STUDIES OF SOLAR RADIATION AND ITS MEASUREMENT

A Thesis submitted

for the degree of

Doctor of Philosophy

by

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This Thesis is

DEDICATED

To my wife Avtar,

daughters

Angie and Sonia

STUDIES OF SOLAR RADIATION AND ITS MEASUREMENT

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Summary

A mathematical model has been developed for predicting the spectral distribution of solar radiation incident on a horizontal surface. The solar spectrum in the wavelength range 0.29 to 4.0 micrometers has been divided in 144 intervals. Two variables in the model are the atmospheric water vapour content and atmospheric turbidity. After allowing for absorption and scattering in the atmosphere, the spectral intensity of direct and diffuse components of radiation are computed. When the predicted radiation levels are compared with the measured values for the total radiation and the values with glass filters RG715, RG630 and OG530, a close agreement (± 5%) has been achieved under clear sky conditions.

A solar radiation measuring facility, close to the centre of Birmingham, has been set up utilising a microcomputer based data logging system. A suite of computer programs in the BASIC programming language has been developed and extensively tested for solar radiation data, logging, analysis and plotting.

Two commonly used instruments, the Eppley PSP pyranometer and the Kipp and Zonen CM5 pyranometer, have been compared under different experimental conditions.

Three models for computing the inclined plane irradiation, using total and diffuse radiation on a horizontal surface, have been tested for Birmingham. The anisotropic-all-sky model, proposed by Klucher, provides a good agreement between the measured and the predicted radiation levels. Measurements of solar spectral distribution, using glass filters, are also reported for a number of inclines facing South.

Key words: solarimetry; spectral distribution; mathematical modelling; direct and diffuse solar radiation; solar radiation on inclined surfaces.

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Chapter 1. INTRODUCTION

1.1 Objectives.

The aims of the work described in this thesis were to study the solar radiation climate of Birmingham, an urban environment, and to investigate the following.

a) To develop a mathematical model for predicting the spectral distribution of solar radiation incident on the earth's surface.

b) To study the solar radiation regimes of non-horizontal surfaces and to investigate the use of horizontal surface solar radiation levels for predicting solar radiation intensity on inclined surfaces.

c) To study some characteristics of solar radiation measuring instruments.

d) To set up a solar radiation measuring facility in Birmingham, using a microcomputer based data logging system.

1.2 Introduction

Addressing the opening session of the International Solar Energy Society, Silver Jubilee Conference in Georgia during May 1981, its president Mr Datta said

> ".....Apart from wood, wind, and water, other sun-based sources are ocean thermal, radiant, wave, tide, and biomass (wood is also biomass as you already know). We therefore are not short of energy sources. There is no crisis of energy; we are short of the economically viable technologies of exploiting these.....".

New developments in solar technology which are likely to enable solar energy to compete with conventional fossil fuel energy sources, demand a better understanding of the quality and quantity of solar radiation available, at the point of application. Future use and applications of solar energy are likely to develop in major population centres and the present investigation is devoted to the study of solar radiation regimes in an urban environment.

Solar energy is an interdisciplinary subject. Architects, engineers, meteorologists, scientists, are all interested in solar radiation, but they have different objectives in their studies. An architect is likely to be interested in solar gain in buildings. A heating engineer will probably be more interested in solar radiation data on inclined planes particularly from the point of view of system design. A physicist developing a selective surface or testing the efficiency of a solar cell is interested in the spectral distribution of incident energy, as well as its total intensity.

1.3 Solar radiation

The spectrum of the radiation from the sun extends from the X-ray region of wavelength 1°A, or below, to radio waves of wavelength 100m and beyond. The energy falling in this whole wavelength range is referred to as the total radiation. However, for most applications of engineering and technology a more limited range of the above spectrum can be considered since ninety-nine per cent of the solar energy is in wavelength range 0.276 to 4.96 microns, Thekaekara (1973).

As the radiation from the sun enters the earth's atmosphere, it suffers partial extinction due to various scattering and absorption processes. The atmospheric constituents such as gases, water vapour and aerosols are responsible for almost all the scattering in the atmosphere.

The part of the solar radiation which does not suffer from scattering arrives at the earth's surface as a parallel beam and is referred to as the beam or direct solar radiation. The sun's visible disk subtends an angle at the earth of only 0.545° of arc. This strong direction dependent component can be optically concentrated as in the case of the 1 MW solar furnace application, in the French Pyrenees, Palz (1978).

Of the radiation from the sun which suffers scattering, part is reflected towards the outer sky and part reaches the earth's surface. The quantity and quality of scattered or sky radiation, is strongly influenced by the presence of clouds. Since 60% of the yearly total radiation in the U.K. on a horizontal surface is made up of diffuse radiation, an understanding of the physical properties of diffuse radiation is of paramount importance, U.K.-I.S.E.S.(1976).

The diffuse radiation reaches the surface of the earth from all parts of the sky but its distribution across the sky is very complex, (Dave,1977), and not isotropic as was assumed earlier. Diffuse radiation is present under all atmospheric conditions. Its proportion of the total radiation may be as low as 10% during a very clear day and for an overcast day 100% of the radiation will be diffuse. Sky radiation cannot be optically focused.

The third component of total radiation is the ground reflected radiation, resulting from the reflection of both direct and diffuse components. Its role is obvious when considering the total incident radiation on inclined planes. In an urban environment, when considering surfaces near to very tall buildings, the contribution made by the reflected radiation can be significant. A factor which determines the magnitude of the reflected component is the surface albedo; defined as the ratio of the intensity of reflected radiation to that of the incident radiation. Albedo values for a number of common surfaces have been published by Kondratyev (1969), and range from 0.2 for soil to 0.8 for snow covered areas. Since most reflecting surfaces are imperfect reflectors, so reflected radiation has a high diffuse component.

The measurement of the spectral distribution of the radiation from the sun has been the subject of a large number of studies, as reported by Moon (1940), Johnson (1954), Makarova and Kharitonov (1969), and Thekaekara et al. (1969).

All solar radiation depletion processes in the atmosphere are wavelength dependent. As a result the spectral distribution of incident radiation at different points on the earth's surface is highly variable.

Devices which are based on, for example photovoltaic cells, are highly sensitive to narrow spectral bands, so the spectral distribution of incident solar radiation is very important, in the designing and testing of such devices.

1.4 Solar radiation measurements

Before 1956, there were two commonly used standards of solar radiation

a) Developed by Abbot in the U.S.A., called the Smithsonian.

b) Developed by K.Angstrom in Europe, named after its proposer.

Comparisons of Smithsonian and Angstrom standards have yielded differences of up to several per cent, Willson (1972).

When 1956 was designated to be the International Geophysical Year by the World Meteorological Organisation (W.M.O.), a new International Pyrheliometric Scale (IPS) was developed as a compromise between the Smithsonian and the Angstrom scales. Recently a new radiometric scale, based on Active Cavity radiometers, has been adopted by the W.M.O. as its radiometric standard. When World Radiometric Reference (W.R.R.) and the IPS were compared, Willson (1973) reported that the IPS scale gave consistently 2.2% lower values.

The World Meteorological Organisation has made the recommendation that from 1st January, 1981, all national meteorological services should reference their radiation measurements to the W.R.R. scale, Painter (1980).

One of the major problems, when using long term solar radiation data from several sources, as has been studied by Rodgers et al. (1978), is to ensure that different data sets are made compatible, before embarking on any serious work. Bahm (1979), has highlighted the problems in using SOLMET, the solar radiation database used in the United States.

A number of instruments have been developed for measuring different components of solar radiation. The W.M.O. (1965), in an effort to standardise the nomenclature, has produced a classification of radiation instruments.

Two types of instruments used are

a) The pyranometer - for measuring the global radiation i.e. direct plus diffuse, and for evaluating the diffuse radiation by the use of a shadow band to cut out the direct radiation component.

b) The pyrheliometer - for independently measuring the direct component of solar radiation.

A number of solar radiation instruments are available commercially, as instanced in a report by the U.S. Dept. of Energy (1980). The two most commonly used pyranometers are Eppley PSP (mainly in U.S.A.) and Kipp and Zonen CM5 (mainly in Europe). Both types of instruments have been used in the present study.

1.5 Solar radiation modelling

The use of mathematical (computer) modelling of solar radiation, has become particularly significant in recent years. The main reasons for this are

a) The amount of measured solar radiation data available for sites worldwide is rather limited.

b) As powerful and cheap digital computers have become widely available, 'total system simulation' has become a very powerful tool as an aid to design. A tested radiation model produces solar radiation values in a suitable format for design studies.

Data for sunshine duration has been available for a long time and for a large number of locations. Day (1961), used sunshine data, to estimate monthly averaged daily global solar radiation incident on a horizontal surface, using the expression

$$G = Go\ [a + b(n/N)] \qquad (1.1)$$

where G = global or total solar irradiation, at the earth's surface.

Go = global irradiation above the atmosphere.

n = duration of bright sunshine.

N = maximum possible duration of sunshine.

a and b are constants.

Using the above approach, Cowley (1978), has produced a set of maps for the U.K., giving monthly average global solar radiation on a horizontal surface. In the above model no distinction is made between the direct and diffuse components of radiation.

Since the optical properties of the beam and the sky radiation are different, recent models have treated these two components separately, Robinson (1966).

However, it is relatively simple to compute the direct component of solar radiation but diffuse radiation causes great problems, as has been outlined by Orgill and Hollands (1977), and Buckius and King (1978). The distribution of diffuse radiation across the sky is very complex, see for example, Dave (1977), Steven (1977), and McGregor (1980).

Cloud type and height data are widely available and clouds have a very strong influence upon the incoming radiation from the sun. A number of studies, have attempted to correlate diffuse radiation with cloud cover. Examples are given by, Atwater et al. (1979), Turner and Mujahid (1979), McGregor (1981). These models give mean monthly radiation intensities of global radiation. In these studies when measured and predicted monthly radiation intensities were compared, deviations varying from less than 1% up to 40%, have been reported.

In addition to the modelling of total radiation, recently an increased interest has been shown by several workers in the modelling of the spectral distribution of incident solar radiation. Work in this area has been published by McCartney (1978), McCartney and Unsworth (1978), Guzzi et al. (1978, 1979). Leckner (1978), has developed a model for computing the spectral distribution of both direct and diffuse radiation components under clear sky conditions. Leckner's work has been further extended by Athwall and Neal (1981).

1.6 Solar radiation on inclined planes

Most of the practical applications of solar energy in the fields of architecture, thermal systems, solar thermal power systems and solar cells, require solar radiation data on inclined surfaces. Measured solar radiation data to date for inclined surfaces is very limited. Two studies by Parmlee (1954), and Liu and Jordan (1961), are cited as 'classical' in the field of solar radiation on inclined planes.

The contribution to the total radiation on a non-horizontal surface from the direct component of solar radiation is relatively easy to compute, simply by applying geometrical relationships. It is the diffuse contribution which is difficult to deal with since its distribution across the sky is highly complex. At one time it was assumed that the sky radiation is distributed isotropically across the sky. This approximation is adequate for the case of an overcast sky, but not so for a partially cloudy and a clear sky, Temps and Coulson (1977). Page (1978), has reported the development of a model for estimating the solar radiation intensity on inclined and vertical surfaces, from the available hourly global and diffuse irradiance data on a horizontal surface. It involves the evaluation of a number of correlation coefficients which can only be carried out if long term data is available for the site under consideration. Klein (1976), in his review paper, has dealt with the calculation of monthly average values on tilted surfaces.

Klucher (1979), has developed an algorithm for computing inclined plane solar radiation values from measured total and diffuse radiation on a horizontal plane. This anisotropic-all-sky model, has been developed by Klucher, for Cleveland, Ohio from the measured solar radiation data for inclines of 37 and 60 degrees to the horizontal and facing South. The above model has been tested for four widely separated Indian stations, Garg and Garg (1981), and it gave radiation values which are in good agreement with the measured data.

1.7 Summary of the contents of the thesis

The present investigation is aimed at studying the solar radiation regimes in an urban environment. The site under study, is located close to the centre of Birmingham, which is situated in the heart of the industrial English Midlands (latitude 52° 30'N; longitude 1° 55'W; mean height above sea level 100m).

The physical nature of the earth's atmosphere is discussed. The theory of scattering and absorption processes are presented. The extinction of incoming solar radiation by atmospheric aerosols, has been expressed in terms of a turbidity factor and the effect of a number of different turbidity factors are discussed.

A mathematical model has been developed for predicting the spectral intensity distribution, on a horizontal plane, for a given location. The two variables in the model are the atmospheric water vapour content and the atmospheric turbidity. A computer program has been written in the FORTRAN programming language, for implementing the above model. Sensitivity analysis results are presented.

The results of the mathematical model are compared with the author's measured values for

i) global radiation.

ii) diffuse radiation.

iii) total radiation in 3 spectral bands.

A limited number of measurements of Angstrom turbidity for the Birmingham area are also presented. The limitation on the readings was due to availability of equipment which was on loan to the University for a short period, by the courtesy of The U.K. Atomic Energy Authority.

General principles for solar radiation measuring instruments are discussed, together with calibration of radiation instruments, and the need for improved calibration standards.

Results of comparisons for the Kipp and Zonen CM5 and the Eppley PSP pyranometers are presented under a number of different experimental conditions.

A programme of measuring the intensity of solar radiation, was initiated in June 1980. A suite of computer programs was developed in the BASIC language, for recording, processing and plotting of solar radiation data, using a microcomputer. Details of the software developed and the quality of solar radiation data recorded, are given.

The importance of solar radiation data for non-horizontal surfaces is discussed. Three mathematical models for predicting solar radiation on inclined planes, from given total and diffuse radiation on a horizontal plane, have been tested for an urban environment.

Solar radiation in four wavebands has been measured for several inclined planes facing South, using glass filters in conjunction with Eppley PSP pyranometers.

The last chapter presents a summary of the conclusions reached, during the present investigations. A number of suggestions for possible future work is also included in this chapter.

Chapter 2. SOLAR RADIATION THROUGH THE EARTH'S ATMOSPHERE

2.1 Introduction

Radiation from the sun is isotropic but only about 0.5×10^{-9} of it reaches the earth's atmosphere and this amounts to about 1.6×10^{17}W, for the earth as a whole. 34% of this radiation from the sun which enters the earth's atmosphere, is reflected back into space, 66% is absorbed by the earth's atmosphere, land surface and oceans, of which 17% is used up in the evaporation/rainfall cycle. Only about 7.0×10^{12}W are absorbed by the earth's plants, and less than 0.5% of that gets converted into food.

The starting point for this chapter is the solar radiation outside the earth's atmosphere. The physical nature of the earth's atmosphere, together with solar radiation depletion processes, scattering due to particulates and gas molecules, and absorption by atmospheric constituents, are presented in the following sections.

2.2 The solar spectrum and solar constant

The solar constant is defined as the flux of solar radiant energy, outside the earth's atmosphere, across a surface of unit area orientated normal to the solar beam at the mean distance between the sun and the earth.

Measurements of the solar constant, to determine if it changes with time or with solar activity, formed the major objective of the Smithsonian Astrophysical Observatory's work, from 1902 to the mid 1950's. A review of this work has been presented by Hoyt (1979). With technological progress, further ground measurements along with measurements from, high flying aircraft, balloons, space probes and satellites, have been carried out. Hickey (1978), has given a survey of the different methods and different instruments which have been used for evaluating the solar constant. For some time a value of 1353 Wm^{-2} for the solar constant had been used by NASA, Coulson(1975), but Hickey (1979), has suggested a value of 1370 $\pm$1 Wm^{-2}. The latter value is adjusted to the World Radiometric Reference Scale. Almost all solar radiation effects in the atmosphere and on the earth are wavelength dependent. Important processes such as photosynthesis and atmospheric chemical processes, are dependent upon narrow wave bands in the solar spectrum.

A number of studies , for measuring the spectral distribution of solar radiation outside the earth's atmosphere, have been reported by, Makarova and Kharitonov (1969), Willson(1971), Thekaekara(1973), and Goldberg(1980). Figure 2.1, shows the standard curve of extraterrestrial solar spectral irradiance, in the wavelength range from 0.29 to 4.0 microns, after Thekaekara(1973).

2.3 The earth's atmosphere

To understand the interaction of solar radiation with the earth's atmosphere it is essential that the composition of the earth's atmosphere is understood. It is composed of a group of nearly permanent gases and a group of gases with variable concentration, (these are shown in tables 2.1 and 2.2.,respectively). In addition, the atmosphere also contains various solid and liquid particles such as aerosols, water drops and ice crystals, the concentrations of which are highly variable both in time and space.

It is apparent from table 2.1 that nitrogen, oxygen, and argon account for more than 99.99% of the permanent gases. These gases have virtually constant volume ratios up to an altitude of 60 Km in the atmosphere.

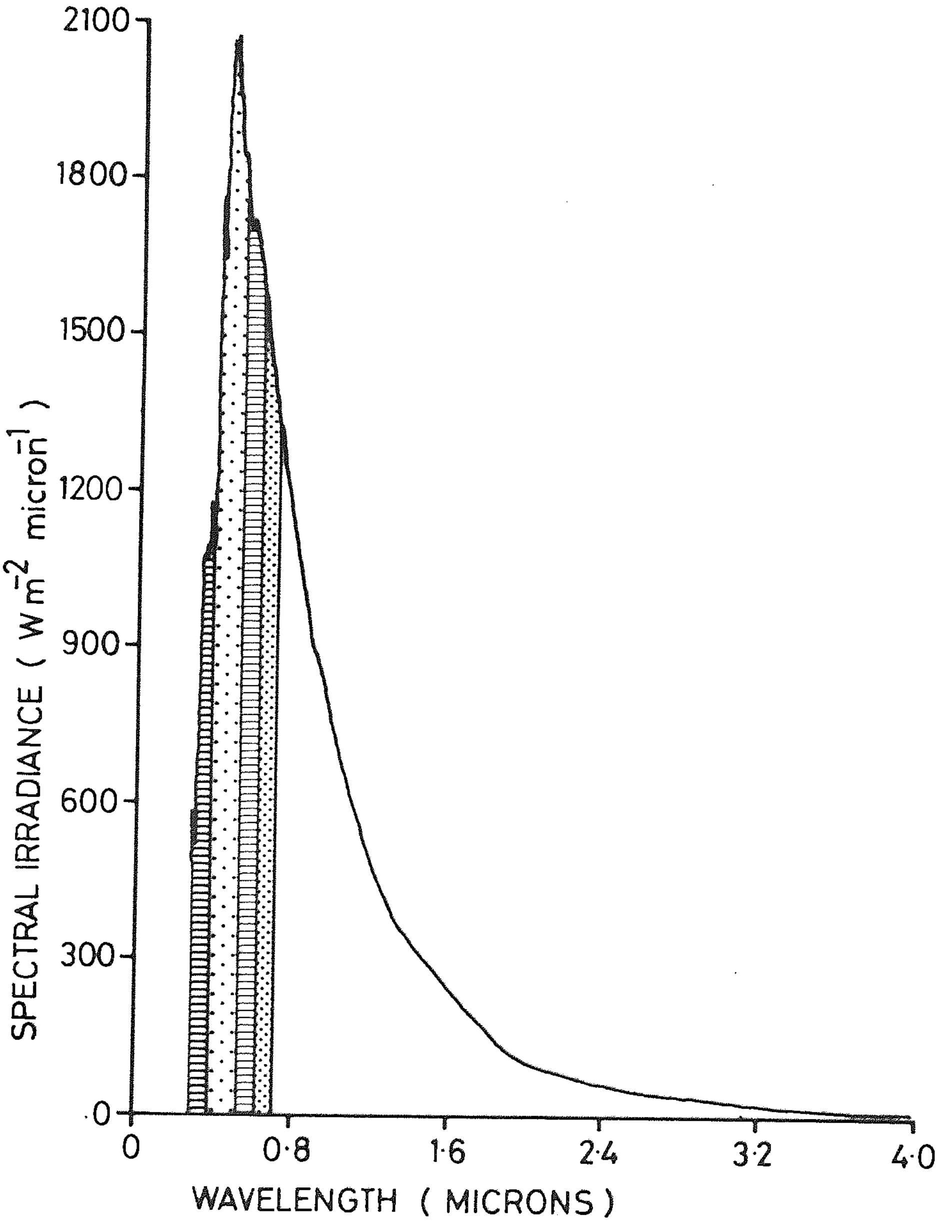


Fig 2.1 Distribution of solar radiation outside the earth's atmosphere, Thekaekara (1973). Cut-off wavelengths at 0.385, 0.529, 0.623 and 0.707 microns, are shown.

The concentration of carbon dioxide varies as a result of the combustion of fossil fuels, absorption and release by the oceans and photosynthetic processes. Water vapour concentration varies greatly both in space and time depending upon the atmospheric conditions. Its variation is extremely important in the radiative absorption and emission processes. Ozone concentration also changes with respect to time and space, and it occurs principally in altitudes from about 15 Km to 30 Km, where it is both produced and destroyed by photochemical reactions.

All of the gases listed in tables 2.1 and 2.2, are responsible for the scattering of sunlight and the consequent polarization characteristics. Also equally important are the variable solid and liquid particles suspended in the atmosphere since they play an important role in absorption and scattering of solar radiation, and in the physics of clouds and precipitation.

For the purpose of modelling, the atmosphere is divided into several parts, based on altitude profiles of pressure, temperature, rate of change of temperature with altitude and density. Several atmospheric models have been developed, of which the most significant are: the constant density, the isothermal, and polytropic models.

Various 'standard atmospheres' have been established from time to time as reference for general scientific purposes and for designing and testing of aerospace vehicles. One such atmosphere, the United States Standard Atmosphere-1962, is shown in fig. 2.2 .

2.3.1 Atmospheric aerosols

Atmospheric air is never free from particles which have different origins and a range of sizes and chemical compositions. An aerosol is a dispersal system of small particles suspended in a gas; the term "haze aerosol" emphasizes the particle nature of size. For this condi-

CONSTITUENT	% by volume
Nitrogen (N_2)	78.084
Oxygen (O_2)	20.948
Argon (Ar)	0.934
Carbon dioxide (CO_2)	0.033
Neon (Ne)	18.18×10^{-4}
Helium (He)	5.24×10^{-4}
Krypton (Kr)	1.14×10^{-4}
Xenon (Xe)	0.089×10^{-4}
Hydrogen (H_2)	0.5×10^{-4}
Methane (CH_4)	1.5×10^{-4}
Nitrous Oxide (N_2O)*	0.27×10^{-4}
Carbon Monoxide (O)*	0.19×10^{-4}

Table 2.1 The permanent constituents of the earth's atmosphere- Liou (1980).

CONSTITUENT	% by volume
Water vapour (H_2O)	0 - 0.04
Ozone (O3)	$0 - 12 \times 10^{-4}$
Sulphur dioxide (SO_2)*	0.001×10^{-4}
Nitrogen dioxide (NO_2)*	0.001×10^{-4}
Amonia (NH_3)*	0.004×10^{-4}
Nitric Oxide (NO)*	0.0005×10^{-4}
Hydrogen Sulphide (H_2S)*	0.00005×10^{-4}
Nitric acid vapour (NHO_3)	Trace

Table 2.2 The variable constituents of the earth's atmosphere - Liou (1980).

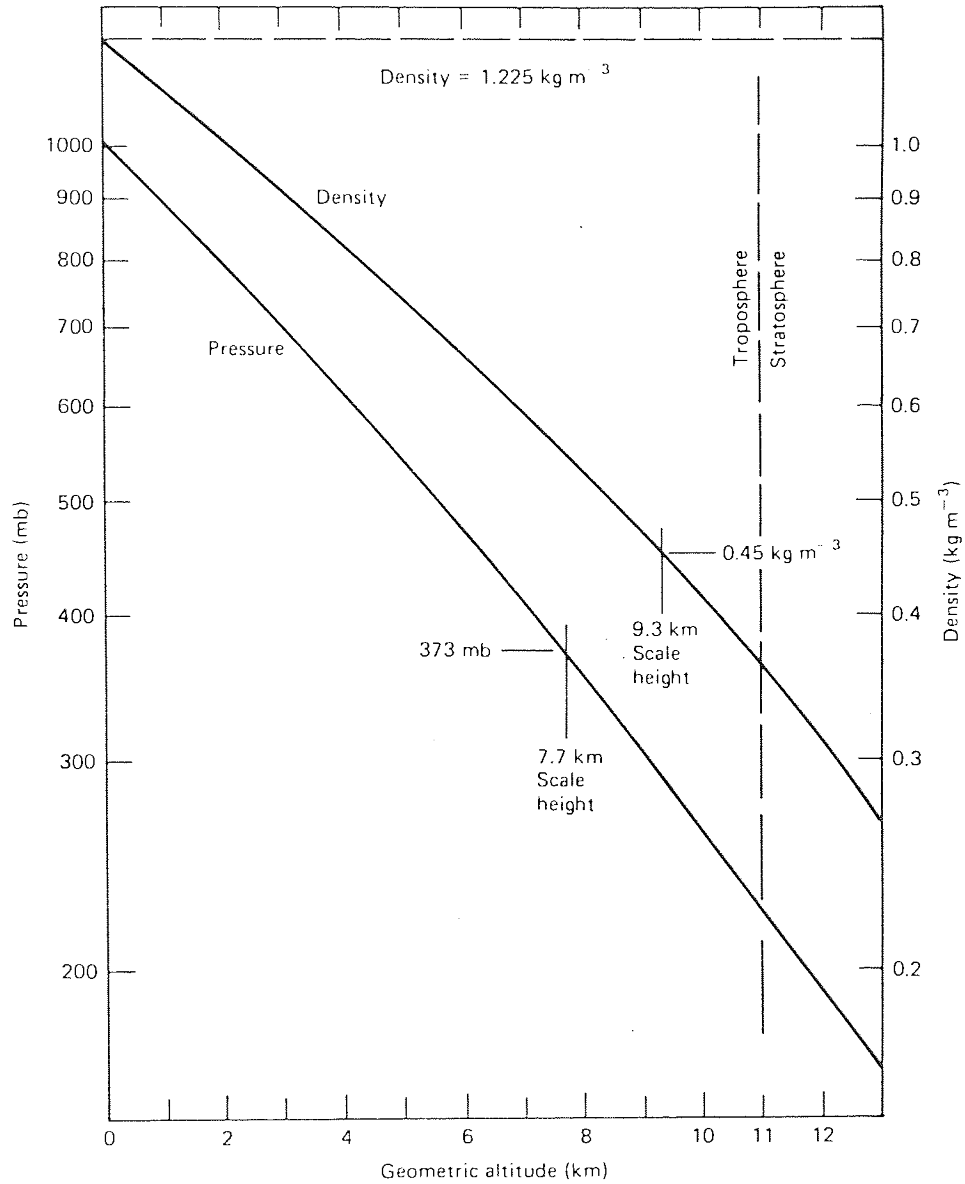


Figure 2.2 United States Standard Atmosphere 1962. Pressure, density, and average scale height in the troposphere. Source, McCartney, (1976).

tion from the optical standpoint, haze is a condition where the scattering property of the atmosphere is greater than that attributable to the gas molecules but less than that of fog. Haze scattering imparts a grey hue to the sky and is usually the determining factor of visibility.

An analysis of the particles in the atmosphere indicate the diversity of origin and distances travelled from the source. Cosmic dust, volcanic ash, foliage exudations, combustion products and sea salt, are all found in varying amounts in haze. For our purposes the size range of haze particles has been assumed to be from about 0.01 to 10.0 microns. Aerosols remain suspended in the atmosphere for varying and indefinite periods of time. They are transported by horizontal and vertical currents.

The particles involved can be divided into two types: dust grains which are nonhygroscopic and particles of salt which are highly hygroscopic. McCartney (1976), has given a detailed account of the origins of both types of particles and their 'life' stories.

2.3.2 Haze particle characteristics

The main characteristics of particles are their; size, type, density and vertical distribution. The hygroscopic particles present in haze can be divided into three classes according to their radii,

Aitken nuceli with radii <0.1 micron.

large particles with radii 0.1 to 1.0 micron.

gaint particles with radii > 1.0 micron.

The manner in which the particle population is spread over the range of sizes is defined by the size distribution function.

The total cross-sectional area of the particles within a unit volume can be expressed by,

$$A = \pi \int_0^\infty r^2 \, n(r) \, dr \qquad (2.1).$$

r = particle radius

n(r) = no of particles per unit interval of radius and per unit volume.

The scattering of electromagnetic radiation by an aerosol is proportional to the total cross sectional area as in equation 2.1 .

There are a number of ways in which the particle size distribution can be expressed. A function proposed by Deirmendjian (1969), has an exponential form.

$$n(r) = a \, r^{v_0} \exp^{(-br^s)} \qquad (2.2).$$

where a, b, v_0 and s are positive constants.

Junge (1963), has suggested a power law size distribution.

$$n(r) = \frac{dN}{d \log r} = c \, r^{-v} \qquad (2.3).$$

where N = no of particles per unit volume, from the smallest size limit up to size r.

c is a constant whose value depends on the concentration. distribution curve.

v is a constant.

Plots are shown in fig. 2.3, for typical continental type and maritime type aerosols, using power-law size distributions of particles. A striking feature of this distribution is its linearity over a size range of about two orders of magnitude.

Several models, have been developed, for vertical profiles of haze particles and are discussed by Penndorf(1954) and Elterman (1964). Elterman(1964), has shown the profile,(solid line in fig. 2.4), as part of his atmospheric attenuation model. This was later

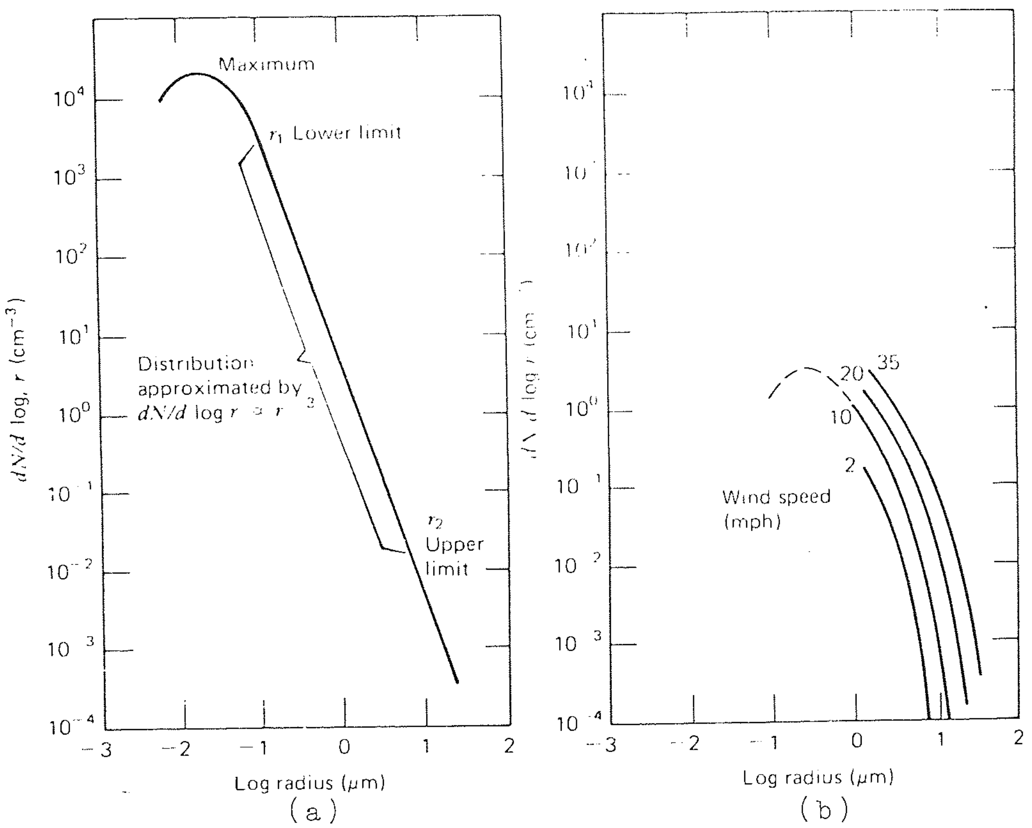


Figure 2.3 Power law size distributions of particles in continental and maritime aerosols, according to the power law, equation (2.3).
(a) Continental type, (b) Maritime type.
From, Junge (1960).

revised by Elterman, to incorporate new information (shown by the dotted line in fig. 2.4).

2.4 Rayleigh scattering

Consider a small homogeneous, isotropic, spherical particle whose radius is much smaller than the wavelength of incident radiation. The incident radiation produces a homogeneous electric field E_o, the applied field. Since the particle is very small, the applied field generates a dipole configuration on it. The electric field caused by the electric dipole, modifies the applied field inside and near the particle.

$$P_o = a_o E_o \tag{2.4}$$

where a_o = polarizability of a small particle.

E_o = applied field.

P_o = induced dipole moment per unit volume in the direction of E_o.

The applied field, generates oscillations of an electric dipole in a fixed direction. The oscillating dipole, in turn, produces a plane polarized magnetic wave.

The total scattered intensity of the unpolarized sunlight incident on a molecule in the direction of θ is then given by

$$I = \frac{I_o}{r^2} a_0^2 \left(\frac{2\pi}{\lambda}\right)^4 \left[\frac{1 \pm \cos^2\theta}{2}\right] \tag{2.5}$$

where I_o = incident intensity.

I = resultant scattered intensity.

λ = wavelength of incident radiation.

r = distance between the dipole and the observation point.

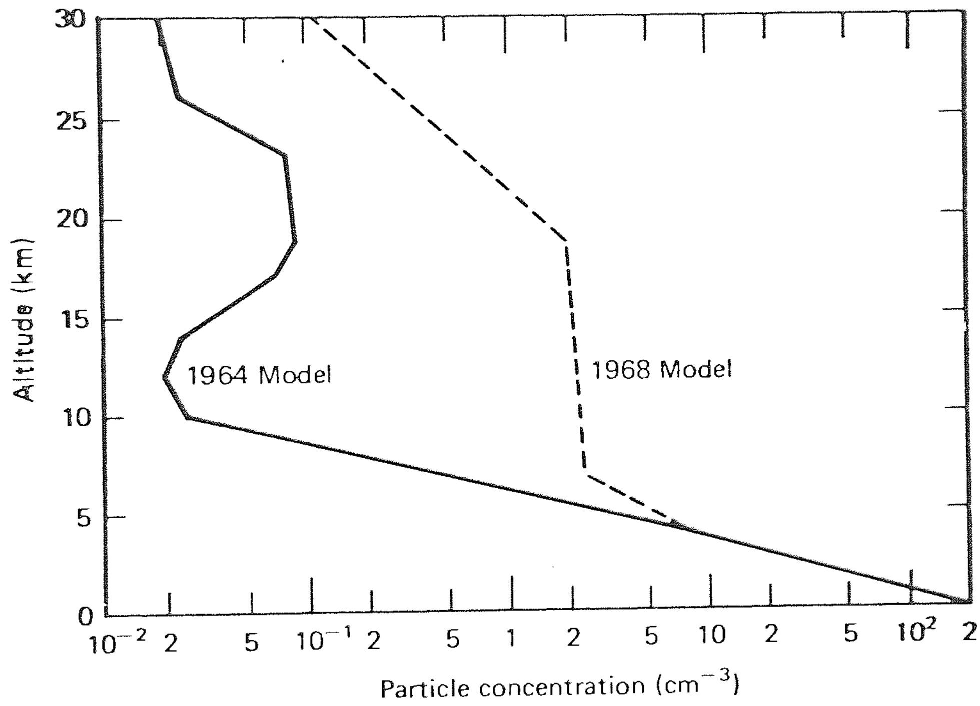


Figure 2.4 Vertical profile of particle concentration for an atmospheric attenuation model. Source, Elterman (1968).

This is the original formula derived by Rayleigh and is relevent to the scattering of sunlight by air molecules and is referred to as Rayleigh Scattering.

There are three main factors which affect the characteristics of the scattered wave. These are the polarizability , the phase function and the scattering cross-section .

The polarizability a_o is expressed as

$$a_o = \frac{3}{4\pi N_s} \left(\frac{m^2 - 1}{m^2 + 2} \right) \qquad (2.6).$$

N_s = total number of molecules per unit volume.

m = nondimensional refractive index of molecules.

The evaluation of the phase function is necessary in order to determine the angular distribution of the scattered energy with multiple scattering and radiative transfer analyses, as given by Liou (1980).

$$\int_0^{2\pi}\int_0^{\pi} \frac{P(\cos\Theta)}{4\pi} \sin\Theta \, d\Theta \, d\phi = 1 \qquad (2.7).$$

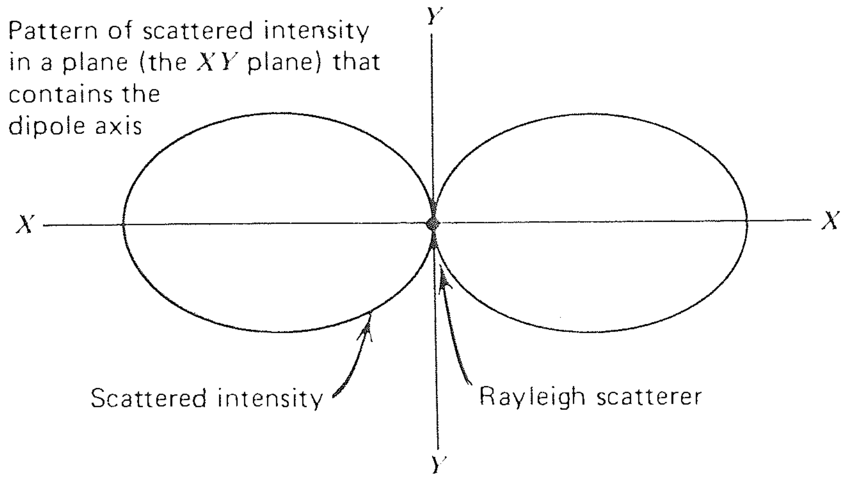
where $$P(\cos\Theta) = \tfrac{3}{4}\,(1 + \cos^2\Theta) \qquad (2.8).$$

The scattering cross-section is given by

$$\sigma_s = \frac{8\pi^3}{3\lambda^4 N_s^2} \, (m_r - 1)^2 \, f(\gamma) \qquad (2.9).$$

Here a correction factor f(γ), is added to take into account the anisotropy of air molecules, with a value of 1.06 .

Figure 2.5, shows the angular distribution of the degree of linear polarization for a Rayleigh particle in the case of unpolarized incident light.



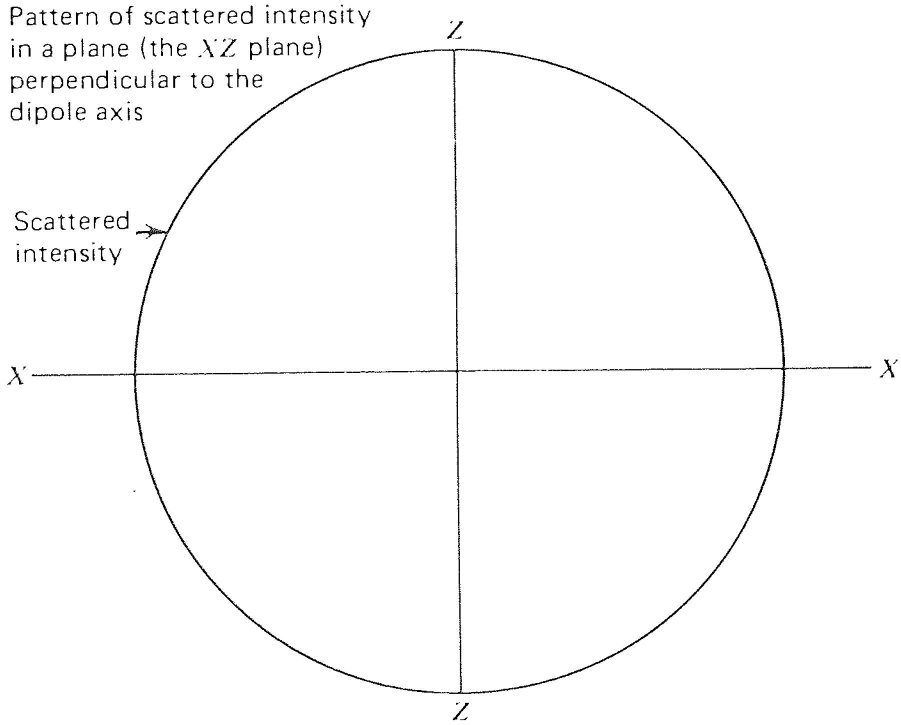


Figure 2.5 Patterns of scattered intensity for polarized incident light. Source, McCartney (1976).

