STUDYING ON AVERAGE HOURLY AND MONTHLY SOLAR RADIATION AT MYITKYINA IN MYANMAR

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***Abstract*— In this paper, hourly terrestrial radiation direct beam, diffuse and solar radiation are modelled and calculated based on daily measured data for a horizontal surface. In addition, the same parameters were modeled for inclined surfaces. The important trends of the solar radiation on tilted surfaces as a function of time and direction are being presented and discussed. The comparison of some results with measured data from other sources shows on good agreement. The effect of tilt angle and orientation on the incident solar radiation fluxes are presented along with optimum surface tilt angles and directions for maximum solar radiation collection in Myitkyina area, Myanmar. The results are presented in this paper to be quite useful for quick estimation of solar radiation for calculations of cooling load and solar collector performance.**

***Index Terms*—solar time, , hourly extra-terrestrial solar radiation, beam radiation and diffuse radiation on horizontal surface, clear day solar radiation on tilted surface**

1) INTRODUCTION

Solar radiation data is a fundamental input for solar energy applications such as photovoltaics, solar thermal systems and passive solar design. The data should be contemporary, reliable and readily available for design, optimization and performance evaluation of solar technologies for any particular geographical location. As solar energy is accepted as a key alternative energy source for the future, solar energy is being critically considered for satisfying significant part of the energy around the World. In this respect, the importance of solar radiation data for design and efficient operation of solar-energy system has been acknowledged.

As solar irradiance passes through a clean and dry atmosphere, it gets attenuated by permanent atmospheric constituents, whose content is nearly invariable. Due to this, solar irradiance at the earth's surface can be expressed as a function of optical thickness only. The attenuation processes are completely defined by the standard compositions of the ideal atmosphere. Two additional attenuation mechanisms take place in a real atmosphere, namely, absorption by water vapour and scattering by aerosol particles also known as atmospheric turbidity. The determination of turbidity is one of the important factors in climate modeling, climate change and in pollution studies. Specific solar radiation information is to estimate atmospheric turbidity, which is a measure of the total amount of aerosol integrated through the vertical atmospheric column.

Solar radiation is the principle energy source for physical, chemical and biological processes on the earth's surface that drives processes as diverse as snow melting, evapotranspiration and crop growth. It also provides the energy for soil heat flux, soil temperature, surface and air temperature, water loss through evaporation and transpiration, plant and animal activity. The amount of solar energy reaching the earth's surface is mainly affected by solar geometry, geomorphologic and climatic factors. Solar geometry and geomorphologic factors control the radiation characters.

2) THEORY OF SOLAR RADIATION

The solar radiation received at different latitudes and in different seasons varies because the axis of rotation of the earth is not perpendicular to the ecliptic plane, but inclined at a fixed angle of 23.45°.The geographic coordinate system is a coordinate system that enables every location on the Earth to be specified via two angles, the longitude (L) and the latitude (ϕ).The reference plane is the equatorial plane that is perpendicular to the rotation axis and intersecting the surface of the Earth along the equator. Circles intersecting earth's surface parallel to the equator determine the latitude. The latitude is defined as the angle between the equatorial plane and a line from the earth's centre and a location on the surface of the earth. By definition the latitude is positive in the northern hemisphere and negative in the southern hemisphere. For the determination of the longitude, one needs a plane perpendicular to the equator including the rotational axis. This plane will create a circle of intersection, or two half circles going from one pole to the other named meridians. The zero longitude is by definition the meridian passing through Greenwich, UK. The longitude of any location is determined by the angle between the zero meridian and the meridian passing through the location, with positive values for locations west of Greenwich and negative values for locations east of Greenwich. Sometimes, theWest/East suffix is used after the value of longitude.

