CLASSICS

Solar radiation data is necessary for calculating cooling load for buildings, prediction of local air temperature and for the estimating power that can be generated from photovoltaic cells. Solar radiation falling on the surface of the earth is measured by instruments called pyranometers. The weather service in most countries have many stations to measure solar radiation using pyranometers. In India pyranometers have been used for a long time. The data obtained from these instruments were not available easily for use by scientists and engineers. The book *Handbook of Solar Radiation Data for India* by Anna Mani in 1980 was the first comprehensive document that provided this data for many stations in India. This book has become a reference material for meteorologists, energy experts and airconditioning engineers. We have given below some excerpts from the first chapter of this book.

J Srinivasan

Handbook of Solar Radiation Data for India

By Anna Mani

CHAPTER 1

Introduction

1.1. *The sun and its radiation*

The electromagnetic radiation emitted by the sun covers a very large range of wavelengths, from radiowaves through the infrared, visible and ultraviolet to X-rays and gamma rays. However, 99 per cent of the energy of solar radiation is contained in the wavelength band from 0.15 to 4 μm, comprising the near ultraviolet, visible and near infrared regions of the solar spectrum, with a maximum at about 0.5 μm. About 40 per cent of the solar radiation received at the earth's surface on clear days is visible radiation within the spectral range .4 to .7 μm, while 51 per cent is infrared radiation in the spectral region .7 to 4 μm. The total radiation emitted by the sun in unit time remains practically constant. The variations actually observed in association with solar phenomena like sunspots, prominences and solar flares are mainly confined to the extreme ultraviolet end of the solar spectrum and to the radiowaves. The contribution of these variations to the total energy emitted is extremely small and can be neglected in solar energy applications.

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The planet earth revolves around the sun in an elliptical orbit of very small eccentricity with the sun at one of the foci, completing one revolution in one year. The axis of rotation of the earth is inclined at about 23½ degrees with respect to the plane of orbital revolution and is directed always to a fixed point in space. As a consequence of this geometry of the sun and the earth, large seasonal variations occur in the amount of solar radiation received at different latitudes of the earth. The largest annual variations occur near the two poles and the smallest near the equator.

During the course of its annual motion around the sun in an elliptical orbit, the earth comes nearest to the sun each year around January 5 (perihelion) and farthest around July 5 (aphelion). The sun-earth distance at perihelion is 1.471×10^8 km and at aphelion 1.521×10^8 km. The mean distance is 1.496×10^8 km, which is known as 1 Astronomical Unit. Due to the variations in the sun-earth distance, the solar radiation intercepted by the earth varies by ± 3.3 per cent around the mean value, being maximum at the beginning of January and minimum at the beginning of July.

Of the entire quantity of radiant energy emitted by the sun's spherical surface, only a small fraction (4.5×10^{-10}). is actually intercepted by the planet earth. The amount of solar energy falling in unit time on unit area, held normal to the sun's rays outside the earth's atmosphere when the earth is at the mean distance from the sun, is called the Solar Constant. According to the latest measurements, the solar constant has a value of 136 mW/cm^2 or 1.36 kW/m^2 or 1.95 calories/cm^2 per minute.

1.2. *Interaction of the sun's radiation with the earth's atmosphere*

Since the earth is surrounded by an atmosphere which contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter and clouds of various types, marked depletion of solar energy takes place during its passage through the atmosphere to the surface of the earth. In a cloudfree atmosphere, the depletion occurs by three distinct physical processes operating simultaneously: (i) selective absorption by molecular oxygen, ozone, carbon dioxide, and water vapour in certain specific wavelengths; (ii) Rayleigh scattering by molecules of the different gases that constitute the atmosphere; and (iii) Mie scattering. In Rayleigh scattering, where the size of the scattering particles is small compared with the wavelength of light, the intensity of scattering follows the well-known λ^{-4} law, as a consequence of which a spatial redistribution of the energy of the incoming radiation takes place in the scattered light, the shorter wavelengths predominating and giving rise to the blue of the sky. Roughly one half of the scattered radiation is lost to space and the remaining half is directed downwards to the earth's surface from different directions as diffuse radiation. In Mie scattering where the sizes of the scattering particles, mostly dust, are comparable with the wavelength of visible and infrared radiation, a depletion in the solar radiation occurs both by true scattering (involving a redistribution of incident energy) as well as by absorption by the particles, wherein a part of the radiant energy is transformed into heat. This type of scattering also leads to a fraction of the solar radiation being lost to space and another fraction being directed downwards as diffuse radiation, Unlike Rayleigh scattering, however, the dust-scattering process is more complicated and the redistribution of energy is much more asymmetrical with respect to the different directions when compared to Rayleigh scattering. Because of absorption by oxygen and ozone at high levels of the atmosphere, the short-wavelength limit of solar radiation received at the earth's surface is approximately 0.29μ.