2.5 Light scattering by particles in the atmosphere: greater than those contributing to Rayleigh scattering.

The earth's atmosphere contains clouds and aerosols as mentioned in (2.3.2), with sizes (greater than 1 micron), which are much larger than the wavelength of the incoming shortwave radiation. Thus the dipole mode of the electric field, which leads to the development of the Rayleigh scattering theory, is not applicable. Because of the large particle size, the incident beam of light induces high order modes of polarization configuration, which requires more advanced mathematical treatment than for Rayleigh scattering.

The starting point for the development of Mie Scattering Theory (1908), is the setting up and solution of Maxwell's equations. The derivation of the solution of the vector wave equation in spherical coordinates leads to a formal solution of the scattering problem. Since the full explanation of Mie theory is rather complex, only a summary will be presented, in the present discussion. Fuller details of the theory have been given by McCartney (1976) and Liou (1980).

A very important quantity is one which includes the ratio of the particle radius and the wavelength of the incident radiation. It is expresed as

$$e_o = \frac{2\pi r}{\lambda} \qquad (2.10).$$

If the particle dimensions are comparable with the wavelength of the incident radiation, we cannot, as in the Rayleigh case, consider the field to be constant over the particle diameter. The proper radiation field of the particle, therefore, cannot be taken to be that caused by a dipole.

The angular distribution of the scattered radiation intensity, is determined by the following Mie formulae, as given by McCartney (1976).

$$f(e_0, m, \theta) = \frac{\lambda^2}{4\pi^2} \times \frac{i_1 + i_2}{2} = \frac{\lambda^2}{4\pi^2} i \qquad (2.11).$$

e_0 = size parameter

θ = angle of scattering

m = complex refractive index.

i_1 and i_2 = intensities of scattered radiation polarized in two perpendicular planes.

$$i_1(e_0, m, \theta) = |S_1|^2 = \left| \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left[a_n \Pi_n + b_n T_n\right] \right|^2 \qquad (2.12).$$

$$i_2(e_0, m, \theta) = |S_2|^2 = \left| \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left[a_n T_n + b_n \Pi_n\right] \right|^2 \qquad (2.13).$$

Each intensity function is thus found as the sum of an infinite series. Each series converges slowly, and when e_0 is greater than unity, the number of terms required is somewhat greater than the value of e_0. When the value of e_0 is less than 1 and m equals approximately 1, the first term in each series corresponds to Rayleigh scattering. Figure 2.6 shows the angular patterns of scattered intensity from particles of three sizes.

The total scattering cross section σ_p is defined as the cross-section of an incident wave, acted on by the particle, having an area such that the power flowing across it is equal to the total power scattered in all directions.

$$\sigma_p = \frac{8\pi^4 r^6}{\lambda^4} \left(\frac{m^2-1}{m^2+2}\right) \times (1 + \cos^2\theta) \qquad (2.14).$$

Values of total scattering cross-section cover a wide range greater than the corresponding range of geometric cross sections. The two are related by the efficiency factor Q_{sc}, often called the Mie coefficient which is the ratio of the scattering to the geometric cross section. Figure 2.7 shows a plot of scattering efficiency

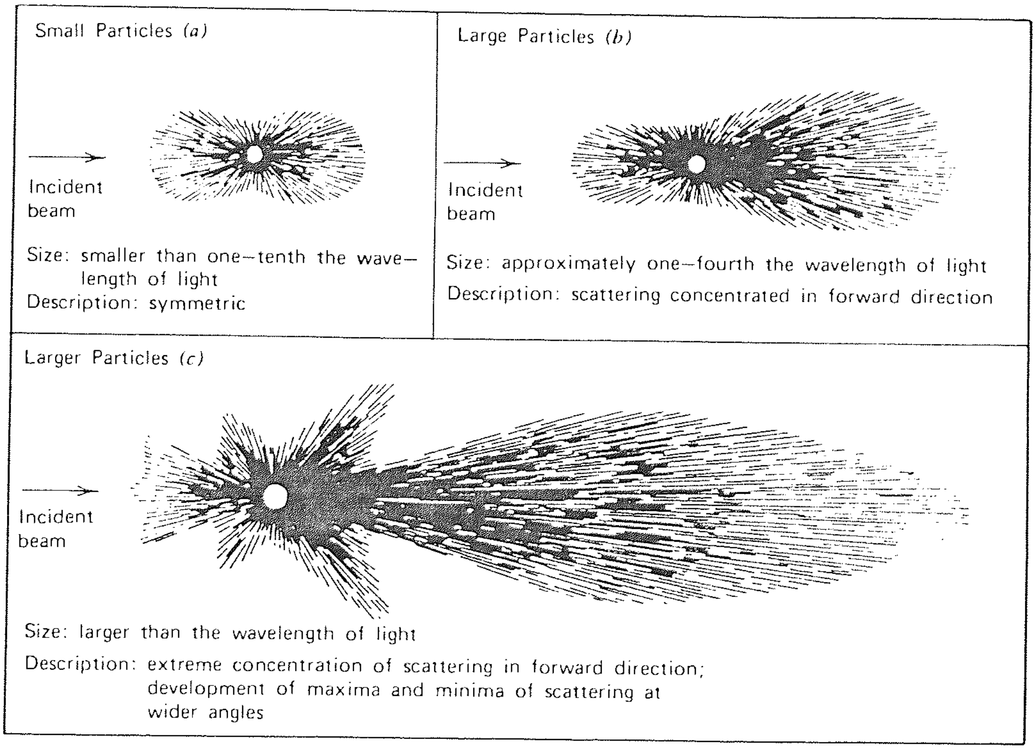


Figure 2.6 Augular patterns of scattered intensity from particles of three sizes. (a) small particle, (b) large particle, (c) larger particles. Source, McCartney (1976).

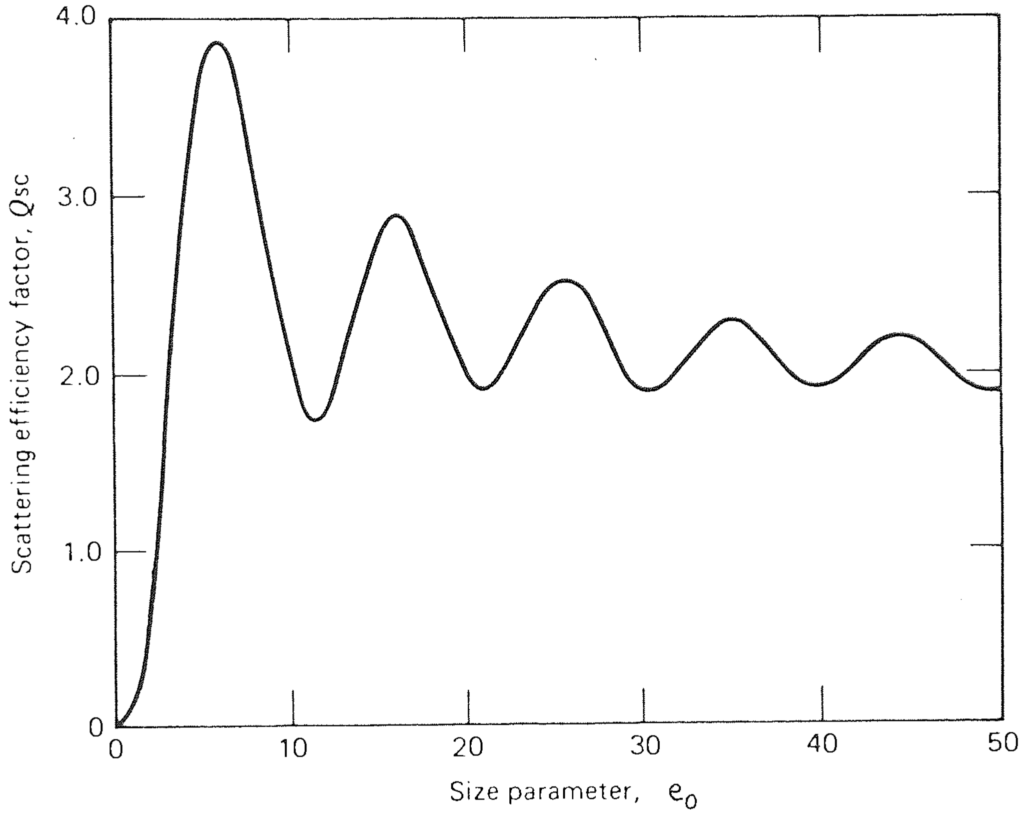


Figure 2.7 Scattering efficiency factor versus size parameter for water droplets. Source, List (1966).

factor versus size parameter for water droplets.

The difference between the flux removed from the incident beam and the totally scattered flux must be attributed to absorption by the particle. Absorption occurs when the refractive index is complex and the absorbed energy goes into heating the particle . In so far as attenuation or extinction of the flux is concerned, it makes no difference whether flux removal is caused by scattering or absorption. A simple transmission measurement does not distinguish between the two processes. Thus the total extinction is given by

$$Q_{ex} = Q_{sc} + Q_{ab} \qquad (2.15)$$

The theory of the interactions between an incident wave and the absorbing material of a particle has been given by Johnson et al. (1954), Van de Hulst (1957), and Kerker (1969).

2.6 Atmospheric turbidity

An index of turbidity can be used to estimate the amount of radiant flux which is absorbed and scattered by atmospheric aerosols and a number of different turbidity indexes have been developed, by several workers, including Linke (1929), Angstrom (1961), Schuepp(1949), and Unsworth and Monteith (1972). The atmospheric turbidity is closely related to the air mass value. The air mass is defined in terms of the atmospheric pathlength through which a beam of light, from the sun has to travel.

Linke considered that a logical unit of attenuation is that of a Rayleigh atmoshpere, i.e. an atmosphere composed entirely of particles causing Rayleigh Sacterring and defined a turbidity factor as the number of Rayleigh atmospheres required to produce a measured amount of attenuation. The original method was based on the total radiation in the direct solar beam, but in later work the problem of variable amounts of water vapour was partially alleviated by confining the measurements to energy at wavelengths less than 0.63 microns.

The Linke turbidity factor has been found useful for comparisons of atmospheric turbidity under different conditions, but it suffers from one serious difficulty. Measurements have shown that the Linke turbidity factor varies with air mass even when atmospheric conditions are unchanged, the reason being that the wavelength dependencies of water vapour absorption, aerosol absorption and scattering, are quite different from that of Rayleigh scattering.

In order to take account of the differences in transmission characteristics between aerosols and Rayleigh particles A.K.Angstrom represented the normal thickness of the atmosphere as

$$T_a(\lambda) = \beta \lambda^{-\alpha} \qquad (2.16).$$

where α = wavelength exponent.

β = turbidity coefficient.

Considerable effort has been spent by Schuepp (1949) and A.K.Angstrom(1961), in determining the magnitude and variability of the wavelength exponent. From a theoretical standpoint, the limit of the wavelength exponent should be approximately 4 for very small particles and 0 for very large particles. The extensive work on observations in the natural atmosphere indicate that a good average value is, 1.3±0.2, with practical limits lying between about 0.5 and 1.6.

Unsworth and Monteith (1972) used an integral turbidity coefficient, to describe aerosol attenuation in a finite waveband.

$$T(\Delta\lambda) = \left[\ln\{I_*(\Delta\lambda)\} - \ln\{I(\Delta\lambda)\}\right]/m \qquad (2.17).$$

where $I(\Delta\lambda)$ = direct irradiance in waveband $\Delta\lambda$.

$I_*(\Delta\lambda)$ = irradiance from an aerosol free atmosphere in the same wave band.

m = air mass

McCartney (1975), has reported calculated integral turbidity coefficients for the wavelength bands

a) 0.3 to 0.63 microns.

b) 0.3 to 0.71 microns.

c) 0.3 to 3.0 microns.

All three coefficients of turbidity are in use, in different parts of the world. Rodgers et al. (1978), have presented a comparison between different turbidity coefficients and have developed relationships between the Linke, Schuepp(Angstrom), and Unsworth and Monteith, turbidity coefficients.

In this work, a few measurements of Angstrom turbidity have been made for the Birmingham area and the results are presented in chapter 4, section 1 .

2.7 Absorption in the atmosphere

The total energy for an isolated molecule is made up of four contributions: electronic, vibrational, rotational and translational.

The first three types are quantized and take discrete values only, these values being specified by one or more quantum numbers. Any combination of quantum numbers defines an energy state or a quantum state. The change in energy can be expressed as

$$\Delta E = \frac{hc}{\lambda} \qquad (2.18).$$

where c = speed of light.

h = Planck's constant.

λ = wavelength in metres.

The most general transition involves simultaneous changes in electronic, vibrational, and rotational energy. For absorption or emission to take place, matter must interact with an incident field of electromagnetic radiation, which in turn must either involve an electric or a magnetic dipole or quadrupole moment. Electric dipole transitions are the strongest and are called permitted transitions.

The nature of a transition can be specified in terms of the quantum numbers of the upper and lower states. Because of the discrete nature of the energies involved in absorption and emission, all processes are selective.

If a molecule absorbs energy in excess of the ionisation energy the binding energy will be insufficient to hold the molecule together. Excessive elctronic excitation leads to ionization. Excessive vibrational excitation results in chemical decomposition.

Waves with shorter wavelengths posses higher energies. Short wavelength solar radiation causes the ionisation of nitrogen and oxygen, in the upper atmosphere. These gaseous ions are vital for radio communications.

Solar radiation is absorbed in the atmosphere mainly by O_2, O_3, N_2, CO_2, H_2O, O, N, although NO, N_2, CO_2, CH_4, which occur in very small quantities, also exhibit absorption spectra. Absorption spectra due to electronic transitions of molecular and atomic oxygen and nitrogen, and ozone occour chiefly in the ultra violet region, while those due to the vibrational and rotational transitions of triatomic molecules such as H_2O, O_3 and CO_2, lie in infra red region of the spectrum. There is very little absorption in the visible region. Most of the ultra violet radiation is absorbed in the upper atmosphere by species of oxygen and nitrogen.

A great variety of photochemical processes take place in the upper atmosphere, because of the absorption spectrum of various molecules and atoms in the solar ultra violet region. Such processes, involving various forms of oxygen, are important in determining the amount of ozone in the stratosphere.

Absorption bands in the solar near infra red region are chiefly due to vibrational and rotational transitions. The most important absorber in the atmosphere is water vapour. Carbon dioxide also has weak absorption bands in the solar spectrum, the most important one being near 2.7 microns.

Water vapour absorbs solar radiation in the vibrational and rotational bands which are centered at 0.94, 1.1, 1.38 and 1.87 microns. Carbon dioxide exhibits a number of weak absorption bands at 2.0, 1.6, and 1.4 microns, which can be ignored for most practical purposes. However the 2.7 micron band of CO_2, is the more important one for solar energy calculations. Figure 2.8 shows a graphical representation of atmospheric absorption. All the corresponding absorption coefficients need to be included in any solar radiation model.

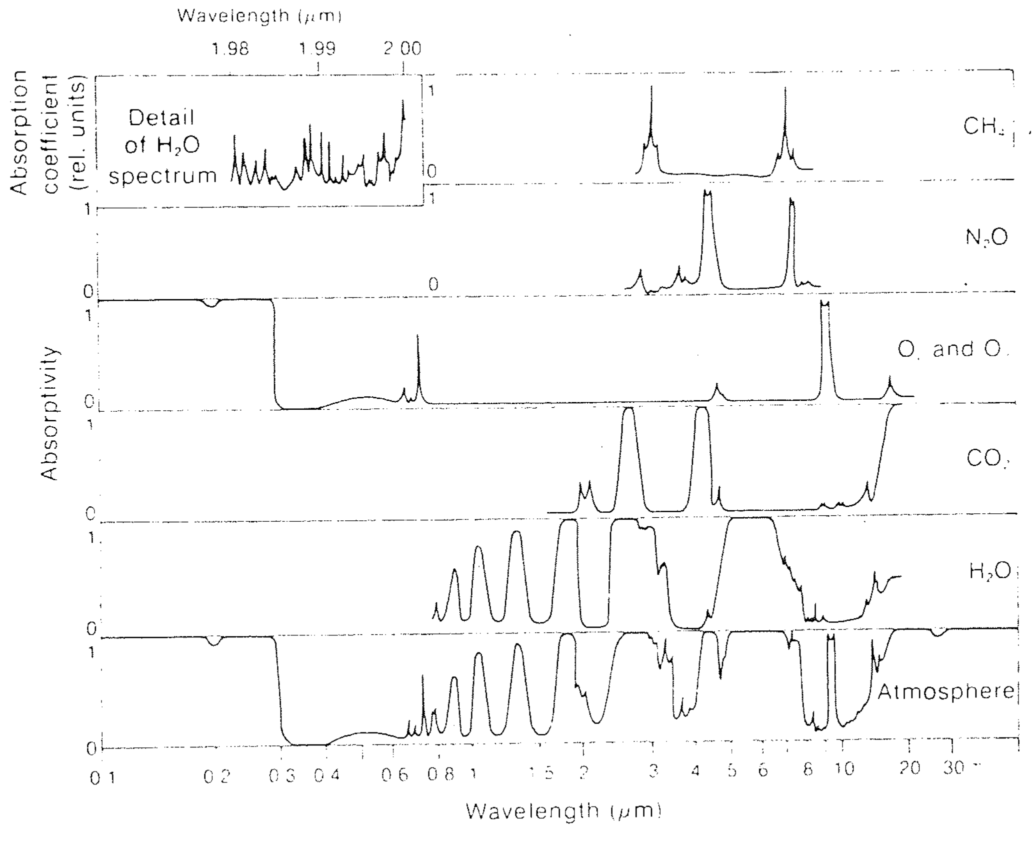


Figure 2.8 Absorptivity at various wavelengths by constituents of the atmosphere and by the atmosphere as a whole. Source, Neiburger et al. (1973).

Chapter 3. MATHEMATICAL MODELLING OF SOLAR RADIATION

3.1 Introduction

With recent interest in the nature and application of solar radiation, there is a need for more reliable solar radiation data nationally and worldwide. This requirement may be approached in two ways.

i) To set up an extensive nationwide monitoring network with standard instrumentation and then making this data available to interested parties.

ii) To understand the factors which broadly determine the levels of radiation for a site and then to use a model to predict the radiation levels.

The first approach has its limitations in that, for financial and practical reasons, it will be very difficult to set up and run a large network of solar radiation measuring stations over a long period. The second practical difficulty will be in storing large amounts of data and making it available as and when necessary, to the user, in a format which can be used without further effort and at a reasonable cost.

The second approach uses the fact that some radiation data is already available and, allowing for various factors, the typical levels of radiation can be predicted under specific conditions. With the wide availability of large computers at a reasonable cost, the designers of solar energy systems have a very powerful tool in their hands for simulating complex systems in order to optimise their technical and economic performance. The latter method can provide data in a form which can be used directly in simulation studies both, for total and spectral distribution. According to Robinson (1966), the intensity of solar radiation falling on a particular surface is determined by a number of factors i.e. astronomical, geographical, geometrical, physical and meteorological.

These factors need to be considered in the computation of solar radiation intensity for a given location and given time.

Since the intensity of solar radiation falling on to a surface follows the inverse square law, the distance between the sun and the earth is important. The earths orbit is elliptical and this causes the intensity of solar radiation outside the earth's atmosphere to vary by about $\pm 3.5\%$, during the year.

As the earth revolves around the sun it is inclined at an angle of 23.5^{o}. This inclination determines the length of a day and gives rise to the seasons. It also influences the angle between the direct beam and any surface.

The intensity of solar radiation falling on a unit area varies with the distance from the equator. The length of a day and the angle of elevation of the sun depend upon the latitude of a given location. As the earth spins around its axis different parts of the earth are facing the sun, and this is related to the longitude of a place.

The height above the sea level is also important as the air pressure and other meteorological variables are related to the height above sea level for a given location.

3.2 Calculating the position of the sun

Two angles, solar altitude and solar azimuth, define the position of the sun in the sky, as shown in fig. 3.1. Sun charts have been developed for given longitudes and latitudes which enable one to read off the solar altitude and azimuth for a given place and time. One such chart has been developed by Bennett (1980), as in fig. 3.2 .

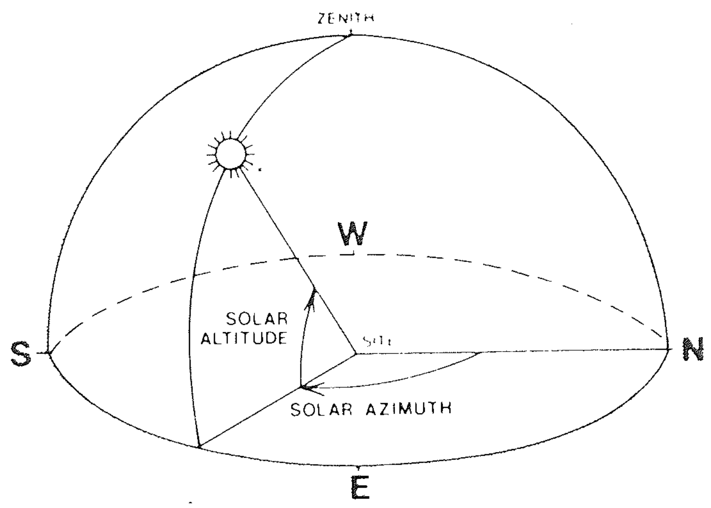


Figure 3.1 Two angles - solar altitude (elevation) and solar azimuth - define the position of the sun in the sky.

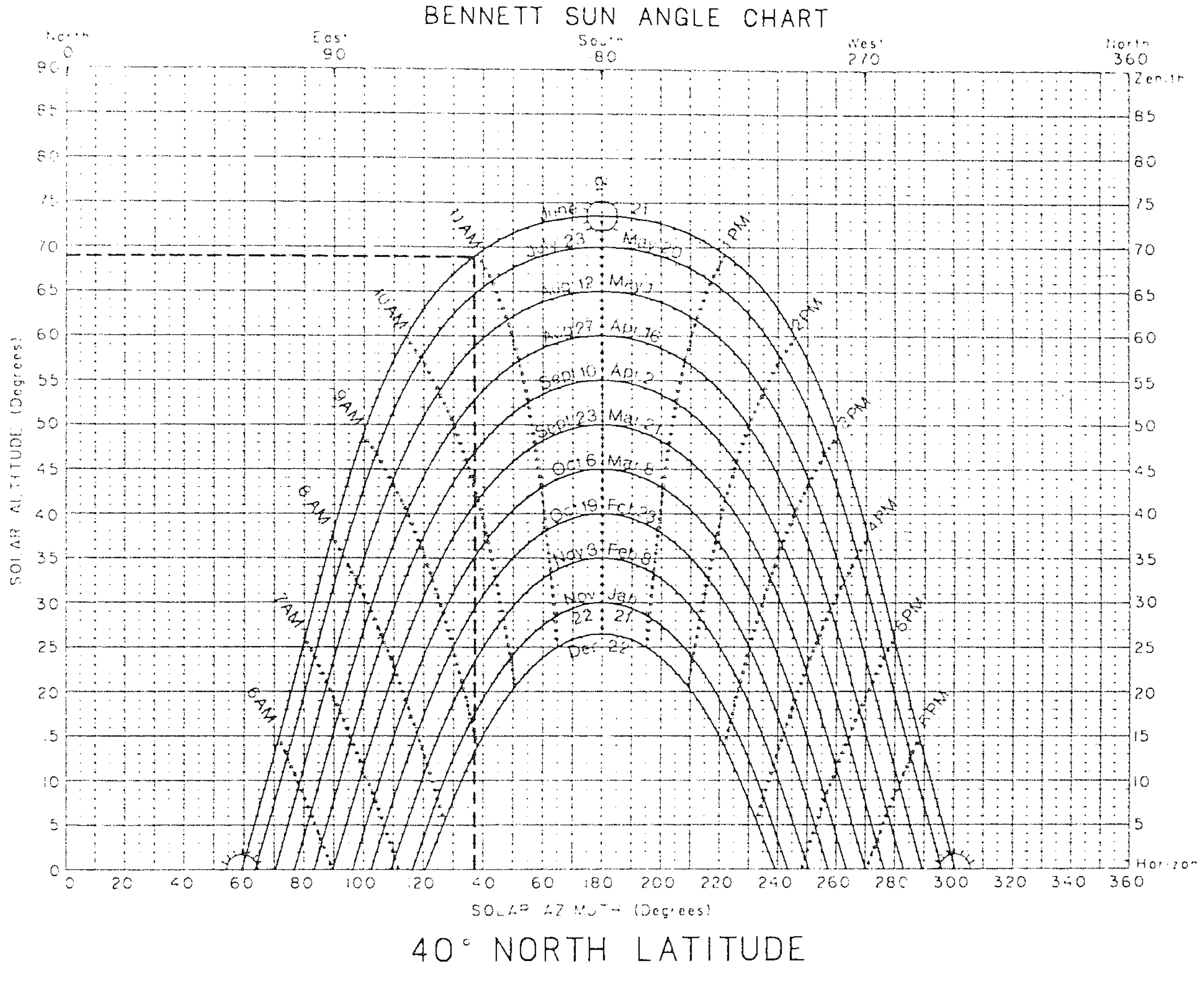


Figure 3.2 Shows, Bennett sun angle chart. This figure shows how solar elevation (altitude) and azimuthal angles can be found. For Philadelphia, in this example (latitude 40^0N) on June the 21st at 11 a.m. Source, Bennett (1980).

However, using electronic computers, the task of finding the position of the sun can be expressed in terms of a number of mathematical equations. The algorithm used in this work is that developed by Walraven (1978).

The earth makes an elliptical path during its journey around the sun, as in fig. 3.3 . The equatorial plane of the earth makes an angle of approximately 23.5^{o} with respect to the plane of the orbit of the earth about the sun. It is the angle of tilt that causes the elevation of the sun at noon to vary throughout the year. The time in this work has been expressed in days from January 1st, 1980, Greenwich Mean Time (G.M.T). From this the longitude of the sun, right accesion and declination angles have been expressed in a number of equations, as given by Walraven (1978), and have been adjusted for this work.

The angle of elevation and azimuth can be expressed as

$$\sin E = \sin\phi \sin\delta + \cos\phi \cos\delta \cos H \qquad (3.1).$$

$$\sin A = \cos\delta \sin H / \cos E \qquad (3.2).$$

where ϕ = local altitude

H = right accesion minus the local siderial time.

δ = angle of declination.

For a given date, latitude, longitude, the angles of elevation and azimuth of the sun can be computed, for any time interval. An accuracy of 0.01 degree, has been claimed by Walraven.

Archer (1980) , Barlow (1980), Barlow (1980a) and Wilkinson (1981), have suggested some improvements and corrections to Walraven's algorithm which have been included in this model. Both sunrise and sunset do not occur exactly at the time when the elevation of the sun is zero. This phenomenon is due to atmospheric refraction and the

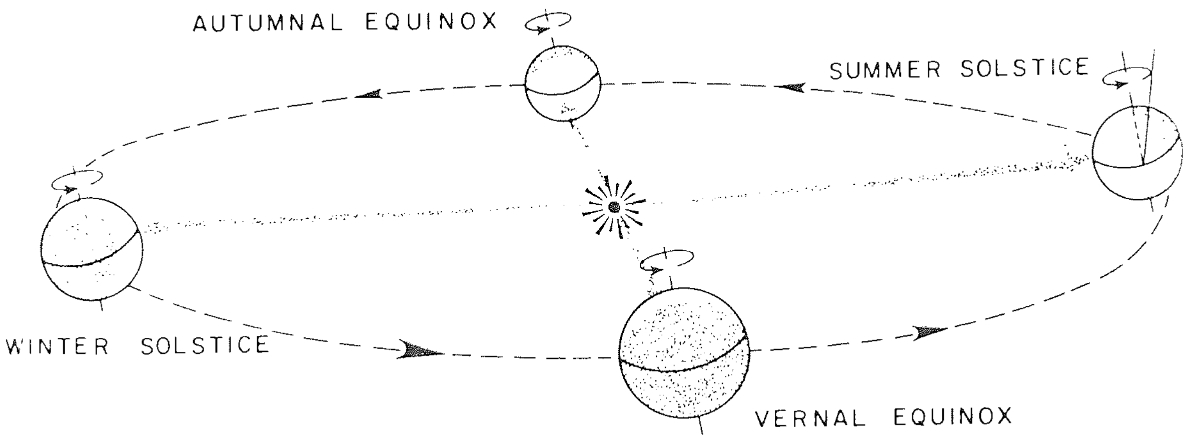


Figure 3.3 The earth's orbit about the sun and effects of the obliquity of the ecliptic on the seasons. Source, Liou (1980).

curvature of the earth.

The required apparent zenith angle Z1 can be calculated, using an algorithm suggested by Archer(1980), which takes account of refraction due to the earth's atmosphere.

$$Z1 = Acos\{ABS(cosZ) + 0.0083((1.0/0.9555) + 20.26) * ABS(cosZ)) - 0.047121\} \qquad (3.3).$$

where Z = zenith angle.

3.3 The present mathematical model

A mathematical model has been developed for predicting the total and spectral intensity of solar radiation, on a horizontal surface, along the lines suggested by Leckner (1978). The two variables in the model are the atmospheric water vapour content and the turbidity of the atmosphere. Similar work has been reported by Guzzi et al. (1978, 1979).

The depletion of irradiance intensity due to the atmospheric constituents, has been computed, starting with the solar energy outside the earth's atmosphere, at the mean distance between the earth and the sun. The part of the spectrum important for solar energy applications has been divided into 144 intervals, in the wavelength range from 0.29 to 4.0 microns.

The attenution of solar radiation by the earth's atmosphere has been expressed in terms of transmittance coefficients, which are wavelength dependent. The transmittance coefficients are defined for paths through the atmosphere in terms of relative air mass.

The path length of the solar beam through the atmosphere may be expressed in terms of the elevation of the sun above the earth's surface. For surfaces close to sea level, the air mass **m**, is related to the solar altitude **E** by

$$m = (1/\sin E) \quad \text{for } E > 10 \text{ degrees.} \qquad (3.4).$$

Equation 3.4, is applicable since the height of the earth's atmosphere for practical work can be considered to be 30 Km, whereas the radius of the earth is 6,400 Km. In relative terms for angles of elevation of the sun greater than 10 degrees, the surface of the earth can be approximated to be flat.

For angles of elevation of the sun less than 10 degrees, equation (3.4), overestimates the air mass.

Rodgers et al. (1978), have developed a method of estimating the air mass, by a method of least squares fit to Bompard's measured data from the Smithsonian Meteorological Tables, List(1951).

$$m = \exp\left[\{a_0 + \Sigma a_i (\sin E)^i\}\right] \qquad (3.5).$$

where constants a_i, i=0,1....,6 are given by

a_0 = 3.67985 a_1 = -24.4465

a_2 = 154.017 a_3 = -742.181

a_4 = 2263.36 a_5 = -3804.89

a_6 = 2261.05

Rodgers et al. (1978), claim an agreement to within 0.5% between the air mass value given by the expression in equation (3.5) and Bompard's data.

For points other than those at sea level, the air mass m must be corrected for altitude. The sea level air mass value must be multiplied by p/p_o, where p is the atmospheric pressure at the point and p_o is the standard atmospheric pressure at sea level.

$$p/p_o = \exp\left[\{\frac{a_s}{1000}(-0.1174 - 0.0017\frac{a_s}{1000})\}\right] \qquad (3.6).$$

a_s= altitude of the site above sea level in metres.

Equation (3.6) has been developed by Rodgers et al. (1978), from data in the Smithsonian Meteorological Tables ,List(1951).

From fig. 3.3, it is seen that the distance between the sun and the earth varies throughout the year. The distance varies between $147.1x10^6$ Km in early January, to $152.1x10^6$ Km in early July.

The intensity of radiation from the sun incident outside the earth's atmosphere decreases as the distance between the earth and the sun increases. The values of solar constant and spectral distribution, (as in section 2.2), are defined for the mean sun-earth distance. For this reason the intensity of solar radiation outside the atmosphere can depart from this by as much as $\pm$3.5% .

Since the variation is very nearly sinusiodal, the value of the solar constant correction factor for any day of the year can be calculated from, Rodgers et. al (1978).

$$C = \frac{1}{S_c}\left[\{S_c + \sum_{i=1}^{3}(a_i \cos\omega_j\ ) + b_i\ \sin(\omega_j\ )\}\right] \qquad (3.7)$$

where S_c = solar constant at mean sun earth distance.

J = day number of the year (January 1st = 1).

$\omega = 2\pi/366$.

The constants a_i and b_i,for i = 1 to 3, are as in table 3.1.a

i	a_i	b_i
1	45.326	1.8037
2	0.88018	0.09746
3	-0.00461	0.18412

Table 3.1.a values of a and b as used in equation (3.7)

The advantage of the expression in equation (3.7), over a graphical or tabulated representation is that the correction factor can be evaluated in a computer program.

3.4 Spectral transmittance functions

As mentioned in section (3.3), the extinction of solar radiation which is due to

i) scattering by atmospheric gases.

ii) absorption by uniformly mixed gases.

Ozone and

Water vapour

iii) extinction by atmospheric aerosols.

can be expressed in terms of transmittance coefficients.

3.4.1 Rayleigh scattering

The physical principles involved have been dealt with in section (2.4). The transmittance function can be expressed as

$$T_r = \exp(-0.008735 \times \lambda^{-4.08} \times m \times p/p_o) \quad (3.8.a).$$

where m = air mass.

p_o = 1013 mb.

p is the actual pressure in mb.

The factor 4.08, in the exponent takes account of the non-spherical shape of air molecules.

3.4.2 Ozone absorption

The transmittance of a path through the atmosphere is given by

$$T_{oz} = \exp \{- K(\lambda) \times l \times m\} \quad (3.8.b).$$

The absorption coefficients K/cm, obtained from Vigroux (1953), are listed in appendix **A.** The total amount of ozone in a vertical column, reduced to normal pressure and temperature, 1 $cm_{n.t.p}$ varies with; latitude, longitude and also with season at high altitudes. However, space and time variation in ozone concentration have little effect on global radiation, Robinson (1966), so that a mean value of 34 mm may be used. This has been the procedure adopted in this study.

3.4.3 Aerosol extinction

The extinction due to atmospheric aerosols which are always present, can be expressed in terms of a turbidity factor, given by

$$T_a = \exp\{ -\beta \lambda^{-\alpha} m\} \qquad (3.9).$$

where α is the wavelength coefficient.

β is the Angstrom turbidity coefficient.

The value of the turbidity coefficient varies, depending on whether the air originates over a continent or over a sea. The two are referred to as continental or marine type airmass.

A reasonable value for the wavelength coefficient has been suggested as 1.3±0.2, Angstrom(1961), from his extensive work of observations in the natural atmosphere.

Values of turbidity, for the model used in this work, have been taken from data provided by, the National Climatic Center(1974). Table 3.1 shows typical, monthly average values of turbidity for Aberporth (U.K.), which are used in this model.

3.4.4 Absorption by water vapour and other gases

A generalised transmission function can be expressed as, (Leckner, 1978),

$$T_i = \exp\left[\left\{ \frac{-0.3 K_i X}{(1 + 25.25 K_i X)^{.45}}\right\}\right] \qquad (3.10).$$

which is valid for the wavelength range used in this model. An effective absorption coefficient, K_i, for each wavelength interval,

MONTH	Water Vapour*(1) Content (mm)	Angstrom*(2) Turbidity
Jan	5	0.136
Feb	5	0.124
Mar	6	0.162
Apr	7	0.174
May	10	0.163
June	15	0.164
July	20	0.240
Aug	20	0.253
Sept	15	0.184
Oct	10	0.126
Nov	7	0.081
Dec	5	0.078

Table 3.1 Average monthly values of water vapour content of the atmosphere and Angstrom turbidity.

*(1) after Souster et al. (1979).
*(2) from Environmental Data Service (1974)

needs to be chosen.

The pathlength X is in cm when water vapour is considered and in Km for uniformly mixed gases. Absorption coefficients for water vapour and for uniformly mixed gases are listed in appendix **A**.

The transmittance function as in equation(3.10)is dependent on the selected size of the wavelength intervals. With the wavebands used in this model, some accuracy is lost during the computation of transmittance coefficients for water vapour and gases . These discrepencies may amount to an increase in absorptance, of a few per cent at high air mass values.

The absorptance coefficients, in appendix **A**, apply to homogeneous media. For vertical paths through the atmosphere, McClatchey et al. (1972) and Selby and McClatchey(1975), have given the following relationships, for overall coefficients.

$$X_w = \int_0^\infty \rho_\omega(h) \left[\frac{P(h)}{P_0} \left\{ \frac{T_0}{T(h)} \right\}^{0.5} \right]^{0.9} dh \qquad (3.11).$$

$$X_g = \int_0^\infty \frac{\rho(h)}{\rho_0} \left[\frac{P(h)}{P_0} \left\{ \frac{T_0}{T(h)} \right\}^{0.5} \right]^{0.9} dh \qquad (3.12).$$

here index o denotes normal conditions.

p = Total pressure.

T = absolute temperature.

ρ = density of air.

ρ_ω = water vapour density.

h = altitude above sea level.

By integrating equations (3.11 and 3.12), for standard atmospheres, as given by McClatchey et al. (1972), average values of constants can be evaluated, which in turn give

$$X_w = 0.795 \text{ W cm}^{-1}. \qquad (3.13).$$

$$X_g = 4.71 \text{ Km} . \qquad (3.14).$$

where w is the integrated amount of water vapour in a vertical column. With these reduced paths, the transmittance functions for a path at air mass m are

$$T_{wi} = \exp\left[\{-\frac{0.3\ K_{wi}\ X_w\ m}{(1+25.25\ K_{wi}\ X_w\ m)^{0.45}}\}\right] \qquad (3.15).$$

$$T_{gi} = \exp\left[\{-\frac{1.41\ K_{gi}\ m}{(1+118.3\ K_{gi}\ m)^{0.45}}\}\right] \qquad (3.16).$$

In the model the average monthly water vapour content of the atmosphere has been used for Kew, after Souster et al. (1979). These are shown in Table 3.1 .

3.5 Direct and diffuse radiation

The direct spectral irradiance E_i on a surface element, at ground level, can be computed from

$$E_i = (E_{oi}\ T_{ri}\ T_{ozi}\ T_{wi}\ T_{gi}\ T_{ai}) / \sin E \qquad (3.17).$$

where E_{oi} = exterrestrial spectral irradiance.

E = the angle of elevation of the sun.

T_{ri}, T_{ozi}, T_{ai}, T_{wi}, and T_{gi} are atmospheric transmittace coefficients for Rayleigh scattering, ozone, aerosols, water vapour and gases, respectively.

Total direct radiation is given by

$$T_E = \sum_{i=1}^{n} E_i\ \Delta\lambda_i \qquad (3.18).$$

The distribution of the radiation in the diffuse field is the result of some extremely involved and complex physical processes. The total diffuse radiation is made up of contributions from

i) Scattering by gas molecules (Rayleigh Scattering).

ii) Scattering by particulates (Mie Scattering).

iii) Small contributions from various reflection processes.

In the present modelling approach under consideration, there are two interrelated problems, Leckner (1980).

a) The spectral variation of diffuse radiation.

b) The radiance distribution over the clear sky.

