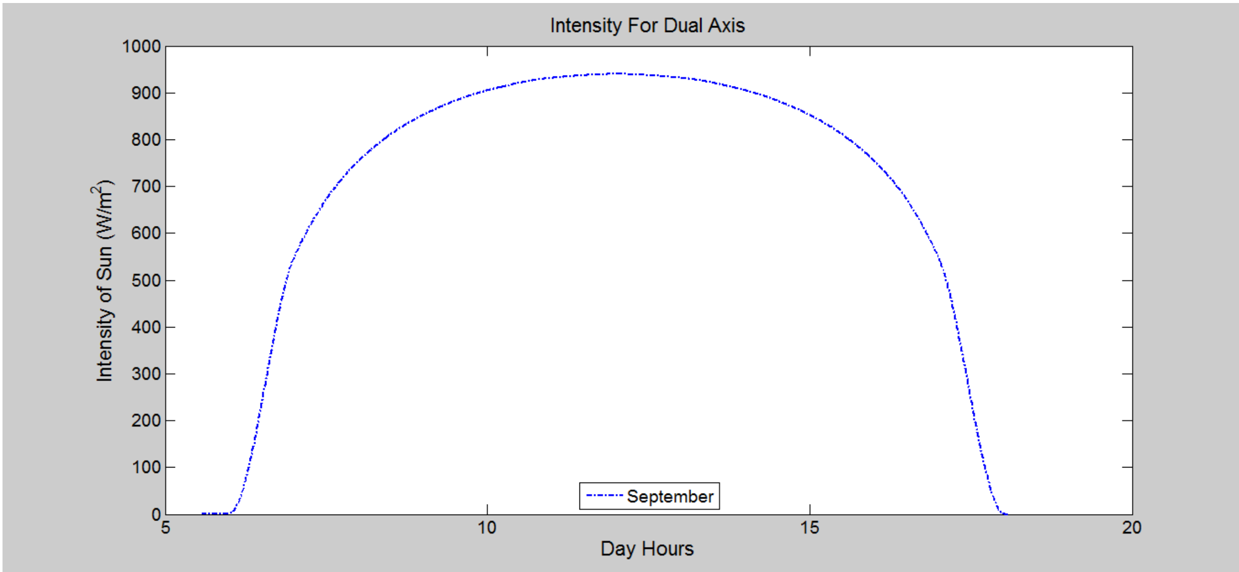
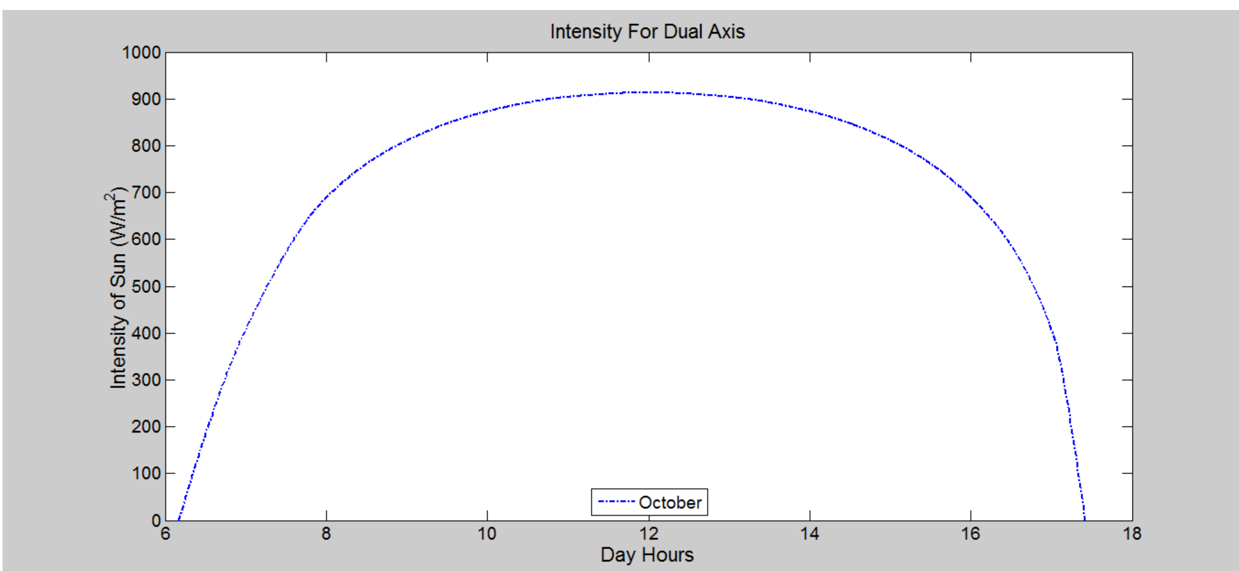
15
20

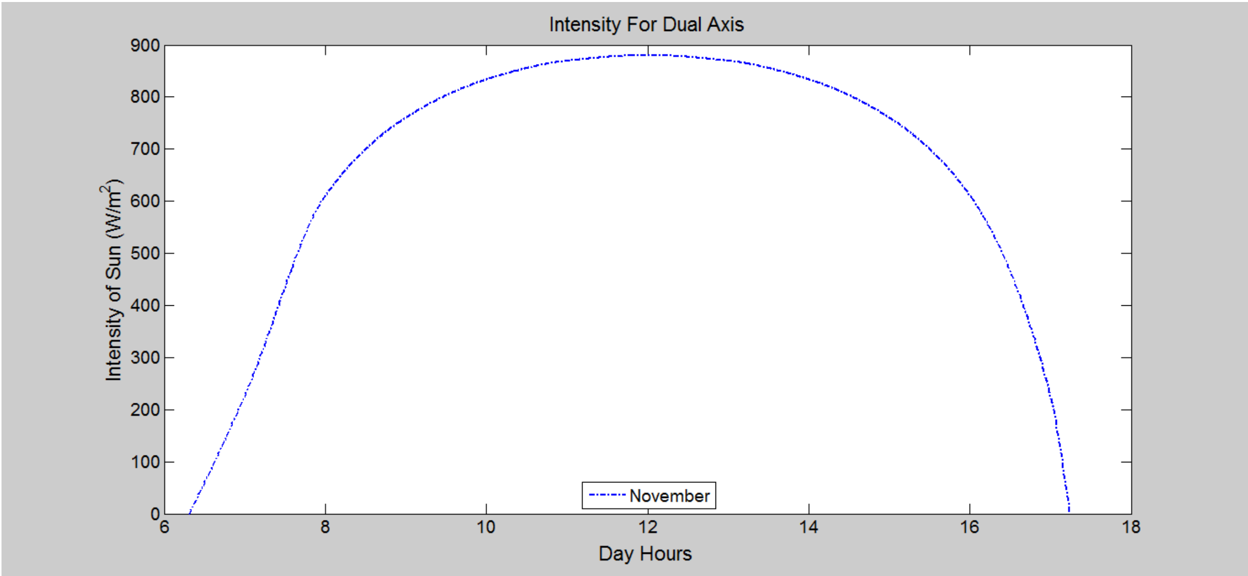
September:



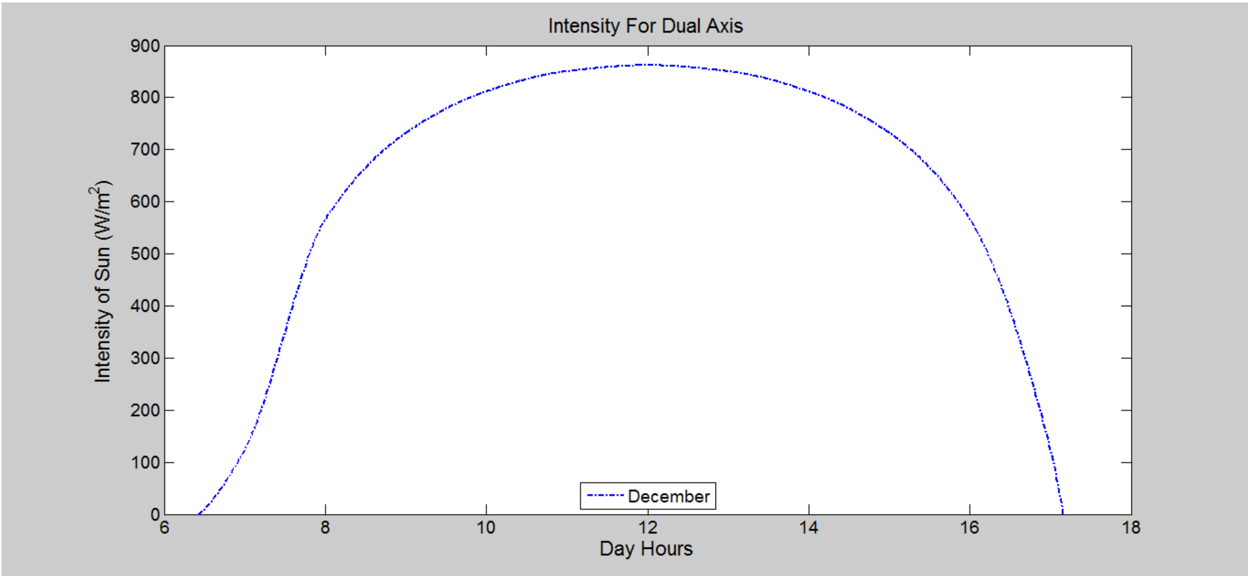
October:



November:



December:



3.1.2 Cumulative Incident Energy:

3.1.2.1 For a Particular Day for Every Month:

15-Jan	7295.3
15-Feb	8064.4
15-Mar	8729.7
15-Apr	9353.6
15-May	9749.3
15-Jun	9879.8
15-Jul	9823.4
15-Aug	9531.1
15-Sep	8924.9
15-Oct	8284.5
15-Nov	7481
15-Dec	7029.7

3.1.2.2 For Particular Months:

Incident Energy (Wh/m^2)

Dual Axis	Wh/m^2		Wh/m^2
Jan	7295.3	31	226154.3
Feb	8064.4	28	225803.2
Mar	8729.7	31	270620.7
Apr	9353.6	30	280608
May	9749.3	31	302228.3
Jun	9879.8	30	296394
Jul	9823.4	31	304525.4
Aug	9531.1	31	295464.1
Sep	8924.9	30	267747
Oct	8284.5	31	256819.5
Nov	7481	30	224430
Dec	7029.7	31	217920.7

3.1.2.3 For a particular year:

Incident Energy (Wh/m^2):

(226154.3+225803.2+270620.7+280608+302228.3+296394+304525.4+295464.1+267747+256819.5+224430+217920.7) = 3168715 Wh= 3.1687 MWh.

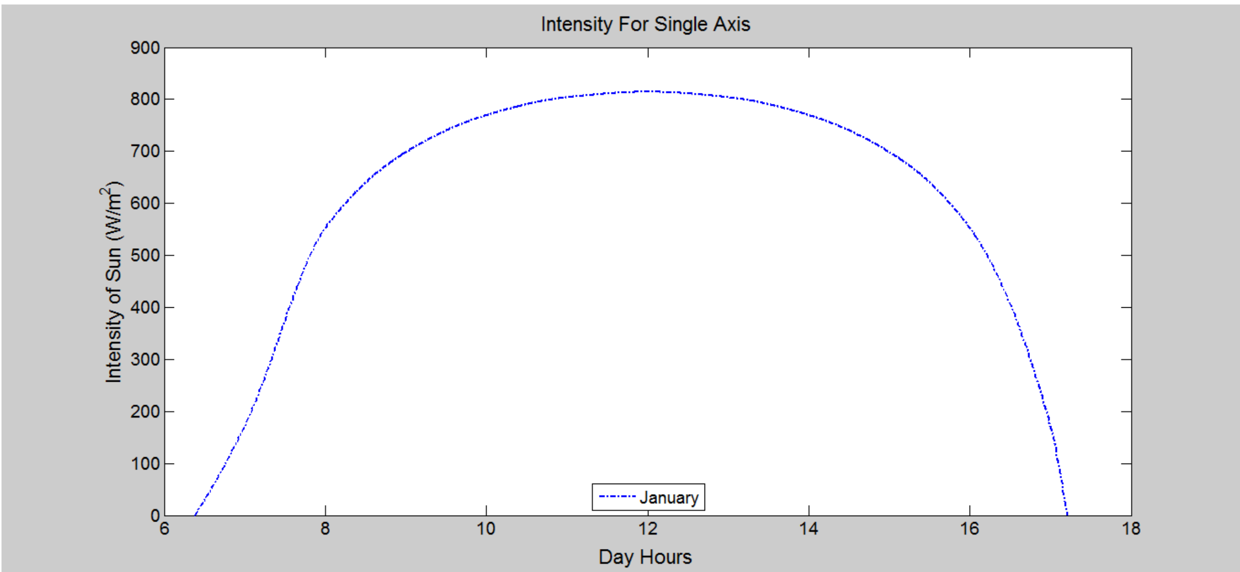
3.2 Single Axis:

In this part we will see the calculations of solar irradiance and incident energy for single axis solar tracker.

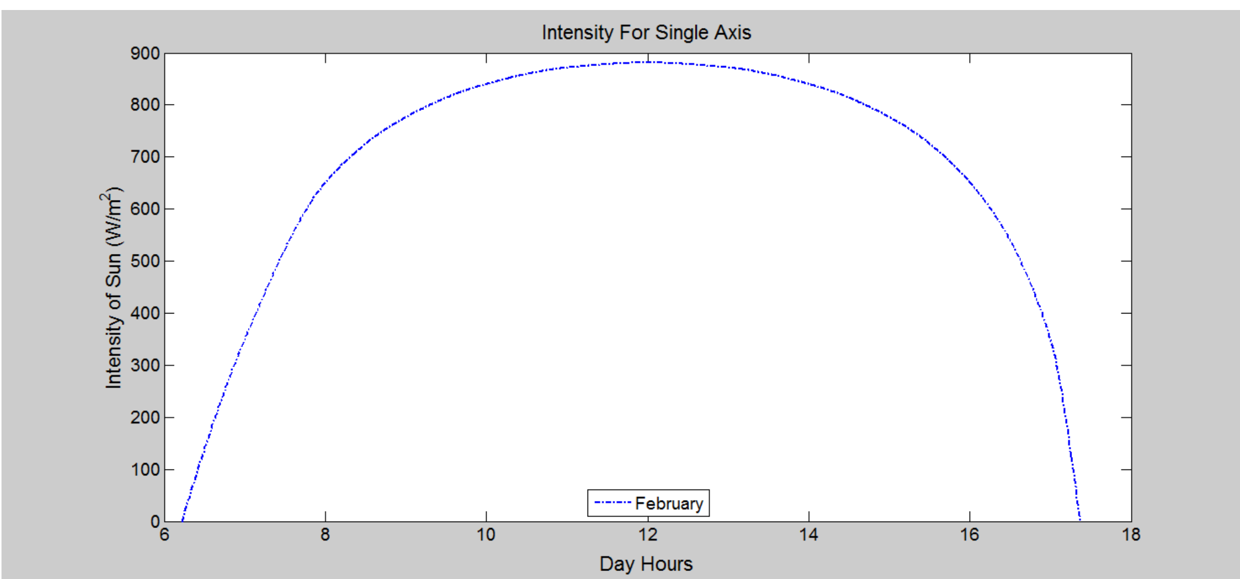
3.2.1 Monthly Solar Irradiance:

The value of solar irradiance for a day of every single month is given below by using plots:

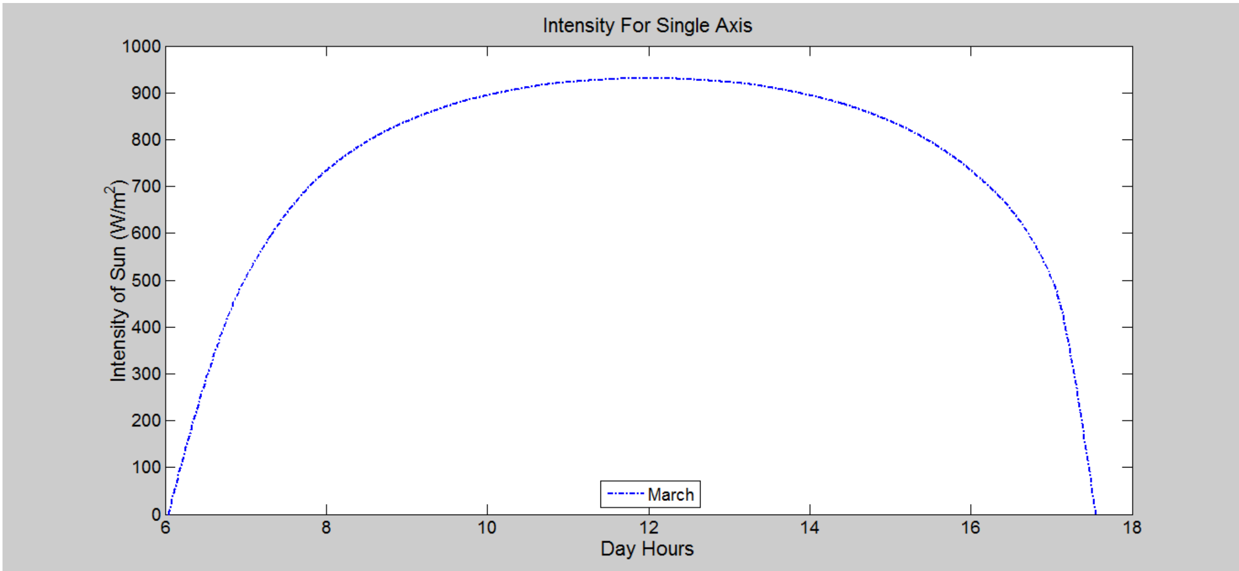
January:



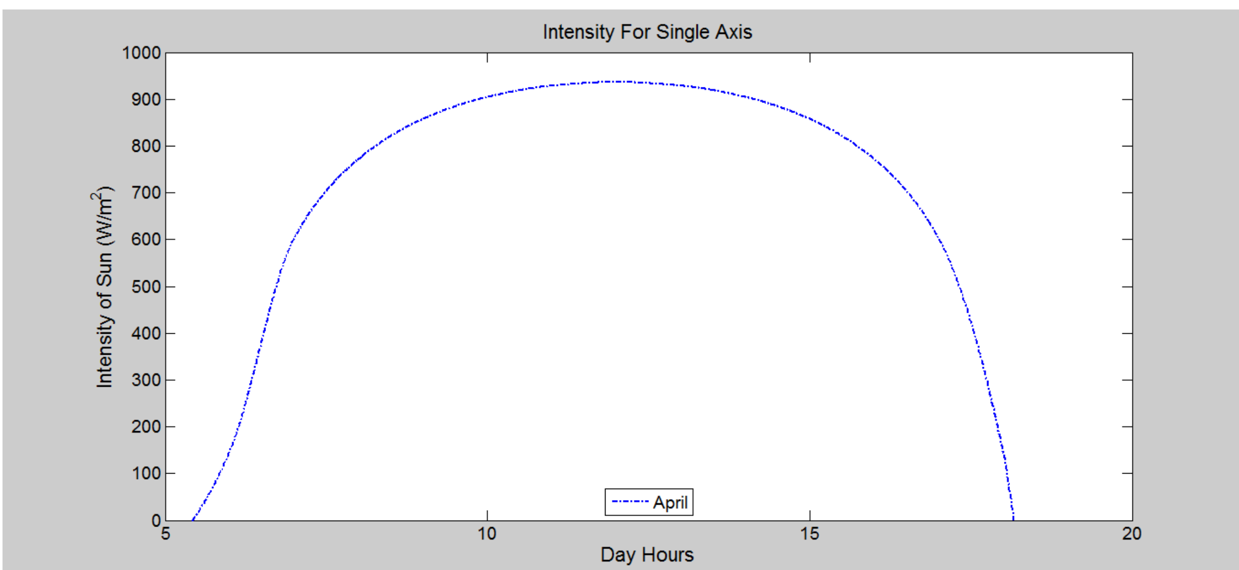
February:



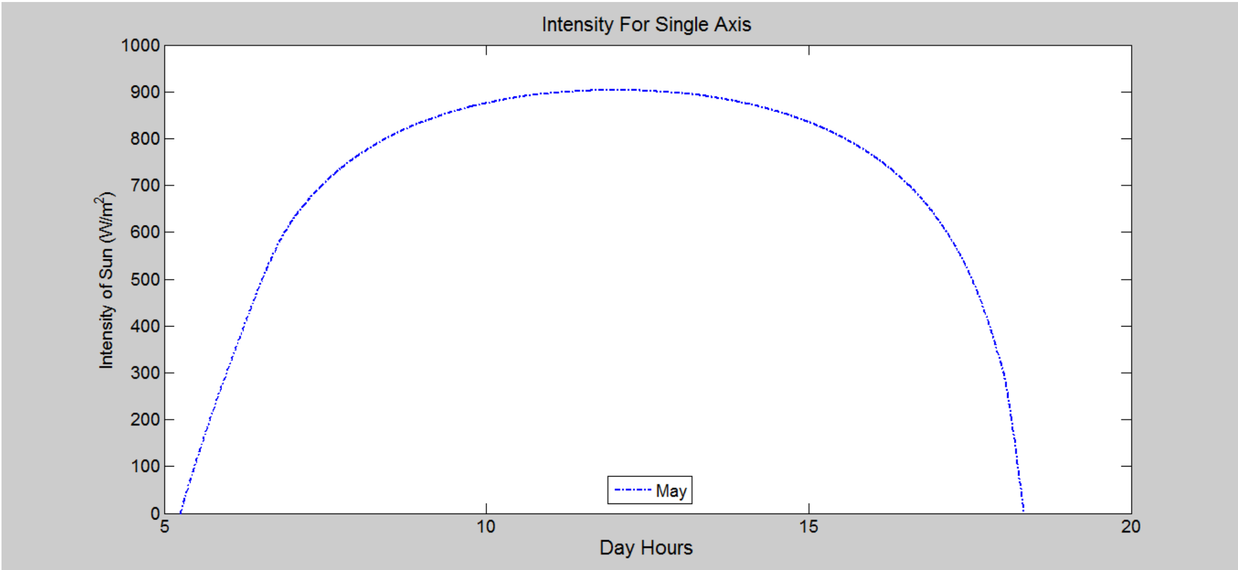
March:


Intensity For Single Axis
1000
900
800
700
600
500
400
300
200
100
0
6
8
10
12
14
16
18
Intensity of Sun (W/m2)
Day Hours
March

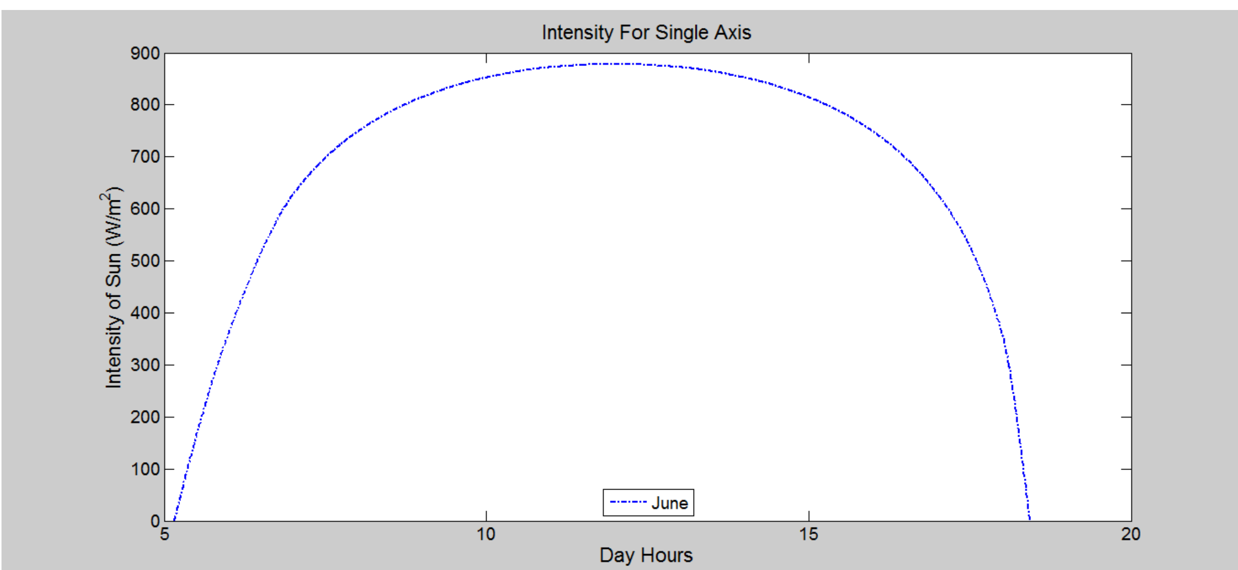
April:


Intensity For Single Axis
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Intensity of Sun (W/m2)
Day Hours
April

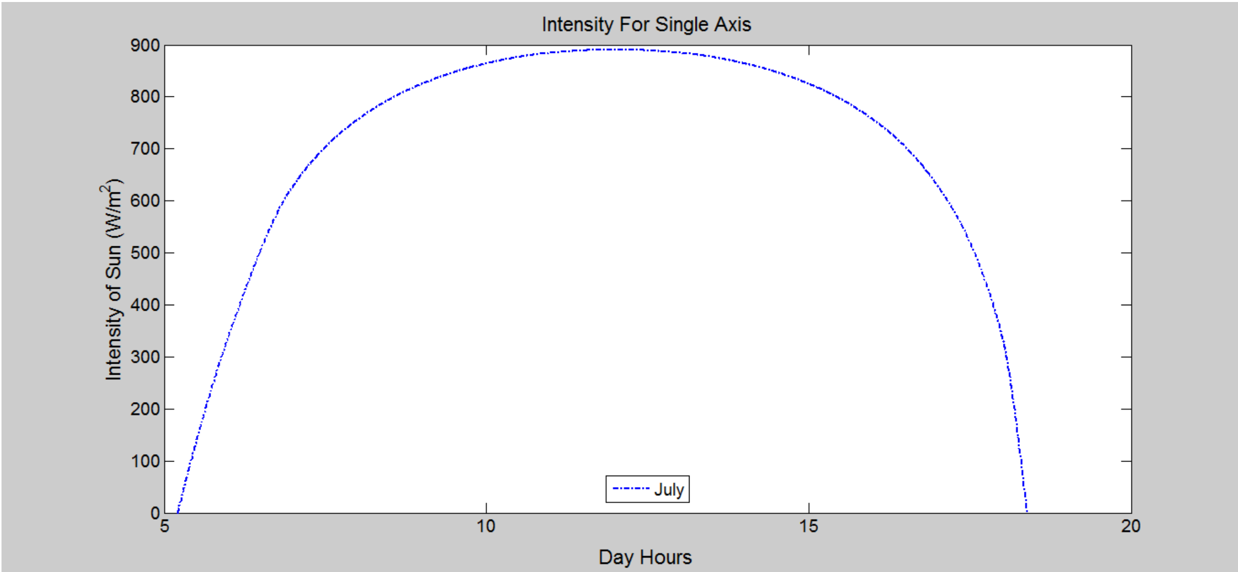
May:


Intensity For Single Axis
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
May

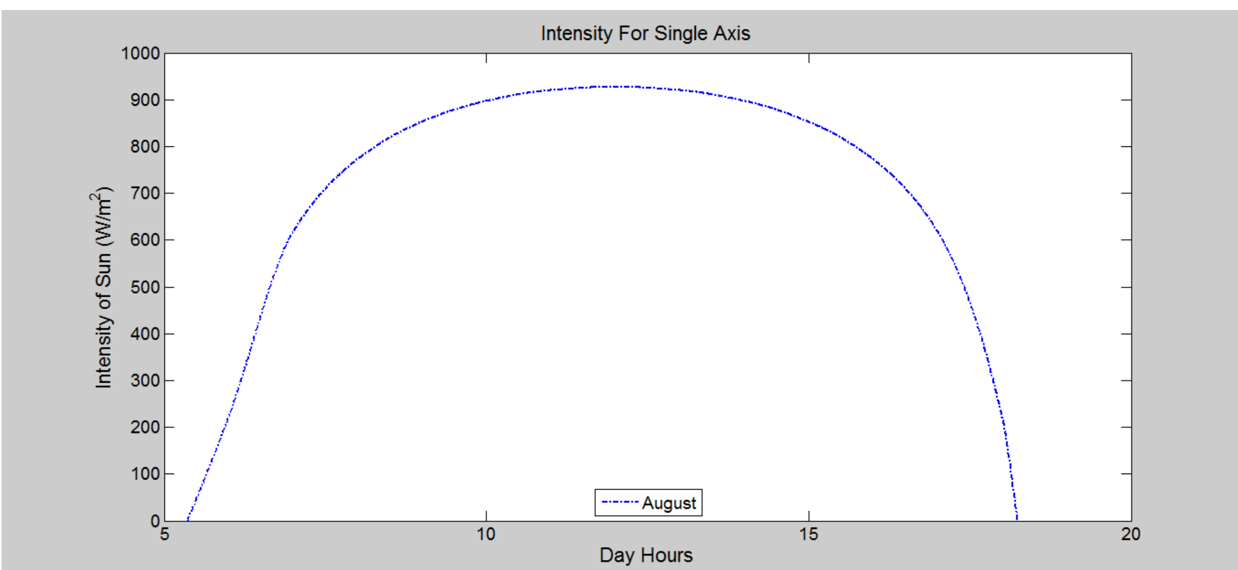
June:


Intensity For Single Axis
Intensity of Sun (W/m2)
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
June

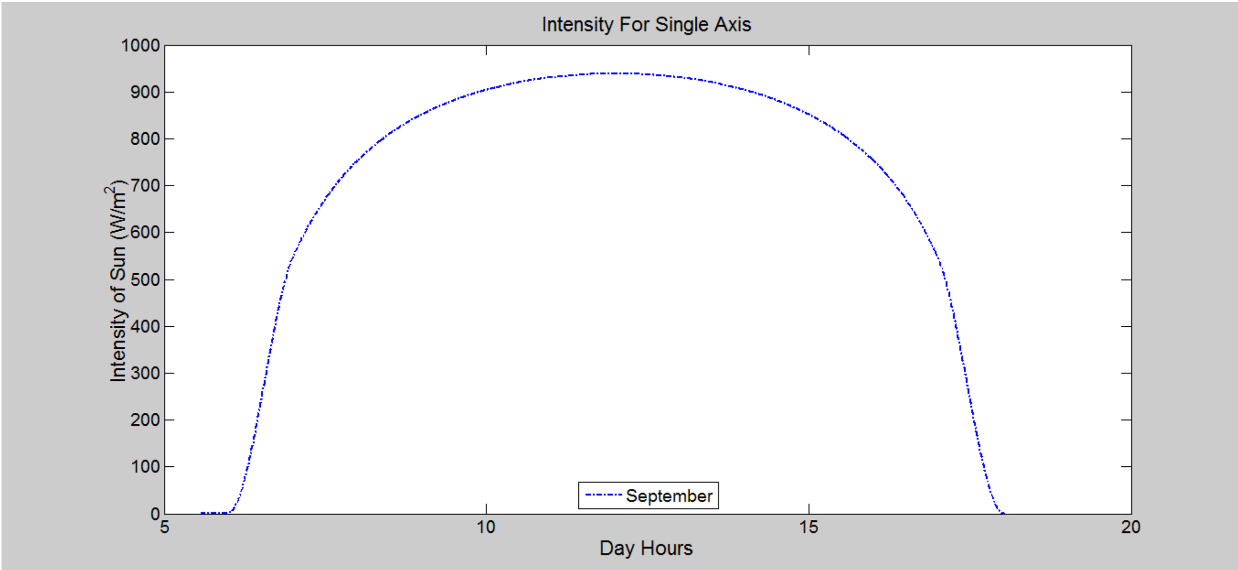
July:


Intensity For Single Axis
Intensity of Sun (W/m2)
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
July

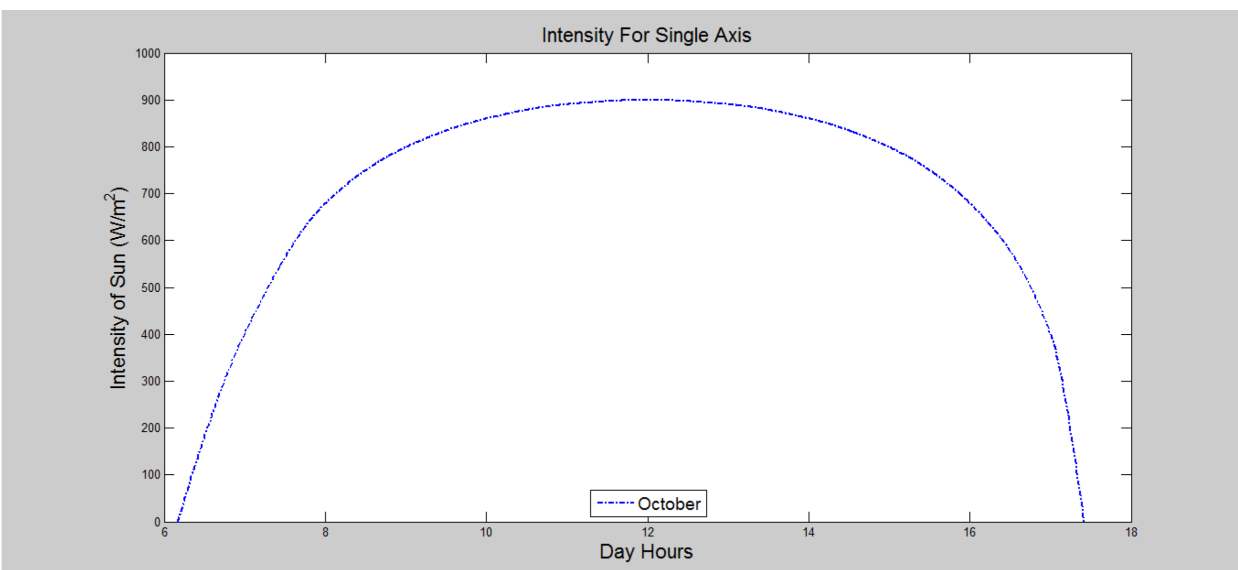
August:


Intensity For Single Axis
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
August

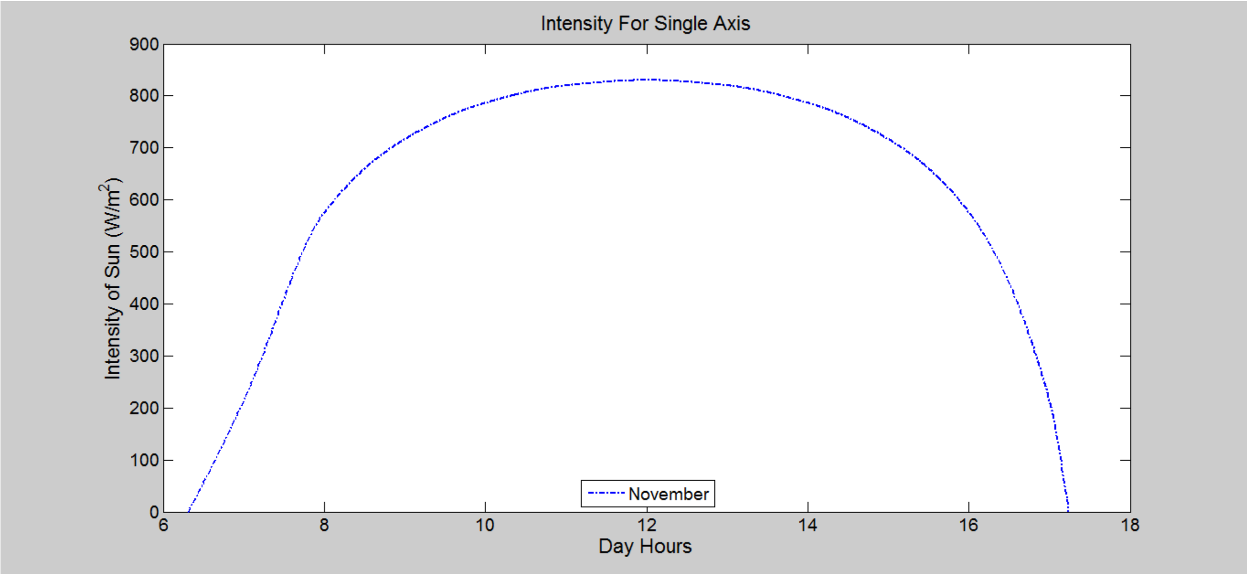
September:



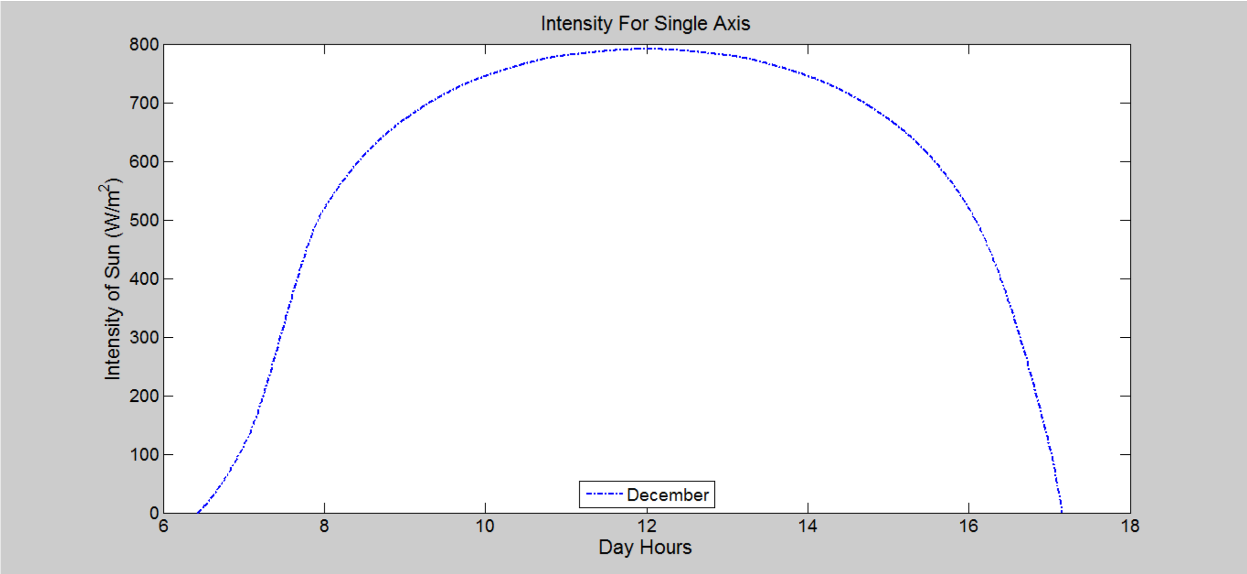
October:



November:



December:



3.2.2: Cumulative Incident Energy:

3.2.2.1: For a Particular Day For Every Month:

Incident Energy	
Day	Single Axis
15-Jan	6806.5
15-Feb	7858.8
15-Mar	8721.9
15-Apr	9213.8
15-May	9213.2
15-Jun	9070.6
15-Jul	9149
15-Aug	9270.1
15-Sep	8917
15-Oct	8160.2
15-Nov	7055.5
15-Dec	6453.3

3.2.2.2: For a particular month:

Incident Energy (Wh/m^2):

Single Axis	Wh/m^2		Wh/m^2
Jan	6806.5	31	211001.5
Feb	7858.8	28	220046.4
Mar	8721.9	31	270378.9
Apr	9213.8	30	276414
May	9213.2	31	285609.2
Jun	9070.6	30	272118
Jul	9149	31	283619
Aug	9270.1	31	287373.1
Sep	8917	30	267510
Oct	8160.2	31	252966.2
Nov	7055.5	30	211665
Dec	6453.3	31	200052.3

3.2.2.3: For a particular year:

Incident Energy (Wh/m^2):

(211001.5+220046.4+270378.9+276414+285609.2+272118+283619+287373.1+267510+252966.2+211665+200052.3) = 3038753.5 Wh=3.04 MWh

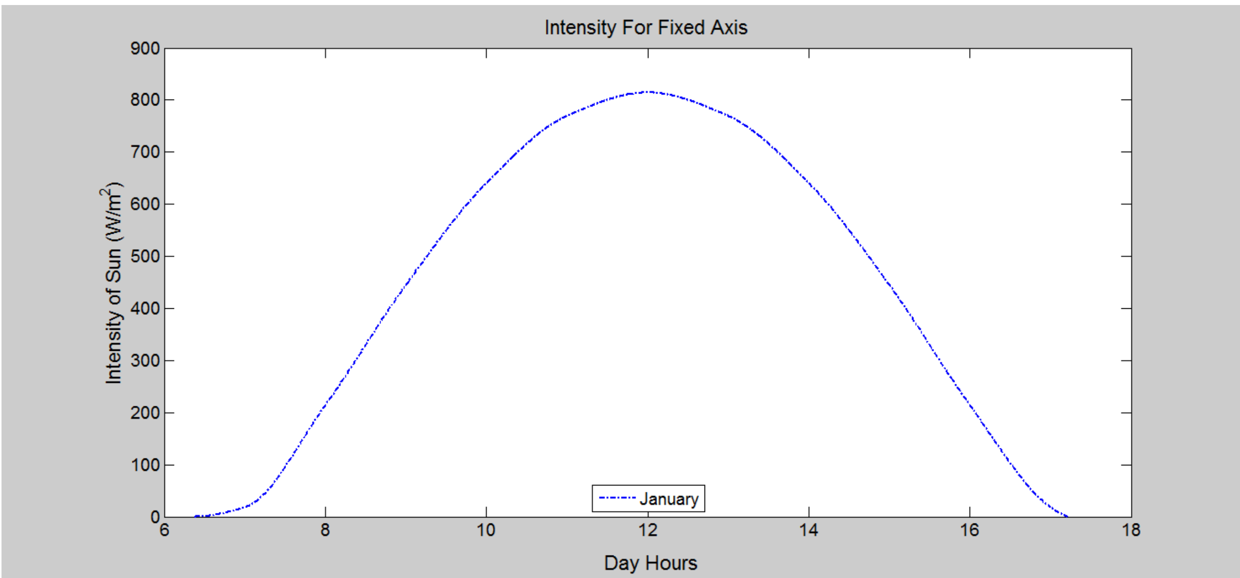
3.3 Fixed Axis:

In this part we will see the calculations of solar irradiance and incident energy for single axis solar tracker

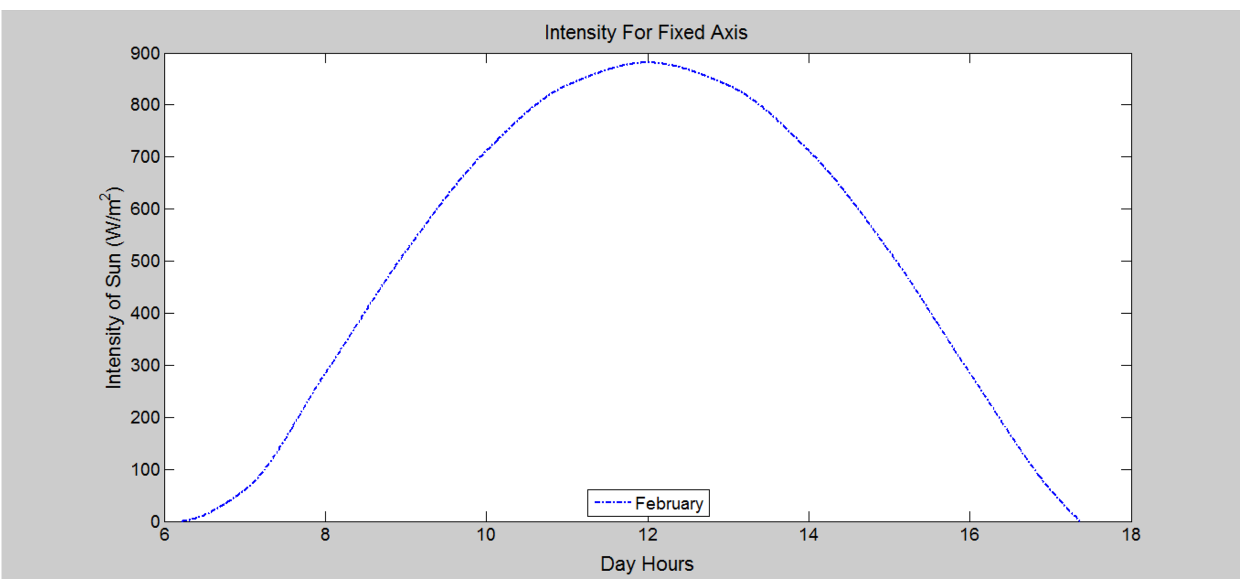
3.3.1 Monthly Solar Irradiance:

The value of solar irradiance for a day of every single month is given below by using plots:

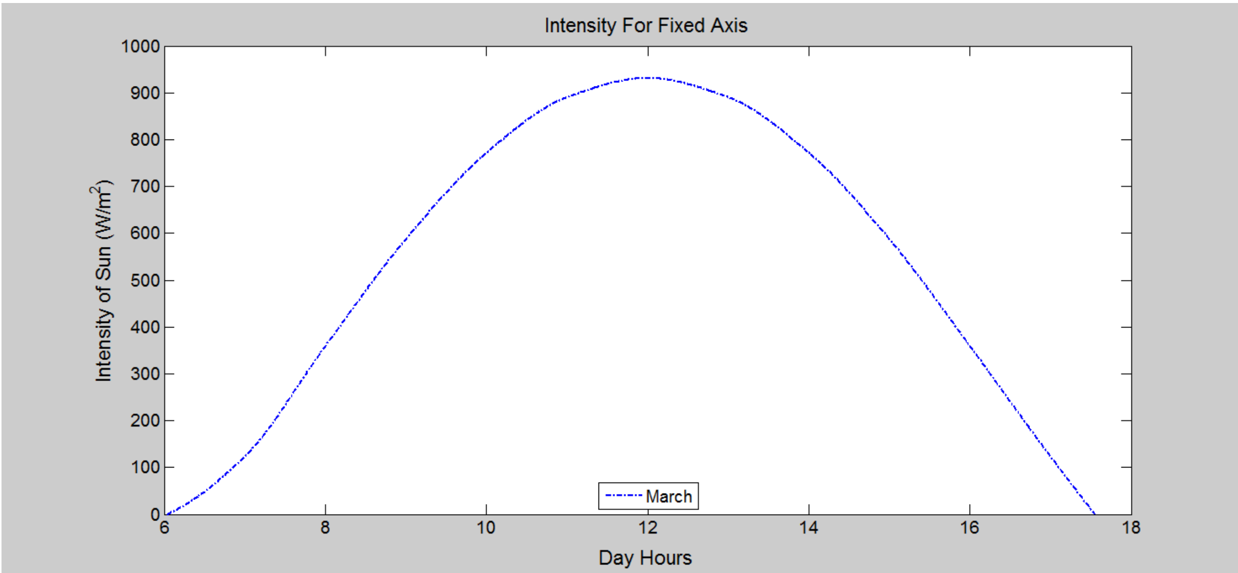
January:



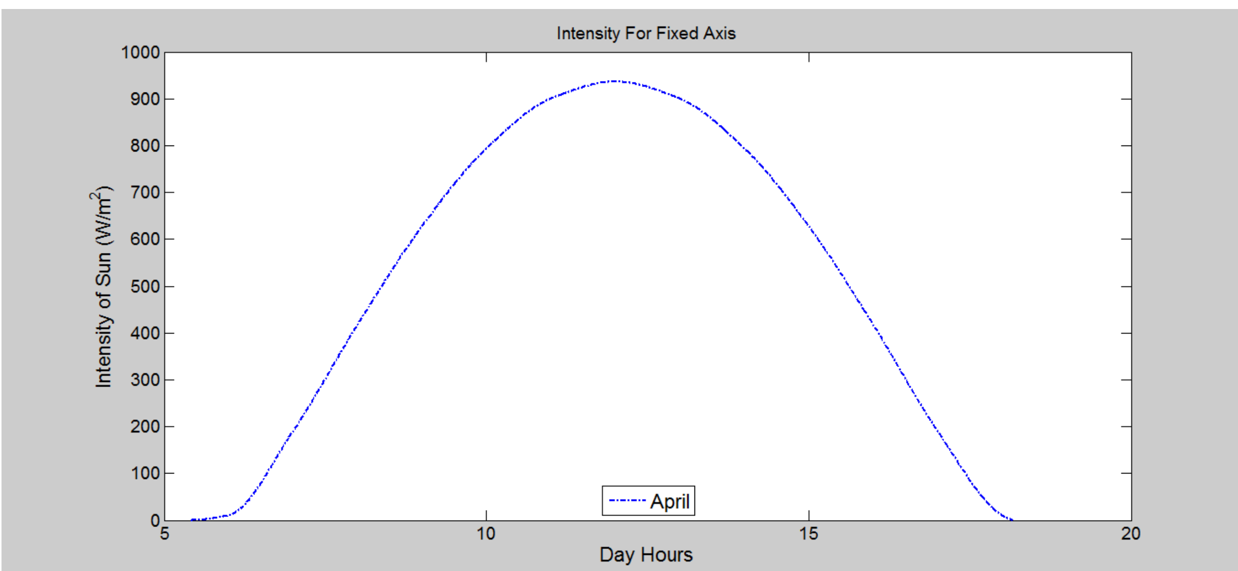
February:



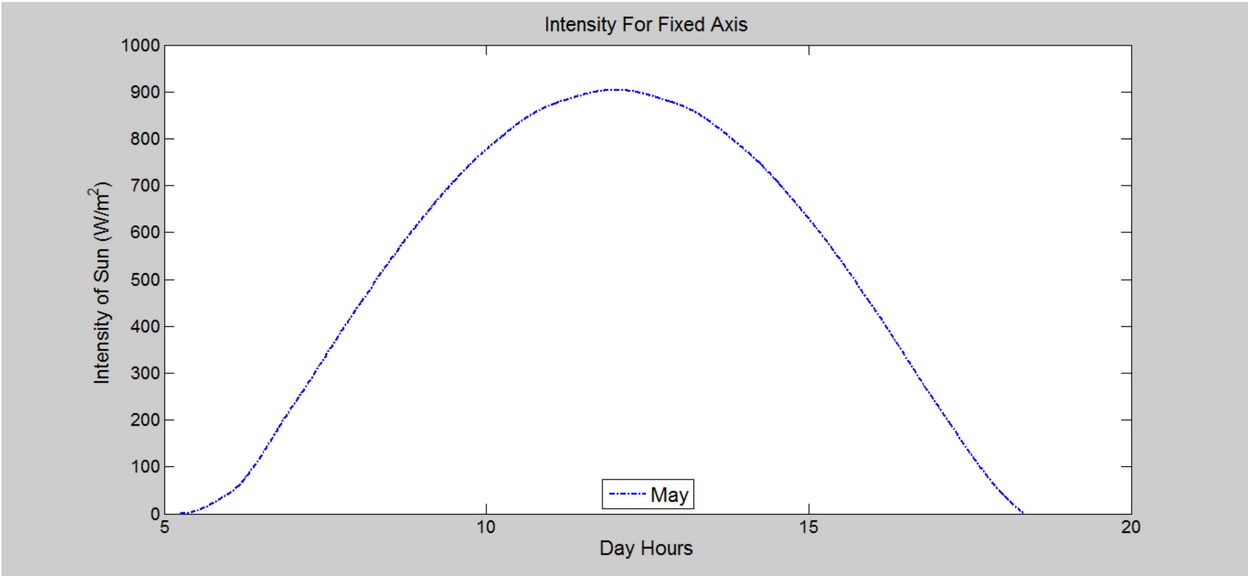
March:


Intensity For Fixed Axis
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
6
8
10
12
14
16
18
Day Hours
March

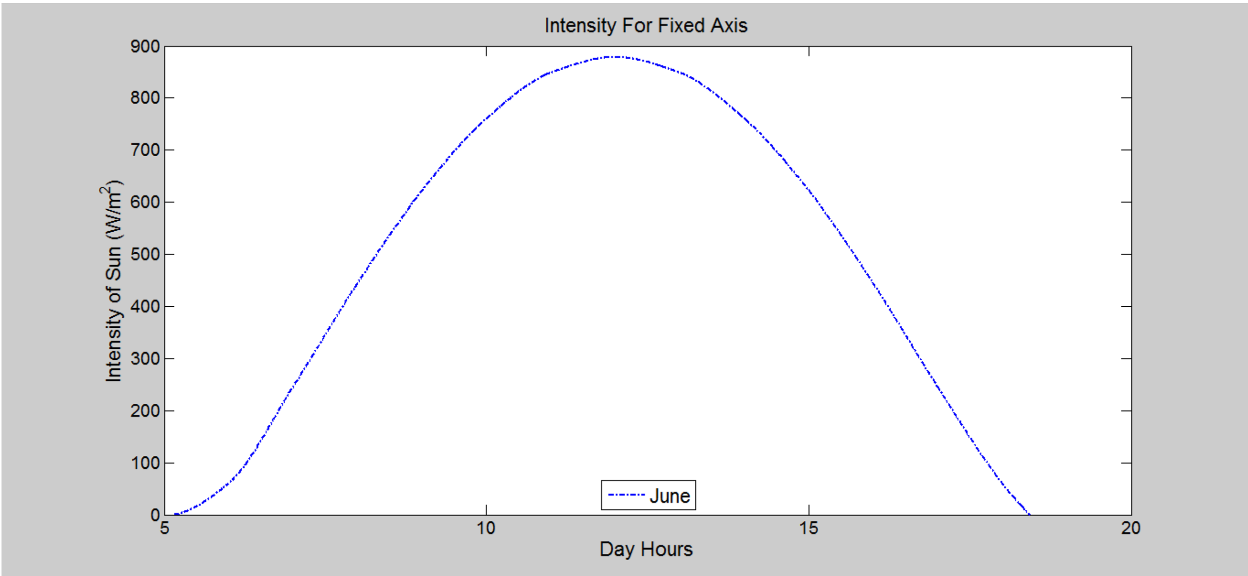
April:


Intensity For Fixed Axis
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
April

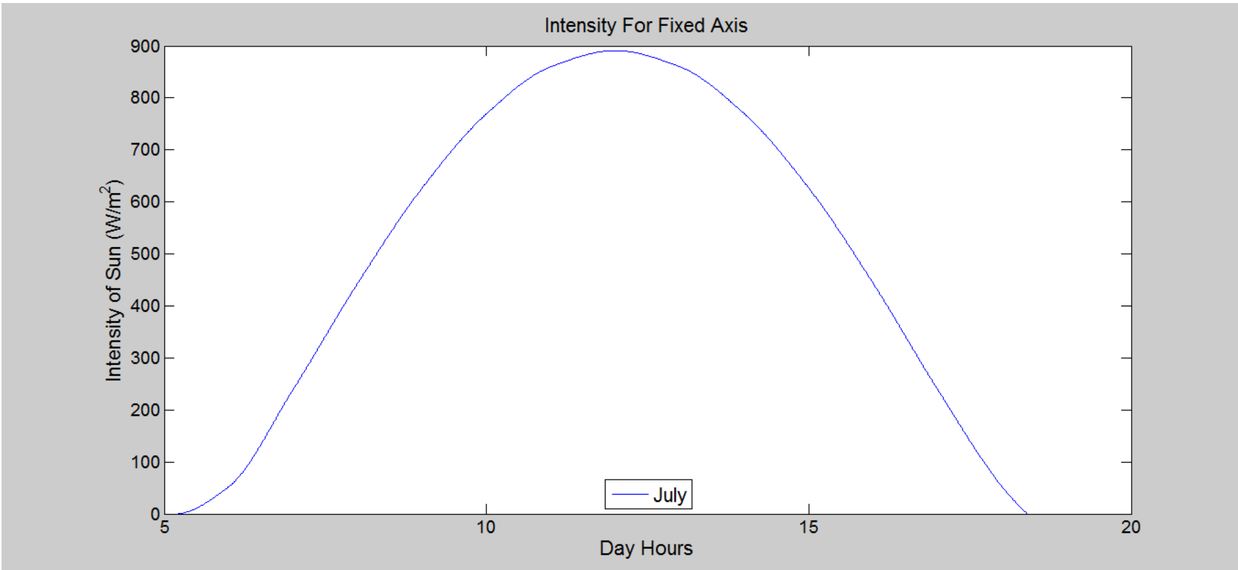
May:


Intensity For Fixed Axis
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
May

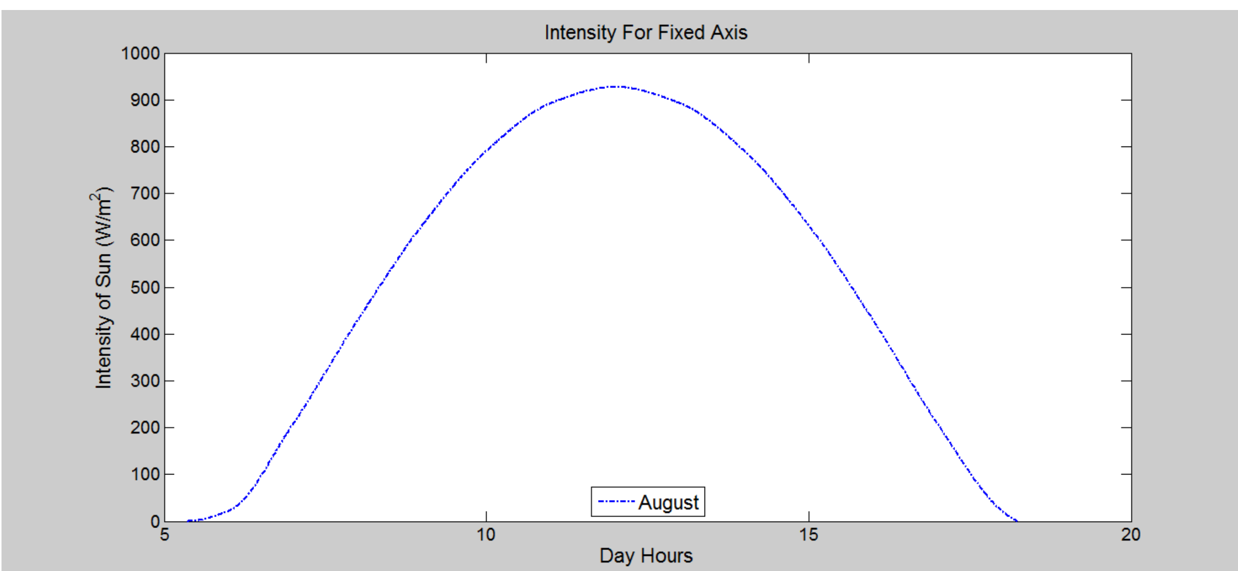
June:


Intensity For Fixed Axis
Intensity of Sun (W/m2)
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
June

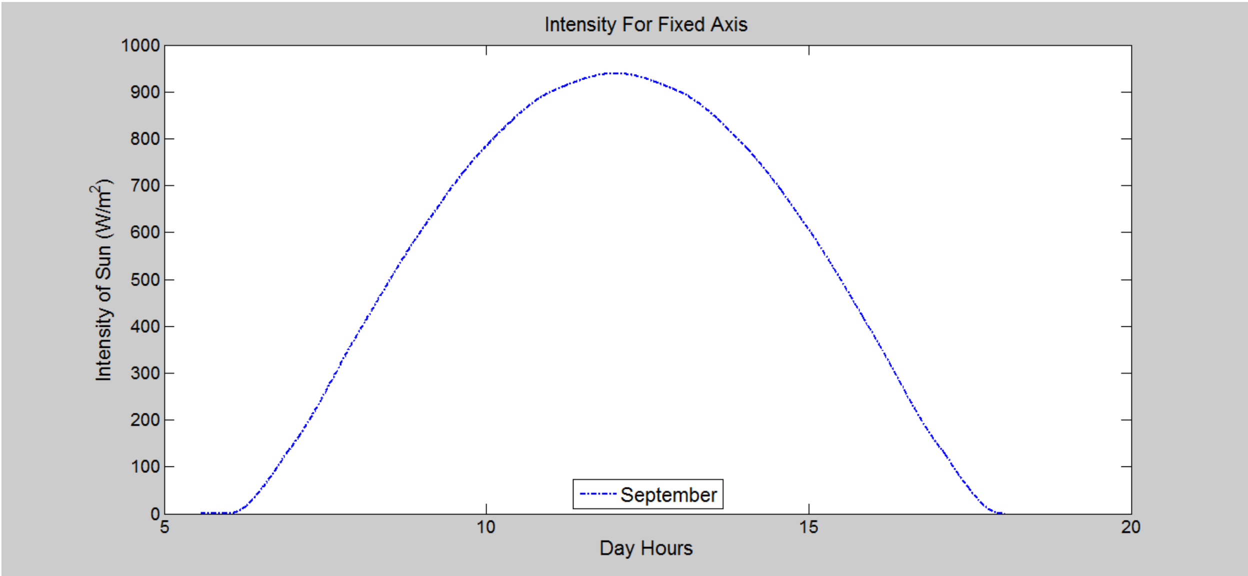
July:


Intensity For Fixed Axis
Intensity of Sun (W/m2)
Day Hours
July
0
100
200
300
400
500
600
700
800
900
5
10
15
20

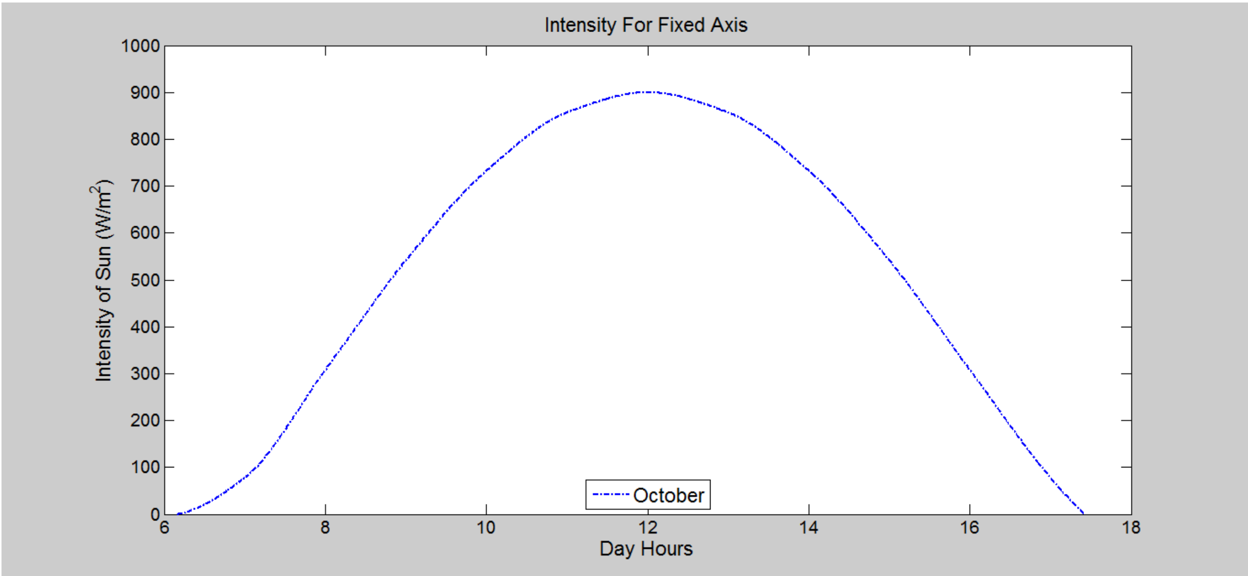
August:


Intensity For Fixed Axis
Intensity of Sun (W/m2)
Day Hours
August
0
100
200
300
400
500
600
700
800
900
1000
5
10
15
20

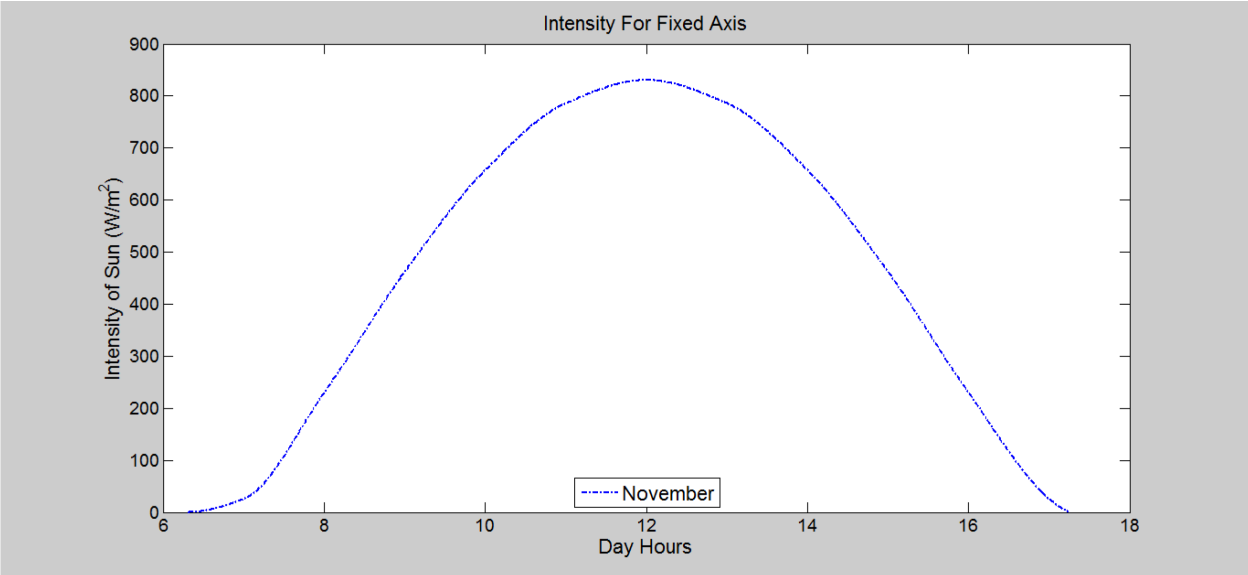
September:



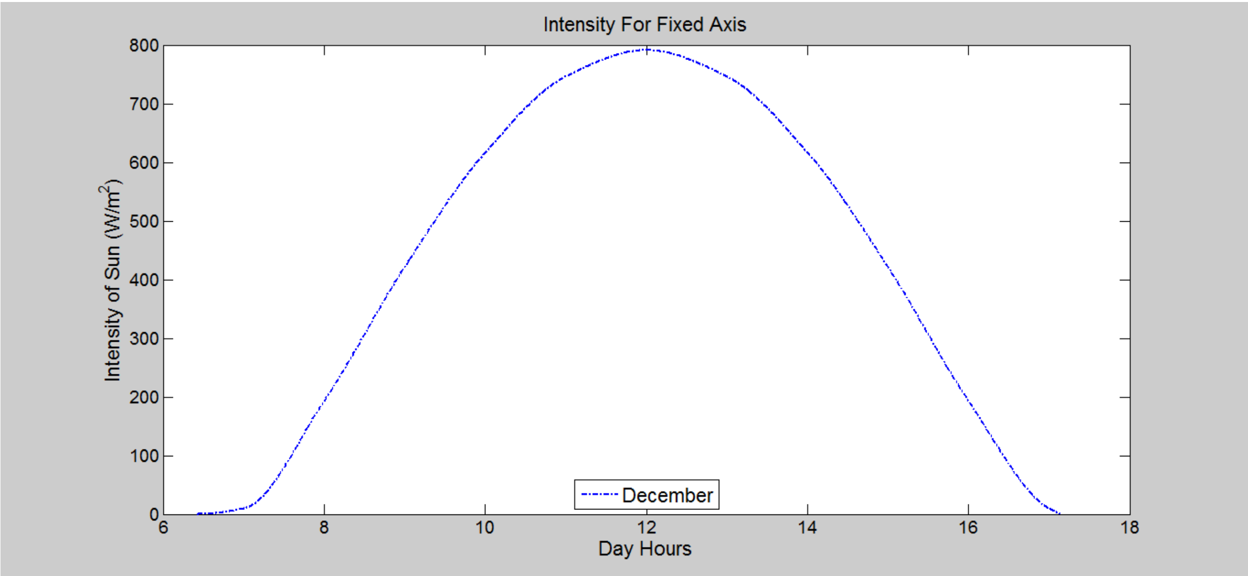
October:



November:



December:



3.3.2 Cumulative Incident Energy

3.3.2.1 for a Particular Day:

Fixed Axis	Wh/m^2
15-Jan	4990
15-Feb	5709
15-Mar	6395.8
15-Apr	6817.9
15-May	6890.6
15-Jun	6843.2
15-Jul	6871.8
15-Aug	6874
15-Sep	6584.5
15-Oct	5933.8
15-Nov	5153.4
15-Dec	4765.8

3.3.2.2 for Particular Months:

Fixed Aixs	Wh/m^2		Wh/m^2
Jan	4990	31	154690
Feb	5709	28	159852
Mar	6395.8	31	198269.8
Apr	6817.9	30	204537
May	6890.6	31	213608.6
Jun	6843.2	30	205296
Jul	6871.8	31	213025.8
Aug	6874	31	213094
Sep	6584.5	30	197535
Oct	5933.8	31	183947.8
Nov	5153.4	30	154602
Dec	4765.8	31	147739.8

3.3.2.3 For a Particular Year:

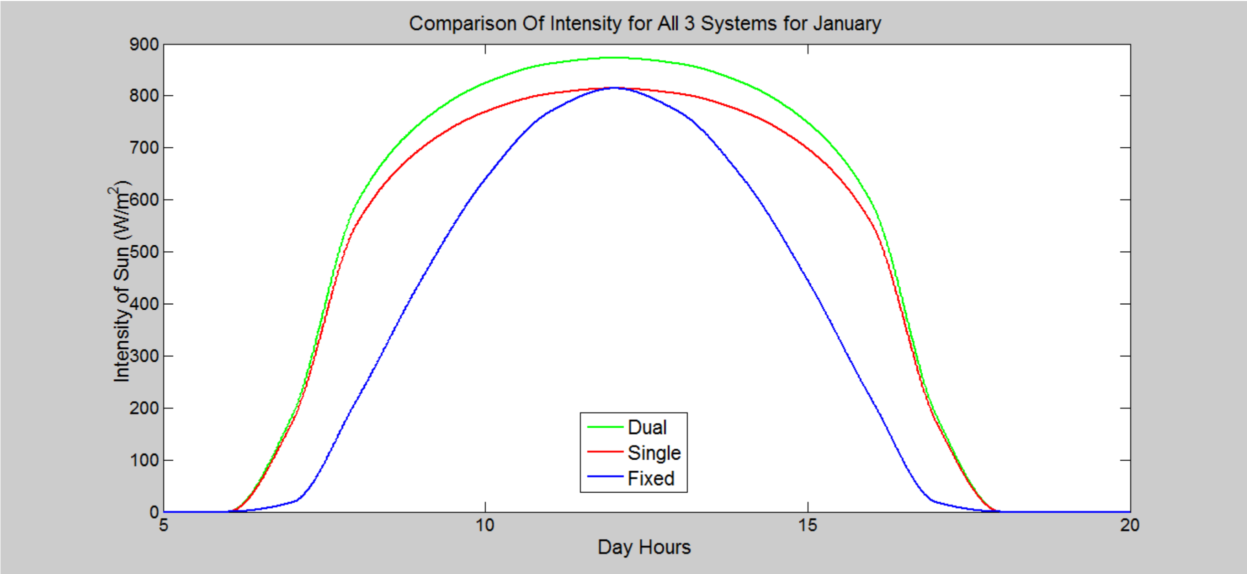
Incident Energy: (Wh/m^2)

154690+159852+198269.8+204537+213608.6+205296+213025.8+213094+197535+183947.8+ 154602+147739.8 = 2246198 Wh = 2.2461 Mw

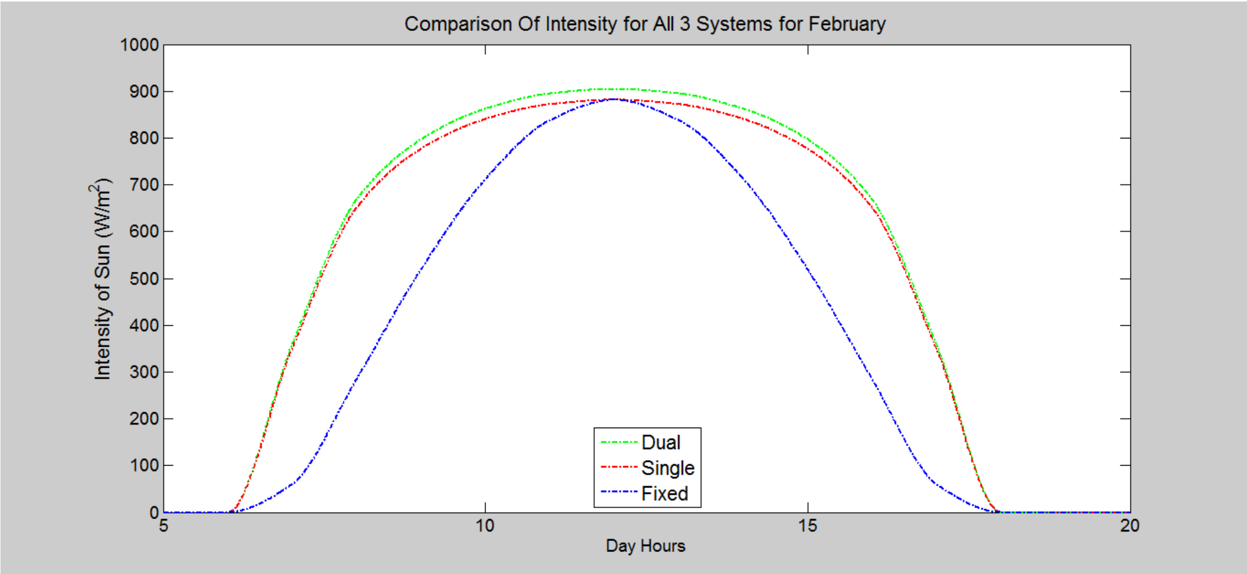
3.4 Comparing Intensity and Energy Collected By Different Tracking Systems

3.4.1 Comparison of Single, Fixed and Dual Axis Intensity:

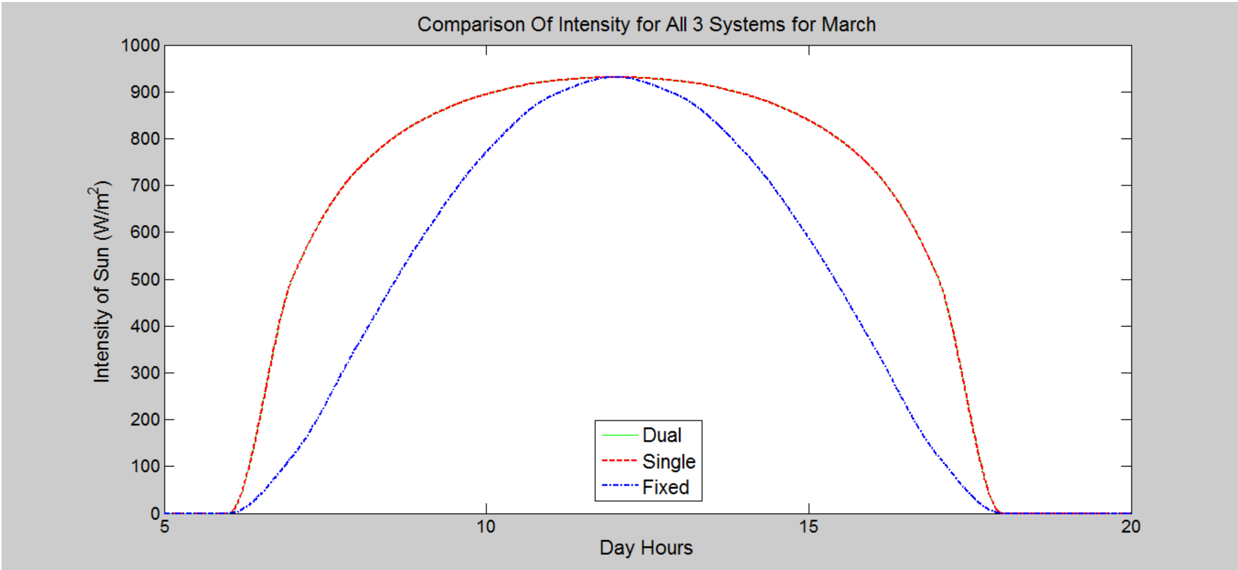
January:



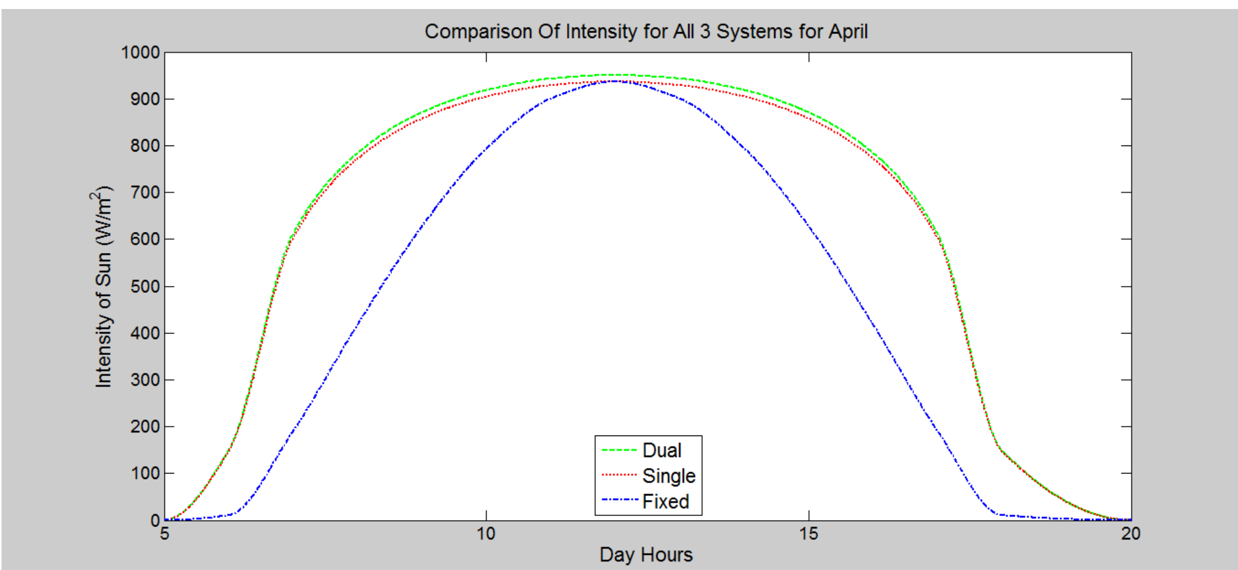
February:



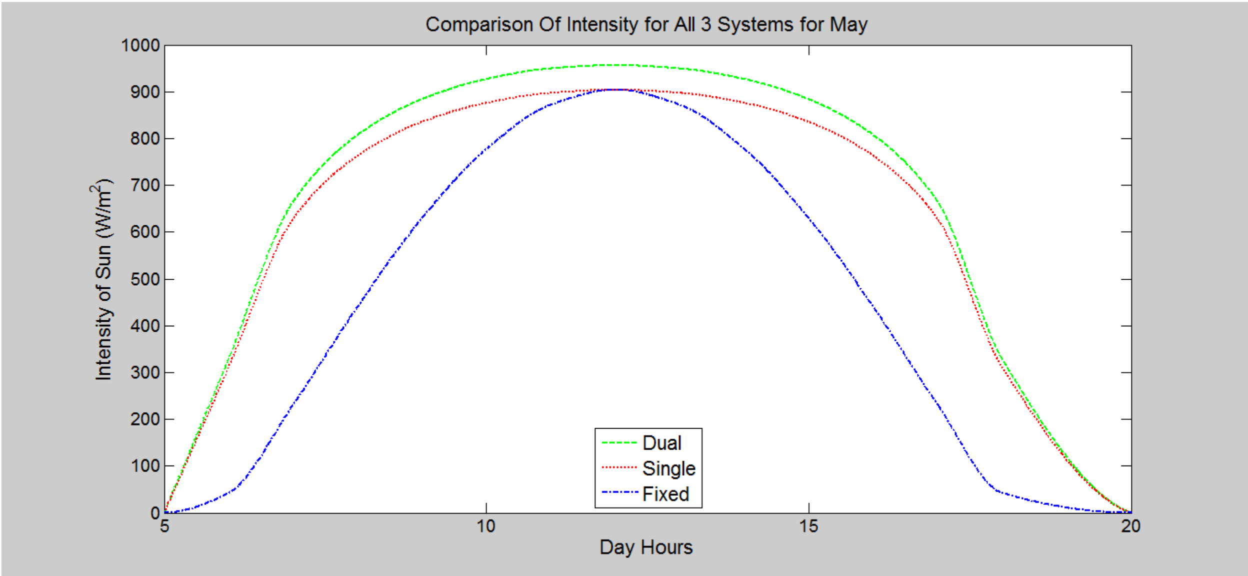
March:


Comparison Of Intensity for All 3 Systems for March
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
Dual
Single
Fixed

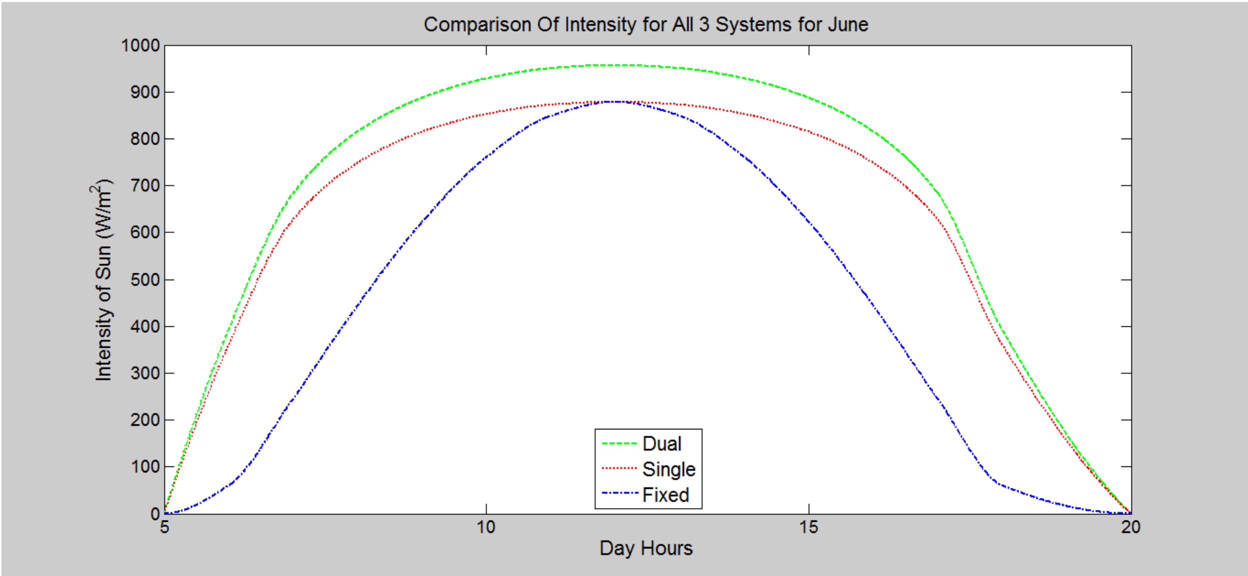
April:


Comparison Of Intensity for All 3 Systems for April
Intensity of Sun (W/m2)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Day Hours
Dual
Single
Fixed

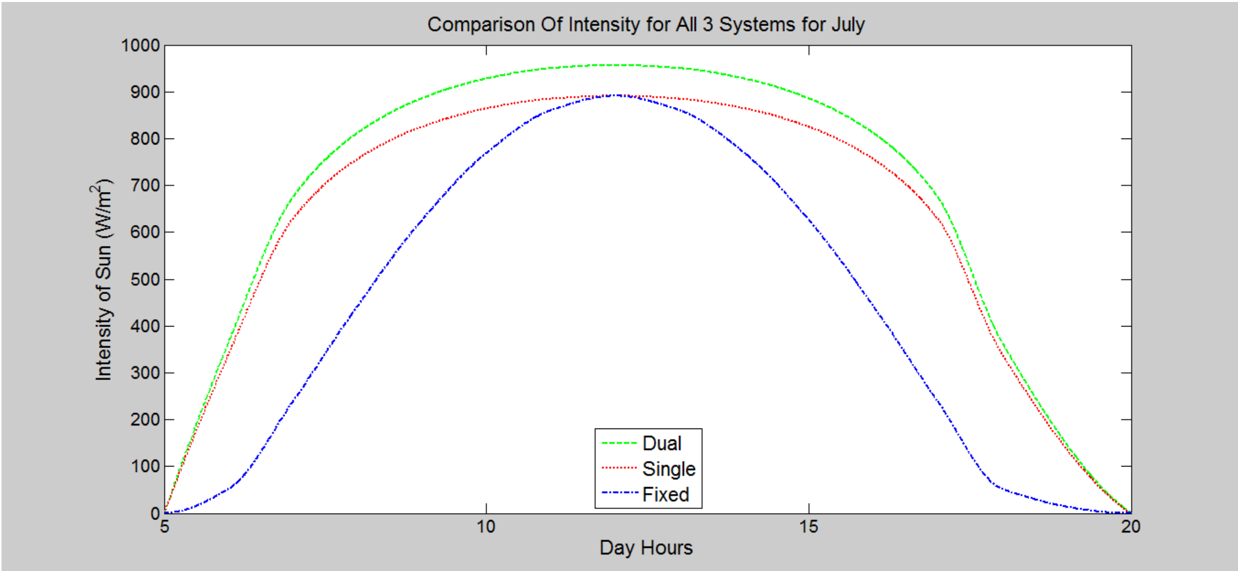
May:


Comparison Of Intensity for All 3 Systems for May
Intensity of Sun (W/m2)
Day Hours
Dual
Single
Fixed
0
100
200
300
400
500
600
700
800
900
1000
5
10
15
20

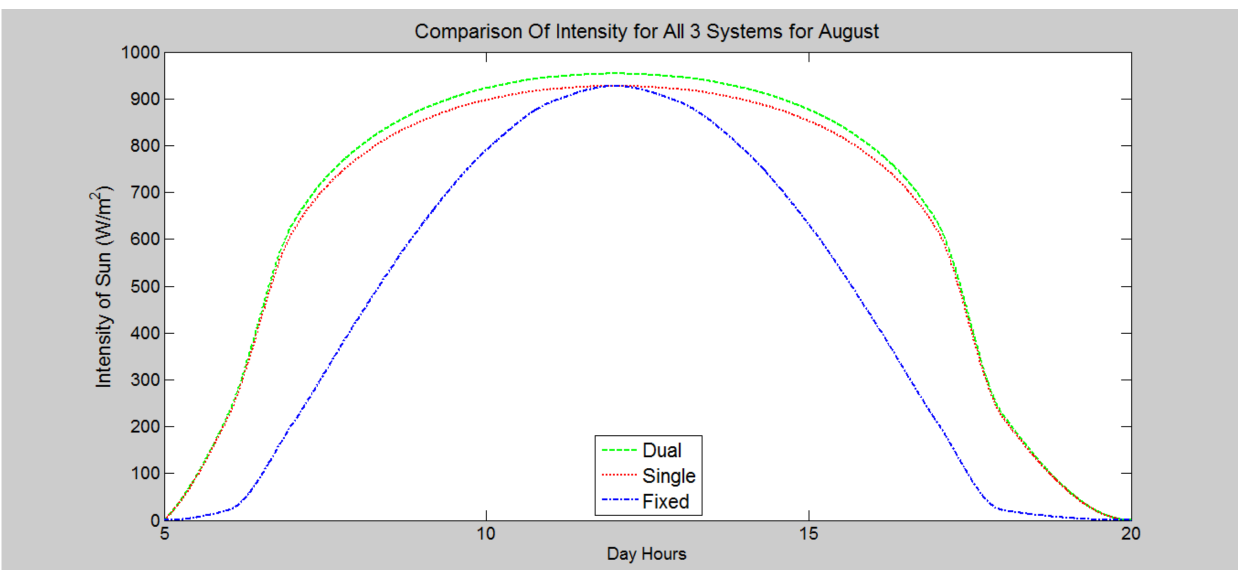
June:


Comparison Of Intensity for All 3 Systems for June
Intensity of Sun (W/m2)
Day Hours
Dual
Single
Fixed
0
100
200
300
400
500
600
700
800
900
1000
5
10
15
20

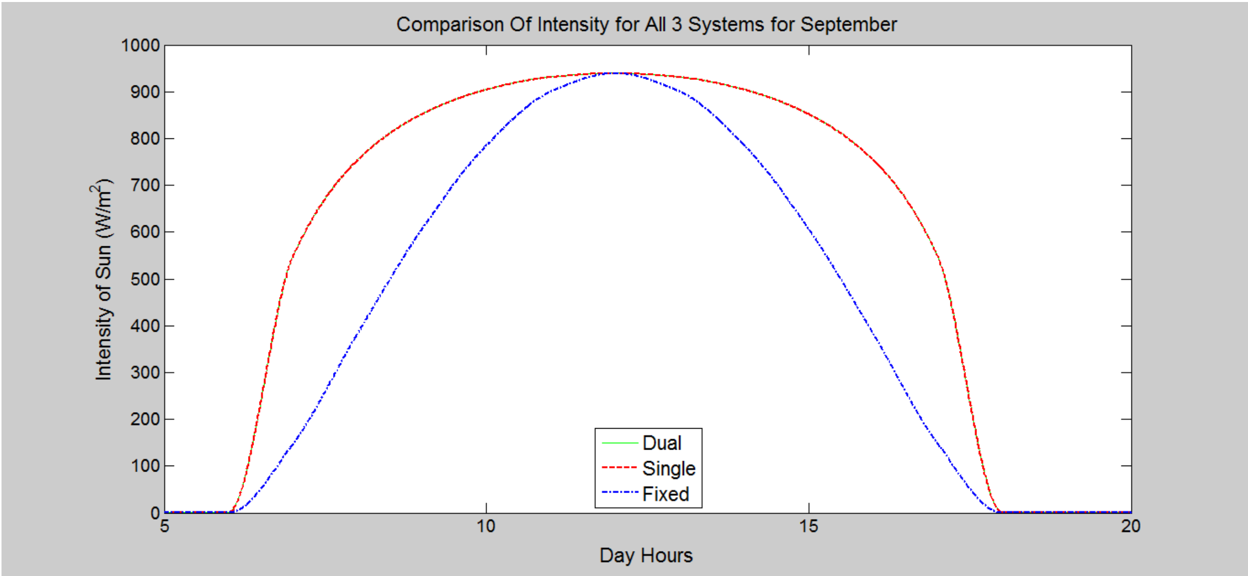
July:


Comparison Of Intensity for All 3 Systems for July
Intensity of Sun (W/m²)
Day Hours
Dual
Single
Fixed
0
100
200
300
400
500
600
700
800
900
1000
5
10
15
20

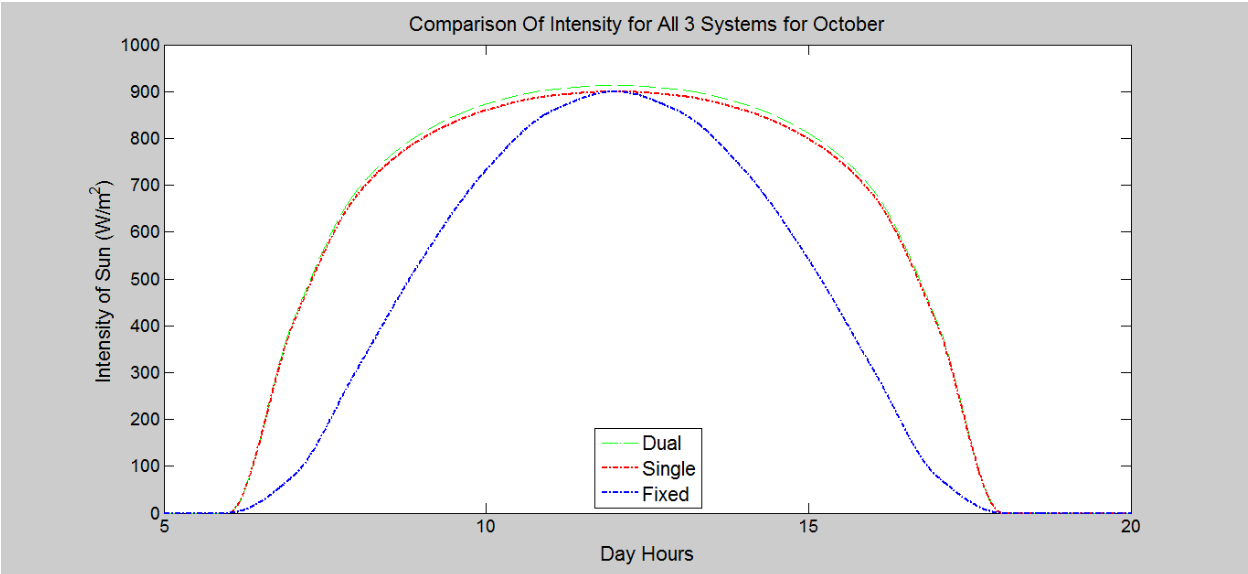
August:


Comparison Of Intensity for All 3 Systems for August
Intensity of Sun (W/m²)
Day Hours
Dual
Single
Fixed
0
100
200
300
400
500
600
700
800
900
1000
5
10
15
20

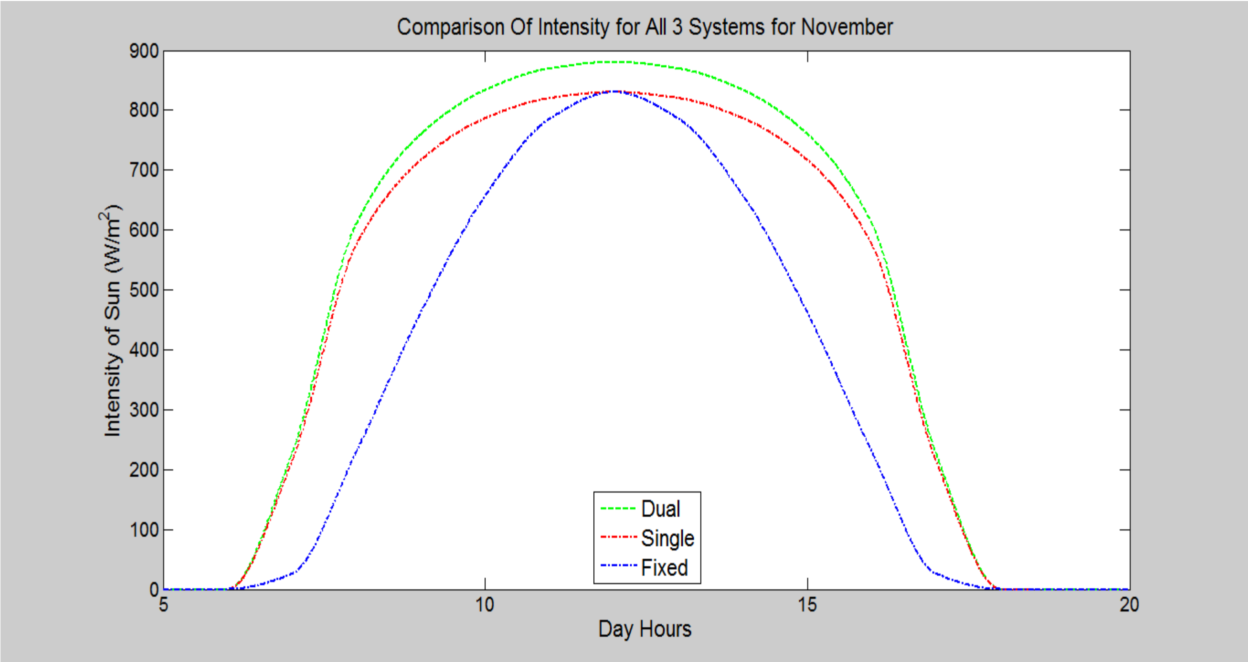
September:



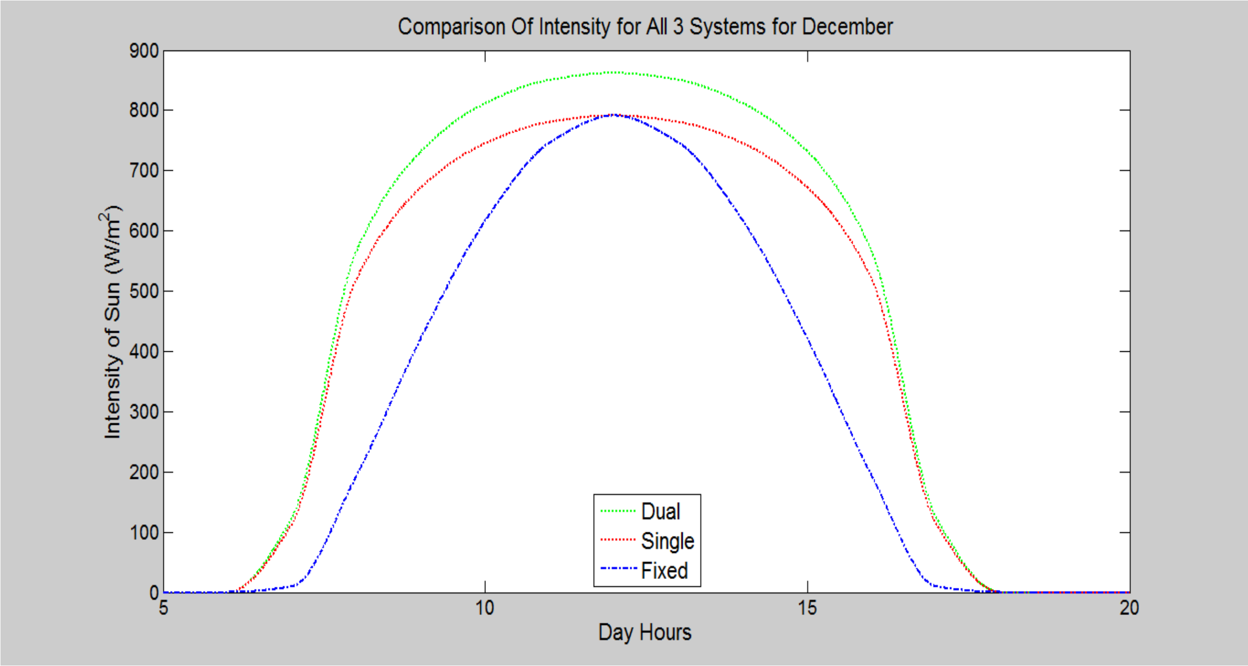
October:



November:

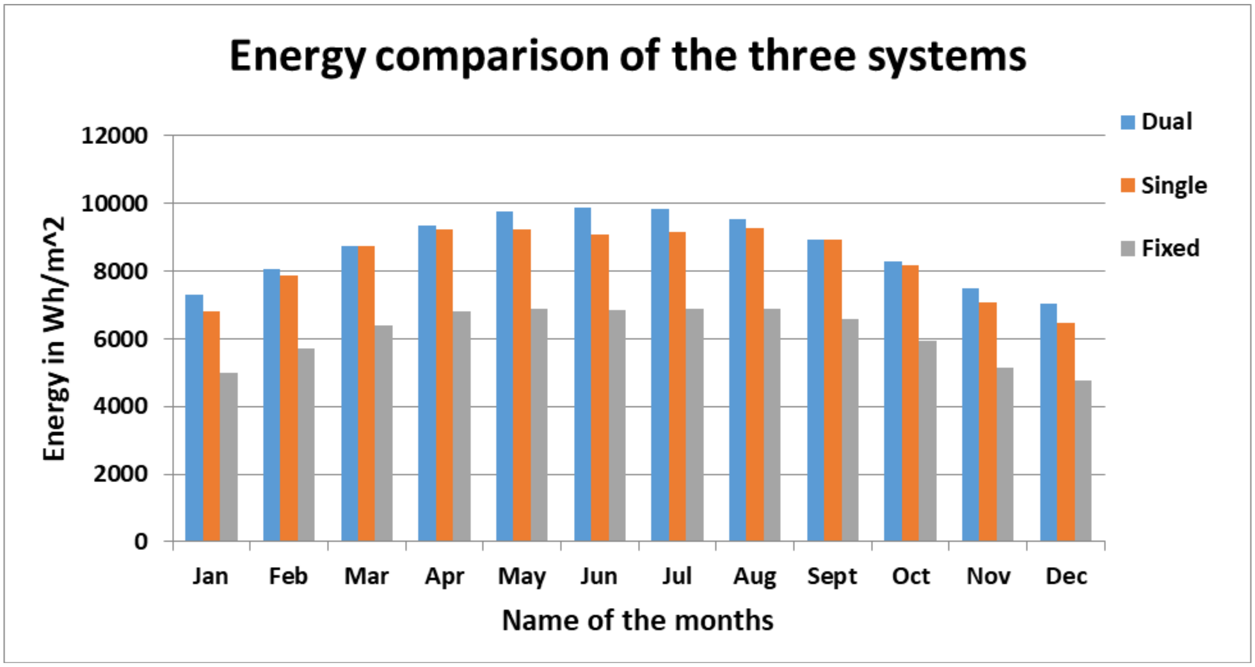


December:

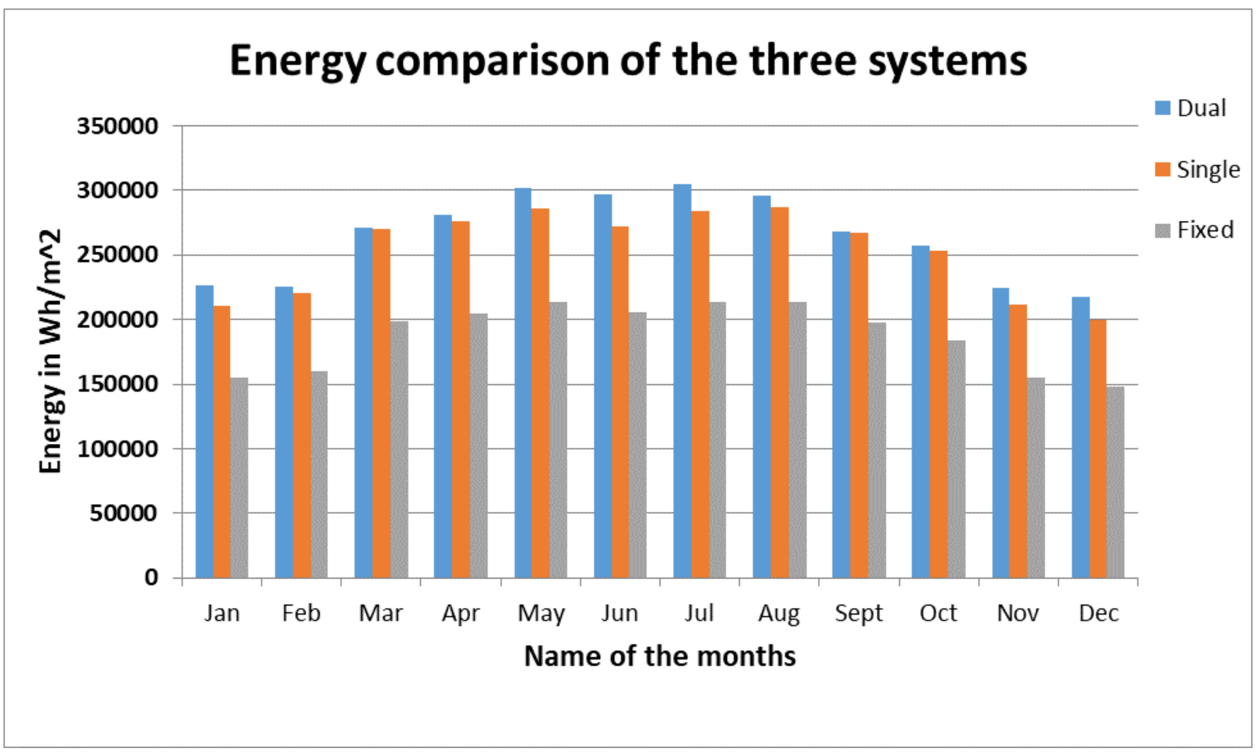


3.4.2 Comparison of Single, Fixed and Dual Axis Incident Energy:

3.4.2.1Daily Based Incident Energy:



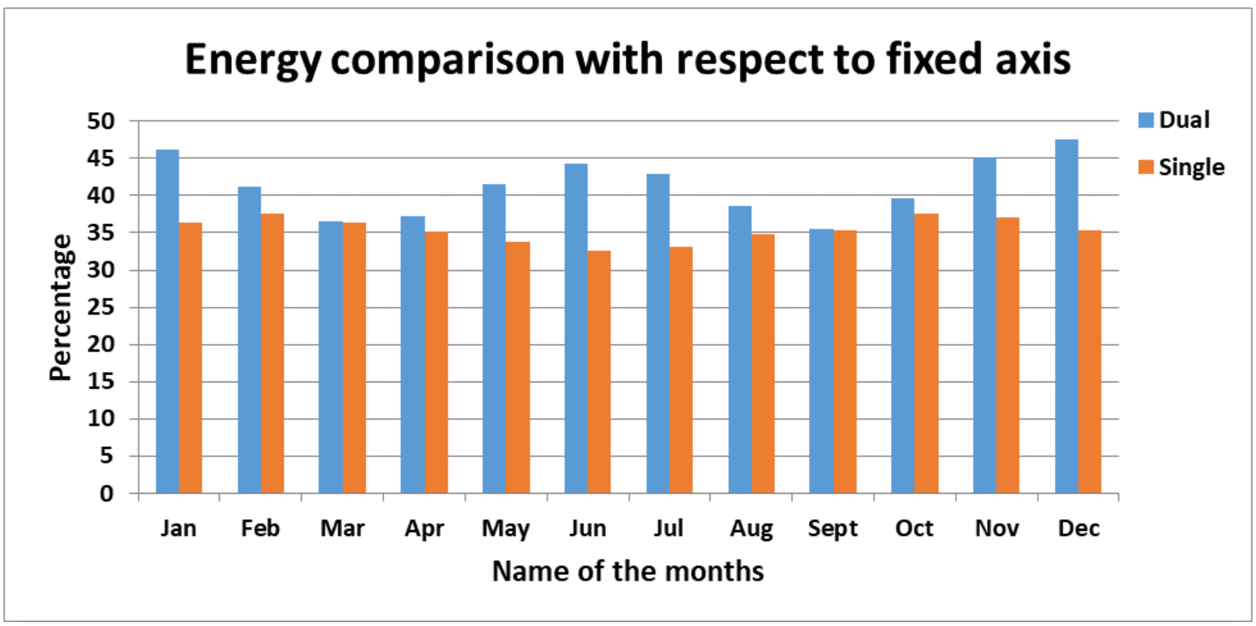
3.4.2.2Month Based Incident Energy:



3.4.3 Comparison of Monthly Single and Dual Axis Energy with Respect to Fixed Axis:

Monthly Energy Difference		
Month	Dual Axis	Single Axis
January	46.19%	36.41%
February	41.26%	37.66%
March	36.49%	36.37%
April	37.19%	35.14%
May	41.48%	33.71%
June	44.37%	32.54%
July	42.95%	33.14%
August	38.65%	34.86%
September	35.54%	35.42%
October	39.62%	37.52%
November	45.17%	37.12%
December	47.50%	35.40%

Energy Difference:



3.4.4 Comparison of Yearly Energy Difference of Single and Dual Axis with Respect to Fixed Axis.

Yearly Total Energy	
	Mwh
Dual Axis	3.17
Single Axis	3.04
Fixed Axis	2.25
Yearly Energy Difference	
Dual Axis	41.07%
Single Axis	35.30%

Observation:

As demonstrated in the calculation above, dual axis solar tracker with respect to Bangladesh, yields 3.17 MWh worth of energy for a particular year. Single axis solar tracker generates 3.04 Mwh and fixed axis generates 2.25 MWh. Single axis produces about 35.30.% more energy compared to that of fixed axis and dual axis tracker produces about 41.07% more energy in relation to fixed axis. By using a dual axis tracker, we can accumulate about 5.77 % more energy in a particular year.

