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Simulation of Solar Radiation System

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Abstract: In this research work, a mathematical model for simulation of the solar radiation system has been developed by using a system dynamics methodology. Bangladesh is used here for model validation. The simulated results obtained from this model have compared with the experimental results and found reasonably a good agreement. Therefore the performance of the model is to be expected as satisfactory.

Key words: Solar radiation, system dynamics methodology, beam radiation, diffuse radiation

INTRODUCTION

The sun is an effective black body whose outer surface has a temperature of 6000^0 K[1] and is emitting an incredible amount of solar radiation. The earth intercepts only two-billionth of this radiation and saves all life on the planet from freezing to death[2]. Besides, the emitting radiation can be used as an alternative source of energy for mankind by using modern technology. Since in this century, we have virtually identified the whole successful functioning economic system with a steady increasing consumption of energy. When solar radiation/energy is used to generate electrical/mechanical energy for any specific place, it must be needed to forecast solar energy which will convert to electrical energy to recover the demand. Hence, the amount of solar energy for that place must be known.

Technology for measurements of solar radiation is costly and has instrumental hazard. So an alternative method for estimation of solar radiation is required. The system dynamics methodology is used here to simulate the solar radiation system, which is comparatively a new innovation, in comparison with the known methods of operation research. This method has been extensively used by Forrester[3,4] for industrial dynamics, Meadows[5] for commodity production cycle, Wadhawa[6] for regional planning, Syeed[7] for rural development and Alam[8,9] for rural energy system planning. In this paper a mathematical model is developed to simulate the availability of solar radiation in Bangladesh using system dynamics methodology.

Definitions of Solar Radiation Used in Mathematical Model: For understanding the mathematical model, it is required to define some parameters of the solar system. These are as follows.

Irradiance: The rate at which radiant energy is incident on a unit surface area. The symbol I is used with appropriate subscripts for the beam and diffuse radiation.

Beam Radiation (I_b): The solar radiation received from the sun without being scattered by the atmosphere is called beam radiation. It is direct solar radiation.

Diffuse Radiation (I_d): Solar radiation whose direction has been changed through scattering by the atmosphere is known diffuse radiation.

Global Radiation or Terrestrial/Total Solar Radiation (I_h): The sum of beam and diffuse radiation in hourly on a surface is called global or total solar radiation, i.e. $I_h = I_b + I_d$.

Solar Time: Solar time is the time based on the apparent angular motion of the sun across the sky. Solar noon is the time where the sun crosses the meridian of the observer. There is a difference between clock time and solar time because the solar time varies at any instant depending on the east-west displacement. Solar time is related to standard time by Duffie and Beckman[10]:

$$\text{Solar time (t)} = \text{standard time} - 4(L_{st}-L_{loc}) + E \qquad (1)$$

Where:

L_{st} = Standard meridian for the local time zone,
L_{loc} = Longitude of the location in equation in degrees west,
E = 229.2x(0.000075+0.001868B-0.03277SinB-0.014615CosB-0.04089Sin28
B = (n-1)360/365,
n = Day of the year numbered from 1st January. $1 \le n \le 365$

Solar Geometry/Earth Angle: Earth angle and its components (Fig. 1) are described in the following ways.

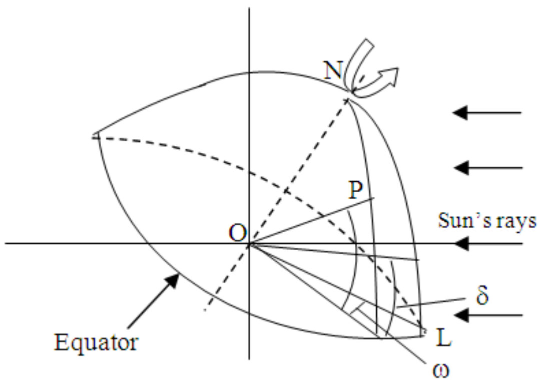

Fig. 1: Basic Sun Earth Angle

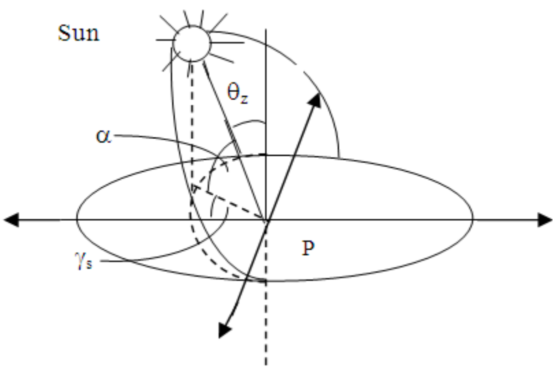

Fig. 2: Angles to Describe the Position of the Sun the Sky

(i) Latitude (ϕ): The latitude is the angular distance of the point on the earth measured north or south of the equator is latitude $-90° \le \phi \le 90°$.

