STUDY OF SOLAR IRRADIANCE ESTIMATION MODEL

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Abstract*—This paper investigates the estimation of solar radiation estimation in different parts of India. Commonly used solar radiation estimation models for predicting hourly and daily were reviewed in terms of usability in different climatic condition and in terms of accuracy. After that ASHRAE model was selected for making visual basic based windows software for predicting solar radiation for different parts of India. Statistical analysis was carried out for ASHRAE clear sky solar radiation estimation model using MBE (Mean Bias Error) and RMSE (Root Mean Square Error). Clearness factors were calculated to consider effect of climatic condition on solar radiation for different locations.*

Keywords—solar radiation estimation, ASHRAE model, clearness factors, India, diffuse radiation, global radiation

1.INTRODUCTION

Solar radiation is prime source for many physical, chemical and biological process on the earth's surface. Solar-irradiance coming to the earth can be absorbed, diffused or reflected by solid materials. An availability, accurate estimation of monthly mean values of daily, global and diffuse radiation on a horizontal surface is essential to design any solar energy system. Also Components of solar radiation (Beam-irradiance and diffuse-irradiance) are also required for building efficient solar-energy project or system.

To study or observe and learn any solar-architected-project it is essential requirement to get information of solar-energy in terms of three main params namely solar-irradiance, directs-solar-irradiance and diffuse-solar-irradiance. The solar-irradiance that we can obtain on earth's exterior is a crucial necessity for calculation of the how solar-projects are performing and assessment of efficiency of solar-energy-systems for solar-energy-architectures

Because of needs and scarce nature of solar radiation measurement, a number of models with changing degree of difficulty, detail and accurateness have been developed. Some of these models are site dependent and requires local parameters such as type, amount and distribution of clouds, fractional sunshine, atmospheric turbidity, and predicated water content.

Also to build efficient solar energy project components (Beam and diffuse) of solar radiation are also needed. ASHRAE can predicts the clear sky beam and diffuse radiation on horizontal surface at any location. while designing solar energy project or system, it is also needed to know radiation values at hourly interval which enable us to derive precise information about the performance of solar energy system.

The ASHRAE clear sky model appears to be general enough for above objectives. It can estimate "clear sky" solar radiation estimation at any location. However, one of its disadvantage is that it is for "clear sky" as name suggest and developed for basic atmosphere. As solar radiation reaching Earth's surface depends upon the climatic condition so we have to take an account of climatic condition in form of clearness factors. A daily total radiation is obtained by integrating the hourly distribution. Based on that a clearness factor (<1) is obtained for every month to adjust the clear sky radiation in order to account for the effects of local weather condition. when ASHRAE clear sky model estimation was multiplied this clearness factor, the accuracy improves and the results agrees very well with the estimation.

So in this paper ASHRAE clear sky model is used to estimate the hourly, daily, and monthly average hourly radiation on horizontal surfaces of India and also monthly clearness factors are obtained for climatic conditions.

2.METHODLOLOGY OF ASHRAE METHOD

As per the ASHRAE [3] recommendation solar radiation estimation procedure was adopted. Hourly global radiation (I), hourly beam-radiation(Ibn) and hourly-diffuse-radiation(Id) on the horizontal surface on a sky without any clouds or we can say clear-day are calculated using the below equations [2].

$$I = DNI * \cos\theta_z$$
$$DNI = A * \exp(-B/\cos\theta_z)$$
$$DHI = C*DNI$$

Where, A is the apparent solar-irradiance-constant, B is the atmospheric-extinction-coefficient

C is the diffuse-sky-factor. The θz in those equations is the zenith angle [2].

$$\cos z = \cos\delta * \cos\varphi * \cos\omega + \sin\delta * \sin\varphi$$

Where,

δ is the solar declination
φ is s the latitude of the station
ω is the hour angle

