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MONTHLY MEAN HOURLY DIFFUSE SOLAR RADIATION FOR LESOTHO

K. K. GOPINATHAN

Department of Physics, National University of Lesotho, Roma, Lesotho, Southern Africa

ABSTRACT

The applicability of Liu and Jordan's method to calculate the hourly diffuse solar radiation was tested for two locations in South Africa by comprison with the available measured data. The excellent agreement between measured and estimated values suggested the suitability of Liu and Jordan model to the Southern African region. The calculated hourly diffuse radiation data can serve as a useful reference for radiation applications.

INTRODUCTION

The calculation of energy used in buildings and the performance of solar devices require long term measured data of meteorological parameters including solar radiation. The assessment of merit of solar devices depends on the availability of good data on insolation. The only measurements of solar radiation for which long term records are available from large number of locations are measurements of hemispherical insolation on horizontal surface. However, in order to predict the energy of solar collectors, one needs to know both the beam and the diffuse components of insolation.

Diffuse solar radiation on horizontal surfaces finds applications in getting global radiation on tilted surface, illumination design inside a building ets. But as compared to the measurement of global radiation, diffuse radiation is measured only at a few places. However, diffuse radiation values can be estimated from theoretical models and various correlations are available in the literature to estimate monthly mean daily diffuse radiation on a horizontal surface. Examples of such correlations include the ones by Liu and Jordan (1960), Page (1961), Iqbal (1979), Collares-Pereira and Rabl (1979), and Gopinathan (1988a).

For many solar energy applications computation of long term average hourly diffuse radiation is needed. Hourly values of solar radiation allow us to derive precise information about the performance of solar energy systems. However, the measured hourly data are available for a few location only. While the number of stations recording daily insolation has increased rapidly in recent, years experimental

After establishing the applicability of Liu and Jordan model to Southern African region, the model was used to calculate the ratio of hourly to daily diffuse radiation for six locations in Lesotho. The stations in Lesotho selected for study are Leribe, Letseng, Maputsoe, Maseru, Oxbow and Thaba Tseka. The r_d ratios were then used, along with the monthly mean daily diffuse radiation, to calculate the hourly diffuse radiation for the these locations. Monthly mean daily diffuse radiation needed for the study were obtained from the results published by Gopinathan (1988 b) for these stations.

RESULTS AND DISCUSSION

The estimated values of monthly average daily diffuse radiation for the South African locations are in Figures 1 and 2. Figures 1 and 2 are for Bloemfontein and Pretoria respectively and the estimated and measured values of hourly global radiation presented are for January and July. The measured data for both the stations are shown by the solid lines and the estimated values by the dotted lines. The upper pair of curves in both the figures are for January and the lower pair for July. The monthly mean hourly diffuse radiation presented in the figures are in MJm^{-2}. The time indicated in the figures is in solar time. The local time is converted into solar time using the procedure given by Duffie and Beckman (1980). The hourly radiation is plotted at the mid point of each hour.

The agreement between experimental and theoretical curves is excellent for both the locations. This is true for January and July and the correspondance is very close during both the summer and winter months. The theoretical method presented by Liu and Jordan is thus very accurate and well applicable to locations in the Southern African region. Equation 1 is then used to estimate hourly to daily ratio of diffuse radiation and the monthly mean hourly diffuse radiation for six locations in Lesotho. Using the values of the hour angle W_s around the solar noon, ratios of the hourly diffuse to daily diffuse are estimated for these locations and the results are presented in figures 3-8. Figures 3-8 are for Leribe, Letseng, Maputsoe, Maseru, Oxbow and Thaba Tseka, respectively. The r_d ratios are plotted as a function of day length (or sunset hour angle) for each month, for each of the hour $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, $4\frac{1}{2}$ and $5\frac{1}{2}$ measured from solar noon. A smooth curve can be observed for each hour and thus a set of curves for each station. Using these ratios and the reported values of monthly mean daily diffuse radiation (Gopinathan, 1988 b). hourly diffuse radiations are calculated for the six locations. The estimated values of monthly mean hourly diffuse radiation are presented in Table 1. The latitude (ϕ) and the elevation (h) of the locations are also included in the table.

