Estimation of Solar Radiation in Brunei Darussalam

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ABSTRACT

Solar irradiance data obtained from the Meteorological Services of Civil Aviation of Brunei Darussalam during parts or most of the periods from January 1987 through December 1992 have been analyzed and utilized using the empirical model developed by Ångström [1-2] to predict the availability of solar radiation at the four districts of Brunei Darussalam which are Brunei/Muara, Belait, Temburong and Tutong. It is noted that the theoretical model of Ångström is suitable for estimating solar irradiance for any location in Brunei Darussalam.

1. INTRODUCTION

Brunei Darussalam, located between 4° 00′ and 5° 02′ of latitude North, enjoys a tropical humid climate, with warm temperatures all year long and a well-defined rainy season. Because of high humidity, air conditioning is really a requirement. For domestic hot water needs, solar water heaters are actually a competitive alternative for the hot water production.

Development of solar research program must always start with a study of solar radiation data at a site of the region of interest. Long-term measurements of solar radiation of a horizontal surface, however, exists for only relatively few meteorological stations. For places where it is not directly measured, solar radiation can be estimated using models and empirical correlations. One such method is the correlation developed by Ångström [1-2], Back et. al. [3] and others [4-5] between solar radiation and the duration of sunshine, which is measured at many meteorological stations. This correlation has been used by many researchers [6-10] to draw solar radiation maps with better details than would be possible using only directly measured data.

The present study stems from the need for knowledge of solar radiation data in Brunei Darussalam and to fill the gap of the radiation data for places lacking direct radiation measurements. In this paper the available data in relation to recordings of sunshine duration for Brunei Darussalam are examined.

2. SOLAR DATA MEASUREMENTS

Brunei Darussalam has four districts: Belait, Brunei/Muara, Temburong, and Tutong. The geographical locations of these districts is given in Table 1.

There are three meteorological stations in Brunei Darussalam. Only the station located at Brunei International Airport records solar radiation and bright sunshine hours. It is equipped with Epply black

Table 1. Geographical locations of the four districts of Brunei Darussalam.

District	Latitude (North)	Longitude (East)
Brunei/Muara	4° 54′	114° 57′
Belait	4° 18′	114° 41′
Temburong	4° 47′	114° 30′
Tutong	4° 37′	115° 11′

and white pyranometer and Campbell-Stokes recorder and is fully automatic. Data are recorded on hourly basis. In the present study the measured values of solar radiation and bright sunshine hours, recorded in Brunei/Muara district, are taken as the same for Belait, Temburong, Tutong districts. The data used in this project covers a period from 1987 to 1993.

3. METHODOLOGY

Many models have been devised for the prediction of the amount of solar radiation incident on a horizontal surface at the earth's surface. One of these methods, developed by Ångström [1-2]and later modified by Page [8], is used in the present study. The monthly mean daily solar radiation on a horizontal surface, $\bar{H}_{cal}$, for four districts of Brunei Darussalam, was calculated using the well-known Ångström correlation [1-3]:

$$\frac{\bar{H}_{cal}}{\bar{H}_o} = a + b\,\frac{\bar{S}}{\bar{S}_o} \qquad (1)$$

where

$\bar{H}_o$ is the monthly mean extraterrestrial radiation on the horizontal surface

$\bar{S}$ is the monthly average daily sunshine duration

$\bar{S}_o$ is the maximum possible monthly average daily sunshine duration i.e. length of the day

$\frac{\bar{H}_{cal}}{\bar{H}_o}$ is called monthly average clearness index (K_T)

$\frac{\bar{S}}{\bar{S}_o}$ is the fraction of maximum possible number of bright sunshine hours

a and b are regression coefficients.