The solar declination angle δ can be given as (Howell et al., 1982; Duffie and Beckman, 1991) [8]

$$\delta = 23.45 * sin\left(\frac{360(D+284)}{365}\right)$$

where D the number of days of the year starting from January 1. The hour angle ω is an angular measure of time and is equivalent to 15^0 per hour with morning (+) and afternoon (-). It is measured from noon-based local solar time (ST) from the equation given by [8]

$$\omega = 15*(12-ST)$$

The local solar time (ST) is calculated from the local standard time (LT) and the equation of time (ET) is given later by

$$ST = LT + ET/60 - 4/60(L_s - L_L)$$

where L_S is the standard meridian for the local time zone (longitude of the time zone) a L_L is the longitude of the location in degrees west $.0^0 < L_L < 360^0$. [8]

Where equation of time (ET) is obtained from formulae given by Tasdemiroglu (1988) as:

$$ET = 9.87*\sin 2B - 7.53*\cos B - 1.50 \sin B$$

The input to the ASHRAE clear-sky model is, thus, complete by specifying values for nine parameters, namely: A, B, C, ET, δ, φ, L_S, L_L, and local standard time (LT). The model solar data given by ASHRAE (1985) for each month are given in Table 1 for the first three parameters [8].

The other parameters are specific to the location of place where data is to be estimate. The final parameter stated as the local standard time or local time (LT) is the only one varying parameter which is input for calculations at any required time on the given day.

Here, task was to obtain a value of the solar-params (A, B, C) for other days than the 21st day of the month throughout the year. We can obtain these solar-params using interpolation methods. In this study the values of A, B and C obtained using curve fitting to trigonometry function of cosine function of the day number D to be valid for all the years [9].

$$A = 1162.12 + 77.0323 * cos\left(\frac{D*360}{365}\right)$$

$$B = 0.171076-0.0348944 * cos\left(\frac{D*360}{365}\right)$$

$$A = 0.0897334 - 0.0412439 * cos\left(\frac{D*360}{365}\right)$$

Where unit of A is W/m^2 and B and C are dimensionless

TABLE 1-ASHRAE CONSTANTS FOR 21st DAY OF EACH MONTH

Months	A	B	C
Jan 21	1229.475	0.142	0.058
Feb 21	12313.713	0.144	0.060
March 21	1185.340	0.156	0.071
Apr 21	1134.900	0.180	0.097
May 21	1103.375	0.196	0.121
June 21	1087.613	0.205	0.134
July 21	1084.460	0.207	0.136
Aug 21	1106.528	0.201	0.122
Sep 21	1150.663	0.177	0.092
Oct 21	1191.645	0.160	0.073
Nov 21	1220.018	0.149	0.063
Dec 21	1232.628	0.142	0.057

3.FINDING CLEARNESS FACTORS

The ASHRAE model based software was run to calculate the solar radiation for each day of the year at one-hour time increments. The run is performed for each location of the different sites of which measured data were available and the monthly average solar radiation is calculated from the hourly results. The monthly values of beam radiation (DNI) and diffuse radiation (DHI) and global hourly radiation (GHI) were compared with the corresponding monthly measured values obtain from. The comparison was done for the 8 different sites with one year of measurement data and clearness factors are calculated [9] .

$$CF1 = DNI_{Measured} / DNI_{Calculated}$$

$$CF2 = DHI_{Calculated}/DHI_{Measured}$$

$$CF3 = GHI_{Measured}/GHI_{Calculated}$$

Then Clearness factors are used to modify equation and modified equation can be written as below.

$$DNI_{MODIFIED} = DNI * CF1$$
$$= A * \exp(-B/\cos\theta_z) * CF1$$

$$DHI_{MODIFIED} = DHI * CF2$$
$$= C * DNI * CF2$$

$$I_{MODIFIED} = I * CF3$$

A modified ASHARE equations were than used to estimate solar radiation for some sites.

4.METHODS FOR STATASTICAL COMPARISION

The following other parameters are specific to the location MBE (Mean Bias Error), which allows the comparison of the actual deviation between the estimated and measured value of each term. RMSE (Root Mean Square Error) is the standard deviation of the residuals. In other words it tells you concentrated the data is around the line of best fit. The Ideal value of RMSE is zero. In everyday life smaller the values of RMSE better the equations performance is.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(I_{ESTIMATED} - I_{MEASURED})$$

$$RMSE = [\frac{1}{n}\sum_{i=1}^{n}(I_{ESTIMATED} - I_{MEASURED})^2]^{1/2}$$

5.VISUAL BASIC BASED SIMULATION

A Visual Basic code was written to calculate the Instantaneous global, beam and diffuse radiation as well as total daily radiation and average monthly radiation components. The code is written according to ASHRAE model for clear sky condition. It can estimate solar radiation on horizontal surface for selected date.