Chapter:4 : Calculation of Direct Beam Plus Diffusion Incident Energy

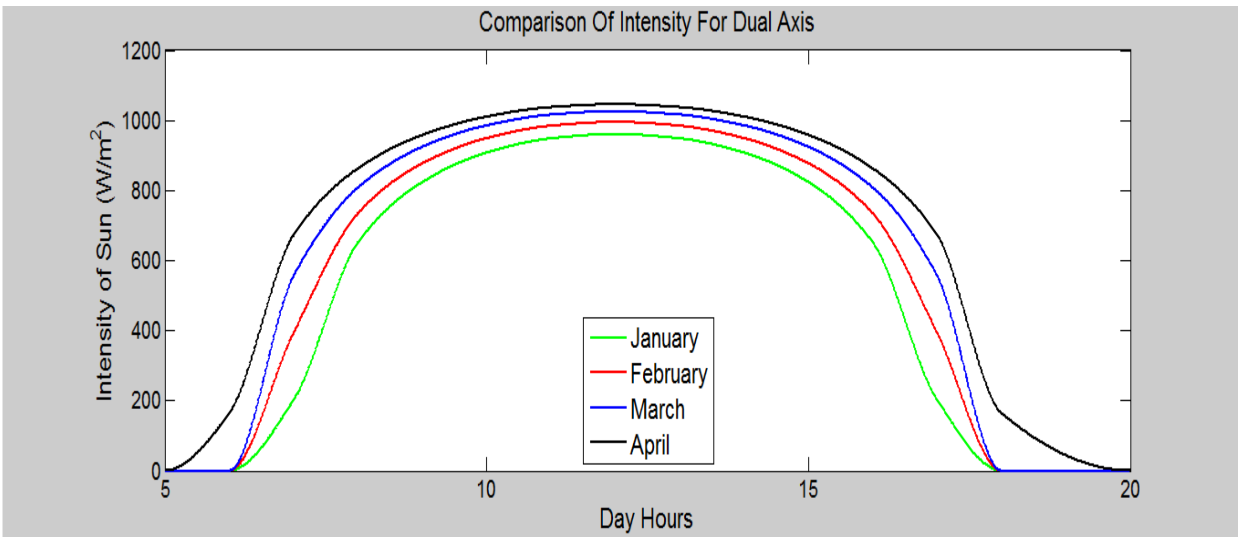
4.1 Dual Axis:

In this part we will try to visualize the amount of solar irradiance and incident energy while considering diffusion energy for Dual Axis solar tracker.

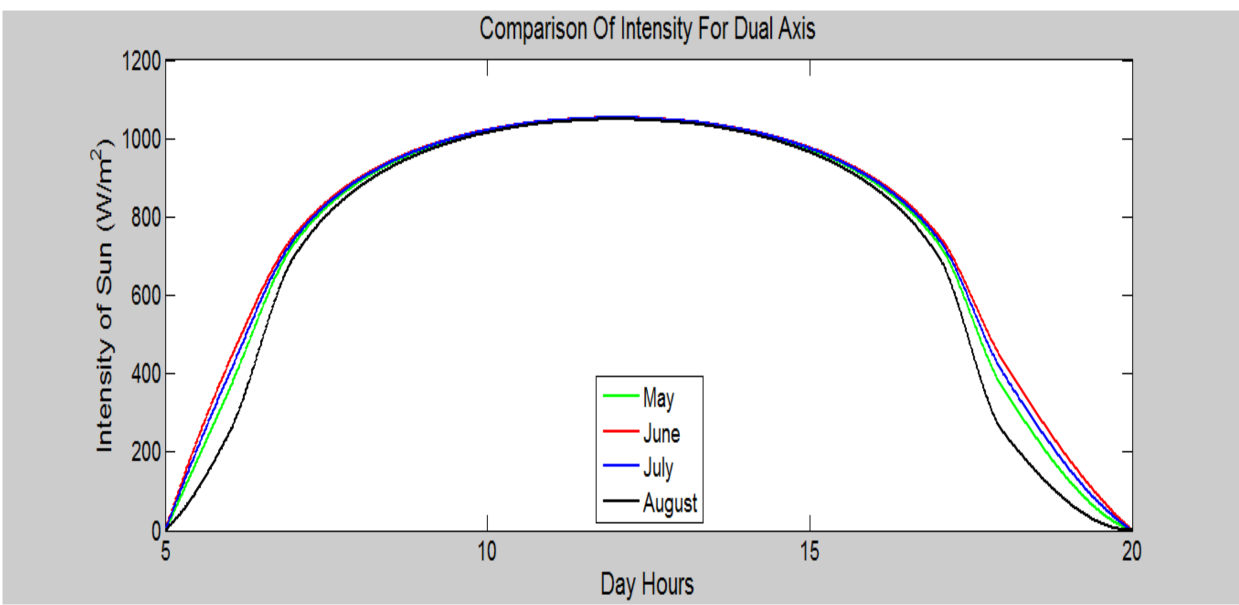
4.1.1 Monthly Solar Irradiance:

4.1.2 Comparing Plots :

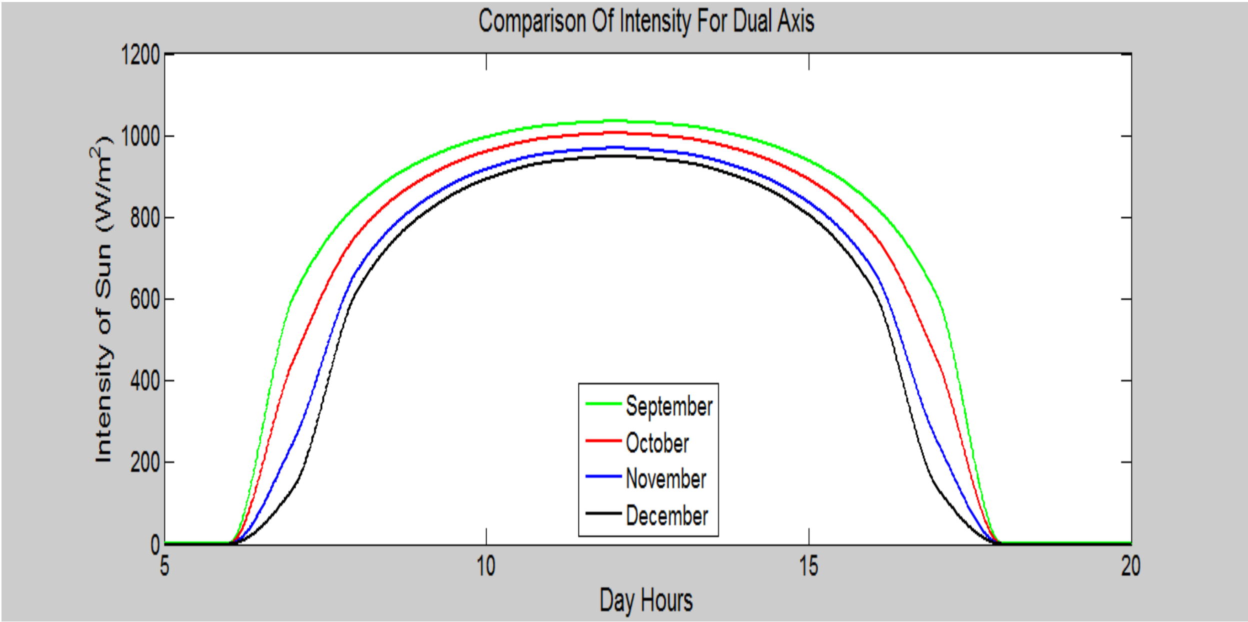
January-April:



May-Aug:4



September-December:



4.1.3 Cumulative Incident Energy:

4.1.3.1 For a Particular Day for Every Month:

ENERGY	Wh/m^2
Daily:	
	Dual Axis
15-Jan	8024.9
15-Feb	8870.8
15-Mar	9602.6
15-Apr	10289
15-May	10724
15-Jun	10868
15-Jul	10806
15-Aug	10484
15-Sep	9817.5
15-Oct	9113
15-Nov	8229.1
15-Dec	7732.7

4.1.3.2 For Particular Months:

Dual axis	Wh/m^2		Wh/m^2
Jan	8024.9	31	248771.9
Feb	8870.8	28	248382.4
Mar	9602.6	31	297680.6
Apr	10453	30	313590
May	11086	31	343666
Jun	11300	30	339000
Jul	11207	31	347417
Aug	10735	31	332785
Sep	9819	30	294570
Oct	9113	31	282503
Nov	8229.1	30	246873
Dec	7732.7	31	239713.7

4.1.3.3 For a Particular Year:

Incident Energy (Wh/m^2):

248771.9+248382.4+297680.6+313590+343666+339000+347417+332785+294570+282503+246873+239713.7 =3534953Wh =3.535 MWh

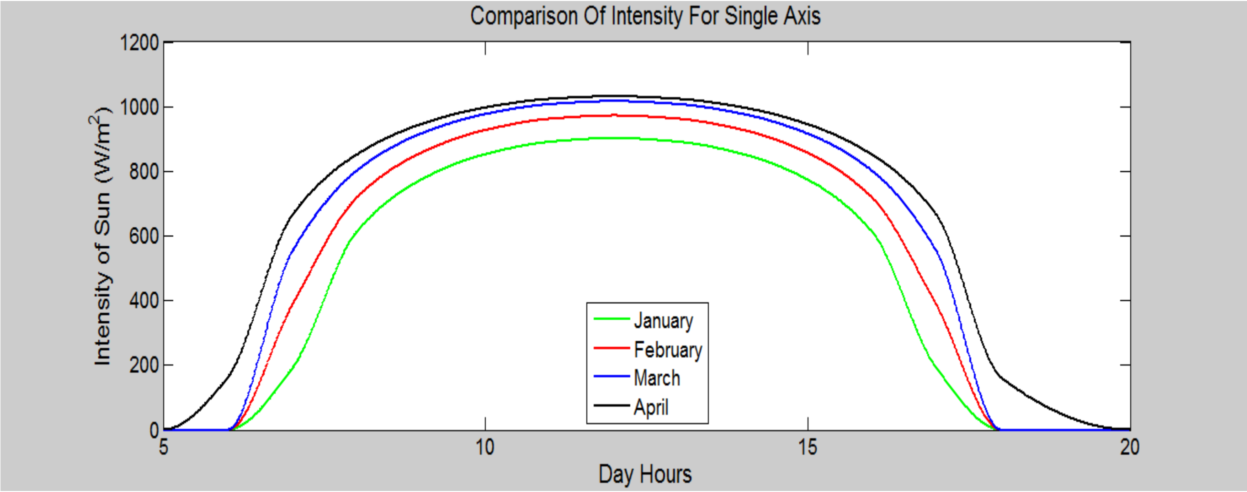
4.2 Single Axis:

In this part we will try to visualize the amount of solar irradiance and incident energy while considering diffusion energy for Single Axis solar tracker.

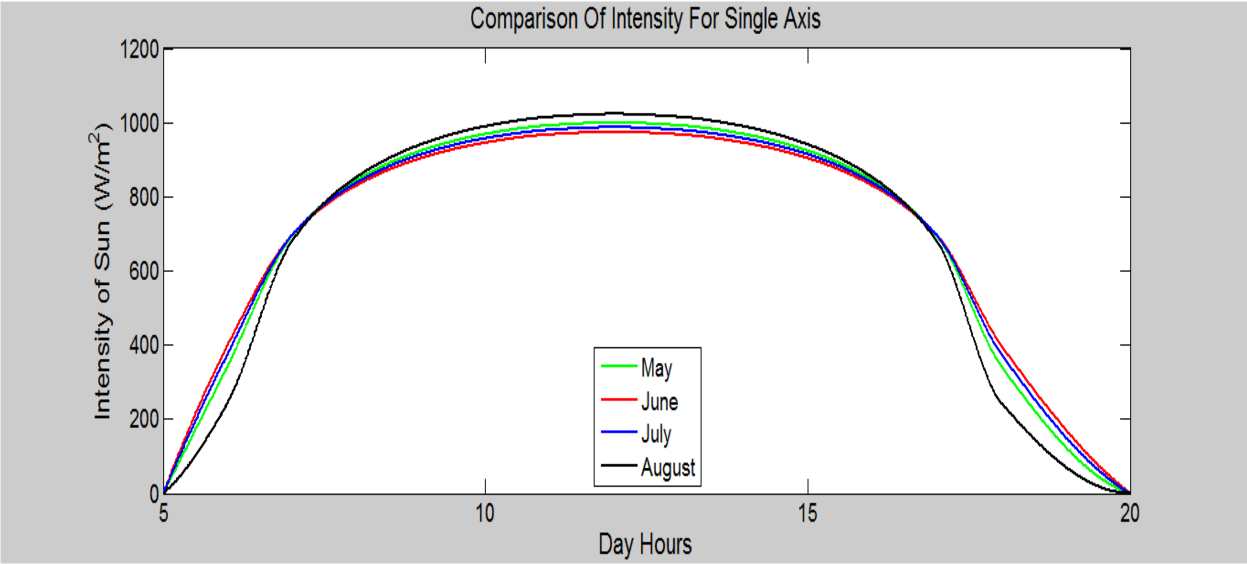
4.2.1 Monthly Solar Irradiance:

4.2.2 Comparing Plots :

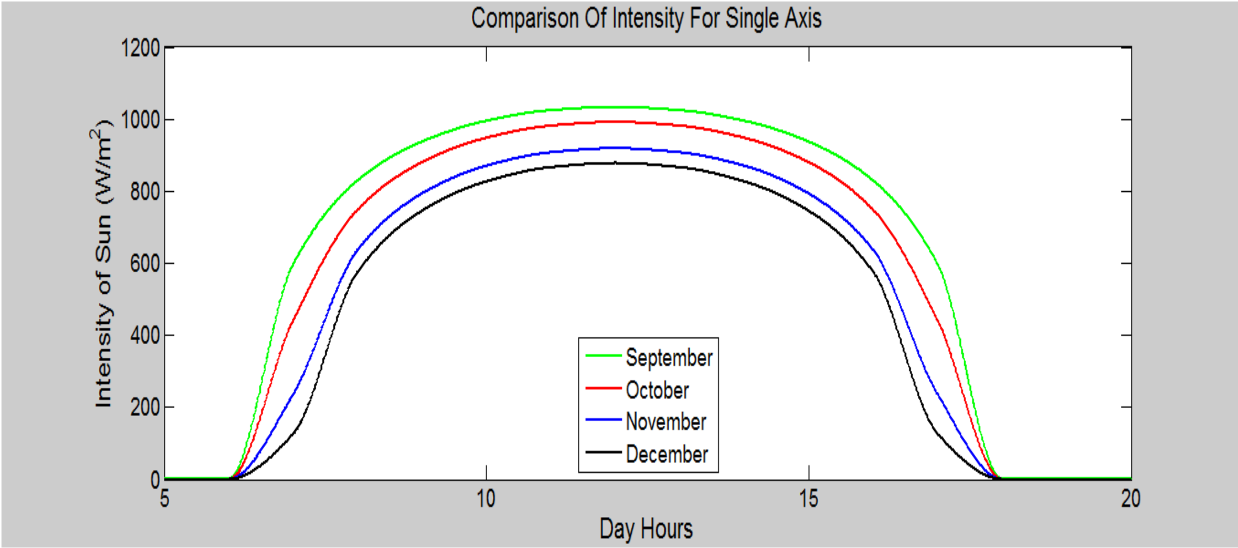
January-April :



May-August:



September-December:



4.2.3 Cumulative Incident Energy:

4.2.3.1 For a Particular Day for Every Month:

ENERGY	Wh/m^2
Daily:	
	Single Axis
15-Jan	7536
15-Feb	8664.3
15-Mar	9515.4
15-Apr	10149
15-May	10188
15-Jun	10059
15-Jul	10131
15-Aug	10223
15-Sep	9798.6
15-Oct	8988.7
15-Nov	7803.5
15-Dec	7156.3

4.2.3.2 For Particular Months:

Single axis	Wh/m^2		Wh/m^2
Jan	7536	31	233616
Feb	8664.3	28	242600.4
Mar	9515.4	31	294977.4
Apr	10310	30	309300
May	10532	31	326492
Jun	10485	30	314550
Jul	10507	31	325717
Aug	10468	31	324508
Sep	9800.1	30	294003
Oct	8988.7	31	278649.7
Nov	7803.5	30	234105
Dec	7156.3	31	221845.3

4.2.3.3 For a Particular Year:

Incident Energy (Wh/m^2):

233616+242600.4+294977.4+309300+326492+314550+325777+324508+294003+278619.7+234105+221845.3 = 3400364Wh= 3.4 MWh

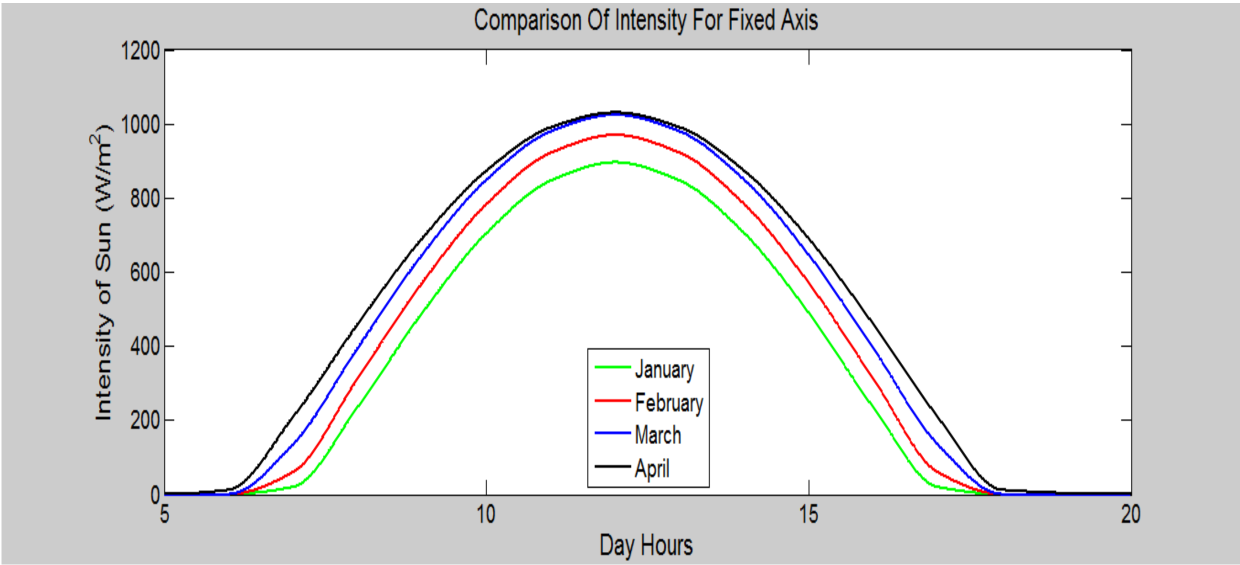
4.3 Fixed Axis:

In this part we will try to visualize the amount of solar irradiance and incident energy while considering diffusion energy for Single Axis solar tracker.

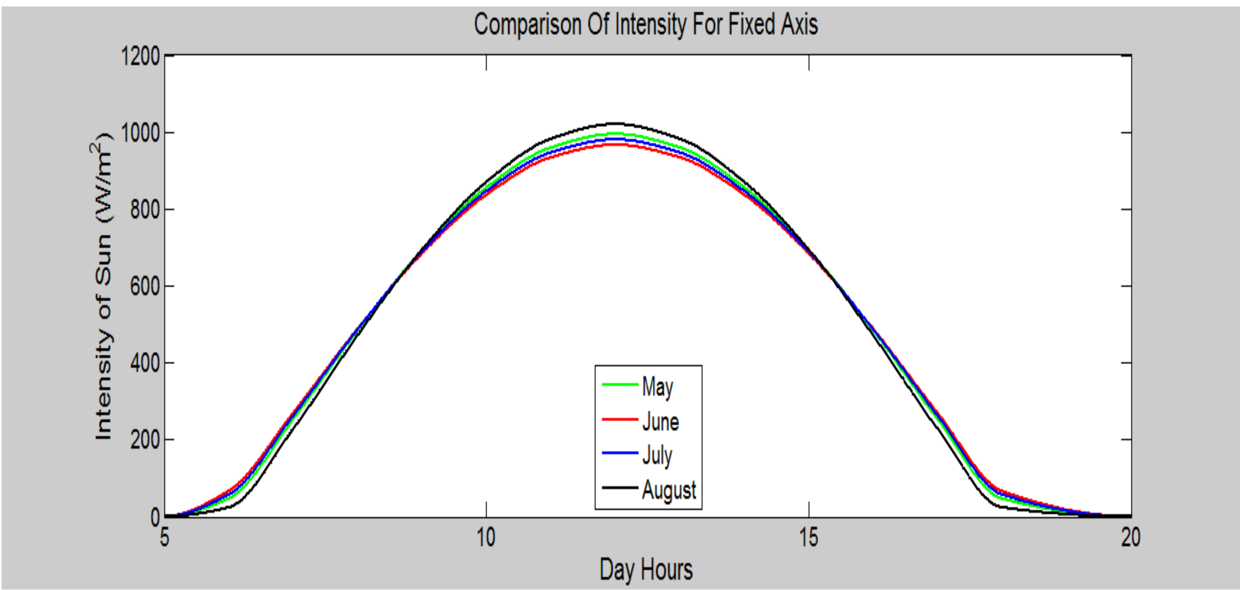
4.3.1 Monthly Solar Irradiance:

4.3.2Comparing Plots :

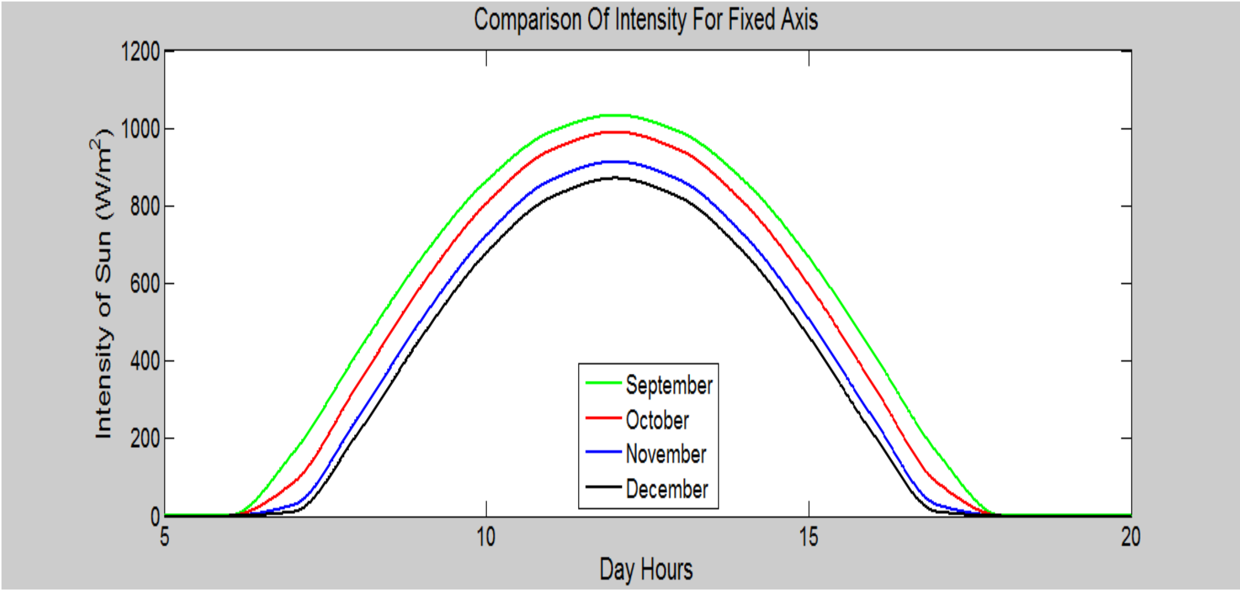
January-April:



May-August:



September-December:



4.3.3 Cumulative Incident Energy:

4.3.3.1 For a Particular Day for Every Month:

Fixed Axis	Wh/m^2
15-Jan	5489
15-Feb	6267.9
15-Mar	7035.4
15-Apr	7099.6
15-May	7578.3
15-Jun	7527.5
15-Jul	7558.9
15-Aug	7561.4
15-Sep	7243
15-Oct	6527.2
15-Nov	5670.7
15-Dec	5242.4

4.3.3.2 For Particular Months:

Fixed Axis	Wh/m^2		Wh/m^2
Jan	5489	31	170159
Feb	6267.9	28	175501.2
Mar	7035.4	31	218097.4
Apr	7099.6	30	212988
May	7578.3	31	234927.3
Jun	7527.5	30	225825
Jul	7558.9	31	234325.9
Aug	7561.4	31	234403.4
Sep	7243	30	217290
Oct	6527.2	31	202343.2
Nov	5670.7	30	170121
Dec	5242.4	31	162514.4

4.3.3.3 For a Particular Year:

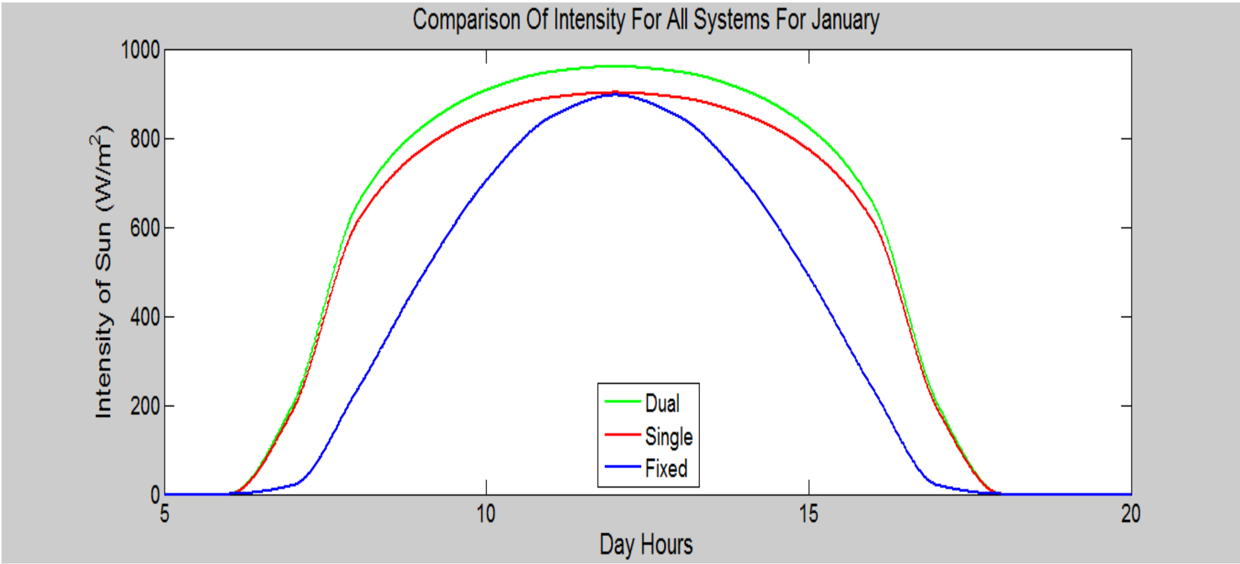
Incident Energy (Wh/m^2):

170159+175501.2+218097.4+212988+234927.3+225825+234325.9+234403.4+217290+202343.2+170121+162514.4= 2458496 Wh = 2.46 MWh

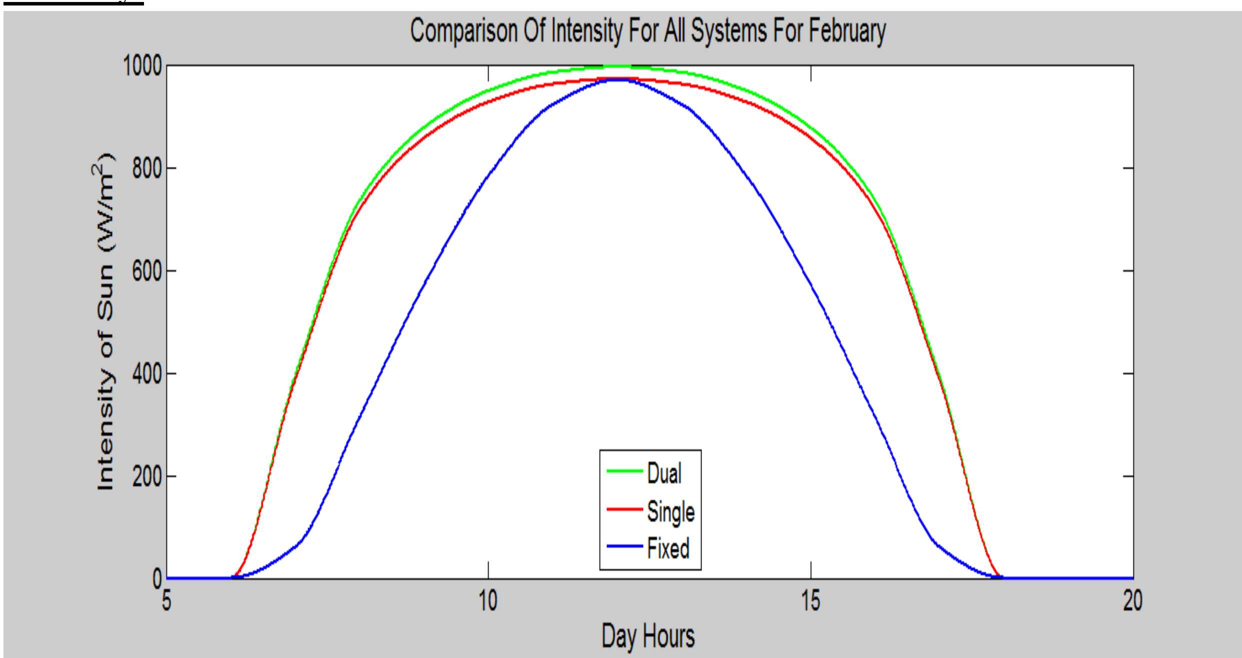
4.4 Comparing Intensity and Energy Collected by Different Tracking Systems:

4.4.1 Comparison of Single, Fixed and Dual Axis Intensity:

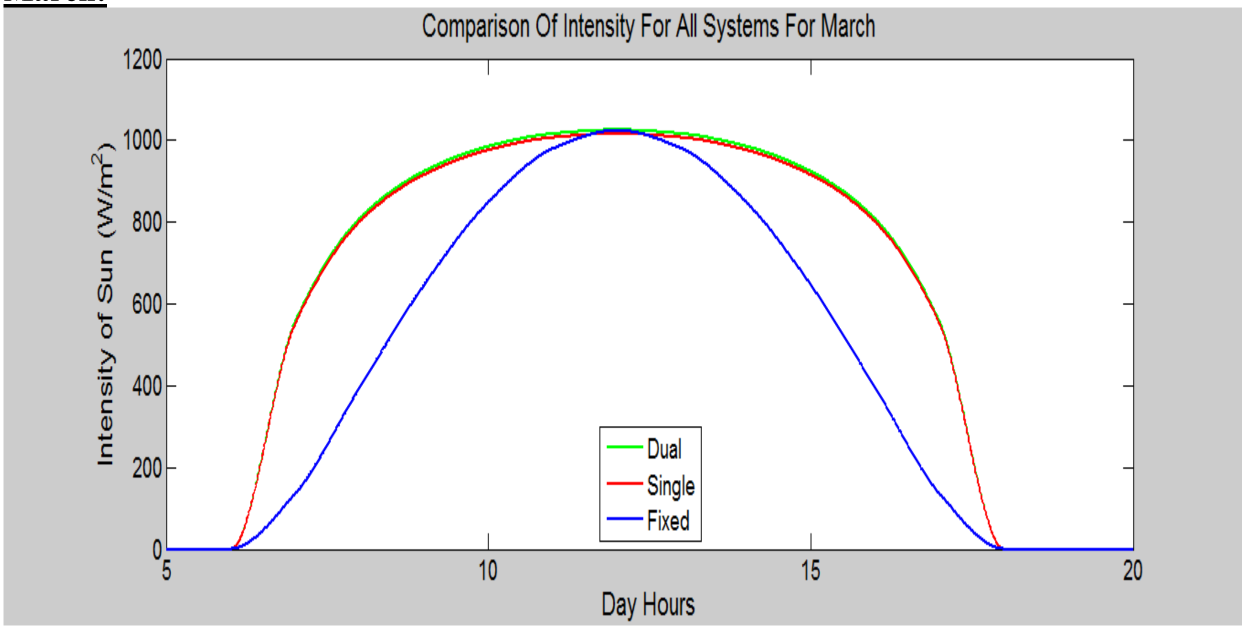
January:



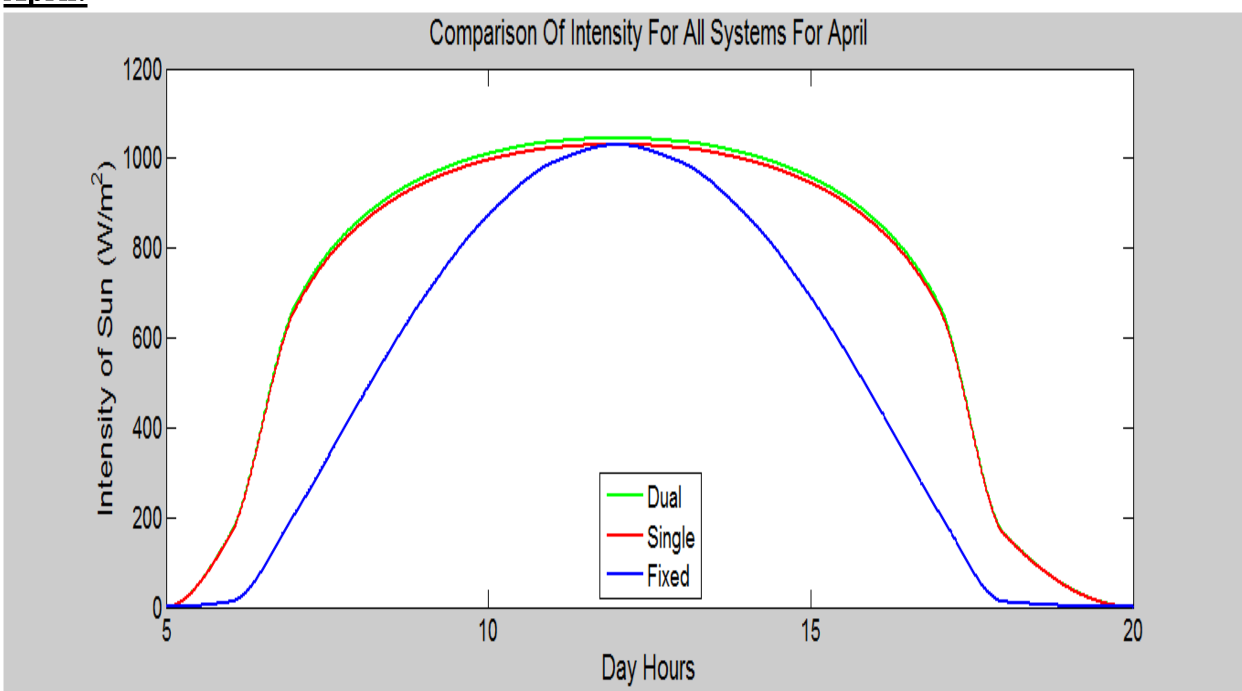
February:



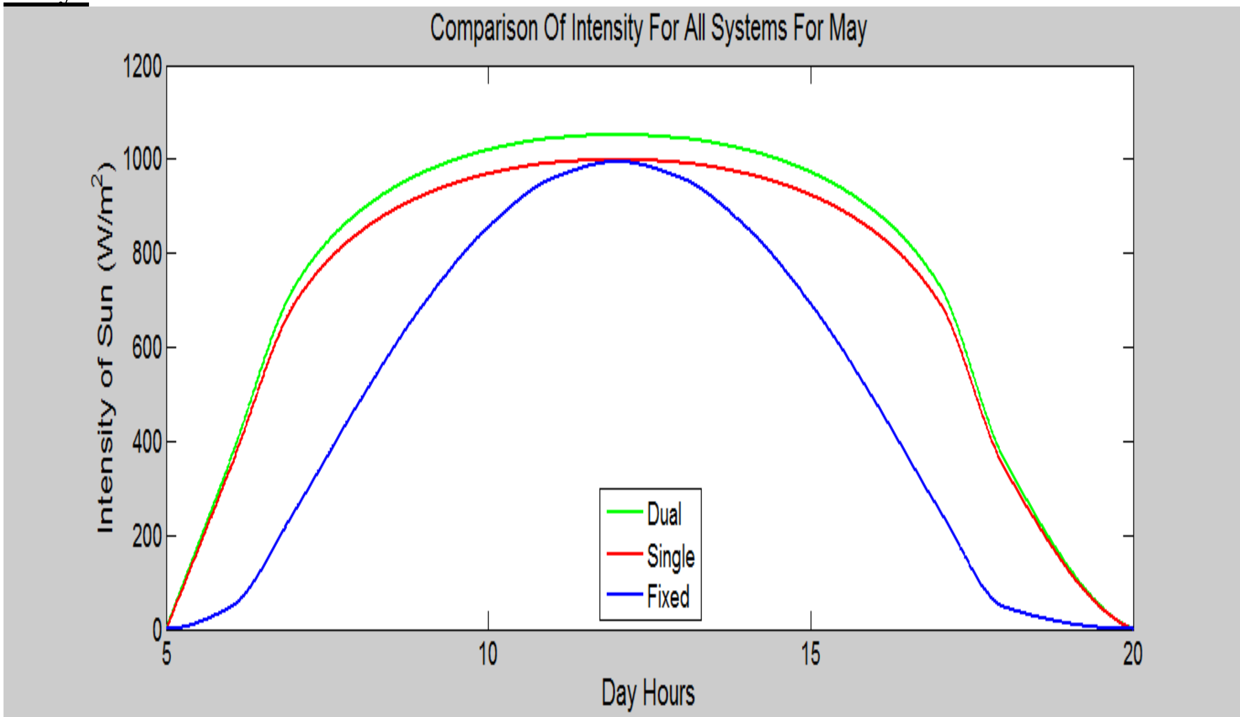
March:


Comparison Of Intensity For All Systems For March
Intensity of Sun (W/m2)
0
200
400
600
800
1000
1200
5
10
15
20
Day Hours
Dual
Single
Fixed

April:

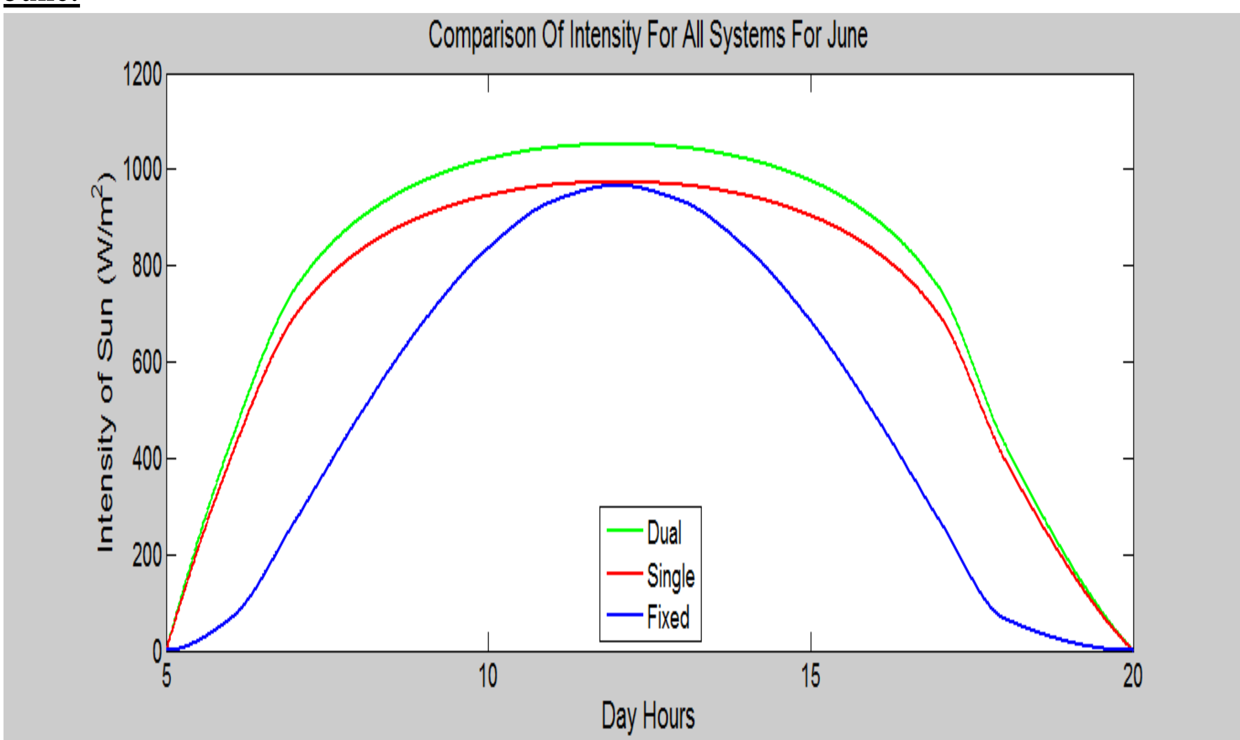

Comparison Of Intensity For All Systems For April
Intensity of Sun (W/m2)
0
200
400
600
800
1000
1200
5
10
15
20
Day Hours
Dual
Single
Fixed

May:



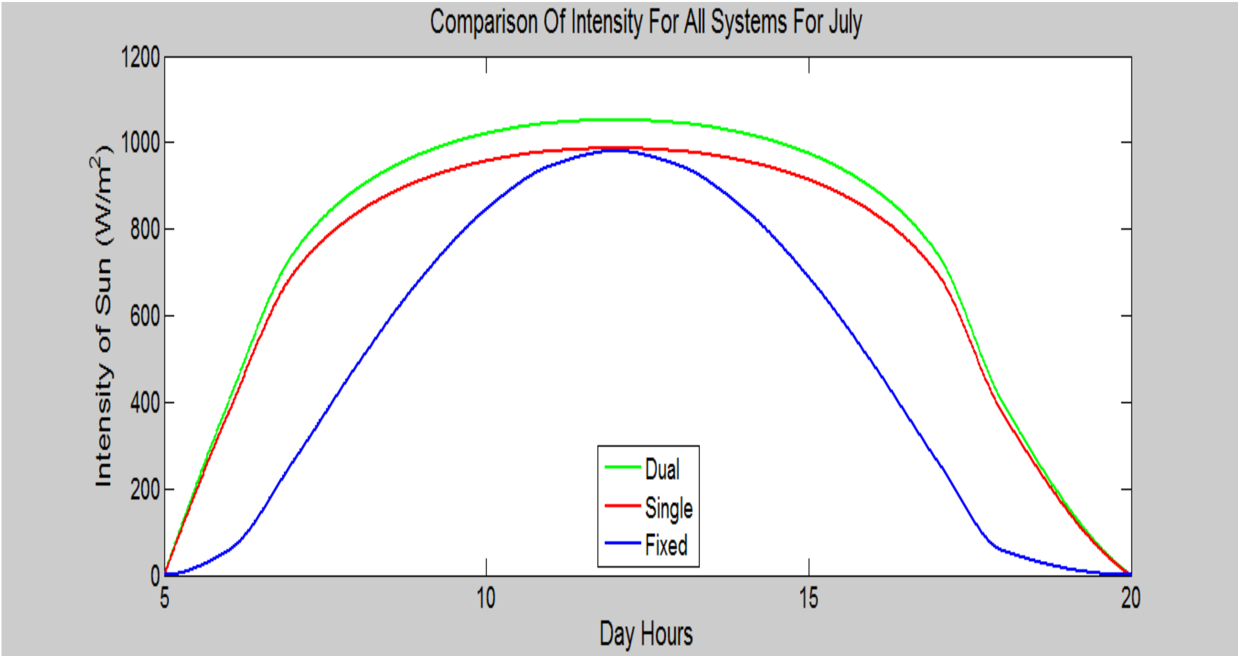
Comparison Of Intensity For All Systems For May
Intensity of Sun (W/m2)
1200
1000
800
600
400
200
0
5
10
15
20
Day Hours
Dual
Single
Fixed

June:

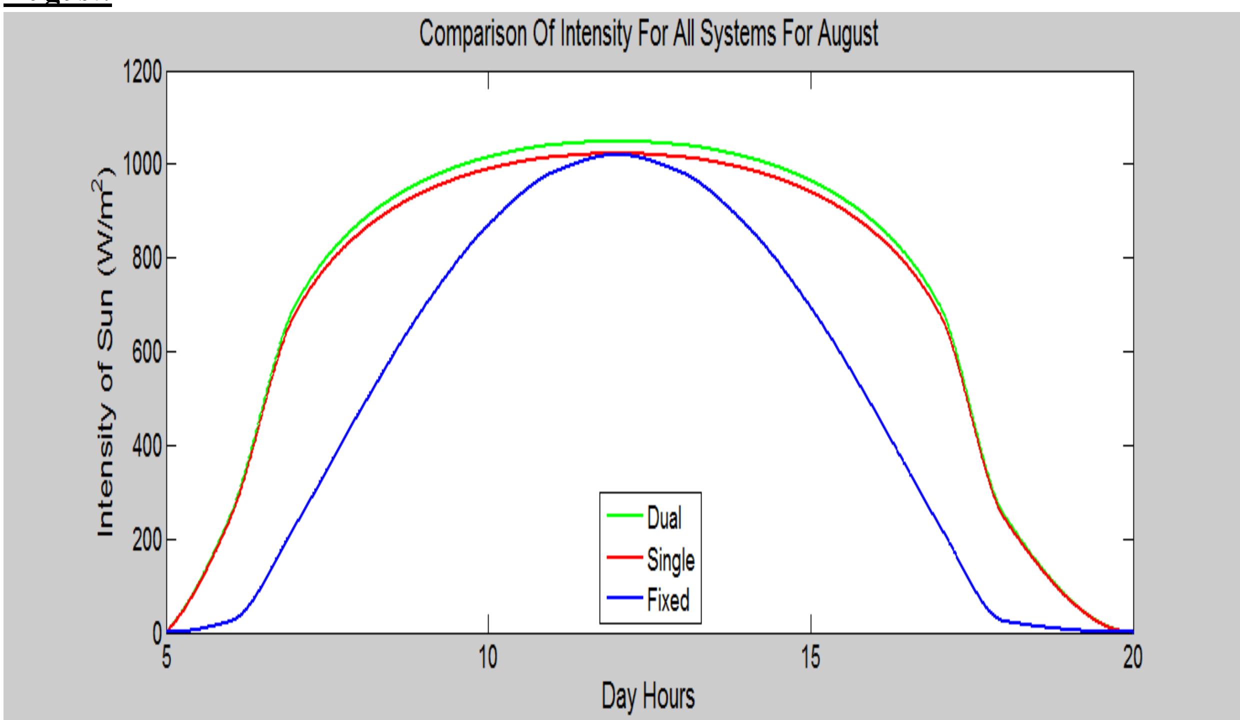


Comparison Of Intensity For All Systems For June
Intensity of Sun (W/m2)
1200
1000
800
600
400
200
0
5
10
15
20
Day Hours
Dual
Single
Fixed

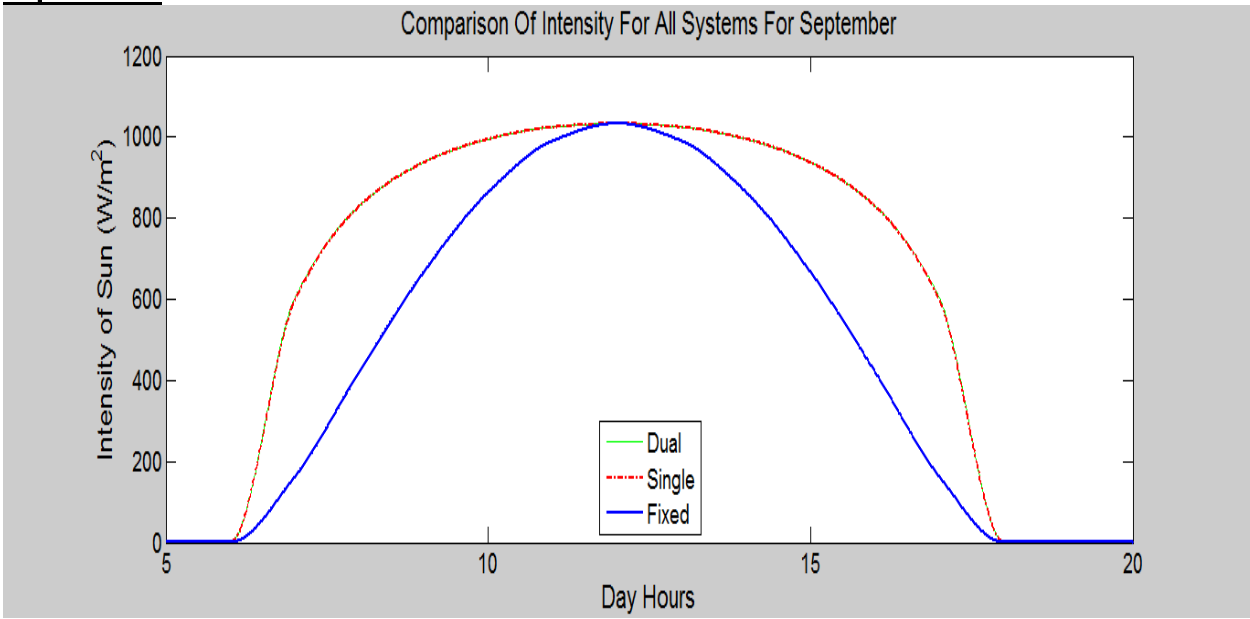
July:


Comparison Of Intensity For All Systems For July
Intensity of Sun (W/m²)
1200
1000
800
600
400
200
0
5
10
15
20
Day Hours
Dual
Single
Fixed