Values of S_o were calculated from Cooper's formula [11]:

$$S_o = \frac{2}{15} \cos^{-1} (-\tan \phi \tan \delta) \tag{2}$$

In this equation ϕ and δ denote latitude of the location and declination angle respectively. Declination angle was evaluated using the equation obtained by Cooper [11]:

$$\delta = 23.45 \sin \left[\frac{360}{365} (284 + D)\right] \tag{3}$$

D is the day of the year ($1 \leq D \leq 365$) starting with 1 January. The extraterrestrial radiation on a horizontal surface was computed using the relation [11]:

$$H_o = \frac{24 \times 3600\, G_{sc}}{\pi} \left[1 + 0.033 \cos \left(\frac{360\, D}{365}\right)\right] \times \left[\cos\phi \cos\delta \cos \omega_s\right] + \left(\frac{2 \pi \omega_s}{360}\right) \sin \phi \sin \delta \tag{4}$$

where G_{sc} is the solar constant (1373 Wm^{-2}), and ω_s represents the sunset hour angle given by [11]:

$$\omega_s = \cos^{-1} (-\tan \phi \tan \delta) \tag{5}$$

Computer programs were developed to calculate $\bar{H}_o$ and $\bar{S}_o$. The computed values of $\bar{H}_o$ and $\bar{S}_o$ for four districts of Brunei Darussalam, namely, Brunei/Maura, Belait, Temburong and Tutong are given in Table 2.

The values of $\bar{H}_{cal} / H_o$ and $\bar{S} / S_o$ were computed for each month. Accordingly, 12 equations (one for each month) for each district were developed. The regression coefficients a and b for different locations were calculated using Eqs. (6) and (7) as developed by Reitveld [12]:

$$a = 0.10 + 0.24 \left(\frac{\bar{S}}{\bar{S}_o}\right) \tag{6}$$

$$b = 0.38 + 0.08 \left(\frac{\bar{S}}{\bar{S}_o}\right) \tag{7}$$

The regression coefficients are given in Table 3.

4. RESULTS AND DISCUSSION

The results indicate that the regression coefficients, a and b for the four districts of Brunei Darussalam are mostly identical. This is because of the fact that the variation of latitude between these

Table 2. Monthly average daily hours of bright sunshine, $\bar{S}$ (hrs), monthly mean extraterrestrial radiation on a horizontal surface, $\bar{H}_o$ (MJm^{-2}), and the average daylength of the month, $\bar{S}_o$ (hrs), of Brunei Darussalam.

Month	$\bar{S}$	Brunei/Muara		Belait		Tutong		Temburong	
		$\bar{H}_o$	$\bar{S}_o$	$\bar{H}_o$	$\bar{S}_o$	$\bar{H}_o$	$\bar{S}_o$	$\bar{H}_o$	$\bar{S}_o$
Jan.	7.34	34.41	11.75	34.66	11.78	34.46	11.76	34.53	11.76
Feb.	7.35	36.23	11.84	36.41	11.86	36.26	11.85	36.31	11.85
Mar.	7.93	37.64	11.97	37.70	11.98	37.65	11.97	37.67	11.97
Apr.	8.47	37.59	12.11	37.52	12.10	37.57	12.11	37.56	12.10
May	7.60	36.39	12.22	36.22	12.20	36.36	12.22	36.31	12.21
Jun.	7.46	35.47	12.28	35.26	12.25	35.43	12.27	35.37	12.26
Jul.	7.47	35.76	12.25	35.57	12.22	35.73	12.25	35.67	12.24
Aug.	7.24	36.87	12.16	36.76	12.14	36.84	12.15	36.81	12.15
Sep.	6.89	37.39	12.02	37.40	12.02	37.39	12.02	37.39	12.02
Oct.	7.33	36.45	11.89	36.59	11.90	36.48	11.89	36.51	11.89
Nov.	6.97	34.69	11.77	34.92	11.80	34.73	11.78	34.79	11.79
Dec.	7.45	33.67	11.72	33.95	11.75	33.73	11.73	33.80	11.74

Table 3. Regression coefficients of the four districts of Brunei Darussalam.