Figure 1 shows schematically the geometry of the sun-earth relationships. The eccentricity of the earth's orbit is such that the distance between the sun and the earth varies by 1.7%. At a distance of one astronomical unit, 1.495×10^{11} m, the mean earth-sun distance, the sun subtends an angle of 32. The radiation emitted by the sun and its spatial relationship to the earth result in a nearly fixed intensity of solar radiation outside of the earth's atmosphere. The solar constant (G_{SC}) is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere.

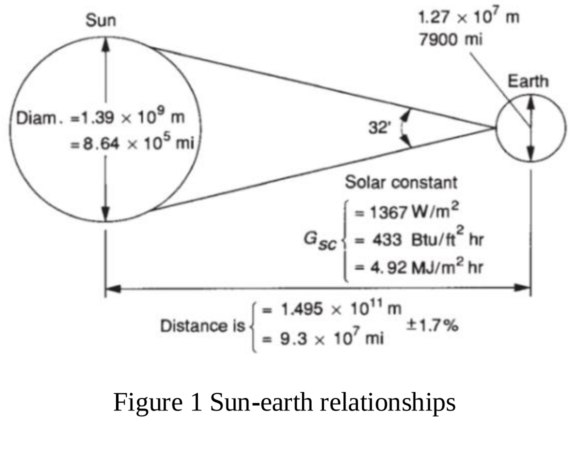

Figure 1 Sun-earth relationships

(i) Basic Earth-Sun Angles

The position of a point P on the earth's surface with respect to the sun's ray is know at any instant if the latitude, l, and hour angle, ω, for the point, and the sun's declination angle, δ, are known. Figure 2 shows these fundamental angles. Point P represents a location on the northern hemisphere.

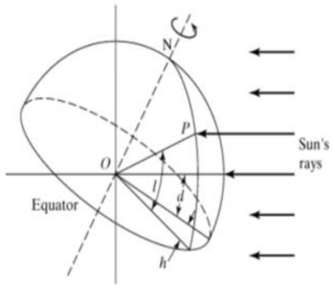

Figure 2 Latitude, hour angle, and sun's declination angle

The latitude, l, is the angular distance of the point P north (or south) of the equator. It is the angle between the line OP and the projection of OP on the equatorial plane. Point O represents the center of the earth. The calculation of the various solar angles can be simplified by the adoption of a consistent sign convention. As part of this sign convention, north latitudes are positive and south latitudes are negative.

The hour angle, ω, is the angle measured in the earth's equatorial plane between the projection of OP and the projection of a line from the center of the sun to the center of the earth. At solar noon, the hour angle is zero. The hour angle expresses the time of day with respect to solar noon. One hour of time is represented by 360÷ 24 = 15 degrees of hour angle. As part of the convention, the hour angle is negative before solar noon and positive after solar noon.

The sun's declination angle, δ, is the angular distance of a sun's rays north (or south) of the equator. It is the angle between a line extending from the center of the sun to the center of the earth and the projection of this line upon the earth's equatorial plane. The declination is positive when the sun's rays are north of the equator and negative when they are south of the equator. At the time of the winter solstice, the sun's rays are 23.5 degrees south of the earth's equator (δ= -23.5°). At the time of the summer solstice, the sun's rays are 23.5 degrees north of the earth's equator (δ= 23.5°). At the equinoxes, the sun's declination is zero.

(β) Slope, the angle between the plane of the surface in question and the horizontal; $0^\circ \le \beta \le 180^\circ, \beta > 90^\circ$ means that the surface has a downward-facing component.)

(γ) Surface azimuth angle, the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive; $-180^\circ \le \gamma \le 180^\circ$.

(θ) Angle, the angle between the beam radiation on a surface and the normal to that surface.

(θz) Zenith angle, the angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface.

(αs) Solar altitude angle, the angle between the horizontal and the line to the sun, that is, the complement of the zenith angle.

(γs) Solar azimuth angle, the angular displacement from south of the projection of beam radiation on the horizontal plane, shown in Figure 2.3. Displacements east of south are negative and west of south are positive.

