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Generation of an Annual Typical Meteorological Solar Irradiance on Tilted Surfaces for Armidale NSW,Australia

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Abstract:-This paper aims to estimate solar irradiance on tilted surfaces for Armidale NSW, Australia.The most common data for describing the local solar climate is through what is called Typical Meteorological Year data (TMY). Typical solar radiation data is very important for the calculations of many solarapplications. In this study, typical solar radiation years on tilted surfaces of five inclination angles (15°, 30°, 45°, 60° and 75°) for Armidale town in New South Wales in Australia are generated from the typical solar radiation years on horizontal surfaces developed earlier by the writer in a former article based on the daily and monthly solar radiation data measured and collected for 23 years during the period 1990 to 2012, utilising the Finkelstein-Schafer statistical method. The study outcome is expected to show how solar radiation is potential in Armidale NSW and would be a real help for solar energy generation systems' designers in this region for all building applications varying between residential, educational, administrative and commercial for sizing and maximising efficiency of such systems by using the tabular TYR outcome for the each day of the year. Specially for calculating the energy output of solar arrays through the day while the sun is moving around the fixed angle array surface. This would really give a real picture of actual energy generation utilising inclined solar arrays.

Keywords: *Armidale NSW,test meteorological year, test reference year, solar radiation; tilted surfaces*

I. INTRODUCTION

The most common data for describing the local solarclimate is through what is called Typical Meteorological Year data (TMY). To determine TMY data, various meteorological measurements are made at hourly intervals over a number of years to build up a picture of the local climate. A simple average of the yearly data underestimates the amount of variability, so the month that is most representative of the location is selected. For each month, the average solar radiation over the whole measurement period is determined, together with the average solar radiation in each month during the measurement period. The data for the month that has the average solar radiation most closely equal to the monthly average over the whole measurement period is then chosen as the TMY data for that month. This process is then repeated for each month in the year. The months are added together to give a full year of hourly samples. There is no strict standard for TMY data so the user must adjust the data to suit the application. Considerable care must be taken with sample periods. Solar radiation data is a crucial parameter for the prediction of long-term performance of solar energy generation systems. As well, it is a key input in modelling and designing of solar energy applications. Thus, a need for a reliable source of solar radiationdata has to be readily available for particular settlement locations.

The need for a one-year representative daily meteorological data led to the development of methodologies known as the Typical Meteorological Year (TMY), alternatively called Test Reference Year (TRY) [1]. TMY or TRY is a representative data that consists of the month selected from the individual years and concatenated to form a complete year. However, A TMY is not necessarily a good indicator of conditions over the next year or even the next five years. Rather, TMY represents conditions judged to be typical over a long period of time [2]. Typical weather year data sets can be generated for several climatic variables such as temperature, humidity, wind speed, etc. or only for solar radiation speed. Various trials have been made to generate such weather databases for different areas around the world [1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13 & 14].

A variety of numerical models for calculating solar irradiance on tilted surfaceswere described and evaluated using data for any location on the earth. While all the hourly models have a common approach for calculating the direct component of solar irradiance, there are a variety of methods for calculating diffuse irradiance based on the portion of the sky hemisphere within the field of view of the surface. A less significant distinction between the models is in the methods used to calculate the amount of radiation received as a result of reflection from adjacent surfaces [16].

The hourly solar radiation data required for solar energy system design evaluation and performance studies are generally not available for a number of sites, especially for those in remote locations. As such, accurate determination of hourly solar radiation data is important at both horizontal surfaces and inclined surfaces. A model to estimate global solar radiation using temperature and sunshine hour data has been

developed [17], which is used to calculate the hourly solar radiation data. The hourly solar radiation has also been calculated using [18] daily integration approach from the measured daily solar radiation data. These two predicted hourly solar radiation data values are compared with measured hourly values to test the accuracy of the models. The total solar radiation on the inclined surfaces and vertical surfaces for different orientations has also been estimated. The estimated values are found to be in close agreement with the measured values. The presented method can be used to estimate hourly, global, diffuse solar radiation for horizontal surfaces and total solar radiation on inclined and vertical surfaces at different orientations with a greater accuracy for any location.

Thus, the main aim of this study is to generate representative TYM solar radiation data on tilted surfaces for Armidale NSW, Australia. Inclination angles considered are (15°, 30°, 45°, 60° and 75°).

II. DATA AND LOCATION

The daily mean solar radiation recorded during the period 1994–2010 are utilized to generate the typical solar radiation data. In Australia, meteorological observations are recorded by the Australian Bureau of Meteorology (BOM) weather stations are widely spreader in lots of cities and towns around Australia. In this study, the global solar radiation data recorded by Armidale Airport Weather Automatic Station and published on the BOM's website where it was collected. The missing and invalid measurements account for approximately 0.01% of the whole database of mean solar radiation; those were replaced with the values of preceding or subsequent days by interpolation. During the calculations process, any year found with more than ten days in any month observations not available was excluded. "Table 1" provides geographical information for Armidale town and the periods of the relevant mean solar radiation data.

Table 1 Geographical and mean solar radiation database information of Armidale NSW, Australia

	Longitude (†E)	Latitude(†S)	Elevation (m)	Daily Mean Solar Radiation	
				Period	Total Years
Armidale	151.67	30.52	970-1070	1990—2012	23

