Birzeit University
Faculty of Engineering & Techonology
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ENEE5307

"Project 1"

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Abstract

This work has investigated calculations of solar irradiance in November at Ramallah city.

The three components of irradiance including the direct beam radiation, diffuse radiation, and reflected irradiation quantities from sunrise to sunset were simulated by making use of different formulas relating the day number , altitude angle , tilt angle , solar azimuth angle, incidence angle , and collector azimuth angle. The average daily and monthly peak sun hour (PSH) were calculated in addition to the average total irradiance for the first , middle , and last days of November for five different scenarios of the tilt and collector azimuth angles.

Contents

Acronyms and Abbreviations

m	Air mass ratio
IBC	Direct Beam radiation
IDC	Diffuse Radiation
IRC	Reflected Radiation
IC	Total Irradiance
ρ	Reflectance factor
δ	*Solar Declination angle*
n	*Day number*
L	*Latitude angle*
θ	*Incident angle*
β	*Altitude angle*
φs	Solar azimuth angle
φc	Collector azimuth angle
H	Hour angle
∑. :	Tilt Angle

Chapter 1

Introduction

To be able to quantify the amount of solar energy which the photovoltaic collectors are designed to absorb the three components of solar irradiance should be taken into considerations to come out with good results and understand the whole parameters affecting the behaviour of PV cells and thus improving the design and installation process.
The irradiance components are summarized as follow with the help of accompanying figure [2]:

I. Direct Beam radiation: it is that portion of the radiation beam that passes in a straight line from the sun propagating through the atmosphere to the collector area.
II. Diffuse radiation: it is another component of radiation that strikes the PV collector after being scattered by different obstacles such as clouds, moisture weather, and molecules in air.
III. Reflected Radiation: The last component of solar isolation that yields from radiation reflected by different surfaces near the collectors or panels such as snow, water, or ground surface.

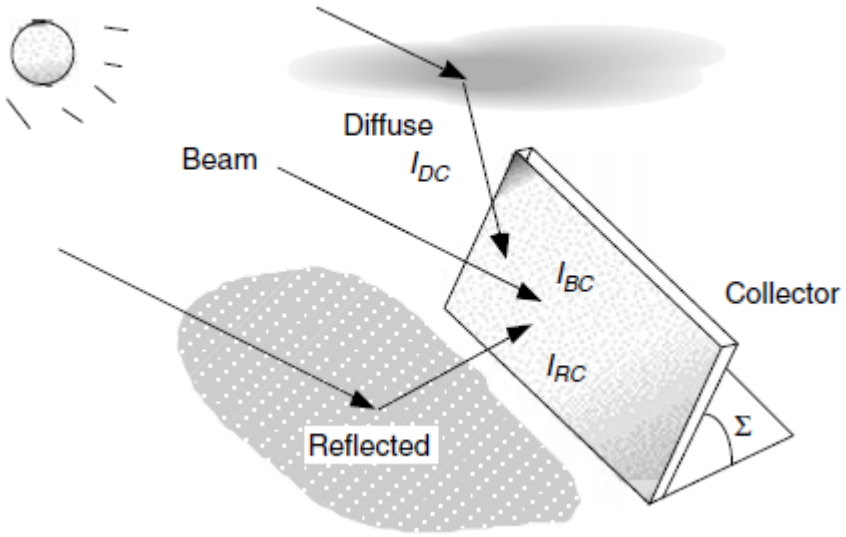


Figure 1 : Different Components of Solar isolation

The equations used to quantify these components of solar radiation are summarized below with the accompanying figure illustrating the angles used:

$$IB = A\, e^{-km} \quad (1)$$

Where A , k ,m are :

$$A = 1160 + 75\, Sin(\left(\frac{360}{365}\right)(n - 275)) \quad (2)$$

$$k = 0.174 + 0.035\, Sin(\left(\frac{360}{365}\right)(n - 100)) \quad (3)$$

$$m = \frac{1}{sin\beta} \quad (4)$$

$$\cos(\theta) = Cos(\beta) * Cos(\varphi s - \varphi c) * Cos(tilt) + Sin(\beta) * Cos(tilt) \quad (5)$$

$$IBC = IB * Cos(\theta) \quad (6)$$

$$C = 0.095 + 0.04 * Sin\left(\left(\frac{360}{365}\right)(n - 100)\right) \quad (7)$$

$$IDC = C * IB * (\frac{1+\cos(tilt)}{2}) \quad (8)$$

$$IRC = \rho * IB * (Sin(\beta) + C) * \left(\frac{1-\cos(tilt)}{2}\right) \quad (9)$$

$$\delta = 23.45 * Sin\left(\left(\frac{360}{365}\right)(n - 81)\right) \quad (10)$$

$$Sin(\beta) = Cos(L) * Cos(\delta) * Cos(H) + Sin(L) * Sin(\delta) \quad (11)$$

$$Sin(\varphi s) = \frac{Cos(\delta) * Sin(H)}{Cos(\beta)} \quad (12)$$

$$H = 15 * (hours\ before\ soler\ noon) \quad (13)$$

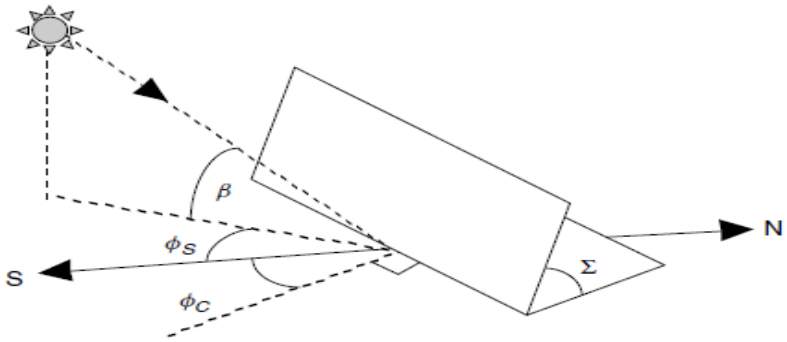


Figure 2 : Illustration of different angles of PV collector

Formulas used in calculations are listed below:

$$\text{IC\_Daily\_avg}\ \frac{sum\ of\ IC\ per\ day}{number\ of\ hours\ from\ sunrise\ to\ sunset} \quad (14)$$

$$\text{IC\_Monthly\_avg}\ \frac{Sum\ of\ IC\ averages\ for\ all\ dys\ in\ the\ month}{number\ days\ in\ the\ month} \quad (15)$$

$$\text{PSH \_daily} = \frac{Sum\ of\ IC\ per\ day}{1000} \quad (16)$$

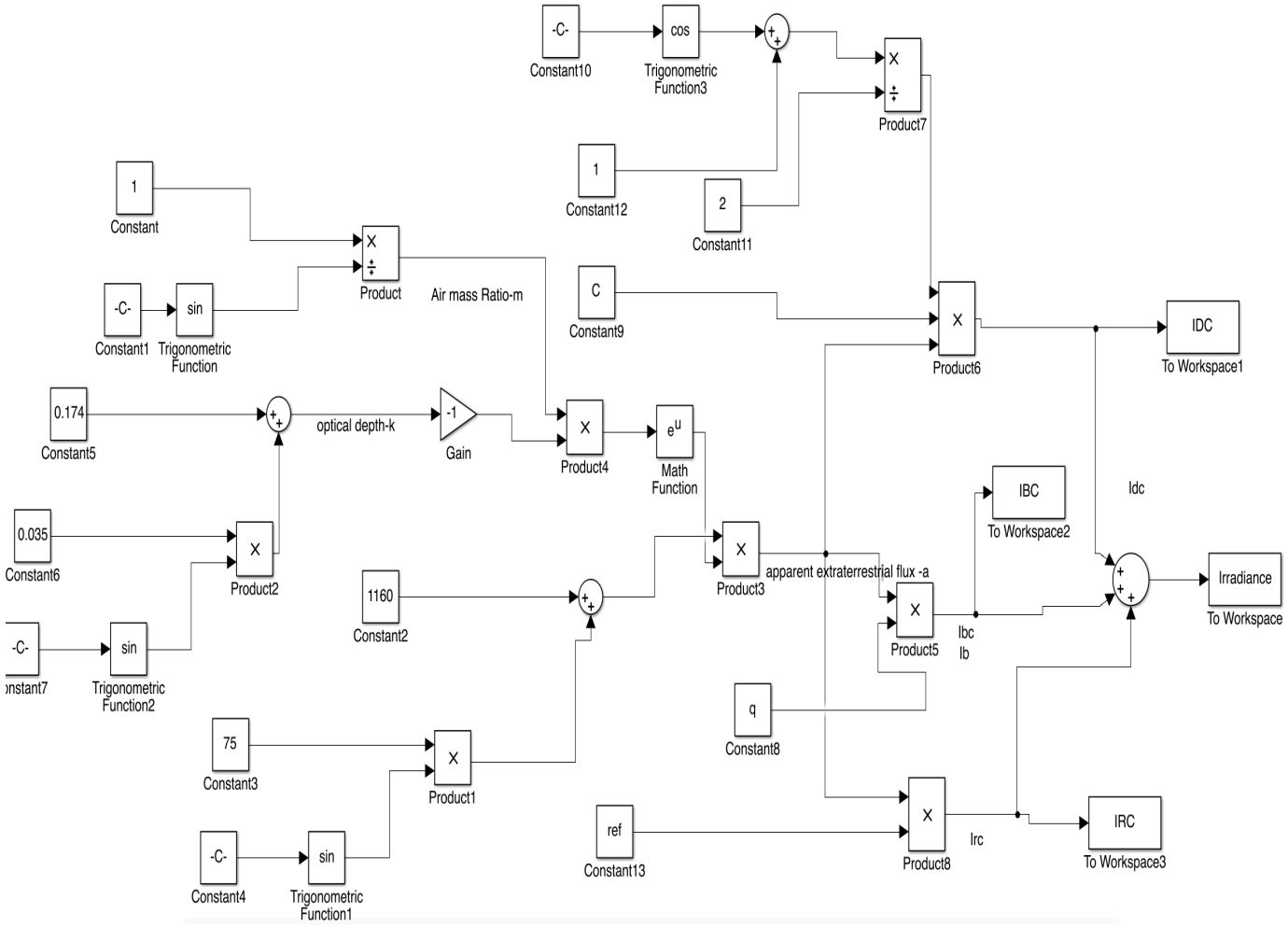
$$\text{PSH\_monthly}\ \frac{Sum\ of\ IC\ per\ month}{1000 * number\ of\ days\ in\ the\ month} \quad (17)$$