From a theoretical point of view Rayleigh scattering is by far the easiest to deal with, basically because far fewer assumptions are made in the application of the theory to a pure Rayleigh scattering atmosphere. Another important consideration is that there is, in general, little variation in time and space of the main Rayleigh scatterers.

On the other hand for Mie scatterers, there is a considerable vertical variation of concentration, composition, shape and size distribution. Concentration of dust particles, ice crystals and water droplets in clouds can show rapid variations in relatively short periods of time so that Mie solutions for atmospheric scattering can only be approximate in nature. During a relatively clear day, however, the major contribution to the diffuse irradiance field is from Rayleigh scattering. The contribution from Mie scattering is much smaller and an approximate empirical approach is likely to give satisfactory results.

In this work the contributions to the diffuse component of radiation have been computed separately from Rayleigh scattering and from aerosols. The phase function value for Rayleigh scattering is 0. 5, and an average value for the aerosol phase function, has been taken from Boer(1977), as 0.63 .

$$\Delta E1 = \Sigma (E_{oi} T_{ozi} T_{gi} T_{wi} T_{ai} - E_i) \quad (3.19).$$

$$\Delta E2 = \Sigma (E_{oi} T_{ri} T_{ozi} T_{gi} T_{wi} - E_i) \quad (3.20).$$

$$D = (K1\ \Delta E1 + K2\ \Delta E2)\cos Z \qquad (3.21).$$

where D = diffuse irradiance

Z = zenith angle

K1 = phase function for Rayleigh scattering.

K2 = phase function for scattering by aerosols.

T_{ozi}, T_{gi} and T_{wi} are transmittance coefficients for ozone, gases and water vapour, respectively.

In the present investigation, average daily values of atmospheric turbidity for the latitude are used. The atmospheric turbidity is highly variable, even for very clear days, variations for the Birmingham area can be seen in figs. 4.1 and 4.2. The aerosol transmittance coefficient expression for T_a in equ. (3.9) is only approximate. Thus the simplified relationships given in equations (3.19) and (3.20) have been used for the present study.

3.6 The present computer program

A computer program has been developed in the FORTRAN programming language, to implement the mathematical model developed in the earlier sections of this chapter. This program was initially written for and run on an ICL 1904 computer at the University of Aston in Birmingham, and was later transferred to a PRIME 500 computer at The Polytechnic, Wolverhampton. A listing of this program is given in appendix B.

The computer program can be divided in two parts.

3.6.1 Position of the sun

Given the latitude, longitude and mean height above sea level, together with the date, the angles of elevation and azimuth can be computed for any specified time interval. The angle of elevation of the sun is used to compute the air mass and the length of day.

For the purpose of this study, the air mass has been computed using mid-hour values as reference. For example, the time say 10.30 a.m., is used to cover the period from 10.00 a.m. to 11.00 a.m.. This procedure has also been used by the U.K. Meteorological Office, for its archived solar radiation data, Elms (1980). When dealing with the early morning and late evening time periods, the time interval may not be a 'whole-hour', thus the mid-period radiation levels are multiplied by an 'hourly-factor' when computing daily totals of radiation.

N.B. All calculations are referenced to Greenwich Mean Time (G.M.T.)

3.6.2 Computation of radiation intensities

Starting with the extraterrestrial radiation after Thekaekara (1973), transmittance functions for ozone, gases, water vapour, Rayleigh scattering and aerosol extinction, were evaluated for all the 144 spectral intervals, in the wavelength range 0.29 to 4.0 microns.

The total radiation , direct and diffuse components were then computed. Daily totals of radiation were computed by multiplying the 'mid-period' irradiance levels with respective time intervals.

The spectral distribution for direct and diffuse radiation was calculated as means for the whole day. To arrive at the daily mean spectral intensity, hourly spectral intensities were added for the whole day and then divided by the number of hourly intervals.

The program can provide solar radiation data output in any one or a combination of the folowing formats.

a)* Daily and hourly totals of direct, diffuse and total radiation throughout the year.

b)* Daily mean or hourly instantaneous spectral irradiance of direct, diffuse and total radiation.

c)* A graphical representation of hourly totals and mean daily spectral distribution intensity for , direct, diffuse and total radiation.

The results for the present mathematical model are presented and discussed in chapter 4.

*-- The mathematical model developed in this chapter can be applied to any location on the earth's surface. Appropriate turbidity and atmospheric water vapour content values will be required.

Chapter 4. EVALUATION AND TESTING OF THE MATHEMATICAL MODEL

4.1 Measurement of Angstrom Turbidity

Data reported on the measured Angstrom turbidity for the U.K. is rather limited. For the U.K., the two main sources of turbidity data are Volz(1978) and the National Climatic Centre, (1977). Volz has reported data for 58 European stations, covering the period from 1963 to 1969. The U.K. station included in Volz's work is Kew(lat. 51^{o} $28'$ N; long. 0^{o} $18'$ W; mean height a.s.l. 50m).

The World Meteorological Organisation has sponsored a world wide programme of monitoring the atmospheric turbidity. This work is carried out in cooperation with the U.S. National Oceanic and Atmospheric Administration(NOAA) and the U.S. Environmental Protection Agency(EPA). The National Climatic Centre, Ashville, U.S.A, has been designated as the agency responsible for the collection and analysis of reported atmospheric turbidity data, and finally of making this data available to interesed parties. The two U.K. stations included in this network are Bowerchalke(lat. 51^{o} $00'$ N; long. 2^{o} $00'$ W; mean height a.s.l. 125m) and Upper Heyford AB(lat. 51^{o} $56'$ N; long. 1^{o} $15'$ W; mean height a.s.l. 136m). Both sites are located in rural surroundings. The amount of turbidity data reported in the W.M.O. network covers more days in a month compared to that by Volz. However only 1, 2 or 3, readings have been taken daily. In the case of only one reading during a day it has been taken near mid-day.

Two methods are employed for measuring Angstrom turbidity, using

(i) a sun photometer

(ii) a pyrheliometer.

Both, reports by Volz and The Natonal Climatic Centre, have included turbidity data which has been measured using a sun photometer and a pyrheliometer. The two techniques give results for Angstrom turbidity which agree to ±0.01, Volz (1978), in the turbidity range 0.05 to 0.55 .

4.1.1 Procedure

In this study an Eppley Normal Incidence Pyrheliometer has been used in conjunction with glass filters for the determination of Angstrom turbidity and the procedure followed is as described by Angstrom, (1961).

The three glass filters RG695, RG630 and OG530, with lower wavelength cut-off at 0.686, 0.623 and 0.529 micrometers respectively, were used together with a clear glass cover. The four sets of readings were taken manually at time intervals of approximately 10 minutes.

Using the glass filters, the energy in appropriate wavelength bands can be expressed as follows

$$I_r = \int_{0.623}^{0.686} F(\lambda)\, d\lambda \qquad (4.1).$$

and

$$I_k = \int_{0}^{0.529} F(\lambda)\, d\lambda \qquad (4.2).$$

where λ = wavelength in microns.

I_r = total energy in the wavelength range from 0.623 to 0.686 micrometers.

I_k = total energy transmitted by the filter OG530.

Using the relationships derived by Angstrom and converted to S.I. units, the above two equations can be expressed as

$$I_r = 126.6 \times e^{-\frac{\beta_1 m}{[0.654]^{1.3}}} \qquad (4.3).$$

and $$I_k = 311.4 \times e^{-\frac{\beta_2 m}{[0.454]^{1.3}}} \qquad (4.4).$$

m = air mass.

α = wavelength coefficient, value of 1.3 has been used in this study.

A solar constant value of 1370 Wm^{-2}, has been used in this work . From the measured solar radiation data, using the relationships in equations 4.3 and 4.4, values for Angstrom turbidity were derived.

$$\beta = \frac{\beta_1^2}{\beta_2} \qquad (4.5).$$

The turbidity values derived in equation 4.5, are likely to have an accuracy of ±10% .

4.1.2 Results

It was only possible to collect a limited set of turbidity data since the pyrheliometer was on loan to the University by the courtesy of the U.K. Atomic Energy Authority, Winfrith. Apart from the restricted time when the instrument was available there was a further limitation since continuous turbidity data could only be collected on clear days.

Figures 4.1.a and 4.1.b, show turbidity plots for two fine clear days, the 27th and the 30th of July 1981, respectively. A summary of this data is given in table 4.1 .

DATE	MEAN	MIN	MAX	DATA POINTS
27/7/81	0.13±0.01	0.11	0.19	67
30/7/81	0.21±0.01	0.16	0.26	52

Table 4.1 Measured turbidity data for Birmingham.

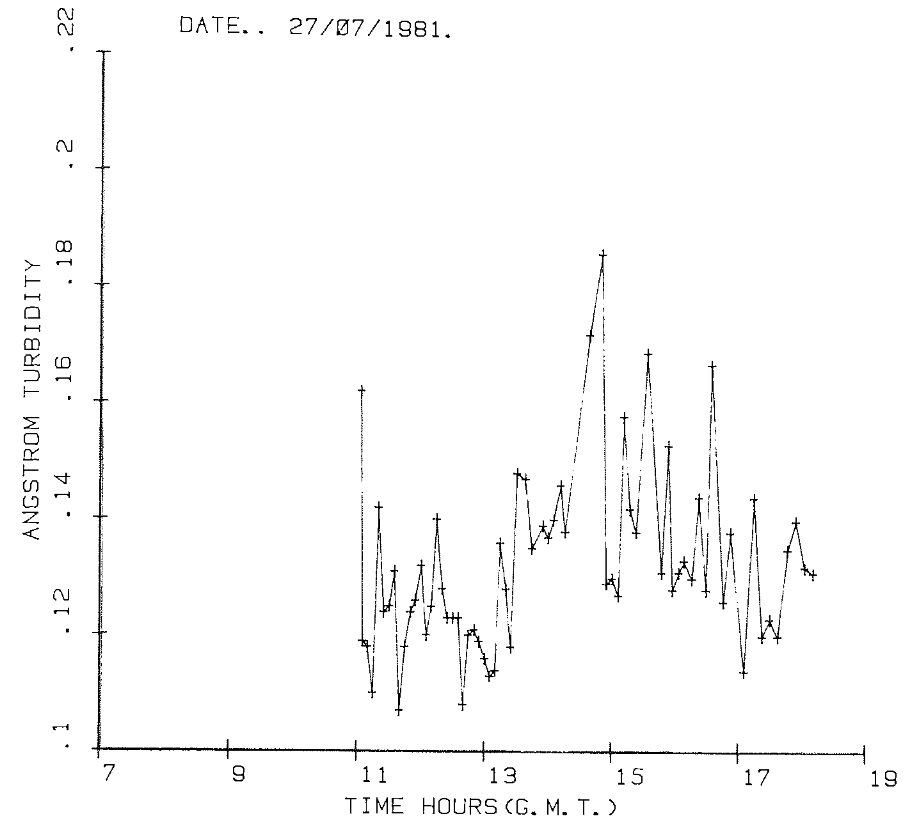


Fig 4.1.a Variation of Angstrom turbidity with time, for Birmingham. Data for 27th July 1981.

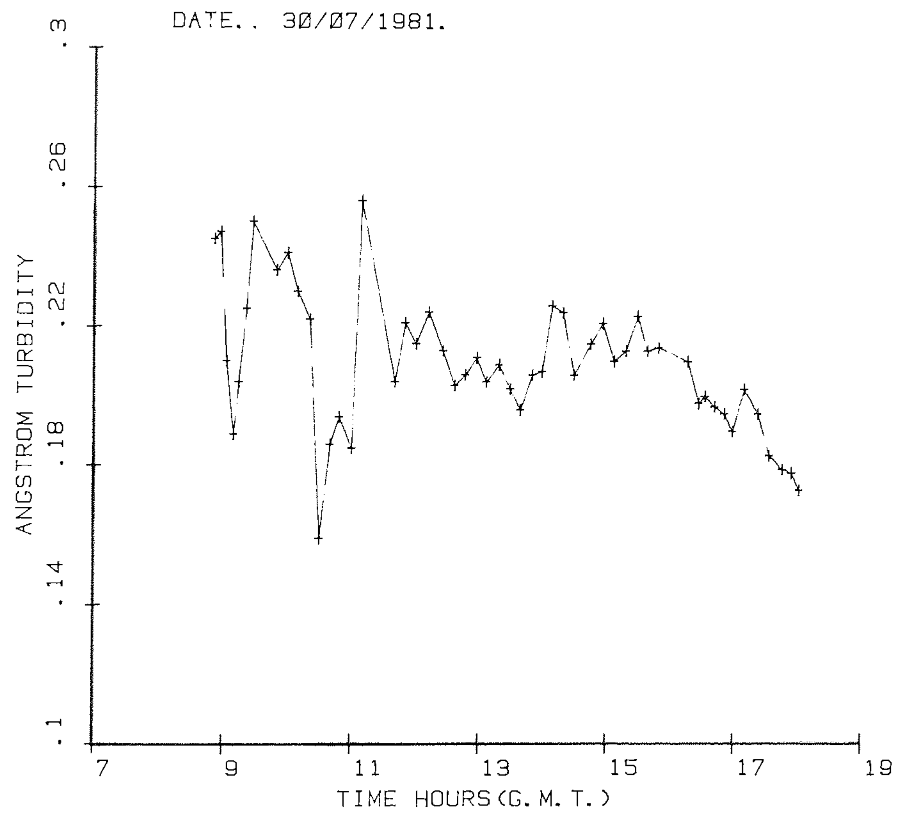


Fig 4.1.b Variation of Angstrom turbidity with time, for Birmingham. Data for 30th July 1981.

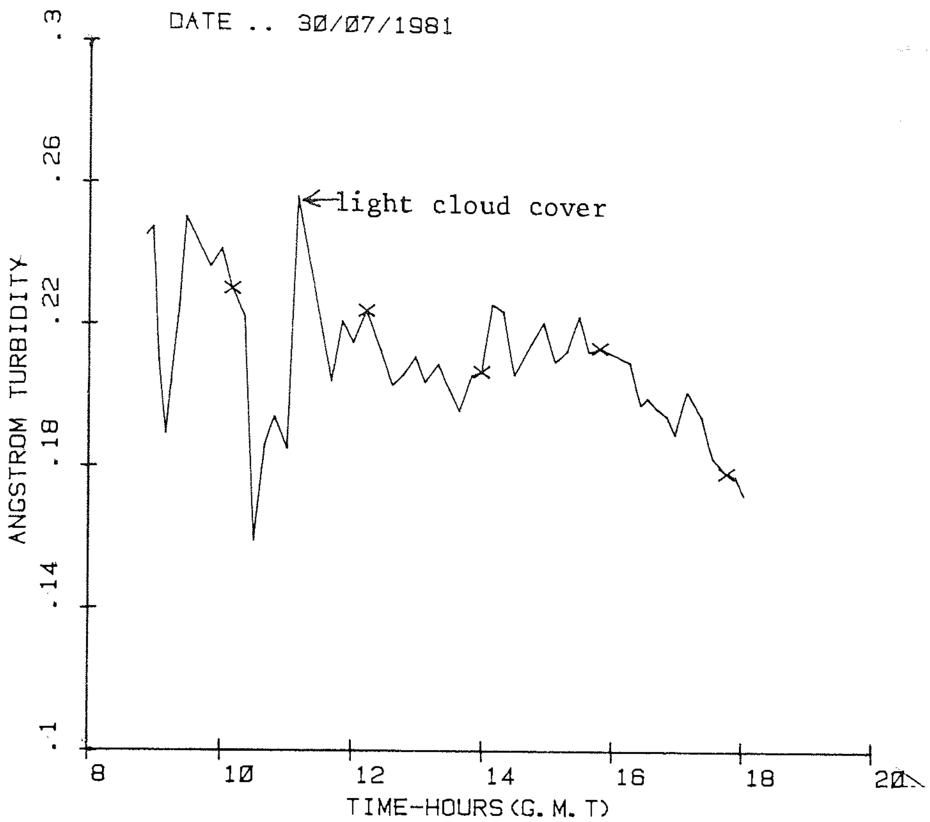


Fig 4.2a Variation of Angstrom turbidity against time, for Birmingham. Data for 30th July 1981.

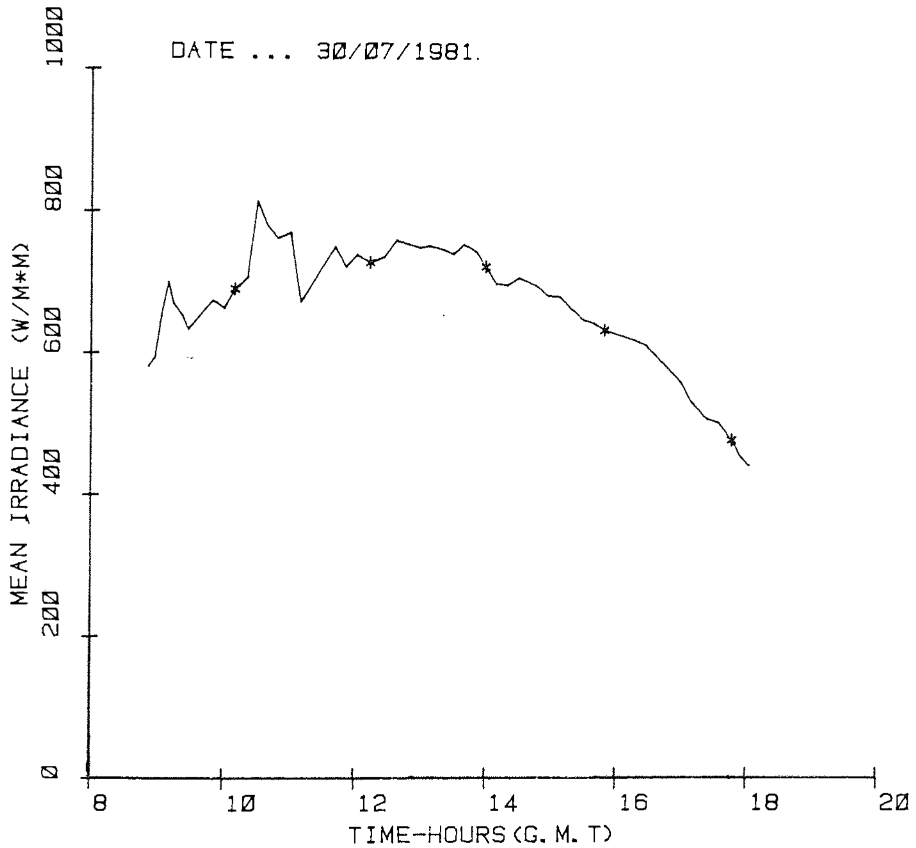


Fig 4.2b Direct radiation along the sun direction. Data for Birmingham. Data for 30th July 1981.

Figure 4.1, shows that even on a fine clear day, there are large fluctuations in measured turbidity data. Figure 4.2 shows the effect of increased atmospheric turbidity, resulting in a decrease in the direct component measured along the direction of the sun.

4.2 The effect of astronomical and geographical factors

Table 4.2, gives the angle of azimuth, times of sunrise and sunset, length of day in hours, angle of elevation of the sun at 12 noon (G.M.T.) and the air mass at midday for Birmingham. For the results in table 4.2, the 15th day of each month, has been used to represent the 'day' for the month.

When the data for two days, the 15th of December and the 15th of June are considered the length of day varies from 7.7 to 16.9 hours. So even if all the other factors determining the intensity of solar radiation incident on a horizontal plane were the same, the difference in length of the day will result in the daily total of radiation for 15th of June being more than twice the total for the 15th of December. The second major factor in the difference is the change in elevation of the sun which was 14.2^{o} on the 15th of December at noon and 60.8^{o} for noon on the 15th of June 1981. The air mass is related to the path length in the earth's atmosphere, through which a beam of light from the sun has to travel before arriving at the earth's surface. The air mass value is 3.92 for the 15th of December and 1.1 for the 15th of June, as shown in table 4.2, at noon.

The expressions for atmospheric transmission due to atmoshperic constituents (section 3.4), include the negative exponentiation of air mass. Comparing the effect of air mass in the transmittance coefficients, it will be 0.3328 for 15th of June and 0.0198 for 15th of December, 1981.

DATE*	AZIMUTH DEGREES	TIME OF SUNRISE (HOURS)	TIME OF SUNSET (HOURS)	DAY LENGTH (HOURS)	ANLGE OF ELEVATION DEGREES	AIR-MASS
Jan	4.17	8.15	16.43	8.28	16.3	3.42
Feb	5.87	7.37	17.38	10.01	24.7	2.30
Mar	5.10	6.33	18.24	11.91	35.3	1.66
Apr	2.80	5.13	19.15	14.23	47.3	1.31
May	1.70	4.14	20.00	15.86	56.4	1.15
June	3.80	3.66	20.62	16.96	60.8	1.10
July	6.12	4.00	20.47	16.48	58.9	1.12
Aug	4.72	4.77	19.61	14.84	51.4	1.23
Sept	0.94	5.65	18.43	12.79	40.4	1.48
Oct	-1.84	6.51	17.26	10.75	28.9	1.99
Nov	-1.93	7.45	16.28	8.83	18.9	2.96
Dec	-0.67	8.16	15.94	7.99	14.2	3.92

* Data for 1981, the 15th day of each month has been used, as a typical day.

Table 4.2 Output from the computer program SPECPR showing the azimuthal angle of the sun at midday, times of sunrise and sunset, day length in hours, angle of elevation of the sun and air mass at 12 noon (G.M.T.). Data for Birmingham (Lat. 52° 30'N; Long. 1° 55'W; mean height above sea level 100m).

The sky radiation is made up of contributions resulting from Rayleigh scattering and scattering due to atmospheric aerosols. Figure 4.3, shows the change in transmission expressed as percentage due to Rayleigh scattering, when the air mass is varied from 1 to 6. Figure 4.4.a shows the variation of transmission resulting from aerosol extinction, when the air mass is varied from from 1 to 6, at a constant turbidity value of 0.15 . A similar effect is shown in fig. 4.4.b, when the turbidity is changed from 0.05 to 0.3, at a constant air mass value of 1.5 .

4.3 Sensitivity analysis

An investigation was carried out to look into the effect on radiation levels of variables in the mathematical model. Two variables having significant effect on the model output were found to be the atmospheric water content and atmospheric aerosol content, expressed as atmospheric turbidity.

Three days in 1981 were selected for carrying out the sensitivity analysis; the 15th of June and 15th of December, representing two extreme sets of data and the 15th of September to represent an intermediate situation. Although the water vapour content of the atmosphere and turbidity levels both vary with time even under stable conditions, average monthly values for both variables have been used in the study. These values are listed in table 3.1 .

In the case of the atmospheric water sensitivity analysis, an appropriate average monthly turbidity value was selected. The water vapour content expressed as an equivalent column of water was varied from 5mm to 24mm, at intervals of 1mm. As a result of increased atmospheric water vapour, the levels of all three, direct, diffuse and total radiation, decrease. Using the radiation levels with 5mm atmospheric water content as the reference, the other levels were

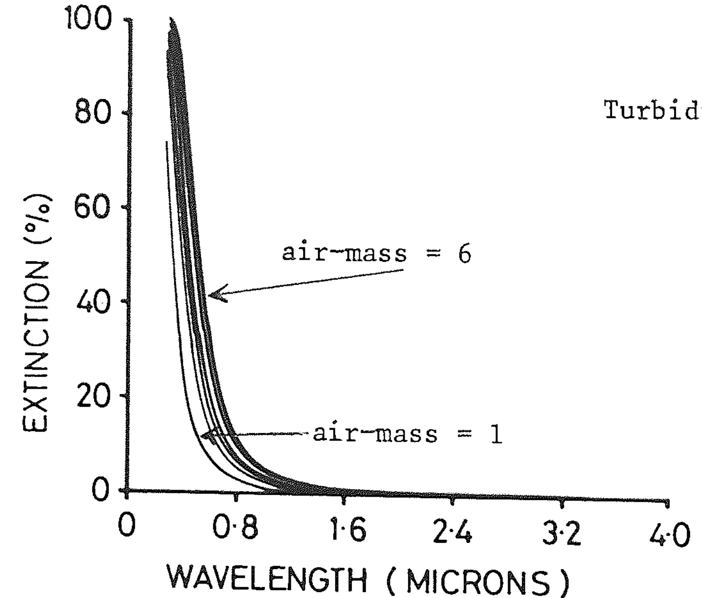


Fig 4.3 The change in transmission, due to Rayleigh scattering as the air mass is increased from 1 to 6.

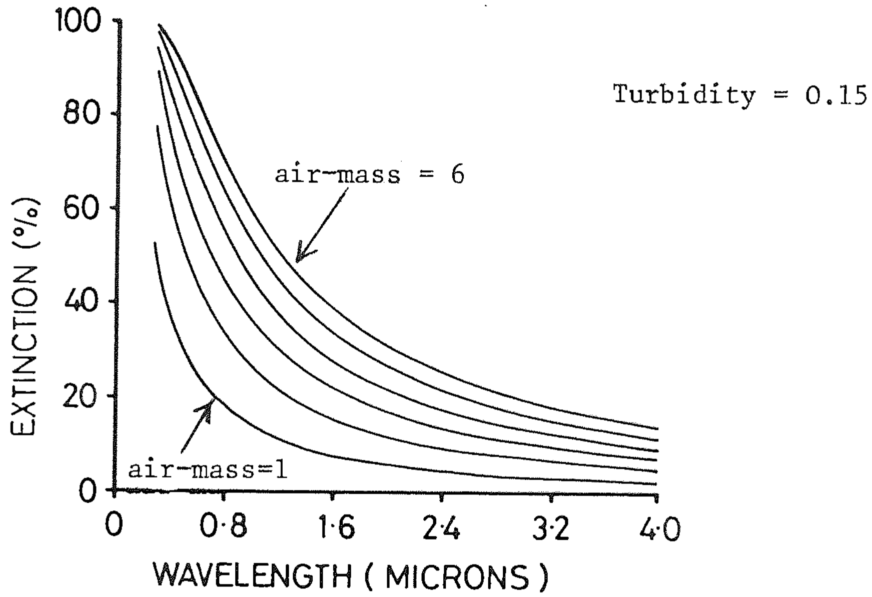


Fig 4.4.a The extinction of the radiation from the sun due to the atmospheric aerosols, as the air mass is increased from 1 to 6

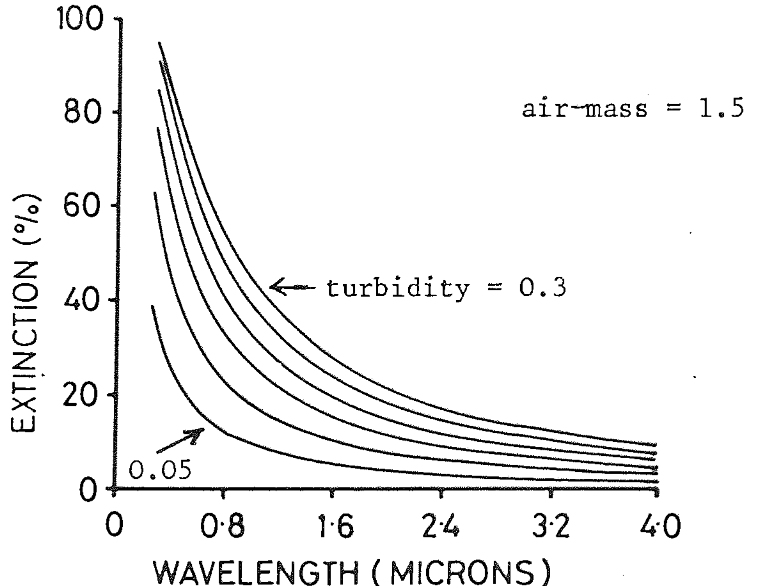


Fig 4.4.b The variation of the extinction of the solar radiation from the sun due to atmospheric aerosols, as the atmospheric turbidity is increased from 0.05 to 0.3.

represented as percentages.

The results are presented in fig. 4.5. Captions a, b and c, refer to results for 15th of September, 15th of December and 15th of June, 1981, respectively. A summary of water vapour sensitivity analysis is also given in table 4.3 , and shows that the reduction in radiation levels for the three days under consideration, resulting from an increase in atmospheric water vapour content from 5mm to 24mm, is less than ~10%. On average the direct component is decreased by ~7%, the diffuse component by ~5% and the total radiation by ~6%, over the test range.

The appropriate value of the average monthly atmospheric water vapour content was selected for the turbidity sensitivity analysis (see table 3.1). The Angstrom atmospheric turbidity was varied from 0.08 to 0.27, at intervals of 0.01. Results for the three days, 15th of September, 15th of December and 15th June, 1981, are shown in figure 4.6 . A summary of the results is also shown in table 4.4 .

As the atmospheric turbidity increases it causes a reduction in direct and total radiation levels, but the intensity of sky radiation is increased. In the present analysis of results, the irradiance levels with atmospheric turbidity being 0.08, are used as the reference. This resulted in giving sky radiation percentages greater than the 100%-allocated to the reference point as shown in table 4.4 . The results presented in fig 4.6 only deal with direct and total radiation but diffuse radiation results are included in table 4.4. The results in table 4.4, show a large seasonal difference between the December and June value. In the case of direct radiation, the radiation levels at 0.27 turbidity are, 60, 38 and 70 percent, for 15th of September, 15th of December and 15th of June, respectively.

WATER VAPOUR SENSITIVITY ANALYSIS

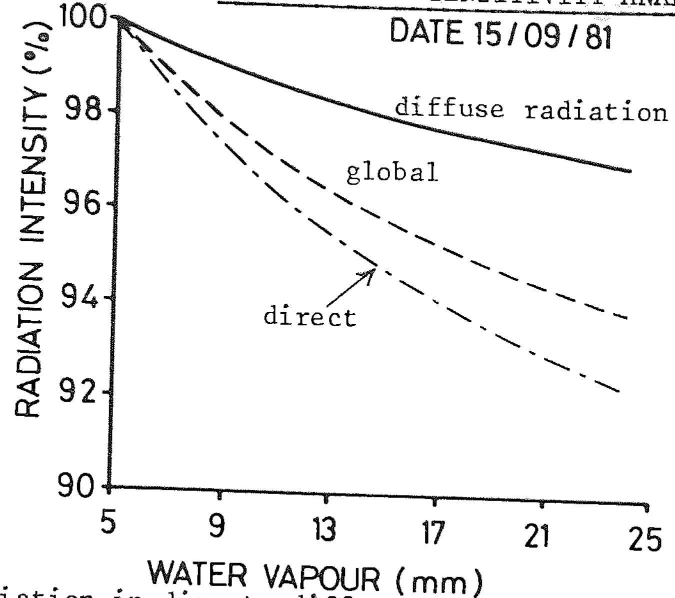


Fig 4.5.a Variation in direct; diffuse and global radiation, as the water vapour is increased from 5 to 24 mm.

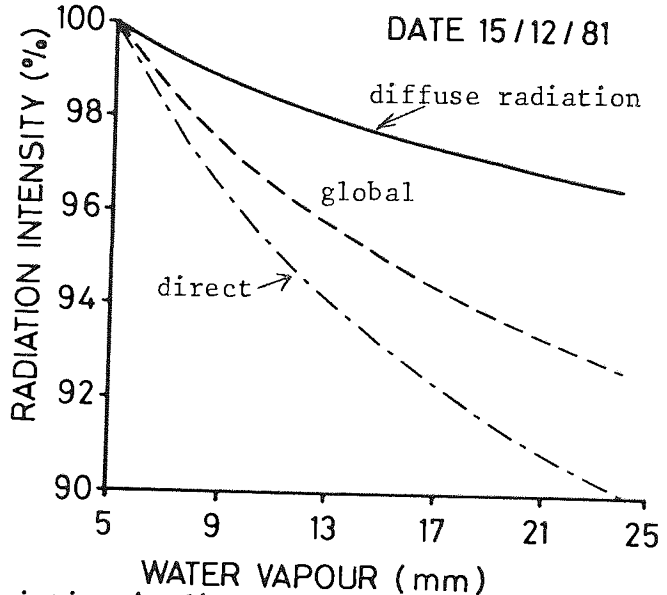


Fig 4.5.b Variation in direct, diffuse and global radiation, as the water vapour is increased from 5 to 24 mm.

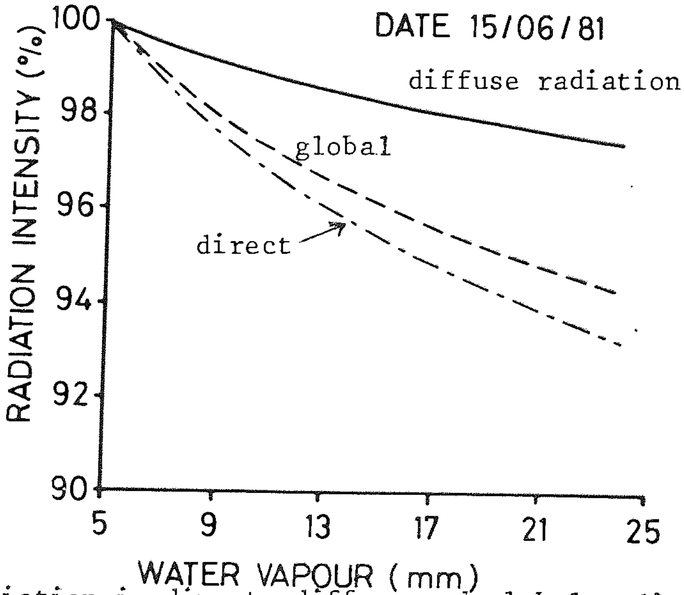


Fig 4.5.c Variation in direct, diffuse and global radiation, as the water vapour is increased from 5 to 24 mm.

WATER VAPOUR (mm)	15/09/1981			15/12/1981			15/06/1981		
	DIRECT %	DIFF %	TOTAL %	DIRECT %	DIFF %	TOTAL %	DIRECT %	DIFF %	TOTAL %
5	100	100	100	100	100	100	100	100	100
9	97.3	99.0	97.8	96.4	98.8	97.4	97.6	99.1	98.1
13	95.5	98.3	96.4	94.0	98.0	95.7	96.0	98.5	96.6
17	94.1	97.8	95.4	92.3	97.4	94.4	94.8	98.1	95.6
21	93.0	97.4	94.5	90.9	96.9	93.4	93.8	97.7	94.8
24	92.3	97.1	94.0	90.0	96.5	92.7	93.2	97.4	94.3

Table 4.3 A summary of the results given by the water sensitivity analysis.

TURBIDITY SENSITIVITY ANALYSIS

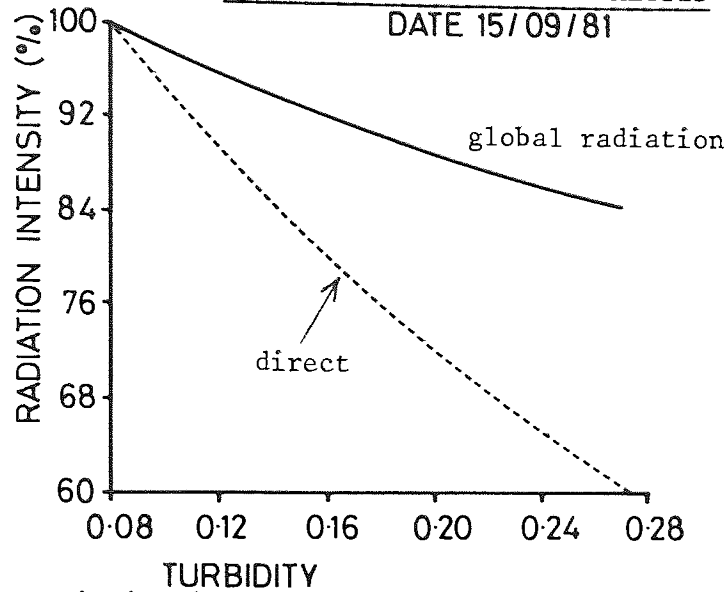


Fig 4.6.a Variation in direct and global radiation as the atmospheric turbidity is increased from 0.08 to 0.28.

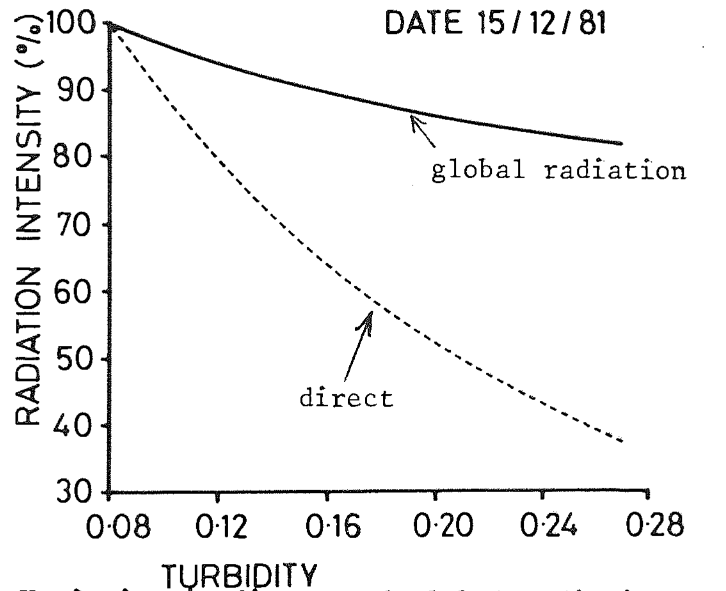


Fig 4.6.b Variation in direct and global radiation as the atmospheric turbidity is increased from 0.08 to 0.28.

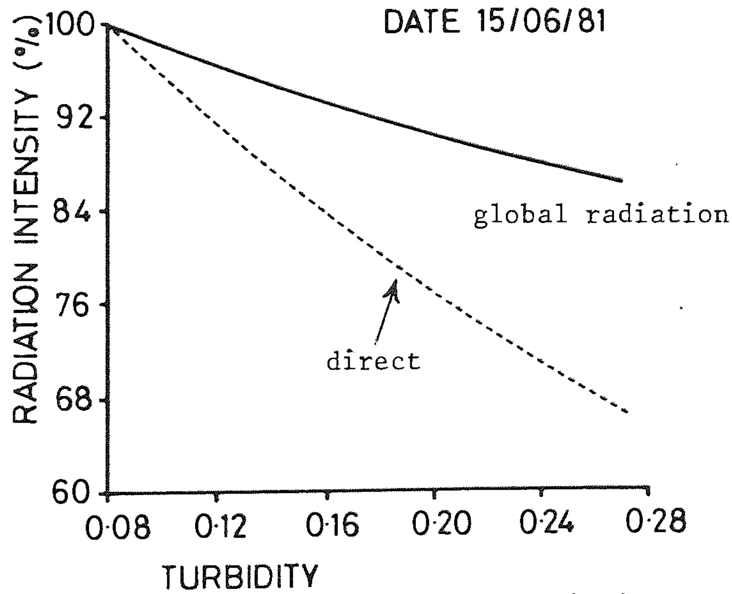


Fig 4.6.c Variation in direct and global radiation as the the atmospheric turbidity is increased from 0.08 to 0.28.

TURBIDITY	15/09/1981			15/12/1981			15/06/1981		
	DIRECT %	DIFF %	TOTAL %	DIRECT %	DIFF %	TOTAL %	DIRECT %	DIFF %	TOTAL %
0.08	100	100	100	100	100	100	100	100	100
0.12	89.4	120	95.7	79.3	114	94.0	91.3	121	96.4
0.16	80.0	136	92.1	63.8	125	89.5	83.7	139	93.2
0.20	72.0	151	89.0	52.1	133	86.2	76.9	155	90.4
0.24	65.1	163	86.3	43.1	139	83.5	70.9	170	88.0
0.27	60.5	172	84.5	37.7	143	81.9	66.8	180	86.3

Table 4.4 A summary of the results given by the turbidity sensitivity analysis program.

