

## Solar energy utilization potential in Jodhpur and New Delhi

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**ABSTRACT.** Average useful solar energies available for utilisation in respect of flat-plate collector kept at optimum tilts in respect of Jodhpur and Delhi were worked out for typical winter and summer months. Based on these average energies, generalised design curves for water heating by flat-plate collectors giving the ratio of useful energy collected by the flat-plate collector to the heat removal efficiency factor in terms of inlet temperature rise over ambient temperature have been prepared. Such design curves based on 90 per cent, 50 per cent and 10 per cent exceedance values of useful energies have also been presented in addition to those using average values. With these design curves the flat-plate collector areas required for various heating loads has been estimated for these stations.

### 1. Introduction

In a developing country like India the utilisation of solar energy which is a readily accessible source of energy is extremely important in view of the chronic shortage of conventional sources of power. In India, not much progress has been made in the direct utilisation of solar energy. The object of this paper is to study in detail the solar radiation that is available for utilisation in various solar devices and to provide design data for flat-plate collector in respect of Jodhpur and New Delhi which represent arid and semi-arid regions of the country respectively.

In India it has been reported by Desikan *et al.* (1959) that diffuse radiation forms a high percentage and thus the use of flat-plate collector which absorbs the direct as well as diffuse solar radiation becomes more significant from the point of view of maximum solar radiation for utilisation purposes.

The utilizability curves as given by Liu and Jordan (1963, 1967) for predicting the normal average performance of the flat-plate collectors have been used for drawing performance curves for Jodhpur and New Delhi based on normal average solar radiation values and also those which are exceeded on 10 per cent, 50 per cent and 90 per cent occasions.

### 2. Solar radiation on horizontal and inclined surfaces

#### (a) Comparison of mean monthly total and diffuse radiation on horizontal surface over Jodhpur and New Delhi

The basic solar radiation data, *i.e.*, total and diffuse solar radiation on horizontal surface for

Jodhpur and New Delhi were taken from Rao and Ganesan (1972). Fig. 1 shows the monthly variation of normal average daily total and diffuse solar radiation on horizontal surface for Jodhpur and New Delhi. It is seen from the figure that the total radiation over Jodhpur is more than that of New Delhi for all the months. The difference is the least (24 cal/sq. cm day) in May and highest (70 cal/sq. cm day) in July and the same when averaged over all the months works out to be 46 cal/sq. cm day. In spite of the same, the mean monthly diffuse radiation over Jodhpur is either equal or less than that of New Delhi for all the months except August which is the mid monsoon month. Especially, the Delhi diffuse radiation value is higher by as much as 46 cal/sq. cm day during the hot weather period of March to June. The suspension of comparatively large amounts of dust in the atmosphere over Jodhpur appears to be a factor which has influence in the above phenomenon especially in view of the fact that the effect is absent in August when the dust generally clears out after good rain. This, however, requires further investigation.

#### (b) Total solar radiation on inclined surface

Solar radiation is generally measured on horizontal surfaces. However, from the point of view of utilisation, a knowledge of solar radiation on the inclined surface is more important since the flat plate collectors are generally kept at optimum tilt so as to receive maximum solar radiation during the desired season of use. Hence, it is necessary to convert the measured radiation values on horizontal surface onto the tilted surface so as to be used for predicting collector

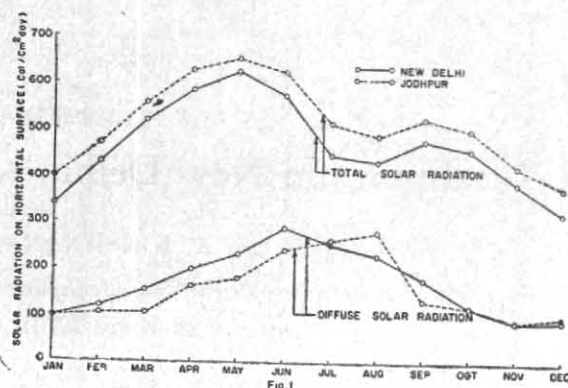


Fig. 1. Monthly variation of total and diffuse solar radiation on horizontal surface

