Pakistan J. Sci. Ind. Res., Vol. 24, Nos 5–6, October – December 1981

CHARACTERISTIC DISTRIBUTION OF TOTAL, DIRECT AND DIFFUSE SOLAR RADIATIONS AT KARACHI, PAKISTAN

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(Received January 27, 1981)

From the available weather data the total, direct and diffuse solar radiation on a horizontal surface for Karachi is estimated. Analysis of the result shows the variation of direct and diffuse components of solar radiations. The sky in summer shows greater contribution of diffuse radiation whereas sky conditions are clear in winter because of less content of dust, water vapours, ozone etc. in the atmosphere. The relationship obtained for Karachi are in close agreement with those developed by Liu and Jordan.

INTRODUCTION

The rapidly growing interest to harness solar energy requires information needed by research workers to use it for practical purposes. For many localities of the world the solar radiation data is available in the form of total solar radiation (direct plus diffuse) while in many cases the value of diffuse radiation is often required. Although the theoretical estimation of diffuse radiation is extremely difficult, it was first attempted by Parmelee [1] for cloudless (clear) days and after that Liu and Jordan [2] extended it to cloudy days as well.

In this paper, an attempt has been made to estimate theoretically the total, direct and diffuse solar radiation on a horizontal surface and its characteristic distribution for Karachi, using Liu and Jordan method [2]. The basic idea of this presentation is to get the theoretical values of total, direct and diffuse radiations for Karachi as no attempt prior to this work has been made by research workers engaged in this field.

The results obtained in this paper will be of immense use for future experimental work at Karachi.

1. *Extraterrestrial Daily Insolation:* (H_o). The extraterrestrial daily insolation received on a horizontal surface at a particular location is given as:

$$H_o = 24/\pi \, r \, I_{SC} \, (\cos L \cos \delta \sin \omega_S + \omega_S \sin L \sin \delta) \quad \ldots 1$$

The above equation gives H_o if parameters such as L, the lattitude of the place, δ, solar declination, r, the ratio of the intensity of radiation at the normal incidence outside the atmosphere to the solar constant and sunset hour angle ω_S are known. The dependence of ω_S on L and δ is of the following form.

$$\cos \omega_S = -\tan L . \tan \delta \quad \ldots\ldots\ldots\ldots\ldots (2)$$

The declination δ for Karachi (Lattitude 24^o. 54′ N) were calculated using the material given in Liu and Jordan paper [2]. The monthwise variation of H_o for a year is given in Fig. 1. The extraterrestrial insolation for the month of January is 580 cal/cm^2/day reaching a maximum of 980 cal/cm^2/day in the month of June every year. This systematic distribution of H_o indicates the availablity of solar radiation over Karachi.

2. *Total, Direct and Diffuse Radiation.* The total solar radiation for the period of five years (1975 – 1979) for Karachi was calculated using Reddy's formula [3].

For the estimation of the total solar radiations parameters employed were: mean length of the day during the month, mean hours of bright sunshine/day during the month, number of rainy days during a month and mean humidity/day in a month [4]. These parameters covering the above mentioned period were obtained from Pakistan Meteorological Department, Karachi Civil Airport [5].

It is well known that the solar radiations travel through the extraterrestrial space as pencil of rays. During its passage through the earth's atmosphere it is split into two components– direct and diffuse radiation.

To compute the monthly average of daily diffuse radiation, the monthly average of the daily total radiation must be known. For example, the monthly average of daily diffuse radiation at Karachi was calculated as follows:

In October, at Karachi, H_o as calculated from equation(1) and also from Fig. 6 (in ref. 2) is 730 cal/cm^2/day, whereas average total solar radiation $\bar{H}$ calculated using Reddy's formula [3], is 476 cal/cm^2/day. Therefore,

$$\bar{K}_T = \frac{\bar{H}}{H_o} = \frac{476}{730} = 0.650$$

Also for $\bar{K}_T$ = 0.650,

$$\frac{\bar{D}}{\bar{H}} = 0.250 \text{ (from Ref. 2)}$$

Hence

$$\bar{D} = (\frac{\bar{D}}{\bar{H}})\ (\bar{H}) = (0.250)\ (476)$$

$$\bar{D} = 119 \text{ Cal/cm}^2\text{/day.}$$

Fig. 1 shows a plot of the values of monthly average of daily total, direct and diffuse radiations alongwith the extraterrestrial daily insolation. On a clear day, in December, about 416 cal/cm^2/day were incident on a horizontal surface. This is about 76% of the extraterrestrial insolation. Out of this 76% available insolation 17% (71 cal/cm^2/day is diffuse and 83% (345 cal/cm^2/day) is direct radiation. The shape of the average daily total radiation is different from that of extraterrestrial insolation. A depression in the curve is seen during the monsoon months July – September when cloud layers of different types and densities causes a large reduction in the solar radiation. These calculations are done assuming minimum possible dust particles and water vapours contents in the atmosphere.

3. *Sky Conditions, Karachi.* The fraction of the extraterrestrial radiation that reaches the earth's surface as total radiation, is a measure of the degree of cloudiness of the sky. Cloudiness index as defined by Liu and Jordan [2] is

$$K_T = \frac{H}{H_o} \qquad \text{.........................(3)}$$

where $\bar{K}_T$ = cloudiness index, H = daily total solar radiation reaching on a horizontal surface and H_o = extraterrestrial daily insolation on a horizontal surface.

It is to be noted that the variation of cloudiness is primarily responsible for the day to day variation of the daily total as well as diffuse radiation during the whole month. The variation of the average cloudiness index $\bar{K}_T$, over the year is shown in Fig. 2. The index is minimum during the month of July indicating the presence of thick clouds and a transmission of only 36% ($K_T = \frac{H}{H_o}$ = 0.359) of the extraterrestrial insolation on a horizontal surface. As a result of this the ratio $\frac{D}{H}$ (diffuse to total) reaches its maximum value ($\frac{D}{H}$ = 0.50) which indicates that about 50% of the daily total radiation is received in the form of diffuse radiations.

In the same Fig. 2, the index K_d i.e. ($\frac{D}{H_o}$) shows a little variaton. In July, the diffuse index is ($K_d = \frac{D}{H_o}$ 0.179) indicating the fact that for this period nearly 18% of the extraterrestrial insolation is received as diffuse radiation.

In the peak summer month, May, the sky is fairly clear ($K_T = \frac{H}{H_o}$ = 0.50) and allows on the average 50% of the extraterrestrial insolation to the horizontal surface. In winter months the clear sky conditions are indicated from the high values of cloudiness index; K_T = 0.70, 0.66 and 0.62 for January, Feburary and March and K_T = 0.65, 0.72, and 0.75 for October, November and December respectively.

From the estimated values of H_o, $\bar{H}$ and $\bar{D}$ the ratios $\frac{D}{H}$ (diffuse to total), $\frac{D}{H_o}$ (diffuse to extraterrestrial) and $\bar{K}_T$ (cloudiness index) are obtained

4. *Statistical Distribution of Total Solar Radiation at Karachi.* A knowledge of the statistical distribution of daily total solar radiation is required to predict the performance of appliances utilizing solar energy. The average K_T value/month for the year is 0.62 which shows that throughout the year on the average 62% of the extraterrestrial insolation is always available. The high value of K_T indicates bright days or high percentage of transmission of total solar radiation. The statistical distribution of daily total solar radiation is catagorized as below:

Period	Percentage of available total solar radiation
January – March	Above 60 %
April – May	Above 50 %
June – July (Monsoon period)	Between 35 – 45 %
August – September	Between 40 – 45 %
October – December	Above 65 %

It is to be observed that in June – July the days are mostly cloudy with low values of K_T and hence the average K_T is also low. From the above values of K_T it is very encouraging to note the higher percentage (high K_T values) for the period January – March and October – December, which is well above 60 % reaching upto a maximum values of