Allowing for seasonal differences, the direct component of radiation decreases by ~45% and the total by ~16%, when the atmospheric turbidity is increased from 0.08 to 0.27. The larger percentage decrease in total and direct radiation for 15th of December results from larger air mass values, as shown in figs. 4.3 and 4.4.

4.4 Results

A typical output from the Computer program, **SPECPR**, developed in the FORTRAN programming language when the mathematical model is implemented as described in Chapter 3, is shown in appendix **B**.

The computer program output can be divided into the following parts.

i) This stage computes the position of the sun during the day; giving angles of elevation and azimuth, at specified time intervals, (1 hour in this work).

ii) The times of sunrise and sunset are computed next, after allowing for the curvature of the earth and refractive processes in the atmosphere. Since the first and last 'time periods' of the day may be less than 60 minutes, a multiplication factor has been introduced, and is used when calculating the daily totals of radiation.

iii) Next the transmittance coefficients for air molecules, aerosols, atmospheric gases, water vapour and ozone, are computed for each spectral interval. Hourly total mean values for direct and diffuse components are evaluated by simple integration. The mean hourly values of irradiance are used for computing the daily totals of radiation.

iv) For the spectral distribution of radiation during the day, hourly spectral contributions are all added for the whole day and a mathematical mean is calculated from the total data. Appendix **C** shows a print out of the mean daily spectral values. Slight variations of this procedure have been used for carrying out the sensitivity analyses and computing the radiation data in spectral bands.

A comparison of the measured and the predicted, hourly mean radiation levels for a horizontal surface is given in figs 4.7 to 4.12. Results are presented in three groups.

i) Total and diffuse radiation (figs. 4.7 and 4.8).

ii) Total and band data with filters RG715 and RG630 (figs. 4.9 and 4.10).

iii) Total and band data with filter OG530 (figs. 4.11 and 4.12).

Three Eppley Precision Pyranometers have been used for measuring all the solar radiation data, presented in this chapter. The diffuse component of radiation was measured using a shadow band in conjunction with an Eppley PSP pyranometer. The solar radiation data in broad bands was measured using Schott glass filters. The measured data presented in figs 4.8, 4.10 and 4.12, represent the mean irradiance calculated for 10 minute periods, from the scans taken every 10 seconds. In figures 4.8,4.10 and 4.12, only every 10th data point has been marked with a symbol. The 10 minute mean irradiance data show clearly any fluctuations in the measured radiation over a short time interval resulting from the presence of thin clouds.

The data shown in figs 4.7, 4.9 and 4.11, are the hourly mean irradiance values for both measured and computed data.

In each set of data in figs. 4.7 to 4.12, data for a relatively clear day (indicated by caption a) and a partially cloudy day (shown by caption b) have been presented in order to test the model.

An analysis has been carried out to test the effect of using measured mean hourly turbidity values in the model. Results are given in tables 4.5 and 4.6, comparing the measured radiation values to the

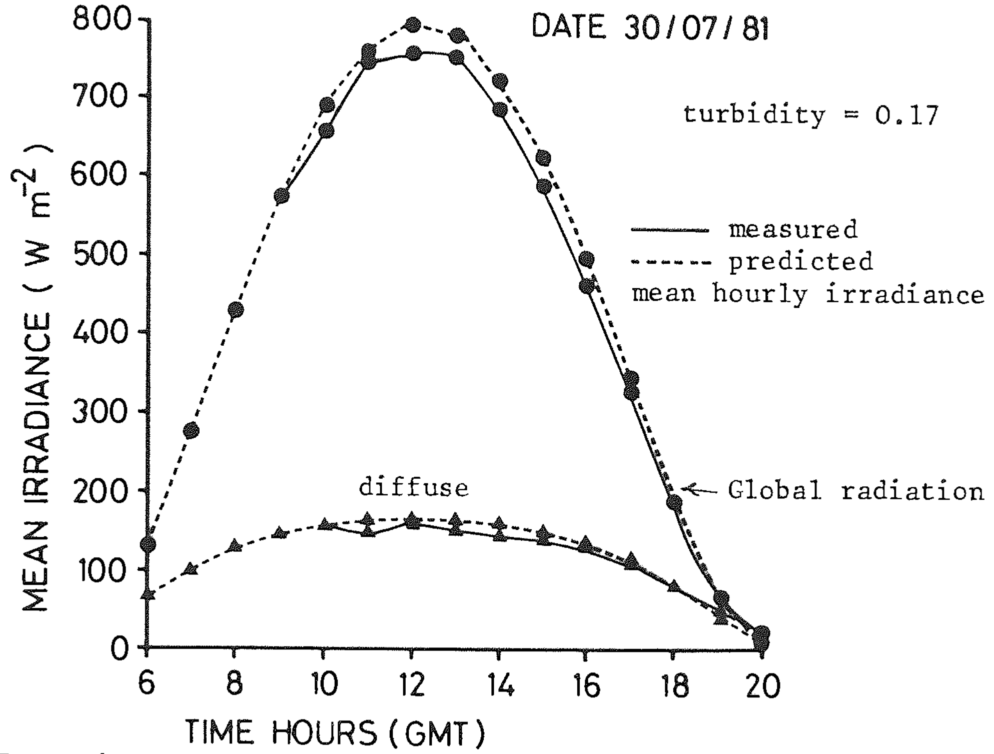


Fig 4.7.a Diffuse and global radiation, for a relatively clear day.

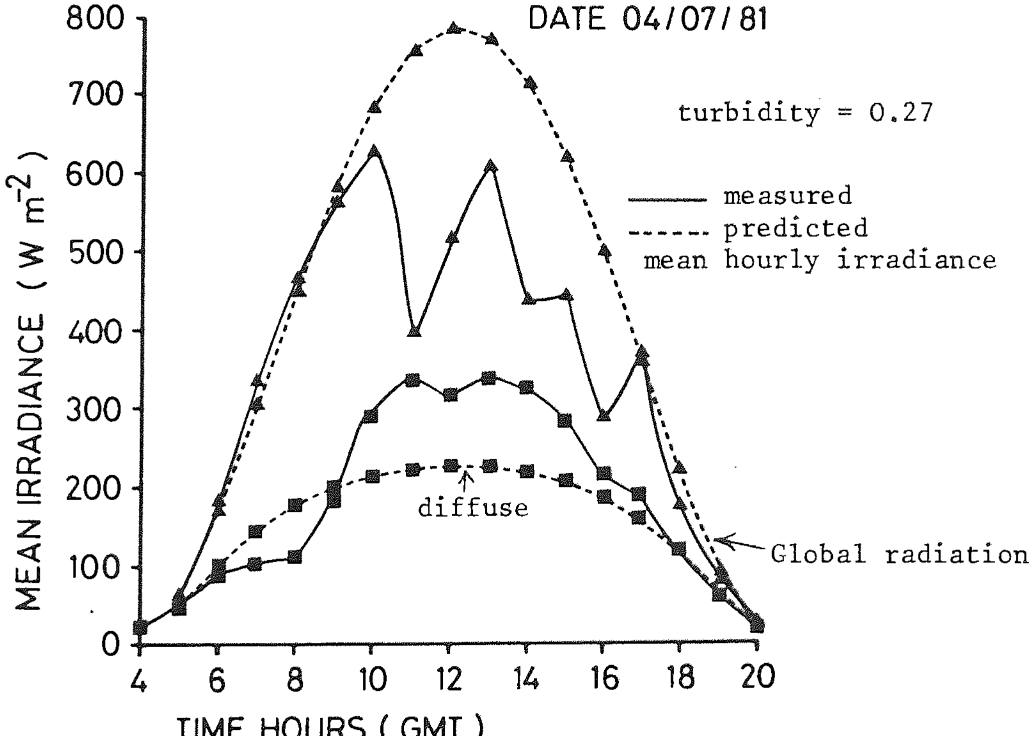


Fig 4.7.6 Diffuse and global radiation, for a partially cloudy day.

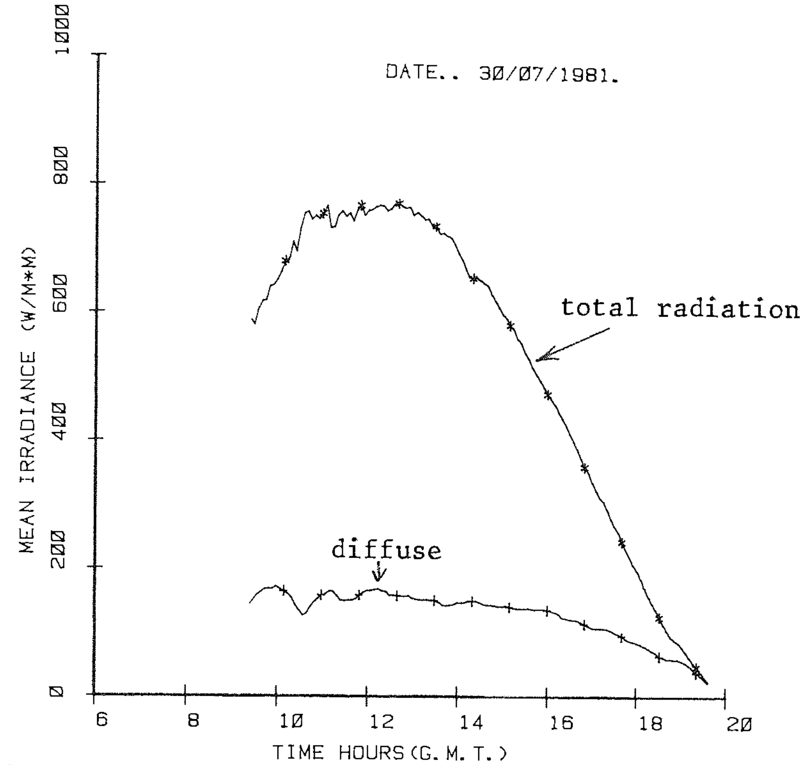


Fig 4.8.a Measured, diffuse and total radiation for a relatively clear day.

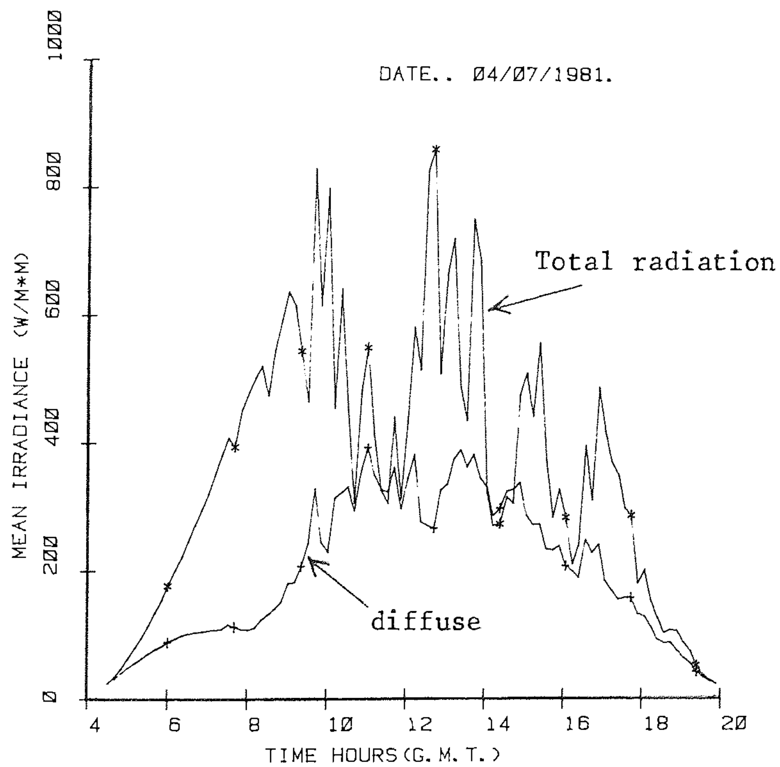


Fig 4.8.b Measured, diffuse and total radiation for a partially cloudy day.

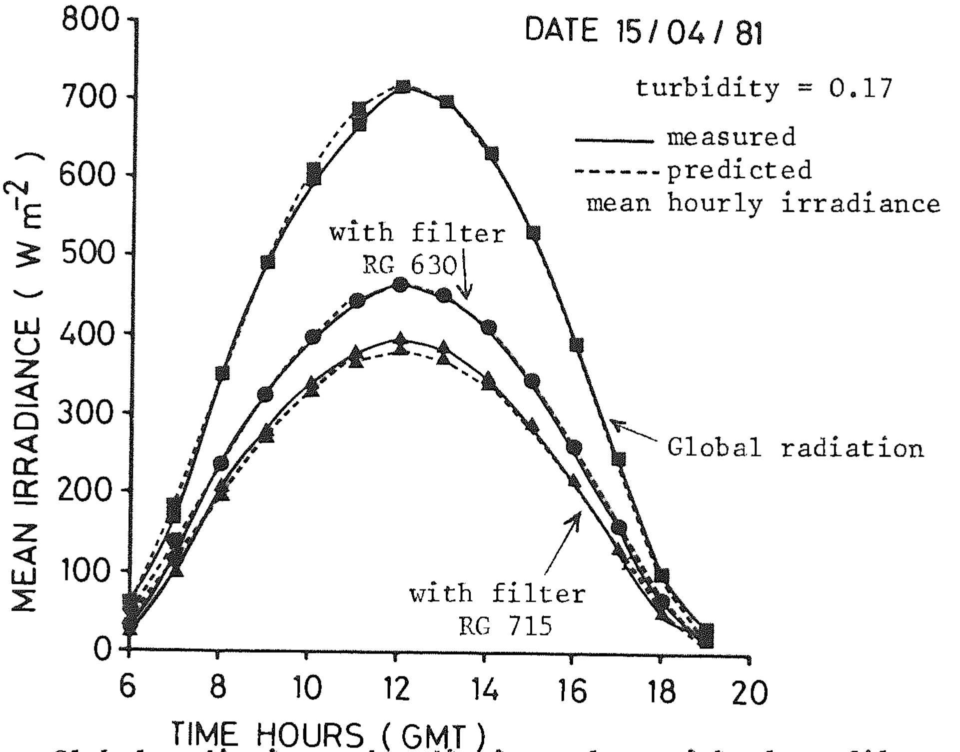


Fig 4.9.a Global radiation and radiation values with glass filters RG 715 and RG 630, for a relatively clear day.

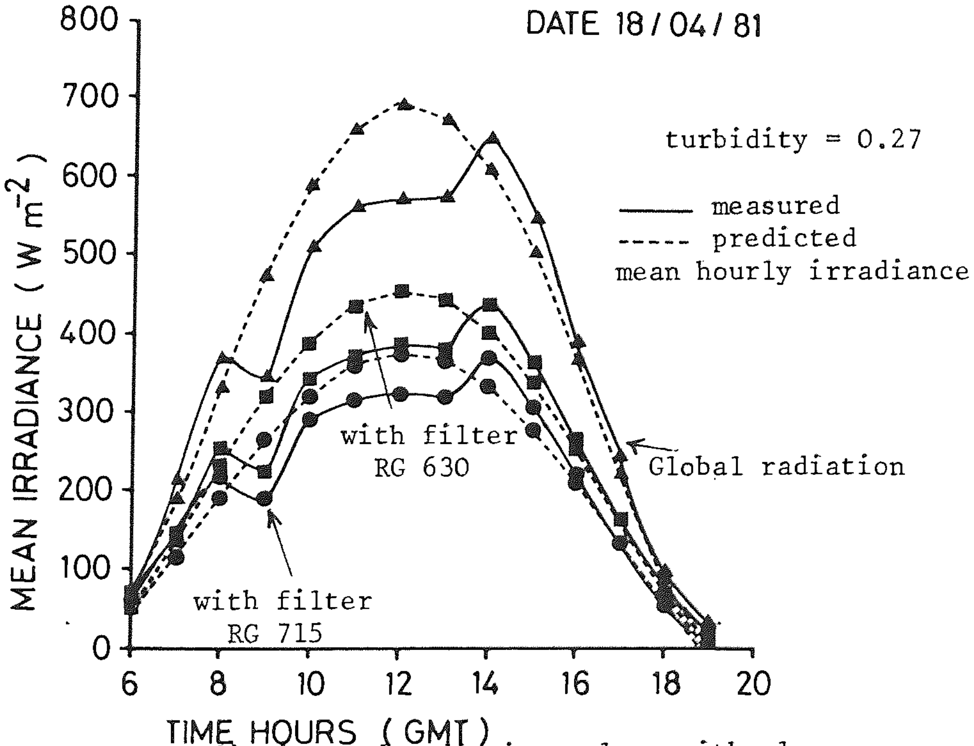


Fig 4.9.b Global radiation and radiation values with glass filters RG 715 and RG 630, for a partially cloudy day.

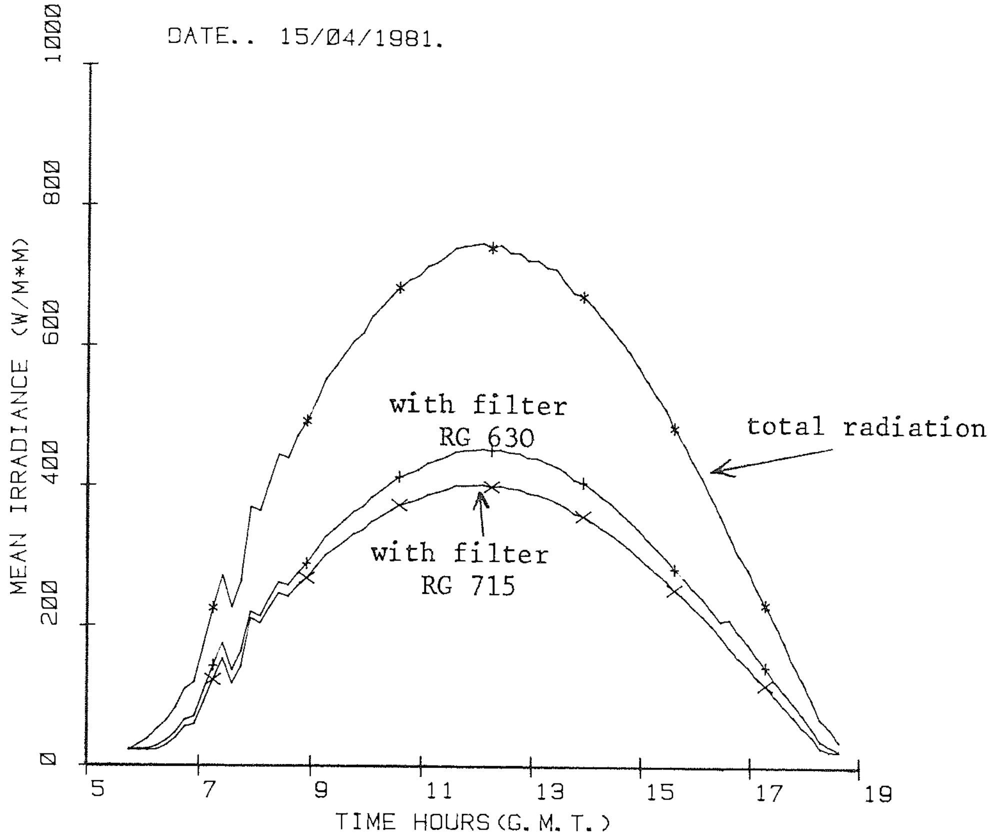


Fig.4.10.a Measured total radiation and data with filters RG 715 and R G 630, for a relatively clear day.

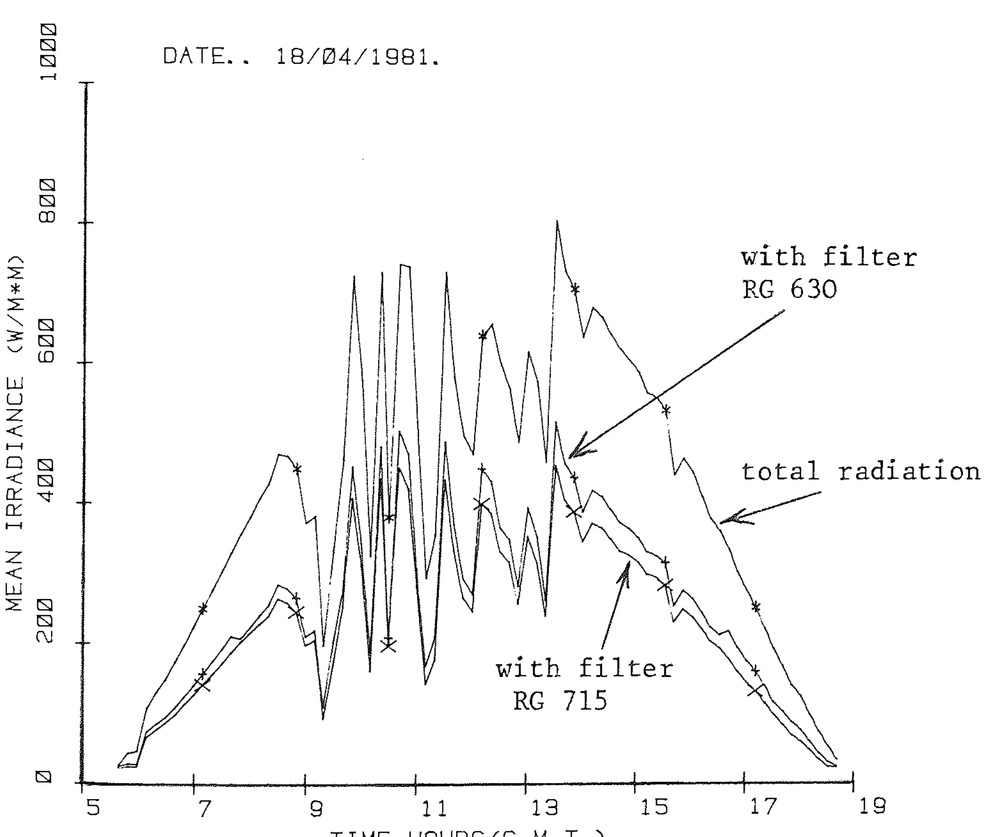


Fig 4.10.b Measured total radiation and data with filters RG 715 and RG 630, for a partially cloudy day.

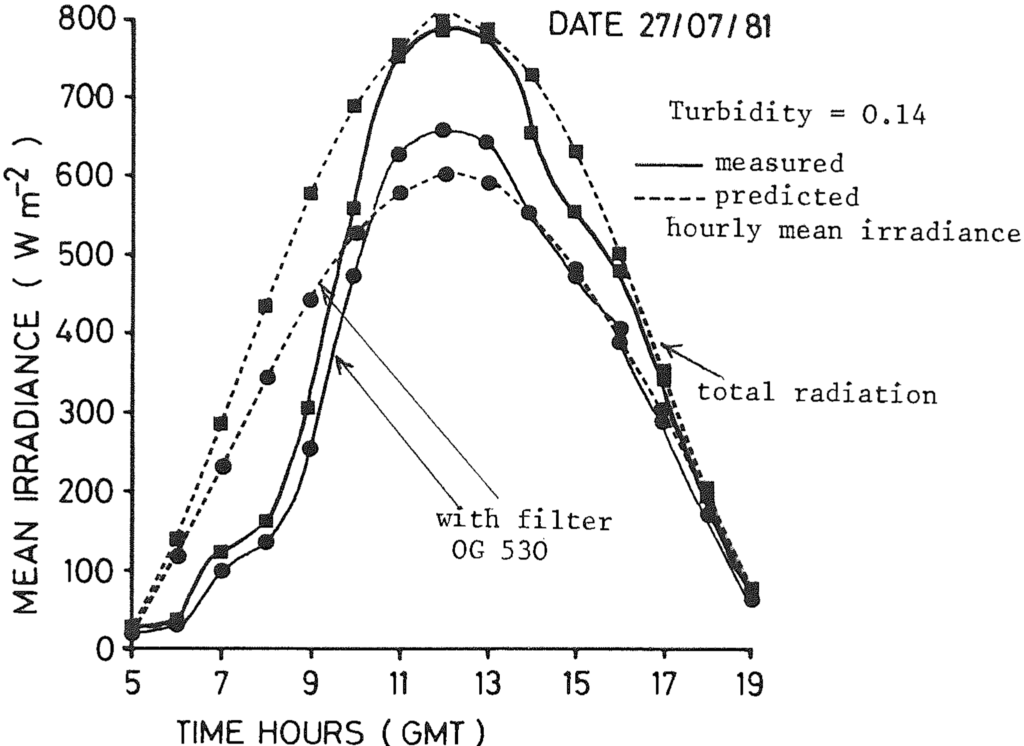


Fig 4.11.a Global radiation and radiation with filter OG 530, for a relatively clear day.

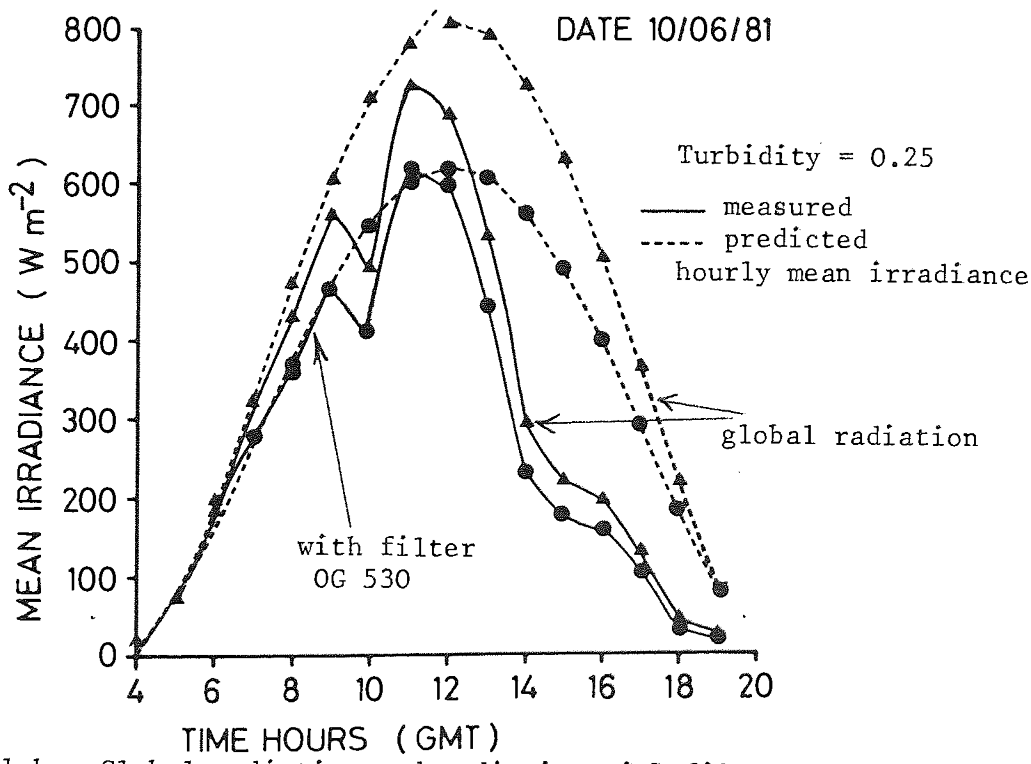


Fig 4.11.b. Global radiation and radiation with filter OG 530, for a partially cloudy day.

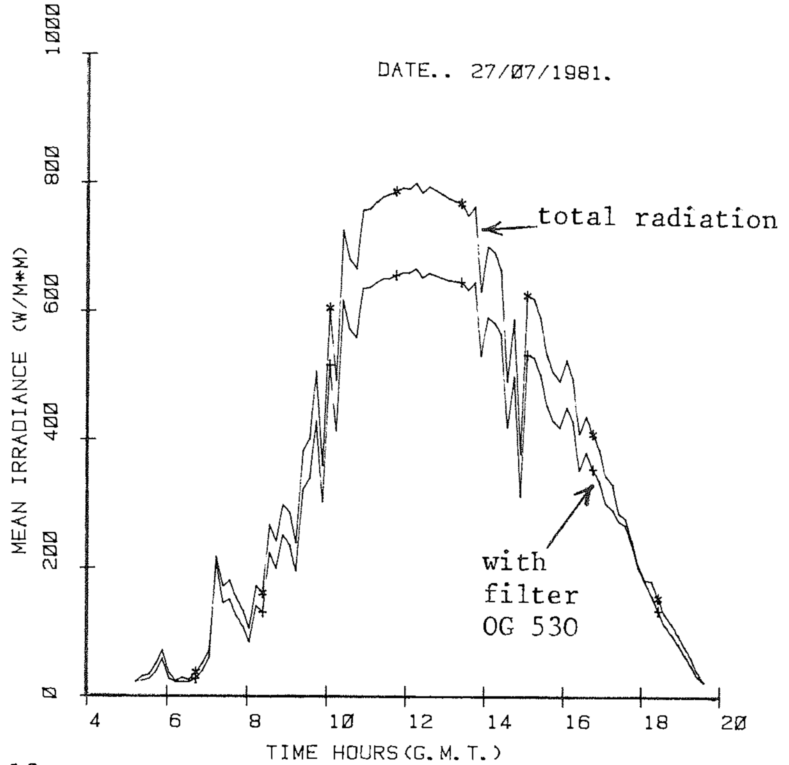


Fig. 4.12.a Measured, total radiation and data with filter OG 530, for a relatively clear day.

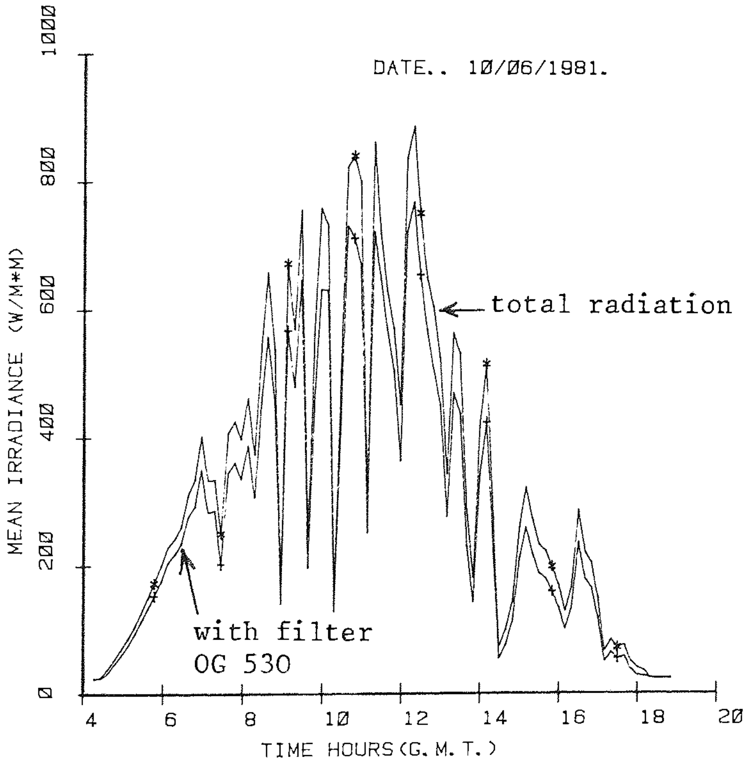


Fig 4.12.b Measured, total radiation and data with filter OG 530, for a partially cloudy day.

DATE, 30TH JULY, 1981

TIME HOURS G.M.T	MEASURED RADIATION VALUES		HOURLY MEAN TURBIDITY	COMPUTED Radiation values using measured mean hourly turbidity values				COMPUTED Radiation values using mean daily turbidity value = 0.17			
	Total	Diffuse		Total	% Diff	Diffuse	% Diff	Total	% Diff	Diffuse	% Diff
10	661	160	0.24	649	1.8	197	23.1	684	3.4	158	1.2
11	750	150	0.19	742	1.0	185	23.3	760	1.3	164	9.3
12	760	161	0.22	766	0.8	199	23.6	794	4.4	167	3.7
13	756	154	0.21	758	0.2	193	25.4	781	3.3	166	7.7
14	689	147	0.21	699	2.8	190	29.2	724	5.0	161	9.5
15	569	141	0.22	602	5.7	181	28.3	627	10.0	152	7.8
16	471	132	0.21	477	1.2	160	21.2	498	5.7	138	4.5
17	333	111	0.20	336	0.9	130	26.1	348	4.5	117	5.4

1) All radiation values are mean hourly irradiance (Wm^{-2}).
2) Measured mean turbidity for the day = 0.21

Table 4.5 Solar radiation values computed, using measured mean hourly turbidity values and a daily mean value for turbidity. The computed values are then compared to the measured total and diffuse radiation. Data for Birmingham, date, 30th July 1981.

DATE, 27TH JULY, 1981

TIME HOURS G.M.T	MEASURED RADIATION VALUES		HOURLY MEAN TURBIDITY	COMPUTED Radiation values using measured mesn hourly turbidity values				COMPUTED Radiation values using mean daily turbidity value = 0.14			
	Total	OG 530		Total	%	OG 530	%	Total	%	OG 530	%
12	793	661	0.13	819	3.2	616	6.8	801	1.0	606	8.3
13	775	649	0.12	810	4.5	609	6.1	789	1.8	597	8.0
14	659	557	0.14	741	12.4	561	0.7	732	11.0	556	0.1
15	558	473	0.15	640	14.6	489	3.3	635	14.1	486	2.7
16	479	412	0.14	515	7.5	397	3.6	506	5.6	392	4.8
17	347	305	0.13	367	5.7	289	5.2	357	2.8	283	7.2

1) All radiation values are mean hourly irradiance (Wm^{-2}).
2) Measured mean turbidity for the day = 0.13

Table 4.6 Solar radiation values computed, using measured mean hourly turbidity values and a daily mean value for turbidity. The computed values are then compared to the measured total radiation and values with filter OG 530. Data for Birmingham, date, 27th July 1981.

radiation values obtained when using; a daily mean turbidity value and measured hourly mean turbidity values.

4.5 Discussion of results

The effect of changes in solar radiation on a horizontal surface resulting from astronomical and geographical factors, can be handled with reasonable accuracy, for example as reported by Robinson, (1966).

The variation in meteorological variables is difficult to predict and changes resulting from them can only be approximately determined. As the sensitivity analysis shows the two variables in the present mathematical model are the precipitable water vapour content and the atmospheric turbidity. Both of these factors are likely to change throughout the day. Guzzi et al. (1978), in their model for computing the spectral distribution of direct radiation at ground level, have made simultaneous measurements of water vapour content using an infrared hygrometer and atmospheric turbidity using a Volz sun photometer.

For the present study, the monthly average values of water vapour content have been taken from Rodgers et al. (1979), who provide data for Kew. Meteorological data e.g. wind speed, hours of sunshine, used in this study was received from the nearby Birmingham University's Meteorological Services.

The atmospheric turbidity for any location depends partly on local weather which determines the input of aerosols from domestic and industrial sources and partly on the history of continental or marine type air mass with aerosol input from distant sources. In discussing the variability of atmospheric turbidity during the day, Volz(1978), states that in the Rhur region of Germany, the turbidity is generally 0.3 to 0.5 up to noon, but sometimes decreases to rural values of around 0.08, during the afternoon. Unsworth and Monteith (1972), have reported that for a rural site, the major changes in turbidity are due to change in air mass type, and local sources are not significant. However, this is not likely to be the case for the urban site under consideration in this study.

The measuring site is located near the centre of Birmingham and is surrounded by several miles of industrial complexes and residential buildings. Fig. 4.1 shows that even during fine sunny weather for the whole day on 30th of July when the conditions were calm, (with a mean hourly wind speed ~1.4 ms^{-1}), the atmospheric turbidity varied from 0.16 to 0.26 during the day with an average value of 0.21$\pm$0.01 . Fig 4.1, for the 27th of July, 1981, another fine day, (with a mean hourly wind speed of ~5 ms^{-1}), the results lie in the lower turbidity levels, and varied from 0.11 to 0.19, giving a mean value of 0.13$\pm$0.01. The lower levels of turbidity on 27th of July, 1981, can be explained in terms of greater dispersal of local aerosols resulting from increased air movements.

The atmospheric turbidity varies with season, giving generally higher values during summer and lower values during the winter. Figure 4.13, shows a plot of monthly mean turbidity values for Bowerchalke, (U.K.), during the year 1972. The atmospheric turbidity also varies considerably from day to day, during a month. The plotted turbidity data, in fig. 4.14 shows the day to day variation in turbidity for Bowerchalke, during June, 1975 . The data reported is for 14 days, ranging in turbidity values from 0.080 to 0.337, with a monthly mean value of 0.196 .

In the present model, daily rather than hourly values of turbidity have been used. For the three relatively cloud free days, shown in figs. 4.8.a, 4.10.a and 4.12.a, turbidity values of 0.17, 0.17 and 0.14, respectively, have been used in the mathematical model. In

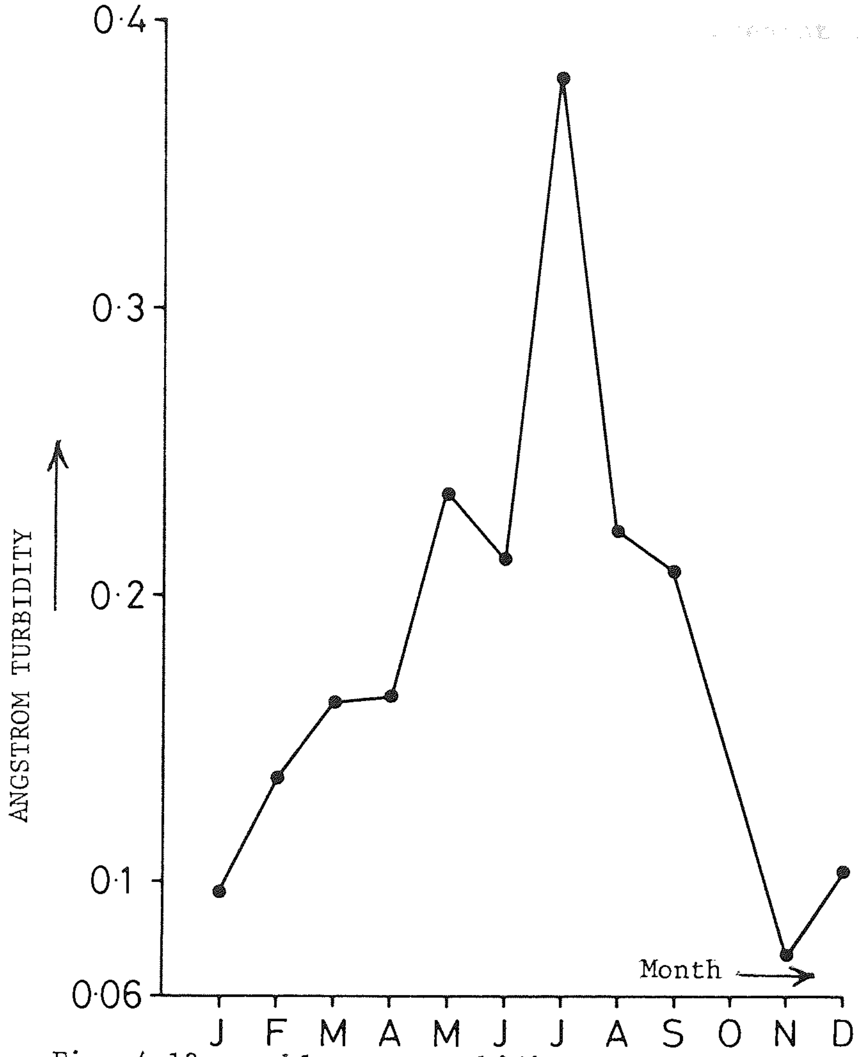


Fig. 4.13 monthly mean turbidity values, for Bowerchalke (U.K). Data for 1972. Source, National Climatic Center (1974).