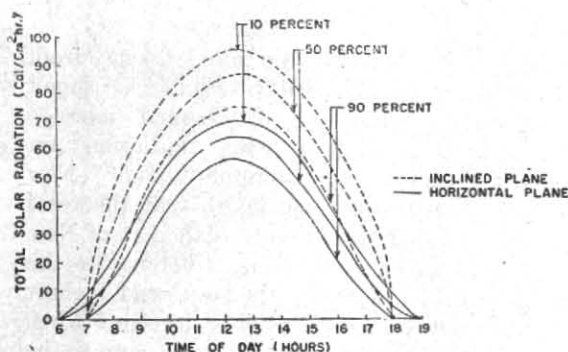


Fig. 2. Jodhpur

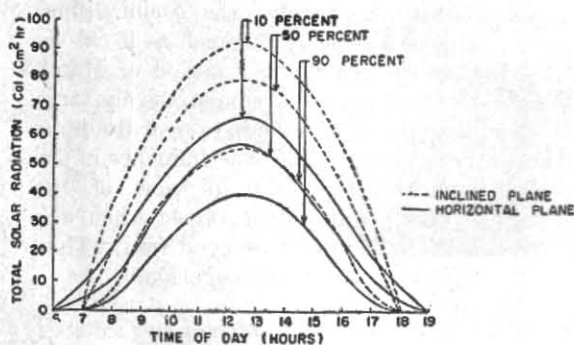


Fig. 3. New Delhi

Fig. 2 and 3. Various exceedance values of total solar radiation on horizontal and inclined plane for January

performance. The various formulae used for predicting direct, diffuse, and reflected solar radiation components and their conversion factors for converting horizontal incidence to incidence on tilted surface are discussed by Garg and Krishnan (1973).

TABLE 1

Average and various exceedance values of total solar radiation ( $\text{cal}/\text{cm}^2 \text{ day}$ ) on horizontal ( $H$ ) and inclined surface ( $H_t$ )

|           | Average |       | 90 percent |       | 50 percent |       | 10 percent |       |
|-----------|---------|-------|------------|-------|------------|-------|------------|-------|
|           | $H$     | $H_t$ | $H$        | $H_t$ | $H$        | $H_t$ | $H$        | $H_t$ |
| New Delhi | 341     | 540   | 233        | 349   | 364        | 550   | 455        | 700   |
| Jodhpur   | 399     | 639   | 337        | 496   | 390        | 635   | 501        | 740   |

Because of the intermittent nature of the radiation and high day-to-day variation due to cloudiness, the solar radiation values which are exceeded on 10 per cent, 50 per cent and 90 per cent have been computed for the two places. These data have been converted onto the optimum tilt for winter use, *i.e.*, latitude of the place plus 15 degrees as determined by Garg (1967) for Jodhpur and New Delhi which is shown in Figs. 2 and 3 respectively. As is to be expected, for all the exceedance values the radiation on the inclined surface is higher than that on the horizontal surface except in the early morning hours and late evening hours. It is interesting to note that the 90 per cent exceedance value in respect of inclined surface is even higher than the 10 per cent exceedance value for radiation over the horizontal plane in case of Jodhpur.

Table 1 shows the average, 90 per cent, 50 per cent and 10 per cent exceedance values of total solar radiation on horizontal surface ( $H$ ) as well as on inclined at optimum tilt ( $H_t$ ) (at an elevation of Lat. plus  $15^\circ$ ) in respect of Jodhpur and New Delhi for the typical winter month of January.

It is seen that though the average radiation on horizontal surface over Jodhpur and New Delhi are only 341 and 399  $\text{cal}/\text{sq. cm}$  day, the actual utilizable energy on inclined surface at optimum tilt are 540 and 639  $\text{cal}/\text{sq. cm}$  day respectively. This result clearly reveals, the enormous possibilities of utilizing solar energy for solar water heating, room heating and drying etc, in winter at these stations. Even the radiation values that would be definitely available for 90 per cent of occasions during January, work out to be 496 and 349  $\text{cal}/\text{sq. cm}$  day for Jodhpur and New Delhi respectively. These values are sufficient for the operation of appliances like solar water heater etc.

