Monthly Mean Daily Utilizability of South India

B. Janarthanan [*], J. Chandrasekaran [*] and S. Kumar [**]

[*] Department of Physics
Sri Ramakrishna Mission Vidyalaya
College of Arts and Science
Coimbatore 641 020
INDIA

[**] Energy Field of Study
School of Environment Resources and Development
Asian Institute of Technology
Pathumthani – 12120
THAILAND

ABSTRACT

The level of solar irradiance is the principle input parameter of any solar apparatus or solar system. Flat-plate solar collectors are solar systems, which have been widely used for water heating by utilizing the level of solar irradiance. For optimum system design, it is necessary to examine the long-term performance of flat plate solar collectors. Utilizability is one of the design methods in designing hot water system by using solar irradiance. Utilizability is the fraction of long-term average radiation which is above the specified critical radiation level that can be collected by an idealized collector for which $F_R(\tau\alpha) = 1$. Utilizability correlations proposed by Klein (1978) and Collares-Pereira and Rabl (1979) have been based on data pertaining to US locations that are temperate regions. Generalized $\bar{k}$ curves developed by Liu and Jordan (1960) have been suspected for tropical locations (Saunier et al., 1987). It is necessary to find the applicability of Klein's utilizability correlations for tropical locations.

In South India, long-term data (five years) for four locations are concentrated to find the data based utilizability correlation and Klein's correlation. The standard deviation and relative standard deviation are noted between data and Klein's utilizability correlation. The results indicate that relative standard deviation between data and Klein's utilizability correlation is less than 7% an average for all the months. Henceforth Klein's utilizability correlation is advisable to find the monthly mean daily utilizability when data based correlations are not available for the locations in South India.

1. INTRODUCTION

Major applications of the utilizability method include: domestic hot water and space heating [1], industrial process heat [2], and photovoltaic systems [3]. Collares-Pereira and Rabl [4,5] and Klein [6] have proposed utilizability correlations based on data pertaining to US locations which are temperate regions. Among all the other utilizability methods, Collares-Pereira and Rabl [4,5] and Klein [6] utilizability correlations are very compatible since they are very simple and easy to apply.

Since the difference between Klein [6] and Collares-Pereira and Rabl [4,5] is very minor, the daily utilizability concept of Klein [6] has been used. The main aim of the present work is to confirm whether the Klein's utilizability correlation is applicable in South India or not. It has been done by finding the data based correlations and Klein's utilizability correlation and compared by standard deviation and relative standard deviation. Monthly mean daily utilizability curves are drawn for both data based correlation and Klein's correlation.

2. DATA USED

In South India, four tropical locations (Chennai, Trivandrum, Port Blair and Minicoy) data of hourly global and diffuse radiation on a horizontal surface for a period of five years are obtained from Indian Meteorological Department. From the hourly global and diffuse radiation data, the monthly mean global and diffuse radiation for all the months have been calculated and used. As it is necessary to find the validity of Klein's correlation for any year, data for the four locations are selected for different years from 1982 to 1995. The latitude and longitude for the specific locations in South India are given below in the Table. 1.

Table 1 Latitude and Longitude of the Locations:

LOCATION	LATITUDE	LONGITUDE
Chennai	13°N	80.18°E
Port Blair	11.67°N	92.72°E
Trivandrum	8.48°N	76.95°E
Minicoy	8. 30°N	73.00°E

3. ADOPTED PROCEDURE

Using the data of monthly global and diffuse radiation the monthly mean daily utilizability fractions were calculated for each month for different critical radiation (I_c) values for horizontal surface utilizing the Klein's [6] concept of daily utilizability. Data based correlation has been found by utilizing the monthly mean global and diffuse radiation. The procedure used is described below.

3.1 Utilizability from Klein method

The correlation is of the form [6]

$$\bar{\phi}_k = exp\,[(A + B\,(R_n / \bar{R})\,(X_c + C\,X_c^2)] \quad (1)$$

where,

$$A = 7.476 - 20\,\bar{k} + 11.188\,\bar{k}^2$$

$$B = -8.562 + 18.679\,\bar{k} - 9.948\,\bar{k}^2$$

$$C = -0.722 + 2.426\,\bar{k} + 0.439\,\bar{k}^2$$

The constants *A*, *B* and *C* used have been taken from Theilacker and Klein [7]. The monthly average daily utilizability can be determined from equation (2) as follows.