Month	Brunei/Muara			Belait			Temburong			Tutong		
	a	b	$a+b$	a	b	$a+b$	a	b	$a+b$	a	b	$a+b$
Jan.	.247	.511	.758	.247	.511	.758	.247	.511	.758	.247	.511	.758
Feb.	.244	.514	.758	.244	.514	.758	.244	.514	.758	.244	.514	.758
Mar.	.267	.495	.762	.267	.495	.762	.267	.495	.762	.267	.495	.762
Apr.	.267	.495	.762	.267	.495	.762	.267	.495	.762	.267	.495	.762
May	.244	.513	.757	.245	.513	.758	.244	.513	.757	.244	.513	.757
Jun.	.238	.519	.757	.238	.519	.757	.238	.519	.757	.238	.519	.757
Jul.	.240	.517	.757	.241	.517	.758	.240	.517	.757	.240	.517	.757
Aug.	.239	.519	.758	.239	.518	.757	.239	.519	.758	.239	.519	.758
Sep.	.230	.527	.757	.230	.527	.757	.230	.527	.757	.230	.527	.757
Oct.	.243	.515	.758	.243	.515	.758	.243	.515	.758	.243	.515	.758
Nov.	.237	.520	.757	.237	.520	.757	.237	.520	.757	.237	.520	.757
Dec.	.243	.515	.758	.243	.515	.758	.243	.515	.758	.243	.515	.758

districts is less than one degree.

The percentage errors between the theoretically calculated, H_{cal} and measured values of monthly mean daily solar radiation on a horizontal surface, H, for four districts of Brunei Darussalam for the 12 months of the year were determined using Eq. 8 and are given in Table 4.

$$e = \left[\frac{H - H_{cal}}{H}\right] 100 \tag{8}$$

A comparison of the predicted and measured values of monthly mean daily solar radiation was made and is shown in Fig. 1. It demonstrates that the measured values of $\bar{H}$ are in agreement with the predicted values of $\bar{H}_{cal}$. Except for the month of March and April, the percentage errors between the estimated and measured values for the four districts were below 7 %. Percentage errors for the month of March and April were around 9 %.

It is noted that the calculated values of H_{cal} are always higher than the measured values. This is due to the fact that the equations used to evaluate the regression coefficients were developed for different climateorological conditions. This indicates that the method proposed by Rietveld [12] does not show universal applicability in the present form for any location around the world.

The maximum solar radiation in Brunei Darussalam is in the month of March and April. This is in accordance with the measured values of bright sunshine. The measured data on bright sunshine hours (Table 2) for March and April were more than 8 hours, more than any other months. The high solar radiation flux received during these months is due to the relative decrease in the mean cloud cover at low and medium levels of the atmosphere, and hence the decrease in the rainfall compared to that of other months.

It has been observed that during the month of March and April, warm wind blows from Australia towards Brunei Darussalam. Due to this wind, the water vapor in the earth's atmosphere over the country is substantially reduced. Hence, very low absorption of sun's rays occurs. Even in this period, clouds in the sky are of high altitude, and do not affect much the intensity of the solar radiation. This is why Brunei Darussalam receives maximum amount of solar radiation in the months of March and

