Estimation of solar energy potential for Islamabad, Pakistan

Citation for the original published paper (version of record):
Ulfat, I., Javed, F., Abbasi, F. et al (2012). Estimation of solar energy potential for Islamabad, Pakistan. Terragreen 2012: Clean Energy Solutions for Sustainable Environment, CESSE 2012; Beirut; Lebanon; 16 February 2012 through 18 February 2012, 18: 1496-1500.
http://dx.doi.org/10.1016/j.egypro.2012.05.166

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia

Energy Procedia 18 (2012) 1496 – 1500

Estimation of solar energy potential for Islamabad, Pakistan

I. Ulfat [a, b], F. Javed [b, c], F. A. Abbasi [b, d], F. Kanwal [b], A. Usman [e], M. Jahangir [b, d] & F. Ahmed [b]

[a]Department of Applied Physics, Chalmers University of Technology, SE-41296 Göteborg, Sweden
[b]Energy & Environment Research Group, Department of Physics, University of Karachi, Karachi-75270, Pakistan
[c]School of Economics and Management, Department of Statistics, Lund University, SE-22007 Lund, Sweden
[d] Department of Physics, Government National College, Karachi-74800, Pakistan
[e]Pakistan Meteorological Department, Karachi-75270, Pakistan

ABSTRACT

In order to design a solar energy system with optimized performance a through knowledge of solar radiation data for a considerably long period (20-25 years) is a pre-requisite. For developing countries like Pakistan, the need of empirical models to assess the feasibility of solar energy utilization seems inevitable due to the absence and scarcity of trust-worthy solar radiation data. We present such models for the capital city of Pakistan, Islamabad to estimate global and diffuse solar radiation. It is found that with the exception of monsoon month, solar energy can be utilized very efficiently throughout the year. The models suggested could be used for most of the north-eastern areas of Pakistan, which are similar to Islamabad with respect to the climate and the availability of solar radiation but lack in the record of solar radiation data.

Keywords: Solar radiation; Empirical model

1. INTRODUCTION

Pakistan is a high insolation country. It receives about 1KW of solar energy for square meter of its landmass for 6-7 hours on the average per day. The number of sunshine hours amount almost to 3000-3300 per year. The weather is most favourable for the utilization of solar energy. Nevertheless in Pakistan only a very few stations record global solar radiation on a horizontal surface. It is important to mention at this point that the global solar radiation received at the earth surface, composed of the *direct* (arriving directly along the sight from the sun) and *diffuse* (scattered and reflected by the atmosphere) radiations. Despite the fact that the measured data of global solar radiation for some stations is available, the data on diffuse radiation is not available at all, since it is not recorded anywhere in Pakistan. To assess the availability and variation of diffuse and beam radiation, one relies on the estimated values, for a particular location.

The aim of the present paper is to estimate the solar energy potential of the capital of Pakistan named Islamabad by predicting the monthly average global and diffuse radiation on horizontal surface. (The direct radiation can then be found by subtracting the later from the former). Islamabad (Latitude = 33°71′, Longitude = 73°10′) has an area of 120 sq km and a population of around 0.7 million (as per 2009 census). Being the administrative centre of country, Islamabad is a city of strategic location. It is the only city of Pakistan, which was built according to a master plan. The results presented in this particular study are in fact the attempt to extend our previous studies of the same nature for Karachi, Pakistan [1-2].

NOMENCLATURE

H = Monthly average daily global solar radiation on horizontal surface
H_0 = Extra terrestrial solar radiation
H_d = Monthly average diffuse solar radiation
n = Monthly average daily sunshine hours
N = Monthly average day length
K_T (=n/N)= Clearness index
K_d (=H_d / H)= Clearness index
$a_1, a_2, a_1', a_2', a_1'', a_2'', a_1''', a_2''', a_3''', b_1', b_2', b_1'', b_2'', b_1''', b_2''', b_3'''$ = Regression Coefficients

2. METHODS OF PREDICTION

2.1 Prediction of global solar radiation

Solar radiation received at the surface of the Earth is subject to variation due to changes in the extraterrestrial radiation. The radiation emitted by the sun loses its intensity in space only due to the distance traversed. However, as the sun's rays enter the Earth's atmosphere, it continues to suffer additional depletions due to absorption and

 doi:10.1016/j.egypro.2012.05.166

scattering. There are many methods, which have been devised to predict the amount of solar radiation reaching the Earths surface at a given location. The method used here is the one developed by Angstrom [3]:

$$H/H_0 = [a_1 + a_2 (n/N)] \quad ... (2.1)$$

The parameters N and H_0 are determined using the geographical information of the location under consideration [4].