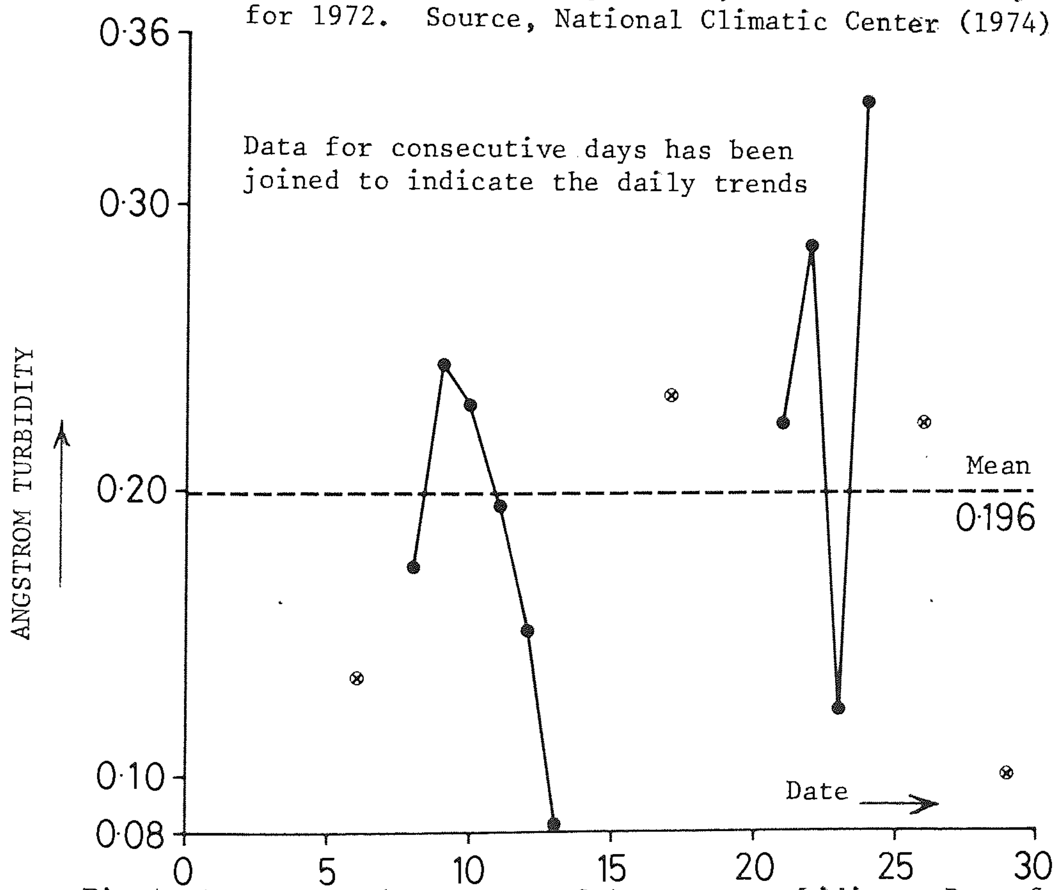


Fig 4.14. Mean daily values of Angstrom turbidity. Data for Bowerchalke (U.K), during June 1975. Source, a report by National Climatic Center(1977).

figs. 4.8.b, 4.10.b and 4.12.b, which present data for partially cloudy days, turbidity values of 0.27, 0.27 and 0.25, respectively, have been substituted in the model.

The mathematical model developed in this work covers a spectral range from 0.29 to 4.0 microns. The instruments used for measuring the radiation, have a wavelength range from 0.285 to 2.8 microns. When comparing the measured and predicted radiation values, the wavelength range from 0.285 to 2.8 microns has been used.

The estimated accuracy of the measured solar radiation data is of the order of; 2-3% for the total radiation, 5-6% for the diffuse radiation and ~5% for the band data using glass filters. The results presented in figs 4.6, 4.8 and 4.10, giving a comparison of mean hourly irradiance levels, between measured and computed data show a very good agreement under relatively clear skies. This level of agreement is in range ~ ±5%.

For the periods when there are departures from clear sky conditions (even for thin or high clouds), Angstrom turbidity cannot be used for expressing the transmittance function. This effect is illustrated in figs. 4.7.b, 4.9.b and 4.11.b .

For the two days , the 27th and the 30th of July, when the turbidity values were measured, there is a good agreement between the measured value and those used in the model. The measured mean turbidity value for the 27th and the 30th of July, of 0.13 and 0.21, agree well with those of 0.14 and 0.17, respectively, as used in the model. During the 30th of July, the presence of thin clouds around midday, is shown by high turbidity values and gaps in the measured turbidity data (measurements of turbidity were made only under cloud free skies). The effect of thin and high clouds, in reducing the total and diffuse radiation levels, is shown in figs. 4.7.a and 4.8.a . The effect of thin and high clouds on the incident radiation and atmospheric turbidity, is again shown for the 27th of July, during early morning and late afternoon, as in figs. 4.1.a, 4.11.a and 4.12.a .

The problem of dealing with diffuse radiation is highly complex. As Leckner (1980), points out, the problem is two fold, the spectral variation of the diffuse radiation and the radiance distribution over the sky.

The total sky radiation during a clear day is made up of contributions from Rayleigh scattering and Mie scattering. Since the Rayleigh scattering is essentially isotropic, approximately 50% of the scattered radiation is forward directed. In respect of Mie scattering, the situation is much more complicated. The angular distribution of the scattered light depends on the particle size, shape, the index of refraction and the wavelength of the light. In general there is more forward scattering and a figure of 63% has been suggested by Boer (1977), after allowing for absorption and back scattering. Steven (1977), has reported that the effect of atmospheric turbidity variability on the distribution of clear sky radiance is small.

In the present investigation an empirical relationship has been used for computing the spectral distribution of sky radiation on a horizontal surface which is based on Leckner's work (1978). Since during a clear day, the sky irradiance forms only about 15% of the total radiation, the percentage errors in computation of total radiation for a clear day will be reduced considerably. The model developed in the present work does give results which are a good approximation to the real situation, as shown in figures 4.7.a and 4.9.a .

When hourly mean values of turbidity are used, some of the fluctuations in turbidity values are 'reduced'. This is especially the case when there are very high and thin clouds in the sky.

The results in tables 4.5 and 4.6, comparing the measured radiation values to those predicted by using daily mean turbidity values and measured mean hourly values of turbidity, can be summarised as follow:

1) In table 4.5, the results with hourly mean turbidity values provide a better agreement for the total radiation values but the predicted diffuse radiation values are rather high.

2) In table 4.6, the discrepancy for total radiation values is slightly higher but the data with filter OG530 is improved.

The discussion relating to turbidity in the earlier part of this section is also applicable to the results in tables 4.5 and 4.6.

Results for the data measured with the filter GG395, have not been included in this study. Solar radiation data measured with filter GG395, gave consistently higher radiation values (after application of the filter factor), than those obtained from the pyranometer with a clear glass outer dome. The manufacturer, The Eppley Laboratory, were unable to provide the answer which was attributed by the author to faulty manufacturing leading to an unreliable filter multiplication factor. The absorption of solar radiation by the filter GG395 was possibly less than was claimed by the manufacturers.

4.6 Conclusions

The mathematical model for predicting, the spectral distribution of solar radiation incident on a horizontal surface, has two variables, the atmospheric water vapour content and the atmospheric turbidity coefficient.

The sensitivity analysis shows that a change in atmospheric turbidity has a significant effect upon the solar radiation incident on a horizontal surface. The atmospheric turbidity can vary considerably during a day even under stable meteorological conditions. It is also a well established effect that, the atmospheric turbidity can vary from day to day, and with season.

Comparisons between the measured and the predicted hourly mean radiation levels, show that the model provides a level of agreement of better than 5%, under clear (cloud free) atmospheric conditions.

In order to refine the model further, it is important that instantaneous measurement of atmospheric turbidity and atmospheric water vapour content, should be made with the measured radiation. In this study the measured spectral data was only available in three broad bands. In any future work it is desirable that measured solar radiation data in a number of narrow bands should be used.

This modelling work has potential for applications where the intensity of solar radiation in a given waveband is important, for example in agriculture, solar cell applications and for material durability testing. With further developments of the model suitable for non-horizontal surfaces, manufacturers of paints and interior designers/decorators are likely to be interested in this work.

Chapter 5. SOLAR RADIATION INSTRUMENTATION

5.1 Introduction

The first recorded measurements of solar radiation intensity were made by Pouillet in 1838. Coulson (1975), has listed the major milestones in the development of solar radiation instrumentation. Yellot (1979), has presented a summary of the historical developments and the present state of solar radiation measuring instruments.

A number of different types of sensors have been used in the past and new instruments are still being developed, for example see, Nurkkanen and Hamalainen (1981). Present needs for solar radiation data can be divided in two areas.

i) long term data.

ii) short term.

Long term solar radiation data involves routine measurements of various components of solar radiation. Gillet and McGregor (1980), indicate that for climatological and architectural studies, an accuracy of the order of ±5% is acceptable. Short term studies are concerned with the testing and evaluation of solar energy equipment, such as solar panels. An accuracy of better than ±1% is desirable for such applications, Gillet (1980).

A lower level of accuracy is acceptable for long term measurements, since solar radiation levels for a given location can vary by as much as 10% from one year to another, U.K. - I.S.E.S. (1976).

The World Meteorological Organisation has the responsibility for international coordination in solar radiation data handling. This organisation, publishes various guidelines for the operation and maintenance of solar radiation recording equipment, W.M.O. (1965).

Another international body, the World Radiation Centre, based in Switzerland, carries out major international research and development work in the field of solar radiation instrumentation and maintainence of standards, Frohlich (1981).

There are a number of different instruments used for measuring different components of solar radiation. In an effort to standardize terminology, the World Meteorological Organisation (1965), through its Commission for Instruments and Methods of Observation, has made recommendations for the classification of solar radiation instruments. The present study is concerned with the use of

i) Pyranometers, for measuring the total and diffuse radiation.

ii) A pyrheliometer, for evaluating the direct radiation component.

A number of studies, on solar radiation instrumentation, have been reported by, Willson (1973), Norris (1973), Hickey (1975), Thekaekara (1976) and Klein et al. (1977). For solar radiation measurements the most widely used instrument is a pyranometer. Denhe (1978), has presented a discussion of the important factors to consider in designing a pyranometer.

a) Sensitivity.

b) Stability.

c) Linearity.

d) Temperature coefficient.

e) Time constant (time response).

f) Spectral homogeneity.

g) Dependence on the angle of incidence (this relates to both zenith and azimuthal angles).

h) Dependence on the angle of inclination.

Other relevent attributes are

i) Size and weight.

j) Instrument tilt.

k) Instrument heat sink.

In addition to the above mentioned properties, the instrument should also be robust and weather proof for field use.

5.2 Radiation sensors

Radiation sensors or detectors of most use in atmospheric problems may be broadly classfied as; thermal detectors and photoelectric detectors of various types.

Thermal detectors include; calorimeters, thermocouples and thermopiles, bolometers and pyroelectric sensors. They all operate on the principle of transforming radiant energy into heat, resulting in a rise in temperature of some material. Thermal detectors respond to the total energy absorbed, so theoretically they are nonselective to the spectral distribution of solar radiation.

Photoelectric detectors can be classified into three major groups; photovoltaic, photoconductive and photoemissive cells. The great advantage of photo detectors is that the sensor is activated by discrete events of photons striking the material, thus resulting in much faster response and higher sensitivity compared to thermal detectors.

5.3 Radiation measuring instruments

Since most radiation measuring instruments for long term monitoring are likely to be left in the open and unattended for long periods of time, then the most desirable features include;

i) Good weather protection.

ii) Minimum need for maintenance.

iii) No requirements for external power sources.

An increasing number of solar radiation measuring instruments are now commercially available and the majority of these instruments are based on the use of thermopiles with the exception of a few which use either a pyroelectric crystal or more recently, a photoelectric detector. All photoelectric detector based instruments suffer from their selective wavelength sensitivity. Figure 5.1, shows a typical response curve for a photovoltaic cell based sensor. Solar cell based pyranometers have been classified as a class **III** instrument by the World Meteorological Organisation, as given by Coulson (1975). The pyranometer classification criteria is reproduced in Table 5.1 .

Thermopile based pyranometers, generally are sensitive to solar radiation in the wavelength range 0.28 to 2.8 microns. For a number of applications it is important to know the spectral distribution of incident solar radiation. There are instruments available which can deal with parts of the solar spectrum of interest. McCartney (1979), has reported the use of a spectral radiometer for measuring direct and global spectral irradiance in the waveband 0.4 to 0.8 microns. Spectral irradiance can also be measured in bands, using glass filters, Angstrom and Drummond (1961). When glass filters are used in conjunction with pyranometers, a filter multiplication factor is applied to take account of the filter optical properties. The filter factor can vary between different glass melts. Hickey et al.(1962), have shown that the optical properties of glass filters can change with temperature.

5.4 Radiation sources

In order to test instruments and equipment it is very important to be able to simulate the intensity and spectral distribution of solar radiation, in the laboratory under controlled conditions.

Simulation of solar radiation is a wide field in its own right.

	1st Class	2nd Class	3rd Class
Sensitivity (W m^{-2})	± 1.0	± 5.0	± 10.0
Stability (% change per year)	± 1	± 2	± 5
Temperature (maximum error due to changes of ambient temperature - %)	± 1	± 2	± 5
Selectivity (maximum error due to parture from assumed spectral response - %)	± 1	± 2	± 5
Linearity (maximum error due to nonlinearity not accounted for - %)	± 1	± 2	± 3
Time constant (maximum)	25 sec	1 min	4 min
Cosine response (deviation from that assumed, taken at Sun elevation 10^{o} on clear day - %)	± 3	± 5-7	± 10
Azimuth response (deviation from that assumed, taken on clear day - %)	± 3	± 5-7	± 10

Table 5.1 Classification of pyranometers. Source, Coulson (1975).

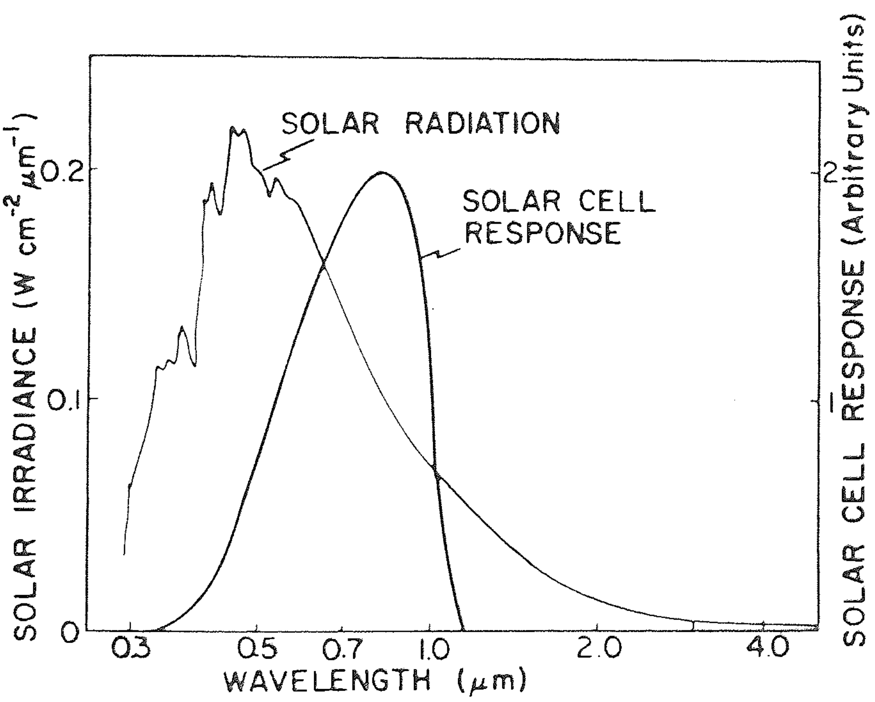


Figure 5.1 Shows a typical response curve for a photovoltaic (solar) cell based sensor. Source, Coulson and Howell (1980).

Various types of lamps have been used; tungsten, xenon and carbon arc. Boettner and Miedler (1963), have reported work, in which a high pressure xenon lamp has been used, with filters, to eliminate the large spikes in the emision of a xenon lamp which occour at 0.83 and 0.88 microns. Bickler (1962), used two sources, a tungsten lamp to simulate the red portion of the spectrum and a xenon arc lamp with absorption filters to simulate the blue proportion.

Beeson (1978), has reported the development of a Compact Source Iodine lamp (CSI) which has a good spectral balance, requiring no additional filters. The CSI lamp has been used in the S.E.R.C. solar simulator, Gillet et al. (1980), developed as a U.K. national facility for the testing of solar panels.

One problem, very difficult if not impossible to solve, is the simulation of the diffuse component of radiation which is always present under outdoor conditions.

5.5 Solar radiation instrument calibration

Before 1956, two radiation standards were in common use.

a) The Smithsonian standard, based on the work of Abbot, was established in 1913. A silver disk Pyrheliometer was manufactured and distributed to several hundred institutions and was recognised by the World Meteorological Organisation as a class I standard instrument.

b) The second standard was developed after the work of K.Angstrom (1899), a Swedish meteorologist. He introduced the modern era of radiometry by the development of his electrical compensation pyrheliometer.

Comparisons of the Angstrom and Smithsonian scales have yielded differences of up to several per cent, Willson (1972).

The International Pyrheliometric Scale (IPS) was a compromise between the Angstrom scale and the Smithsonian scale as they were defined in 1956, as reported by Labs and Neckel (1971). The IPS scale was created to facilitate comparison of irradiance measurements made on a worldwide basis for the International Geophysical Year.

There has always been a need for an instrument, the properties of which can be defined in terms of fundamental physical quantities. A series of instruments, referred to as Active Cavity Radiometers, were developed at the Jet Propulsion Laboratory, U.S.A.. A detailed discussion of Active Cavity Radiometers is given by Willson (1973). After extensive experimental work, in the U.S.A. sponsored by NASA, comparing the IPS 1956 scale and the new radiometric scale, a systematic 2.2% difference has been reported by Willson (1973), with the IPS scale giving consistently lower radiation values.

In 1975 it was agreed by the World Meteorological Organisation (WMO) that a cavity radiometer should provide the world reference, and that a new scale, the World Radiometric Reference (W.R.R) should be established. The WMO has recommended that all solar radiation data measured from January 1st, 1981, should be referenced to the W.R.R. Scale, Painter (1980).

The calibration of solar radiation instruments involves two problems

a) the availability of a suitable source.

b) a radiation standard.

Both of these have been discussed in the previous sections of this chapter. Various national meteorological services use different methods.

The U.K. National Radiation Centre (NRC) now based at Beaufort Park, Bracknell, maintains the U.K. national standards for solar radiation measurements. The indoor calibrations are carried out in a diffuse chamber, using six 600W Tungsten-Halogen lamps, Budgen and

Price (1980). The instruments under test are slowly rotated on a platform. The calibration comparison between the test and the standard is based on readings taken over a 20 minute period, at 10 second intervals.

The outdoor calibrations are carried out using an Angstrom Pyrheliometer as a standard. These outdoor calibrations can only be carried out during the period between March and October. It is considered that, in the U.K., the elevation of the sun is too low for this work during the winter period, Painter (1980). The calibration service for solar radiation measuring instruments, provided by the Met. Office, is only for instrumets placed on a horizontal surface.

Calibration of solar radiation equipment at the U.S. Weather Bureau has been described by Hill (1966). Latimer (1966) and Drummond and Gireer (1966), have given the standard procedures, followed in the North American continent, for the calibration of instruments for the measurement of solar radiation.

5.6 Commonly Used Instruments

Although a large number of solar radiation measuring instruments are commercially available, the two most widely used are those supplied by Eppley (mainly U.S.A) and Kipp and Zonen (mainly in Europe). The two instruments Eppley PSP pyranometer and the Kipp and Zonen CM5 pyranometer will be discussed in the following sections.

The Eppley PSP pyranometer comprises a circular multi-junction thermopile made by electroplating copper on constantan which, when necessary, can be temperature compensated. The thermopile is coated with Parsons' black lacquer to give high absorptivity. Optical compensation for deviation of response from the true cosine relationship has been provided in the Eppley PSP pyranometer. Two glass hemispheres are used to protect the instrument against weather. Some of the properties of the Eppley PSP pyranometer are included in table 5.2.

The thermojunctions of Kipp and Zonen CM5 pyranometer are made of very thin (0.005 mm) blackened strips of manganin and constantan. The 14 thermojunctions are arranged in a 21mm x 11mm rectangular configuration. No temperature compensation is provided. The sensitivity decreases with increasing temperature. The thermopile is protected from the environment by two concentric hemispherical glass domes. The domes cause the incident radiation to be focused into a cusp, as shown by Latimer(1962). There is a change in the instrument output signal for constant incident radiation intensity at different azimuthal angles, because of the assymetry of the thermopile. The 30 cm diameter radiation shield surrounding the outer dome, and coplanar with the sensitive element, prevents direct solar radiation from heating the base of the instrument. Specifications of the CM5 pyranometer are listed in table 5.3 .

5.7 Comparison of Eppley PSP and Kipp CM5 pyranometers

Solar radiation data in Europe has been mainly measured using Kipp and Zonen instruments and solar radiation values in the U.S.A. have been measured using Eppley instruments, Coulson (1975).

The main differences in the two instruments can be classfied as

i) The geometry of the thermopile.

ii) The shape and size of the inner glass dome.

iii) The instrument time constant.

iv) Temperature compensation.

Gillet (1980), in his discussions on the accuracy and operating characteristics of the Kipp CM5, has made a strong case for developing a new and better instrument. However since there are many hundreds of Kipp CM2 and CM5 instruments in use, an assessment of their performance is important.

TABLE 5.2 Eppley precision pyranometer-specifications.

Sensitivity	10 microvolts/Wm^{-2}.
Impedance	600 Ohms.
Temperature dependence	±1% over ambient temperature range -20^{o} to $+40^{o}$ C.
Cosine error	±1% from normalized 0 to 70^{o} zenith and ±3% from $70-80^{o}$ zenith angle.
Linearity	±0.5% from 0 to 2800 Wm^{-2}.
Time response	2 seconds(1/e)*.

*---Eppley Laboratory (1981).

TABLE 5.3 Kipp and Zonen CM5 pyranometer-specifications.

Sensitivity	11 microvolts/Wm^{-2}.
Impedance	10 Ohms.
Temperature dependence	-0.15% per ^{o}C.
Cosine error	±1% from 0 to 75 zenith.
Linearity	±1%.

The Eppley PSP pyranometer is classfied as a Class I instrument by the W.M.O. and the Kipp CM5 pyranometer is classified as a Class II. In this study an Eppley PSP pyranometer has been compared with a Kipp and Zonen CM5 pyranometer.

5.7.1 Results

The three aspects of instrumentation which have been investigated in this work, are

a) The time interval of data recording.

b) Comparison of the Eppley PSP and the Kipp CM5 on a horizontal plane.

c) Comparison of the Eppley PSP and the Kipp CM5 on a number of inclined planes facing South.

The results are presented in figs. 5.2 to 5.11. It is well recognised that the irradiance from the sun passing through the earth's atmosphere can change rapidly, Svendsen (1977). He showed that the time constant for an instrument can be significant, especially if the instrument is moved to scan different parts of the sky.

Results in figures 5.2 to 5.7, are for a horizontal surface. Figures 5.2 and 5.3 show the differences in measured irradiance, over different time intervals, for the Kipp CM5 and the Eppley PSP. The readings were taken every 10 seconds and averaged over a 5 minute period, and are then compared to those taken instantaneously every 5 minutes. Figures 5.4 and 5.5 show a comparison of the output of the Eppley PSP and the Kipp CM5, on a horizontal plane. The results shown in fig. 5.4 and are the mean values of 10 second scans over a 5 minute time period. In figures 5.5 and 5.6, the 10 second scans irradiance values have been averaged over 10 minutes priods. In figures 5.5 and 5.6, a comparison is shown under cloud free conditions and partially cloudy conditions. Figures 5.8 to 5.11, show the comparison of

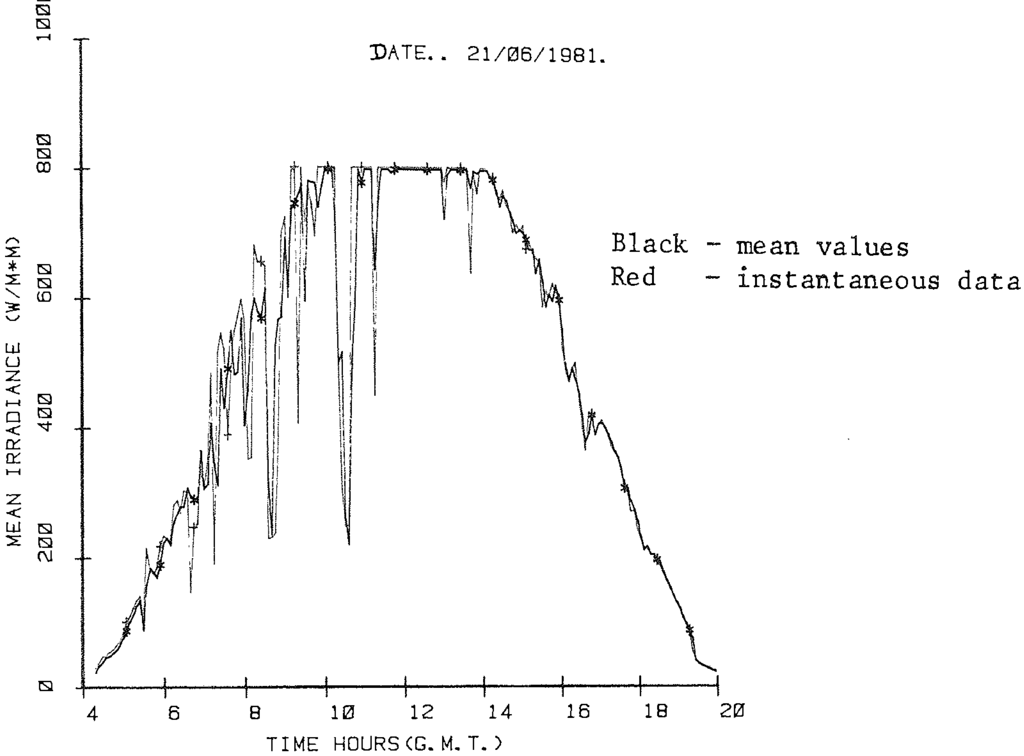


Fig 5.2 The response of the Kipp and Zonen CM5 pyranometer. The mean irradiance over a 5 minute period, from readings taken every 10 seconds is compared to instantaneous readings.

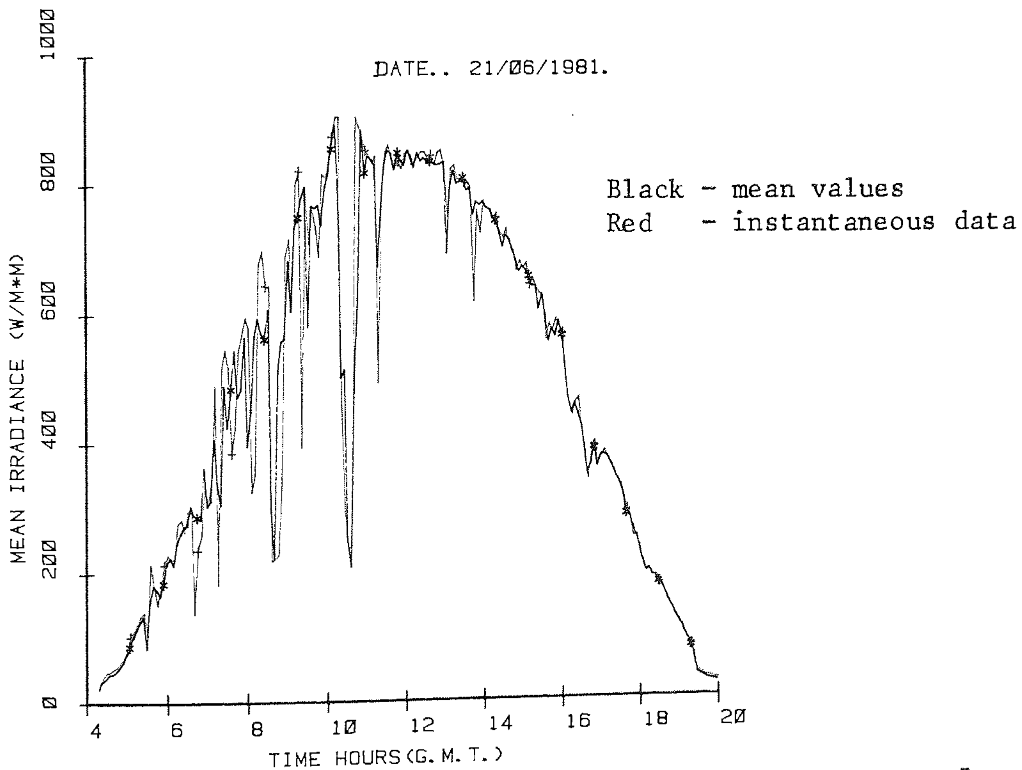


Fig 5.3 Eppley-PSP. Comparison of mean irradiance values over a 5 minute period from 10 seconds scans to instantaneous readings.

Table 5.4 Measured radiation data using Eppley PSP and Kipp CM5 Pyranometers on a horizontal surface. Data for Birmingham, date 21st June, 1981.

Time Hours	Eppley PSP 2*	Eppley PSP 3*	% Diff 4*	Kipp & Zonen 5*	Kipp & Zonen 6*	% Diff 7*	% Diff 8*	% Diff 9*
4	35	32	-8.5	35	32	-8.5	-	-
5	87	82	-5.7	88	83	-9.0	-	-
6	225	214	-4.8	232	220	-5.1	+3.1	-2.7
7	344	342	-	349	348	-	+1.5	+1.7
8	532	524	-1.5	544	536	-1.4	-2.3	-2.2
9	540	590	+9.2	554	599	+8.1	+2.5	+1.5
10	689	706	+2.4	677	694	+2.5	-1.7	-1.6
11	769	722	-6.1	730	696	-4.6	-5.0	-3.6
12	835	839	-	806	805	-	-3.4	-4.0
13	814	806	-1.0	804	799	-1.0	-1.2	-
14	734	752	+2.4	776	790	+2.1	+4.3	+5.0
15	650	655	+1.0	692	698	-	-	+6.6
16	496	500	-	534	538	-	+7.6	+7.0
17	357	359	-	388	390	-	+8.6	+10.5
18	215	222	+1.5	237	244	+2.9	+10.0	+9.9
19	95	101	+6.0	106	112	+6.0	+7.0	+10.8
20	25	25	-	26	28	+8.0	-	-
TOTAL	7442	7471	-	7578	7612	-	1.71	-

2* and 5* Mean irradiance over 10 minutes from scans taken every 10 seconds for the Eppley and the Kipp respectively.

3* and 6* -Instantaneous irradiance, readings taken every 10 minutes, with the Eppley PSP and the Kipp CM5, respectively.

4* and 7* %-difference between mean and instantaneous irradiance values for the Eppley and the Kipp(mean values as reference).

8* % difference for the mean of Eppley and Kipp(Ref. Eppley).

9* % difference for the instantaneous values for Eppley and Kipp(Eppley used as reference).

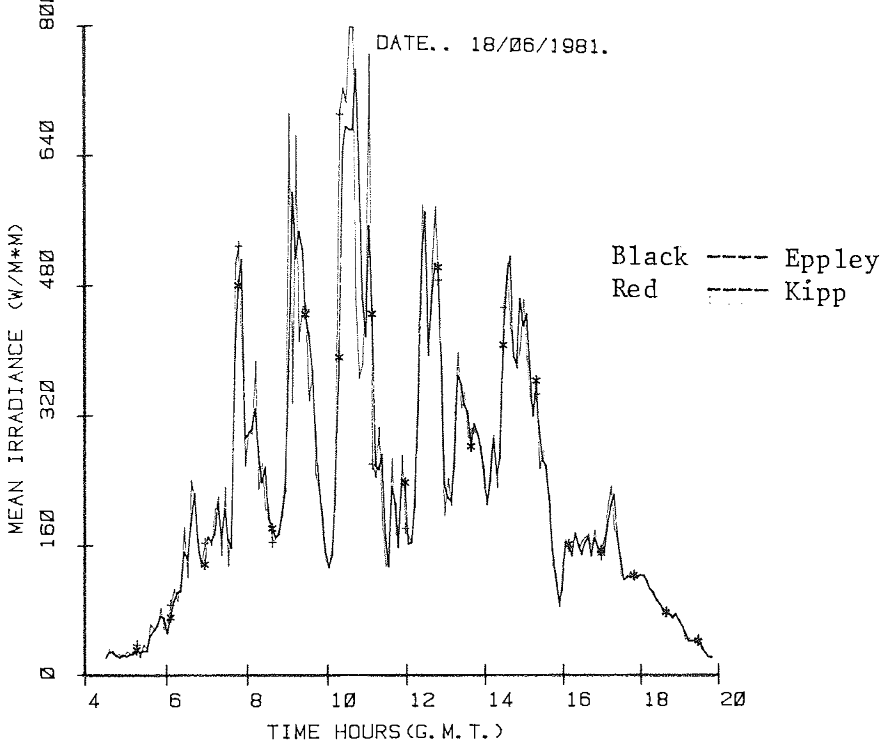


Fig 5.4 A comparison of the responses of an Eppley PSP pyranometer and Kipp CM5 pyranometer, on a horizontal surface. Data values taken at 5 minute intervals.

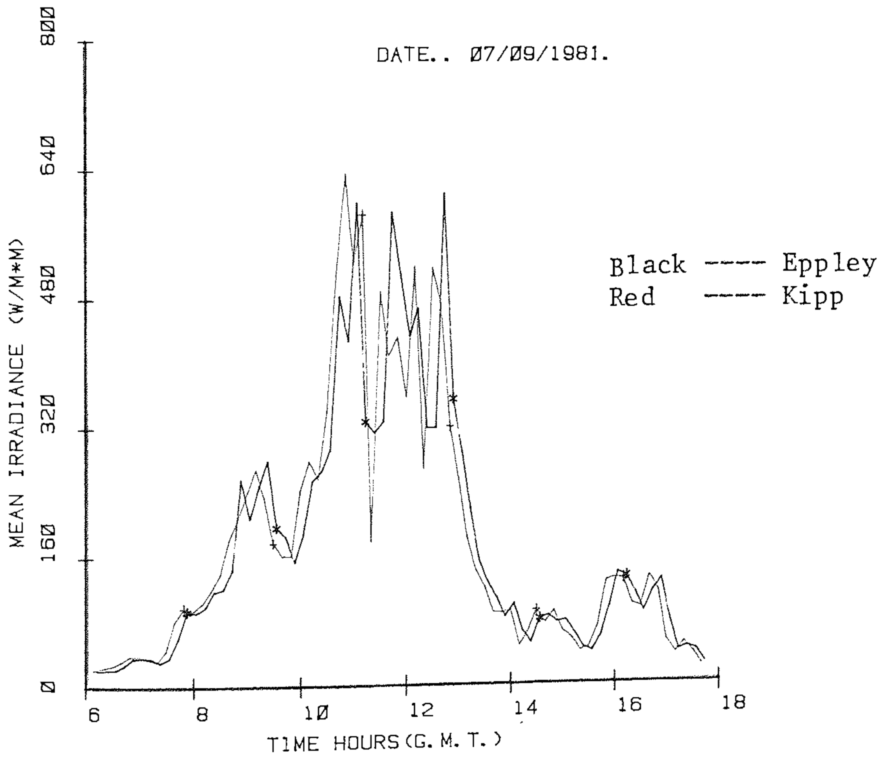


Fig 5.5 A comparison of the responses of an Eppley PSP pyranometer and a Kipp CM5 pyranometer at a horizontal surface. Data values taken at 10 minute intervals.

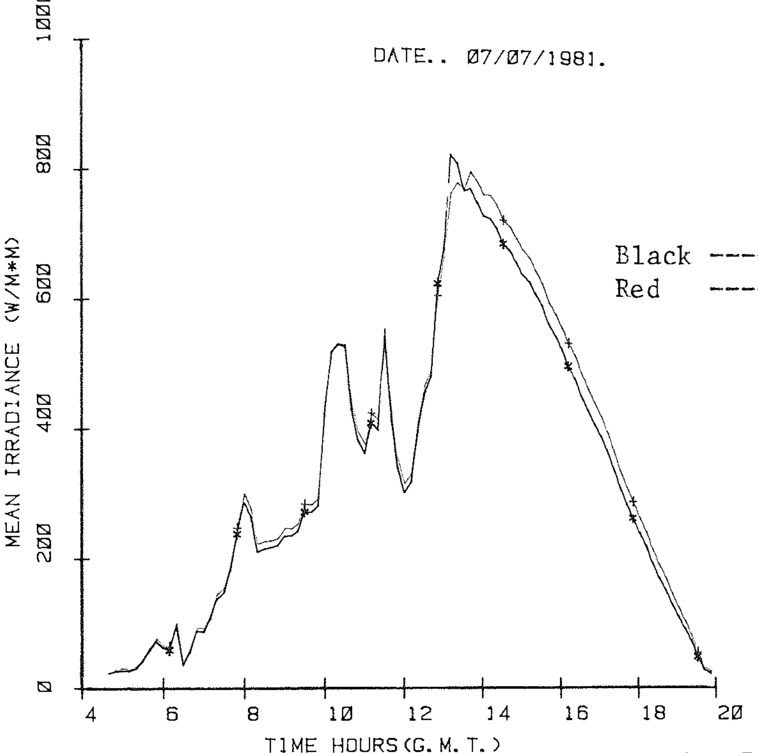


Fig 5.6 A comparison of the responses of an Eppley PSP pyranometer and a Kipp and Zonen CM5 pyranometer, on a horizontal surface. Data time interval 10 minutes averaged from 10 second scans.

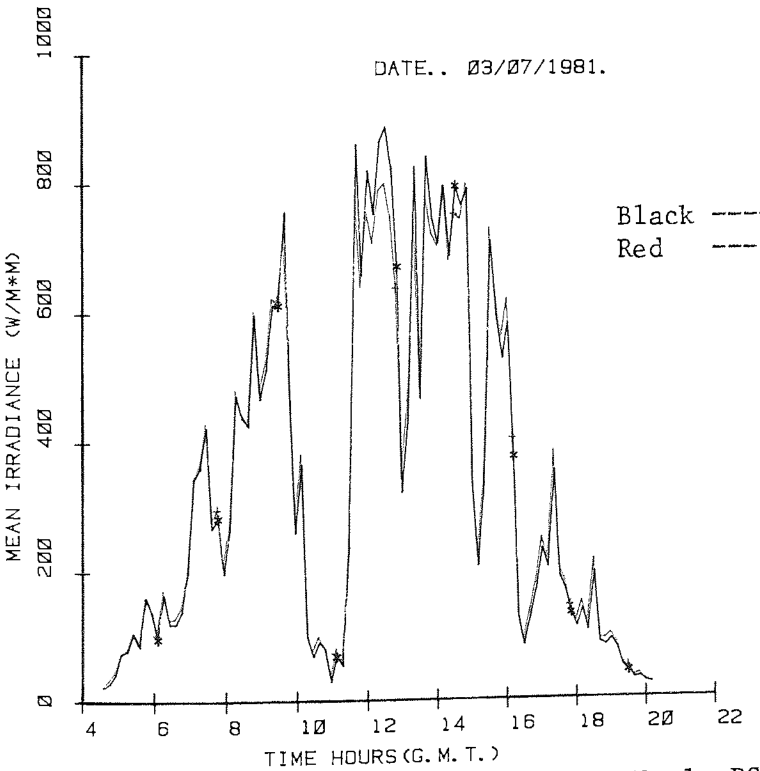


Fig 5.7 A comparison of the responses of an Epply PSP pyranometer and a Kipp CM5 pyranometer, on a horizontal surface. Data time interval 10 minutes, averaged from 10 second scans. Data for a partially cloudy day.