(ii) Longitude: Angular distance measured east and west of the prime meridian is longitude.

(iii) Declination Angle (δ): Angle made by the line joining the center of the sun and the earth with its projection on the equatorial plane, north positive is declination angle. It is zero at the autumnal and vernal equinoxes, is 23.45° at the summer solstice on June 21 and -23.45^0 at the winter solstice on December 21 in the northern hemisphere. The range of declination angle is given by $-23.45^0 \le \delta \le 23.45°$

According to Cooper[11], at the intervening periods of the year δ can be approximated by a sinusoidal variation

$$\delta = 23.45 \mathrm{Sin}\left[360(284+n)/365\right] \qquad (2)$$

(iv) Hour Angle (ω): Angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour is hour angle. It expresses the time of the day with respect to the solar noon. It can be expressed by $\omega = 15(t-12)$.

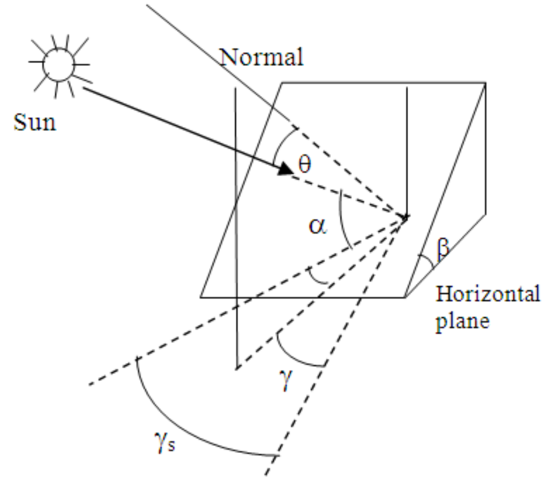

Fig. 3: Angle of Incident on a Plane

Solar Constant (I_{sc}): The solar beingnstant denoted by I_{sc} is the energy from the sun per unit time received on a unit surface area perpendicular to the direction of propagation of radiation at the earth mean distance from the sun outside the atmosphere. The I_{sc}value according to NASA/ASTM is 1353 Watts per square meter[10].

Extraterrestrial Solar Radiation (E_0): The radiation that would be received in the absence of the atmosphere in addition to the solar constant is called extraterrestrial solar radiation.

Angles to Describe the Position of the Sun in the Sky: Figure 2 represents the angles to describe the position of the sun in the sky. Angles are described in the following ways:

(i) Solar Altitude Angle (α_s): It is the angle between the projection of the sun's rays on the horizontal plane the sun's resurrection of the sun's rays.

(ii) Zenith Angle (θ_Z): It is the angle between the sky's rays and a line perpendicular to the plane through the point. Here, $\theta_Z + \alpha_s = \pi/2$.

(iii) Solar Azimuth Angle (γ_s): It is the angular displacement from the south of the projection of beam radiation on the horizontal plane.

Angle Incidence on a Plane: Angles describing the position of a surface in relation to the sun's rays and the earth are defined in this section and described by the Fig. 3.

a. Slope of the surface β is the angle between the plane of the surface and the horizontal.
b. Surface azimuth angle γ is the angle made in the horizontal plane between the line due south and formalojection of the formal to the surface of the horizontal plane.

c. Angle of incidence of radiation on a surface θ is the angle between the beam radiation on a surface and the normal to that surface.

Attenuation of Solar Radiation by Atmosphere: Solar radiation at normal incidence received at the surface of the earth is subject to vary due to changes in the extraterrestrial radiation and to two additional more significant phenomena. These are as follows:

* Atmospheric scattering by air molecules, water vapor and dust and
* Atmospheric absorption by O_3, H_2O and CO_2.

Atmospheric Scattering by Air Molecules, Water-vapor and Dust: Air molecules are very small compared to the wavelengths of radiation in a solar energy spectrum. Water vapor scattering depends on the amount of perceptible water and a scattering coefficient which also be developed for water vapor that varies with λ^{-2}, where λ is the wavelength of the radiation. Dust scatters from particles those are much larger than air molecules and which vary in size and concentration, location, height and time, those are more difficult to assess.