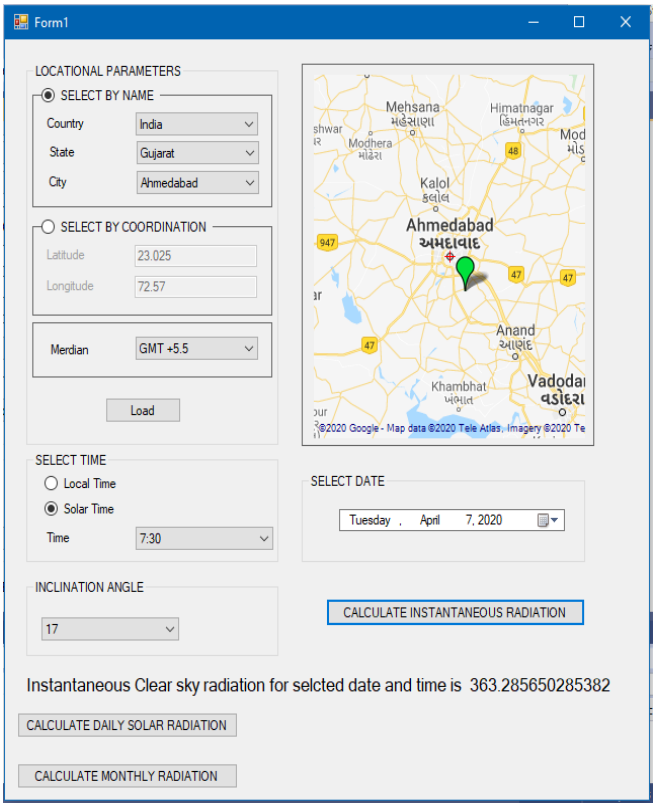

FIGURE 1 –INPUT SCREEN OF VISULA BASIC BASED SOFTWARE

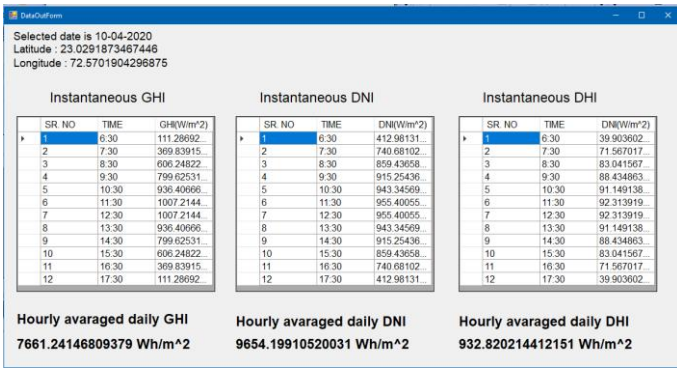

FIGURE 2- INSTANTANEOUS AND HOURLY AVARAGED DAILY SOLAR RADIATION AND ITS COMPONENTS FOR SELECTED DATE

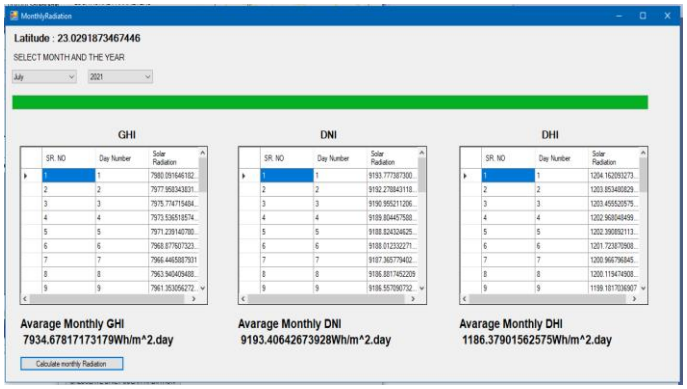

FIGURE 3- HOURLY AVARAGED DAILY AND AVARAGED MONTHLY RADIATION FOR SELECTED MONTH

6.RESULT AND DISCUSSION

To check accuracy of ASHRAE model based software, estimated data calculated from software were compared with Clear sky estimated by PVsyst.