Scenarios included in simulation are summarized in the following table:

Table 1. Five cases used in Simulations

Scenario	Azimuth angle (degree)	Tilt Angle (degree)
1	0	L (32)
2	+15	L(32)
3	-15	L(32)
4	0	+7.5
5	0	-7.5

The Simulink Model that was used in performing the calculations :



Chapter 2

Simulation Results

SIMULATION RESULTS
Task I

Case 1 : Tilt =32 deg, Azimuth = 0 deg;

```
Day 1
    [hours] =          6          7          8          9         10         11         12          1          2          3          4          5
    IDC = 277.7393    9.2530   48.5520   61.2084   66.5752   68.9891   69.6953   68.9891   66.5752   61.2084   48.5520    9.2530
    IBC = -0.0000   31.2817  317.0941  565.3367  753.1031  870.4343  910.3636  870.4343  753.1031  565.3367  317.0941   31.2817
    IRC = -2.7672    0.2303    2.7852    5.2182    7.1004    8.2859    8.6905    8.2859    7.1004    5.2182    2.7852    0.2303
   IC = 274.9721   40.7650  368.4313  631.7633  826.7787  947.7094  988.7494  947.7094  826.7787 631.7633  368.4313   40.7650
```

It was found that :,PSH= 6.5562, IC daily average per hour = 16.8108,
IC monthly average per day =218.5403

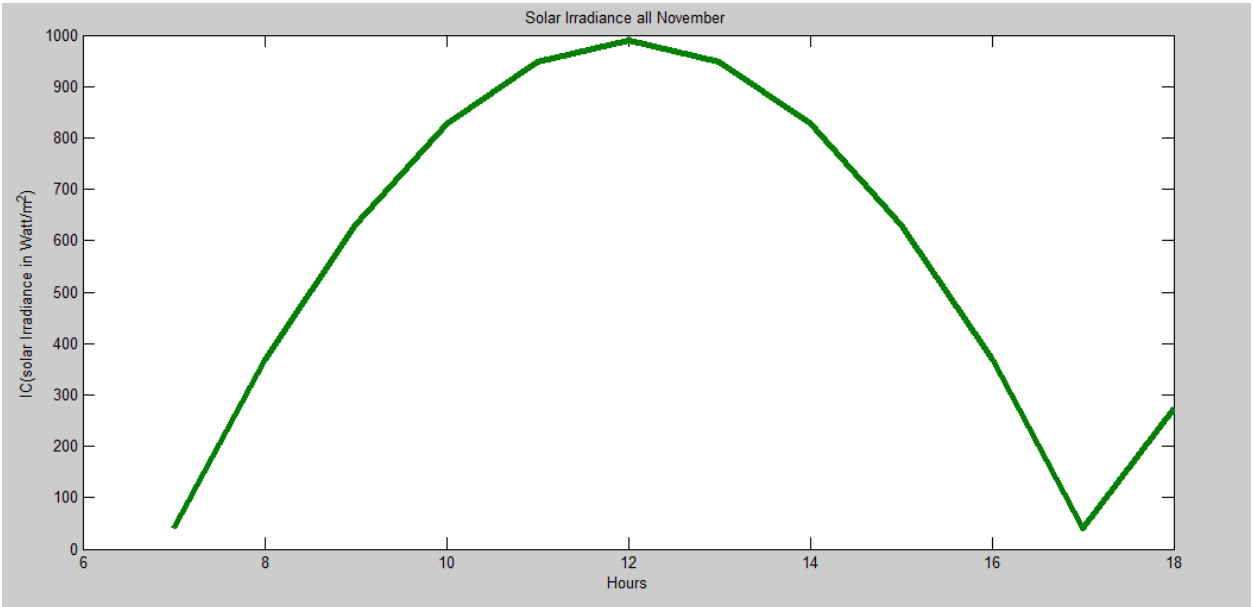


Figure 3: Plot of IC vs day hours case 1 , day 1

Day 15

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
IBC = 0.0000	3.0507	290.8870	547.5314	737.9091	856.0686	896.1841	856.0686	737.9091	547.5314	290.8870	3.0507	
Idc = 277.7393	9.2530	48.5520	61.2084	66.5752	68.9891	69.6953	68.9891	66.5752	61.2084	48.5520	9.2530	
Irc = -2.7672	0.2303	2.7852	5.2182	7.1004	8.2859	8.6905	8.2859	7.1004	5.2182	2.7852	0.2303	
Ic = 274.9721	40.7650	368.4313	631.7633	826.7787	947.7094	988.7494	947.7094	826.7787	631.7633	368.4313	40.7650	

It was found that :,PSH= 6.1739,IC daily average per hour = 15.8306,
IC monthly average per day =205.7972

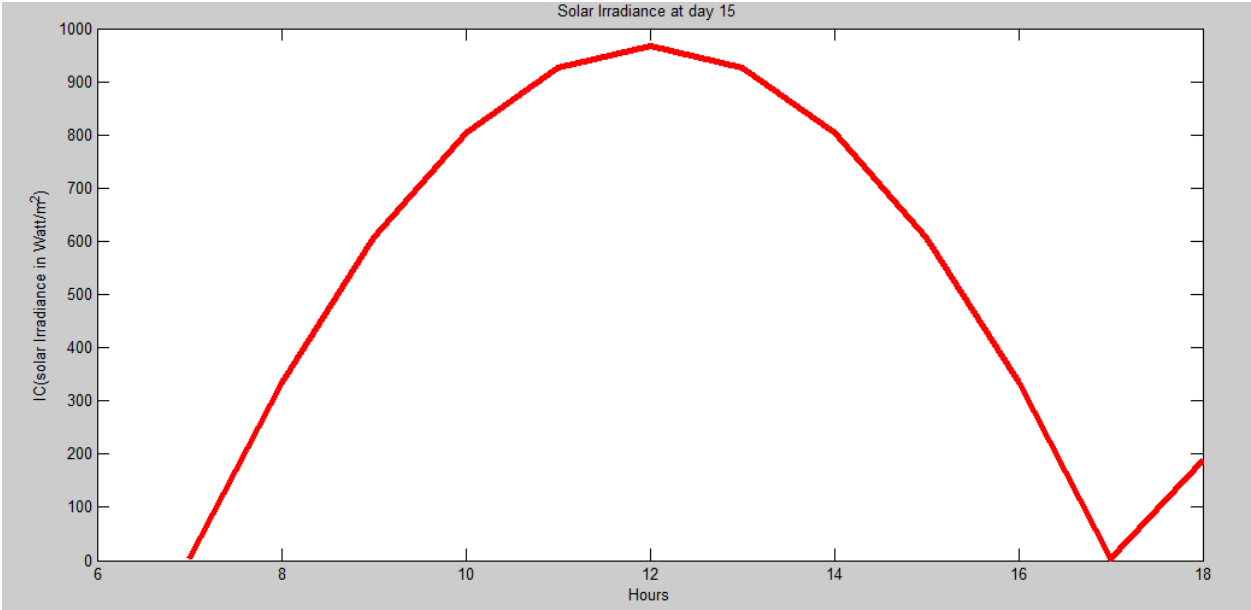


Figure 4: Plot of IC vs day hours case 1 , day 15

Last Day of November

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc =	0.0000	0.0000	267.1521	532.3297	725.0470	843.8549	884.0981	843.8549	725.0470	532.3297	267.1521	0.0000
Idc =	151.8229	0.0000	34.0742	48.0101	53.3915	55.7135	56.3816	55.7135	53.3915	48.0101	34.0742	0.0000
Irc =	-4.1894	0.0000	1.8138	4.1630	6.0012	7.1620	7.5584	7.1620	6.0012	4.1630	1.8138	0.0000
Ic =	147.6335	0.0000	303.0401	584.5028	784.4398	906.7304	948.0381	906.7304	784.4398	584.5028	303.0401	0.0000