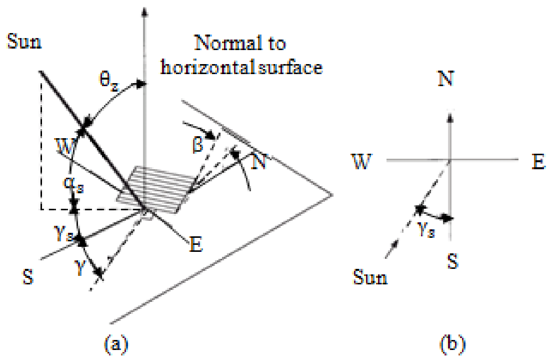

Figure3. (a) Zenith angle, slope, surface azimuth angle, and solar azimuth angle for a tilted surface. (b) Plan view showing solar azimuth angle.

Type of Radiation

There are divided into three types of radiations. They are,

. *Beam Radiation*

The solar radiation received from the sun without having been scattered by the atmosphere.

Diffuse Radiation

The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

Reflected solar radiation

Reflected solar radiation is part of global solar radiation that is reflected by the receiving surface. (mainly the and diffusely by the atmospheric layer between the surface and the point of measurement.)

Solar or short-wave radiation is radiation originating from the sun, in the wavelength range of 0.3 to 3 µm.

Long-wave radiation is originated radiation from sources at temperatures near ordinary ambient temperatures and thus substantially all at wavelengths greater than 3 µm. Long-wave radiation is emitted by the atmosphere, by a collector, or by any other body at ordinary temperatures.

3) DESIGN CALCULATION

1] The Relationship of the Angle of Beam Radiation

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \quad [1]$$

$$\cos\theta = \sin\delta \sin\phi \cos\beta - \sin\delta \cos\phi \sin\beta \cos\gamma + \cos\delta \cos\phi \cos\beta \cos\omega + \cos\delta \sin\phi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \quad [2]$$

$$\cos\theta = \cos\theta_z \cos\beta + \sin\theta_z \sin\beta \cos(\gamma_s - \gamma) \quad [3]$$

$$\cos\omega_s = -\frac{\sin\phi \sin\delta}{\cos\phi \cos\delta} = -\tan\phi \tan\delta \quad [4]$$

$$N = \frac{2}{15} \cos^{-1}(-\tan\phi \tan\delta) \quad [5]$$

2] The Extraterrestrial Radiation on a Horizontal Surface

$$I_o = \frac{12\times3600}{\pi} G_{sc}(1+0.033\cos\frac{360n}{365}) \quad [6]$$
$$[\cos\phi\cos\delta(\sin\omega_2-\sin\omega_1)+\frac{\pi(\omega_2-\omega_1)}{180}\sin\phi\sin\delta]$$

$$I_{on} = G_{sc}\left(1+0.033\cos\frac{360n}{365}\right) \quad [7]$$

$$H_o = \frac{24\times3600}{\pi} G_{sc}(1+0.033\cos\frac{360n}{365})(\cos\phi\cos\delta\sin\omega_s+\frac{\pi\omega_s}{180}\sin\phi\sin\delta) \quad [8]$$

$$G_o = G_{sc}(1+0.033\cos\frac{360n}{365})(\cos\phi\cos\delta\cos\omega+\sin\phi\sin\delta) \quad [9]$$

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega+\sin\phi\sin\delta \quad [10]$$

3]Average Monthly and Clean Sky Solar Radiation

$$a_o^* = 0.4237-0.00821(6-A)^2$$
$$a_1^* = 0.5055+0.00595(6.5-A)^2 \quad [11]$$
$$k^* = 0.2711+0.01858(2.5-A)^2$$

Where, A is the altitude of the absorber in Kilometers. Correction factors area p p l i e dto a_0^*,a_1^*, a n d K^* t o allow for changes in climate types.