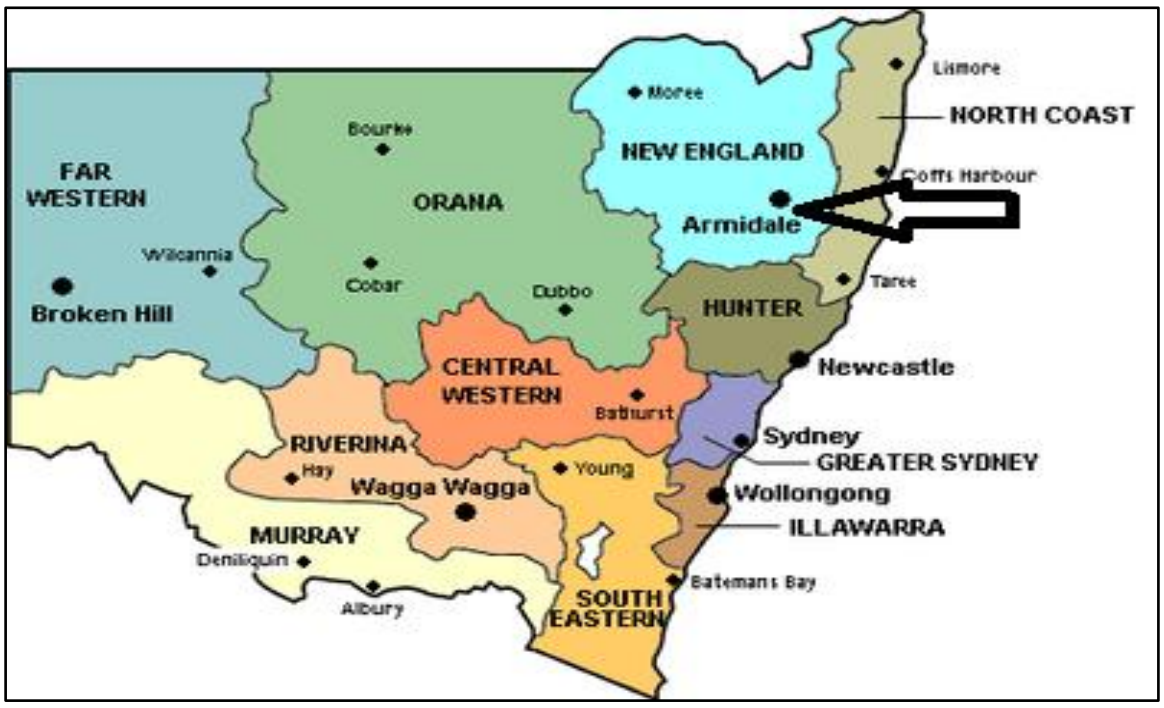

Figure 1 Armidale NSW, Australia location

III. METHODOLOGY

The power incident on a photo voltaic (PV) module depends not only on the power contained in the sunlight, but also on the angle between the module and the sun. When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight (in other words, the power density will always be at its maximum when the PV module is perpendicular to the sun). However, as the

angle between the sun and a fixed surface is continually changing, the power density on a fixed PV module is less than that of the incident sunlight.

The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. The following figure shows how to calculate the radiation incident on a tilted surface (S_{module}) given either the solar radiation measured on horizontal surface (S_{horiz}) or the solar radiation measured perpendicular to the sun ($S_{incident}$).

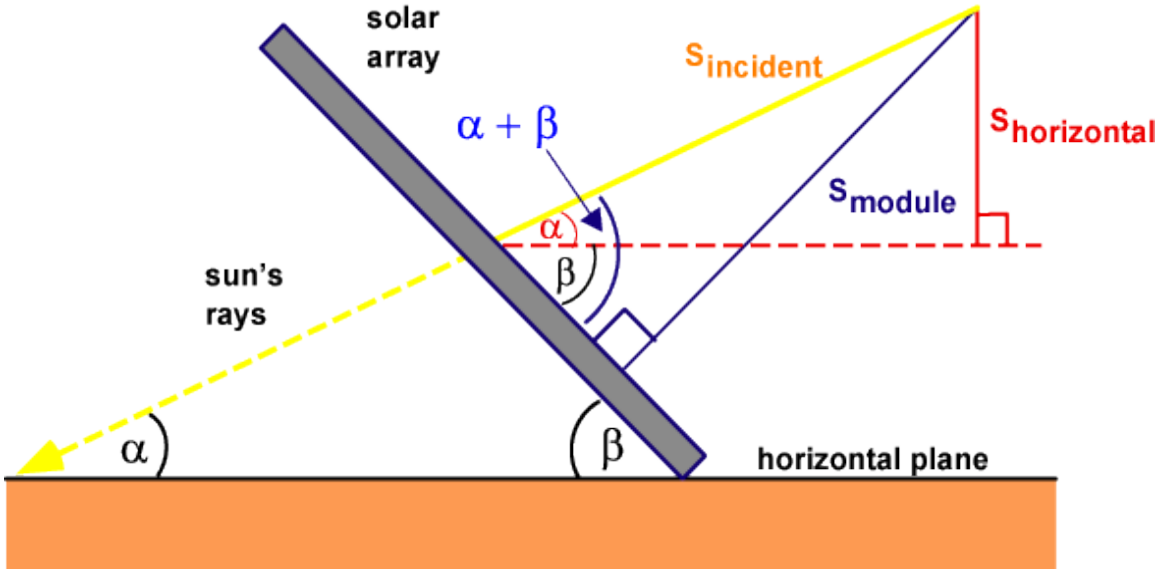

Figure 2 Illustration of sun and array positions and types of incident radiations

The equations relating S_{module}, S_{horiz} and $S_{incident}$ are:

$$S_{horizontal} = S_{incident} \sin\alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

where

α is the elevation angle; and

β is the tilt angle of the module measured from the horizontal.

The elevation angle has been previously given as:

$$\alpha = 90 - \phi + \delta$$

where φ is the latitude; and

δ is the declination angle previously given as:

$$\delta = 23.45^{\circ} \sin\left[\frac{360}{365}(284 + d)\right]$$

where d is the day of the year. Note that from simple math (284+d) is equivalent to (d-81) which was used before. Two equations are used interchangeably in literature.

From these equations a relationship between S_{module} and S_{horiz} can be determined as:

$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin\alpha}$$

IV. GENERATION OF TYPICAL SOLAR RADIATION YEAON TILTED SURFACES

Applying the above methodology for all the months in the database, the Test Reference Year for daily solar radiation data was formed for Armidale.