The total effective scattering on the beam radiation is the product of the three exponential terms, each is a function of wavelength (for air mass λ^{-4} and dust $\lambda^{-0.75}$) and of the amount of molecules, dust and perceptible moisture through which the radiation is transmitted.

Atmospheric Absorption by O_3, H_2O and CO_2: Absorption of radiation in the atmosphere in the solar energy spectrum is due largely to ozone in ultraviolet and water vapor in bands of the infrared. When the wavelength is below 0.29 micrometers, the radiation is almost completely absorbed by the atmosphere. When wavelength varies from 0.29 to 0.35 micrometers, ozone absorption is decreased provided that there is no absorption. There is also a weak ozone absorption band near λ = 0. 64 micrometers.

Formulation of Mathematical Model: Figure 4 shows the flow chart of the solar radiation system. Using this flow diagram, mathematical formulations have been presented here as a model for the solar radiation system.

Variation of Extraterrestrial Radiation: The variation of extraterrestrial solar radiation with respect to time of the year is shown in Fig. 5. Two sources of variation are as follows:

Variation in Radiation Emitted by the Sun: There are conflicting reports in the literature on periodic variations of intrinsic solar radiation. It has been suggested that there is a small variation with different periodicities and variation related to sunspot activities. Others consider the measurement to be included or not indicative of regular variability. Using Nimbus and Mariner satellites over the period of several months, it is shown that the variation is within limits of 0.2% over a time when sunspot activity is very low.

Variation of Earth-Sun Distance: Extraterrestrial radiation depends on earth-sun distance and varies 3% throughout the year. The dependence of extraterrestrial radiation on time of the year, developed by Duffie and Beckman[10], is indicated by the following Eq. 3:

$$E_0 = I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \quad (3)$$

Where:

E_0 = Extraterrestrial radiation measured on in the plane of the nth day of the year

I_{sc} = Solar constant

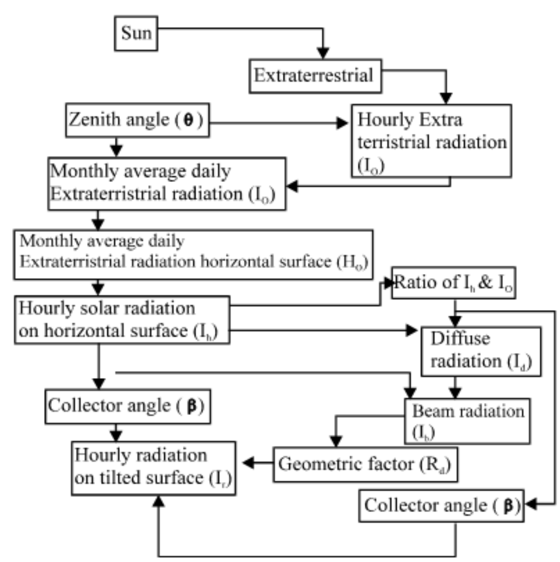

Fig. 4: Flow Diagram of Solar Radiation System

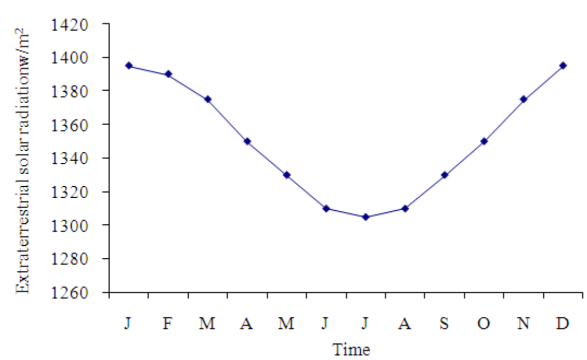

Fig. 5: Variation of Extraterrestrial Radiation with Time (Months)

Extraterrestrial Radiation on Horizontal Surface: The solar radiation outside the atmosphere, that is, the hourly extraterrestrial radiation incident on horizontal plane can be written by the following way[10]:

$$I_0 = I_{sc}\left(1 + 0.033\,\text{Cos}\frac{360n}{365}\right)\text{Cos}\theta_z \tag{4}$$

where, θ_z = Zenith angle of the sun.