It was found that :,PSH= 5.9268,IC daily average per hour = 15.1970,
IC monthly average per day =197.5607

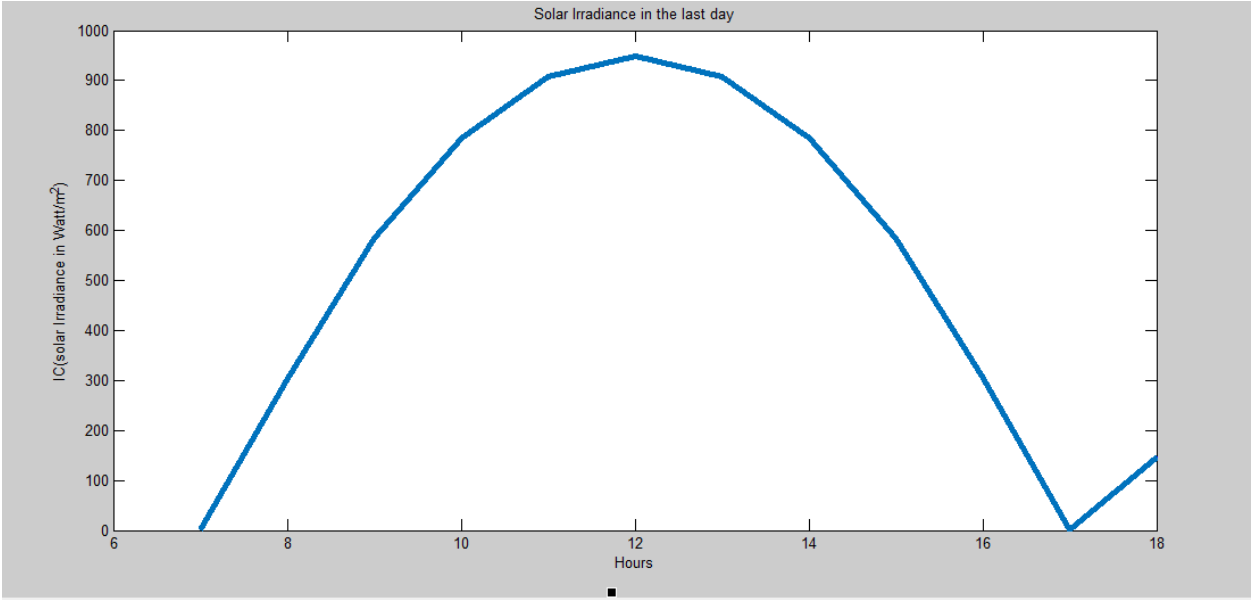


Figure 5: Plot of IC vs day hours case 1 , day 30

Task II

Case 2 : Azimuth Angle = -15 deg at tilt =32 deg

Day 1

```
[hours] =      6      7      8      9     10     11     12      1      2      3      4      5
Ibc [K]= 1.4588 0.0716 0.4740 0.6894 0.8142 0.8785 0.8978 0.8785 0.8142 0.6894 0.4740 0.0716
Idc = 277.7393 9.2530 48.5520 61.2084 66.5752 68.9891 69.6953 68.9891 66.5752 61.2084 48.5520 9.2530
Irc = -2.7672 0.2303 2.7852 5.2182 7.1004 8.2859 8.6905 8.2859 7.1004 5.2182 2.7852 0.2303
Ic [K] = 1.7337 0.0811 0.5254 0.7559 0.8879 0.9557 0.9762 0.9557 0.8879 0.7559 0.5254 0.0811
```

It was found that :,PSH= 9.5963,IC daily average per hour = 24.6058,
IC monthly average per day =319.8754

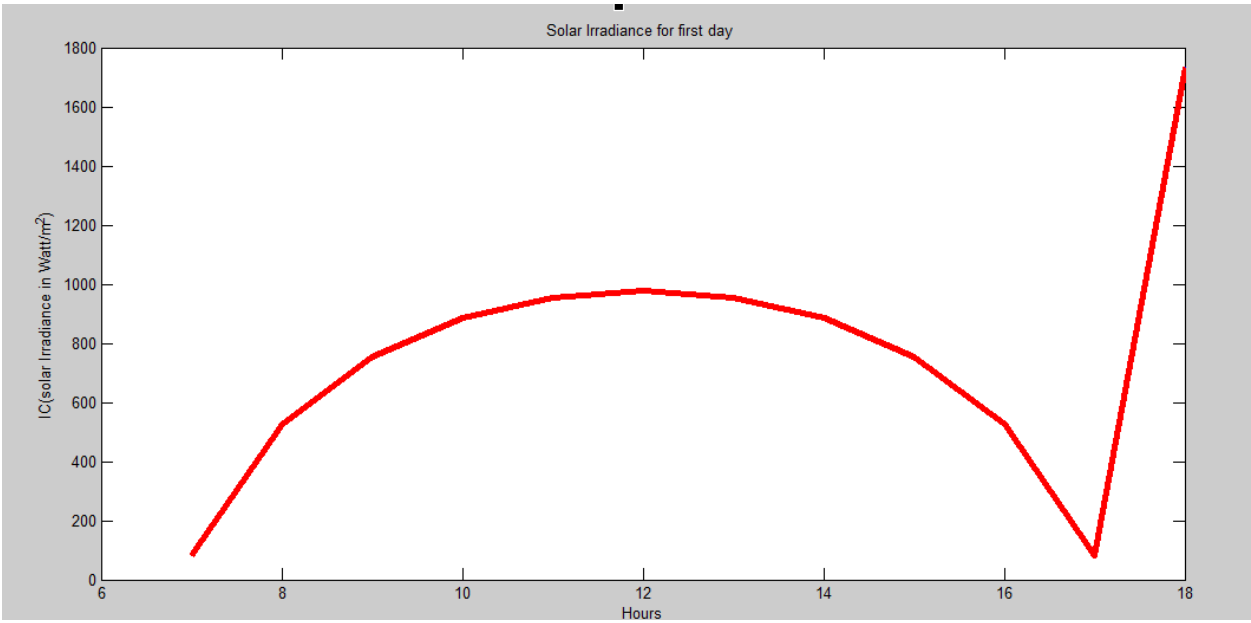


Figure 6: Plot of IC vs day hours case 2 , day 1

Day 15

[hours] = 6 7 8 9 10 11 12 1 2 3 4 5

Ibc [K]= 1.0446 0.0067 0.4254 0.6588 0.7921 0.8615 0.8828 0.8615 0.7921 0.6588 0.4254 0.0067

Idc =193.4656 0.8242 40.6810 54.1454 59.5812 61.9729 62.6664 61.9729 59.5812 54.1454 40.6810 0.8242

Irc = -3.6431 0.0159 2.2327 4.6249 6.4851 7.6582 8.0587 7.6582 6.4851 4.6249 2.2327 0.0159

Ic[K] =1.2344 0.0076 0.4684 0.7176 0.8582 0.9312 0.9536 0.9312 0.8582 0.7176 0.4684 0.0076