The pattern of variation of r_d with time is the same for all the stations. The highest value of hourly radiation is for Maputsoe during December, between 11-12

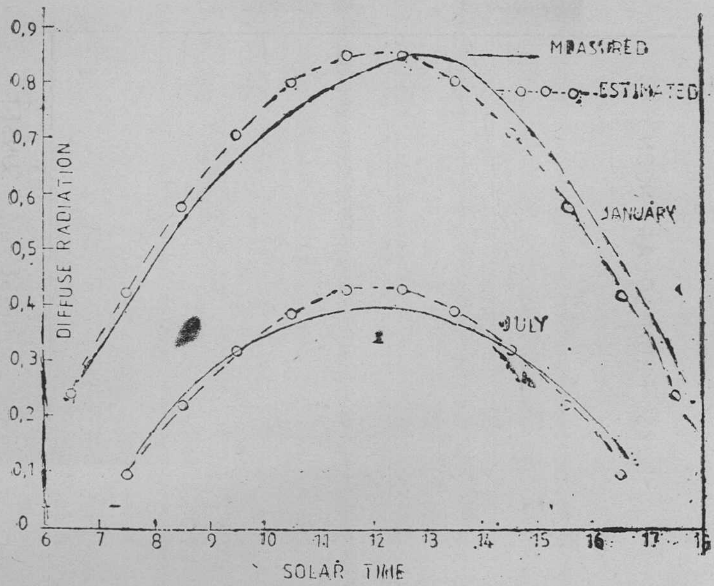

Figure 1. Comparison of experimental and theoretical values of monthly mean hourly diffuse radiation on a horizontal surface for Bloemfontein.

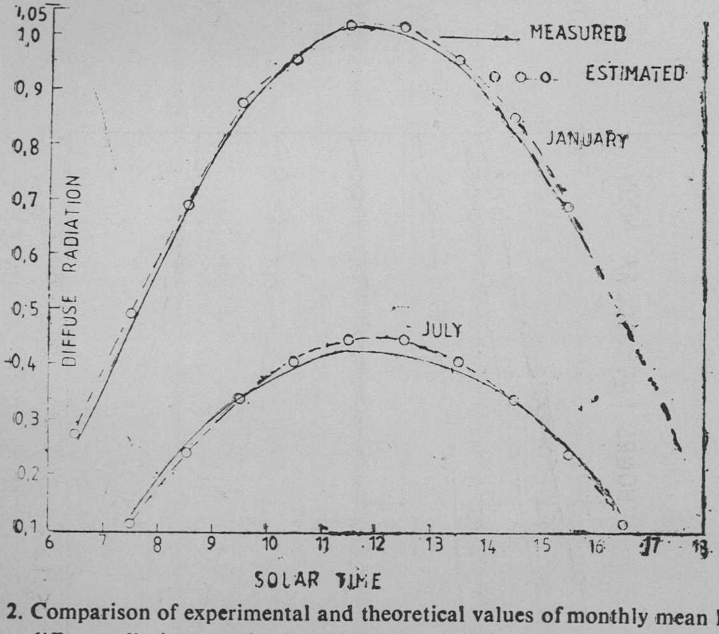

Figure 2. Comparison of experimental and theoretical values of monthly mean hourly diffuse radiation on a horizontal surface for Pretoria.