For a horizontal surface at any time between sunrise and sunset, according to Ref[17], the cosine of zenith angle can be expressed by:

$$\begin{aligned}\text{Cos}\theta_z &= \text{Sin}\delta\text{Sin}\phi\text{Cos}\beta - \text{Sin}\delta\text{Cos}\phi\text{Sin}\beta\text{Cos}\gamma\\ &+\text{Cos}\gamma\text{Cos}\phi\text{Cos}\beta\text{Cos}\omega\\ &+\text{Cos}\gamma\text{Sin}\varphi\text{Sin}\beta\text{Cos}\gamma\text{Cos}\omega + \text{Cos}\text{Sin}\beta\text{Sin}\gamma\text{Sin}\omega\end{aligned} \tag{5}$$

Considering β = 0 and γ = 0, Eq. (5) can be rewritten as:

$$\text{Cos}\theta_Z = \text{Cos}\varphi\text{Cos}\delta\text{Cos}\omega + \text{Sin}\delta\text{Sin}\varphi \tag{6}$$

Combining Eq. (4) and (6), we have

$$I_0 = I_{sc}\left(1 + 0.033\,\text{Cos}\frac{360n}{365}\right)\left(\text{Cos}\varphi\text{Cos}\delta\text{Cos}\omega + \text{Sin}\delta\text{Sin}\varphi\right) \tag{7}$$

The extraterrestrial daily solar radiation on a horizontal surface can be obtained by integrating Eq. (7) over the period from sunrise to sunset. Using $\omega = \omega_s$, we have:

$$\begin{aligned}H_o &= \frac{24}{\pi}I_{sc}\left(1 + 0.033\,\text{Cos}\frac{360n}{365}\right)\\ &\left(\text{Cos}\varphi\text{Cos}\delta\text{Cos}\omega_s + \text{Sin}\delta\text{Sin}\varphi\right)\end{aligned} \tag{8}$$

Where:

H_0 = Daily extraterrestrial solar radiation on a horizontal surface,
ω_s = Sunset hour angle in degrees.

Let us consider, $\text{Cos}\theta_z = 0$ and $\omega = \omega_s$. Using Eq. (6), we have:

$$\text{Cos}\varphi\text{Cos}\delta\text{Cos}\omega_s + \text{Sin}\delta\text{Sin}\varphi = 0$$

Therefore, $\omega_s = \text{Cos}^{-1}\left(-\tan\delta\tan\varphi\right)$ (9)

Estimation of Average Solar Radiation: Radiation data are the best source of information for estimation average incident radiation. Lacking of these data from a nearby location of similar climate like Bangladesh, it is possible to use the empirical relationship to estimate radiation from hours of sunshine or cloudiness.

The original angstrom-type regression Equation related monthly average daily radiation to clear day radiation at any location is as follows:

$$\frac{H_g}{H_c} = a + b\frac{S}{S_0} \tag{10}$$

Where:

$$S_0 = 2\left[\frac{\omega_s}{15}\right]$$

H_g = Monthly average daily global radiation,
H_c = Average clean sky daily radiation on a horizontal surface,
S = Mean monthly average daily sunshine hour,
S_0 = Maximum possible sunshine hour and
a, b = Empirical constant.

The monthly average of maximum possible daily hours of bright sunshine can be computed from the above relation. In Eq. (10), there is instrumental problem and uncertainties in the definition of a clear day. For this reason, Page[12] and others modified the method based on extraterrestrial radiation on a horizontal surface (obtained from Eq. (7), monthly daily average extraterrestrial radiation), rather than on clear day radiation:

$$\frac{H_g}{H_0} = a + b\frac{S}{S_0} \tag{11}$$

Hussain[14] has correlated this Eq. (11) for weather data in Bangladesh as well as Haider[13] and Hussain[14] reported the following angstrom-type regression Equation for Bangladesh:

$$\frac{H_g}{H_0} = 0.18 + 0.39\frac{S}{S_0} \tag{12}$$

Prediction of Hourly Radiation from Daily Radiation Data: When hour-by-hour performance calculations are to be done, it may be necessary to start with daily data and estimated hourly values of the daily numbers (hourly values and daily numbers). In an investigation by Collres- Pereira and Rabl[15] developed an analytical expression for the ratio of hourly to daily global radiation:

$$\frac{I_h}{H_g} = \frac{\frac{\pi}{24}(a + b\text{Cos}\omega)(\text{Cos}\omega - \text{Cos}\omega_s)}{\text{Sin}\omega_s - \frac{(2\pi\omega_s\text{Cos}\omega_s)}{360}} \tag{13}$$

The Coefficients a and b are defined by:

$a = 0.409 + 0.5016\text{Sin}(\omega_s - 60)$,
$b = 0.6609 - 0.4767\text{Sin}(\omega_s - 60)$,

Where, ω = hour angle in degrees and ω_s = sunset hour angle.