2.2 Prediction of diffuse solar radiation:

The diffuse solar radiation H_d can be estimated by an empirical formula, which correlates the diffuse component H_d to the daily total H. Page [5] develops the correlation equation, which is widely used:

$$H_d/H = 1.00\text{-}1.13K_T \quad ...(2.2)$$

Another commonly used correlation is that due to Liu and Jordon and developed by Klein [6], of the form

$$H_d/H = 1.390 - 4.027K_T + 5.53(K_T)^2 - 3.108(K_T)^3 ...(2.3)$$

2.2.1 Estimation of Diffuse Solar Radiation using K_T

In order to get the best relation of K_d as function of K_T (clearness index), the following relationship of first order polynomial using Liu and Jordon and Page method to estimate the diffuse solar radiation is considered as:

$$K_d = H_d/H = a_1' + a_2' (K_T) ... (2.4)$$

The first and second order polynomial equations are also calculated after taking average of the ratio of the diffuse component H_d to the daily total H (H_d/H) calculated by the both Liu and Jordon and Page method given by

$$K_d = H_d/H = a_1'' + a_2'' (K_T) ... (2.5) \quad ; \quad K_d = H_d/H = a_1''' + a_2''' (K_T) + a_3''' (K_T)^2 ...(2.6)$$

2.2.2 Estimation of Diffuse Solar Radiation using (n/N)

We also employed the ratio (n/N), i.e. sunshine hour to day length to obtain the empirical relation of the first order:

$$K_d = H_d/H = b_1' + b_2' (n/N) ... (2.7)$$

The first and second order polynomial equations are also calculated as mentioned in 2.2.1:

$$K_d = H_d/H = b_1'' + b_2'' (n/N) ...(2.8) \quad ; \quad K_d = H_d/H = b_1''' + b_2''' (n/N) + b_3''' (n/N)^2 ...(2.9)$$

Month	K_T	n/N	K_d (LJ)	K_d (Page)
Jan	0.565	0.502	0.319	0.361
Feb	0.596	0.558	0.296	0.326
Mar	0.618	0.596	0.280	0.302
Apr	0.642	0.642	0.262	0.274
May	0.685	0.719	0.228	0.226
Jun	0.693	0.733	0.222	0.217
Jul	0.623	0.606	0.276	0.296
Aug	0.627	0.615	0.273	0.291
Sep	0.657	0.668	0.250	0.258
Oct	0.679	0.703	0.233	0.233
Nov	0.679	0.708	0.233	0.233
Dec	0.592	0.549	0.299	0.331

Table 1: Input parameters

3. RESULTS AND DISCUSSION

Regression analysis yields the coeffiecients for the correlations (2.1)-(2.9) described above. We can thus rewrite all these relations as under:

a. Global:

$$H/H_0 = [0.2883 + 0.5519\ (n/N)]...(2.1)$$

b. Diffuse:

(i) *As a function of K_T*:

From Page:

$$K_d = H_d/H = 1.00 - 1.13\ (K_T)...(2.2)$$

From LJ:

$$K_d = H_d/H = 0.7532 - 0.766\ (K_T)...(2.3)$$

After Average

Linear:

$$K_d = H_d/H = 0.8766 - 0.948\ (K_T)...(2.4)$$

Quadratic:

$$K_d = H_d/H = 0.811 - 0.737\ (K_T) - 0.166\ (K_T)^2...(2.5)$$

(ii) *As a function of n/N*

From Page:

$$K_d = H_d/H = 0.6741 - 0.632\ (n/N)...(2.6)$$

Fro LJ:

$$K_d = H_d/H = 0.5322 - 0.423\ (n/N)...(2.7)$$

After Average

Linear:

$$K_d = H_d/H = 0.6032 - 0.523\ (n/N)...(2.8)$$

Quadratic:

$$K_d = H_d/H = 0.581 - 0.451\ (n/N) - 0.0589\ (n/N)^2...(2.9)$$

Fig. 1 shows the observed and predicted values of H. These estimates are obtained by means of eq. (2.1), which is based on sunshine records. The result of the variation in the intensities of direct and diffuse radiation due to cloudiness is plotted in Fig. 5 to exhibit the trend of percentage variation of direct and solar radiation. The maximum of direct radiation for the months of May and Jun. are quite appreciable. The presence of direct radiation in May and Jun. will be very useful for utilizing it for solar concentrators, solar cookers and solar furnaces etc. The Angstrom model for determination of Global solar radiation and Liu and Jordon and Page model for the estimation of Diffuse solar radiation exhibits the validity of estimation for the location under study.

The monthly average variation of H_d/H from equations (2.2) and (2.3) is shown in Fig. 2. The ratio H_d/H that is the variation due to atmospheric conditions (dust, smoke water vapors and suspended matter) has been given a number of values. The high values during the months of July- Aug are due to the monsoon period at Islamabad.