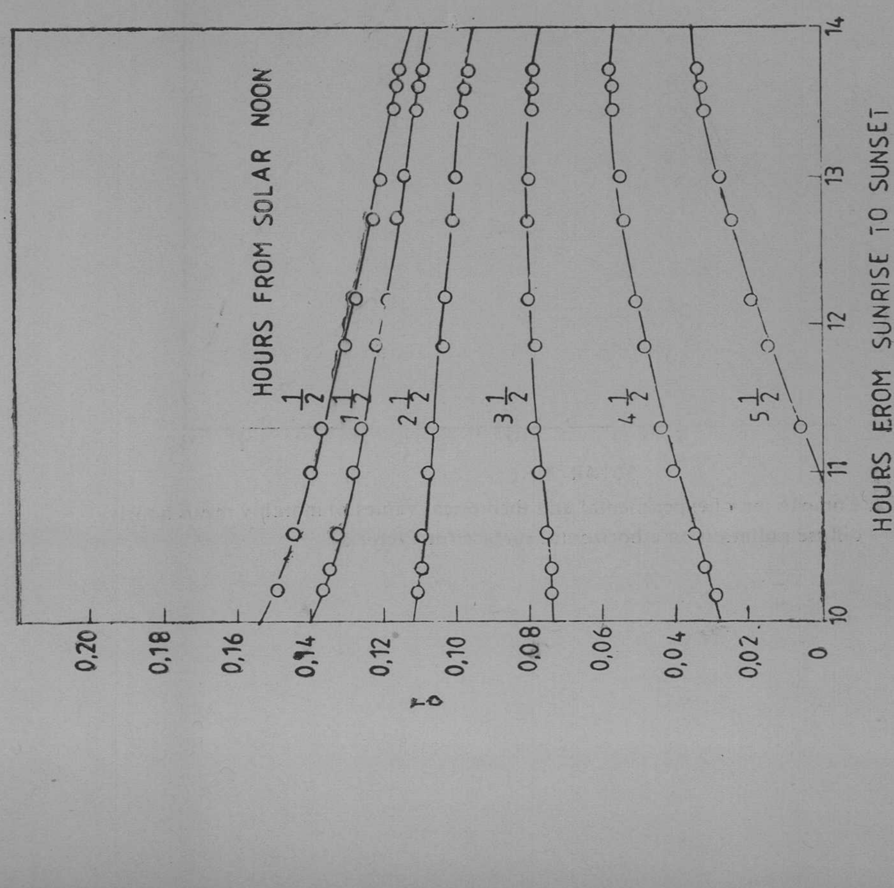

Figure 3. Ratio of hourly to daily daily diffuse radiation for Leribe

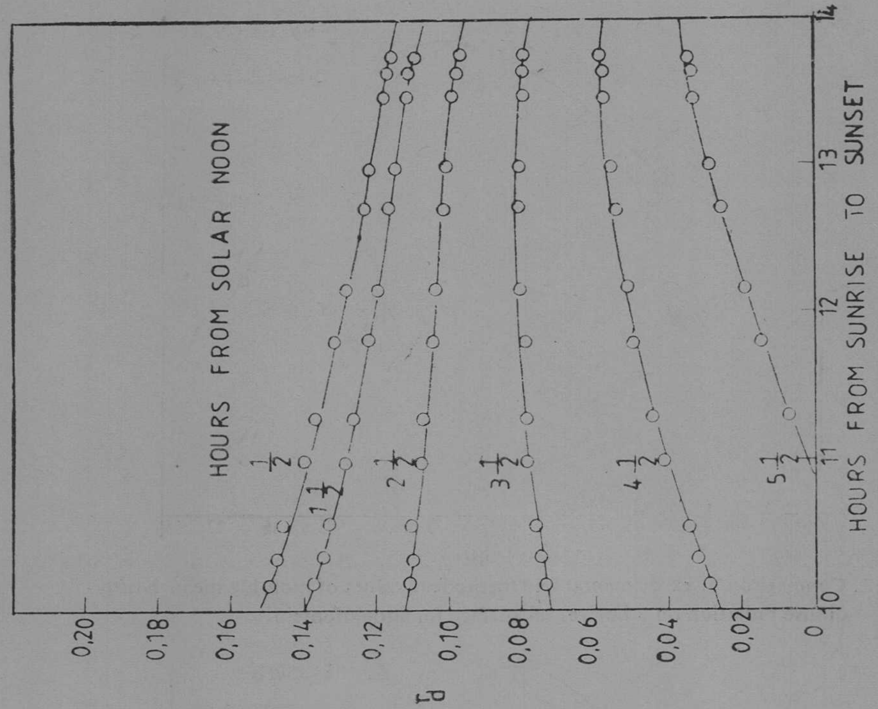

Figure 4. Ratio of hourly to daily diffuse radiation for Letseng

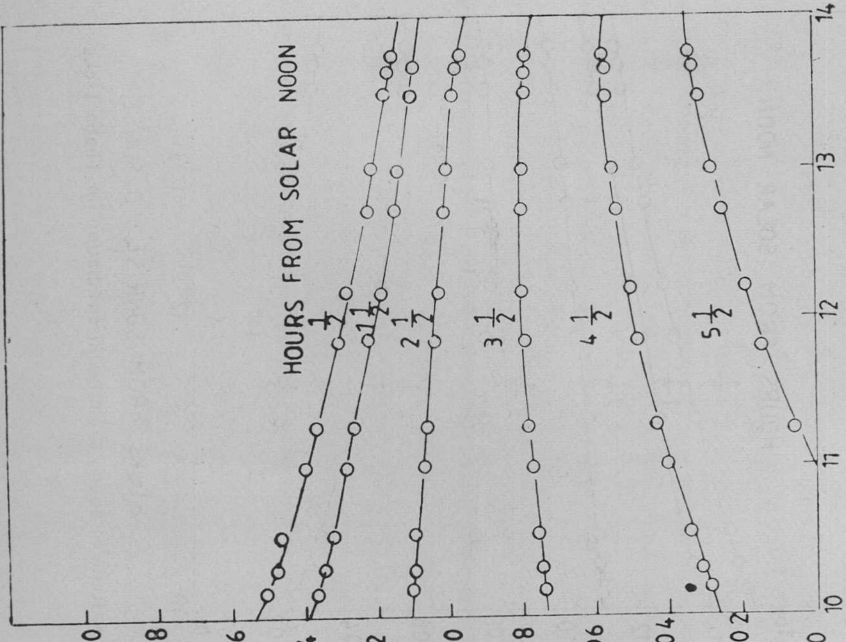