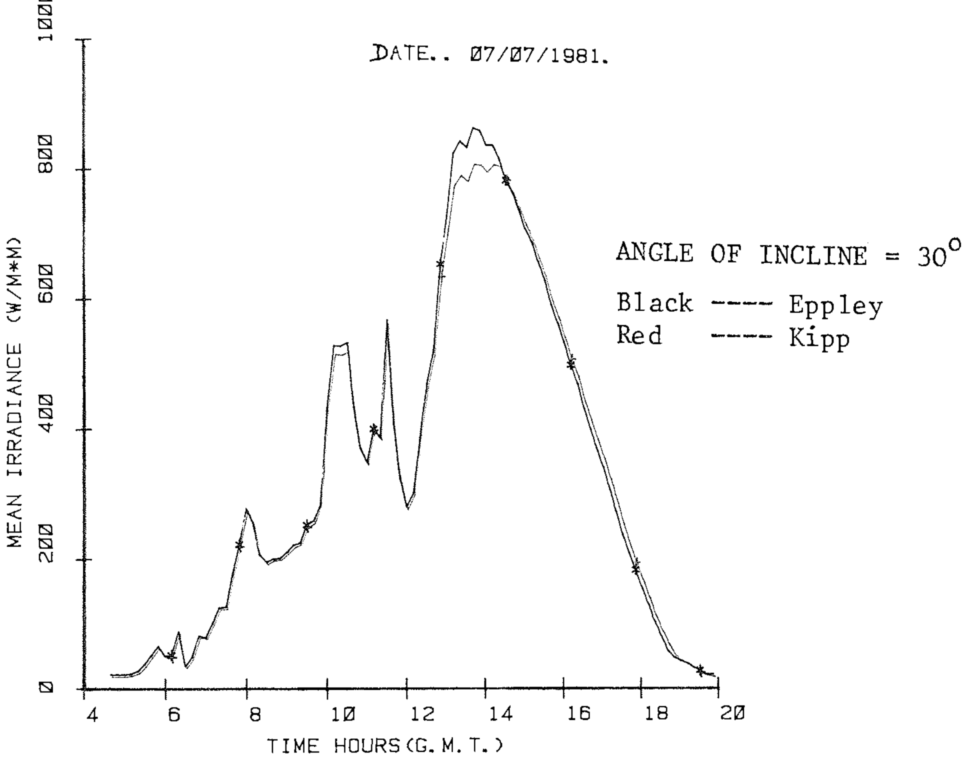


Fig 5.8 Comparison of the responses of an Eppley PSP pyranometer and Kipp and Zonen CM5 pyranometer, at an incline of 30 degrees.

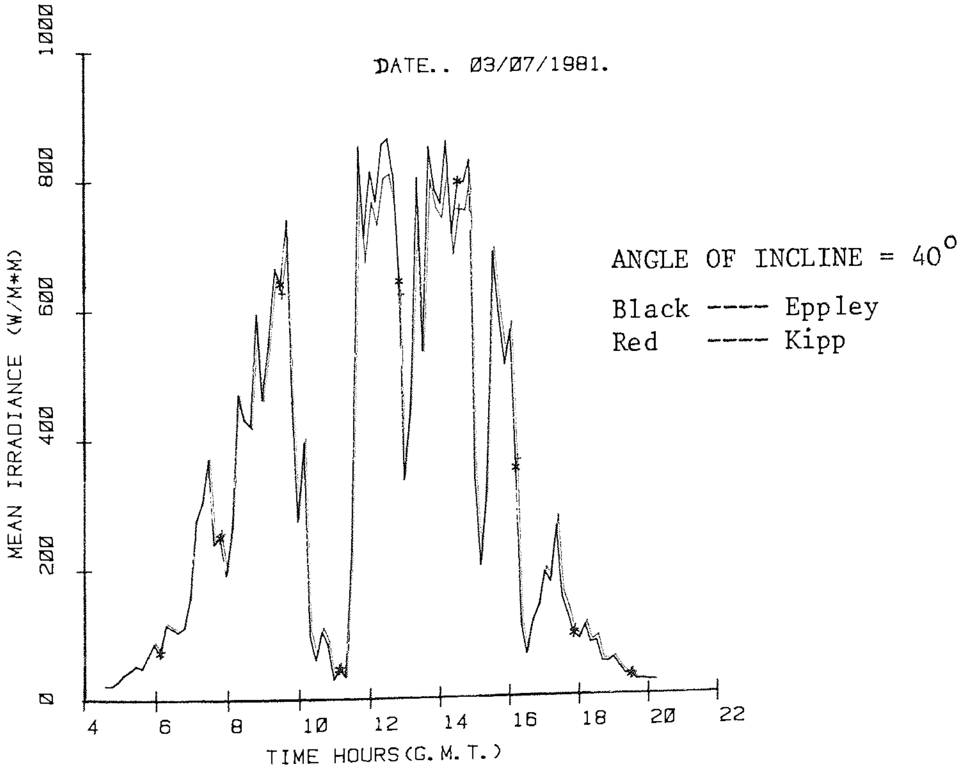


Fig 5.9 Comparison of the responses of the Eppley PSP pyranometer and the Kipp and Zonen CM5 pyranometer at an incline of 40 degrees.

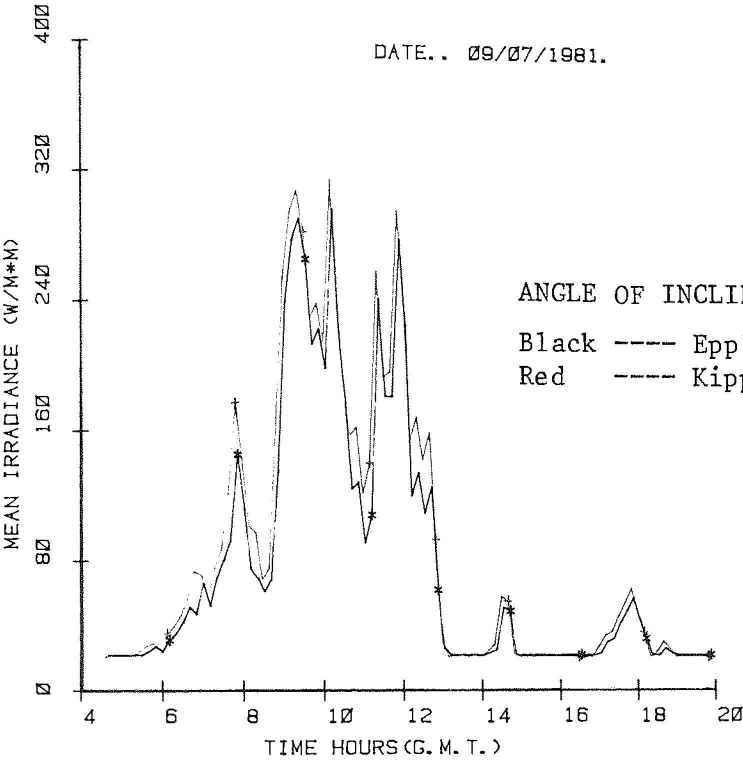


Fig 5.10 Comparison of the Eppley PSP and the Kipp CM5 pyranometers, at an incline of 90 degrees.

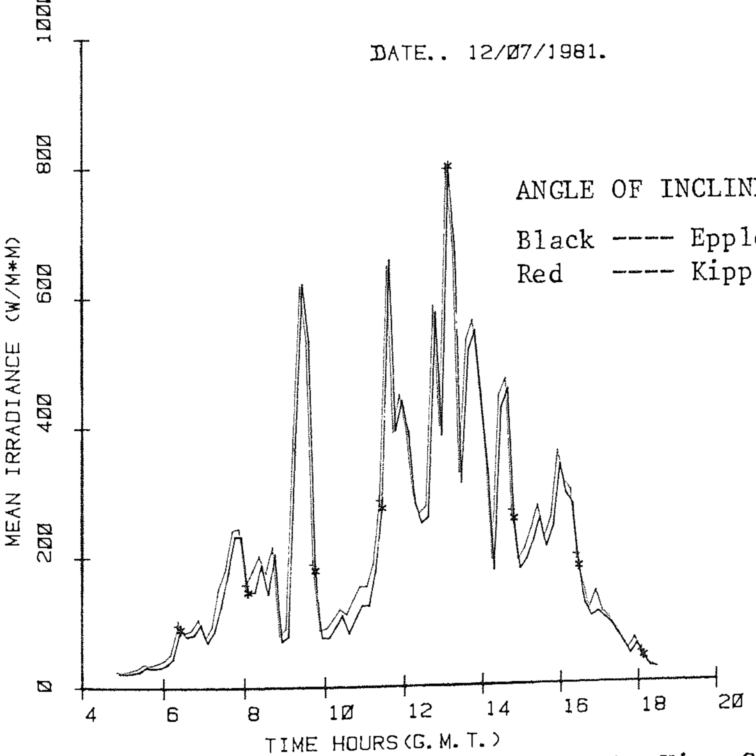


Fig 5.11 Comparison of the Eppley PSP and the Kipp CM5, pyranometers, at an incline of 67 degrees.

the Kipp and the Eppley response for four angles of inclination of 30, 40, 67 and 90 degrees respectively. All the results were recorded at 10 second intervals and averaged over 10 minutes.

N.B. The results presented in figures 5.2 to 5.11, only show symbols marked at every 10th data point. This was done to aid clarity.

5.7.2 Discussion

The results of figures 5.2 and 5.3 are also given in table 5.4 , as the hourly mean radiation values. During the morning there is a large difference between the mean and instantaneous values. At around 9.00 a.m., the Eppley has a difference of 50 Wm^{-2} (9%), and Kipp a difference of 55 Wm^{-2} (9%), between the mean hourly averages and instantaneous hourly values. The daily totals are in very close agreement. In figure 5.2, the plateau is due to the upper cut-off of the interface unit. When the results for the Eppley PSP and the Kipp CM5 are compared around midday the difference is approximately 4% . An interesting feature of the results in table 5.4, are the results during the late afternoon. The Kipp CM5 gives consistently higher radiation values than the Eppley PSP. This difference being up to 10% showing that there is another stronger influence than that resulting from the temperature coefficient.

Allowing for pen alignment, figures 5.4 and 5.5 demonstrate the effect of the slower response of the Kipp pyranometer to changes in the levels of irradiance.

In the results shown in figs. 5.8 to 5.11, as the angle of inclination increases, the Kipp CM5 gives consistently higher radiation values. Justin et al.(1979), have reported an increase in the Kipp CM5 pyranometer response when used on an inclined plane. However the effect of the factors mentioned by Justin et al. has been minimised in this work by providing adequate radiation shielding and ventilation around the back of the instrument.

Solar radiation instrumentation is a field which needs considerable further research in order to achieve the degree of confidence required by solar energy research workers enabling them to compare their results. Three of the main difficulties with which workers are faced are

a) different calibration methods used by different manufacturers.

b) the calibration of instruments may change when used on non-horizontal surfaces(no provision is made for this at present).

c) The use of non-standard equipment by some workers.

This is well illustrated by the example of the monitoring of the diffuse component of radiation, using a shadow band. The Eppley Laboratory and Kipp and Zonen supply their own shadow bands which are different in shape and size. The U.K. Meteorological Office use their own design with Kipp pyranometers, Painter (1981). In the studies reported by Svendsen (1979), and McGregor (1981), a different design of shade ring has been used.

It is very difficult to repeat the work reported by various authors on instrumentation. For example, in a study by Svendsen (1979), he has reported that the degree of variation in the Kipp's calibration factor from the horizontal to the vertical, has been reported as -1%, 0%, +10% and -7% by different authors. Similarly, for the Eppley PSP pyranometer, the change in response of the instrument from horizontal to vertical has been reported by different workers as, 11% (Norris,1974), 4% (Reed,1978) and 1.5% by Goldberg(1980).

Kipp and Zonen have designed a new instrument, Kipp and Zonen(1981), which does attempt to overcome some of the shortcomings of the CM5 and its predecessor the CM2 pyranometer.

The CM10 pyranometer consists of 100 thermocouples imprinted on a ceramic subtrate using thick film techniques. The arrangement of the thermocouples is circular. The temperature coefficient of the receiver is thermistor compensated. The Al_2O_3 subtrate has a high thermal conductivity. Therefore the temperature difference across the subtrate is likely to be less than 3^{o} C, under normal operating conditions. Because of this, heat convection in the inner dome is likely to be negligible and when tilting from the horizontal to the vertical the change in sensitivity of the pyranometer will be less than 0.5% at 1400 Wm^{-2}.

TABLE 5.5 Kipp and Zonen CM10 pyranometer-specifications

Sensitivity	4.5 - 6 microvolts/Wm^{-2}.
Impedance	1100-1500 Ohms.
Response time	< 5 seconds(1/e), 89% value after 24 s.
Spectral range	0.305-2.8microns.(50% transmission pts).
Temperature dependence	$\pm$1% in range -10^{o} to $+40^{o}$ C.
Cosine and azimuth	<$\pm$3% at 80^{o} zenith.

However the above information has been supplied by Kipp and Zonen(1981), and to the best of the author's knowledge no independent results are available to date.

Chapter 6. SOLAR RADIATION DATA : RECORDING AND ANALYSIS

6.1 Objectives

i) To measure the global and the diffuse radiation, together with the spectral distribution of radiation, on horizontal and inclined planes, in an urban environment.

ii) To measure and analyse solar radiation values in order to establish a basis for a long term monitoring programme.

iii) To investigate the validity of the mathematical model developed, using solar radiation data collected locally.

6.2 Introduction

A programme of measuring the intensity of solar radiation was initiated in the Physics Department of the University of Aston in Birmingham, during June, 1980. The measuring site is located close to the Birmingham City centre (lat. $52^{o}\ 30'$ N; long. $1^{o}\ 55'$; mean height above sea level 100m). Solar radiation intensity measurements have been made for the following;

a) Total and diffuse radiation on a horizontal surface.

b) Total radiation on various inclined planes, facing South.

c) Spectral measurements on a horizontal and various inclined planes, using glass filters.

A number of computer programs have been developed in the BASIC programming language for the recording, analysing and plotting solar radiation data. Data was initially recorded on a cassette and subsequently copied to a floppy disc for further processing and storage. The microcomputer, together with its peripheral devices, made it possible to analyse and plot a given set of solar radiation data in a matter of 30 minutes or so after recording it.

6.3 Equipment

The solar radiation intensity sensing equipment was made up of the following;

a) Three Eppley Precision Pyranometers (PSP).

b) A shadow band supplied by Eppley, for use with a PSP pyranometer enabling the evaluation of the diffuse component of radiation.

c) Four glass filters, for use with PSP's, having lower cut-off points at 0.707,0.623,0.529 and 0.385 microns.

d) One Kipp and Zonen CM5 pyranometer.

e) One Kipp and Zonen CM7 albedometer.

g) An Eppley Normal Incidence Pyrheliometer, with 3 glass filters, was available for a short period on loan from The U.K. Atomic Energy Authority.

The electrical signals from the sensors were fed into an electrical interface, capable of handling input from up to 16 channels. The interface unit was designed and manufactured by Aughton Microsystems Limited. It amplifies the signals from solar sensors, (typically in the range 0 to 9.0 mV), and finally provides a signal, in digital form, (in a range 0 to 5V), compatible with the IEEE-488 standard bus.

Solar radiation data were logged and recorded,using an 8K PET microcomputer with a cassette recorder. The recorded data was processed and plotted using the following,

a) A 32K COMMODORE PET microcomputer.

b) A dual drive Floppy disk unit, using 5.25 inch soft sectored floppy disks.

c) A Commodore 3022 Tractor Printer.

d) A Hewlett Packard 7225A graph plotter.

6.4 Procedure

The solar radiation sensors were located on top of a four-storey building. The electrical signals, in the range 0 to 9.0 mV, were transmitted to the data logging unit using a shielded cable in order to minimise any possible electrical noise. The sensors were calibrated by the Meteorological Office to a scale which is traceable to the World Radiometric Reference.

The analogue electrical signals from the sensors were fed to an electrical interface unit where they were amplified by a factor of approximately 600. Because of the design feature of the interface unit, any electrical signal below 0.23mV, corresponding to a radiation level ~20 Wm^{-2}, was treated as zero. An upper limit for the signal had been set at 9.0 mV, corresponding to radiation level of ~850 Wm^{-2}, although this could be adjusted by 10%. The accuracy of the system was claimed by the manufacturers, to be ±10 microvolts.

Calibration of the interface unit was checked at regular intervals for all the channels. For this purpose a simple electrical circuit was constructed to provide a low voltage source and is shown in fig. 6.1. All the electrical components were enclosed in a cast aluminium box in order to minimise any external electrical interference. A computer program for checking the calibration of the interface unit was provided by the equipment suppliers. A listing of this program has been included for completeness in appendix D. Over a period of 15 months no significant change was found in the electrical characteristics of the interface unit.

A typical calibration plot for a data channel is presented in fig. 6.2 . Solar radiation data were validated and partially processed before recording on a cassette. Several days' data were copied to a disk from which hourly and daily totals were computed for each

ZN 423 - Precision voltage reference - 1.26 volts
AB - Precision digital voltmeter. AB' input to interface unit.

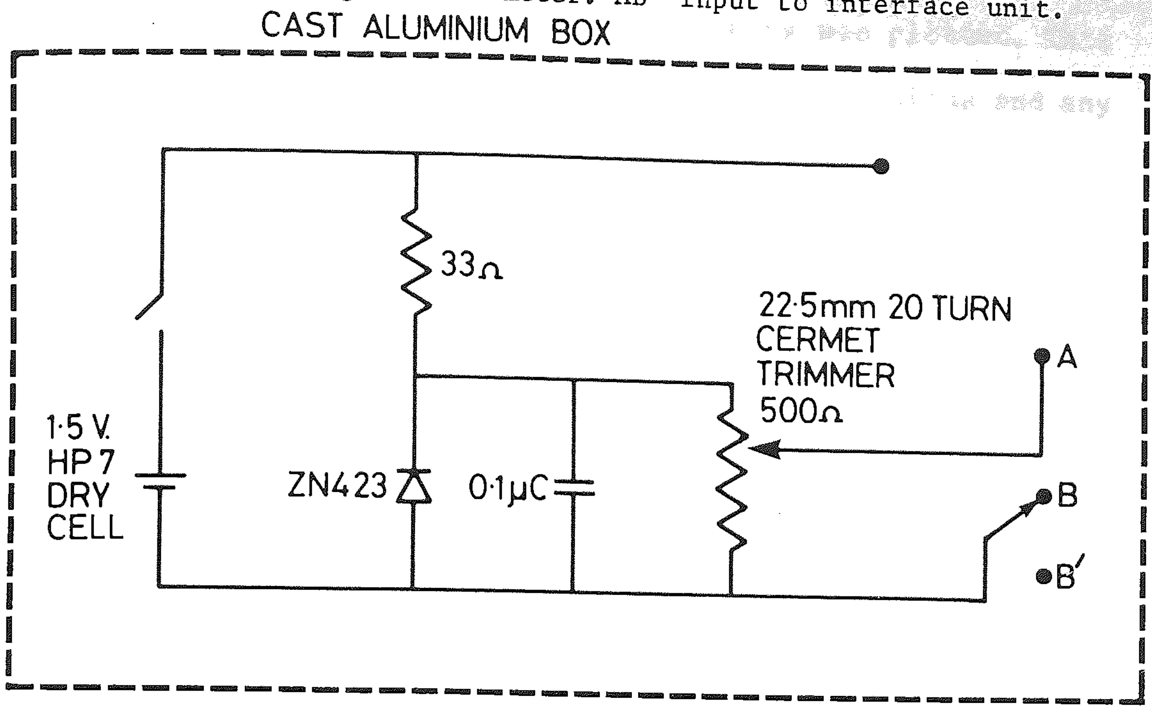


Fig 6.1 Electrical circuit for low voltage source, used for calibration of the interface unit.

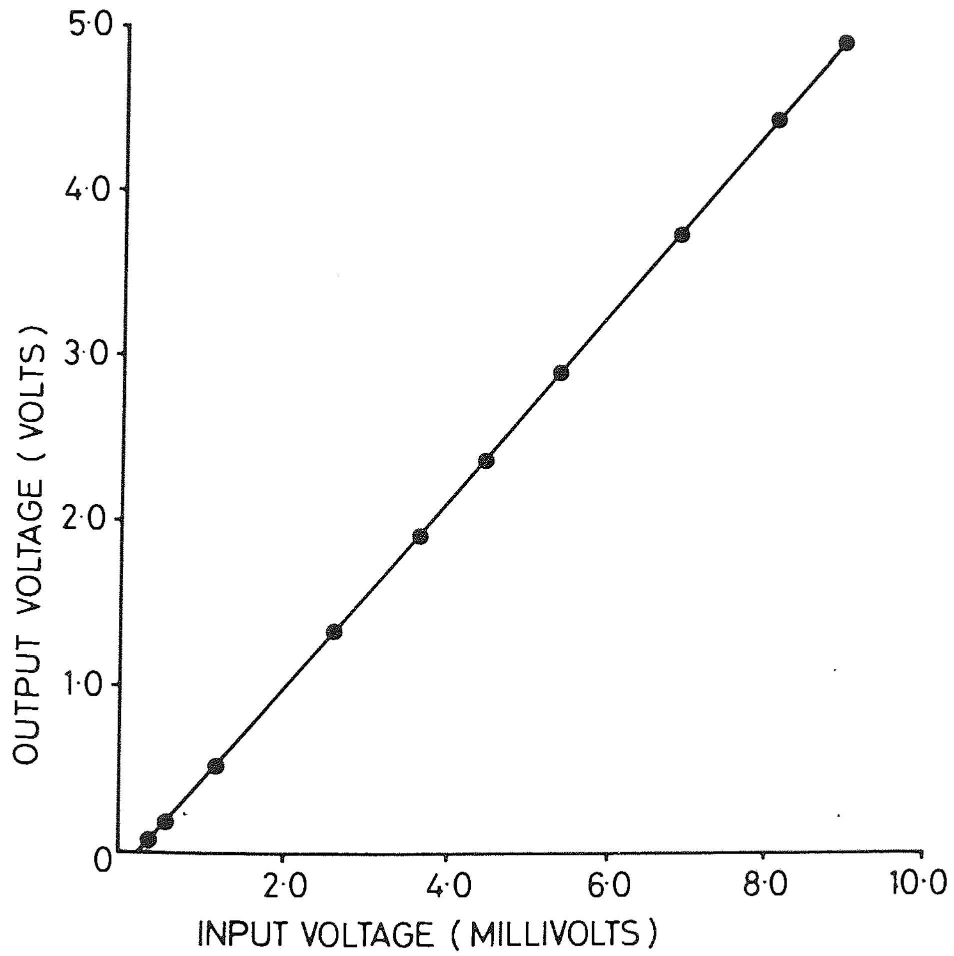


Fig 6.2 A typical calibration plot for channel no 11, of the interface unit, used for solar radiation data acquisition.

channel. For plotting purposes, the data set was separated for a single channel and for each day before anything was plotted. This approach of processing data in stages reduced duplication and any errors during processing could be easily detected.

6.5 Computer software

6.5.1 Program (DAT1)

This program records the incoming electrical signals from the radiation sensors, including the time of data acquisition. Signals from specified channel numbers are recorded at preset time intervals in a 'string form' which helps to reduce any possible errors during data transfer.

A computer based data acquisition system has the capability of operating on a 24-hour basis and this has it's associated problems, the major one being the data storage capacity of the storage device. The system under discussion has a cassette as a storage medium and the capacity is typically 9 to 19k. The storage problem associated with the equipment was dealt with, in the following manner:

The interface unit and the Pet microcomputer can handle up to 16 inputs. All of these may not be in use during any one run. The present computer program has the facility to specify the channel numbers in use.

With solar radiation data, the figures of interest are generally the hourly average values of irradiance and the daily radiation totals. It is recognised from Svendsen(1977), that the data recording time interval can introduce significant errors in recorded hourly irradiation values particularly during partially cloudy days. In order to minimise these errors, the data acquisition time interval should be very small (preferably no greater than the instrument time constant).

The program **DAT1** has the option for scanning the data channels at short intervals, say from 5 seconds upwards. The information can be recorded and the mathematical mean determined after, say 5 or 10 minutes. The mean values can then be stored on a cassette. The program has the option of storing the mean and/or instantaneous irradiance values at preset time intervals.

The above options enable the user to assess the effect of the data acquisition time interval on the overall accuracy of the hourly recorded data.

When the electrical signals from ALL the sensors were zero, no data was written to the cassette. This acted as a 'soft' time switch.

N.B. When the data logging system was operating continously, the internal clock of the microcomputer gained approximately 2 minutes over a 24-hour period. This was due to errors in the 'internal' clock. This problem was resolved by slowing the internal clock by an appropriate time interval at mid-night.

6.5.2 Program (PRO1)

Solar radiation data which had been recorded on a cassette was copied to a disk for further processing and storage. The advantages being that a 5.25 inch soft sectored disk has a much faster data transfer rate and a storage capacity of 170K characters.

At this stage of data copying, labels for data channels were also inserted. If necessary, the system could be reset from the British Summer Time(B.S.T) to Greenwich Mean Time(G.M.T), at this stage.

6.5.3 Program (PRO2)

The diffuse component of irradiance was measured using a shadow band in conjunction with a pyranometer. The shade ring cuts out direct radiation but a correction factor , called the diffuse multiplier, has to be applied to the recorded data. This factor made up for the fraction of the diffuse irradiance component which was also obscured by the shadow band.

When measuring spectral data it was also necessary to apply a correction factor to the radiation data recorded using glass filters in conjunction with Eppley pyranometers. The 'filter factor' values were supplied by the manufacturer.

PRO2 read the copied data from program PRO1 and made adjustments for diffuse irradiance and for data recorded using glass filters.

6.5.4 Program (PRO3)

This program can deal with three modes of recorded data, as given in section (6.5.1).

Hourly mean irradiance values were calculated using the mid-hour as the reference time, e.g. for 11.00 a.m., the data was averaged from 10.30 to 11.30 a.m.. This also is in line with the standard practice used in the U.K. Met. Office archived data.

A date changing routine resets the date at the end of each day. This routine also records the date preceding the daily radiation data.

After a day's data has been processed, daily totals are calculated from the hourly mean values. The errors introduced by this mathematical treatment are likely to be small for the present work, since most of the hourly data was averaged from 360 , compared to the 60 readings for the Meteorological Office recorded data, Cowley(1979).

The routine for converting an electrical signal to the equivalent irradiance value incorporates a calibration factor. An allowance has to be made for the fact that the interface unit treats any electrical signal below 0.23mV as zero.

6.5.5 Program (PRO4)

After processing the solar radiation data, program PRO2 stores hourly and daily totals of solar radiation. These were listed on the line printer using program PRO4. The information printed includes;

i) The date and time when data recording commenced for a given file.

ii) The date before beginning each day's data.

iii) The mean hourly irradiance levels (Wm^{-2}).

iv) The daily and run totals for each channel.

v) The label for each data channel.

vi) The time and date of last data entry.

A typical printout is given in appendix **E.**

6.6 Programs for graphical representation

Since the volume of solar radiation data recorded, during a single day could be very large, a graphical representation can convey a 'synopsis', very conveniently.

A set of three programs have been written to facilitate the plotting of data for a given day on a specified channel number.

6.6.1 Program (PLOT1)

A given data file may contain recorded electrical signals for several days. It was necessary to convert these electrical signals to equivalent irradiance levels and store them, preceded by the date.

i) At the end of day, a marker was stored indicating a change of day.

ii) The data recording time and irradiance level information after conversion was sent to a new file.

N.B. A data destination file name is created within the program. This ensures data security.

6.6.2 Program (PLOT2)

The input to this program is the date for which the data is required for plotting and data source file name (as in 6.6.1).

When the data for a specified day is found it is stored for each channel number. Following this, separate data files are created for each data channel, file names being created within the program.

6.6.3 Program (PLOT3)

This program allows a given data set to be plotted on A4 size paper, using an HP7225A Graph plotter,with various options.

a) The graph(s) which may have the the X-axis parallel to the length of A4 sheet, are referred to as HORIZONTAL GRAPH(s). Alternatively the X-axis may be parallel to the width of A4 sheet and will be referred to as VERTICAL GRAPH(s).

b) There is an option of one, two or three graphs per sheet, each with different scales.

c) There is a facility for plotting more than one set of variables on the same graph.

The procedure is as follows:

i) Data for plotting is input from a disk file,including the number of points to be plotted.

ii) Maximum and minimum values are displayed on the screen for both axes.

iii) Next the axes starting and finishing values are input at the key-pad, including the axes labelling intervals and axes labels.

iv) After drawing the axes, the data points joining routine is called from the program routines. This routine draws a straight line between adjoining data points and prints a symbol at specified intervals.

v) If another plot is required on the same graph, then only two routines are called; the first for reading the data from a file and the second for joining the data points.

vi) The final routine prints the headings for the graph(s).

6.7 Discussion

The importance of the quality of recorded solar radiation data has been emphasized by various publications. For example general guidelines, for the use and maintenance of solar radiation observing instruments have been published by The World Meteorological Organisation (1971).

Cowley(1979), has reported that one of the applications of the present U.K. Meteorological Office recorded solar radiation data is to improve the quality of the archived data. Bahm(1979), in a paper on the evaluation of the quality of solar radiation data available, has outlined some of the problems associated with the existing solar radiation data.

a) There is no standard method for specifying the quality of solar radiation data.

b) The data are often recorded on a variety of instruments and different models give different results.

c) All too often records of instrument calibration, maintenance and associated problems are not recorded.

d) Many instruments come with either insufficient instructions for installation, maintenance and use, or often no instructions at all.

One problem not mentioned by Bahm is that until recently most of the solar radiation data has been recorded using chart recorders. Errors introduced by moving mechanical parts during recording and operator experience during processing are difficult to quantify.

Aspects of quality control for solar radiation data have been detailed by, Wender and Eaton (1980). The quality of data can be examined in terms of; suitability of the measuring site where the sensors are located and calibration and maintenance of radiometers, together with quality control during the recording and processing of data.

A site survey , for the work of this investigation, has been carried out by the Meteorological Office to establish the site's suitability for a long term solar radiation monitoring programme. The main conclusions for the site in Birmingham are summarised below;

i) Corrections of less than 0.05% will be necessary, to the daily totals, for obstructions to diffuse irradiance measurements, assuming an isotropic distribution for the sky irradiance.

ii) For the direct beam from the beginning of May to the middle of August, the amount of total radiation not recorded due to obstruction to the rising sun will be less than 0.01% of the daily total and during October, the obstruction to the setting sun will result in a loss of about 1.0%, to a typical day's total radiation.

However, Seymour(1981), points out that these figures are only approximate, based upon an 'average' day's data.

The solar sensors, both Eppley and Kipp and Zonen, used in this investigation were calibrated in a diffuse hemisphere by the Meteorological Office. The instruments were compared to a transfer standard traceable to the World Radiometric Reference. The accuracy of calibration has been given as ±1.5% .

One of the major sources of errors in evaluating the diffuse component of radiation is in the application of a multiplication factor, which compensates for the proportion of the sky irradiance obscured by the shadow band. Drummond (1964), and Painter(1981), have discussed the complications caused by the anisotropic nature of sky irradiance. Since the diffuse radiation makes up 60% of the total annual radiation for the U.K., as reported in a report by the U.K.-

I.S.E.S.(1976), errors in measurement of diffuse irradiance are quite significant. During the present work, the shadow band correction factors used were those supplied by The Eppley Laboratory. As a precaution, the shadow band positioning was checked daily to make sure that it covered the thermopile.

The calibration of the interface unit is of equal importance as the calibration of radiometers. This was checked on a regular basis for all the channnels. The only limitations of the interface unit were the upper and lower signal threshold values; being 0.23 mV and 9.0mV, respectively corresponding to ~20 and ~850 Wm^{-2}, irradiance levels.

The computer software was designed to allow flexibility and to minimise the possibility of introducing any errors during data transfer. Records of all data recording and processing were kept at ALL stages.

During the period of 15 months of solar radiation data recording, problems were encountered in one case only. These were caused by an intermittent fault in the electrical interface unit, in one data channel. The fault caused some data values to be 10 times larger by shifting the data by one decimal place. The error was corrected by comparing the suspect data with output from another instrument (an Eppley PSP and Kipp and Zonen CM5 in this case).

6.8 Conclusions

The objectives, set out in section 6.1 for this part of the work, have been fully realised. The programme of work under discussion lasted for a period of 15 months. Solar radiation data has been collected and analysed under different experimental conditions. The computer software, developed for recording and analysing solar radiation data, has been entensively tested.

For long term monitoring work, two areas have been identified for improvement; first, the on-line data storage capacity should be increased and second, the lower and upper thresholds for the interface unit need to be extended, particularly when glass filters are used.

The above experimental work has facilitated the collection of very important solar radiation data for Birmingham, a typical urban environment.

Chapter 7. SOLAR RADIATION ON INCLINED PLANES

7.1 Objectives

i) To measure solar radiation on inclined planes and to determine any associated problems.

ii) To investigate the use of a model using horizontal plane solar radiation values for predicting the inclined plane irradiance levels in an urban environment.

iii) To carry out preliminary studies into the spectral distribution of solar radiation on inclined planes.

7.2 Introduction

Solar radiation data on inclined planes is required, for example, in predicting the efficiency of a solar panel and in the design of solar systems. Continous measurements of solar radiation for inclined planes are limited. Since solar radiation data for horizontal surfaces is more readily available it is desirable to develop satisfactory algorithms which can predict inclined plane irradiance levels from given horizontal plane solar radiation data.

Parmlee (1954), has reported extensive measurements of solar radiation intensities on a horizonal surface and on several inclines, under clear sky conditions. From the measured values of solar radiation, Parmlee developed relationships between the direct and diffuse components of radiation, expressed in terms of atmospheric clearness and position of the sun. Results from Parmlee's work have been used by Page (1978), for estimating solar energy on vertical and inclined surfaces. The 'classical' work of Liu and Jordan (1961), has formed the basis of many studies for predicting solar radiation levels on inclined surfaces. In these studies the sky radiation has been assumed to be isotropically distributed across the sky. The Liu and Jordan (1967) method has been used by Villarrubia et al. (1980), for predicting solar radiation data on inclined planes in Spain.

Klein (1976), in his review paper has dealt with the prediction of monthly average values of irradiation on inclined planes. Iqbal (1978) has published an analysis of radiation values for hourly and daily values of irradiation. Steinmuller (1980), has reported on a study in which two solarimeters were used to measure total irradiation on two different inclines, from which correlation relationships have been developed, thus enabling the computation of direct and diffuse irradiation on any other inclined plane. Other solar radiation modelling studies for the inclined plane have been reported by Bugler (1977) and Puri et al. (1980).

Solar radiation on an inclined plane is made up of the following contributions.

i) Direct radiation.

ii) Sky radiation - divided further into hemispherical and circumsolar.

iii) Reflected radiation (from the ground).

Weiss and Lof (1980), have reported a study in which the above three contributions were dealt with separately. The hemispherical diffuse radiation comes from all parts of the sky and has an intensity equal to that measured in regions away from the sun. The beam and circumsolar diffuse radiation are superimposed over the hemispherical diffuse radiation around the sun.

Most of the comments relating to the direct and sky radiation on a horizontal surface are applicable to inclined planes. For overcast days the distribution of diffuse irradiance across the sky is approximately isotropic but for partially cloudy days and clear days the anisotropy is much more pronounced, as reported by Dave (1977), Steven (1977) and Buckius and King (1978).

7.3 Inclined plane models

After a close examination of a large number of models available for predicting solar radiation on inclined planes, the work reported by Klucher (1979) was ultimately selected for the present investigation. It is possible that the mathematical model developed in this work for predicting the spectral distribution of solar radiation, on a horizontal surface (in Chapters 3 and 4), could be further developed and applied to inclined surfaces.

Klucher (1979) based his model for measured solar radiation data on two inclined planes at 37^{o} and 60^{o} facing South. The data set was taken over a six month period (January - June 1977) in Cleveland, (latitude 42^{o}N, longitude 82^{o}W), Ohio, consisting of hourly average insolation measured by pyranometers on horizontal and inclined planes.

Before selecting the Klucher model a comparison between three models was made.

i) An isotropic-sky model after Liu and Jordan (1963).

ii) An anisotropic-clear-sky model, developed by Temps and Coulson (1977).

iii) An anisotropic-all-sky model, developed by Klucher (1979).

The main difference in the three models is the way in which the contributions, from the sky radiation are computed. In order to facilitate discussion later on, a brief description of the three models will now be given.

In the isotropic-sky model by Liu and Jordan (1963), the insolation on a tilted surface towards the equator is given by

$$I_t = \frac{(I_h - I_d)}{\sin\alpha} \cos\psi + I_d \frac{(1+\cos\varepsilon)}{2} \qquad (7.1).$$

where

I_t = total radiation received by the tilted surface.

I_h = total radiation on a horizontal surface.

I_d = diffuse radiation on a horizontal surface.

α = solar elevation angle.

ε = tilt angle above the horizon of the tilted surface.

ψ = angle between sun direction and normal direction of tilted surface.

Temps and Coulson (1977), in an effort to take account of the nature of diffuse irradiance across the sky, introduced two multiplying correction factors for the diffuse irradiance contribution.

i) A factor, A1, to allow for the increase in skylight observed near the horizon during clear days. Where

$$A1 = 1 + \sin^3(\varepsilon/2) \qquad (7.2).$$

ii) An approximation for the sky brightening near the sun, given by a factor B1. Where

$$B1 = 1 + \cos^2\psi \sin^3(90-\alpha) \qquad (7.3).$$

iii) A further factor, C1, to take account of surface reflected enhancement of the total radiation. Where

$$C1 = a\,\{1 - \cos^2(\varepsilon/2) \qquad (7.4).$$

a = surface albedo.

However, it was not necessary to include the C1 factor in this investigation because the experimental design was arranged such that surface reflection was eliminated, see figure 7.1 .

When the two correction terms from equations (7.2) and (7.3) are applied to the isotropic-sky model in equation (7.1) then it becomes.

$$I_t = \frac{(I_h - I_d)}{\sin\alpha} \cos\psi + I_d\{\frac{1+ \cos\varepsilon}{2}\}\{1+ \sin^3(\varepsilon/2)\}$$

$$x \{1+ \cos^2\psi \sin^3(90-\alpha)\} \qquad (7.5).$$

Equation (7.5) is only applicable to clear sky conditions. In an attempt to make the above equation applicable to all sky conditions, Klucher (1979), introduced a modulating factor, F, where

$$F = 1 - (I_d/I_h)^2 \qquad (7.6).$$

Thus the final relationship derived by Klucher takes the form

$$I_t = \frac{(I_h - I_d)}{\sin\alpha} \cos\psi + I_d\{\frac{1+ \cos\varepsilon}{2}\}\{1+ F \sin (\varepsilon/2)\}$$

$$x \{1+F \cos^2\psi \sin^3(90-\alpha)\} \qquad (7.7).$$

In this study, the values of I_t given by equations (7.1), (7.5) and (7.7), which are applicable to the three models, are compared.

7.4 Measurement of radiation on inclined surfaces

In this study, three Eppley Precision Pyranometers were used.

a) One for measuring the total radiation on a horizontal surface.

b) The second incorporated an Eppley shadow band to measure the diffuse radiation on a horizontal plane.

c) The third instrument was used to measure the total radiation on an inclined plane, facing South.

The ground reflected radiation was eliminated by using a screen which was constructed from 25mm aluminium mesh, with the trade name 'aeroweb', and was supplied by the Ciba-Greigy Plastics and Additives Company of Cambridge. The screen was sprayed with matt black paint in order to minimise the reflection of solar radiation incident on it. This screening technique is also used by the U.K. Meteorological

Office when measuring radiation on non-horizontal surfaces, Seymour (1981). Figure 7.1, shows a typical set up of the solar radiation measuring instruments. The inclined plane platform can be easily adjusted to any inclination between 0 and 90 degrees.