Terrestrial Solar Radiation for Beam and Diffuse Radiation: The correlation between hourly diffuse and global radiation developed by Muneer *et al.*[16] can be expressed by the following ways:

Error! Bookmark not defined. when $K_T < 0.175$

$$\frac{I_d}{I_h} = 0.9698 + 0.4353K_T - 3.4499K_T^2 + 2.1888K_T^3$$

When $0.175 < K_T < 0.775$

$$\frac{I_d}{I_h} = 0.26 \qquad \text{When} \quad 0.775 < K_T$$

$$\text{where } K_T = \frac{\text{Total solar radiation on a horizontal surface}}{\text{Extraterrestrial solar radiation on a that surface}}$$

$$= \frac{I_h}{I_0} = \text{Clearness index.}$$

We have, Beam radiation = Hourly radiation – Diffuse radiation

Terrestrial Solar Radiation for Tilted Surface: The hourly solar radiation on a tilted surface is given by considering the radiation to be made up of three components i.e. beam radiation I_b', diffuse solar radiation I_d' and solar radiation diffusely reflected from the ground I_{dg} [18]:

i. e. $I_T = I_b' + I_d' + I_{dg}$

Here:

$$I_b' = I_b + R_b, \; I_d' = I_d\left(\frac{1+\text{Cos}\beta}{2}\right)$$

And:

$$I_{dg} = \left[\frac{(I_b + I_d)\rho(1-\text{Cos}\beta)}{2}\right]$$

$$\text{i.e., } I_T = I_bR_b + I_d\frac{(1+\text{Cos}\beta)}{2} + (I_b + I_d)\rho\frac{(1-\text{Cos}\beta)}{2}$$

$$\text{where } R_b = \frac{\text{Beam radiation on tilted surface}}{\text{Beam radiation on a horizontal surface}}$$

$$= \frac{\text{Sin}\delta\text{Sin}(\varphi-\beta) + \text{Cos}\delta\text{Cos}\omega\text{Cos}(\varphi-\beta)}{\text{Sin}\delta\text{Sin}\varphi + \text{Cos}\delta\text{Cos}\omega\text{Cos}\varphi}$$

=Geometric ratio or geometric factor

β= Angle between horizontal surface and collector surface,

ρ= Diffuse ground reflectance,

ρ= 0.2[16],

ρ= 0. 7 of fresh snow covered countries[16].

Liu and Jordan[17] used the relation for ρ=0. 2 (1-c) +0.7c,

Where, the c=fractional time of a month when the ground in covered in more than one inch of snow.

RESULTS AND DISCUSSION

In this section, the model was simulated during 7 A.M. to 5 P.M. using system dynamics methodology. The diffused solar radiation of the typical days 19th August, hourly radiation on 4th May, diffused radiation on 19th January from horizontal surface are presented and compared with the measurement results[19]. The simulated and measurement results are shown in Fig. 6-8.

Validation of Simulated Results: The model results of hourly and diffused radiation on a horizontal surface for the same above mentioned typical days are compared with the respective experimental data[19] and are shown in Fig. 6-8.

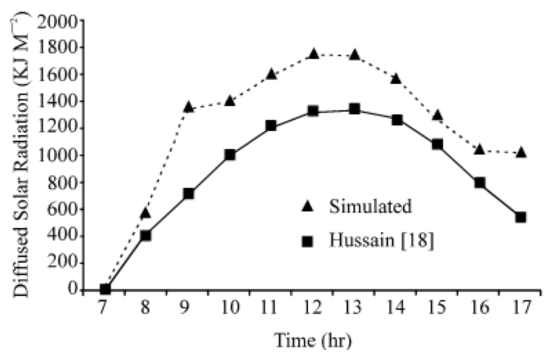

Fig. 6: Simulated and Hussain[18] Diffused Solar Radiation on Aug. 19 for Horizontal Surface where 'a'=0. 18 and 'b'=0. 39

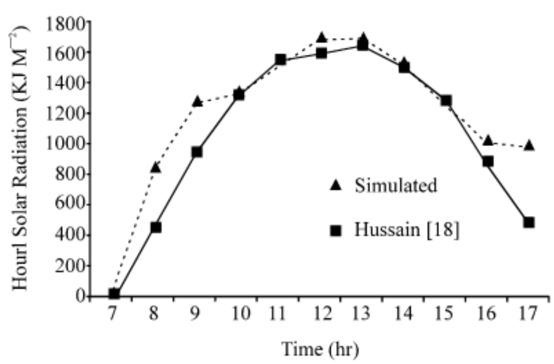

Fig. 7: Simulated and Hussain[18] Hourly Solar Radiation on May 4 for Horizontal Surface where 'a'=0. 175 and 'b'=0. 375