Fig. 6. Ratio of hourly to daily diffuse radiaiion for Maseru

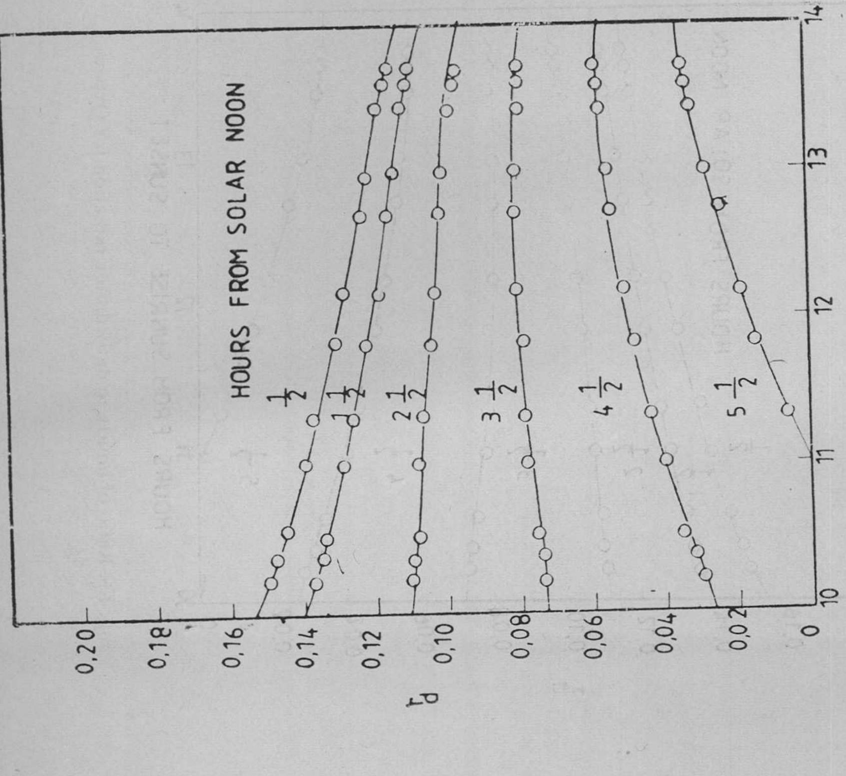

Fig. 5. Ratio of hourly to daily diffuse radiation for Maputsoe

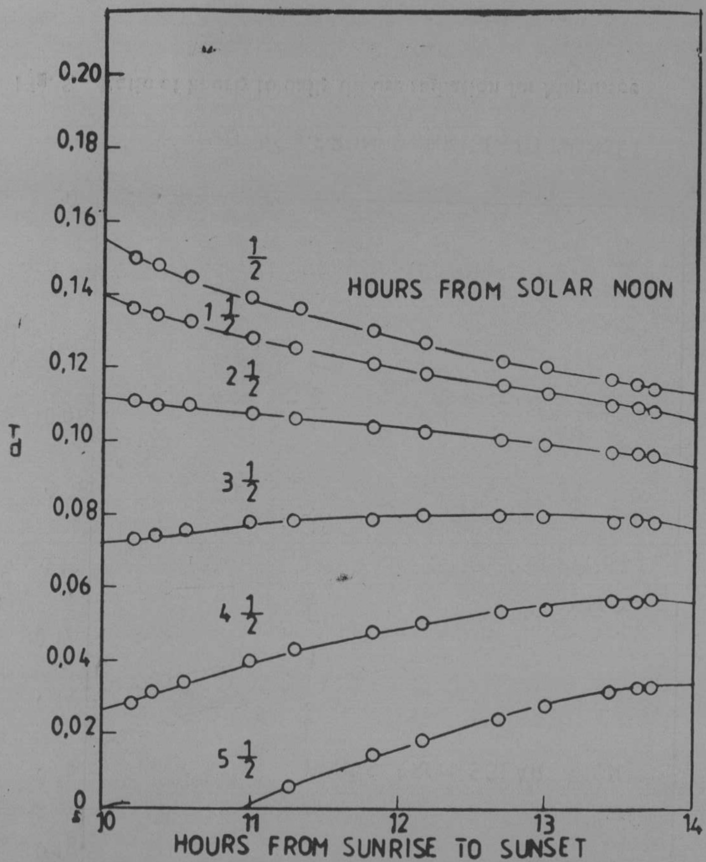