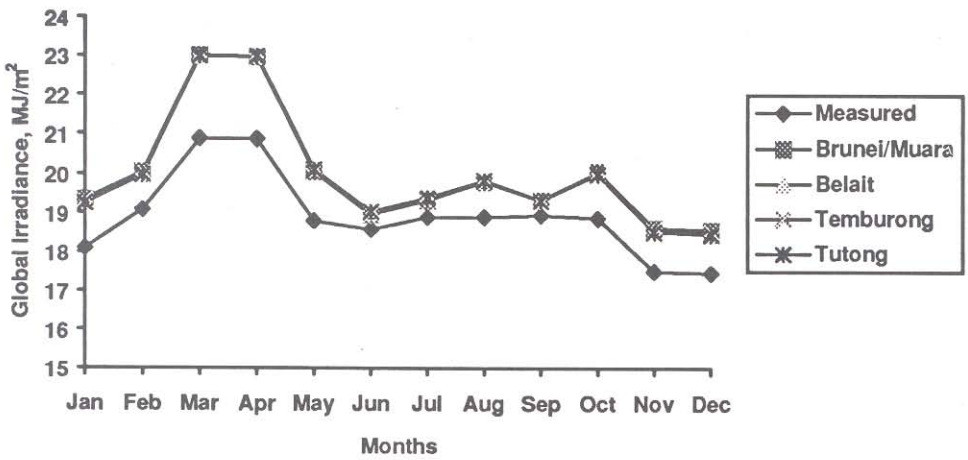

Fig. 1. Comaprison between measured and calculated values of monthly averaged global radiation on horizontal surface, $\bar{H}$ and $\bar{H}_{cal}$(MJ/m²), over the four districts of Brunei Darussalam.

Table 4. Monthly measured average solar irradiance, $\bar{H}$ (MJm^{-2}), computed average solar irradiance, $\bar{H}_{cal}$ (MJm^{-2}) and percentage difference netween measured and estimated values, e, of the four districts of Brunei Darussalam.

Month	Brunei/Muara			Belait			Temburong				Tutong	
	$\bar{H}$	$\bar{H}_{cal}$	e	$\bar{H}$	$\bar{H}_{cal}$	e	$\bar{H}$	$\bar{H}_{cal}$	e	$\bar{H}$	$\bar{H}_{cal}$	e
Jan.	18.10	19.35	6.46	18.10	19.26	6.02	18.10	19.29	6.17	18.10	19.24	5.93
Feb.	19.08	20.04	4.79	19.08	19.98	4.50	19.08	20.01	4.65	19.08	19.97	4.46
Mar.	20.88	23.01	9.26	20.88	22.99	9.18	20.88	22.99	9.18	20.88	22.98	9.14
Apr.	20.87	22.95	9.06	20.87	22.97	9.14	20.87	22.96	910	20.87	22.97	9.14
May	18.79	20.05	6.28	18.79	20.10	6.52	18.79	20.09	6.47	18.79	20.11	6.56
Jun.	18.58	18.95	1.95	18.58	19.01	2.26	18.58	18.99	2.16	18.58	19.03	2.36
Jul.	18.89	19.31	2.18	18.89	19.37	2.48	18.89	19.35	2.38	18.89	19.38	2.53
Aug.	18.89	19.79	4.55	18.89	19.82	4.69	18.89	19.81	4.64	18.89	19.83	4.74
Sep.	18.94	19.32	1.97	18.94	19.31	1.92	18.94	19.32	1.97	18.94	19.31	1.92
Oct.	18.87	20.05	5.89	18.87	20.00	5.65	18.87	20.02	5.74	18.87	19.99	5.60
Nov.	17.50	18.62	6.02	17.50	18.54	5.61	17.50	18.57	5.76	17.50	18.52	5.51
Dec.	17.46	18.57	5.98	17.46	18.47	5.47	17.46	18.51	5.67	17.46	18.45	5.37
Annual Average	18.90	20.00	5.36	18.90	19.99	5.92	18.90	19.99	5.32	18.90	19.98	5.27

April.

The low values of insolation have been observed for the months of November, December and January. These low values are due to the presence of heavy low altitude clouds in the sky. The sun's rays are either absorbed or reflected by these clouds and hence the amount of solar radiation falling at the surface of the earth is low. The total rainfall during these periods is much higher than in other months of the year.

5. CONCLUSIONS

It is possible to compute solar radiation on horizontal surface at any location in Brunei Darussalam using Ångström's model based on sunshine duration.

The pattern of monthly fluctuation of solar radiation is almost the same for all four districts. Peak solar radiation in Brunei Darussalam is in March and April, while in January, November and December, the country receives relatively low amount of insolation.

The monthly average solar radiation over Brunei Darussalam ranges from 17.4 to 21 MJm^{-2}.

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