It was found that :,PSH= 8.5383,IC daily average per hour = 21.8931,

IC monthly average per day =284.6106

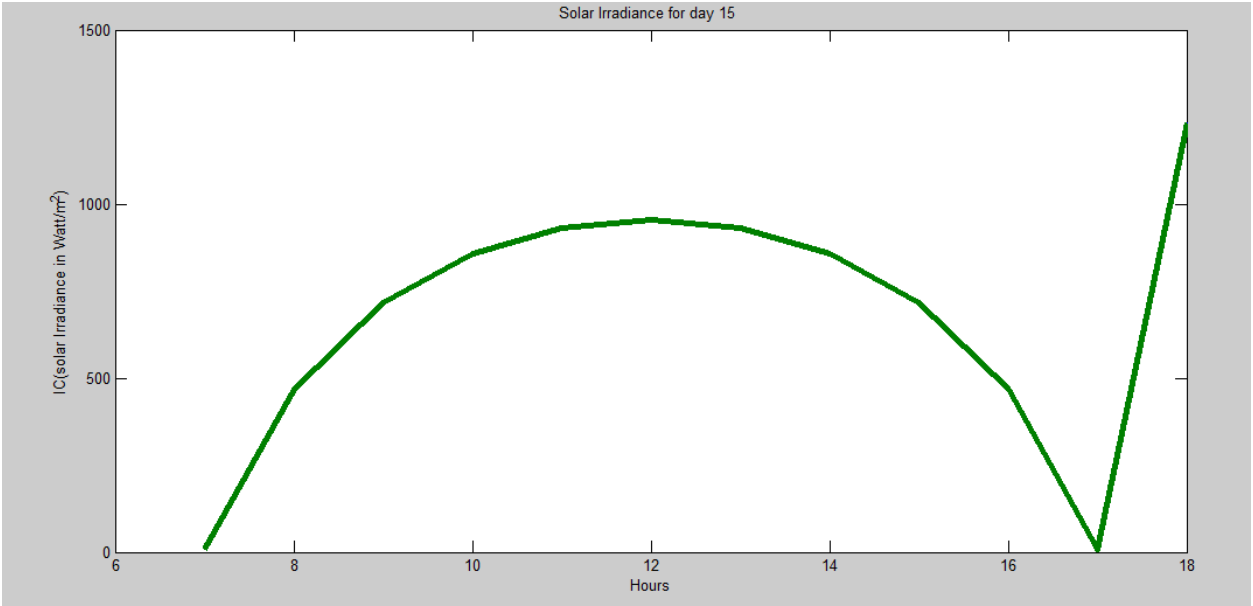


Figure 7: Plot of IC vs day hours case 2 , day 15

Last Day Of November

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc =	856.3191	0.0000	384.5125	634.3626	774.3215	847.5370	870.1772	847.5370	774.3215	634.3626	384.5125	0.0000
Idc =	151.8229	0.0000	34.0742	48.0101	53.3915	55.7135	56.3816	55.7135	53.3915	48.0101	34.0742	0.0000
Irc =	-4.1894	0.0000	1.8138	4.1630	6.0012	7.1620	7.5584	7.1620	6.0012	4.1630	1.8138	0.0000
Ic[K] =	1.0040	0.0000	0.4204	0.6865	0.8337	0.9104	0.9341	0.9104	0.8337	0.6865	0.4204	0.0000

It was found that :,PSH= 7.9630,IC daily average per hour = 20.4179,
IC monthly average per day =265.4329

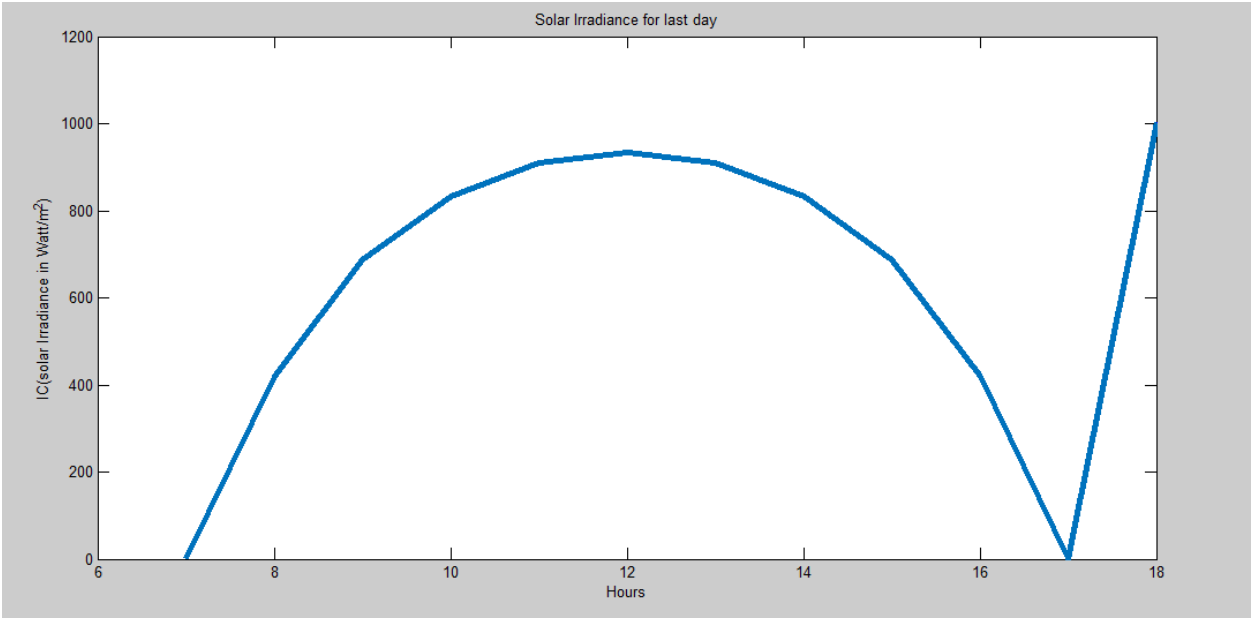


Figure 8: Plot of IC vs day hours case 2 , day 30

Case 3 : Azimuth Angle = +15 deg at Tilt = 32 deg

Day 1

[hours] = 6 7 8 9 10 11 12 1 2 3 4 5

Ibc[K] = 1.4588 0.0716 0.4740 0.6894 0.8142 0.8785 0.8978 0.8785 0.8142 0.6894 0.4740 0.0716

Idc = 277.7393 9.2530 48.5520 61.2084 66.5752 68.9891 69.6953 68.9891 66.5752 61.2084 48.5520 9.2530

Irc = -2.7672 0.2303 2.7852 5.2182 7.1004 8.2859 8.6905 8.2859 7.1004 5.2182 2.7852 0.2303

Ic[K] = 1.7337 0.0811 0.5254 0.7559 0.8879 0.9557 0.9762 0.9557 0.8879 0.7559 0.5254 0.0811

It was found that :,PSH= 9.5963,IC daily average per hour = 24.6058,
IC monthly average per day =319.8754

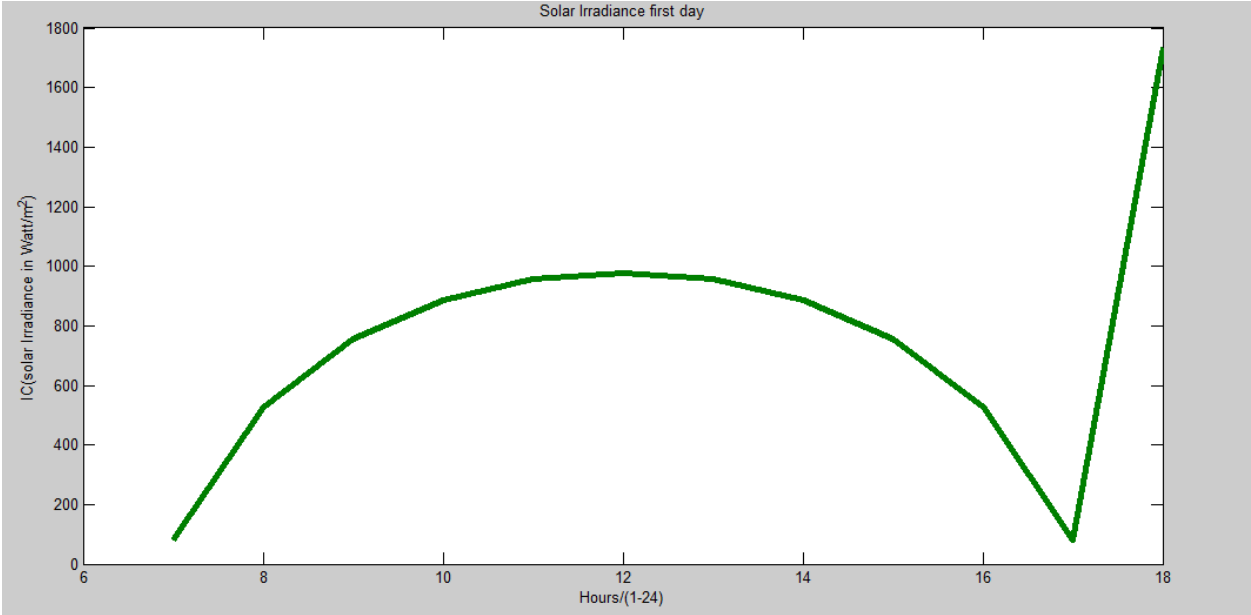


Figure 9: Plot of IC vs day hours case 3 , day 1

Day 15

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc[K] =	1.0446	0.0067	0.4254	0.6588	0.7921	0.8615	0.8828	0.8615	0.7921	0.6588	0.4254	0.0067
Idc =	193.4656	0.8242	40.6810	54.1454	59.5812	61.9729	62.6664	61.9729	59.5812	54.1454	40.6810	0.8242
Irc =	-3.6431	0.0159	2.2327	4.6249	6.4851	7.6582	8.0587	7.6582	6.4851	4.6249	2.2327	0.0159
Ic[K] =	1.2344	0.0076	0.4684	0.7176	0.8582	0.9312	0.9536	0.9312	0.8582	0.7176	0.4684	0.0076