Fig. 7. Ratio of hourly to daily diffuse radiation for Oxbow

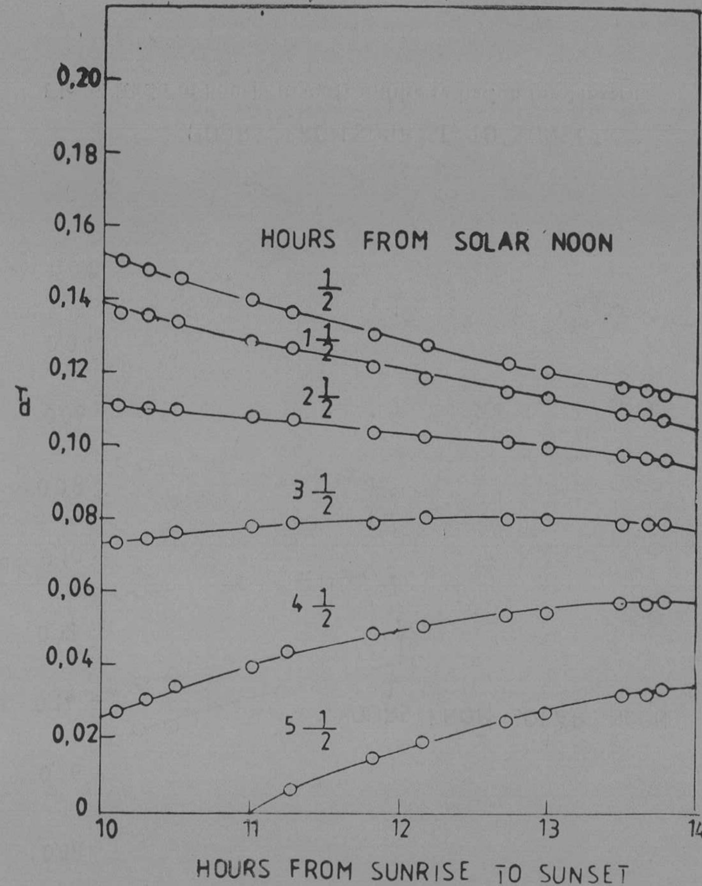

Fig. 8. Ratio of hourly to daily diffse radiation for Thaba Tseka

Table 1. Estimate monthly mean hourly diffuse radiation on a horizontal surface the six station