Table 1: Sensitivity Analysis for Empirical Constant 'a'=0. 14 'b'=0. 34

Time	January				Change per point(%)		May				Change per point(%)		August				Change per point(%)	
	Simulated		Hussain[18]				Simulated		Hussain[18]				Simulated		Hussain[18]			
	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h
7	1.54	7.54	1.23	1	20	86	1.54	7.54	1	1	35	86	1.54	7.54	1	1	35	86
8	488528		277	311	76	69	488	528	410	437	19	20	488	528	415	428	17	23
9	897933		621	642	44	45	897	933	768	937	16	-.42	897	933	729	837	29	11
10	910966		757	924	20	4	910	966	1068	1312	-8.8	-24	910	966	1000	1257	-9	-23
11	1033	1111	885	1138	16	-2	1033	1111	1267	1643	-17	-32	1033	1111	1216	1539	-15	-27
12	1129	1224	968	1244	16	-1	1129	1224	1326	1842	-14	-33	1129	1224	1321	1730	-14	-29
13	1126	1227	966	1213	16	1	1126	1227	1391	1851	-19	-33	1126	1227	1337	1736	-15	-29
14	1011	1109	884	1013	14	9	1011	1109	1246	1656	-18	-33	1011	1109	1270	1589	-20	-30
15	835919		715	866	17	6	835	919	1103	1375	-24	-33	835	919	1081	1321	-18	-30
16	682747		450	577	51	29	682	747	767	875	-11	-14	682	747	797	1000	-14	-25
17	421721		215	561	95	28	421	721	415	484	1.4	48	421	721	535	691	-21	4

Table 2: Sensitivity Analysis for Empirical Constant 'a'=0. 18 'b'=0. 39

Time	January				Change per point(%)		May				Change per point(%)		August				Change per point(%)	
	Simulated		Hussain[18]				Simulated		Hussain[18]				Simulated		Hussain[18]			
	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h
7	1.69	8.2	1.23	1	27	87	1.69	8.2	1	1	40	87	1.69	8.2	1	1	40	86
8	570590277			311	51	47	570	590	410	437	28	25	570	590	415	428	27	27
9	1356	1394	621	642	54	53	1356	1394	768	937	43	32	1356	1394	729	837	46	40
10	1392	1454	577	924	45	36	1392	1454	1064	1312	23	9	1392	1454	1000	1257	28	13
11	1589	1674	885	1138	44	32	1589	1674	1267	1643	20	2	1589	1674	1216	1539	23	8
12	1741	1843	968	1244	44	32	1741	1843	1326	1842	23	.05	1741	1843	1321	1730	24	6
13	1736	1846	966	1213	44	34	1736	1846	1391	1851	19	-2	1736	1746	1337	1736	22	5
14	1557	1606	884	1013	43	36	1557	1606	1246	1656	19	-3	1557	1606	1270	1589	18	1
15	1282	1374	715	866	44	36	1282	1374	1103	1375	13	-.07	1282	1374	1081	1321	15	4
16	1039	1109	450	577	56	47	1039	1109	767	875	26	21	1039	1109	797	1000	23	9
17	1017	1065	215	561	78	47	1017	1065	415	484	59	54	1017	1065	535	691	47	35

Table 3: Sensitivity Analysis for Empirical Constant 'a'=0. 15 'b'=0. 32

Time	January				Change per point(%)		May				Change per point(%)		August				Change per point(%)	
	Simulated		Hussain[18]				Simulated		Hussain[18]				Simulated		Hussain[18]			
	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h
7	1.54	7.74	1.23	1	20	85	1.54	7.74	1	1			1.54	7.74	1	1	40	87
8	426	440	277	311	35	29	426	440	410	437	4	.68	426	440	415	428	2	3
9	855	890	621	642	27	37	855	890	768	937	1	-5	855	890	729	837	14	6
10	865	921	757	924	12	-.3	865	921	1064	1312	-23	-42	865	921	1000	1257	-15	-36
11	981	1059	885	1138	.09	0	981	1059	1267	1653	-29	-55	981	1053	1216	1539	-23	-45
12	1073	1166	968	1244	9	-6	1073	1166	1326	1842	-23	-63	9073	1166	1321	1730	-23	-48
13	1069	1170	966	1213	9	-3	1069	1170	1391	1851	-30	-58	9069	1170	1337	1736	-28	-48
14	960	1057	884	1013	8	4	960	1057	1246	1656	-30	-57	960	1057	1270	1589	-32	-50
15	793	899	715	866	10	1	793	877	1103	1374	-39	-56	793	877	1081	1321	-36	-50
16	649	713	450	577	30	19	649	713	767	875	-18	-22	649	713	767	1000	-22	-40
17	649	693	215	561	66	19	649	693	415	484	36	30	649	693	535	691	17	.28