1. Using the monthly average hourly global radiation, $\bar{k}$ is found for each month, calculate *A*, *B*, and $\bar{C}$.
2. $\bar{R}$ is calculated using the equation A.1.2 of [6]. *R* is a function of R_b and H_d / H. R_b is calculated using expression A.1.4 of [6]. H_d / H can be estimated from the correlation given in [8].
3. R_n is a function of H_d / H, $r_{d,n}$ and $R_{b,n}$, $r_{t,n}$, $r_{,d,n}$ and $R_{b,n}$ can be evaluated using the equation A.2.2, A.2.3, and A.2.4 respectively of [6]. Hence R_n is evaluated.
4. $$X_c = \frac{I_c}{r_{t,n}\,R_n\,\bar{H}} \quad (2)$$
5. Using equation (1) and substituting the values for a given I_c (i.e., for a given X_c) $\bar{\phi}_k$ can be calcalated.

3.2 Utilizability from data

The numerical integration of long term weather data gives the utilizability fraction ϕ_d. The utilizability fraction ϕ_d was calculated for different critical radiation I_c, ranging from 0 to 3.6 MJ/m^2 h in steps of
0.45 MJ/m^2 h by using the following expression.

$$\bar{\phi}_d = \frac{\sum\sum [I_T - I]^+}{\sum\sum I} \qquad (3)$$

I_T was calculated using the following expression given by Liu and Jordan [9] as,

$$I_T = [I - I_d] R_b + I_d [(1+\cos\beta)/2] + I\rho[(1-\cos\beta)/2] \qquad (4)$$

Utilizability can then be calculated by putting [$I_T = I$] in equation (3).

The values obtained from both the equations (1) and (3) were compared by evaluating the standard deviation (SD) given by

$$SD = [(1/n_o) \sum (\bar{\phi}_d - \bar{\phi}_i)^2]^{1/2} \qquad (5)$$

In absolute units and relative standard deviation (RSD) given by

$$RSD = [(1/n_o) \sum ((\bar{\phi}_d - \bar{\phi}_i)/\bar{\phi}_i)^2]^{1/2} \qquad (6)$$

In relative units.

4. DISCUSSION

The values of different critical radiation ratios (I_c) have been plotted for Chennai, Trivandrum, Port Blair and Minicoy for the months of February and August are shown in the figures (Chennai – figure (1-2), Port Blair – figure (3-4), Trivandrum – figure (5-6), Minicoy – figure (7-8)). From the figures it is observed that the two curves both data based and Klein's correlation have conjoint trend. In order to signify the closeness of the two curves, the standard deviation and relative standard deviation have been calculated for each month for the four locations and are presented in the Table 2A and Table 2B.

It is observed that in Chennai the SD varies from 0.026 to 0.162, the average being 0.07897, while the RSD values vary from a minimum of 2.0% to a maximum of 17.18%, the average being 6.44% and in Trivandrum SD varies from 0.022 to 0.1016, the average being 0.0595, while the RSD values vary from a minimum of 1.38% to a maximum of 7.08%, the average being 3.81% and in Port Blair the SD varies from 0.028 to 0.199, the average being 0.0766, while the RSD values vary from a minimum of 1.01% to a maximum of 9.48%, the average being 5.70% and similarly in Minicoy the SD varies from 0.031 to 0.1180, the average being 0.065, while the RSD values vary from a minimum of 1.13% to a maximum of 8.56%, the average being 4.17%.

It is clear that the difference between data based correlation and Klein's correlation for South India which is tropical is less than 7% on the average. Thus in South India, if long term insolation of hourly data are not available, Utilizability concept proposed by Klein [6] and Collares-Pereira and Rabl [4,5] can be utilized with little error.

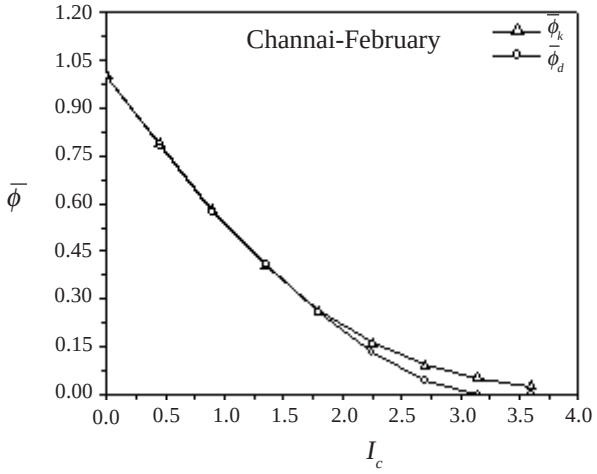

Fig. 1 Monthly mean daily utilizability values in February (both Klein and Data)