It was found that :,PSH= 8.5383,IC daily average per hour = 21.8931,
IC monthly average per day =284.6106

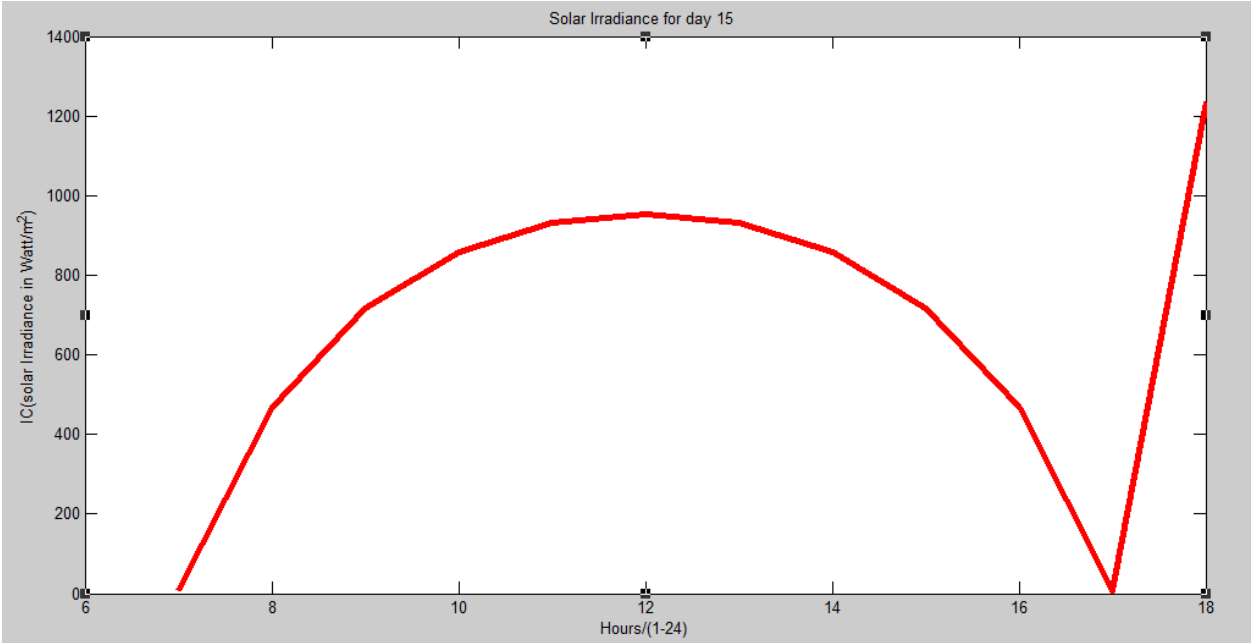


Figure 10: Plot of IC vs day hours case 3 , day 15

Last Day of November

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc =	856.3191	0.0000	384.5125	634.3626	774.3215	847.5370	870.1772	847.5370	774.3215	634.3626	384	0.0
Idc =	151.8229	0.0000	34.0742	48.0101	53.3915	55.7135	56.3816	55.7135	53.3915	48.0101	34	0.0
Irc =	-4.1894	0.0000	1.8138	4.1630	6.0012	7.1620	7.5584	7.1620	6.0012	4.1630	1.8138	0.0
Ic[K] =	1.0040	0.0000	0.4204	0.6865	0.8337	0.9104	0.9341	0.9104	0.8337	0.6865	0.4204	0.0

It was found that :,PSH= 7.9630,IC daily average per hour = 20.4179,
IC monthly average per day =265.4329

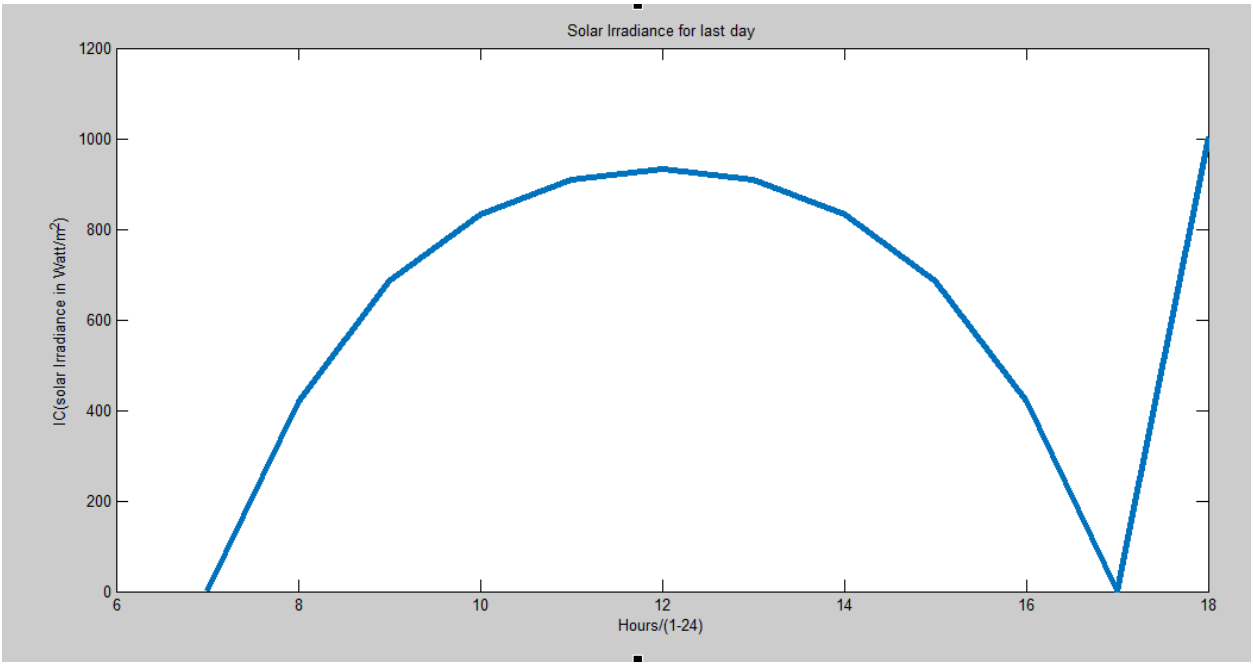


Figure 11: Plot of IC vs day hours case 3 , day 30

Case 4 : Tilt= +7.5 deg @ Azimuth = 0 deg

Day 1

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc[*10000] =	1.2030	0.0190	0.0464	0.0686	0.0846	0.0940	0.0969	0.0940	0.0846	0.0686	0.0464	0.0190
Idc[K] =	9.9519	0.0447	0.0663	0.0741	0.0778	0.0795	0.0800	0.0795	0.0778	0.0741	0.0663	0.0447
Irc =	3.8795	0.1127	0.2983	0.4599	0.5842	0.6623	0.6890	0.6623	0.5842	0.4599	0.2983	0.1127
Ic[10000] =	2.1986	0.0235	0.0530	0.0760	0.0925	0.1020	0.1050	0.1020	0.0925	0.0760	0.0530	0.0235

It was found that :,PSH= 29.8191,IC daily average per hour = 76.4593,
IC monthly average per day =993.9703