Table 4: Sensitivity Analysis for Empirical Constant 'a'=0. 185 'b'=0. 395

Time	January				Change per point(%)		May				Change per point(%)		August				Change per point(%)	
	Simulated		Hussain[18]				Simulated		Hussain[18]				Simulated		Hussain[18]			
	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h
7	1.7	8.29	1.23	1	27	87	1.7	8.29	1	1	41	88	1.7	8.29	1	1	41	88
8	698	718	277	311	60	57	698	718	410	437	41	39	698	718	415	428	40	40
9	1416	1455	621	642	56	55	1416	1455	768	937	45	35	1416	1455	729	837	48	42
10	1456	1518	757	924	48	39	1456	1518	1064	1312	27	13	1456	1518	1000	1257	31	17
11	1662	1748	885	1138	46	34	1662	1748	1276	1643	23	6	1662	1748	1216	1539	27	12
12	1821	1925	968	1244	47	35	1821	1925	1326	1842	27	4	1821	1925	1321	1730	27	10
13	1816	1928	966	1213	47	37	1816	1928	1391	1851	23	4	1816	1928	1337	1736	26	10
14	1629	1735	884	1013	46	41	1629	1735	1246	1656	23	4	1629	1735	1270	1589	22	8
15	1341	1433	715	866	47	39	1341	1433	1103	1375	18	4	1341	1433	1081	1321	19	8
16	1046	1157	450	577	48	50	1046	1157	767	875	29	24	1046	1157	797	1000	27	13
17	1061	1109	215	561	79	49	1061	1109	415	484	60	56	1061	1109	535	691	49	37

Table 5: Sensitivity Analysis for Empirical Constant ‘a’=0.175 ‘b’=0.375

Time	January				Change per point(%)		May				Change per point(%)		August				Change per point(%)	
	Simulated		Hussain[18]				Simulated		Hussain[18]				Simulated		Hussain[18]			
	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h
7	14.66	8.06	1.23	1	26	87	1.66	8.06	1	1	40	87	1.66	8.06	1	1	40	87
8	803	835	277	311	65	62	803	835	410	437	49	48	803	835	415	428	48	48
9	1242	1279	621	642	50	49	1242	1279	768	937	38	27	1242	1279	729	837	41	34
10	1272	1332	577	924	14	31	1272	1332	1064	1312	16	1	1272	1332	1000	1257	21	5
11	1450	1533	885	1138	39	26	1450	1533	1276	1543	12	-.6	1450	1533	1216	1539	16	-.4
12	1588	1689	968	1244	39	26	1588	1689	1326	1600	16	5.6	1588	1689	1321	1737	16	-2
13	1583	1692	966	1213	39	28	1583	1692	1391	1650	12	2.4	1583	1692	1337	1736	15	-2
14	1420	1525	884	1013	38	33	1420	1525	1246	1500	12	1.6	1420	1525	1270	1589	10	-4
15	1170	1260	715	866	39	31	1170	1260	1103	1275	5	-1.7	1170	1260	1081	1321	7	-4
16	950	1019	450	577	52	43	950	1019	767	875	19	14	950	1019	797	1000	16	1
17	934	980	215	561	77	42	934	980	415	484	55	50	934	980	535	691	42	29

Table 6: Sensitivity Analysis for Empirical Constant ‘a’=0. 14 ‘b’=0. 345

Time	January				Change per point(%)		May				Change per point(%)		August				Change per point(%)	
	Simulated		Hussain[18]				Simulated		Hussain[18]				Simulated		Hussain[18]			
	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h	I_d	I_h	I_d	I_h	For I_d	For I_h
7	1.56	7.58	1.23	1	21	89	1.56	7.58	1	1	21	89	1.56	7.58	1	1	21	89
8	526555		277	311	46	44	526	555	410	437	22	21	526	555	415	428	21	23
9	919955		621	642	32	33	919	955	768	937	16	2	919	955	729	837	21	12
10	933990		757	924	19	7	933	990	1064	1312	-14	-32	933	990	1000	1257	-7	-27
11	1059	1138	885	1138	16	0	1059	1138	1276	1643	-19	-44	1059	1138	1216	1539	-14	-35
12	1158	1253	968	1244	16	0.7	1158	1253	1326	1842	-14	-47	1158	1253	1321	1730	-14	-38
13	1155	1257	966	1213	16	3	1155	1257	1391	1851	-20	-47	1155	1257	1337	1736	-15	-38
14	1037	1135	884	1013	14	10	1037	1135	1246	1656	-20	-46	1037	1135	1270	1589	-22	-14
15	856941		715	866	16	8	856	941	1103	1375	-28	-46	856	941	1081	1321	-26	-40
16	699764		450	577	35	24	699	764	767	875	-9	-14	699	764	797	1000	-14	-30
17	697741		215	561	69	24	697	741	415	484	40	35	697	741	535	691	23	6