The test reference years with minimum FS for monthly mean global solar radiation for Armidale are given in "Table 2" [15]. Which shows that, although the big picture that Armidale has a high potential of solarenergy, still there are considerable differences of potentiality in through the months due to the fact that Armidale's winter season (June, July and August) is relatively cloudy. "Table 2", the minimum and maximum values of monthly mean of the daily global solar radiation on a horizontal surface (ITRY) in Armidale, the minimum is 10.41 MJ/m2 day in June and the maximum is 25.88 MJ/m2 day in December.

Table2TestReferenceYearswithminimum (min)FSandmonthlymeanofthesolar radiation($ITRY$) for Armidale NSW, Australia

Month	Year	ITRY (MJ/m^2day)
January	1993	25.33
February	2007	25.18
March	1993	19.68
April	1993	15.98
May	2000	12.4
June	2006	10.41
July	1991	11.44
August	1999	14.62
September	2012	19.11
October	1991	22.00
November	1991	23.59
December	1994	25.88

Extracted from [15]

By applying the methodology to test reference years of horizontal solar radiation data shown in table 3, solar irradiance for module (array) and incident solar radiation are gained for each day of the reference year for prescribed inclination angles(15°, 30°, 45°, 60° and 75°) as tabulated in tables [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 &15], each table represents a month with each day separately.

Table3Daily solar radiation on horizontal surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	29.4	18.1	19.1	18.8	13.5	10.8	10.0	14.5	16.4	20.5	22.3	24.6
2	27.0	22.5	21.8	18.9	12.6	10.6	10.4	14.2	16.3	19.4	22.9	25.0
3	27.2	23.2	21.1	17.8	13.9	9.00	11.2	13.6	16.1	19.3	23.4	26.0
4	26.1	26.1	22.0	19.0	13.0	10.7	10.0	13.2	17.5	20.9	23.1	25.7
5	23.2	25.5	19.8	16.8	12.0	10.9	12.0	13.3	15.8	21.2	21.3	25.4
6	23.2	23.5	21.3	19.5	14.7	11.6	11.2	14.3	18.7	19.9	22.3	23.8
7	26.6	21.5	19.4	18.8	14.5	9.70	10.8	13.7	17.0	21.4	24.1	26.1
8	25.1	23.2	20.3	16.4	12.8	10.3	10.7	14.9	17.0	21.6	22.0	26.8
9	24.9	23.2	19.5	16.2	13.4	10.6	9.60	14.9	15.7	22.3	23.2	24.8
10	26.4	24.1	21.0	17.4	12.9	10.7	11.2	15.4	18.7	21.5	24.7	22.7
11	26.4	24.3	21.4	16.3	12.8	10.1	11.4	15.1	18.3	22.4	24.2	24.7
12	26.7	21.4	20.2	16.5	12.6	11.6	10.3	15.2	18.4	22.8	25.3	26.3
13	26.1	22.4	21.0	16.4	12.5	9.80	9.90	15.7	20.4	23.7	24.4	28.3
14	25.6	20.2	21.1	14.9	12.7	10.2	10.2	15.6	19.7	21.9	26.9	25.8
15	25.7	19.7	21.9	16.7	12.9	10.5	11.6	15.6	19.3	23.2	23.8	25.2
16	26.6	20.3	21.9	15.7	12.2	10.5	12.4	14.3	19.7	23.6	22.5	27.0
17	25.1	23.9	19.3	15.4	11.5	11.2	12.1	14.4	19.2	22.5	21.3	28.3
18	25.1	22.2	20.7	16.2	11.1	10.6	10.7	14.0	19.7	23.0	21.5	26.0
19	22.1	21.8	20.9	15.2	12.4	9.50	12.2	14.6	20.0	21.8	25.5	27.1
20	28.4	22.8	20.5	15.4	12.4	9.90	12.4	13.9	19.9	23.6	24.2	26.8
21	27.3	23.4	19.8	16.2	11.3	10.6	12.4	15.5	19.9	22.9	21.3	28.1
22	25.0	21.3	17.8	15.7	11.9	10.6	12.2	14.3	21.2	24.3	24.2	26.4
23	23.5	23.2	18.8	16.2	12.2	10.4	12.7	12.8	21.8	24.4	23.7	27.9
24	25.6	23.3	20.3	14.6	12.0	11.1	11.6	16.1	20.2	21.3	25.6	24.3
25	20.8	19.0	19.5	14.6	12.2	11.0	10.8	16.8	21.5	22.9	25.3	26.2
26	25.4	21.5	17.8	14.9	11.9	10.3	9.60	16.2	20.5	20.0	26.3	26.3
27	25.2	21.5	19.4	13.7	12.2	9.80	11.4	15.5	21.5	21.3	26.1	19.8
28	27.2	25.5	17.9	13.1	11.7	10.6	11.7	15.3	21.6	26.9	26.5	26.2
29	26.8	18.3	18.5	15.1	11.4	11.2	13.6	14.9	22.1	25.5	25.7	28.3
30	27.4		15.8	14.9	11.5	9.70	13.3	14.0	23.7	21.3	26.0	26.1
31	22.8		18.7		11.0		12.8	15.9		22.6		28.4

Extracted from [15]

