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Solar insolation curves

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ABSTRACT. Curves for the variations in the intensity of direct solar radiation, incident at sea level on a surface normal to the sun's rays, with solar altitudes for different water vapour and dust contents of the atmosphere are given in this paper. These curves facilitate easy computations of the solar insolation for any conditions of atmosphere and situation, on clear days.

Calculations carried out using these curves compare well with the observed values generally.

1. Introduction

Thermal comfort in tropical buildings depends largely on the exclusion or reduction of the incident solar radiation in the summer months. When considering such problems it is essential to obtain an estimate of the radiation intensities on horizontal, vertical and slanting surfaces, at different places, seasons and times. In the tropics observed data on such intensities are meagre especially for Indian towns. Computational methods have therefore to be used. Such methods have been adopted by a number of workers (Moon 1940, Kennedy 1949, Fritz 1957, Black 1956, Ramdas and Yagnanarayana 1956, Threlkeld and Jordon 1957).

2. Basis for the computation

The computation of direct solar insolation on the earth's surface depends on the experimental proof (Langley 1881, Abbot and Aldrich 1934, Abbot 1935, Hand 1937, Nicolet 1951, Stair *et al.* 1954, Johnson 1954) that the radiant energy in the solar spectrum incident above the earth's atmosphere remains fairly constant, and is based on an understanding of the nature and magnitude of the spectral attenuation of that energy during its passage through the earth's atmosphere.

3. Solar constant

The International Meteorological Society accepted a value, 1·97 gm cal/sq. cm/min for the solar constant at mean solar distance. Recent observations made by Nicolet (1951) and Johnson (1954), indicated a value 2·00 gm cal/sq. cm/min with a probable error of $\pm$ 2 per cent. The ellipticity of the earth's orbit brought about a variation of $\pm$ 3·5 per cent from its mean value.

Moon (1940) compared the data obtained by several workers on the spectral distribution of solar energy above the earth's atmosphere and proposed a standard curve for use in engineering computations. Moon's curve gave a lower value for the solar constant (1·896 gm cal/sq. cm/min) but most of the previous computations for solar radiation intensities at the earth's surface were based on his curve. Recently Threlkeld and Jordon (1957) have carried out their computations with the help of a more accurate spectral distribution curve obtained by Johnson (1954). The best estimate would indicate broadly a spectral distribution of energy, 7-8 per cent in the ultraviolet, 41-42 per cent in the visible and 51 per cent in the infra-red regions.

4. Atmospheric attenuation

The factors that deplete the solar energy in its passage through the earth's atmosphere are (*i*) scattering due to air molecules and the liquid and solid particulate matter suspended in air, and (*ii*) absorption by ionised oxygen atoms, ozone and water vapour and carbon dioxide. By applying Bouguer's equation to the data obtained by Fowle (1915) and others (Abbot *et al.* 1923, Gotr *et al.* 1934), Moon obtained the equation for total spectral transmission factor due to both scattering and absorption as

$$T_\lambda = [(T_{a\lambda})^{p/760} (T_{w\lambda})^{w/20} (T_{d\lambda})^{d/800} \times (T_{O_{3}\lambda})^{O_3/2\cdot 5} (T'_{w\lambda})^{w/20}]^m$$

where m is the air mass=cosec θ where θ is the solar altitude. The first three terms refer to the loss through scattering by air, water vapour and dust respectively and the last two terms refer to the loss through absorption by ozone and water vapour respectively. T_λ is the total absorption at λ wavelength.

Following the method used by Moon and Fritz (1955) and adopting Johnson's solar spectral energy distribution curve above the earth's atmosphere, Threlkeld and Jordon (1957) computed the solar radiation intensities on the earth's surface at sea level at sixtythree chosen wavelengths between $0\cdot295$ and $2\cdot13$ μ, for different air masses, depths of precipitable water and dust contents, $2\cdot5$ mm of ozone was assumed as a constant for the atmosphere. The atmospheric transmission factor is obtained as the ratio between the intensities at sea level and above the earth's atmosphere given by the integrated areas under the corresponding solar spectral distribution curves. The computed data were presented as curves giving these factors as functions of air mass and precipitable water for different dust contents. The data in themselves are extremely valuable. Their presentation can however be considerably altered to improve their utility. The authors have instead calculated the direct solar intensities at sea level incident on a surface normal to the rays for different solar altitudes and have presented the results as curves for different conditions. The solar altitudes at different times for the day throughout the year, at any latitude are known. It is then possible to compute the hourly variations and daily totals of the incident solar radiation for any day of the year, on any horizontal, vertical or slanting surface at any place.

5. Present work

Curves connecting normal incident energy with solar altitude have been prepared for different precipitable water and dust contents. These curves are presented in Figs. 1 to 4.