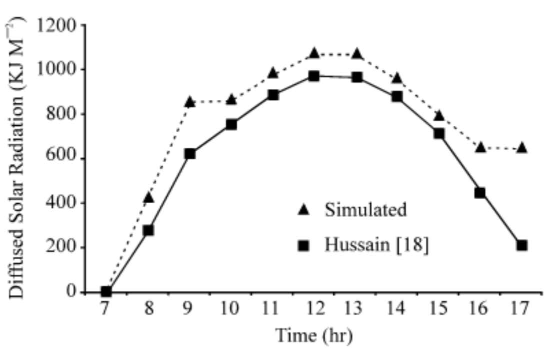

Fig. 8: Simulated and Hussain[18] Diffused Solar Radiation on Jan. 19 for Horizontal Surface ‘a’=0. 15 and ‘b’=0. 32

The simulated radiation is higher than that of experimental measured data due to instrumental error, the ambient air temperature, the thermal characteristics of the solar system and including the availability of solar energy. The agreement between simulated results and Ref [19] found satisfaction in the sets 'a' = 0.18 and 'b' = 0.39 for August; 'a' = 0.175 and 'b' = 0.357 for May and 'a' =0. 15 and 'b' =0. 32 for January.

The values of empirical constants a and b in Angstrom-type regression equation $\frac{H_g}{H_0} = a + b\frac{S}{S_0}$ are 0.18 and 0.39 respectively reported by Hussain and Haider[13]. The simulated values are compared with the reported values of[19] for the month of January, May and August shown in Fig. 6-8 for different sets of parameters [a=0. 18 and b=0. 39, a=0. 185 and b=0. 395, a=0. 175 and b=0. 375, a=0. 15 and b=0. 32, a=0. 14 and b=0. 34 and a=0. 14, b=0. 345]. The sensitivity analysis of the parameters is shown in Table 1-6. The best agreement was found between the simulated results and experimental results in the month of January, when a=0. 15 and b=0. 32, May, when a=0. 175 and b=0. 375 and August, when a=0. 18 and b=0. 39. Therefore it is concluded that the radiations usually vary with the weather variation and the constant a and b will be varied accordingly. It is also shown that the radiation depends on the other constants such as diffuse ground reflectance (ρ), ground to a collector angle (β) and range of latitude (ϕ). In case of Bangladesh, ρ = 0.2, β = 24.5° and $\phi = 20^0 34^/ - 26^0 38$ are used here along with the above set values of a and b for model validation. This model is also applicable to any other country with respect to availability of the said parameters for the concerned country.

CONCLUSION

The model for simulation of the solar radiation system is justified for different sets of parameters. The model has the best relation with hourly and diffuse radiation for clear sunny days. The performance of the model is found satisfactory as well as system dynamics methodology is applicable to simulate the solar radiation system. Bangladesh has got ample solar insulation and has the same level of solar insulation throughout the country[17]. It can be started from above discussion that the solar radiation in Bangladesh is maximum in April-May and minimum in December-January.

Nomenclature:

E_0 = Extraterrestrial solar radiation
I_{sc} = Solar constant
n = Day of the year
δ = Declination angle (degrees)
I_0 = Hourly extraterrestrial solar radiation on a horizontal surface
H_0 = Daily extraterrestrial solar radiation on a horizontal surface
H_g = Monthly average daily global radiation on a horizontal surface
H_c = Average clean sky daily radiation on a horizontal surface
a, b = Constants in the drying rate equation
ϕ = Latitude
ω = Hour angle
S = Mean monthly average daily sunshine hour
S_0 = Maximum possible sunshine hour
I_b = Beam radiation on the horizontal surface
I_h = Hourly solar radiation on a horizontal surface
I_d = Hourly diffuse radiation on a horizontal surface
I_T = Hourly solar radiation on a tilted surface
R_b = Geometric factor or Geometric ratio.

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