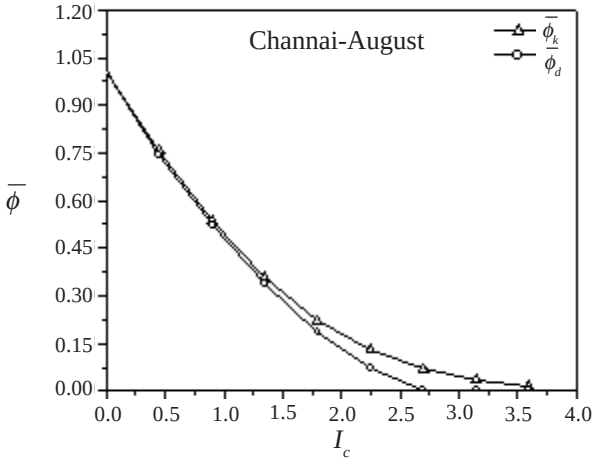

Fig. 2 Monthly mean daily utilizability values in August (both Klein and Data)

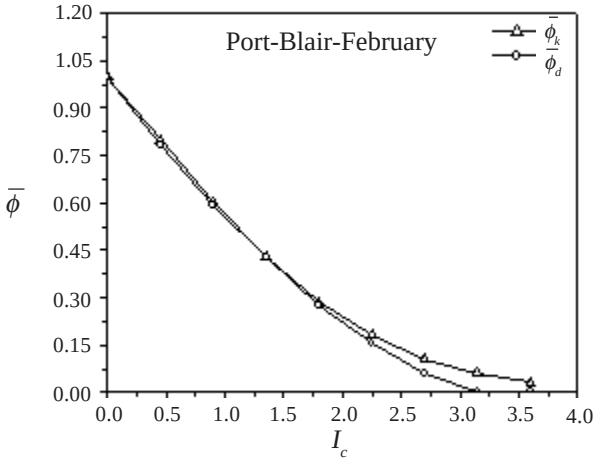

Fig. 3 Monthly mean daily utilizability values in February (both Klein and Data)

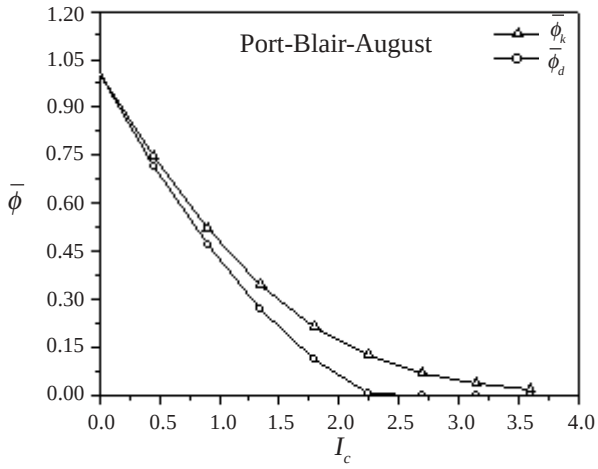

Fig. 4 Monthly mean daily utilizability values in August (both Klein and Data)

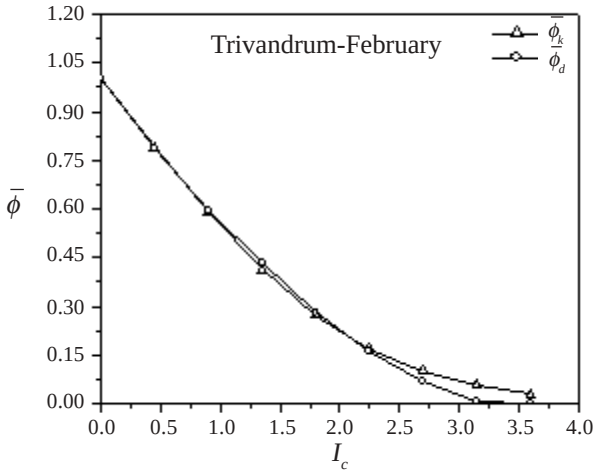

Fig. 5 Mc and Data)