Station	Hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		HOURLY DIFFUSE RADIATION IN MJ m^{-2}											
LERIBE	11-12, 12-1	0.94	0.90	0.83	0.55	0.52	0.41	0.39	0.60	0.67	0.84	0.92	0.94
$\phi=28.53°S$	10-11, 1-2	0.89	0.84	0.77	0.51	0.48	0.37	0.36	0.56	0 62	0.79	0.87	0.89
h=1670m	9-10, 2-3	0.79	0.74	0.66	0.43	0.39	0.30	0,29	0.47	0.53	0.69	0.77	0.79
	8-9, 3-4	0.64	0,59	0.51	0.32	0.27	0.20	0.20	0.34	0.41	0.54	0 62	0.64
	7-8, 4-5	0.·6	0.41	0.33	0.18	0.13	0.08	0.09	0.18	0.25	0.37	0.44	0-47
	6-7, 5-6	0.27	0.21	0.12	0.02	—	—	—	—	0.08	0.17	0.25	0.28
LETSENG	11-12, 12-1	0.83	0.80	0.74	0.62	0.49	0.48	0 46	0.58	0.70	0.78	0 82	0.81
$\phi=29.0°S$	10-11, 1-2	0.78	0.75	0.69	0 57	0.45	0:43	0.42	0.53	0.65	0.73	0.77	0.77
h=3085m	9-10, 2-3	0.69	0.66	0.59	0.48	0.37	0.35	0.34	0.45	0.55	0 64	0.68	0.68
	8-9, 3-4	0.56	0.52	0.46	0.36	0-26	0.23	0.23	0 32	0.42	0.50	0.55	0.56
	7-8, 4-5	0.41	0.36	0.30	0.20	0.12	0.09	0.10	0.17	0.26	0.34	0.40	41
	6-7, 5-6	0.24	0.18	0.11	0.03	—	—	—	—	0.08	0.16	0.22	24
MAPUTSOE	11-12, 12-1	0.94	0.93	0.79	0.64	0 54	0.46	0.56	0.58	0.68	0.87	0.92	0.96
$\phi=28.89°S$	10-11, 1-2	0.82	0.88	0.74	0.60	0.50	0.42	0.51	0.53	0.63	0.81	0 87	0.90
h=1670 m	9-10, 2-3	0.79	0.77	0.63	0.50	0.41	0.34	0.42	0.45	0.54	0.71	0.77	0.80
	8-9, 3-4	0.64	0.61	0.49	0.37	0.28	0.23	0.28	0.32	0.41	0.56	0.62	0.66
	7-8, 4-5	0.47	0.43	0.31	0.21	0.13	0.09	0.12	0.17	0.25	0.38	0.45	0.48
	6-7, 5-6	0.27	0.21	0.12	0.03	—	—	—	—	0.08	0.18	0 25	0.28
MASERU	11·12, 12-1	0.91	0.85	0.80	0.68	0.53	0.48	0.47	0:53	0.61	0.85	0.90	0.87
$\phi=29.32°S$	10-11. 1-2	0.86	0.80	0.74	0.63	0.49	0.44	0.43	0.49	0.57	0.80	0.85	0.83
h=1571 m	9-10, 2-3	0.76	0.70	0.64	0.53	0.40	0.35	0.35	0.41	0.49	0.70	0.75	0.73
	8-9, 3-4	0.62	0.56	0.50	0.39	0.28	0.23	0.24	0.29	0.37	0.55	0.61	0.60
	7-8, 4-5	0.45	0.39	0.32	0.22	0.13	0.09	0.10	0.15	0.23	0.37	0.44	0.44
	6-7, 5-6	0.26	0.20	0.12	0.03	—	—	—	—	0.07	0.18	0.24	0.26