Table 4 January's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW,Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
1		1	29.4	27.4	23.52	18.05	11.34	3.87	29.65
2		2	27	25.15	21.58	16.55	10.38	3.51	27.24
3		3	27.2	25.32	21.72	16.64	10.42	3.5	27.45
4		4	26.1	24.29	20.82	15.94	9.96	3.31	26.34
5		5	23.2	21.58	18.49	14.14	8.82	2.91	23.42
6		6	23.2	21.57	18.47	14.1	8.78	2.86	23.43
7		7	26.6	24.71	21.14	16.13	10.02	3.23	26.87
8		8	25.1	23.31	19.92	15.19	9.41	2.99	25.36
9		9	24.9	23.11	19.74	15.02	9.29	2.92	25.17
10		10	26.4	24.48	20.89	15.88	9.79	3.03	26.69
11		11	26.4	24.46	20.86	15.84	9.73	2.97	26.7
12		12	26.7	24.72	21.06	15.97	9.78	2.93	27.02
13		13	26.1	24.15	20.55	15.56	9.5	2.8	26.42
14		14	25.6	23.67	20.12	15.21	9.26	2.67	25.93
15		15	25.7	23.74	20.16	15.21	9.23	2.68	26.04
16	**January**	16	26.6	24.55	20.83	15.69	9.48	2.62	26.96
17		17	25.1	23.15	19.61	14.75	8.87	2.39	25.46
18		18	25.1	23.12	19.57	14.69	8.8	2.31	25.47
19		19	22.1	20.34	17.19	12.88	7.68	1.96	22.44
20		20	28.4	26.11	22.05	16.48	9.78	2.43	28.85
21		21	27.3	25.39	21.84	16.65	10.37	3.55	27.57
22		22	25	23.25	20	15.25	9.5	3.25	25.25
23		23	23.5	21.86	18.8	14.34	8.93	3.06	23.74
24		24	25.6	23.81	20.48	15.62	9.73	3.33	25.86
25		25	20.8	19.34	16.64	12.69	7.9	2.7	21.01
26		26	25.4	23.62	20.32	15.49	9.65	3.3	25.65
27		27	25.2	23.44	20.16	15.37	9.58	3.28	25.45
28		28	27.2	25.3	21.76	16.59	10.34	3.54	27.47
29		29	26.8	24.92	21.44	16.35	10.18	3.48	27.07
30		30	27.4	25.48	21.92	16.71	10.41	3.56	27.67
31		31	22.8	21.2	18.24	13.91	8.66	2.96	23.03

Table 5 February's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW,Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
32		1	18.1	16.83	14.48	11.04	6.88	2.35	18.28
33		2	22.5	20.93	18	13.73	8.55	2.93	22.73
34		3	23.2	21.58	18.56	14.15	8.82	3.02	23.43
35		4	26.1	24.27	20.88	15.92	9.92	3.39	26.36
36		5	25.5	23.72	20.4	15.56	9.69	3.32	25.76
37		6	23.5	21.86	18.8	14.34	8.93	3.06	23.74
38		7	21.5	20	17.2	13.12	8.17	2.8	21.72
39		8	23.2	21.58	18.56	14.15	8.82	3.02	23.43
40		9	23.2	21.58	18.56	14.15	8.82	3.02	23.43
41		10	24.1	22.41	19.28	14.7	9.16	3.13	24.34
42		11	24.3	22.6	19.44	14.82	9.23	3.16	24.54
43		12	21.4	19.9	17.12	13.05	8.13	2.78	21.61
44		13	22.4	20.83	17.92	13.66	8.51	2.91	22.62
45	**February**	14	20.2	18.79	16.16	12.32	7.68	2.63	20.4
46		15	19.7	18.32	15.76	12.02	7.49	2.56	19.9
47		16	20.3	18.88	16.24	12.38	7.71	2.64	20.5
48		17	23.9	22.23	19.12	14.58	9.08	3.11	24.14
49		18	22.2	20.65	17.76	13.54	8.44	2.89	22.42
50		19	21.8	20.27	17.44	13.3	8.28	2.83	22.02
51		20	22.8	21.2	18.24	13.91	8.66	2.96	23.03
52		21	23.4	21.76	18.72	14.27	8.89	3.04	23.63
53		22	21.3	19.81	17.04	12.99	8.09	2.77	21.51
54		23	23.2	21.58	18.56	14.15	8.82	3.02	23.43
55		24	23.3	21.67	18.64	14.21	8.85	3.03	23.53
56		25	19	17.67	15.2	11.59	7.22	2.47	19.19
57		26	21.5	20	17.2	13.12	8.17	2.8	21.72
58		27	21.5	20	17.2	13.12	8.17	2.8	21.72
59		28	25.5	23.72	20.4	15.56	9.69	3.32	25.76
60		29	18.3	17.02	14.64	11.16	6.95	2.38	18.48

Table 6 March's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW,Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
61		1	19.1	17.76	15.28	11.65	7.26	2.48	19.29
62		2	21.8	20.27	17.44	13.3	8.28	2.83	22.02
63		3	21.1	19.62	16.88	12.87	8.02	2.74	21.31
64		4	22	20.46	17.6	13.42	8.36	2.86	22.22
65		5	19.8	18.41	15.84	12.08	7.52	2.57	20
66		6	21.3	19.81	17.04	12.99	8.09	2.77	21.51
67		7	19.4	18.04	15.52	11.83	7.37	2.52	19.59
68		8	20.3	18.88	16.24	12.38	7.71	2.64	20.5
69		9	19.5	18.14	15.6	11.9	7.41	2.54	19.7
70		10	21	19.53	16.8	12.81	7.98	2.73	21.21
71		11	21.4	19.9	17.12	13.05	8.13	2.78	21.61
72		12	20.2	18.79	16.16	12.32	7.68	2.63	20.4
73		13	21	19.53	16.8	12.81	7.98	2.73	21.21
74		14	21.1	19.62	16.88	12.87	8.02	2.74	21.31
75		15	21.9	20.37	17.52	13.36	8.32	2.85	22.12
76	**March**	16	21.9	20.37	17.52	13.36	8.32	2.85	22.12
77		17	19.3	17.95	15.44	11.77	7.33	2.51	19.49
78		18	20.7	19.25	16.56	12.63	7.87	2.69	20.91
79		19	20.9	19.44	16.72	12.75	7.94	2.72	21.11
80		20	20.5	19.07	16.4	12.51	7.79	2.67	20.71
81		21	19.8	18.41	15.84	12.08	7.52	2.57	20
82		22	17.8	16.55	14.24	10.86	6.76	2.31	17.98
83		23	18.8	17.48	15.04	11.47	7.14	2.44	18.99
84		24	20.3	18.88	16.24	12.38	7.71	2.64	20.5
85		25	19.5	18.14	15.6	11.9	7.41	2.54	19.7
86		26	17.8	16.55	14.24	10.86	6.76	2.31	17.98
87		27	19.4	18.04	15.52	11.83	7.37	2.52	19.59
88		28	17.9	16.65	14.32	10.92	6.8	2.33	18.08
89		29	18.5	17.21	14.8	11.29	7.03	2.41	18.69
90		30	15.8	14.69	12.64	9.64	6	2.05	15.96
91		31	18.7	17.39	14.96	11.41	7.11	2.43	18.89