TABLE 2 –ESTIMATED GLOBAL SOLAR RADIATION DATA USING ASHRAE BASED SOFRWARE AND PVsyst FOR AHMEDABAD

Time	21st Feb (PVsyst)	21st Feb (ASHRAE)	21st Jul (PVSyst)	21st Jul (ASHRAE)
6:30	0.1773	0.0035	0.17	0.18038
7:30	0.194	0.231	0.396	0.418705
8:30	0.431	0.475	0.608	0.6320
9:30	0.633	0.674	0.795	0.8065
10:30	0.782	0.816	0.935	0.9298
11:30	0.869	0.890	1.013	0.9936
12:30	0.866	0.890	1.025	0.9936
13:30	0.834	0.816	0.978	0.9298
14:30	0.715	0.674	0.874	0.8065
15:30	0.537	0.474	0.684	0.6320
16:30	0.315	0.231	0.484	0.4187
17:30	0.074	0.0035	0.261	0.18038

Figure 4 shows the plot of estimated data of Table 2 for 21st Feb. It can be observed that clear sky solar radiation by both software is pretty close. Figure 5 shows plot for 21st july.

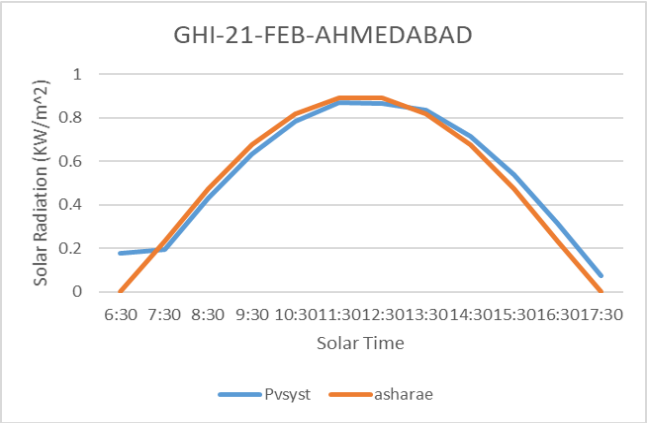

FIGURE 4 – ESTIMATED VALUES OF HOURLY CLEAR SKY RADIATION (I) BY ASHRAE BASED SOFTWARE AND PVSyst ON 21ST FEB.

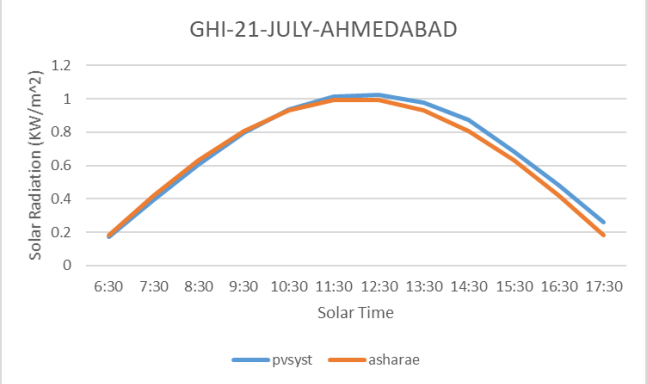

FIGURE 5 – ESTIMATED VALUES OF HOURLY CLEAR SKY RADIATION (I) BY ASHRAE BASED SOFTWARE AND PVSyst ON 21st JULY.

Statastical analysis was carried out using MBE and RMSE. Table shows the MBE and RMSE values for Ahmedabad for 21st Feb and 21st July.

TABLE 3 – STATASTICAL ANALYSIS OF DATA IN TABLE 2

	21ST FEBRUARY	21ST JULY
MBE	0.020311906	0.025142617
RMSE	0.06784175	0.043868521

Same procedure of statistical analysis using MBE and RMSE was carried out for chennai on 21st Feb and 21st July. Table 4 shows clear sky estimated data using ASHARE based software and PVSyst for Chennai.