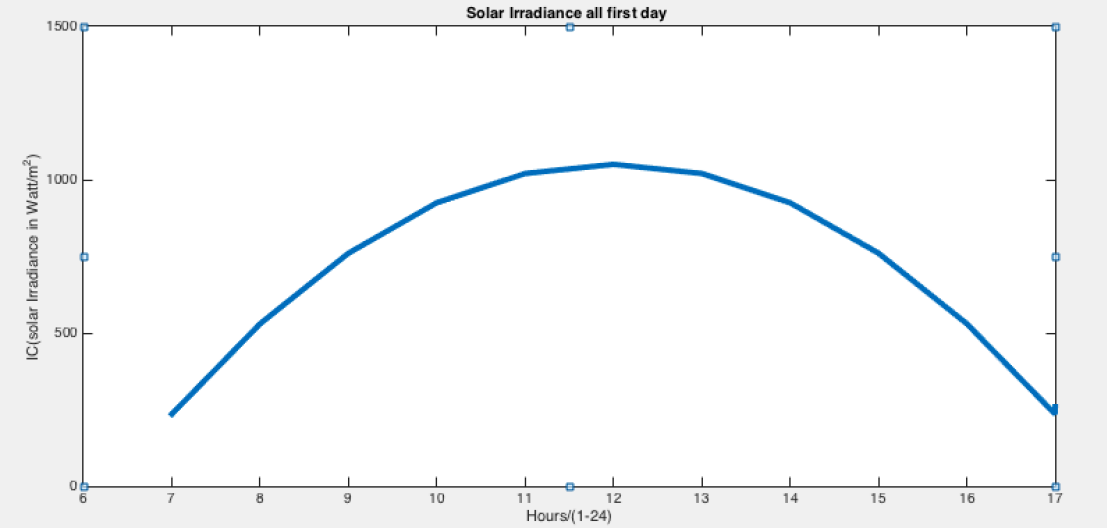


Figure 12:Plot of IC vs day hours case 4, day 1

Day 15

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc [K]=	3.8368	0.1830	0.4561	0.6777	0.8387	0.9335	0.9640	0.9335	0.8387	0.6777	0.4561	0.1830
Idc[K] =	3.1050	0.0400	0.0601	0.0673	0.0706	0.0722	0.0726	0.0722	0.0706	0.0673	0.0601	0.0400
Irc =	0.8561	0.1042	0.2873	0.4472	0.5703	0.6477	0.6741	0.6477	0.5703	0.4472	0.2873	0.1042
Ic[K] =	6.9426	0.2231	0.5166	0.7455	0.9099	1.0064	1.0373	1.0064	0.9099	0.7455	0.5166	0.2231

It was found that :,PSH= 14.6029,IC daily average per hour = 37.4435,
IC monthly average per day =486.7650

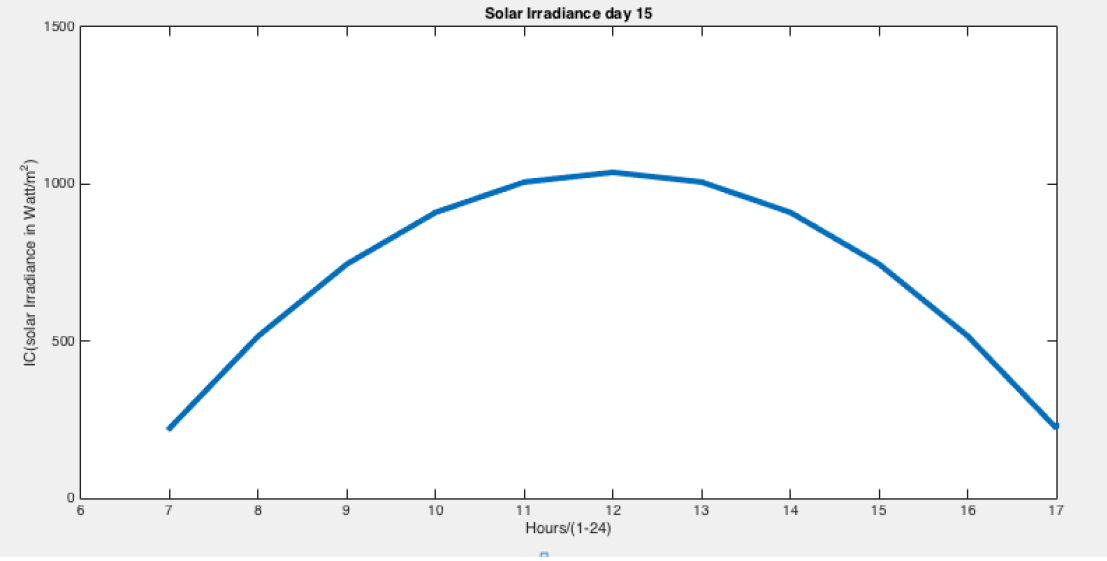


Figure 13:Plot of IC vs day hours case 4 , day 15

Last Day of November

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc [K]=	2.0303	0.1777	0.4505	0.6714	0.8322	0.9277	0.9587	0.9277	0.8322	0.6714	0.4505	0.1777
Idc [K]=	1.5788	0.0359	0.0545	0.0611	0.0641	0.0655	0.0659	0.0655	0.0641	0.0611	0.0545	0.0359
Irc[K] =	0.2572	0.0975	0.2782	0.4365	0.5584	0.6351	0.6613	0.6351	0.5584	0.4365	0.2782	0.0975
Ic [K]=	3.6093	0.2137	0.5054	0.7329	0.8969	0.9938	1.0252	0.9938	0.8969	0.7329	0.5054	0.2137

It was found that :,PSH= 11.1243,IC daily average per hour = 28.5239,
IC monthly average per day =370.8104

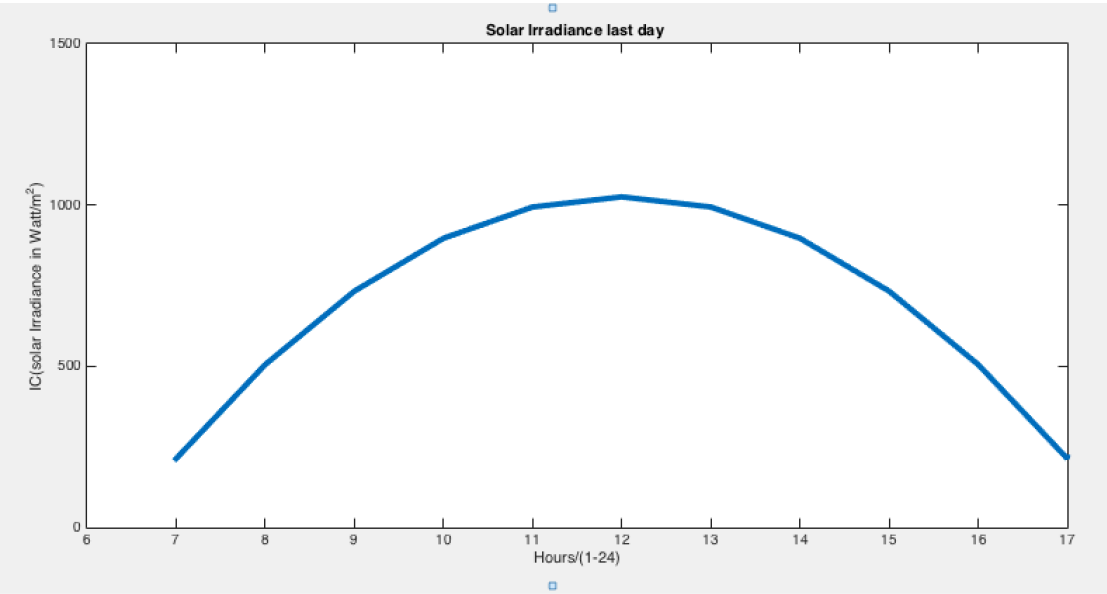


Figure 14:Plot of IC vs day hours case 4 , day 30

Case 5 : Tilt= -7.5 deg @ Azimuth = 0 deg

Day 15

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc[K] =	0.0058	0.2886	0.5554	0.7715	0.9258	1.0110	1.0331	1.0110	0.9258	0.7715	0.5554	0.2886
Idc =	2.3953	50.3607	63.8764	69.3754	72.0573	73.3472	73.7352	73.3472	72.0573	69.3754	63.8764	50.3607
Irc =	0.0026	0.1727	0.3578	0.5180	0.6411	0.7186	0.7450	0.7186	0.6411	0.5180	0.3578	0.1727
Ic[K] =	0.0082	0.3391	0.6196	0.8414	0.9985	1.0850	1.1076	1.0850	0.9985	0.8414	0.6196	0.3391

It was found that :,PSH= 8.8860,IC daily average per hour = 22.7847,
IC monthly average per day =296.2011

Day 1

[hours] =	6	7	8	9	10	11	12	1	2	3	4	5
Ibc[K] =	0.0019	0.2740	0.5426	0.7602	0.9152	0.9992	1.0177	0.9992	0.9152	0.7602	0.5426	0.2740
Idc =	0.9111	53.8457	69.5863	75.9418	79.0296	80.5120	80.9575	80.5120	79.0296	75.9418	69.5863	53.8457
Irc =	0.0009	0.1677	0.3547	0.5165	0.6408	0.7190	0.7456	0.7190	0.6408	0.5165	0.3547	0.1677
Ic [K]=	0.0028	0.3280	0.6125	0.8367	0.9948	1.0804	1.0994	1.0804	0.9948	0.8367	0.6125	0.3280

It was found that :,PSH= 8.7969,IC daily average per hour = 22.5561,
IC monthly average per day =293.2295