Table 7 April's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW,Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
92		1	18.8	17.48	15.04	11.47	7.14	2.44	18.99
93		2	18.9	17.58	15.12	11.53	7.18	2.46	19.09
94		3	17.8	16.55	14.24	10.86	6.76	2.31	17.98
95		4	19	17.67	15.2	11.59	7.22	2.47	19.19
96		5	16.8	15.62	13.44	10.25	6.38	2.18	16.97
97		6	19.5	18.14	15.6	11.9	7.41	2.54	19.7
98		7	18.8	17.48	15.04	11.47	7.14	2.44	18.99
99		8	16.4	15.25	13.12	10	6.23	2.13	16.56
100		9	16.2	15.07	12.96	9.88	6.16	2.11	16.36
101		10	17.4	16.18	13.92	10.61	6.61	2.26	17.57
102		11	16.3	15.16	13.04	9.94	6.19	2.12	16.46
103		12	16.5	15.35	13.2	10.07	6.27	2.15	16.67
104		13	16.4	15.25	13.12	10	6.23	2.13	16.56
105		14	14.9	13.86	11.92	9.09	5.66	1.94	15.05
106	**April**	15	16.7	15.53	13.36	10.19	6.35	2.17	16.87
107		16	15.7	14.6	12.56	9.58	5.97	2.04	15.86
108		17	15.4	14.32	12.32	9.39	5.85	2	15.55
109		18	16.2	15.07	12.96	9.88	6.16	2.11	16.36
110		19	15.2	14.14	12.16	9.27	5.78	1.98	15.35
111		20	15.4	14.32	12.32	9.39	5.85	2	15.55
112		21	16.2	15.07	12.96	9.88	6.16	2.11	16.36
113		22	15.7	14.6	12.56	9.58	5.97	2.04	15.86
114		23	16.2	15.07	12.96	9.88	6.16	2.11	16.36
115		24	14.6	13.58	11.68	8.91	5.55	1.9	14.75
116		25	14.6	13.58	11.68	8.91	5.55	1.9	14.75
117		26	14.9	13.86	11.92	9.09	5.66	1.94	15.05
118		27	13.7	12.74	10.96	8.36	5.21	1.78	13.84
119		28	13.1	12.18	10.48	7.99	4.98	1.7	13.23
120		29	15.1	14.04	12.08	9.21	5.74	1.96	15.25
121		30	14.9	13.86	11.92	9.09	5.66	1.94	15.05

Table 8 May's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW,Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
122		1	13.5	12.56	10.8	8.24	5.13	1.76	13.64
123		2	12.6	11.72	10.08	7.69	4.79	1.64	12.73
124		3	13.9	12.93	11.12	8.48	5.28	1.81	14.04
125		4	13	12.09	10.4	7.93	4.94	1.69	13.13
126		5	12	11.16	9.6	7.32	4.56	1.56	12.12
127		6	14.7	13.67	11.76	8.97	5.59	1.91	14.85
128		7	14.5	13.49	11.6	8.85	5.51	1.89	14.65
129		8	12.8	11.9	10.24	7.81	4.86	1.66	12.93
130		9	13.4	12.46	10.72	8.17	5.09	1.74	13.53
131		10	12.9	12	10.32	7.87	4.9	1.68	13.03
132		11	12.8	11.9	10.24	7.81	4.86	1.66	12.93
133		12	12.6	11.72	10.08	7.69	4.79	1.64	12.73
134		13	12.5	11.63	10	7.63	4.75	1.63	12.63
135		14	12.7	11.81	10.16	7.75	4.83	1.65	12.83
136		15	12.9	12	10.32	7.87	4.9	1.68	13.03
137	**May**	16	12.2	11.35	9.76	7.44	4.64	1.59	12.32
138		17	11.5	10.7	9.2	7.02	4.37	1.5	11.62
139		18	11.1	10.32	8.88	6.77	4.22	1.44	11.21
140		19	12.4	11.53	9.92	7.56	4.71	1.61	12.52
141		20	12.4	11.53	9.92	7.56	4.71	1.61	12.52
142		21	11.3	10.51	9.04	6.89	4.29	1.47	11.41
143		22	11.9	11.07	9.52	7.26	4.52	1.55	12.02
144		23	12.2	11.35	9.76	7.44	4.64	1.59	12.32
145		24	12	11.16	9.6	7.32	4.56	1.56	12.12
146		25	12.2	11.35	9.76	7.44	4.64	1.59	12.32
147		26	11.9	11.07	9.52	7.26	4.52	1.55	12.02
148		27	12.2	11.35	9.76	7.44	4.64	1.59	12.32
149		28	11.7	10.88	9.36	7.14	4.45	1.52	11.82
150		29	11.4	10.6	9.12	6.95	4.33	1.48	11.51
151		30	11.5	10.7	9.2	7.02	4.37	1.5	11.62
152		31	11	10.23	8.8	6.71	4.18	1.43	11.11