7.5 Method of analysis of the data

Solar radiation data was recorded using a microcomputer based, data logging system. The sensors were scanned at 10 second intervals and a mean of 60 readings at 10 minute intervals was recorded on a computer readable media. All the data analysis was based on the mean irradiance values for the 10 minute intervals .

When the data was analysed for hourly time intervals, a mean of six recorded values was computed and assigned to the mid time of the interval. For example the data from 10.40 to 11.30 a.m., was averaged and assigned to 11.05 a.m. . An algorithm, proposed by Walraven (1978), was written in the BASIC programming language and adapted for a COMMODORE microcomputer. This 'position of the sun' program computed the angle of elevation of the sun, and the azimuthal angle at a given time.

The angle between the sun direction and the normal direction to the tilted surface was computed, using the following relationship, from Duffie and Beckman (1974).

$$\cos\psi = \cos(\phi-\varepsilon)\cos\delta\cos\omega + \sin(\phi-\varepsilon)\sin\delta \qquad (7.8).$$

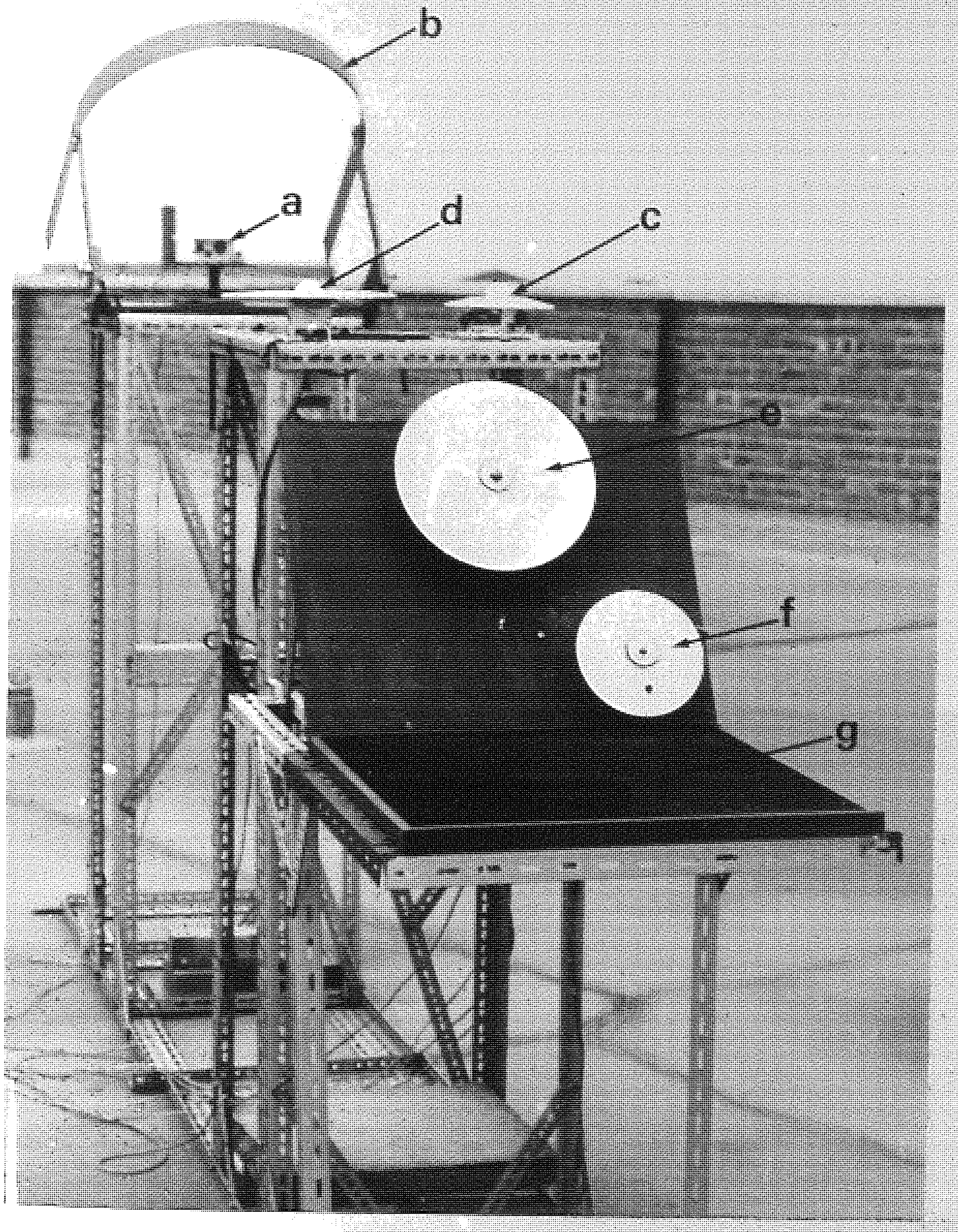
where ψ = the angle of incidence of beam radiation, the angle being measured between the beam and the normal to the plane.

ω = hour angle (solar noon being zero).

ε = the angle between the horizontal and the inclined plane.

ϕ = latitude (north positive).

δ = solar declination.



F gure 7.1 A typical set up of solar radiation measuring instruments
(a) Eppley PSP pyranometer - diffuse radiation.
(b) Shadow band.
(c) Eppley PSP pyranometer - total radiation on horizontal surface.
(d) Kipp & Zonen CM7 albedometer.
(e) Kipp & Zonen CM5 - inclined plane solar radiation.
(f) Eppley PSP pyranometer - total radiation on inclined plane.
(g) 25mm thick aluminium mesh - for cutting off the ground reflected radiation.

The relationships of equations (7.1), (7.5) and (7.7), were used to compute the theoretical values of inclined plane irradiance levels from the measured total and diffuse radiation on a horizontal plane.

7.6 Results

The results can be divided in two parts

Part 1. A comparison of the three models by

i) Liu and Jordan.

ii) Temps and Coulson.

iii) Klucher.

Results are presented for a number of inclines, varying from 30 to 90 degrees.

In figures 7.2 to 7.6, the caption

.a .... refers to the Liu and Jordan, isotropic-sky model.

.b .... refers to the Temps and Coulson anisotropic-clear-sky model.

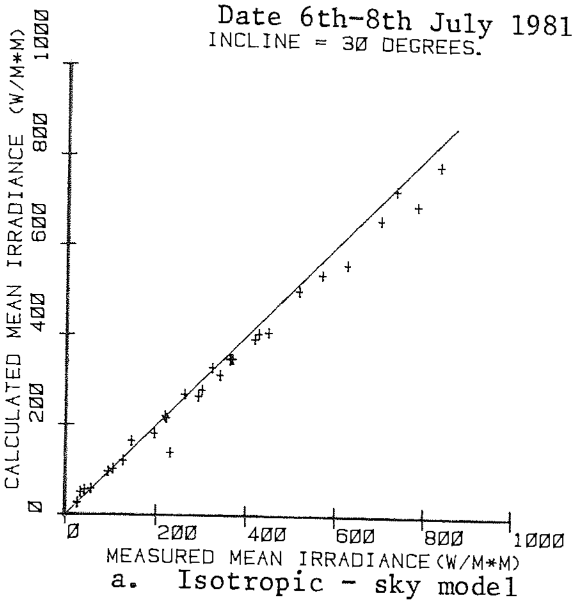
.c .... refers to Klucher's anisotropic-all-sky model.

Part 2 Another important factor in the testing of mathematical models is the time interval over which the radiation values are calculated. Figures 7.7 and 7.8, present results for two inclines of 30 and 67 degrees, respectively. The algorithm used in these calculations is based on Klucher's anisotropic-all-sky model. The three graphs in each figure, compare the calculated and measured radiation values for 3 time intervals of

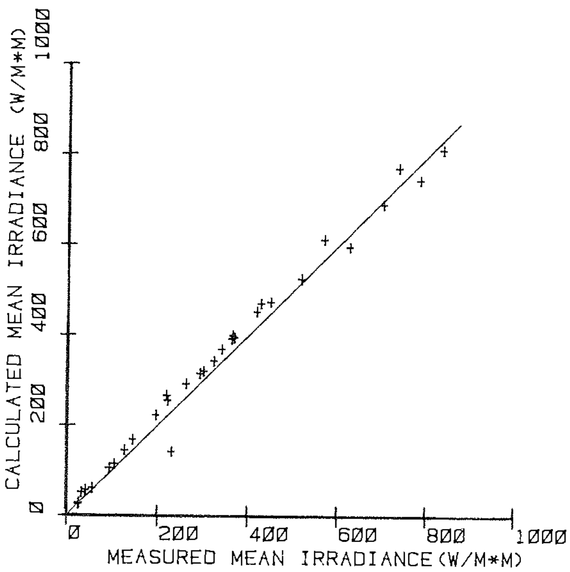
i) 60 minutes.

ii) 30 minutes.

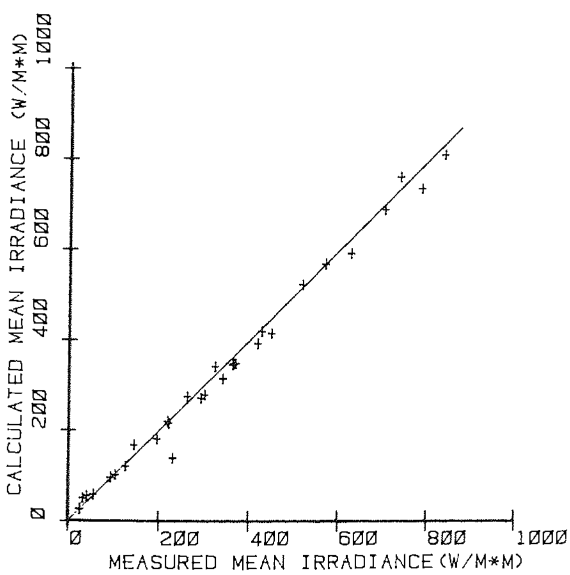
iii) 10 minutes.



a. Isotropic - sky model

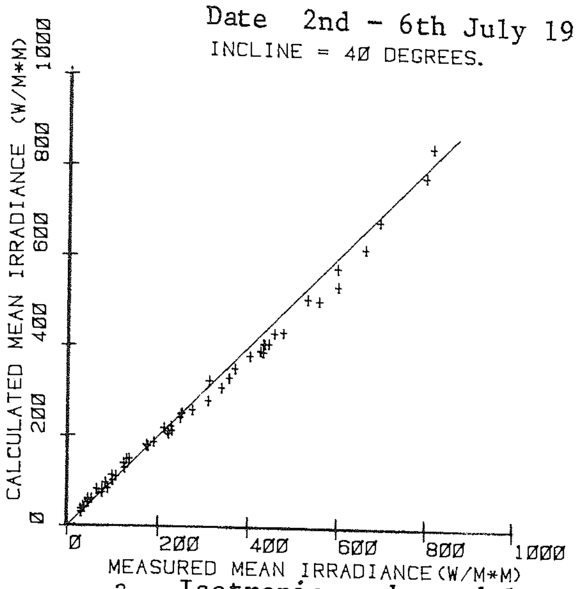


b. Anisotropic - clear - sky model

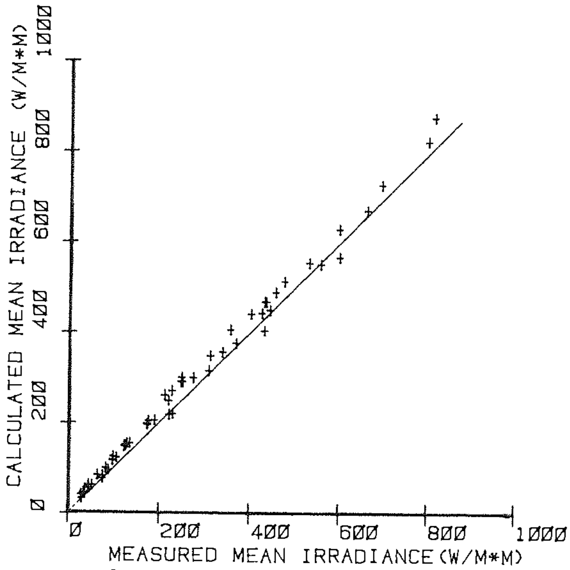


c. Anisotropic - all - sky model

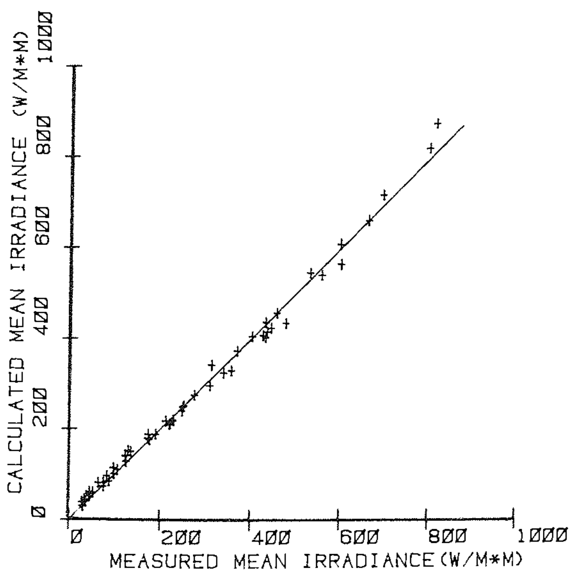
Fig 7.2 Comparison of three inclined plane models. Angle of incline 30 degrees.



a. Isotropic - sky model



b. Anisotropic - clear - sky model

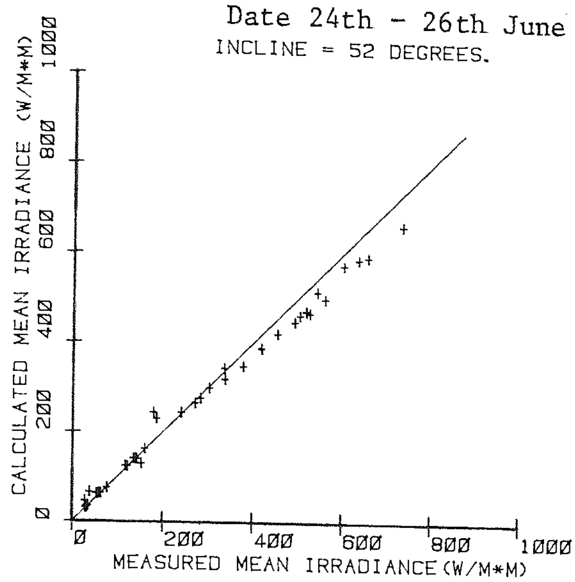


c. Anisotropic - all - sky model

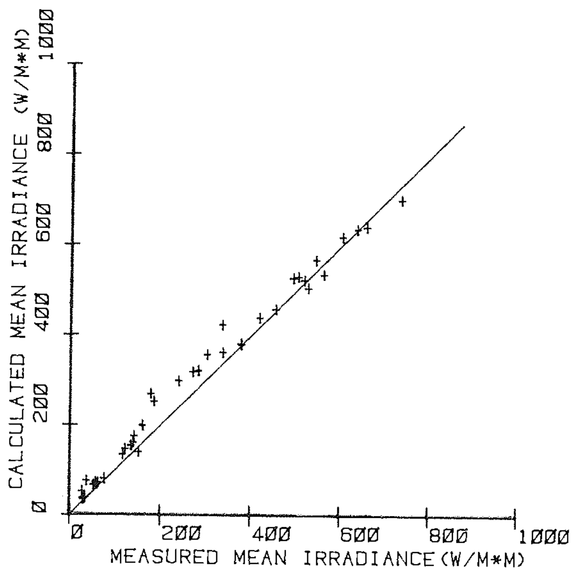
Fig 7.3 Comparison of three inclined planed models. Angle of incline 40 degrees.

Date 24th - 26th June 1981

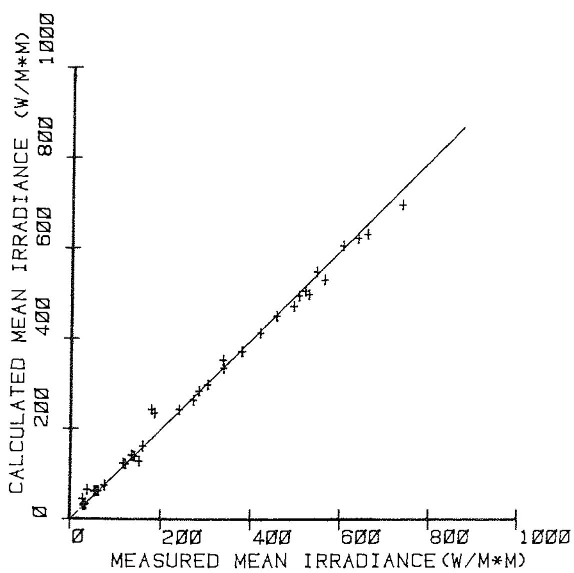
INCLINE = 52 DEGREES.



a. Isotropic - sky model

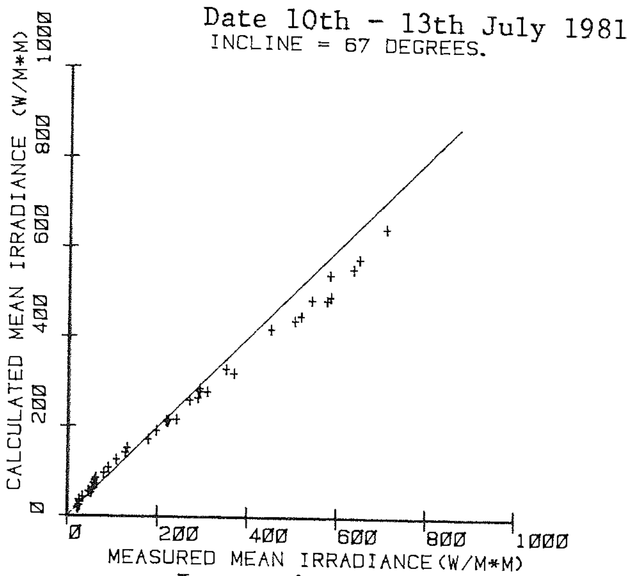


b. Anisotropic - clear - sky model

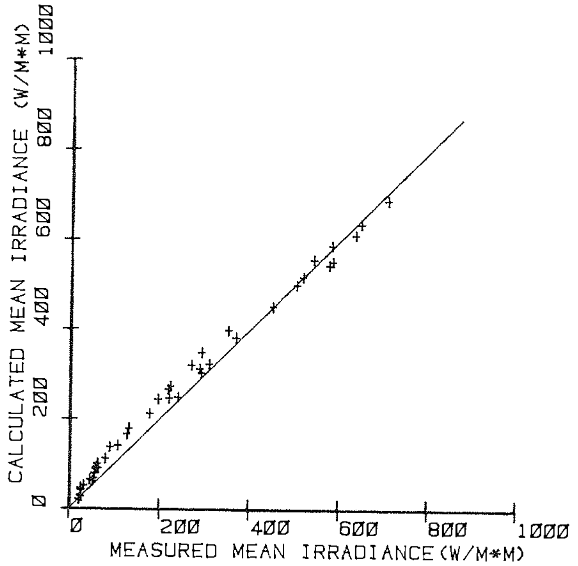


c. Anisotropic - all - sky model

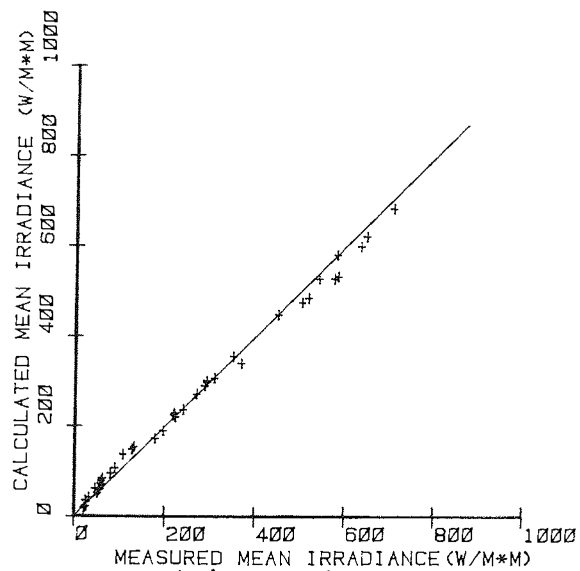
Fig 7.4 Comparison of three inclined plane models. Angle of incline 52 degrees.



a. Isotropic - sky model

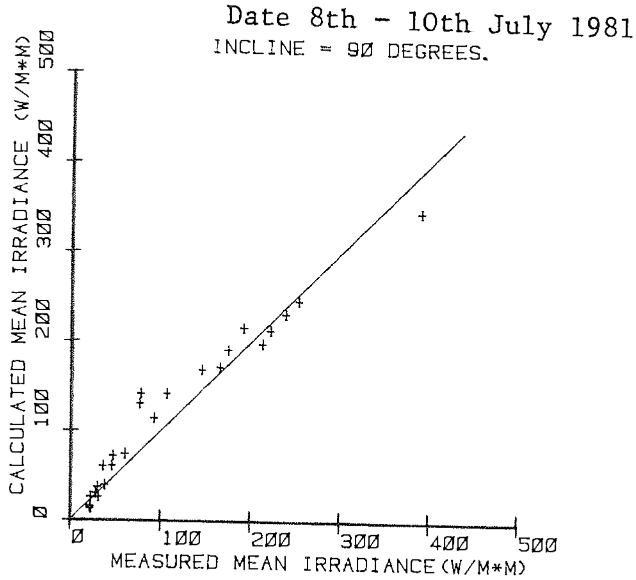


b. Anisotropic - clear - sky model

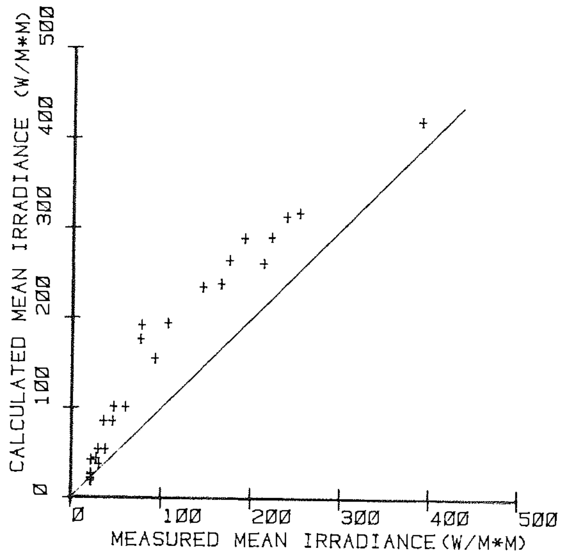


c. Anisotropic - all - sky model

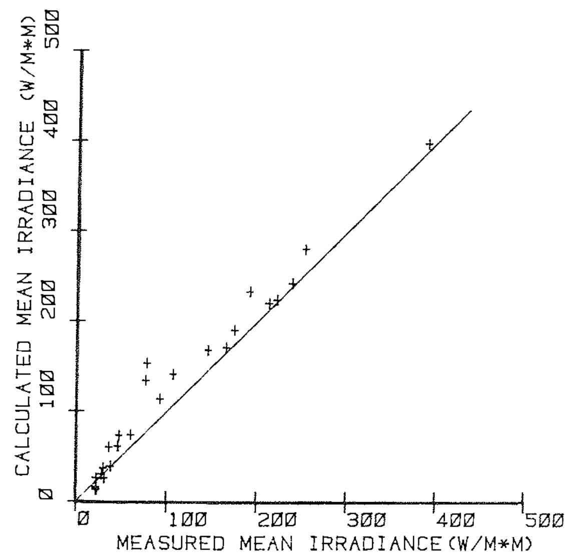
Fig 7.5. Comparison of three inclined plane models. Angle of incline 67 degrees.



a. Isotropic - sky model



b. Anisotropic - clear - sky model



c. Anisotropic - all - sky model

Fig 7.6 Comparison of three inclined plane models. Angle of incline 90 degrees.

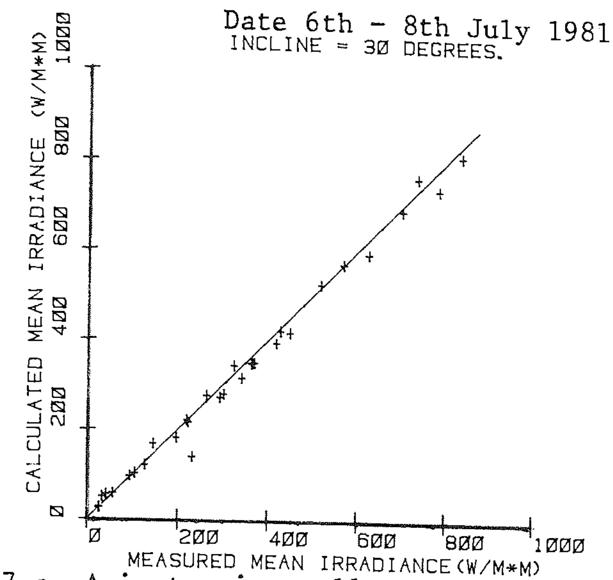


Fig 7.7.a Anisotropic - all - sky model.
Data time interval 60 minutes.

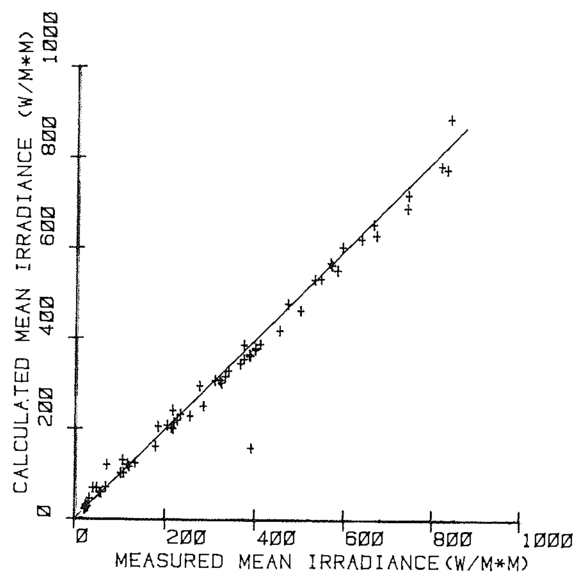


Fig 7.7.b Anisotropic - all - sky model.
Data time interval 30 minutes.

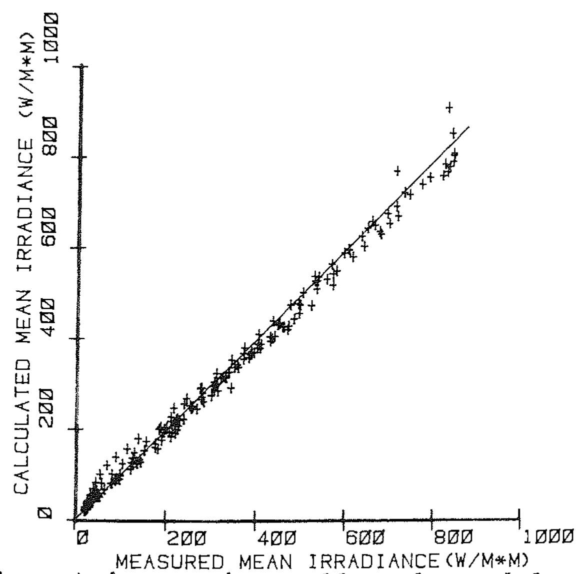


Fig 7.7.c Anisotropic - all - sky model.
Data time interval 10 minutes.

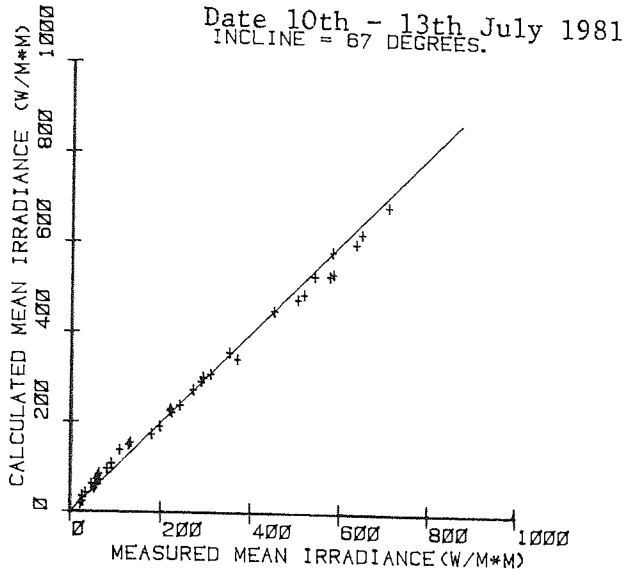


Fig 7.8.a. Anisotropic - all - sky model.
Data time interval 60 minutes.

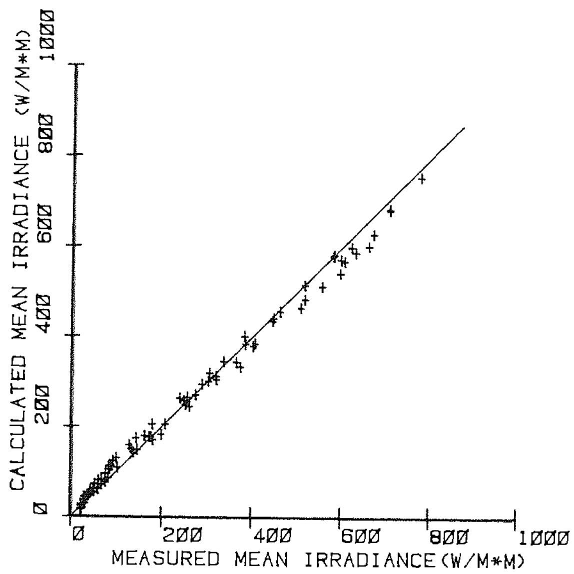


Fig 7.8.b Anisotropic - all - sky model.
Data time interval 30 minutes.

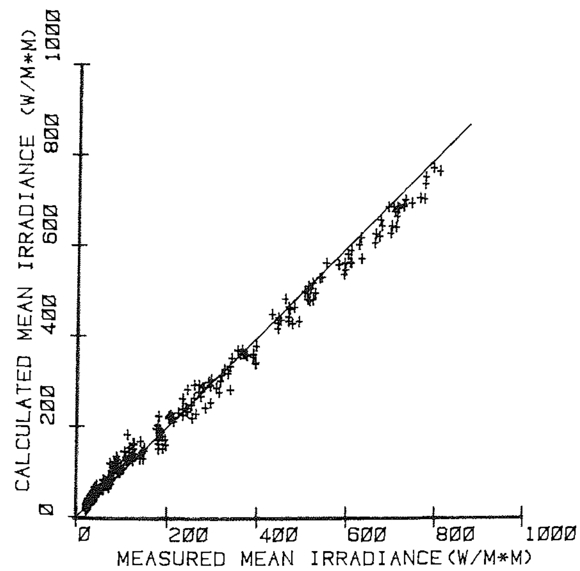


Fig 7.8.c. Anisotropic - all - sky model.
Data time interval 10 minutes.

7.7 Discussion of results

The Eppley Precision pyranometers used in this study were calibrated by the U.K. Meteorological Office, on a horizontal plane, to an accuracy of ±1.5%. In a number of studies, for example by Norris(1974), Reed(1978) and Goldberg(1980), it has been shown that the calibration of a pyranometer changes when used on a non-horizontal surface. Norris reports a change in calibration factor from the horizontal to an incline of 90^{o} as 11%, but later studies by Reed and Goldberg, report this shift to be ~2% . These studies have been carried out in a laboratory under controlled conditions using artificial light sources and it is difficult to estimate any deviations from this when the pyranometers are used in the 'field', as the meteorological conditions can be significantly different.

The diffuse radiation component has been measured using a shadow band and evaluated by applying a multiplication factor to the readings to take account of the sky radiation obscured by the shadow band. The accuracy of the measured radiation data is; 2-3% for the total radiation on a horizontal surface, ~5% for the diffuse radiation on a horizontal surface, and ~5% for the total radiation data on inclined planes.

The results presented in figs. 7.2, 7.3, 7.4 and 7.5, for angles of inclination of 30, 40, 52 and 67 degrees, respectively, are in general agreement with the conclusions reached by Klucher (1979).

The isotropic-sky model, proposed by Liu and Jordan, provides close agreement between the measured data for the Birmingham area and predicted values, for low irradiance levels. This is generally the case with overcast skies, when the approximation of isotropic sky flux distribution is close to the real situation. The levels of irradiance to which the above agreement applies, range from approximately $400Wm^{-2}$

at an incline of 30 degrees, to 200 Wm^{-2} at an incline of 67 degrees. This is likely to result from relatively lower irradiance intensity incident at higher angles of incline because the 'visible' proportion of the sky decreases. At higher irradiance levels than 400 Wm^{-2}, the isotropic-sky model, consistently predicts lower levels of irradiance than the measured data.

The anisotropic-clear-sky model, proposed by Temps and Coulson (1977), provides a good agreement between the measured and predicted values at higher irradiance levels, i.e. 400 Wm^{-2} and upwards. This is likely to be the case when the skies are relatively clear. However, the anisotropic-clear-sky model overestimates the total inclined plane irradiance at low radiation levels.

As the angle of tilt increases from 30 to 67 degrees, the portion of the sky which is not seen by the instrument also increases. This results in a lower proportion of the sky radiation which is intercepted by the inclined plane.

The anisotropic-all-sky model proposed by Klucher, seems to overcome the apparent shortcomings of the earlier models. For overcast skies when the direct component of radiation is nearly zero, the modulating factor approximates to zero, resulting in an isotropic-sky model. During a clear day the modulating factor is nearly 1, thus the Klucher model then approximates to the anisotropic-clear-sky model. For the anisotropic-all-sky model, as in figures 7.2.c to 7.4.c the measured and predicted irradiances, agree to within $\pm 25Wm^{-2}$, giving scatter of less than $\pm 5\%$.

The results presented in fig. 7.6, for an inclined plane of 90 degrees, seem to show greater scatter than at lower angles of incline for all three models. This scatter has been 'amplified' by the smaller range of the two axes. The predicted irradiance levels are higher than the measured data. The deviation of predicted irradiance values, for the Klucher model is 30 Wm^{-2}, resulting in the higher percentage (10%) of disagreement.

Figures 7.7 and 7.8, show a comparison of the predicted and measured values, at inclines of 30 and 67 degrees respectively, when the data is averaged over 10, 30 and 60 minute intervals (all for the Klucher model). As the time interval decreases, the spread of data increases as might be expected. The general conclusions can be reached as those for the hourly data. Irradiance values agree well for the data which is averaged over both 10 and 30 minutes intervals.

The conclusions reached in this study are in general agreement with those reported by Garg and Garg (1981), and Stewart et al. (1981).

Garg and Garg, using Klucher's algorithm have compared the measured and predicted radiation on a plane inclined at 45^o, for four widely separated Indian stations, viz. Delhi(28^o 38'N), Poona (18^o 29' N), Calcutta (22^o 36'N), and Madras (13^o 8'N). When comparing the daily totals of predicted and measured radiation, for radiation over 9 days, Garg and Garg, report that the predicted radiation was lower than the measured data in each case, the error ranging from 0.08% to 6.74%, with a mean value of ~3% .

Stewart et al. (1981), have used hourly solar radiation data in their study, measured for a site at Albany , NY, U.S.A., (lat. 42^o 42'; long. 73^o50'; elev 79m). They report that when the measured and predicted data (derived using Klucher's algorithm), were compared there was a standard error of 4.7% for an incline of 33^o rising to 10.6% for an incline of 90^o, for a surface facing South.

7.8 Spectral distribution of solar radiation on inclined planes

Published data for spectral distribution of solar radiation on inclined planes does not exist as far as the author is aware. The spectral distribution of solar radiation for an inclined plane is significant, when calculating the energy contributions from an array of solar cells at non-horizontal surfaces.

7.8.1 Measurement

The spectral distribution in this study has been measured using Eppley PSP pyranometers in conjunction with glass filters. Three Eppley PSP pyranometers were placed on an inclined assembly, facing South, (as in figure 7.1) . One pyranometer was used to measure the total radiation incident on the inclined plane and two other instruments had their outer glass hemisphere replaced with a schott glass filter.

In all, four glass filters were used; RG715, RG630, OG530 and GG395, with the lower wavelength cut-off at 0.707, 0.623, 0.529 and 0.385 micrometers, respectively. The filter multiplication factors, to allow for transmittance factors, applied in these tests were those supplied by The Eppley Laboratory. The ground reflected component of radiation was eliminated as mentioned in section 7.4.

7.8.2 Results and discussion

Solar radiation data was measured for 4 inclines, ranging from 30 to 70 degrees. Since there were only three pyranometers available, only two glass filters could be used at any one time.

The results of spectral band solar radiation are presented in figures 7.9 to 7.16 . The data is provided in two sets.

i) total radiation and with filters RG715 and RG630 .

(figures 7.9 to 7.12).

ii) Total radiation and data with glass filter OG530.

When solar radiation data is measured using glass filters, errors due to glass filter characteristics are added to the instrumental errors. As far as the author is aware no studies have so far been reported in which the problems arising from the use of glass filters at inclined planes have been investigated. The total errors are estimated to be 4-5% for the total radiation measurements and 7-8% in measurements using glass filters.

Results obtained using filter GG395 are not included in this thesis for the reasons stated in Chapter 4, section 5.

Results are presented as the hourly mean radiation levels for the total radiation and data measured with glass filters. Ratios of the individual data values, from 10 seconds scans and averaged over 10 minute periods, have been computed for the data with three glass filters and the total radiation. Figures 7.10, 7.12, 7.14 and 7.16, give plots of the ratios of irradiance measured with filters to the total measured irradiance.

As the measured data set is rather limited and the errors in data measured with glass filters are rather large (7-8%), it is only possible to observe general trends in the data reported in this section.

When the mean ratio values were examined there is very small change when the angle of inclination is increased from 30° to 67°. However, appreciable differences were observed between the data for relatively clear days and for mainly cloudy days. Under nearly cloud free skies, the ratio mean values for RG715, RG630 and OG530 filters are; 0.54, 0.66, and 0.81, respectively. Under mainly partially cloudy conditions the corresponding ratios are; 0.49, 0.63, and 0.78, respectively.

The corresponding ratios for radiation measured on a horizontal plane with filters RG715, RG630 and OG530, were

a) 0.56, 0.66 and 0.84, respectively, under cloud free skies.

b) 0.57, 0.67 and 0.84, respectively, under partially cloudy sky conditions.

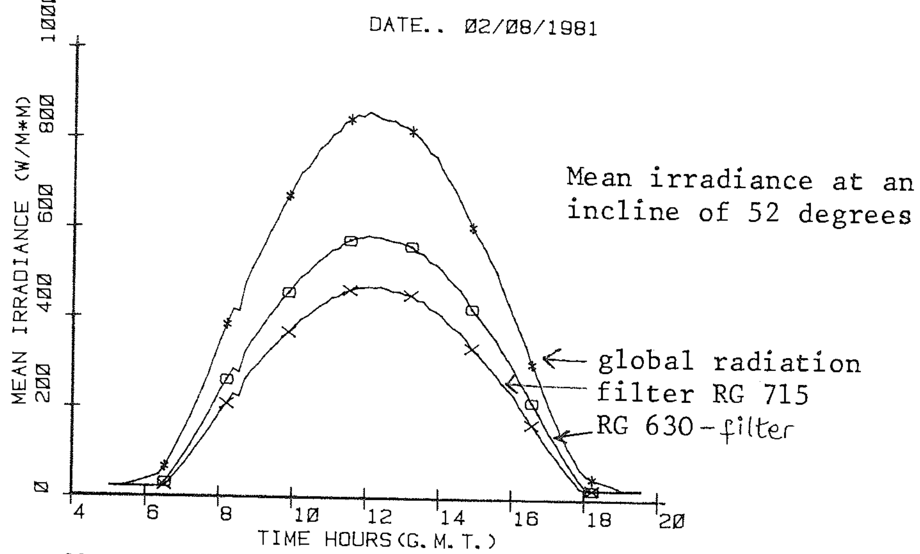


Fig 7.9.a Measured global radiation and values using filters RG 715 and RG 630, for a relatively clear day.