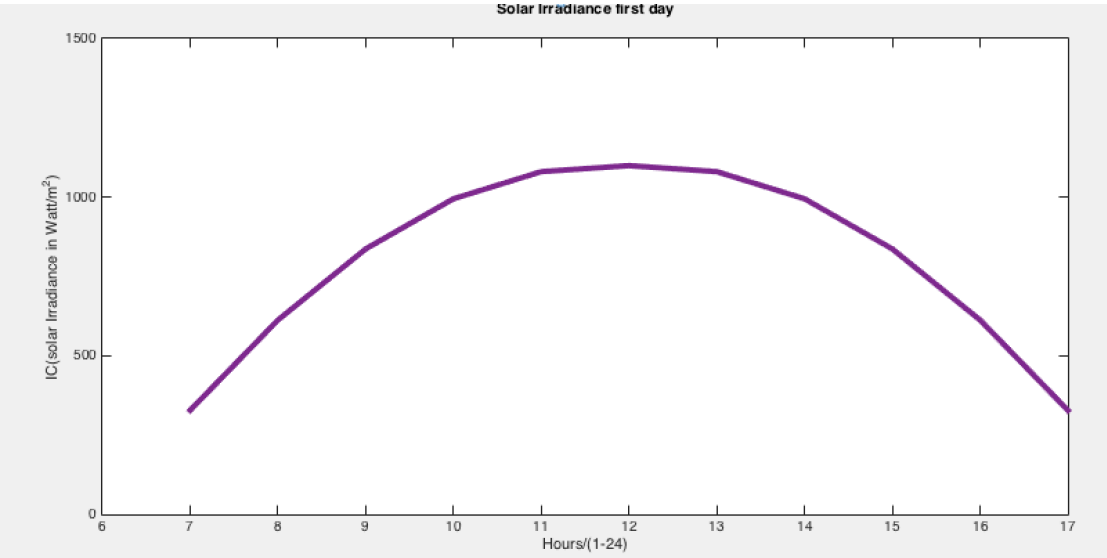


Figure 15:Plot of IC vs day hours case 5 , day 1

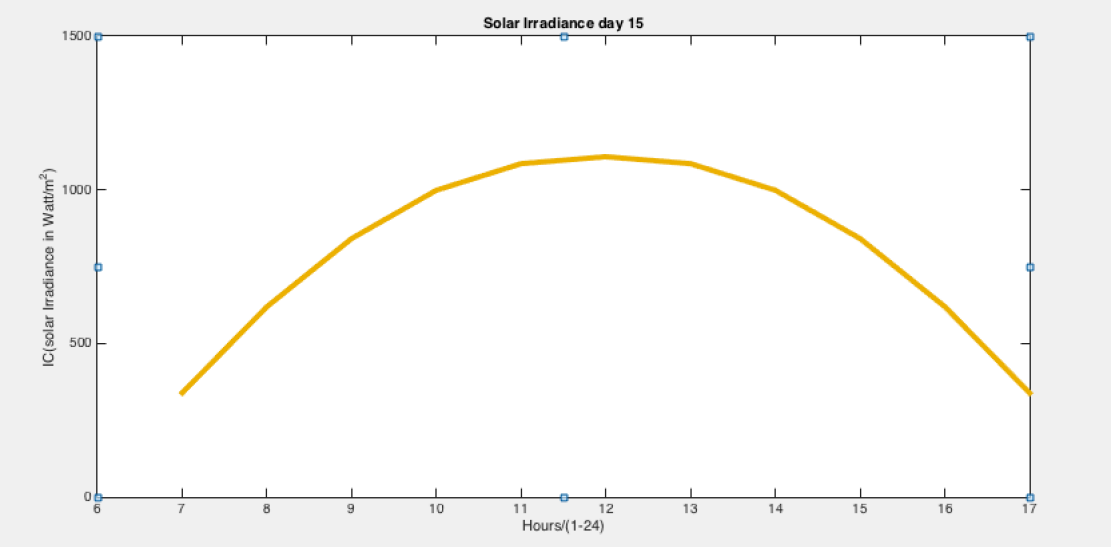


Figure 16: Plot of IC vs day hours case 5 , day 15

Last Day of November

[hours] = 6 7 8 9 10 11 12 1 2 3 4 5

Ibc[K] = 0.0108 0.3002 0.5653 0.7799 0.9335 1.0196 1.0437 1.0196 0.9335 0.7799 0.5653 0.3002

Idc =3.8526 46.7331 58.4260 63.2088 65.5476 66.6740 67.0130 66.6740 65.5476 63.2088 58.4260 46.7331

Irc = 0.0047 0.1761 0.3592 0.5179 0.6399 0.7167 0.7429 0.7167 0.6399 0.5179 0.3592 0.1761

Ic[K] =0.0147 0.3471 0.6241 0.8436 0.9997 1.0869 1.1115 1.0869 0.9997 0.8436 0.6241 0.3471

It was found that :,PSH= 8.9405,IC daily average per hour = 22.9243,

IC monthly average per day =298.0157

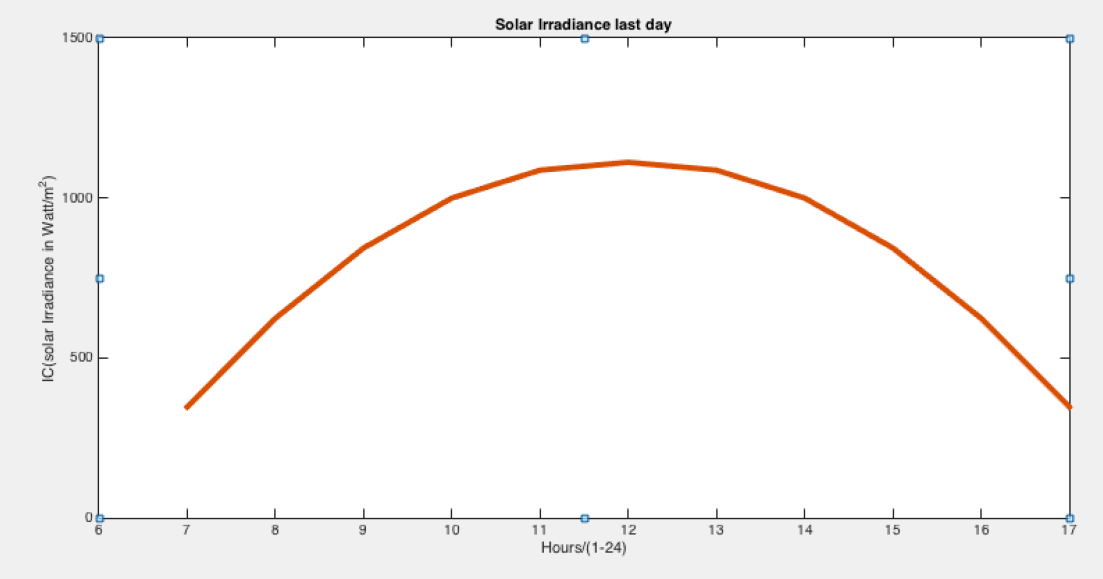


Figure 17: Plot of IC vs day hours case 5 , day 30

Task 3

First online tool to do solar irradiance calculations is from the website [3] (see reference) :

PV EDUCATION.ORG

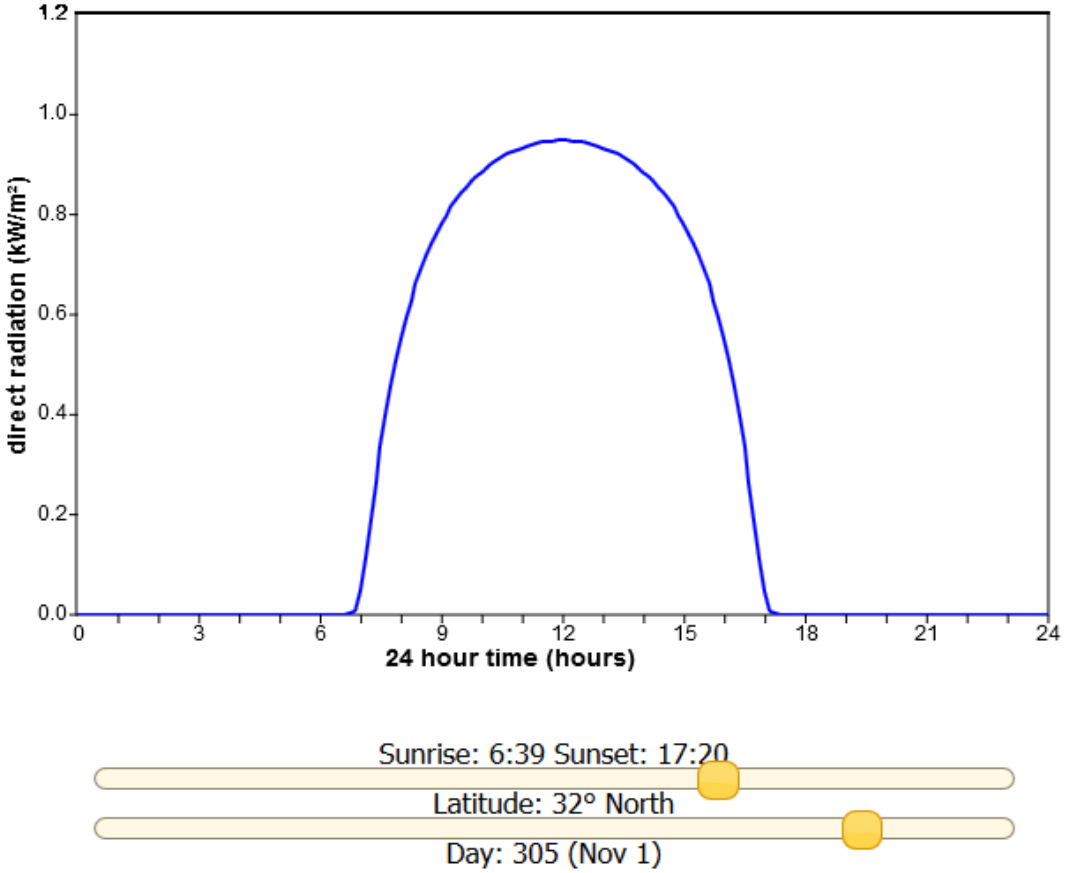


Figure 18:online tool to do solar irradiance calculations

Another website is : Meteoexploration.com ,see [4] , The following is an example of calculation on day 15 ,November