Table 9 June's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
153		1	10.8	10.04	8.64	6.59	4.1	1.4	10.91
154		2	10.6	9.86	8.48	6.47	4.03	1.38	10.71
155		3	9	8.37	7.2	5.49	3.42	1.17	9.09
156		4	10.7	9.95	8.56	6.53	4.07	1.39	10.81
157		5	10.9	10.14	8.72	6.65	4.14	1.42	11.01
158		6	11.6	10.79	9.28	7.08	4.41	1.51	11.72
159		7	9.7	9.02	7.76	5.92	3.69	1.26	9.8
160		8	10.3	9.58	8.24	6.28	3.91	1.34	10.4
161		9	10.6	9.86	8.48	6.47	4.03	1.38	10.71
162		10	10.7	9.95	8.56	6.53	4.07	1.39	10.81
163		11	10.1	9.39	8.08	6.16	3.84	1.31	10.2
164		12	11.6	10.79	9.28	7.08	4.41	1.51	11.72
165		13	9.8	9.11	7.84	5.98	3.72	1.27	9.9
166		14	10.2	9.49	8.16	6.22	3.88	1.33	10.3
167	**June**	15	10.5	9.77	8.4	6.41	3.99	1.37	10.61
168		16	10.5	9.77	8.4	6.41	3.99	1.37	10.61
169		17	11.2	10.42	8.96	6.83	4.26	1.46	11.31
170		18	10.6	9.86	8.48	6.47	4.03	1.38	10.71
171		19	9.5	8.84	7.6	5.8	3.61	1.24	9.6
172		20	9.9	9.21	7.92	6.04	3.76	1.29	10
173		21	10.6	9.86	8.48	6.47	4.03	1.38	10.71
174		22	10.6	9.86	8.48	6.47	4.03	1.38	10.71
175		23	10.4	9.67	8.32	6.34	3.95	1.35	10.5
176		24	11.1	10.32	8.88	6.77	4.22	1.44	11.21
177		25	11	10.23	8.8	6.71	4.18	1.43	11.11
178		26	10.3	9.58	8.24	6.28	3.91	1.34	10.4
179		27	9.8	9.11	7.84	5.98	3.72	1.27	9.9
180		28	10.6	9.86	8.48	6.47	4.03	1.38	10.71
181		29	11.2	10.42	8.96	6.83	4.26	1.46	11.31
182		30	9.7	9.02	7.76	5.92	3.69	1.26	9.8

Table 10 July's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
183		1	10	9.3	8	6.1	3.8	1.3	10.1
184		2	10.4	9.67	8.32	6.34	3.95	1.35	10.5
185		3	11.2	10.42	8.96	6.83	4.26	1.46	11.31
186		4	10	9.3	8	6.1	3.8	1.3	10.1
187		5	12	11.16	9.6	7.32	4.56	1.56	12.12
188		6	11.2	10.42	8.96	6.83	4.26	1.46	11.31
189		7	10.8	10.04	8.64	6.59	4.1	1.4	10.91
190		8	10.7	9.95	8.56	6.53	4.07	1.39	10.81
191		9	9.6	8.93	7.68	5.86	3.65	1.25	9.7
192		10	11.2	10.42	8.96	6.83	4.26	1.46	11.31
193		11	11.4	10.6	9.12	6.95	4.33	1.48	11.51
194		12	10.3	9.58	8.24	6.28	3.91	1.34	10.4
195		13	9.9	9.21	7.92	6.04	3.76	1.29	10
196		14	10.2	9.49	8.16	6.22	3.88	1.33	10.3
197		15	11.6	10.79	9.28	7.08	4.41	1.51	11.72
198	**July**	16	12.4	11.53	9.92	7.56	4.71	1.61	12.52
199		17	12.1	11.25	9.68	7.38	4.6	1.57	12.22
200		18	10.7	9.95	8.56	6.53	4.07	1.39	10.81
201		19	12.2	11.35	9.76	7.44	4.64	1.59	12.32
202		20	12.4	11.53	9.92	7.56	4.71	1.61	12.52
203		21	12.4	11.53	9.92	7.56	4.71	1.61	12.52
204		22	12.2	11.35	9.76	7.44	4.64	1.59	12.32
205		23	12.7	11.81	10.16	7.75	4.83	1.65	12.83
206		24	11.6	10.79	9.28	7.08	4.41	1.51	11.72
207		25	10.8	10.04	8.64	6.59	4.1	1.4	10.91
208		26	9.6	8.93	7.68	5.86	3.65	1.25	9.7
209		27	11.4	10.6	9.12	6.95	4.33	1.48	11.51
210		28	11.7	10.88	9.36	7.14	4.45	1.52	11.82
211		29	13.6	12.65	10.88	8.3	5.17	1.77	13.74
212		30	13.3	12.37	10.64	8.11	5.05	1.73	13.43
213		31	12.8	11.9	10.24	7.81	4.86	1.66	12.93

Table 11 August's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
214		1	14.5	13.49	11.6	8.85	5.51	1.89	14.65
215		2	14.2	13.21	11.36	8.66	5.4	1.85	14.34
216		3	13.6	12.65	10.88	8.3	5.17	1.77	13.74
217		4	13.2	12.28	10.56	8.05	5.02	1.72	13.33
218		5	13.3	12.37	10.64	8.11	5.05	1.73	13.43
219		6	14.3	13.3	11.44	8.72	5.43	1.86	14.44
220		7	13.7	12.74	10.96	8.36	5.21	1.78	13.84
221		8	14.9	13.86	11.92	9.09	5.66	1.94	15.05
222		9	14.9	13.86	11.92	9.09	5.66	1.94	15.05
223		10	15.4	14.32	12.32	9.39	5.85	2	15.55
224		11	15.1	14.04	12.08	9.21	5.74	1.96	15.25
225		12	15.2	14.14	12.16	9.27	5.78	1.98	15.35
226		13	15.7	14.6	12.56	9.58	5.97	2.04	15.86
227		14	15.6	14.51	12.48	9.52	5.93	2.03	15.76
228		15	15.6	14.51	12.48	9.52	5.93	2.03	15.76
229	**August**	16	14.3	13.3	11.44	8.72	5.43	1.86	14.44
230		17	14.4	13.39	11.52	8.78	5.47	1.87	14.54
231		18	14	13.02	11.2	8.54	5.32	1.82	14.14
232		19	14.6	13.58	11.68	8.91	5.55	1.9	14.75
233		20	13.9	12.93	11.12	8.48	5.28	1.81	14.04
234		21	15.5	14.42	12.4	9.46	5.89	2.02	15.66
235		22	14.3	13.3	11.44	8.72	5.43	1.86	14.44
236		23	12.8	11.9	10.24	7.81	4.86	1.66	12.93
237		24	16.1	14.97	12.88	9.82	6.12	2.09	16.26
238		25	16.8	15.62	13.44	10.25	6.38	2.18	16.97
239		26	16.2	15.07	12.96	9.88	6.16	2.11	16.36
240		27	15.5	14.42	12.4	9.46	5.89	2.02	15.66
241		28	15.3	14.23	12.24	9.33	5.81	1.99	15.45
242		29	14.9	13.86	11.92	9.09	5.66	1.94	15.05
243		30	14	13.02	11.2	8.54	5.32	1.82	14.14
244		31	15.9	14.79	12.72	9.7	6.04	2.07	16.06