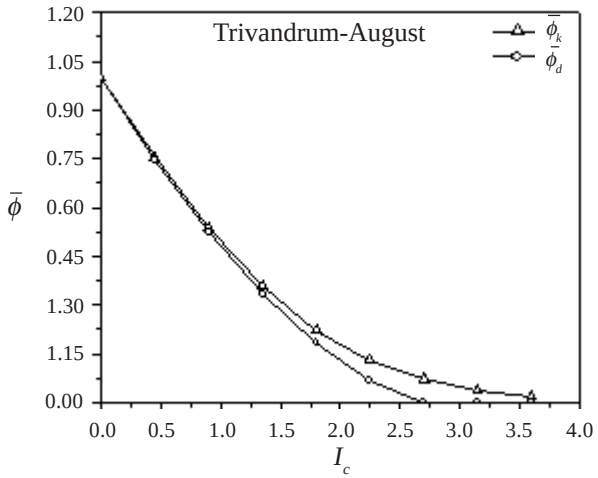

Fig. 6 Monthly mean daily utilizability values in August (both Klein and Data)

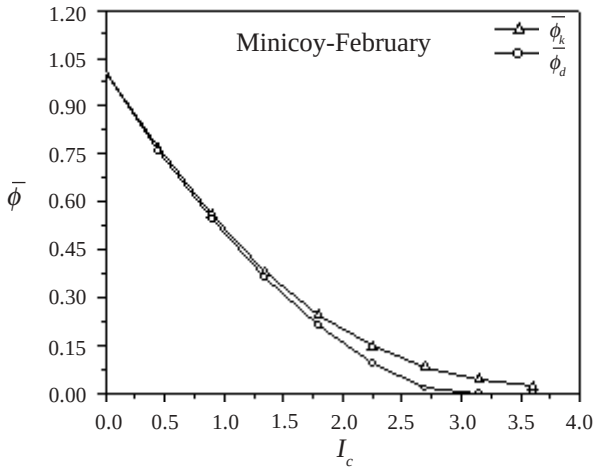

Fig. 7 Monthly mean daily utilizability values in February (both Klein and Data)

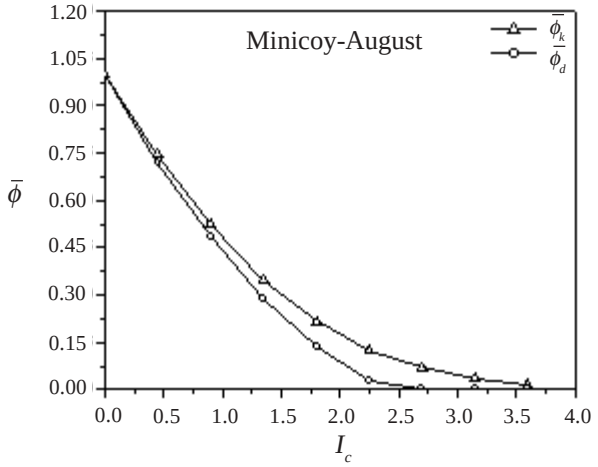

Fig. 8 Monthly mean daily utilizability values in August (both Klein and Data)

Table 2A Standard Deviation and Relative Standard Deviation between Data Based and Klein's Correlation for Chennai and Trivandrum

Month	Chennai		Trivandrum	
	SD	RSD (%)	SD	RSD (%)
January	0.094	10.25	0.073	4.33
February	0.026	2.04	0.022	1.66
March	0.056	2.07	0.046	1.38
April	0.027	2.00	0.028	2.15
May	0.029	2.25	0.034	2.70
June	0.120	17.18	0.072	3.59
July	0.117	7.89	0.100	7.08
August	0.035	2.59	0.039	3.00
September	0.120	7.83	0.082	5.24
October	0.084	5.94	0.052	3.50
November	0.073	5.20	0.059	4.39
December	0.162	12.00	0.101	6.72

Table 2B Standard Deviation and Relative Standard Deviation between Data Based and Klein's Correlation for Port Blair and Minicoy

Month	Port Blair		Minicoy	
	SD	RSD (%)	SD	RSD (%)
January	0.088	8.22	0.056	2.24
February	0.029	2.19	0.036	2.62
March	0.046	1.42	0.031	1.13
April	0.028	2.15	0.039	2.82
May	0.030	2.30	0.055	4.14
June	0.101	1.01	0.058	2.18
July	0.127	9.15	0.118	8.56
August	0.066	4.81	0.056	3.93
September	0.199	8.05	0.115	7.89
October	0.046	3.20	0.063	4.30
November	0.123	9.48	0.049	3.27
December	0.111	7.32	0.106	6.94

5. CONCLUSION

In this study, it is confirmed that if long term insolation of hourly data are not available for locations in South India, it is advisable to handle Klein's correlation for the calculation of Utilizability fraction. This result indicates that the relative standard deviation between the correlations is less than 7% an average for all the four locations in South India. Hence, in South India Klein's utilizability correlation can be used to estimate the daily utilizability and the useful energy is collected by a flat plate solar thermal collector.