The precipitable water and dust content of the atmosphere vary from place to place and time to time. Observational data are however not generally available for any place in India. One can, however, assume that normally, the precipitable water will decrease in summer and increase in monsoon months. On the other hand the dust content increases in summer and decreases in monsoon months. A clear atmosphere may contain less than 200 dust particles per c.c. Smoky industrial atmosphere may contain about 800 particles per c.c.

In the absence of any measured data, a standard atmosphere is arbitrarily defined as having 760 mm of atmospheric pressure, $2\cdot5$ mm of ozone, 15 mm of precipitable water and 300 dust particles per c.c. The corresponding curve (Fig. 2, curve 5) is used for computing the direct solar radiation (Seshadri *et al.* see reference) on clear days.

6. Comparison of the observed and computed values

The observed data for Roorkee and Madras on certain clear days were compared with the computed values for the same days, to assess how far the arbitrarily assumed standard atmosphere was justifiable under Indian conditions.

At Roorkee, observations were made with a pyrheliometer on the direct solar radiation intensities normal to the sun's rays on a few clear days in summer and winter months at specific times, 8·30 A.M, 11·30 A.M., 2·30 P.M. and 5·30 P.M., covering low, medium and high solar altitudes. The corresponding computed values are

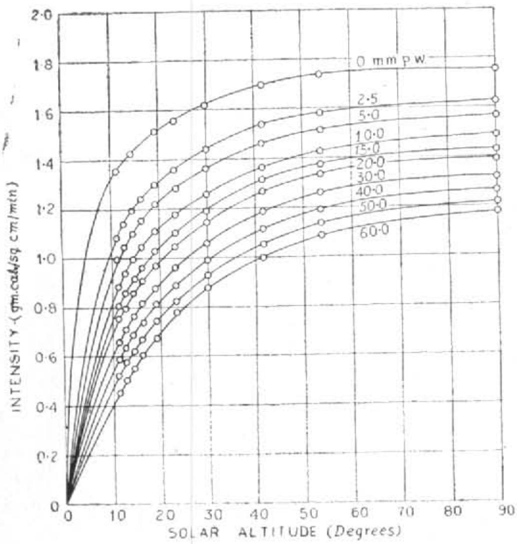

Fig. 1. 100 dust particles per c. c.

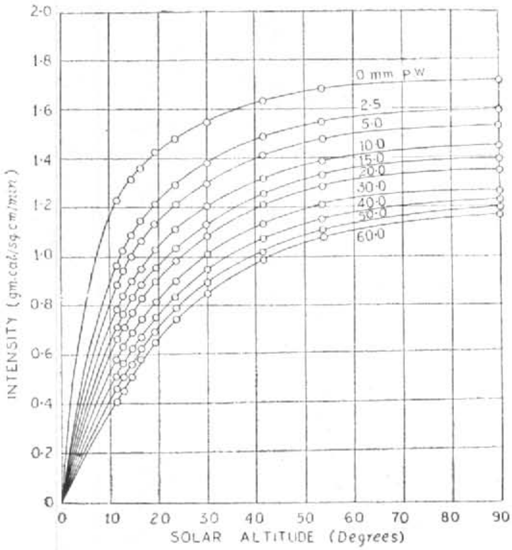

Fig. 2. 300 dust particles per c. c.

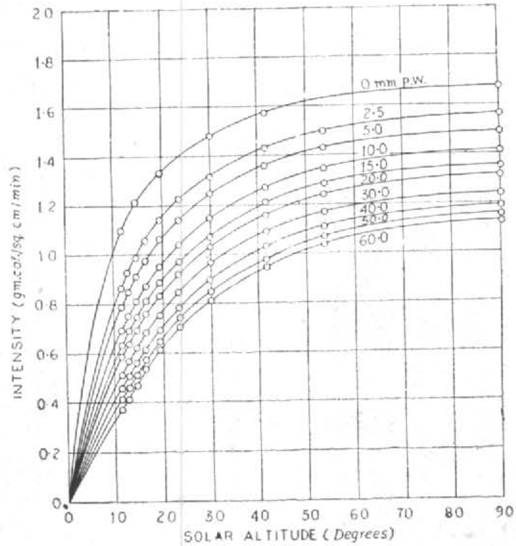

Fig. 3. 500 dust particles per c. c.