TABLE 4 –ESTIMATED GLOBAL SOLAR RADIATION DATA USING ASHRAE BASED SOFRWARE AND PVsyst FOR CHENNAI.

Time	21st Feb (PVsyst)	21st Feb (ASHRAE)	21st Jul (PVSyst)	21st Jul (ASHRAE)
6:30	0.01364	0.02771	0.105	0.1262551
7:30	0.261	0.293	0.353	0.37636
8:30	0.5	0.551	0.567	0.602916
9:30	0.718	0.76437	0.782	0.787707
10:30	0.878	0.91486	0.914	0.91825
11:30	0.969	0.9928	1.003	0.9858
12:30	0.984	0.9928	1.015	0.9858
13:30	0.926	0.91486	0.961	0.91825
14:30	0.793	0.764	0.841	0.7877
15:30	0.596	0.5519	0.663	0.6029
16:30	0.35	0.293	0.442	0.3763
17:30	0.084	0.02771	0.194	0.126

Figure 6 and Figure 7 shows the plot of clear sky estimated data of global solar radiation for Chennai for 21st Feb and 21st July respectively.

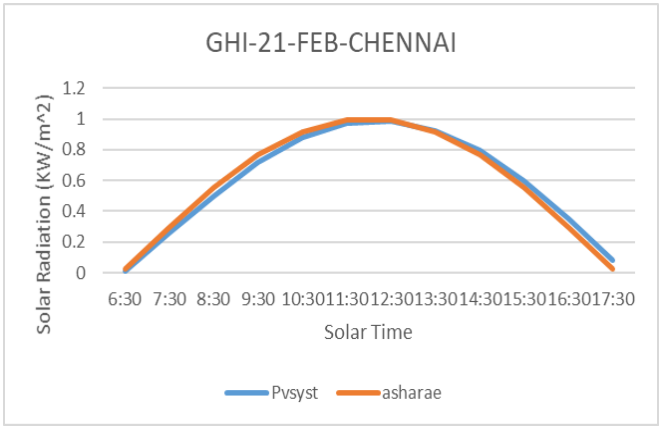

FIGURE 6 – ESTIMATED VALUES OF HOURLY CLEAR SKY RADIATION (I) BY ASHRAE BASED SOFTWARE AND PVSyst ON 21ST FEB FOR CHENNAI

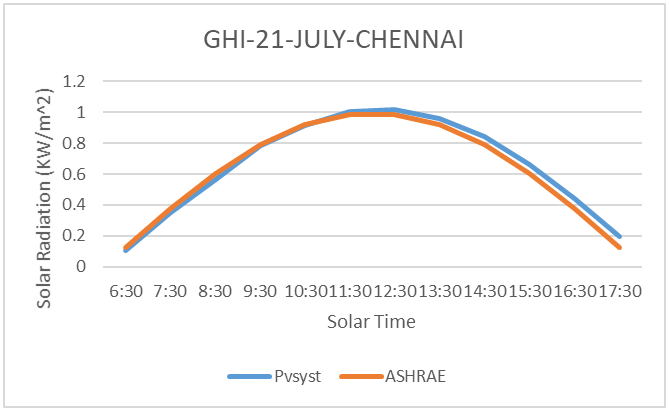

FIGURE 7 - ESTIMATED VALUES OF HOURLY CLEAR SKY RADIATION (I) BY ASHRAE BASED SOFTWARE AND PVSyst ON 21ST JULY FOR CHENNAI

TABLE 5 – STATASTICAL ANALYSIS OF DATA IN TABLE 4

	21ST FEBRUARY	21ST JULY
MBE	-0.001523082	0.038015
RMSE	0.020450166	0.041494423

From Table 3 and Table 5 we can say that ASHRAE model can be used to estimate clear sky radiation in India.

Here note that clear sky radiation varies from real radiation as in reality radiation is affected by climatic parameters like type and amount of clouds, precipitation, humidity etc. So the Clearness factors were developed. Since Measured data were not available. Measured data were taken from research paper for 8th July for Aligarh. Clearness factors were calculated for month of July and modified ASHARE equation based solar radiation were calculated. TABLE 6 shows data of measured, ASHRAE model based estimation and modified ASHRAE based estimation.