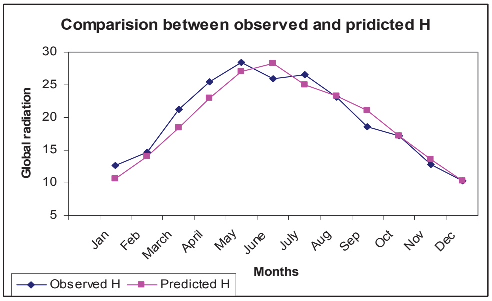

Fig. 1: Comparison between observed and predicted values of monthly average daily global solar radiation

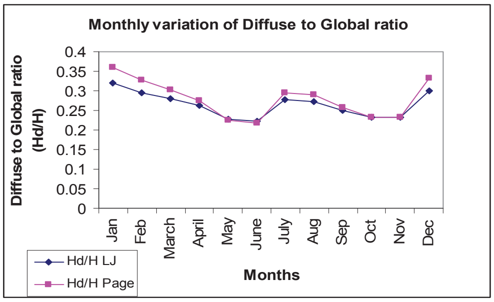

Fig. 2: Monthly variations of H_d/H

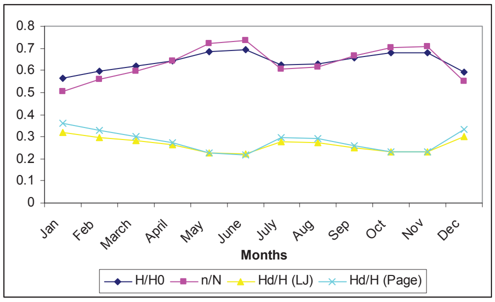

Fig. 3: Monthly variation of H/H_0, n/N and H_d/H (LJ, Page)

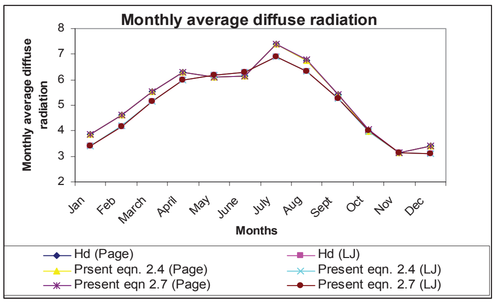

Fig. 4: Monthly average daily diffuse radiation from Liu and Jordon, Page, Equation 2.4 and equation 2.7

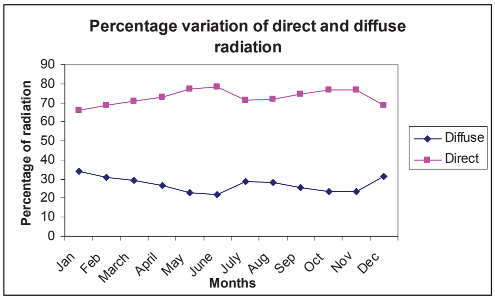

Fig. 5: Percentage variation of Direct and Diffuse radiation

The monthly average daily diffuse solar radiation, H_d, estimated through Page, Liu and Jordon, and the present correlations is presented graphically in Fig. 4. From the curve, it is observed that the Liu and Jordon estimates are lower, while the Page estimates are higher, throughout the year

The monthly average daily diffuse radiation, H_d, has a range of 3.15 MJ/m^2/d (Nov.) – 7.14 MJ/m^2/d (July). The trend of variation of diffuse radiation from all these relations is almost identical, showing a peak during the monsoon months of July- August. During these months, the sky is mostly heavily overcast, contributing more to the diffuse radiation.

The monthly variation of H/H_0, the fraction of possible duration of sunshine hour's n/N, and the fraction of diffuse solar radiation are shown in Fig. 3. The highest value of the ratio H/H_0 is equal to 0.69, and it is in June. It is interesting to observe that the curves of H/H_0 and n/N drop in the months of June – August, whereas the H_d/H curve peaks in these months. The peak value of n/N occurs in June. and it is 0.733. Fig. 3 also shows the agreement between the values of H_d/H calculated by equations Page and Liu and Jordon. Both show similar trends. The maximum value of H_d/H appears in August.

CONCLUSION

The work reported in the paper indicates that the solar energy utilization has bright prospects for Islamabad, Pakistan. The estimated values of global and diffuse radiation reveals that solar radiation can be very efficiently used to compensate for the energy deficit. Especially in summer the solar radiation reaches its maximum, which could solve part of the energy problem and reduce the consumption of electricity by utilizing solar energy. Therefore, this information contributes to the existing solar radiation in Islamabad and nearby areas with same geographical conditions.

REFERENCES

[1] Ahmad F. Hussain S. A., Naqvi S. M. M. R. and Akhtar, M. W., 1981.Characteristic Distribution of Total, Direct and Diffuse solar radiation at Karachi, Pak. Jour. Sci & Res., 24 (1981), and references therein

[2] Ahmed F.; Ulfat I. Empirical models for the correlation of monthly average daily global solar radiation with hours of sunshine on a horizontal surface at Karachi, Pakistan, Turkish Journal of Physics, 28 (2004), and references therein

[3] Angström A., "Solar and terrestrial radiation" Quart. J. Roy. Met. Soc. 50 (1924)

[4] Duffie J. A. and Beckman W. A., Solar Engineering of Thermal Processes. 2nd Edition, John-Wiley & Sons, New York (1991)

[5] Page J. K., "The estimation of monthly mean values of daily total short wave radiation on vertical and inclined surfaces from sunshine records for latitudes 40°N–40°S" In: Proceedings of UN conference on new sources of energy (1961)

[6] Liu Y. H. and Jordan R. C., The inter relationship and characteristic distribution of direct, diffuse and total solar radiation from metrological data. Solar Energy, 4 (1960)