### 3. Development of the design curves for flat plate collector for water heating

#### (a) Theory of method used for preparing design curves

The basic heat balance equation for the flat



plate collector can be written as :

Useful heat derived from the collector =

Heat absorbed—thermal losses

$$i.e., q_u = q_a - q_l \quad (1)$$

The energy absorbed by the collector,  $q_a$  per unit of area per unit of time is given as :

$$q_a = \left[ \frac{I_{Th} - I_{dh}}{R R_R \tau_R \alpha_R} \right] R_D \tau_D \alpha_D + I_{dh} \frac{R_d \tau_d \alpha_d}{D S} + I_{Th} \quad (2)$$

where,

$\tau_D, \tau_d, \tau_R$  = transmittance of cover glass for direct diffuse and reflected radiation respectively.

$\alpha_D, \alpha_d, \alpha_R$  = absorptivity of collector plate for direct, diffuse and reflected radiation respectively.

$I_{Th}, I_{dh}$  = hourly total and diffuse radiation on horizontal surface (cal/cm<sup>2</sup> hr)

$R_D, R_d, R_R$  = conversion factors to convert horizontal incidence to incidence on tilted collector surface for direct, diffuse and reflected components of solar radiation respectively.

$R$  = albedo of the ground,

$D$  = dirt correction factor, and

$S$  = shading correction factor

For practical purposes  $\alpha_D, \alpha_d$  and  $\alpha_R$  are assumed to be same, i.e.,  $\alpha$ . The values of dirt correction factor,  $D$  for various inclined glass plated and plastic films have been worked out by Garg (1972). As indicated in the same, a value of 0.94 has been taken as dirt correction factor. The shading correction factor which is a function of the latitude of the place and the dimension of the flat-plate collector can be taken as 0.98 as shown by Hottel and Woertz (1954) and Garg (1972). Thus equation (2) can be written as

$$q_a = I_{Ti} (\tau\alpha)_e \quad (3)$$

where,

$I_{Ti}$  = hourly solar radiation on inclined surface (cal/sq. cm<sup>2</sup> hr), and

$(\tau\alpha)_e$  = suitable mean value of transmittance and absorptance product. This term here includes allowance for dirt and shading.

The heat loss from the collector plate depends on a number of factors, such as (i) temperature of

the absorber plate, (ii) the emissivity of collector plate, (iii) temperature of ambient air and sky conditions, (iv) number of glass plates, their optical properties and spacing, (v) insulation type and its thickness on the edges and rearside, (vi) tilt of the collector from horizontal and (vii) wind speed over the absorber.

All these factors were studied in detail earlier by Garg (1972) and various heat transfer correlation were developed for finding out the heat loss from the collector plate under a given situation. The thermal loss from the collector plate per unit of area and time may be written in the simplified form as :

$$q_l = U_L (t_p - t_a) \quad (4)$$

where,

$U_L$  = overall heat loss coefficient from the collector plate to the outside air including the rear and edge loss (Kcal/m<sup>2</sup> hr °C)

$t_p$  and  $t_a$  = average plate and ambient air temperature (°C)

In the above studies by Garg (1972) simplified design curves for finding out,  $U_L$  for various values of plate temperature,  $t_p$ , air temperature,  $t_a$ , for single and double glass covers and for ordinary black and selective black painted collector plates have been given. It is seen from these curves that for climatic condition that generally exist in India and for collector plate with temperature nearly 60°C the value of  $U_L$  can be taken as 6.0 Kcal/m<sup>2</sup> hr°C. This value of  $U_L$  has been taken in the present study.