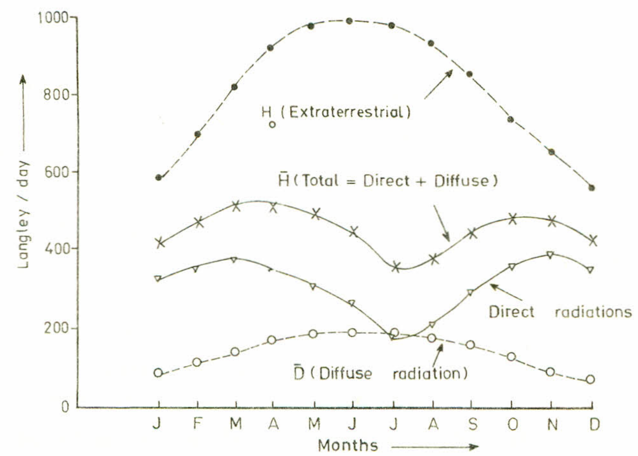

Fig. 1. A plot of the monthly variation of total, direct and diffuse solar radiations at Karachi (Lattitude = 24° $54'$ N)

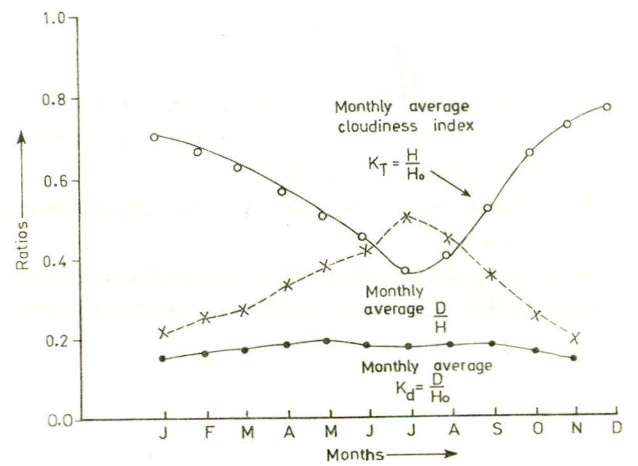

Fig. 2. Behaviour of the cloudiness index K_T, D/H and D/H_o during a year for Karachi (Lattitude = 24° $54'$ N)

72, 75 and 70 % for the months of November, December and January. These are winter months in northern hemisphere and solar energy is in great demand during these months for prospective utilization

5. *Direct and Diffuse Radiation: Monthly Variation* A large variation in intensities of direct and diffuse radiation due to cloudiness have been indicated as stated earlier. The intensity of direct radiation is determined by the amount of water vapours, dust particles, ozone etc. in the atmosphere. The values are estimated on the basis of Liu and Jordan [2]. These results are plotted in Fig. 3, to show the trend of percentage variation of direct and diffuse radiation. The peak values of direct radiation for the months of November, December and January are quite appreciable. The percentage of diffuse radiaton contributing to total radiation is low for winter months (bright clear sky) and attains a peak value of 50 % in the month of July which is also confirmed with the low values of K_T and high values of D/H From Fig. 3 it is quite clear that with the exception of June – July the conditions are very much in favour of solar energy application.

6. *Relationship Between Monthly Average Daily Diffuse and Monthly Average Daily Total Radiation.* The relation between monthly average daily diffuse and monthly average daily total radiations for Karachi is worked out and is shown in Fig. 4. the monthly average daily diffuse radiations were calculated according to the method illustrated in Sec. 2 of this paper. The plot between $\frac{\bar{D}}{\bar{H}}$ and $\frac{\bar{D}}{H_o}$ applies well to the correlation developed by Liu and Jordan [2] for monthly average daily diffuse radiation and monthly average daily total radiation. From Fig. 4, it can be concluded that even during monsoon months the percentage of diffuse radiations does not exceeds 50% while for the rest of the year K_T values are quite high. The minimum value