In a cloudy atmosphere, considerable depletion of the direct solar radiation takes place. A large fraction is reflected back to space from the tops of clouds, another part transmitted downwards to the earth as diffuse radiation and a small fraction absorbed by the clouds. Dense dark clouds of appreciable vertical depth can cut off as much as 80 per cent of the incident energy, but thinner clouds deplete only 20 to 50 per cent of the radiant energy, depending on their depth and liquid water content. The effect of an increase in dust in the atmosphere is to decrease the direct solar radiation and increase the diffuse radiation. When the cloud amount increases from zero to about 4 or 5 octas of the sky, there is a corresponding increase in diffuse radiation. However, when the cloud amount increases still further to overcast conditions, a decrease in diffuse radiation takes place, largely because of increased absorption and reflection from cloud tops.

The fraction of the total solar radiant energy reflected back to space through reflection from the tops of clouds, scattering by atmospheric gases and dust particles and by reflection at the earth's surface is called the albedo of the earth-atmosphere system and has a value of about 0.30 for the earth as a whole. The mean monthly value of the intensity of direct solar radiation normal to the solar beam actually received at the earth's surface at noon time in India varies from 0.51 to 1.05 kW/m^2, depending on latitude, altitude of the station, and season.

The solar radiant energy in the shortwave spectrum falling on the earth's surface as well as that absorbed by the atmosphere is re-emitted back into space as longwave radiation.

This longwave radiation has the characteristics of blackbody radiation in the temperature range of about –60° to + 30°C. Since, in the long run, the earth's mean surface temperature as well as the mean temperature of the atmosphere remains unchanged, it follows that the net heat absorbed by the earth-atmosphere system from the shortwave solar radiation is equal to the net heat emitted as longwave radiation by the planet earth and its atmosphere.

1.3 *Terminology of radiation parameters*

For practical purposes it is convenient to divide the entire radiation regime within the earth's atmosphere into two parts, the solar or shortwave radiation and the terrestrial or longwave radiation. This is possible because solar radiation corresponds approximately to blackbody radiation at about 6000°K, the energy of which is almost entirely (99%) confined to wavelengths less than 4μ, while the radiation emitted by the earth and its atmosphere, which corresponds approximately to blackbody radiation at temperatures less than 300°K, has, for all practical purposes, its energy between the wavelength limits 4 to 100 μm. Thus, a division of the spectrum at about 4 μm effectively separates the solar and terrestrial radiation as shortwave and longwave radiation.

The different radiation parameters are defined below:

(a) Direct solar radiation at normal incidence, I_N, is the quantity of shortwave solar radiant energy emitted by the solid angle subtended by the visible disc of the sun and passing through a unit area held normal to the solar beam at the earth's surface in unit time.

(b) Global solar radiation, G, is the total quantity of shortwave radiant energy emitted by the sun's disc as well as that scattered diffusively by the atmosphere and clouds passing through a unit area in the horizontal in unit time. The global solar radiation is also referred to as incoming total shortwave radiation, $K\downarrow$.

(c) Direct solar radiation on a horizontal surface, I_H, is the quantity of solar radiant energy emitted from the solid angle subtended by the visible disc of the sun and passing through a unit area in the horizontal in unit time. This is also called the vertical component of the direct solar radiation.

(d) Diffuse solar radiation, D, is that part of shortwave radiation scattered by the atmosphere reflected diffusely and transmitted by clouds and passing through unit horizontal area in unit time. This radiation comes from a solid angle of 2π with the exception of the solid angle subtended by the sun's disc. There is a simple relation between G, D and I_H and I_N, given by

$$I_H = (G - D) \text{ and } I_N = \frac{(G - D)}{\sin h}$$

where h is the angle of elevation of the sun.

(e) Reflected solar radiation, $K\uparrow$, is that part of the incoming shortwave radiation which is reflected by the earth's surface and diffused by the atmospheric layer between the ground and the point of observation. The albedo of the earth's surface, A, is expressed as the ratio of the reflected solar radiation to the global solar radiation,

$$A = \frac{K\uparrow}{G}.$$

(f) Upward longwave radiation, $L\uparrow$, is the quantity of longwave radiation emitted upwards by the earth's surface and the shallow layer of atmosphere below the level of the measuring instrument, and passing through unit area in the horizontal in unit time.

(g) Downward longwave radiation, $L\downarrow$, is the longwave radiation emitted downwards by the earth's atmosphere and passing through a unit horizontal area at the level of the instrument in unit time.

(h) Net longwave radiation, L^*, is the difference between the outgoing and incoming longwave radiation and is given by $L^* = L\uparrow - L\downarrow$.

(i) Net radiation, Q^*, is the difference between the total incoming short and longwave radiation and the outgoing short and longwave radiation and is given by $Q^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow$.

Other radiation parameters of interest are direct, global, or diffuse solar radiation in restricted portions of the solar spectrum and various atmospheric turbidity factors.