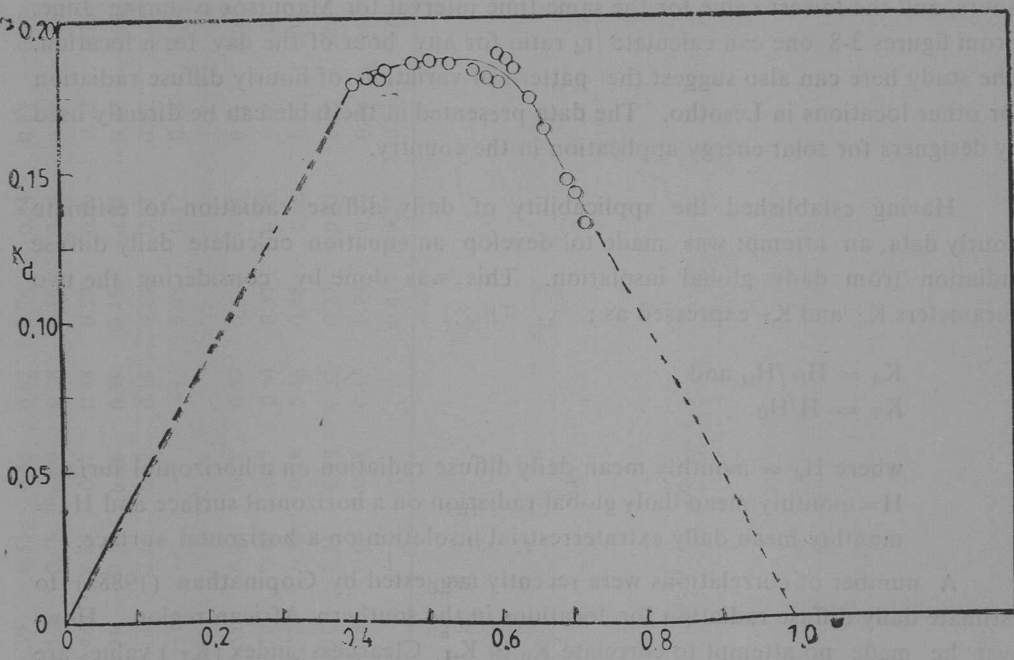

Fig. 9. The relation between daily total radiation and daily diffuse radiation on a horizontal surface