TABLE 6 – MEASURED, ASHRAE BASED ESTIMATION AND MODIFIED ASHRAE BASED ESTIMATION DATA FOR 8TH JULY ALIGARH

Time	8th July (Measured)	8th July (ASHRAE)	8TH July (Modified ASHRAE)
6:30	0.0778	0.218	0.143
7:30	0.2319	0.443	0.292
8:30	0.4270	0.645	0.425
9:30	0.5919	0.810	0.534
10:30	0.7030	0.928	0.611
11:30	0.5706	0.986	0.650
12:30	0.7437	0.986	0.650
13:30	0.7096	0.926	0.611
14:30	0.6231	0.810	0.534
15:30	0.4942	0.645	0.425
16:30	0.3186	0.443	0.292
17:30	0.1625	0.218	0.141

Statistical analysis was carried out for ASHRAE based model and modified ASHRAE based model with respect to measured available data on 8th July in Aligarh. Table shows MBE and RMSE for ASHRAE and modified ASHRAE respectively.

TABLE 7 – STATASTICAL ANALYSIS OF DATA IN TABLE 6

	ASHRAE	MODIFIED ASHRAE
MBE	0.200341667	-0.028825
RMSE	0.216844631	0.0697535

From Table-7 we can conclude that modified ASHRAE method is more accurate in terms of estimation of solar radiation.

After that clearness-factors were calculated for different 4 cities which were from same climatic zone.

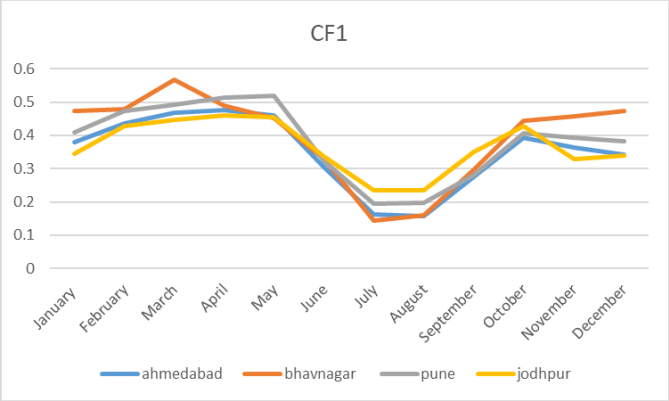

FIGURE 8 - CLEARNESS FACTOR CF1 FOR AHMEDABAD, CHENNAI, PUNE AND BHAVNAGAR

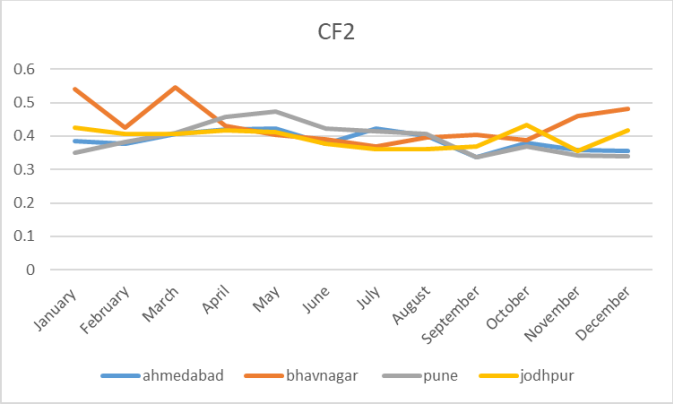

FIGURE 9 - CLEARNESS FACTOR CF2 FOR AHMEDABAD, CHENNAI, PUNE AND BHAVNAGAR

From Figure-8 and Figure-9 we can observe that clearness factors varies in same manner for the same climatic zone and are nearly identical.

7. CONCLUSION

This paper investigates about the solar radiation estimation for the different parts in India. From the results from the software based on ASHRAE based solar radiation method, we can conclude that Clear-Sky estimation can achieved by ASHARE based solar radiation estimation method for different parts of India. Also clearness-factors can be calculated using available measured data and ASHRAE based calculation. Result comparing clearness-factors for 4 different cities shows that as clearness-factors varies in same manner and are nearly same for same climatic zones. So using this calculated clearness-factors we can use it to estimate solar radiation for other places in same climatic zone.

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