The correction factor

$$r_0 = \frac{a_o}{a_o^*},\ r_1 = \frac{a_1}{a_1^*},\ r_k = \frac{k}{k^*} \quad [12]$$

$$\tau_b = a_o + a_1\exp(-k/\cos\theta_z) \quad [13]$$
$$G_{cnb} = G_{on}\tau_b \quad [14]$$
$$G_{cb} = G_{on}\tau_b\cos\theta_z \quad [15]$$
$$I_{cb} = I_{on}\tau_b\cos\theta_z \quad [16]$$
$$I_{cnb} = I_{on}\tau_b \quad [17]$$
$$\eta_d = 0.271-0.294\eta_b \quad [18]$$
$$G_{cd} = G_{on}\tau_d\cos\theta_z \quad [19]$$
$$I_{cd} = I_{on}\tau_d\cos\theta_z \quad [20]$$
$$I_{Tc} = I_{cb}+I_{cd} \quad [21]$$

4]Distribution of Clearly and Cloudy Days and Hours

$$T_d = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \quad [22]$$

$$\frac{\overline{H}}{\overline{H}_0} = a+b\left[\frac{\overline{n}}{T_d}\right] \quad [23]$$

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_o} \quad [24]$$

$$\omega_{si}' = \min\begin{bmatrix}\cos^{-1}(-\tan\varphi\tan\delta)\\ \cos^{-1}(-\tan(\varphi-\beta)\tan\delta)\end{bmatrix} \quad [25]$$

$$\overline{R}_b = \frac{\cos(\varphi-\beta)\cos\delta\sin\omega_{si}'+(\frac{\pi}{180})\omega_{si}'\sin(\varphi-\beta)\sin\delta}{\cos\varphi\cos\delta\sin\omega_s+(\frac{\pi}{180})\omega_s\sin\varphi\sin\delta} \quad [26]$$

For $\omega_s > 81.4^\circ$ and $0.3 \le \overline{K}_T \le 0.8$,

$$\frac{\overline{H}_d}{\overline{H}} = 1.311-3.022\overline{K}_T+3.427\overline{K}_T^2-1.821\overline{K}_T^3 \quad [27]$$

$$\overline{H}_T = \overline{H}(1-\frac{\overline{H}_d}{\overline{H}})\overline{R}_b+\overline{H}_d(\frac{1+\cos\beta}{2})+\overline{H}\rho_g(\frac{1-\cos\beta}{2}) \quad [28]$$

$$K_T = \frac{I_{TC}}{I_O} \quad [29]$$

$$\frac{I_d}{I_{Tc}} = 0.9511-0.1604k_T+4.388k_T^2-16.638k_T^3+12.336k_T^4 \quad [30]$$

$$I_b = I_{Tc}-I_d \quad [31]$$

For $\beta = 30^\circ$ and $\rho_g = 0.6$,

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\cos\omega+\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\cos\omega+\sin\phi\sin\delta} \quad [32]$$

$$I_T = I_bR_b+I_d(\frac{1+\cos\beta}{2})+I_{Tc}\rho_g(\frac{1-\cos\beta}{2}) \quad [33]$$

Nomenclature

G_{cb}	The clear sky horizontal beam radiation	W/m^2
G_{cd}	The clear sky horizontal diffuse radiation	W/m^2
G_{cnb}	The clear sky beam normal radiation	W/m^2
G_o	Extraterrestrial radiation	W/m^2
G_{on}	Normal extraterrestrial radiation	W/m^2
G_{SC}	Solar constant	W/m^2
$\overline{H}$	Monthly average total insolation on a terrestrial horizontal surface	MJ/m^2
$\overline{H}_d$	The diffuse radiation on a horizontal surface	MJ/m^2
$\overline{H}_O$	Monthly average total insolation on an Extraterrestrial horizontal surface	MJ/m^2
$\overline{H}_T$	The average monthly total solar irradiation on on inclined surface	MJ/m^2
I_b	Hourly direct beam solar radiation on Horizontal surface	MJ/m^2
I_c	Total clear sky radiation	MJ/m^2
I_{cb}	The clear sky beam horizontal radiation for hourly	MJ/m^2
I_{cd}	The clear sky diffuse horizontal radiation for hourly	MJ/m^2
I_{cnb}	The clear sky beam normal radiation for hourly	MJ/m^2
I_d	Hourly diffuse solar radiation on horizontal Surface	MJ/m^2
I_o	Hourly extraterrestrial solar radiation on horizontal surface	MJ/m^2
I_{on}	Normal extraterrestrial radiation for hourly	MJ/m^2
I_T	The total irradiation on tilted surface	MJ/m^2
I_{Tc}	Total clear sky radiation	MJ/m^2
$\overline{K}_T$	The daily clearness index	-
n	The day of the year	-
R_b	The ratio of the daily beam radiation on tilted surface	-
T_d	Monthly average of longest day length	-
τ_b	The atmospheric transmittance for beam radiation	-
τ_d	The atmospheric transmittance for diffuse radiation	-