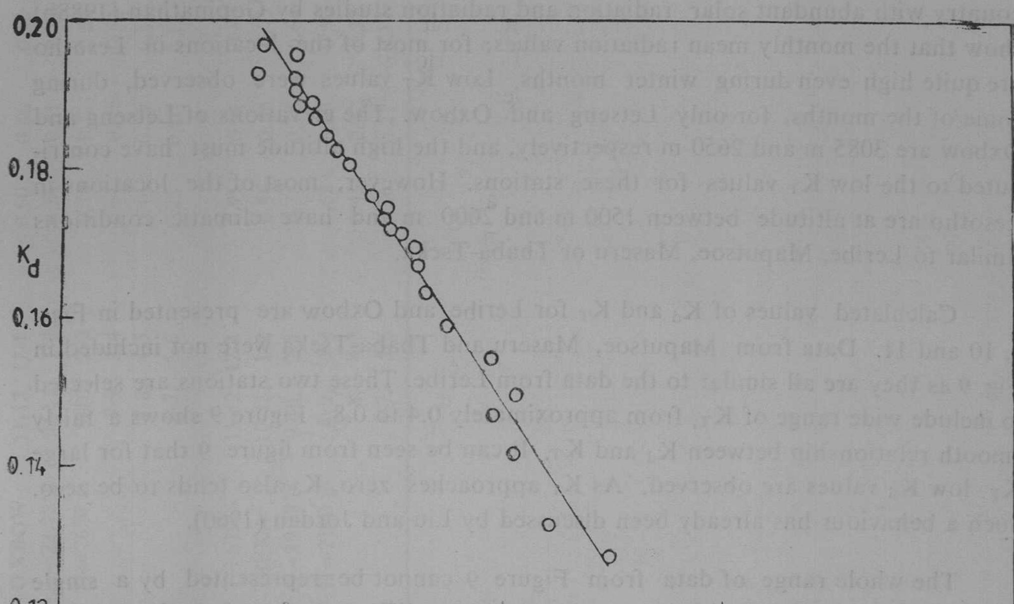

Fig. 10. Correlation between K_d and K_T

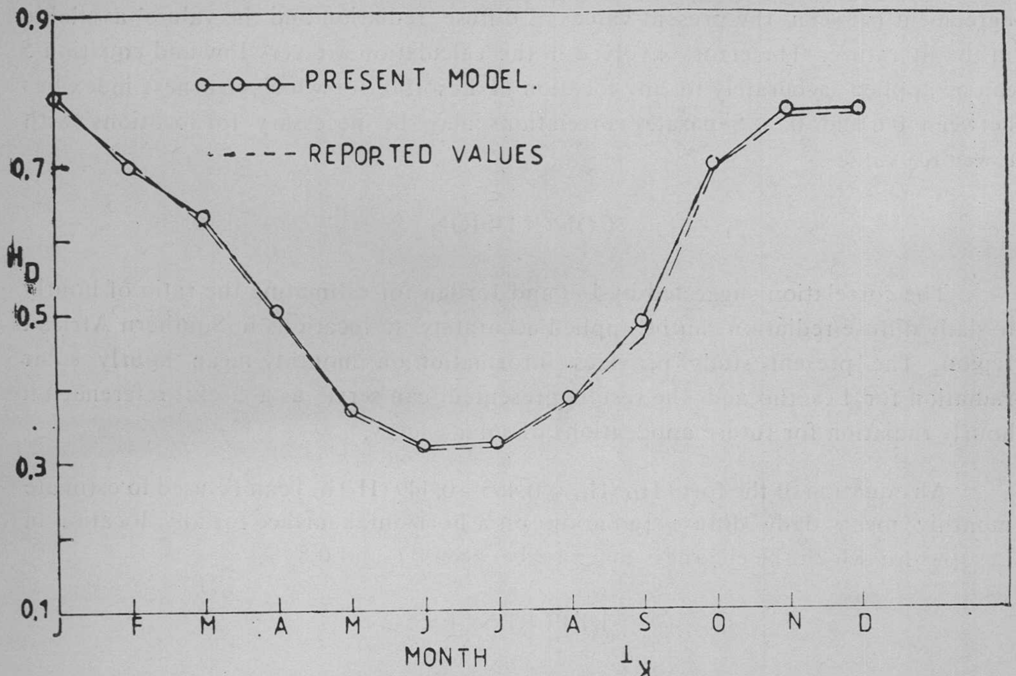

Fig 11. Comparison between estimated and reported monthly mean daily diffuse radiation on a horizontal surface for Maseru

in Lesotho lie between 0.6 and 0.8 and an attempt was made here to obtain an empirial relationship between K_d and K_T for the range $0.6 < K_T < 0.8$. K_d and K_T values for Leribe, Maputsoe and Thaba-Tseka are presented in Figure 10. The K_T values for all the three locations lie in the range between 0.6 and 0.8. Figure 10 clearly demonstrates the linear dependence of K_d on K_T in the range $0.6 < K_T < 0.8$. Data from these three stations were then used in a linear regression analysis to obtain a mathematical relationship between K_d and K_T. Proper computer programmes were written for the analysis. An expression of the form

$$H_D / H_O = 0.463 - 0.449 \, (H/H_O) \tag{5}$$

was obtained from the regression analysis, to express the dependence of H_D / H_O on H/H_O with the coefficient of correlation=0.990 and Standard error estimat=2.579×10^{-3}.

The applicability of the developed correlation was tested by estimating monthly mean daily diffuse radiatian for Maseru, a station which was not included in the regression analysis for developing equation 5. The estimated values of daily diffuse radiation for Maseru alongwith the reported data (Gopinathan, 1988b) for that station are presented in Figure 11. As seen from Figure 11, there is a remarkable agreement between the present values of diffuse rediation and the values available in the literature. The errors involved in the calculation are very low and equation 5 can be applied accurately to any location in Lesotho, for which clearness index lies between 0.6 and 0. 8. Separate correlations may be necessary for locations with lower K_T values.

CONCLUSION

The correlation suggested by Liu and Jordan for estimating the ratio of hourly to daily diffuse rediation can be applied accurately to locations in Southern African region. The present study provides information on monthly mean hourly solar radiation for Lesotho and the results presented can serve as a useful reference on hourly radiation for future applications of solar energy.

An equation of the form $H_D/H_O = 0.463 - 0.449 (H/H_O)$ can be used to estimate monthly mean daily diffuse radiation on a horizontal surface for any location in Lesotho for which the clearness index lie between 0.6 and 0.8.

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