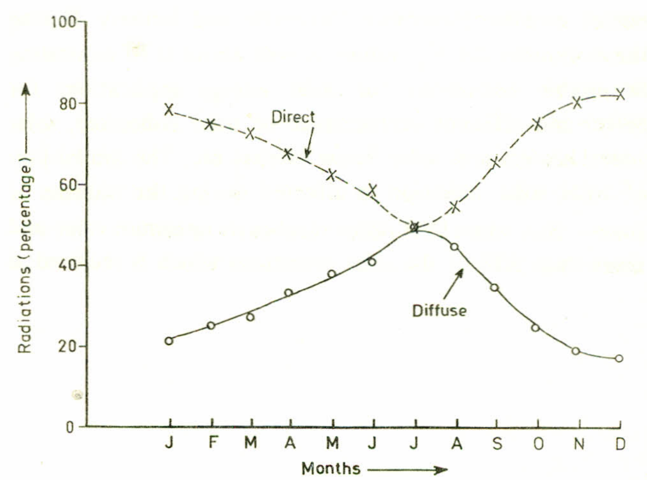

Fig. 3. Graph showing the pattern of variation of direct and diffuse radiations at Karachi for a year. (Lattitude = 24° $54'$ N)

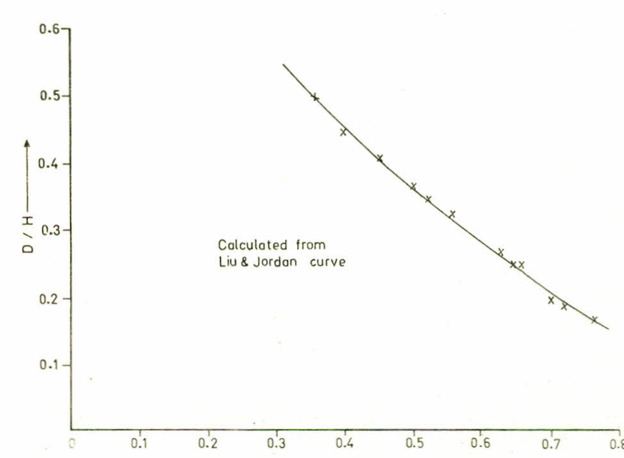

Fig. 4. A relationship between K_T and D/H Calculated from Liu and Jordan curve for Karachi.

of K_T estimated during the year is 0.359 (July) which indicates that even for worst sky conditons the availibility of total solar radiation from extraterrestrial insolation is above 35 %, whereas, the maximum available total solar radiation is above 75 % in the month of December.

DISCUSSIONS

The analysis of the calculated results show the amount of solar radiation incident on the horizontal surface at Karachi. From these estimates one can easily predict the performance of appliances which utilize solar energy. The extraterrestrial insolation over Karachi is transmitted fairly well throughout the year and fortunately due to our geographical location (lattitude = 24^{o}. 54′ N) there is a large percentage of total solar radiation (direct plus diffuse) available from extraterrestrial insolation during the winter months, November, December and January. During these months the K_T values is well above 0.70 exhibiting favourable conditions for solar energy applications for better and efficient performance of solar collectors, solar water heaters and solar house heaters etc. The availability of total solar radiation is affected during the months of June – July when D/H ratios reaches its optimum value and more than 50% of the solar radiations which is recieved, is diffuse. The ratios K_T are indicating a very special feature of the cloudiness at Karachi. The sky is mostly clear throughout the year except in the months of June – July when heavy overcast sky is seen over Karachi for monsoon rains. However, it is to be noted that even in these months rainy days are only few and the rains are scattered. The present theoretical estimates will serve as a guideline for better and efficient utilization of solar energy.

Acknowledgement. The authors are thankful to Prof. S. M. A. Trimizi, Vice-Chancellor, Karachi University for his encouragement to pursue these studies. We also thank Pakistan Meteorological Department, Karachi Civil Airport for providing us the useful data.

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