Table 12 September's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
245		1	16.4	15.25	13.12	10	6.23	2.13	16.56
246		2	16.3	15.16	13.04	9.94	6.19	2.12	16.46
247		3	16.1	14.97	12.88	9.82	6.12	2.09	16.26
248		4	17.5	16.28	14	10.68	6.65	2.28	17.68
249		5	15.8	14.69	12.64	9.64	6	2.05	15.96
250		6	18.7	17.39	14.96	11.41	7.11	2.43	18.89
251		7	17	15.81	13.6	10.37	6.46	2.21	17.17
252		8	17	15.81	13.6	10.37	6.46	2.21	17.17
253		9	15.7	14.6	12.56	9.58	5.97	2.04	15.86
254		10	18.7	17.39	14.96	11.41	7.11	2.43	18.89
255		11	18.3	17.02	14.64	11.16	6.95	2.38	18.48
256		12	18.4	17.11	14.72	11.22	6.99	2.39	18.58
257		13	20.4	18.97	16.32	12.44	7.75	2.65	20.6
258		14	19.7	18.32	15.76	12.02	7.49	2.56	19.9
259	**September**	15	19.3	17.95	15.44	11.77	7.33	2.51	19.49
260		16	19.7	18.32	15.76	12.02	7.49	2.56	19.9
261		17	19.2	17.86	15.36	11.71	7.3	2.5	19.39
262		18	19.7	18.32	15.76	12.02	7.49	2.56	19.9
263		19	20	18.6	16	12.2	7.6	2.6	20.2
264		20	19.9	18.51	15.92	12.14	7.56	2.59	20.1
265		21	19.9	18.51	15.92	12.14	7.56	2.59	20.1
266		22	21.2	19.72	16.96	12.93	8.06	2.76	21.41
267		23	21.8	20.27	17.44	13.3	8.28	2.83	22.02
268		24	20.2	18.79	16.16	12.32	7.68	2.63	20.4
269		25	21.5	20	17.2	13.12	8.17	2.8	21.72
270		26	20.5	19.07	16.4	12.51	7.79	2.67	20.71
271		27	21.5	20	17.2	13.12	8.17	2.8	21.72
272		28	21.6	20.09	17.28	13.18	8.21	2.81	21.82
273		29	22.1	20.55	17.68	13.48	8.4	2.87	22.32
274		30	23.7	22.04	18.96	14.46	9.01	3.08	23.94

Table 13 October's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
275		1	20.5	19.07	16.4	12.51	7.79	2.67	20.71
276		2	19.4	18.04	15.52	11.83	7.37	2.52	19.59
277		3	19.3	17.95	15.44	11.77	7.33	2.51	19.49
278		4	20.9	19.44	16.72	12.75	7.94	2.72	21.11
279		5	21.2	19.72	16.96	12.93	8.06	2.76	21.41
280		6	19.9	18.51	15.92	12.14	7.56	2.59	20.1
281		7	21.4	19.9	17.12	13.05	8.13	2.78	21.61
282		8	21.6	20.09	17.28	13.18	8.21	2.81	21.82
283		9	22.3	20.74	17.84	13.6	8.47	2.9	22.52
284		10	21.5	20	17.2	13.12	8.17	2.8	21.72
285		11	22.4	20.83	17.92	13.66	8.51	2.91	22.62
286		12	22.8	21.2	18.24	13.91	8.66	2.96	23.03
287		13	23.7	22.04	18.96	14.46	9.01	3.08	23.94
288		14	21.9	20.37	17.52	13.36	8.32	2.85	22.12
289		15	23.2	21.58	18.56	14.15	8.82	3.02	23.43
290	**October**	16	23.6	21.95	18.88	14.4	8.97	3.07	23.84
291		17	22.5	20.93	18	13.73	8.55	2.93	22.73
292		18	23	21.39	18.4	14.03	8.74	2.99	23.23
293		19	21.8	20.27	17.44	13.3	8.28	2.83	22.02
294		20	23.6	21.95	18.88	14.4	8.97	3.07	23.84
295		21	22.9	21.3	18.32	13.97	8.7	2.98	23.13
296		22	24.3	22.6	19.44	14.82	9.23	3.16	24.54
297		23	24.4	22.69	19.52	14.88	9.27	3.17	24.64
298		24	21.3	19.81	17.04	12.99	8.09	2.77	21.51
299		25	22.9	21.3	18.32	13.97	8.7	2.98	23.13
300		26	20	18.6	16	12.2	7.6	2.6	20.2
301		27	21.3	19.81	17.04	12.99	8.09	2.77	21.51
302		28	26.9	25.02	21.52	16.41	10.22	3.5	27.17
303		29	25.5	23.72	20.4	15.56	9.69	3.32	25.76
304		30	21.3	19.81	17.04	12.99	8.09	2.77	21.51
305		31	22.6	21.02	18.08	13.79	8.59	2.94	22.83