Location:	Ramallah
Latitude dec. deg: (conversion tool)	32
Longitude dec. deg: (conversion tool)	35
Day:	15
Month:	November
Altitude (m):	10
Visibility (km)	50
Temperature °C:	25
RH (0-100):	60
Ozone thickness:	0.0230
Albedo ground (0-1):	0.14
Timezone (timezone map):	-1
Slope	
Orientation (0-360):	180
Tilt (0-90):	32

Calculate

Figure 19: online tool to do solar irradiance calculations ,parameters settings wall

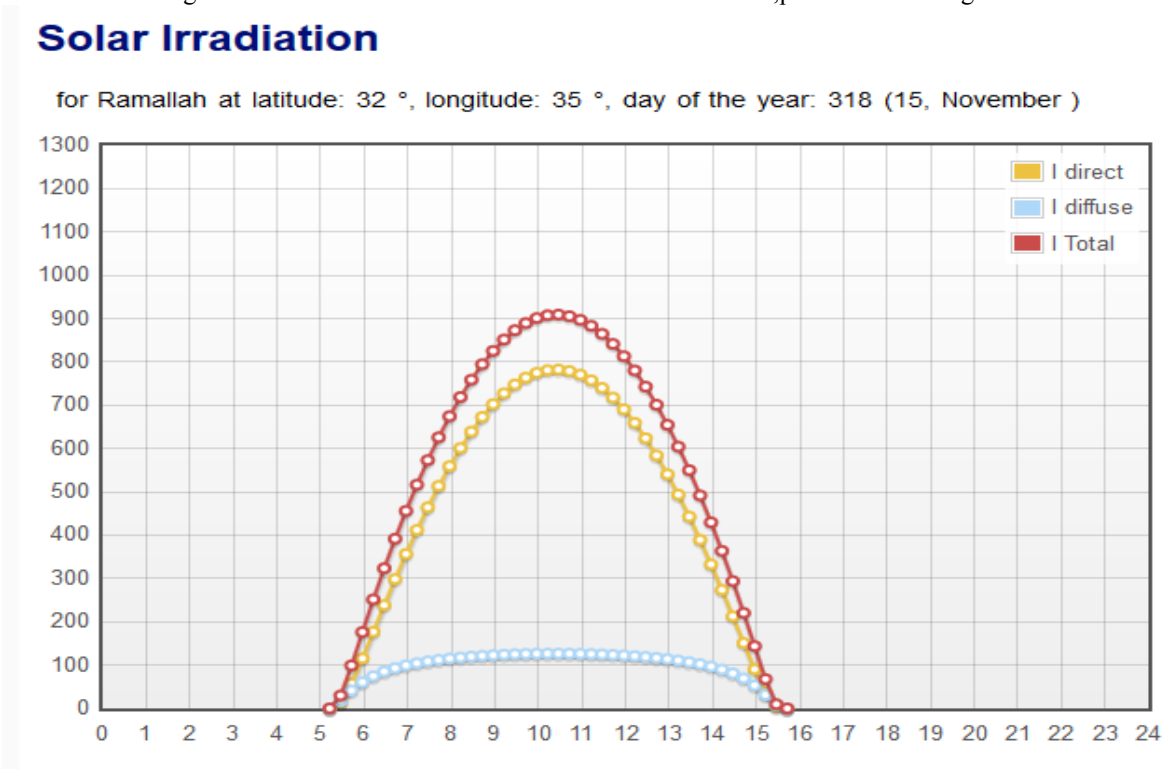


Figure 20: online tool to do solar irradiance calculations

Another website is [4]: Satellite Application Facility on Climate Monitoring

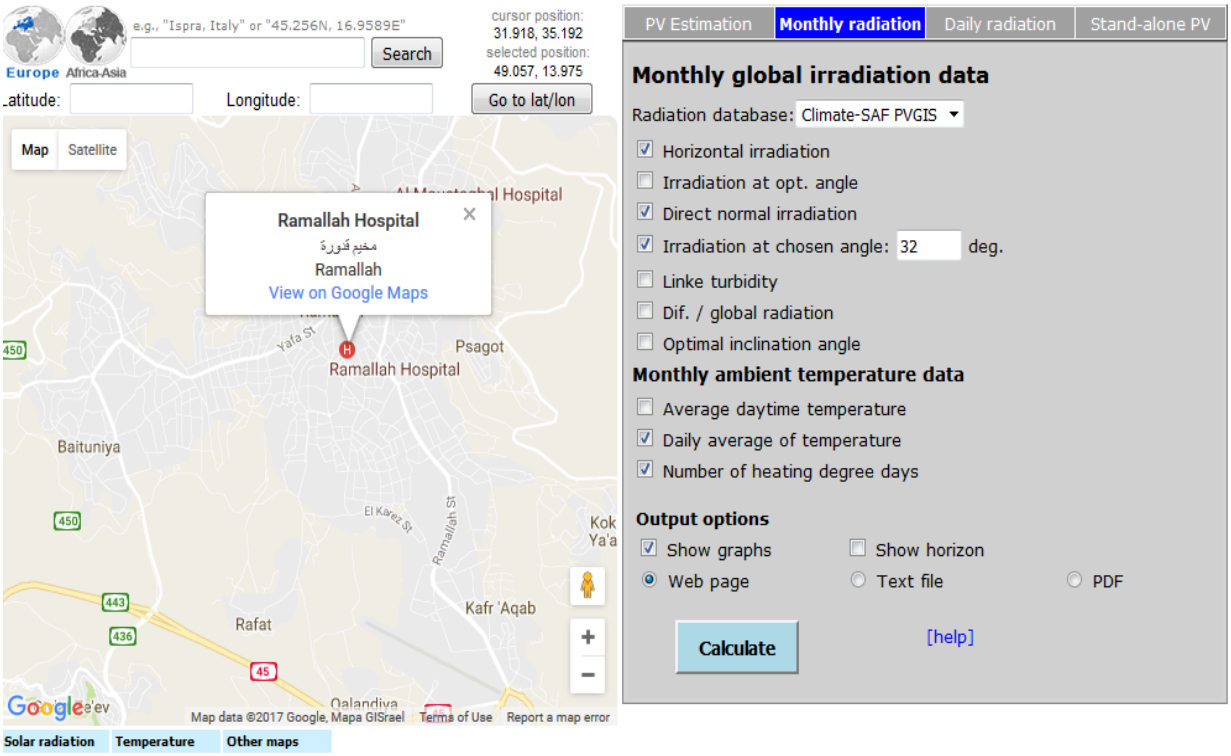


Figure 21: online tool to do solar irradiance calculations

Chapter 3

Conclusion

The optimum angles play a very important part in collecting the most possible energy from the sun. In the present project, several cases were taken in November's month, the calculation were done for the whole month and for the first, day fifteenth and the last day of the month for five different scenarios.

It was found that the optimum tilt angle to be used in November or in winter should be around 45 degrees .The tilt angle 15 degrees is not suitable for use in November because it does not collect the most possible irradiance for the pv modules, it may be very optimum if the optimum output is desired to be at summer or June.

It was also found that tilt angles 7.5 and 15 degrees are not suitable for November since the captured irradiance by the PV panels would not be optimum, these tilt angles may be useful in months like April or may where the number of day is 74 or 100 or at this range.

Chapter 4

References

[1] https://www.timeanddate.com/sun/palestine/ramallah?month=11&year=2016
[2] Renewable and Efficient Electric Power Systems ,Gilbert M .Masters ,Stanford university , 2nd edition
[3] http://pveducation.org/pvcdrom/calculation-of-solar-insolation
[4] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php