Greek Letter

B	The surface slope	degrees
θ_z	Zenith angle	degrees
ω	Hour angle	-
ω_s	The solar angle	degrees
ω'_{si}	The sunset hourly angle	degrees
ϕ	Latitude	degrees
ρ_g	The ground reflectance	-

4) Design Results

1)Estimation of the Solar Radiation for Myitkyina

Latitude (forMyitkyina) = ϕ = 25°22'
For May 13, 12:00 AM to 1:00 PM at Myitkyina
n = 121+i=121+13=134

Table 1. Relationship of Hour-Pair of Day and Hour Angle for Myitkyina

Hours	ω_1(Degree)	ω_2(Degree)	ω(Degree)
6:00-7:00AM	-90	-75	-82.5
7:00-8:00AM	-75	-60	-67.5
8:00-9:00AM	-60	-45	-52.5
9:00-10:00AM	-45	-30	-37.5
10:00-11:00AM	-30	-15	-22.5
11:00-12:00AM	-15	0	-7.5
12:00-1:00PM	0	15	7.5
1:00-2:00PM	15	30	22.5
2:00-3:00PM	30	45	37.5
3:00-4:00PM	45	60	52.5
4:00-5:00PM	60	75	67.5
5:00-6:00PM	75	90	82.5

Table 2. Zenith Angle and Transmittance with Hour-Pair of Day for May 13, Myitkyina

Hours	$\cos\theta_z$	τ_b	τ_d
6:00-7:00AM	0.24749	0.29179	0.18521
7:00-8:00AM	0.46376	0.45636	0.13683
8:00-9:00AM	0.65767	0.54447	0.11093
9:00-10:00AM	0.81599	0.59320	0.09659
10:00-11:00AM	0.92794	0.61977	0.08879
11:00-12:00AM	0.98589	0.63162	0.08530
12:00-1:00PM	0.98589	0.63162	0.08530
1:00-2:00PM	0.92794	0.61977	0.08879
2:00-3:00PM	0.81599	0.59320	0.09659
3:00-4:00PM	0.65767	0.54447	0.11093
4:00-5:00PM	0.46376	0.45636	0.13683
5:00-6:00PM	0.24749	0.29179	0.18521

Table 3. The Solar Radiation with Hour-Pairs for May 13, Myitkyina

Hours	G_{cnb} (W/m²)	G_{cb} (W/m²)	G_{cd} (W/m²)	$G_{Tc}=G_{cb}+G_{cd}$ (W/m²)
6:00-7:00AM	390.04118	96.53129	61.27201	157.80330
7:00-8:00AM	610.02499	282.90519	84.82320	367.72839
8:00-9:00AM	727.80329	478.65439	97.52077	576.17516
9:00-10:00AM	792.94159	647.03241	105.35546	752.38787
10:00-11:00AM	828.45821	768.75951	110.13466	878.89417
11:00-12:00AM	844.29833	832.38528	112.41326	944.79854
12:00-1:00PM	844.29833	832.38528	112.41326	944.79854
1:00-2:00PM	828.45821	768.75951	110.13466	878.89417
2:00-3:00PM	792.94159	647.03241	105.35546	752.38787
3:00-4:00PM	727.80329	478.65439	97.52077	576.17516
4:00-5:00PM	610.02499	282.90519	84.82320	367.72839
5:00-6:00PM	390.04118	96.53129	61.27201	157.80330