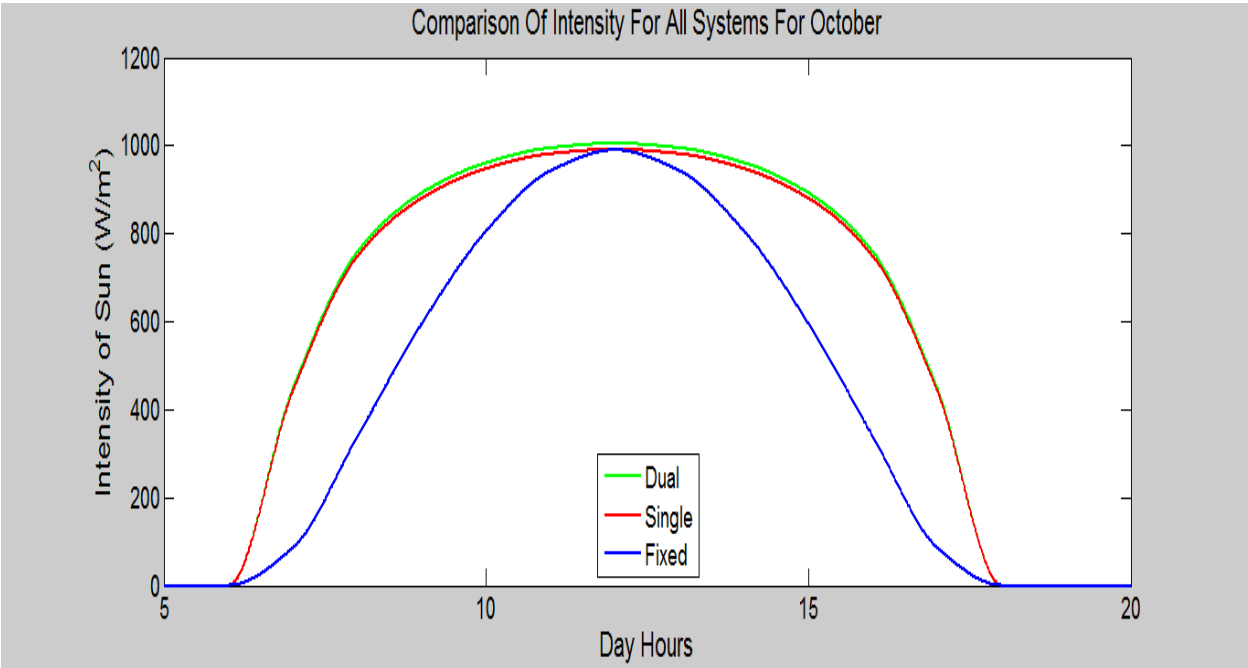
August:


Comparison Of Intensity For All Systems For August
Intensity of Sun (W/m²)
1200
1000
800
600
400
200
0
5
10
15
20
Day Hours
Dual
Single
Fixed

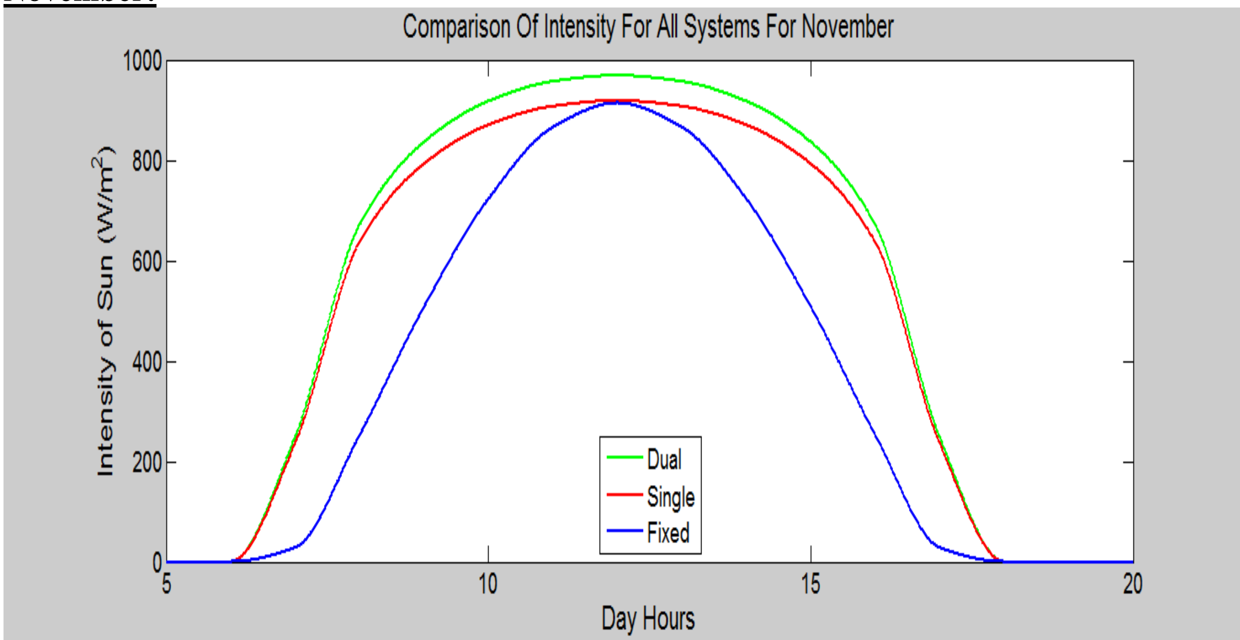
September:



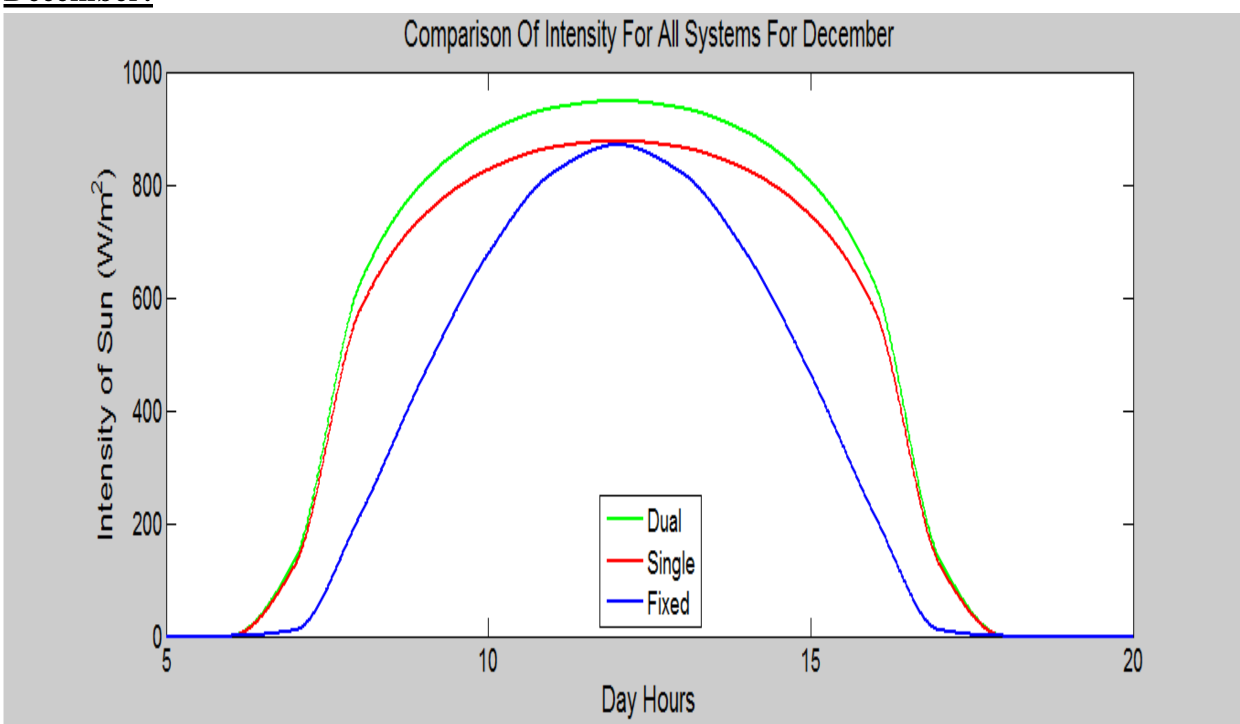
October:



November:

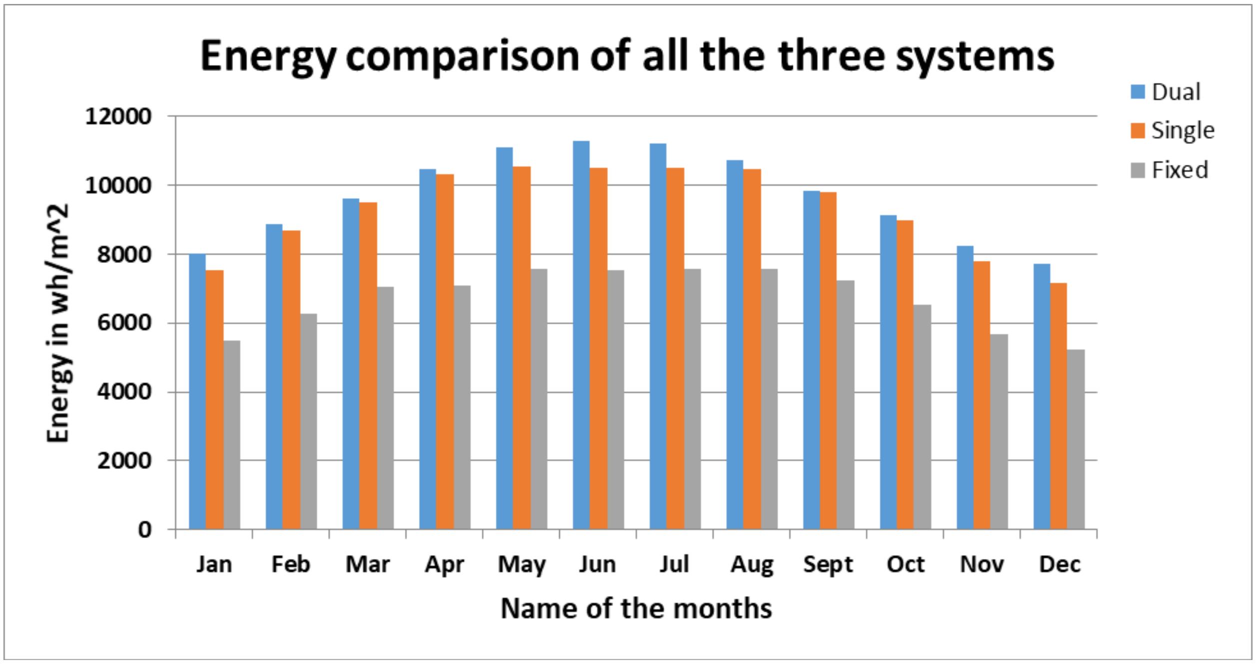


December:

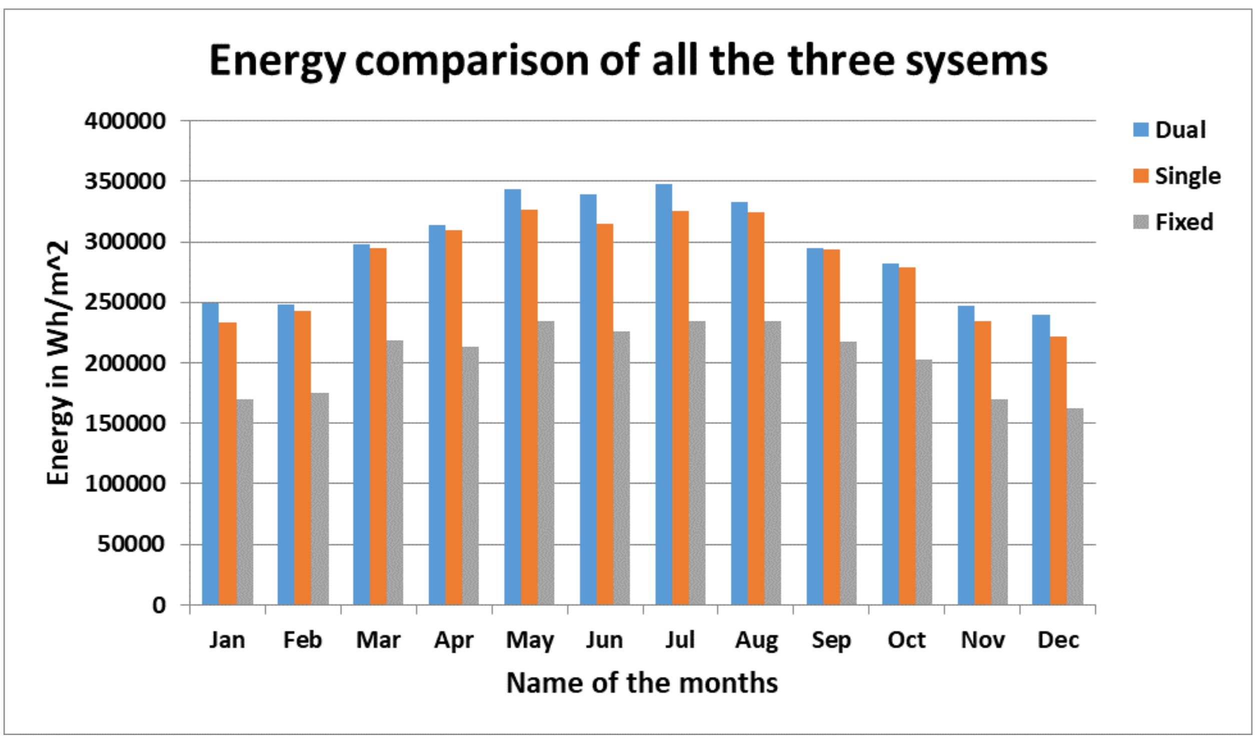


4.4.2 Comparison of Single, Fixed and Dual Axis Intensity:

4.4.2.1 Daily Based Incident Energy:



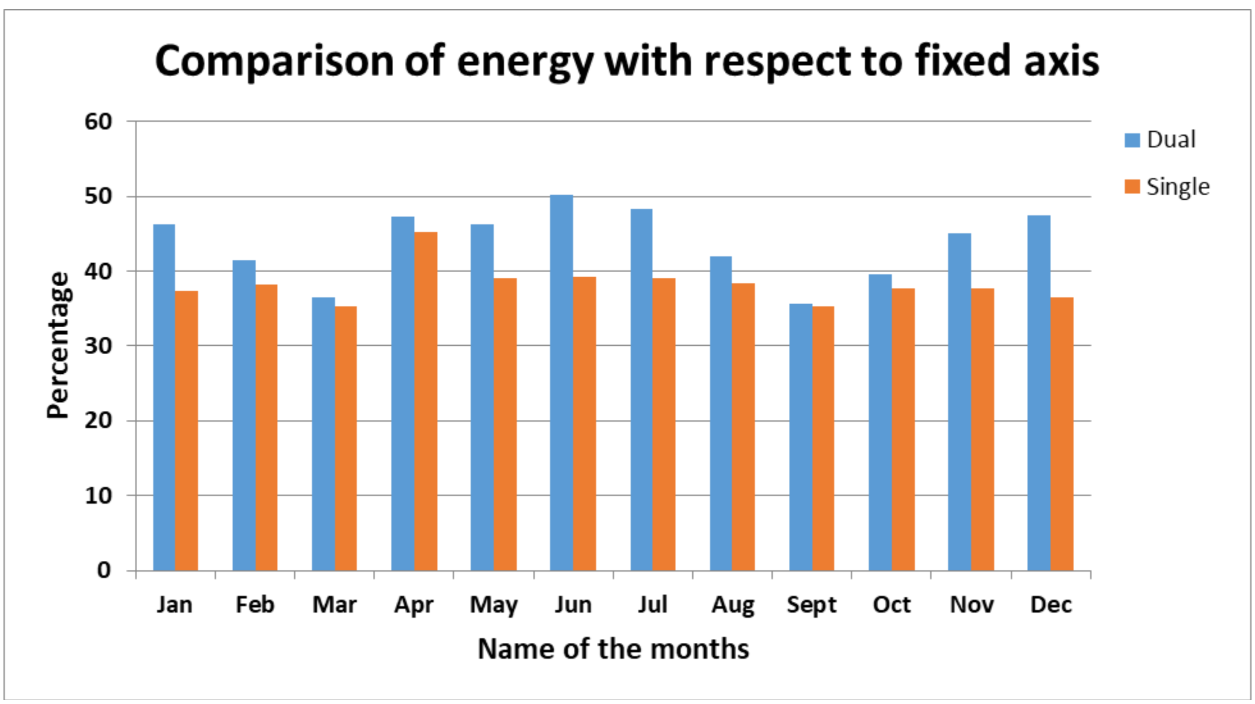
4.4.2.2 Month Based Incident Energy:



4.4.3 Comparison of Monthly Dual & Single Axis Energy with Respect to Fixed Axis:

Energy Difference in Percentage					
Monthly					
Name of Months	Dual Axis (wh/m^2)	Single Axis (wh/m^2)	Fixed Axis (wh/m^2)	Difference between Dual Axis and Fixed Axis (%)	Difference between Single Axis and Fixed (%)
Jan	248771.9	233616	170159	46.19967207	37.29276735
Feb	248382.4	242600.4	175501.2	41.52746534	38.23290097
Mar	297680.6	294977.4	218097.4	36.48975183	35.2503056
Apr	313590	309300	212988	47.23364697	45.21944898
May	343666	326492	234927.3	46.28610638	38.97575974
Jun	339000	314550	225825	50.11624045	39.28927267
Jul	347417	325717	234325.9	48.2623133	39.0017066
Aug	332785	324508	234403.4	41.97106356	38.43997143
Sept	294570	294003	217290	35.56537346	35.30443187
Oct	282503	278649.7	202343.2	39.61576174	37.71142297
Nov	246873	234105	170121	45.11612323	37.61087696
Dec	239713.7	221845.3	162514.4	47.50305204	36.5080879
Yearly					
	3534952.6	3400363.8	2458495.8	43.78517954	38.31074269
				(%)	
			Deifference	5.474436849	

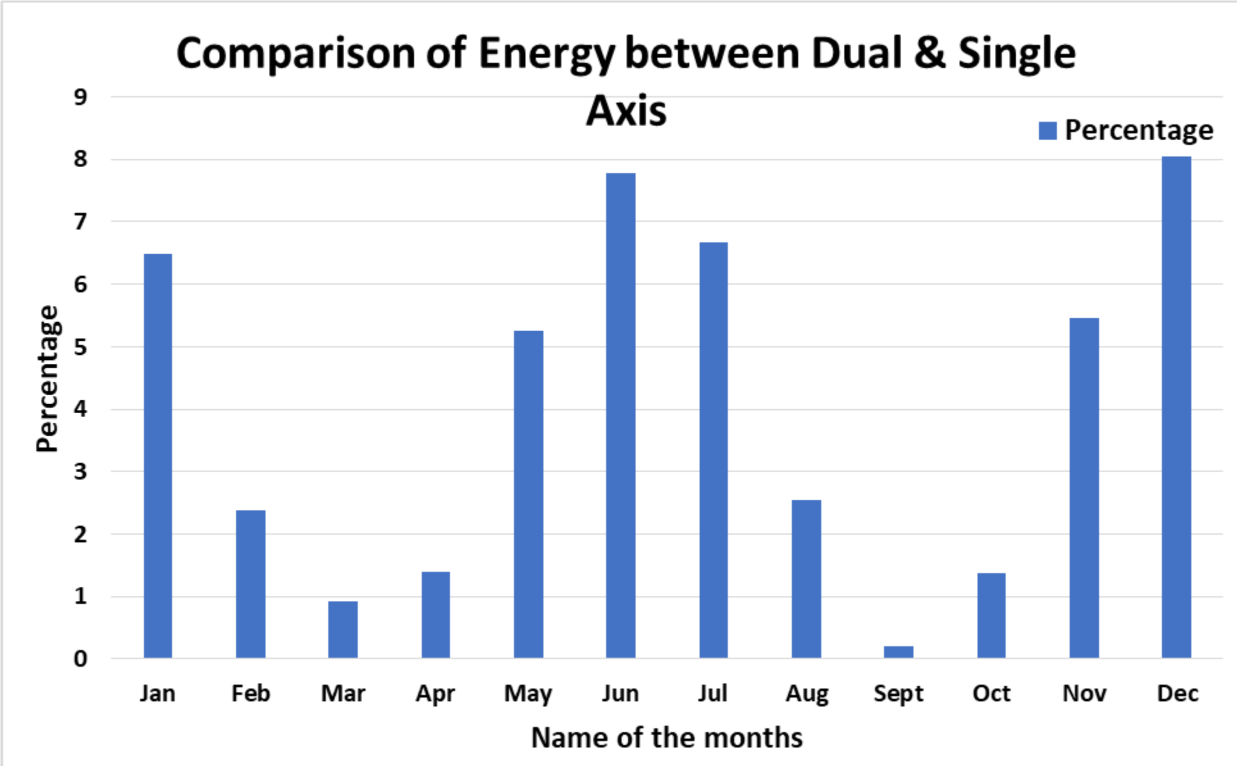
4.4.3.1Energy Difference Plot:



4.4.4 Comparison of Monthly Dual & Single Axis Energy:

Energy Difference in Percentage			
Monthly			
Name of Months	Dual Axis	Single Axis	Difference between Dual Axis and Single Axis
	(wh/m^2)	(wh/m^2)	(%)
Jan	248771.9	233616	6.487526539
Feb	248382.4	242600.4	2.383343144
Mar	297680.6	294977.4	0.916409189
Apr	313590	309300	1.38700291
May	343666	326492	5.260159514
Jun	339000	314550	7.773009061
Jul	347417	325717	6.662225183
Aug	332785	324508	2.550630493
Sept	294570	294003	0.192855175
Oct	282503	278649.7	1.382847353
Nov	246873	234105	5.453962965
Dec	239713.7	221845.3	8.054441541
Yearly	(wh/m^2)	(wh/m^2)	(%)
	3534952.6	3400363.8	3.958070604

4.4.4.1 Energy Difference Plot:



4.4.5 Comparison of Yearly Energy Difference of Single and Dual Axis with Respect to Fixed axis:

Yearly Total Energy	MWh	
Dual Axis	3.54	
Single Axis	3.4	
Fixed Axis	2.46	
Yearly Energy Difference in percantage		
	Dual Axis	Single Axis
	(%)	(%)
	43.79	38.31

Discussion:

As demonstrated in the calculation above, dual axis solar tracker with respect to Bangladesh While considering Diffusion Energy, yields 3.54 MWh worth of energy for a particular year. Single axis solar tracker generates 3.4 Mwh and fixed axis generates 2.46 MWh.

Single axis produces about 38.31% more energy compared to that of fixed axis and dual axis tracker produces about 43.79% more energy in relation to fixed axis. By using a dual axis tracker, we can accumulate about 5.47 % more energy in a particular year.

The deviation between Dual and Single axis that has been portrayed above which is 3.95%, not much significant in terms of figurative value.

Chapter 5: Cloud effect on Solar Incident Energy

As we all know that sun doesn't shine in the same way all over the year due to seasonal variations and cloud coverage. Though we conjure up of having 6 seasons but basically it is the monsoon that devour most of the sunshine while rearing the sun. So it is quite apparent that it affects the amount of solar energy that can be harnessed over a particular year. In our instance cloud coverage is quite a big factor as we are willing to differentiate the performance between Dual axis & Single axis tracking system.

In order to highlight on the actual effect of the cloud coverage primarily we need to obtain the number of days that have clouds over head. There are several ways of surveying that but in our instance we utilized the knowledge of Insolation to figure out the number of cloudy days throughout the year.

5.1 Cloud Effect Calculation Process

5.1.1 Insolation

Solar insolation is the measure of sun's radiation energy that is received by a given horizontal surface on a given time window that apparently relies on the altitude of the sun and cloud coverage. The following figure emphasizes on the amount of month wise insolation throughout the year.

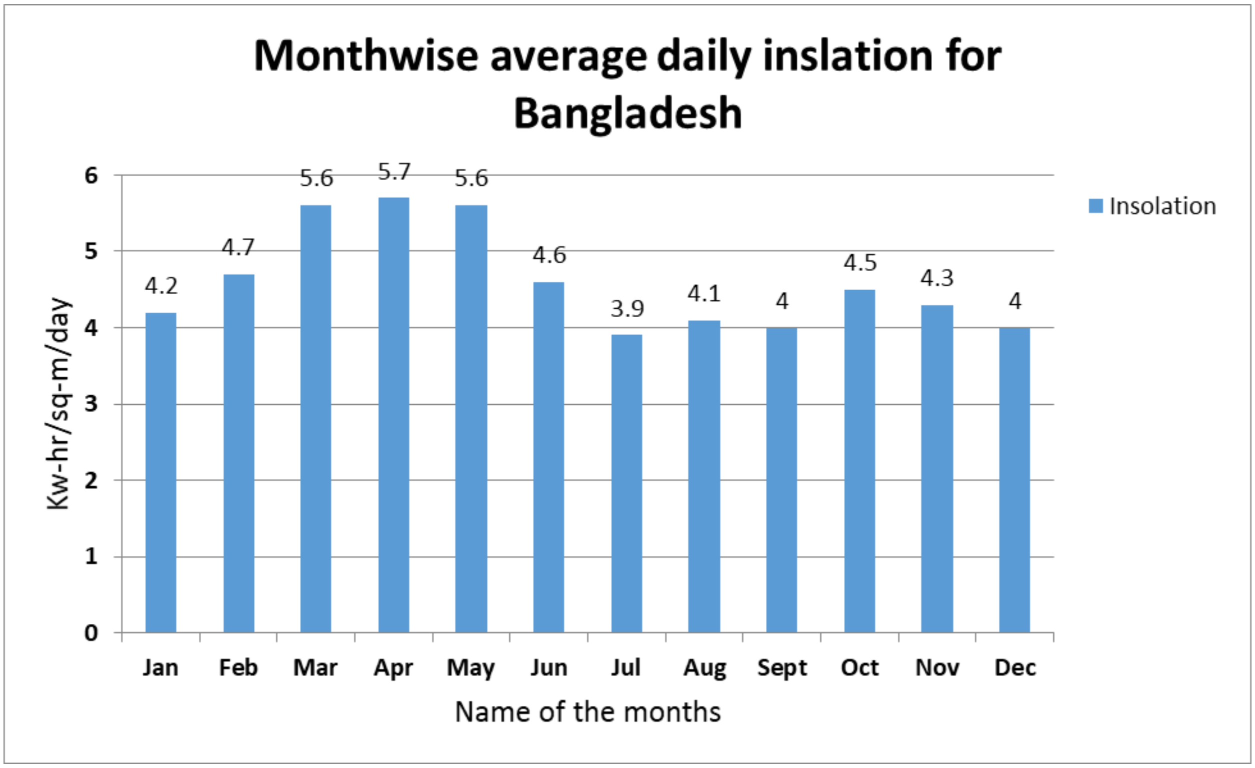


Figure:5.1 Amount of Monthly Insolation for Bangladesh

Our next procedure was acquiring the amount of energy on sunny days as well as on cloudy days. Here energy of sunny day refers to the energy that is received on a pure shiny day while having the sun directly overhead and cloudy days' energy refers to 20% of the energy on sunny day. While doing so we utilized set of mathematical equations that are provided below.

$$E_{sunny} = \int_{Sun\ rise}^{Sun\ set} (I\sin\alpha + 0.2I)\, dx$$

$$E_{Cloudy} = \int_{Sun\ rise}^{Sun\ set} 0.2I\, dx$$

Next approach was to find the approximate number of sunny days and cloudy days by using the subsequent equations.

$$E_{Direct} = x * E_{Sunny} + y * E_{Cloudy}$$

$$x + y = Total\ Days_{particular\ month}$$

Here x is no. of sunny days while y is the cloudy days.