Now the heat balance equation can be written as

$$q_u = I_{Ti} (\tau\alpha)_e - U_L (t_p - t_a) \quad (5)$$

Usually the average plate temperature,  $t_p$  is not known. So it would be convenient to put the equation in terms of the inlet fluid temperature,  $t_1$  which is easily measured, by introducing heat removal efficiency factor,  $F_R$  as

$$q_u = F_R [I_{Ti} (\tau\alpha)_e - U_L (t_1 - t_a)] \quad (6)$$

where  $F_R = F_p F_f$

Here,  $F_p$  is a design constant for collector plate efficiency and can be determined from the geometrical specification and the heat transfer characteristics of the collector as shown by Bliss (1959).  $F_f$  is known as flow factor and can be written as

$$F_f = \frac{GC_p}{F_p U_L} \left[ 1 - e^{-F_p U_L / GC_p} \right] \quad (7)$$

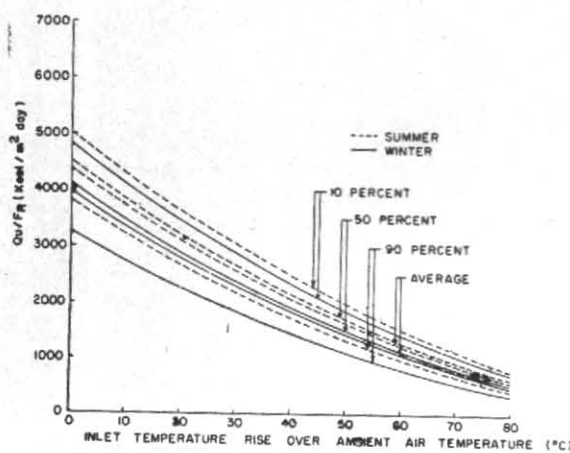


Fig. 4. Jodhpur

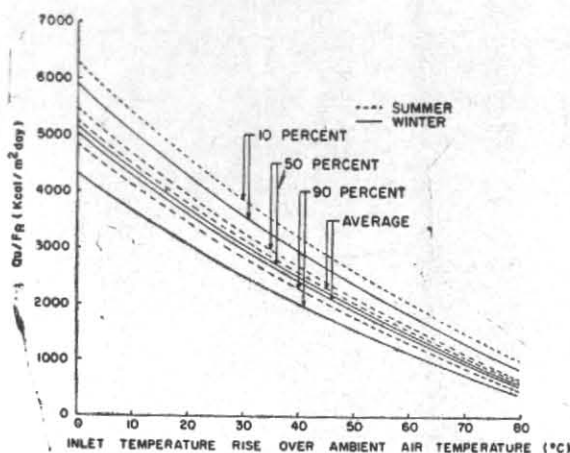


Fig. 5. New Delhi

Design curves for flat plate collector for summer and winter use for various exceedance values

where  $G$  = mass flow rate of the fluid through the collector ( $\text{kg}/\text{m}^2 \text{ hr}$ ) and

$C_p$  = specific heat of the fluid ( $\text{Kcal}/\text{kgm}^\circ\text{C}$ )

The above equation can be put in terms of critical intensity ( $I_c$ ), i.e., the intensity below which solar energy collection should not be attempted. Thus

$$q_u = F_R (\tau\alpha)_e (I_{T_i} - I_c) \quad (8)$$

$$\text{where, } I_c = U_L (t_1 - t_a) / (\tau\alpha)_e \quad (9)$$

Hence, as suggested by Liu and Jordan (1963, 1967) the average hourly rate of useful energy collection, for a month can be calculated as

$$\bar{q}_u = F_R (\tau\alpha)_e \bar{I}_{T_i} \phi \quad (10)$$

$$\text{where } \phi = \frac{1}{n} \sum \frac{(I_{T_i} - I_c)^+}{I_{T_i}} \quad (11)$$

Here,  $\phi$  is known as utilizability and is defined as the useful energy that is being collected by an idealised collector.  $\bar{I}_{T_i}$  is the average hourly radiation incident on the collector surface, plus (+) sign indicates that only positive values are considered and  $n$  is the total number of hours considered.

The utilizability curves based on Eq. (11) have been given by Liu and Jordan for various values of  $K_T$ . These curves have been used for design purposes in the present study.