6. NOMENCLATURE

A, *B* and *C*: Coefficients in equation (1)

F_R : Collector overall heat removal efficiency factor (dimensionless)

H_d : Daily diffuse radiation on a horizontal surface (MJ/m^2)

$\overline{H}_d$: Monthly average daily diffuse radiation on a horizontal surface (MJ/m^2)

H_g : Daily global radiation on a horizontal surface (MJ/m^2)

$\overline{H}_g$: Monthly average daily global radiation on a horizontal surface (MJ/m^2)

$\overline{H}_T$: Monthly average daily global radiation on a tilted surface (MJ/m^2)

I : Hourly global solar radiation incident on a horizontal surface (MJ/m^2)

I_c : Critical radiation level (MJ/m^2 hour, W/m^2)

I_d : Hourly diffuse radiation incident on a horizontal surface (MJ/m^2)

I_T : Hourly total solar radiation incident on a tilted surface (MJ/m^2)

$\overline{k}$: Ratio of the monthly average daily global radiation on a horizontal surface to the monthly average daily extraterrestrial radiation on horizontal surface (dimensionless)

N : Number of days

n : Number of hours

n_o : Number of data

$\overline{R}$: Ratio of monthly average daily global radiation on a tilted surface to that on a horizontal

surface (dimensionless)

R_n : Ratio of radiation on a tilted surface to that on a horizontal surface at noon (dimensionless)

R_b : Ratio of daily beam radiation on a tilted surface to that on a horizontal surface (dimensionless)

R_b : Ratio of monthly average daily beam radiation on a tilted surface to that on a horizontal surface (dimensionless)

$R_{b,n}$: Ratio of beam radiation on a tilted surface to that on a horizontal Surface at noon (dimensionless)

$r_{t,n}$: Ratio of radiation at noon to the daily total radiation (dimensionless)

$r_{d,n}$: Ratio of diffuse radiation at noon to the daily diffuse radiation (dimensionless)

X_c : Monthly average critical radiation ratio given by Equation (2) (dimensionless)

Greek Letters

$\bar{\phi}$: Monthly average daily utilizability (dimensionless)

$\bar{\phi}_d$: Monthly average daily utilizability using data expression (2) (dimensionless)

ϕ_k : Monthly average daily utilizability using Klein's expression (1) (dimensionless)

$\tau\alpha$: Monthly average transmittance-absorptance product (dimensionless)

ω_s : Sunset hour angle on a horizontal surface (degrees)

$\omega s'$: Sunset hour angle on a tilted surface (degrees)

ρ : Ground reflectance assumed to be 0.2

β : Slope of the collector plane with respect to the horizontal (degrees)

7. REFERENCES

[1] Klein, S.A.; and Beckman, W.A. 1979. A General Design Method for Closed Loop Solar Energy Systems, *Solar Energy* 22: 269-282.

[2] Gordon, J.M. and Rabl, A. 1982. Design, Analysis and Optimization of Solar Industrial Process Heat Plants without Storage, *Solar Energy* 28: 519-530.

[3] Siegel, M.D.; Klein, S.A.; and Beckman, W.A. 1981. A Simplified Method for Estimating the Monthly Average Performance of Photovoltaic Systems, *Solar Energy* 26: 413-423.

[4] Collares-Pereira, M.; and Rabl, A. 1979a. Derivation of Method for Predicting Long Term Average Energy Delivery of Solar Collectors, *Solar Energy* 23: 223-233.

[5] Collares-Pereira, M.; and Rabl, A. 1979b. Simple Procedure for Predicting Long Term Average Performance of Non-Concentrating and of Concentrating Solar Collectors, *Solar Energy* 23: 235-253.

[6] Klein, S.A. 1978. Calculation of Flat Plate Collector Utilizability, *Solar Energy* 21: 393-402

[7] Theilacker, J.C., and Klein, S.A. 1980. Improvements in the Utilizability Relationships. In *American Section of International Solar Energy Society Meeting Proceedings*, Phoenix, Arizona, USA, 271-275.

[8] Muneer, T.; and Hawas, H.M. 1984. Correlation between Daily Diffuse and Global Radiation for India, *Energy Conservation and Management* 24: 151-154.

[9] Liu, B.Y.H.; and Jordan, R.C. 1963. A rational procedure for predicting the long-term average performance of flat-plate solar energy collectors, *Solar Energy 7*: 53-74.