While using the following set of equations we finally figured out the number of sunny and cloudy days. In the equation (4.3), E_{Direct} refers to the energy that we procured from insolation.

$$E_{Direct} = Total\ Days_{particular\ month} * E_{Insolation}$$

	Sunny Days	Cloudy days
Jan	28	3
Feb	23	5
Mar	25	6
Apr	20	10
May	18	13
Jun	12	18
jul	9	22
Aug	11	20
Sept	13	17
Oct	21	10
Nov	25	5
Dec	26	5

Table:5.1 No. of Sunny & Cloudy Days

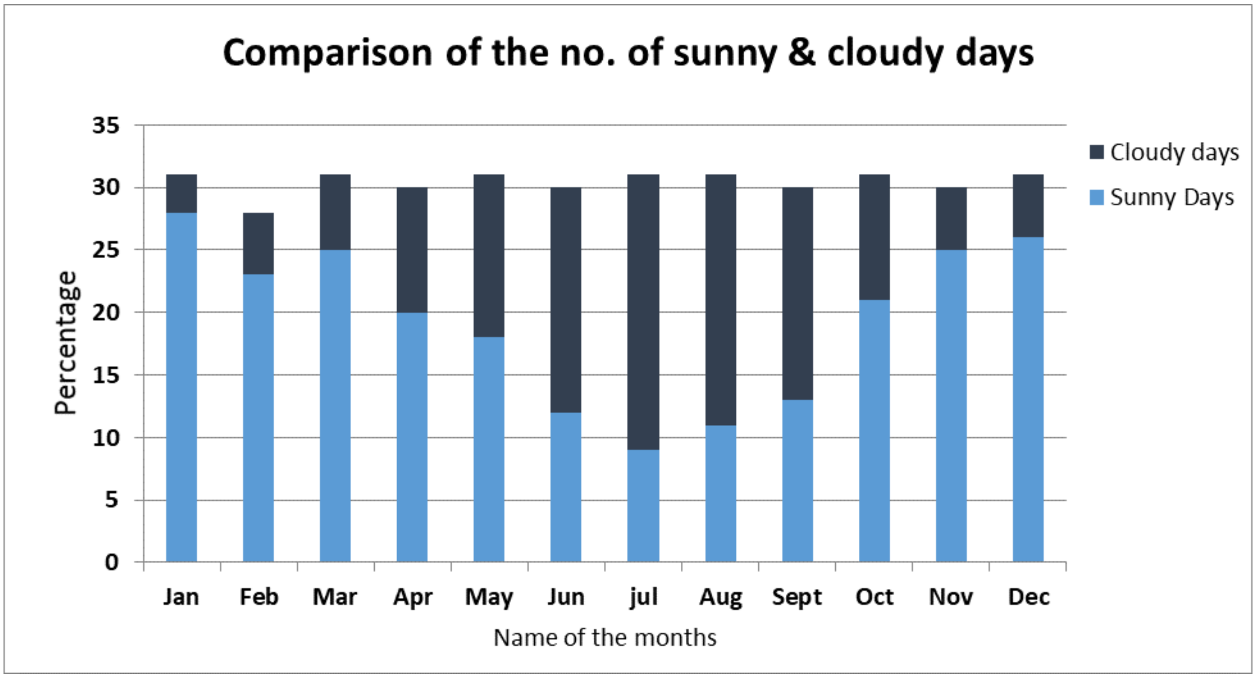


Figure:5.2 No. of Sunny & Cloudy Days

The subsequent table and figure gives us a clear idea of how the number of sunny days and cloudy days are sorted throughout a particular year.

Our next approach was to calculate the amount of actual energy after the cloud effect is considered. To do so we obtained the total value of energy of both total sunny and cloudy days, finally added them up to find the energy of a whole month. We repeated the whole procedure to chalk up the energy received for all the months of a particular year.

5.2: Calculation of Incident Energy Considering Cloud Effect

	Dual axis		Dual axis
Name of Months	Wh/m^2	No. of days	Wh/m^2
Jan	8024.9	28	224697.2
Feb	8870.8	23	204028.4
Mar	9602.6	25	240065
Apr	10453	20	209060
May	11086	18	199548
Jun	11300	12	135600
Jul	11207	9	100863
Aug	10735	11	118085
Sep	9819	13	127647
Oct	9113	21	191373
Nov	8229.1	25	205727.5
Dec	7732.7	26	201050.2

Table:5.2 Month wise total Sunny Days Energy for Dual Axis

	Single axis		Single axis
Name of Months	Wh/m^2	No. of days	Wh/m^2
Jan	7536	28	211008
Feb	8664.3	23	199278.9
Mar	9515.4	25	237885
Apr	10310	20	206200
May	10532	18	189576
Jun	10485	12	125820
Jul	10507	9	94563
Aug	10468	11	115148
Sep	9800.1	13	127401.3
Oct	8988.7	21	188762.7
Nov	7803.5	25	195087.5
Dec	7156.3	26	186063.8

Table:5.3 Month wise total Sunny Days Energy for Single Axis

Name of Months	Fixed Axis Wh/m^2	No. of days	Fixed Axis Wh/m^2
Jan	5489	28	153692
Feb	6267.9	23	144161.7
Mar	7035.4	25	175885
Apr	7099.6	20	141992
May	7578.3	18	136409.4
Jun	7527.5	12	90330
Jul	7558.9	9	68030.1
Aug	7561.4	11	83175.4
Sep	7243	13	94159
Oct	6527.2	21	137071.2
Nov	5670.7	25	141767.5
Dec	5242.4	26	136302.4

Table:5.4 Month wise total Sunny Days Energy for Fixed Axis

Cloudy day Energy			
	Direct Energy (Wh/m^2)		Cloudy day Energy (20% of direct)
Name of Months			(Wh/m^2)
Jan	8024.9	0.2	1604.98
Feb	8870.8	0.2	1774.16
Mar	9602.6	0.2	1920.52
Apr	10453	0.2	2090.6
May	11086	0.2	2217.2
Jun	11300	0.2	2260
jul	11207	0.2	2241.4
Aug	10735	0.2	2147
Sept	9819	0.2	1963.8
Oct	9113	0.2	1822.6
Nov	8229.1	0.2	1645.82
Dec	7732.7	0.2	1546.54

Table:5.5 Daily based Cloudy Days Energy throughout the year

In table 4.5 we considered daily energy for every month's day 15^{th} as we assumed that the energy varies within that range over the month.

Energy affected due to cloud			
	No. of Cloudy days	Cloudy day Energy(20% of direct)	Total
		(Wh/m^2)	(Wh/m^2)
Jan	3	1604.98	4814.94
Feb	5	1774.16	8870.8
Mar	6	1920.52	11523.12
Apr	10	2090.6	20906
May	13	2217.2	28823.6
Jun	18	2260	40680
jul	22	2241.4	49310.8
Aug	20	2147	42940
Sept	17	1963.8	33384.6
Oct	10	1822.6	18226
Nov	5	1645.82	8229.1
Dec	5	1546.54	7732.7

Table: 5.6 Month wise total Cloudy Days Energy throughout a year

By adding the total sunny days energy and cloudy days energy we obtain total cloud affected energy throughout the year. Following tables show the total energy for every month for each tracking system.

Dual Axis			
Name of the Months	Total Sunny Days Energy	Total Cloudy Days Energy	Total Energy
	(Wh/m^2)	(Wh/m^2)	(Wh/m^2)
Jan	224697.2	4814.94	229512.14
Feb	204028.4	8870.8	212899.2
Mar	240065	11523.12	251588.12
Apr	209060	20906	229966
May	199548	28823.6	228371.6
Jun	135600	40680	176280
jul	100863	49310.8	150173.8
Aug	118085	42940	161025
Sept	127647	33384.6	161031.6
Oct	191373	18226	209599
Nov	205727.5	8229.1	213956.6
Dec	201050.2	7732.7	208782.9

Table:5.7 Cloud Affected total Energy for Dual Axis

Single Axis			
Name of the Months	Total Sunny Days Energy	Total Cloudy Days Energy	Total Energy
	(Wh/m^2)	(Wh/m^2)	(Wh/m^2)
Jan	211008	4814.94	215822.94
Feb	199278.9	8870.8	208149.7
Mar	237885	11523.12	249408.12
Apr	206200	20906	227106
May	189576	28823.6	218399.6
Jun	125820	40680	166500
jul	94563	49310.8	143873.8
Aug	115148	42940	158088
Sept	127401.3	33384.6	160785.9
Oct	188762.7	18226	206988.7
Nov	195087.5	8229.1	203316.6
Dec	186063.8	7732.7	193796.5

Table:5.8 Cloud Affected total Energy for Single Axis

Fixed Axis			
Name of the Months	Total Sunny Days Energy	Total Cloudy Days Energy	Total Energy
	(Wh/m^2)	(Wh/m^2)	(Wh/m^2)
Jan	153692	4814.94	158506.94
Feb	144161.7	8870.8	153032.5
Mar	175885	11523.12	187408.12
Apr	141992	20906	162898
May	136409.4	28823.6	165233
Jun	90330	40680	131010
jul	68030.1	49310.8	117340.9
Aug	83175.4	42940	126115.4
Sept	94159	33384.6	127543.6
Oct	137071.2	18226	155297.2
Nov	141767.5	8229.1	149996.6
Dec	136302.4	7732.7	144035.1

Table:5.9 Cloud Affected total Energy for Fixed Axis

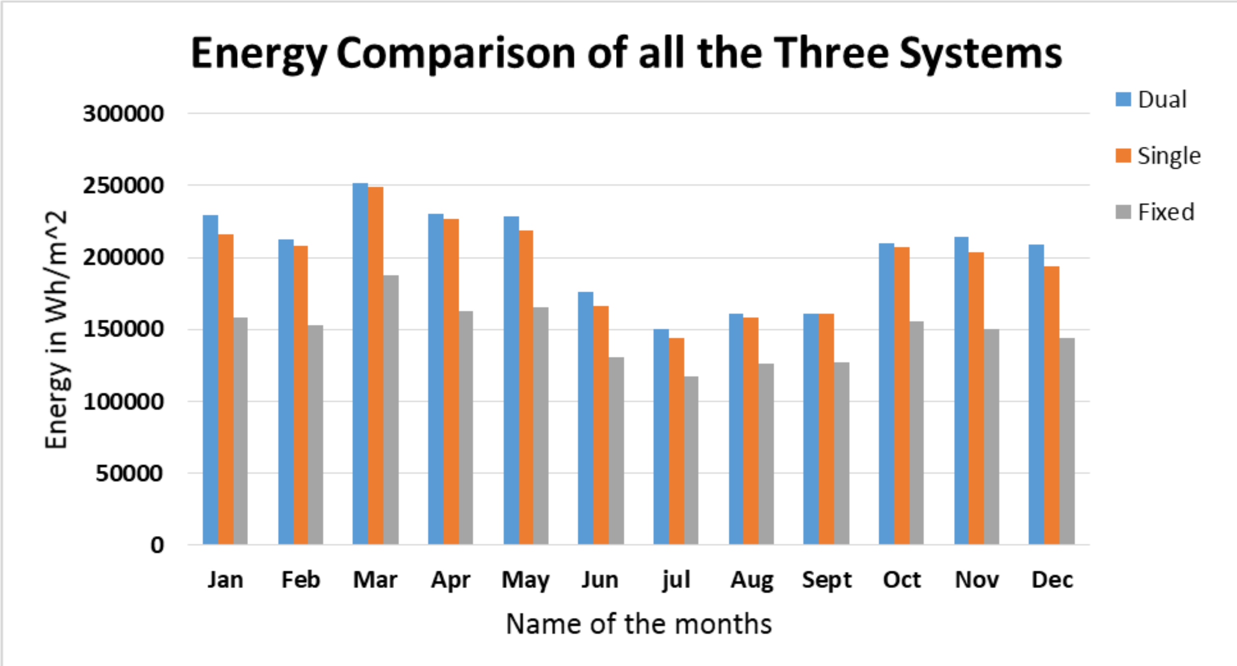


Figure:5.3 Comparison of Monthly Cloud Affected Energy

				Difference with recpect to Fixed Axis (%)	
	Dual Axis	Single Axis	Fixed Axis	Dual Axis	Single Axis
Name of Months	Wh/m^2	Wh/m^2	Wh/m^2	(%)	(%)
Jan	229512.14	215822.94	158506.94	44.79627201	36.15993092
Feb	212899.2	208149.7	153032.5	39.12025223	36.01666313
Mar	251588.12	249408.12	187408.12	34.24611484	33.08287816
Apr	229966	227106	162898	41.1717762	39.41607632
May	228371.6	218399.6	165233	38.21185841	32.17674435
Jun	176280	166500	131010	34.55461415	27.08953515
jul	150173.8	143873.8	117340.9	27.98078078	22.61180884
Aug	161025	158088	126115.4	27.68067976	25.35186028
Sept	161031.6	160785.9	127543.6	26.25611948	26.06347947
Oct	209599	206988.7	155297.2	34.96637415	33.28553251
Nov	213956.6	203316.6	149996.6	42.64096653	35.54747241
Dec	208782.9	193796.5	144035.1	44.95279276	34.54810668
Yearl Energy	Wh/m^2	Wh/m^2	Wh/m^2	(%)	(%)
	2433185.96	2352235.86	1778417.4	36.81748811	32.26568256
					(%)
				Difference=	4.551805545

Table:5.10 Energy Difference between Dual & Single Axis with respect to Fixed Axis

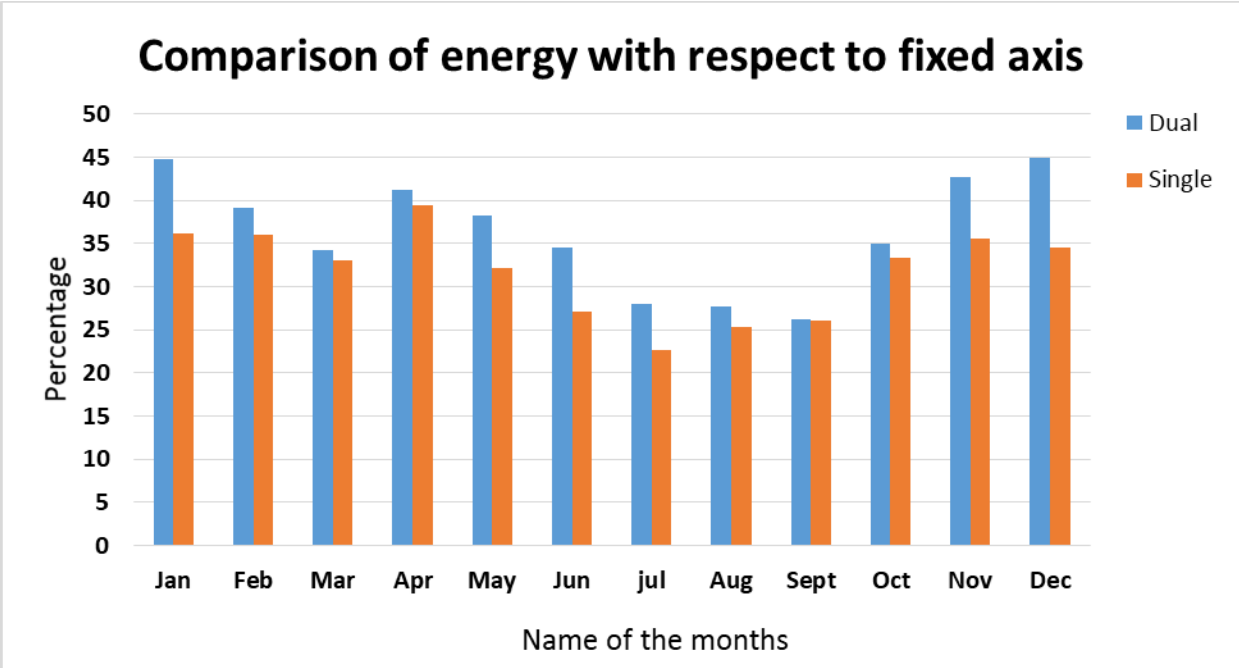


Figure:5.4 Energy Difference for Cloud Affected Monthly Energy

Table 4.8 and figure 4.4 gives us a clear view about how energy is deviated for different types of tracking systems due to cloud effect from month to month. Moreover, it focuses on the yearly total energy difference in percentage between Dual and Single axis with respect Fixed axis.

Energy Difference in percentage			
Monthly	Dual Axis	Single Axis	Difference
	(Wh/m^2)	(Wh/m^2)	(%)
Jan	229512.14	215822.94	6.34279192
Feb	212899.2	208149.7	2.281771244
Mar	251588.12	249408.12	0.874069377
Apr	229966	227106	1.25932384
May	228371.6	218399.6	4.565942428
Jun	176280	166500	5.873873874
jul	150173.8	143873.8	4.378837565
Aug	161025	158088	1.857826021
Sept	161031.6	160785.9	0.152811907
Oct	209599	206988.7	1.261083335
Nov	213956.6	203316.6	5.233217553
Dec	208782.9	193796.5	7.733060195
Yearly	Dual Axis	Single Axis	Difference
	(Wh/m^2)	(Wh/m^2)	(%)
	2433185.96	2352235.86	3.441410846

Table:5.11 Energy Difference in percentage between Dual & Single Axis

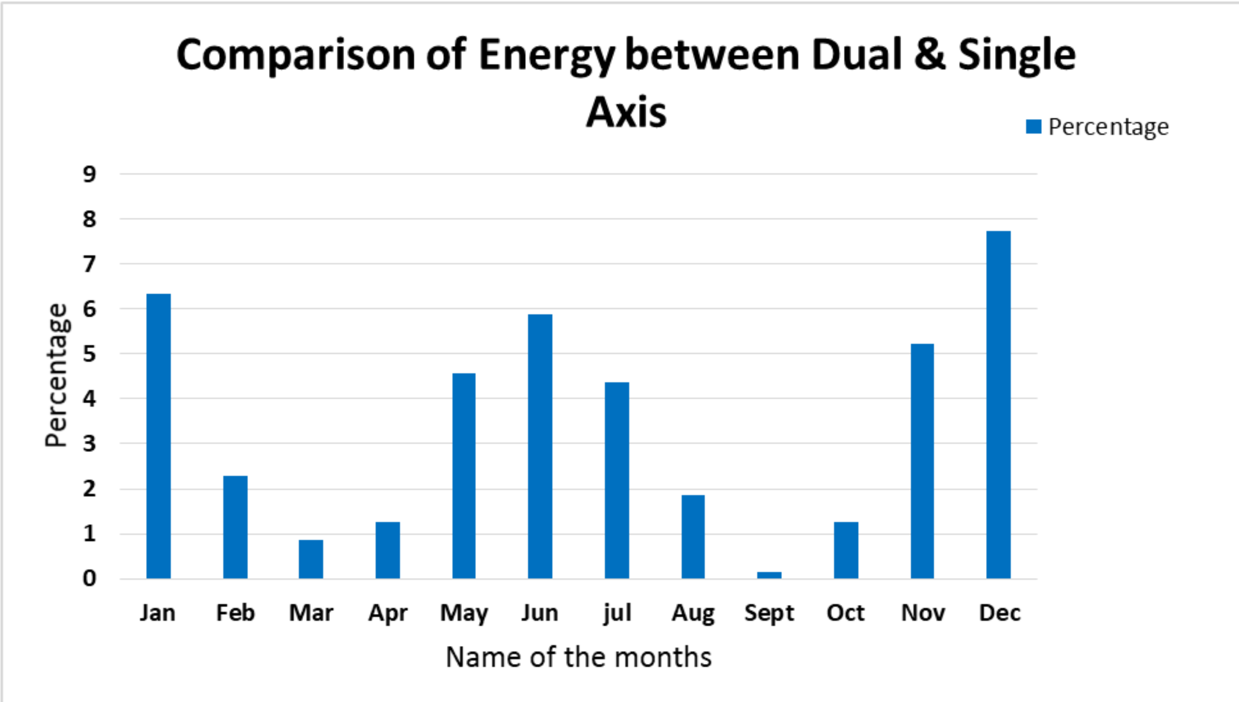


Figure:5.5 Energy Difference in percentage between Dual & Single Axis

The above table 4.9 and the associated figure 4.5 portrays the energy difference between energy of dual and single axis which elucidates the marginal deviation of the two tracking systems.

5.3 Discussion:

Our analysis is based on two main issues and that are electrical output of the two systems and finally the cost consideration of the two.

5.3.1 Electrical Output:

Basically the substantial amount for modern day solar panels in up to 10% of the actual energy that is received by the panel from the sun. we tried to portray that amount for both our dual & single axis in the following table of calculations.

Name of Months	Dual Axis (wh/m^2)	Single Axis (wh/m^2)
Jan	229512	215823
Feb	212899	208150
Mar	251588	249408
Apr	229966	227106
May	228372	218400
Jun	176280	166500
jul	150174	143874
Aug	161025	158088
Sept	161032	160786
Oct	209599	206989
Nov	213957	203317
Dec	208783	193797
Yearl Energy		
In Wh/m^2	2433187	2352238
In KWh/m^2	2433.187	2352.238
Electrical output :	**(Kwh/m^2)**	
	Dual Axis	Single Axis
	243.3187	235.2238

Table:5.12 Yearly Electrical Output for Dual & Single Axis

Let’s assume that we have 10 panels with each having a dimension of 1m x 1m. so the final dimension wise electrical output will change as follows.

let's ssume standard panel dimension =					1m^2 x 1m^2
if we consider 10 panels total area of panel=					10 m^2
Total Electrical Output :(Kwh)				Dual Axis	Single Axis
				2433.18596	2352.23586
Difference in Output:(Kwh)					
		80.9501	units		

Table:5.13 Yearly Electrical Output considering standard panel size

As we know that output of 1 KWh of electrical energy is considered as 1 unit so the above table elucidates the difference of yearly electrical output between dual and single axis which is 80.95 units not that imperatively large.

5.3.2 Cost Consideration:

Apparently it is quite an important factor that we must consider before going in to any factual implementation. Here we tried to compare the two systems by means of money they are going to cost and eventually recoup at the end of the year.

Cost in Taka

Per unit cost in **BDT**	10 Taka	
Total Units	80.9501 units	
Total Unit Price	809.501	Taka

So total difference in terms of cost between dual and single: 809.501 BDT

Chapter:6 Conclusion

All the calculations that we have been through portrays the very fact that there is no significant deviation in between the two systems that are Dual Axis and Single Axis. If we closely focus on the energy difference of yearly energy where we considered both Direct & Diffusion factors the number is quite low with respect to fixed axis and even smaller when considered among only the two. Figuratively the numbers are given below.

Tracker System	Yearly Energy, wh/m^2	% Difference
Fixed	2458495.8	0
Single	3400363.8	38.31074269
Dual	3534952.6	43.78517954
Difference		5.474436849

Table:4.14 Difference between Dual and Single Axis Yearly Energy

Moreover, while regarding the values after cloud effect is considered we can notice that even though the values have decreased but the difference between the two systems has also condensed proportionally.

Tracker System	Yearly Energy Output, kwh/m^2	Electrical Unit	% Difference	Value in Tk
Fixed	177.8417	1778.417	0	0
Single	235.2238	2352.238	32.26582967	23,522.38
Dual	243.3187	2433.187	36.81757428	24,331.87
Difference			4.551744613	809.49

Table:4.15 Difference between Dual and Single Axis cloud affected Yearly Energy

The differences with respect to fixed axis in terms of both cloud influenced and uninfluenced values are 5.47% & 4.55% which illustrates a deviation of 0.91%. On the other hand, the direct differences between Dual and Single axis with both regarding and not regarding the cloud effect are 3.96% & 3.44% that has a variance of 0.52%. In both the cases we can observe that the deviations are not that much significant.

Once and for all it can be portrayed that the systems have no significant difference in between them while considering all the factors that we have mentioned above. If compared, the electrical output is quite small of dual axis and has no significance over single axis's electrical output. The cost deviates by only 809.5 BDT which might even end up not being able to recover the factual implementation cost that would incur.

The values would have deviated more between dual and single axis if the region or location was different but in terms of Bangladesh the main fact is that the degree to which the declination angles varies from month to month throughout the year is quite small. If the deviation of the angle was larger than the solar energy absorbed over the year would have been even much larger. To add up in figure4.2 we can visualize that the sky of Bangladesh is covered by clouds most of the time during the Month of May, June, July & August when the amount of radiation is large in number which is truly an irony.

Appendix:

Mat lab Codes:

1) **The following code has been used to find the solar intensity:**

```
function I=Intensity(n,T,q)
a=q*(sind((360/365)*(n-80)));
Sr=12-((1/15)*(acosd(-tand(a)*tand(q))));
Ss=12+((1/15)*(acosd(-tand(a)*tand(q))));
ws=acosd((-tand(a)*tand(q)));
t=Ss-Sr;
w=(-ws+(((2*ws)/t)*(T-Sr)));
A=asind((sind(a)*sind(q))+(cosd(a)*cosd(q)*cosd(w)));
M=(1/cosd(90-A));
I=1367*((0.7)^(M^(0.678)));
End
```

2) **Code for finding sunrise time:**

```
function S=Sunrise(n,q)
a=q*(sind((360/365)*(n-80)));
S=12-((1/15)*(acosd(-tand(a)*tand(q))));
End
```

3) **Code for finding sunset time:**

```
function S=Sunset(n,q)
a=q*(sind((360/365)*(n-80)));
S=12+((1/15)*(acosd(-tand(a)*tand(q))));
end
```