Table 14 November's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
306		1	22.3	20.74	17.84	13.6	8.47	2.9	22.52
307		2	22.9	21.3	18.32	13.97	8.7	2.98	23.13
308		3	23.4	21.76	18.72	14.27	8.89	3.04	23.63
309		4	23.1	21.48	18.48	14.09	8.78	3	23.33
310		5	21.3	19.81	17.04	12.99	8.09	2.77	21.51
311		6	22.3	20.74	17.84	13.6	8.47	2.9	22.52
312		7	24.1	22.41	19.28	14.7	9.16	3.13	24.34
313		8	22	20.46	17.6	13.42	8.36	2.86	22.22
314		9	23.2	21.58	18.56	14.15	8.82	3.02	23.43
315		10	24.7	22.97	19.76	15.07	9.39	3.21	24.95
316		11	24.2	22.51	19.36	14.76	9.2	3.15	24.44
317		12	25.3	23.53	20.24	15.43	9.61	3.29	25.55
318		13	24.4	22.69	19.52	14.88	9.27	3.17	24.64
319		14	26.9	25.02	21.52	16.41	10.22	3.5	27.17
320	**November**	15	23.8	22.13	19.04	14.52	9.04	3.09	24.04
321		16	22.5	20.93	18	13.73	8.55	2.93	22.73
322		17	21.3	19.81	17.04	12.99	8.09	2.77	21.51
323		18	21.5	20	17.2	13.12	8.17	2.8	21.72
324		19	25.5	23.72	20.4	15.56	9.69	3.32	25.76
325		20	24.2	22.51	19.36	14.76	9.2	3.15	24.44
326		21	21.3	19.81	17.04	12.99	8.09	2.77	21.51
327		22	24.2	22.51	19.36	14.76	9.2	3.15	24.44
328		23	23.7	22.04	18.96	14.46	9.01	3.08	23.94
329		24	25.6	23.81	20.48	15.62	9.73	3.33	25.86
330		25	25.3	23.53	20.24	15.43	9.61	3.29	25.55
331		26	26.3	24.46	21.04	16.04	9.99	3.42	26.56
332		27	26.1	24.27	20.88	15.92	9.92	3.39	26.36
333		28	26.5	24.65	21.2	16.17	10.07	3.45	26.77
334		29	25.7	23.9	20.56	15.68	9.77	3.34	25.96
335		30	26	24.18	20.8	15.86	9.88	3.38	26.26

Table 15 December's Daily solar radiation on tilted surfaces valuesobtainedfromTestReferenceYear data for Armidale NSW, Australia

				Array Tilt Angle in Degrees					
				15□	30□	45□	60□	75□	
Day Serial	Month	Day	S_{horiz}	S_{module}	S_{module}	S_{module}	S_{module}	S_{module}	$S_{incident}$
336		1	24.6	22.88	19.68	15.01	9.35	3.2	24.85
337		2	25	23.25	20	15.25	9.5	3.25	25.25
338		3	26	24.18	20.8	15.86	9.88	3.38	26.26
339		4	25.7	23.9	20.56	15.68	9.77	3.34	25.96
340		5	25.4	23.62	20.32	15.49	9.65	3.3	25.65
341		6	23.8	22.13	19.04	14.52	9.04	3.09	24.04
342		7	26.1	24.27	20.88	15.92	9.92	3.39	26.36
343		8	26.8	24.92	21.44	16.35	10.18	3.48	27.07
344		9	24.8	23.06	19.84	15.13	9.42	3.22	25.05
345		10	22.7	21.11	18.16	13.85	8.63	2.95	22.93
346		11	24.7	22.97	19.76	15.07	9.39	3.21	24.95
347		12	26.3	24.46	21.04	16.04	9.99	3.42	26.56
348		13	28.3	26.32	22.64	17.26	10.75	3.68	28.58
349		14	25.8	23.99	20.64	15.74	9.8	3.35	26.06
350		15	25.2	23.44	20.16	15.37	9.58	3.28	25.45
351		16	27	25.11	21.6	16.47	10.26	3.51	27.27
352	**December**	17	28.3	26.32	22.64	17.26	10.75	3.68	28.58
353		18	26	24.18	20.8	15.86	9.88	3.38	26.26
354		19	27.1	25.2	21.68	16.53	10.3	3.52	27.37
355		20	26.8	24.92	21.44	16.35	10.18	3.48	27.07
356		21	28.1	26.13	22.48	17.14	10.68	3.65	28.38
357		22	26.4	24.55	21.12	16.1	10.03	3.43	26.66
358		23	27.9	25.95	22.32	17.02	10.6	3.63	28.18
359		24	24.3	22.6	19.44	14.82	9.23	3.16	24.54
360		25	26.2	24.37	20.96	15.98	9.96	3.41	26.46
361		26	26.3	24.46	21.04	16.04	9.99	3.42	26.56
362		27	19.8	18.41	15.84	12.08	7.52	2.57	20
363		28	26.2	24.37	20.96	15.98	9.96	3.41	26.46
364		29	28.3	26.32	22.64	17.26	10.75	3.68	28.58
365		30	26.1	24.27	20.88	15.92	9.92	3.39	26.36
366		31	28.4	26.41	22.72	17.32	10.79	3.69	28.68

V. CONCLUSION

The globalsolar radiation onhorizontalsurfaceshas beencollected and calculations have been conducted tocalculatethemonthly averagedailysolarirradianceoninclinedsurfacesfromtheglobalsolarirradiance.

Typical solar radiation data is very important for calculations concerning many solar energy generation systems and for building energy calculation modelling and analysis. In this study, test reference years for daily solar radiationon tilted surfaces with prescribed angles (15°, 30°, 45°, 60° and 75°)for Armidale town NSW, Australia are generated using 23 years of the meteorologically measured data. As well, the results show that Armidale has a high potential of solar energy through most of the year except for the winter months, which is still potential but not high. The generated test reference year would be a very useful reference for solar energy systems designers for any type of building applications as it helps calculating the actual energy generated during the daily sun movements around fixed solar arrays.

It is worth mentioning that well such TYM study has been developed for Armidale for mean wind speed measured at 10 meter height [19]. So concurrently with this study, hybrid solar and wind energy systems can be investigated, examined and designed for Armidale based on this study and study [16] concurrently.

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