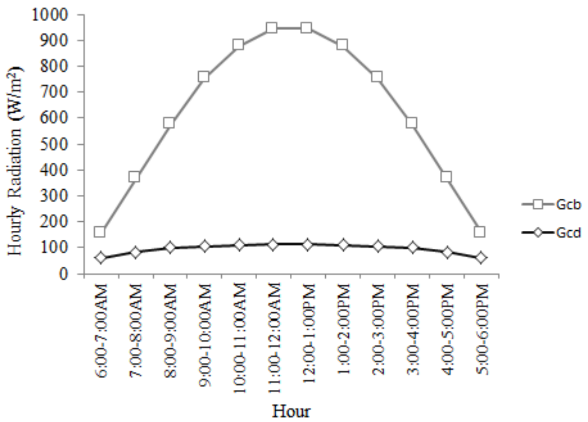

Figure 4. The Solar Radiation with Hour- Pairs for May 13, Myitkyina

Table 4. The Hourly Radiation with Hour-Pairs for May 13, Myitkyina

Hours	I_{cnb}(MJ/m²hr)	I_{cb} (MJ/m²)	I_{cd} (MJ/m²)	$I_{Tc}=I_{cb}+I_{cd}$(MJ/m²)
6:00-7:00AM	1.22434	0.30301	0.19233	0.49534
7:00-8:00AM	1.91486	0.88804	0.26626	1.15430
8:00-9:00AM	2.28457	1.50249	0.30612	1.80861
9:00-10:00AM	2.48904	2.03103	0.33071	2.36174
10:00-11:00AM	2.60052	2.41313	0.34571	2.75884
11:00-12:00AM	2.65025	2.61285	0.35286	2.96571
12:00-1:00PM	2.65025	2.61285	0.35286	2.96571
1:00-2:00PM	2.60052	2.41313	0.34571	2.75884
2:00-3:00PM	2.48904	2.03103	0.33071	2.36174
3:00-4:00PM	2.28457	1.50249	0.30612	1.80861
4:00-5:00PM	1.91486	0.88804	0.26626	1.15430
5:00-6:00PM	1.22434	0.30301	0.19233	0.49534

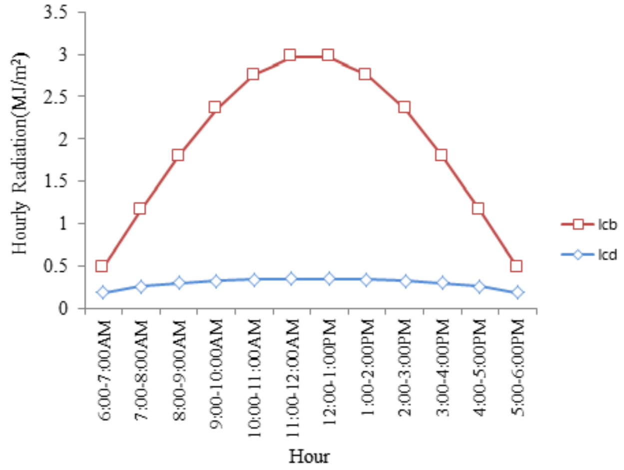

Figure 5. The Hourly Radiation with Hour- Pairs for May 13, Myitkyina

Table 5. Total Monthly Average Solar Radiation for Myitkyina

Month	ω_s (degree)	$\bar{H}_o$ (MJ/m²)	T_d	$\bar{H}$ (MJ/m²)
January	79.25445	23.65081	10.56726	14.90152
February	83.28315	27.82192	11.10442	17.24687
March	88.48202	32.88869	11.79760	20.00148
April	94.29932	37.36801	12.57324	22.29187
May	99.09257	39.75193	13.21232	23.37453
June	101.68466	40.50988	13.55795	23.64670
July	100.78874	40.11936	13.43849	23.47714
August	96.79835	38.39933	12.90645	22.73208
September	91.23419	34.80378	12.16456	20.96861
October	85.61061	29.85478	11.41475	18.34479
November	80.71381	24.99652	10.76184	15.65447
December	78.30151	22.62722	10.44020	14.31444