#### (b) Design curves for New Delhi and Jodhpur

The ratio of useful heat derived by the collector per day ( $q_u$ ) and the heat removal efficiency factor ( $F_R$ ) referred to in Eq. (6) is a design constant for the flat-plate collector of the solar water heater; because  $F_R$  depends not only on the heat transfer characteristics of the collector but also on the geometrical specifications of the collector. Hence in the design curves presented in Figs. 4 and 5, the above ratio has been plotted versus the rise of inlet temperature of water over the ambient temperature for Jodhpur and New Delhi respectively. These curves have been presented for a typical winter month, namely, January and a typical summer month, namely, May. Design curves have been prepared on the basis of average values as well as various exceedance values. In these design curves, the optimum tilts of  $(L+15)^\circ$  is taken for winter and  $(L-15)^\circ$  for summer. These curves have been plotted for collectors having lamp black surface (absorptivity for solar radiation is 0.95) and single glass cover having extinction coefficient equal to 0.062 per cm. From such curves, the potentialities of heating water using solar energy can be estimated.

#### (c) Illustrating the use of design curves

The above mentioned design curves are extremely useful to determine the collector area required for flat-plate collectors for a given heating requirement. The collector area required for a given load can be computed by the method given in Appendix. For instance the collector area ( $\text{m}^2$ ) required to heat 140 litres of water (sufficient hot water for a family of five persons) upto  $55^\circ\text{C}$  in

the afternoon of January are given below :

|             | Delhi | Jodhpur |
|-------------|-------|---------|
| Average     | 2.31  | 1.69    |
| 10 per cent | 1.88  | 1.42    |
| 50 per cent | 2.27  | 1.62    |
| 90 per cent | 2.87  | 1.97    |

Thus it is seen that 2 sq. metres collector area in respect of Jodhpur and 3 sq. metres in respect of Delhi would serve the purpose on 90 per cent occasions.

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## APPENDIX

## Method for determining collector area of flat-plate collector from design curves

With the help of the design curves presented in the text, the collector area required for a given load can be computed as given in the following steps :

*(i) Load calculation*

Load on a system is defined as the amount of kilocalories required to heat required amount of water to the design temperature.

$$\text{Load} = \text{mass of water} \times \text{specific heat (design water temp.—morning water temp.)}$$

Morning water temperature ( $t$ ) at a place as given by Liu and Jordan (1963, 1967) may be approximately given as :

$$t = (0.8 t_{\min} + 0.2 t_{\max})$$

where  $t_{\min}$  and  $t_{\max}$  are the minimum and maximum temperature of the day respectively.

*(ii) Mean temperature of operation*

The ambient air temperature and also the incoming water temperature is continuously varying. Hence mean temperature level of collection is determined as follows —

Temperature level of operation ( $\Delta t$ ) = mean incoming water temperature ( $t_1$ ) — mean day time ambient temperature ( $t_a$ )

Here  $t_1$  and  $t_a$  can be computed by the following empirical relations :

$$t_1 = 5.0 (\text{Design maximum water temp.} + \text{morning water temp.})$$

$$t_a = 0.7 t_{\max} + 0.3 t_{\min}$$

*(iii) Computation of  $F_R$* 

Heat removal efficiency factor can be computed with the help of the expression described in the text. For its determination the values of  $F_p$ ,  $U_L$  and  $C_p$  should be known.  $F_p$  can be known from the design constants of the flat-plate collector.  $U_L$  has been discussed earlier. The mass flow rate ( $G$ ) for natural circulation type of water heater can be taken as 40 kgm/m<sup>2</sup> hr. The value of  $F_R$  for an optimized type of tube in plate type collector as developed by Garg (1970) comes to be 0.86.

*(iv) Daily collection*

Consulting the appropriate design curves for the particular locality and season and temperature level of operation as discussed above, the value  $Q_u/F_R$  is obtained. Using the value of  $F_R$  as discussed in step (iii), average daily collection per m<sup>2</sup>,  $Q_u$  in kilocalories is then known.

*(v) Area estimation*

$$\text{Area of collector (m}^2\text{)} = \frac{\text{Load in Kcal (}Q_L\text{)}}{\text{Average daily collection (}Q_u\text{)}}$$