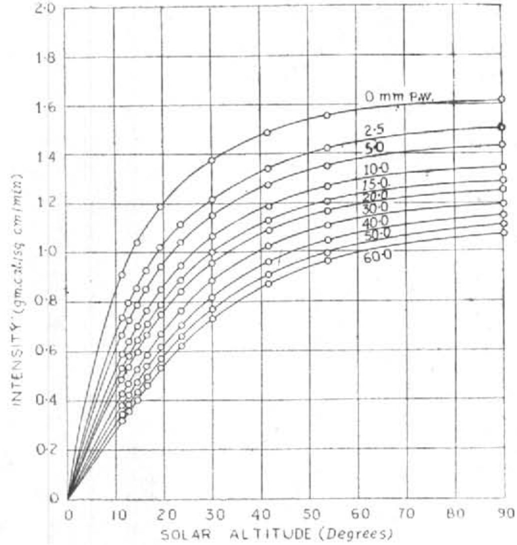

Fig. 4. 800 dust particles per c. c.

Figs. 1-4. Curves of direct solar radiation intensities normal to the rays for different precipitable water at sea level, 760 mm

plotted against the observed values in Fig. 5. It can be seen that practically all the points cluster round the theoretical 45° line, the maximum deviation being only about 5 per cent. The discrepancies are due to the slight variations in the atmospheric conditions from the assumed standards.

Observations were taken on 21 January 1959 from 8 A.M. to 4 P.M. at hourly intervals. Their values and the corresponding calculated values are plotted and shown in Fig. 6. The atmosphere was misty upto about 10 A.M. and hence a large difference between the calculated and observed values was noted. Between 10 A.M. and 4 P.M.

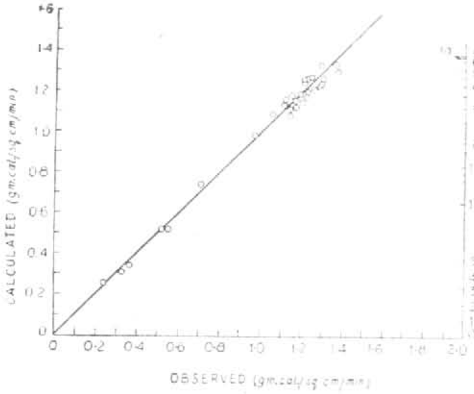

Fig. 5. Observed and calculated direct solar radiation intensities normal to the rays for different solar altitudes

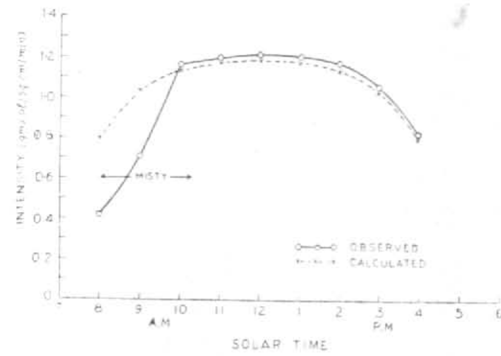

Fig. 6. Observed and calculated direct solar radiation intensities normal to the rays at Roorkee on 21 Jan 1959

both the curves lie quite close to each other. That the observed values are higher to a small extent than the calculated ones throughout, may be ascribed to the slightly lower water vapour and dust contents present than those assumed for the standard atmosphere.

It was also felt desirable to compare the calculated values with the measured data at another quite different latitude. Recorded charts of total (direct plus diffuse) solar radiation on a horizontal surface, were obtained from the Madras Meteorological station. One clear day in each of the months, January, February, March, April and May 1958 were taken for purposes of comparison. It is not possible to compare this measured data directly with the computed direct radiation values. It is however known that the diffuse radiation on clear days varies from 10 to 20 per cent of the total radiation depending upon the solar altitude. The lower the altitude, the higher is the value generally. The diffuse component is taken as 20 per cent of the total (25 per cent of the direct) for low solar altitudes (upto 8 A.M. and after 4 P.M.) and 15 per cent of the total (about 17·5 per cent of the direct) for medium and high solar altitudes. The computed direct radiation intensities were increased by the percentages indicated above and the total radiation intensities thus obtained were compared with the observed ones. The corresponding curves are presented in Figs. 7 to 11.

There is good correspondence generally between the two curves for each day. Round about noon however the calculated value is uniformly higher than the observed value. Figs. 9, 10 and 11 for March, April and May show that the calculated values are throughout slightly higher than the observed ones and the differences are maximum at noon. This indicates that at Madras which is a coastal city with generally higher values of humidity, the precipitable water content is probably higher than 15 mm during these months. The values were recalculated accordingly for a precipitable water content of 20 mm for these days. The curves obtained are also presented in the same figures (Figs. 9—11). The new curves in general are closer to the corresponding observed ones; but the differences at noon hours still persist. This suggests that the value of 15 per cent diffuse to total radiation, at high solar altitudes, may have to be reduced, especially on very clear days. If the factor is assumed as about 11 per cent equivalent to a value 12·5 per cent of the direct radiation, the correspondence between the two curves can be improved considerably.