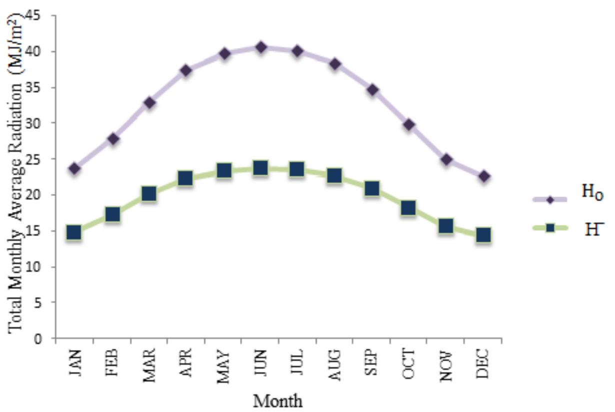

Figure 6. Total Monthly Average Solar Radiation for Myitkyina

Table 6. Total Monthly Average Solar Radiation at Slope Surface forMay 13,Myitkyina

Symbol	β=0°	β=30°	β=45°	β=60°	β=75°
$\bar{R}_b$	0.98625	0.83554	0.67112	0.46096	0.21939
$\bar{H}_d$ (12:00AMto1:00PM)	23.16521	21.42093	19.57034	17.2212	14.5339

Table 7. Total Monthly Average Solar Radiation for Tilt Angle 30° at Myitkyina

Month	$\bar{K}_T$	ω_{si} (degree)	$\bar{R}_b$	$\bar{H}_d$ (MJ/m²)	$\bar{H}_T$ (MJ/m²)
January	0.63006	91.89697	1.60013	4.64821	21.44222
February	0.61990	91.18988	1.38216	5.53264	22.16169
March	0.60816	90.26948	1.15743	6.62132	22.60226
April	0.59655	89.23738	0.96254	7.60619	22.27752
May	0.58801	88.39227	0.83554	8.15117	21.42094
June	0.58373	87.93938	0.77689	8.33519	20.78102
July	0.58518	88.09549	0.79644	8.24539	20.92509
August	0.59199	88.79575	0.89307	7.84742	21.68072
September	0.60248	89.78089	1.05884	7.04569	22.29910
October	0.61447	90.77856	1.27464	5.97178	22.20309
November	0.62627	91.64171	1.51603	4.93482	21.58962
December	0.63262	92.06302	1.65857	4.43312	21.19624

5) CONCLUSION

This paper defines the direct, diffuse and reflected solar radiation on inclined surface as known the meaning of clearness index to calculate the hourly and montly solar radiatuion on surface of various orientations and tilt angles. The knowledge of the solar radiation received by an inclined surface is necessary for most applications and studies involving solar systems. The method to calculate the radiation on aninclined surface at an hourly or monthly basis is necessary.

In this paper, the prediction of hourly terrestrial solar radiation on a horizontal surface: direct beam and diffuse from measured daily averaged solar radiation on the same surface has been conducted. Table (4) and (7) are quite useful for quick estimation of solar radiation for calculations of cooling load and solar collector performance. The monthly average total radiation is 21.42094 MJ/m^{2}and the total hourly average radiation for

May, Myitkyina is 3.53970 MJ/m^2. So, the paper can easily support to estimate the solar radiation for the choosen location that the solar radiation with the explained equations can be employed any location.

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