Investigations are in progress, at Roorkee to study the variation in the diffuse

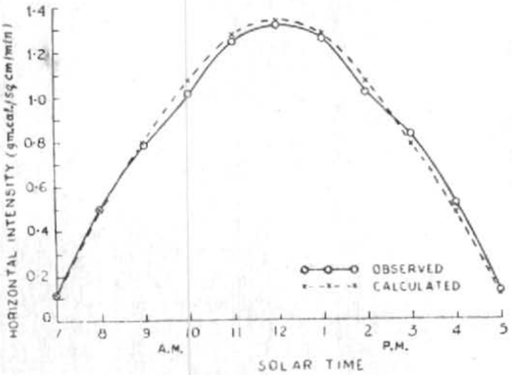

Fig. 7. Observed and calculated total (direct & diffuse) horizontal intensities at Madras on 21 January 1958

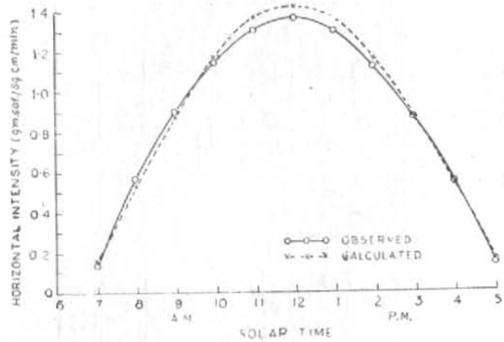

Fig. 8. Observed and calculated total (direct & diffuse) horizontal intensities at Madras on 11 February 1958

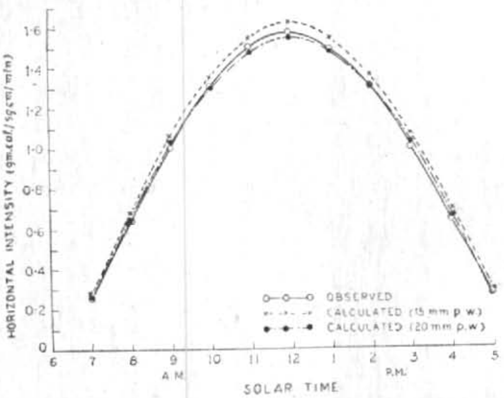

Fig. 9. Observed and calculated total (direct & diffuse) horizontal intensities at Madras on 27 March 1958

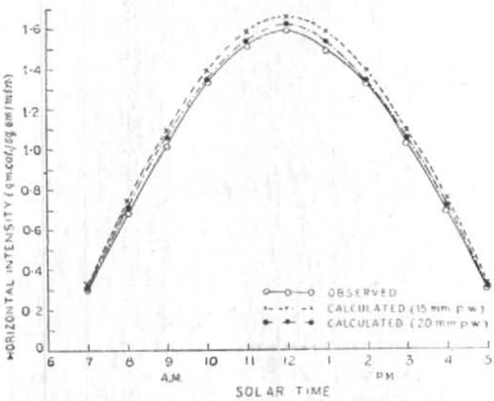

Fig. 10. Observed and calculated total (direct & diffuse) horizontal intensities at Madras on 22 April 1958

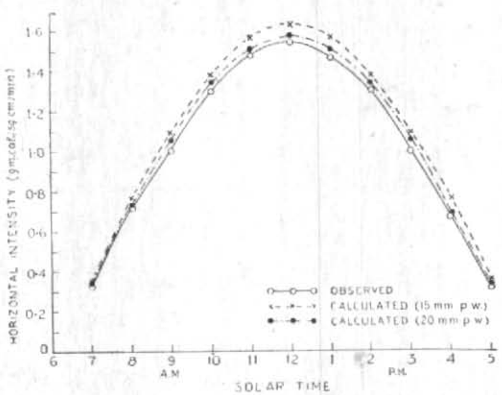

Fig. 11. Observed and calculated total (direct & diffuse) horizontal intensities at Madras on 28 May 1958

component with solar altitude. Simultaneous measurements of the total and direct solar radiation at different times of clear days are being made over and extended period. The results may facilitate computations at other Indian latitudes as well.

7. Conclusions

If the data on the amount of precipitable water and dust contents of the atmosphere are available, it is possible to estimate the direct solar radiation intensities to a high degree of accuracy from the curves presented in this paper. However even in the absence of such data estimation of the solar radiations based on the assumed standard conditions can be within about 8 per cent of the actual values. This accuracy would appear to be sufficient for engineering and architectural use.

The curves for direct solar insolation presented in this paper simplifies to a great extent the calculations involved in estimating the solar radiation intensities.

8. Acknowledgements

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