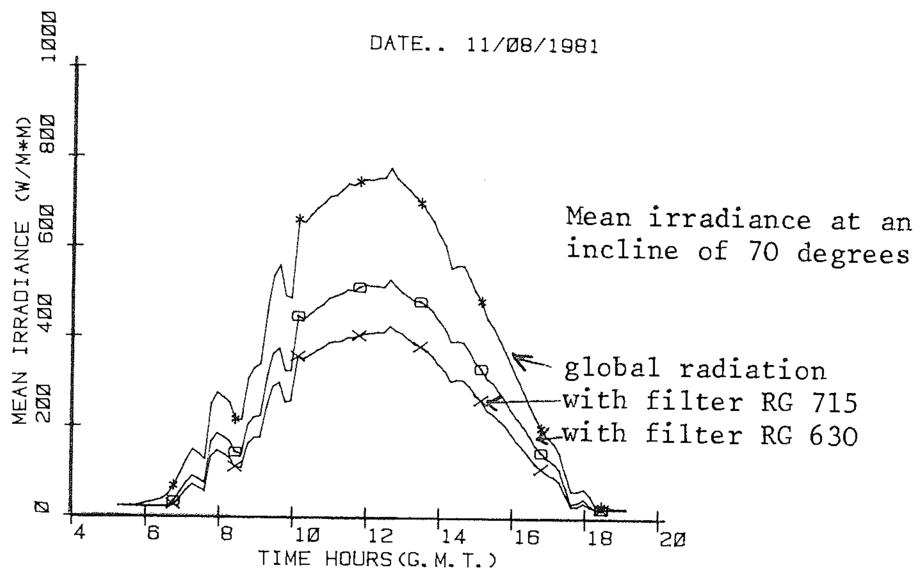


Fig 7.9.b Measured global radiation and values using filters RG 715 and RG 630, for a relatively clear day.

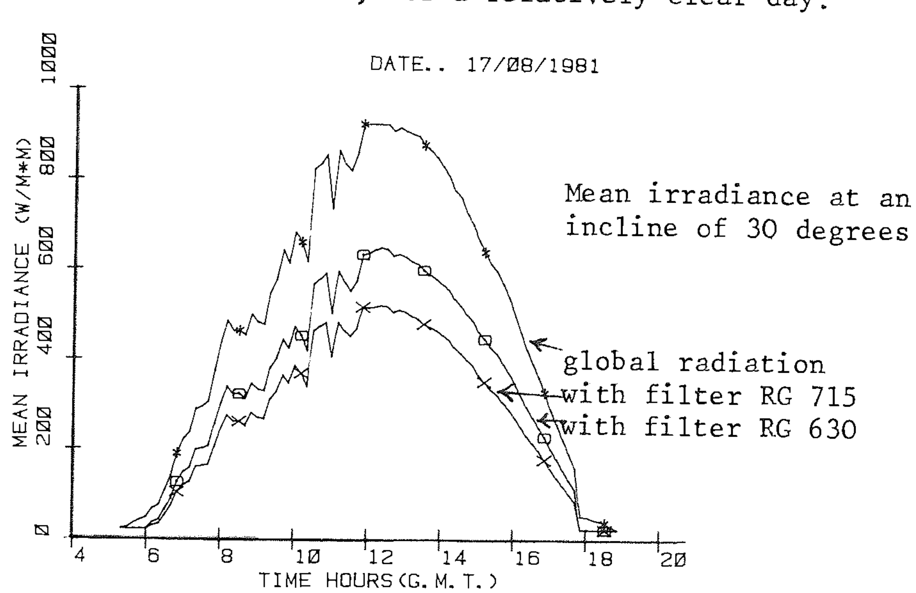


Fig 7.9.c. Measured global radiation and values using filters RG 715 and RG 630 for a relatively clear day.

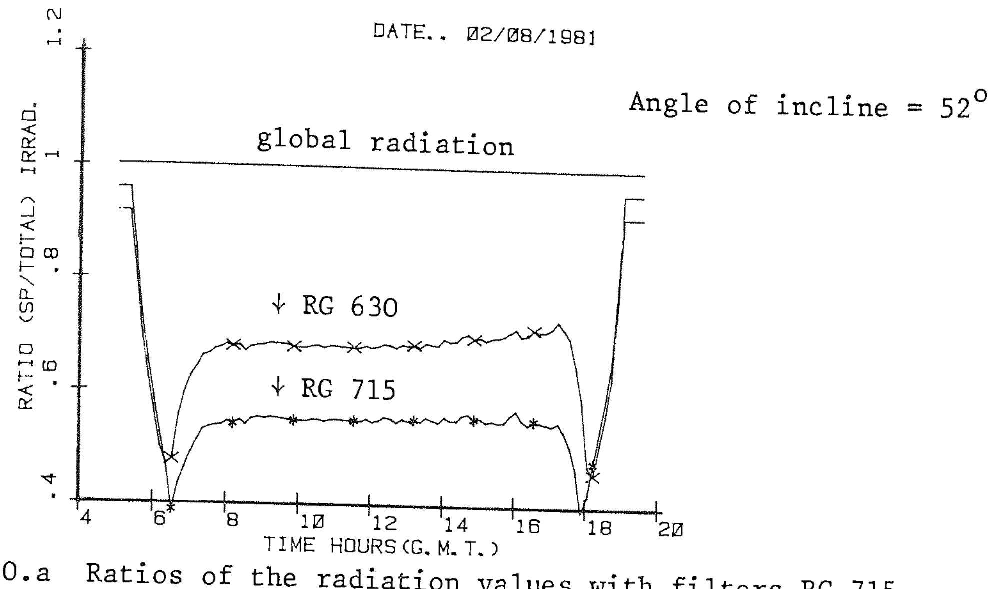


Fig 7.10.a Ratios of the radiation values with filters RG 715 and RG 630, to the mean global irradiance, for a relatively clear day.

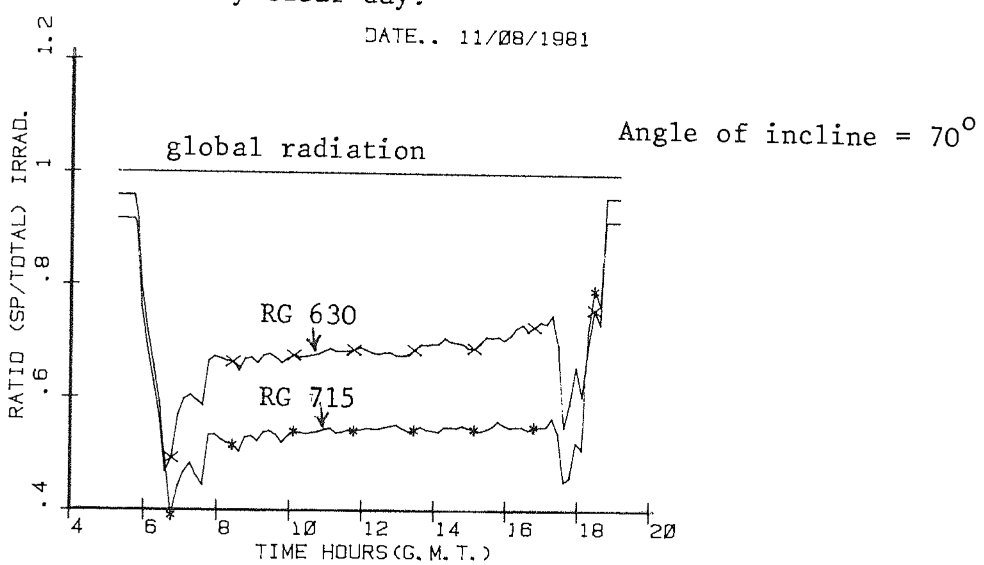


Fig 7.10.b Ratios of the radiation values with filters RG 715 and RG 630, to the mean global irradiance, for a relatively clear day.

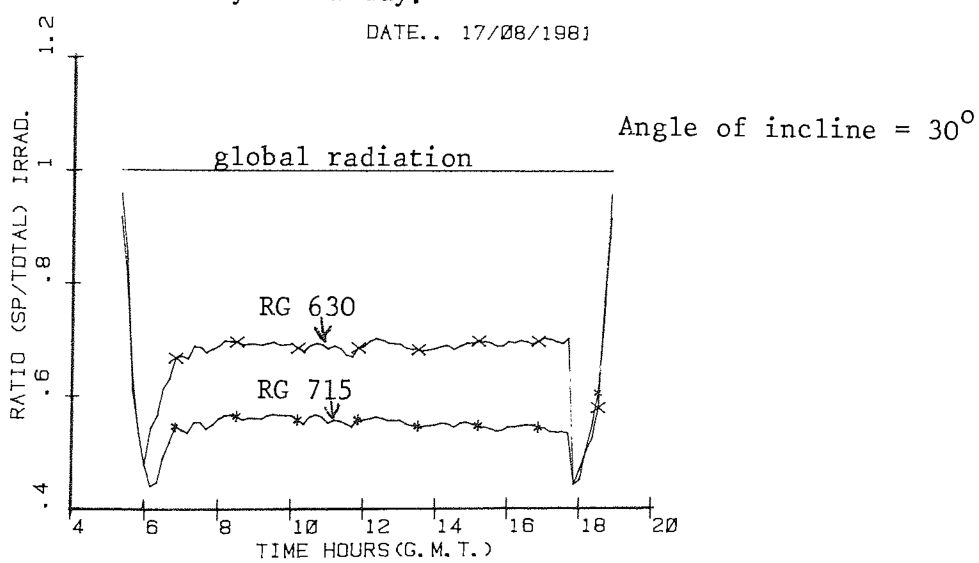


Fig 7.10.c Ratios of the radiation values with filters RG 715 and RG 630, to the mean global irradiance, for a relatively clear day.

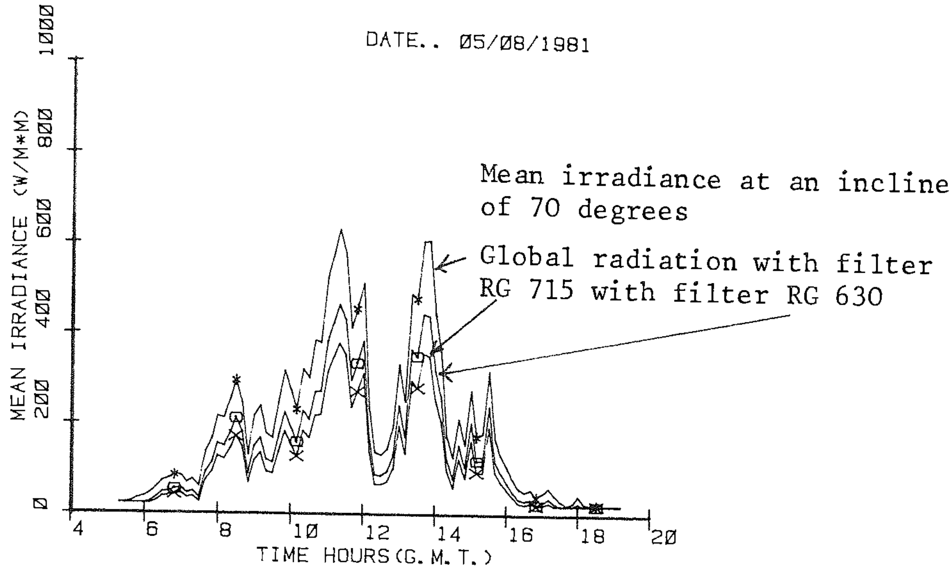


Fig 7.11.a Measured global radiation and values using filters RG 715 and RG 630, for a partially cloudy day.

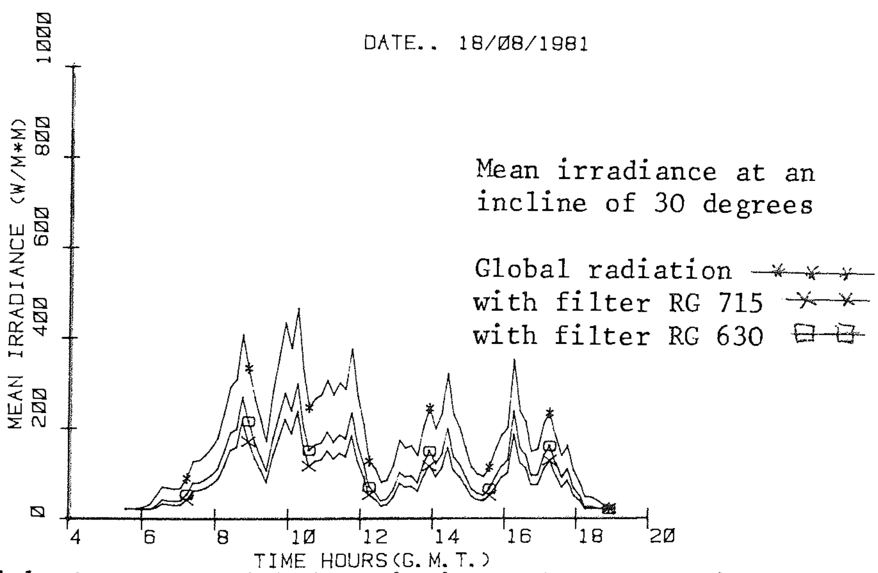


Fig 7.11.b Measured global radiation and values using filters RG 715 and RG 630, for a partially cloudy day.

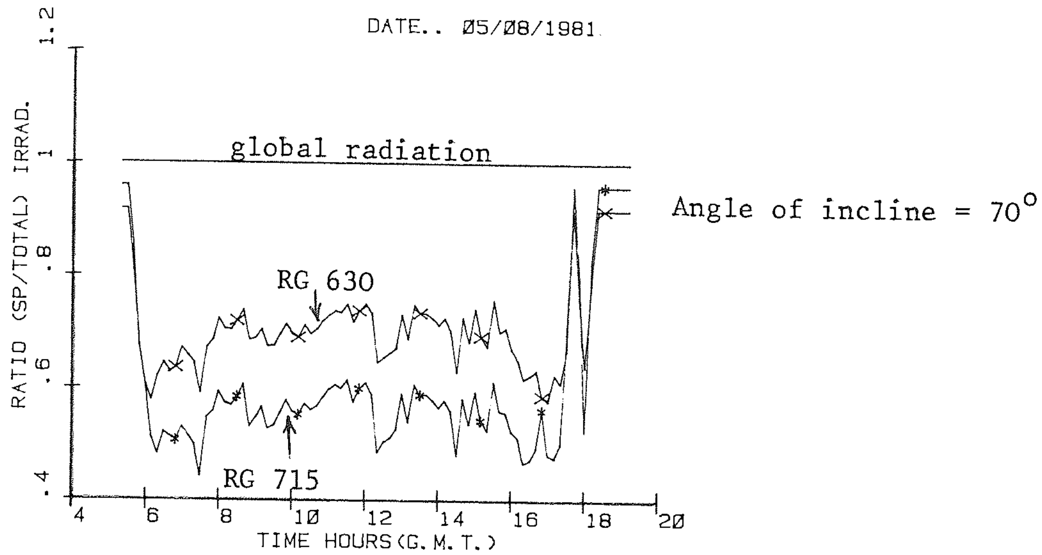


Fig 7.12.a Ratios of the radiation values with filters RG 715 and RG 630, to the mean global irradiance, for a partially cloudy day.

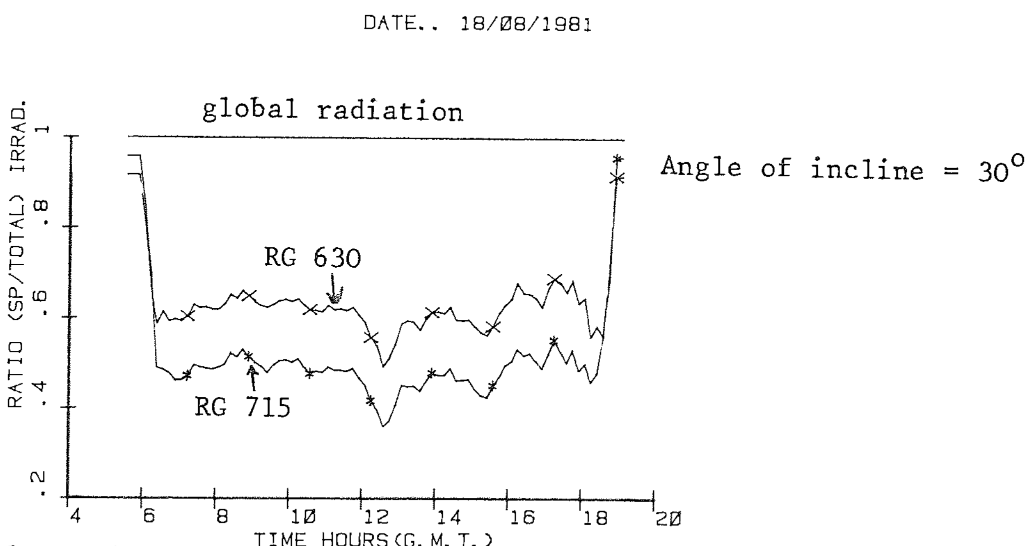


Fig 7.12.b Ratios of the radiation values with filters RG 715 and RG 630, to the mean global irradiance, for a partially cloudy day.

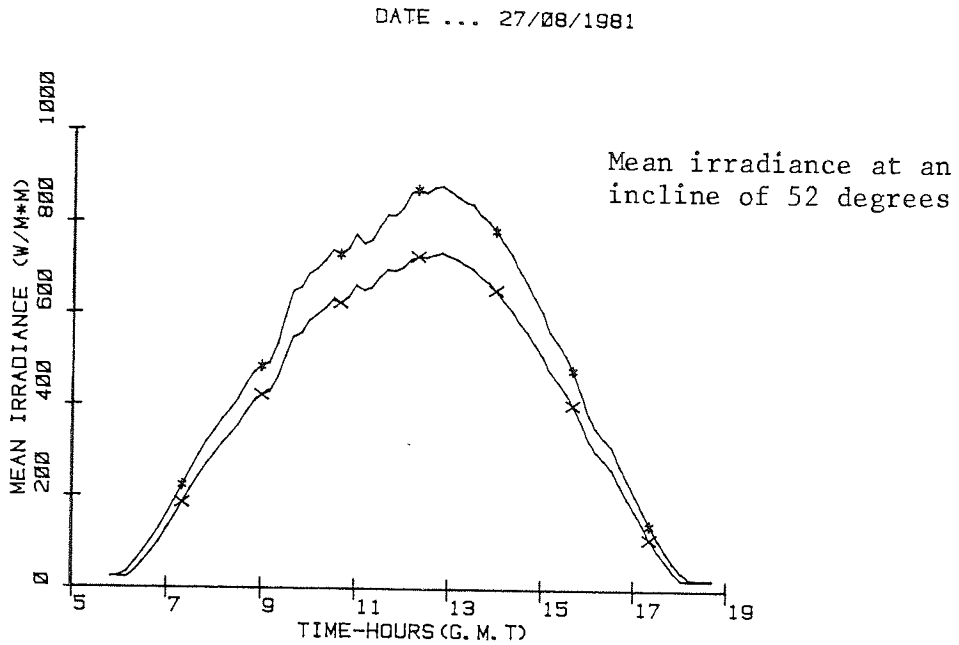


Fig 7.13.a Measured global radiation and values using filter OG 530, for a relatively clear day.

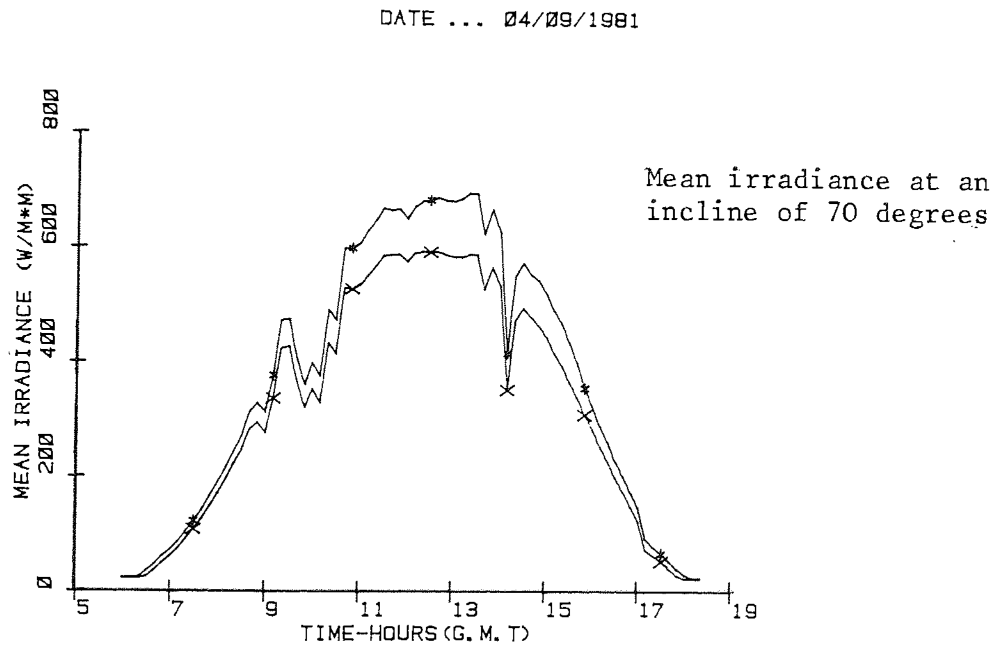


Fig 7.13.6 Measured global radiation and values using filter OG 530, for a relatively clear day.

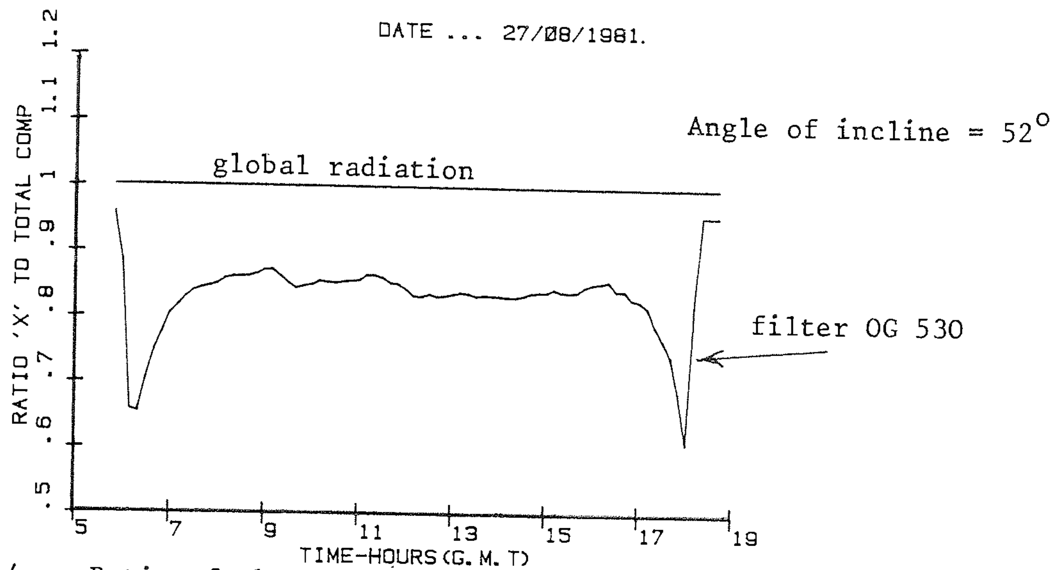


Fig 7.14.a Ratio of the radiation values with filter OG 530 to the mean global irradiance, for a relatively clear day.

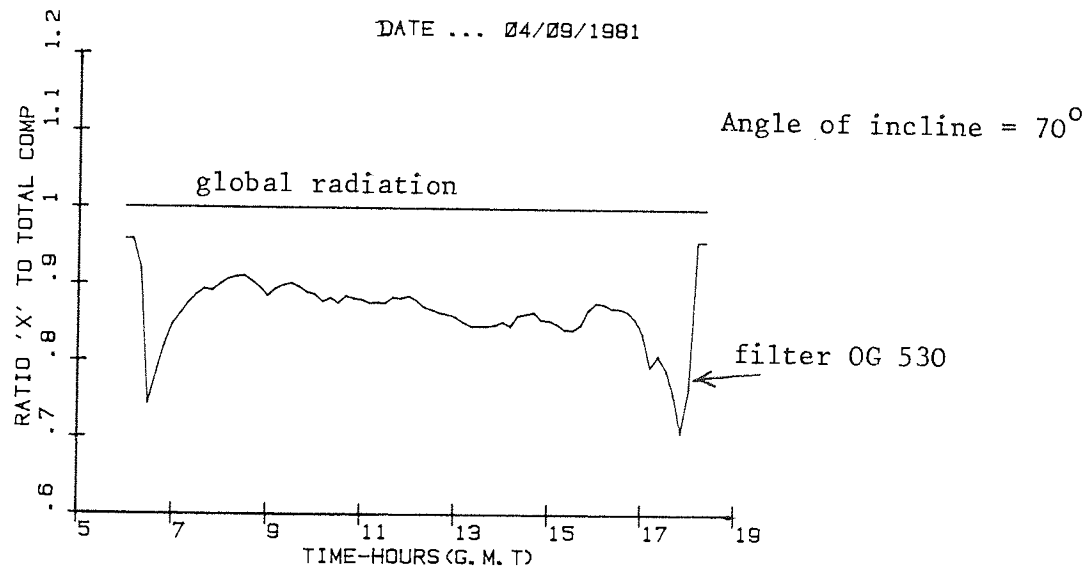


Fig 7.14.b Ratio of the radiation values with filter OG 530 to the mean global irradiance, for a relatively clear day.

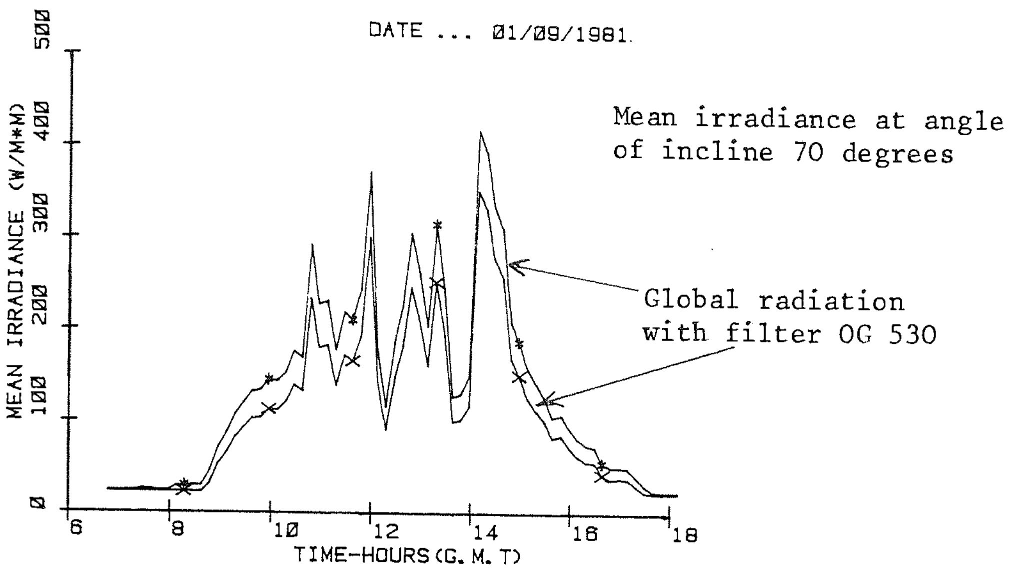


Fig 7.15.a Measured global radiation and values using filter OG 530, for a partially cloudy day.

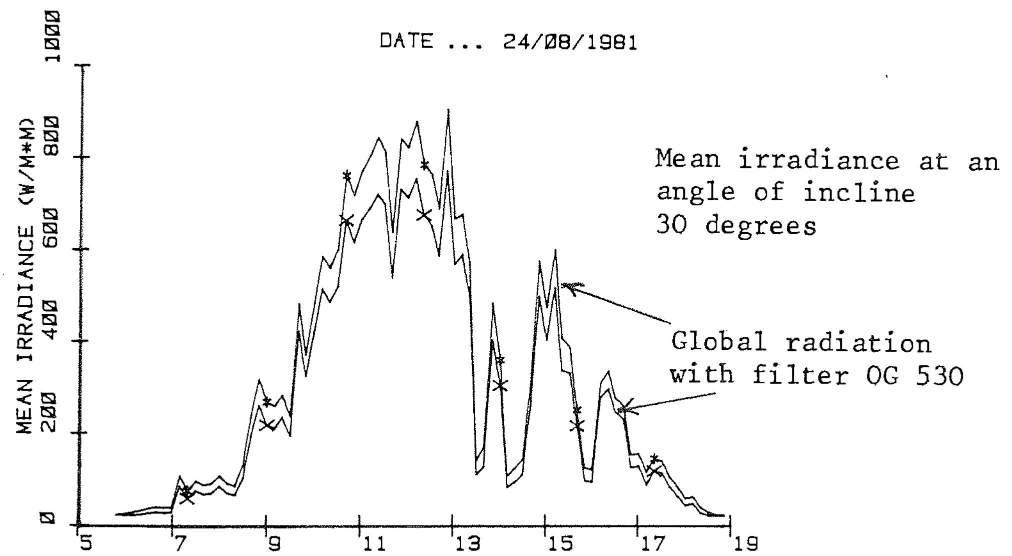


Fig 7.15.b Measured global radiation and values using filter OG 530, for a partially cloudy day.

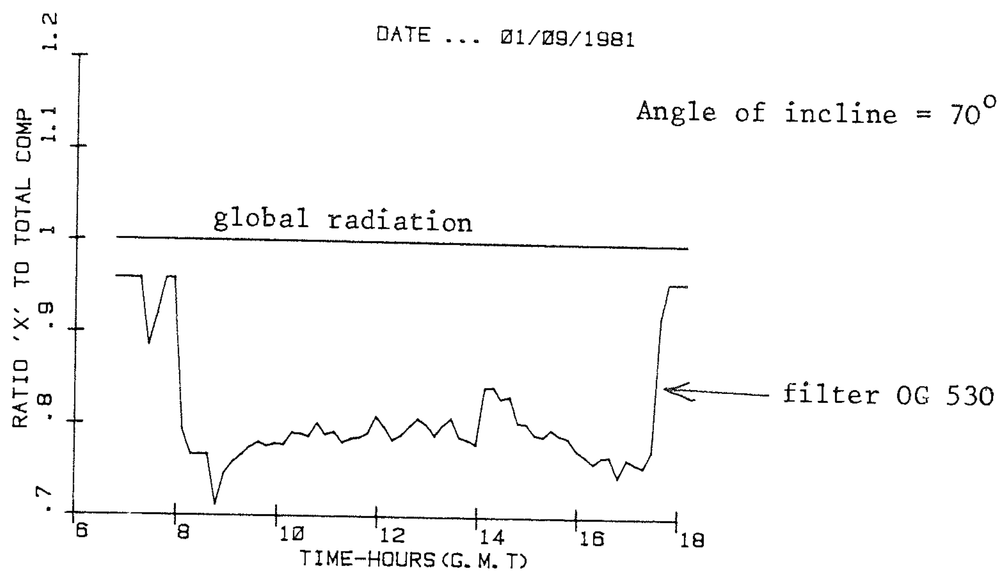


Fig 7.16.a Ratio of the radiation values with filter OG 530 to the mean global irradiance for a partially cloudy day.

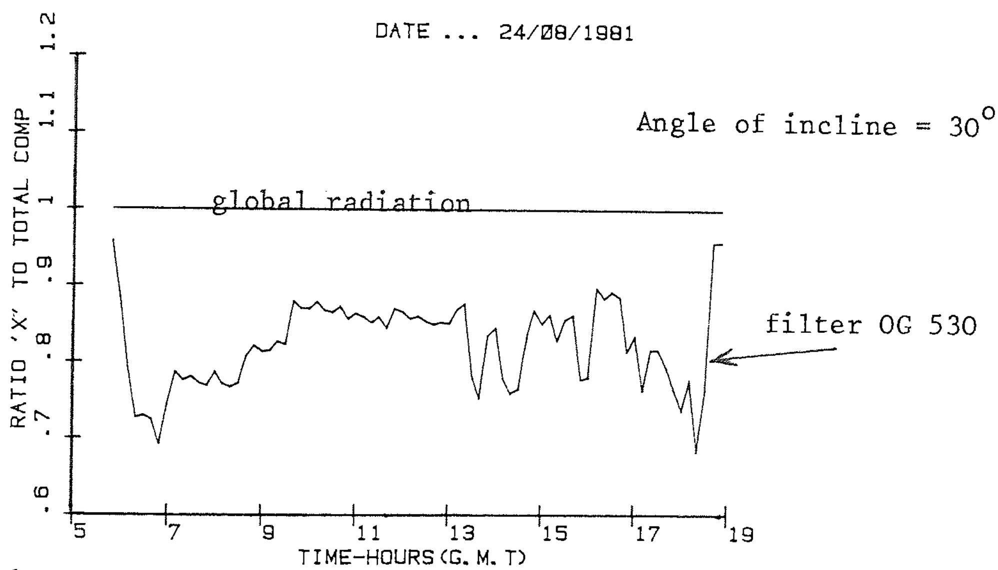


Fig 7.16.b Ratio of the radiation values with filter OG 530 to the mean global irradiance, for a partially cloudy day.

Chapter 8. SUMMARY AND SUGGESTIONS FOR FUTURE WORK

The work reported in this study can be divided into three broad areas.

1) Development and testing of a mathematical model, for predicting the spectral distribution of solar radiation, incident on a horizontal surface. This radiation can be integrated to give total and diffuse radiation on a horizontal surface.

ii) A study of solar radiation measuring instruments and comparison of two commonly used radiometers, the Eppley Precision Pyranometer and the Kipp and Zonen CM5 pyranometer.

iii) Testing of three mathematical models, for predicting inclined plane solar radiation levels from given total and diffuse radiation on a horizontal surface.

For the purposes of testing the mathematical models and instrumentation studies, a solar radiation intensity measuring facility was set up. A suite of programs was developed in the BASIC programming language which handled the functions of solar radiation data logging, recording and processing.

A computer program was written in the FORTRAN programming language for implementing the mathematical model developed in this study which predicts the spectral distribution of solar radiation incident on a horizontal surface in an urban environment.

8.1 Main conclusions

The mathematical model developed in Chapter 3, provides a good agreement between the measured and predicted solar radiation data for a relatively clear day.

A simple empirical relationship has been used for computing the contributions from sky radiation. This seems to provide a reasonable approximation of the real situation. This model can only be applied to relatively clear days because Angstrom turbidity can only be measured for clear sky conditions. Diffuse irradiance only makes up about 15% of the total radiation incident on a horizontal surface during a clear day, so the percentage errors in total radiation due to uncertainties in diffuse irradiance are likely to be small.

When allowance is made for the variation of the atmospheric turbidity and the atmospheric water vapour content during a day, the mathematical model reported in this study provides data which agrees to ±5%, with the measured solar radiation data.

The Eppley PSP pyranometer is classified as Class a I and the Kipp CM5 pyranometer as a Class II instrument by the World Meteorological Organisation. The Eppley PSP's better response results from its circular shape of thermopile, temperature compensation and lower time constant than the Kipp CM5. When the two instruments were calibrated by the U.K. Meteorological Office, to the World Radiometric Reference, the Eppley and the Kipp differed by 2.1% and 2.9%, respectively. The results of this study indicate that when the results for hourly mean irradiance, given by Eppley PSP and Kipp CM5 are compared, they agree to within ±3% for a horizontal surface. The agreement between the Eppley PSP and Kipp CM5 is better than ±0.5% when daily radiation values were compared.

The work on testing of mathematical models for predicting solar irradiance levels on an inclined plane, from given total and diffuse irradiance on a horizontal surface, indicate that the model after Klucher (1979), provides results which agree to within ±5%, with the measured solar radiation in an urban environment. The measured radiation data has an accuracy of 4-5% . The work reported in this study was carried out only for surfaces facing South.

The measured solar radiation data on inclined planes for the spectral distribution of solar radiation indicates that the ratio of data obtained using glass filters to total radiation, does not change with increased angle of incline from 30° to 70°. The mean ratio values with glass filters RG715, RG630 and OG530, were calculated to be 0.54, 0.66 and 0.82, respectively, under relatively clear skies, with an experimental error of 7-8% .

8.2 Suggestions for future work

For any long term solar radiation mathematical modelling work, availability of good quality measured data is very important. This data can either be collected by using a large number of single sensor instruments or using a compound instrument, as reported by Nurkkanen and Hamalainen (1981).

With the availability and setting up of a microcomputer based data recording system, as in this study, any future work on a large and long term solar radiation monitoring programme should not prove to be too difficult. Most of the software necessary has already been developed and tested. This could be incorporated into a larger scale solar radiation monitoring programme.

Two areas of work in assessment of solar resources are

i) the spectral distribution of incident radiation.

ii) the solar radiation intensity falling on non-horizontal surfaces of any orientation.

The work reported in this study has involved using four glass filters, for the measurement of the spectral distribution of solar radiation. There is a need to extend this work either using a larger number of instruments with glass filters or using a combination of instruments covering different spectral ranges, as for example reported by McCartney (1979).

This study has dealt with inclined plane solar radiation data only on surfaces facing South. There is a need for extending this work to other directions. Stewart et al. (1981), have reported that when the results for inclined surfaces facing East and West, were compared to those for South facing surfaces, much larger deviations from the measured data were observed, when Klucher's algorithm was used.

For any solar energy system, values of various meteorological variables are also necessary. Therefore the setting up and integration of a meteorological station with the solar radiation recording facility, in an urban environment, is highly desirable.

For certain solar energy applications the availability of solar radiation data over a large geographical area can be important. At present satellites are used for monitoring the meteorological variables and for weather forecasting. Information relating to the atmospheric transmission of solar radiation can be extracted from satellite photographs. Such work covering large regions of the South American continent has been reported by Albino de Sousa (1976), and Hernendez (1976). Tarpley(1979) and Gautier et al.(1980), have reported work in which information from the GOES satellite has been used for estimating the incident solar radiation intensity at ground level, for the U.S.A. Guiter et al. have reported that agreement between the pyranometer measured and predicted data was better than 9% for daily radiation totals.

With increased interest in solar energy applications in heating and cooling, the idea of a 'Solar Index' has been under discussion in the U.S.A. for some time, The Eppley Laboratory (1981). It is proposed that the 'Solar Index' should form part of the evening weather report. In order that the 'Solar Index' be acceptable to both the television stations and the viewing audience, it should

i) be easily understood by the viewers.

ii) have general application.

iii) be in meaningful physical units.

iv) be comparable at various locations throughout the country.

v) be presented regularly.

With the technology and present resources available, it should be possible to develop techniques which will enable one to develop correlations between satellite pictures and likely solar irradiance levels, for urban environments.

This technique could possibly be further developed in the forecasting of expected irradiance levels, with a lead time of 24 hours, as with the present practices for weather forecasting. Using this approach it will be possible to disseminate solar radiation intensity information, quickly and to a wide audience. The satellite pictures can also complement the archived solar radiation data received from the national network of solar radiation measuring stations.

Discussions between the University of Aston and the Appleton Laboratory have already taken place with a view to the interpretation of satellite pictures and atmospheric water vapour content.

APPENDIX —— A

Listing of wavelength, extraterrestrial radiation and absorption coefficients; for ozone, water vapour and atmospheric gases as used in the solar radiation mathematical model described in chapter 3.

1. WAVELENGTH----- micrometers.
2. EXTT COMP----- is the extraterrestrial radiation, i.e. solar radiation outside the earth's atmosphere, averaged over small waveband centred at wavelenghts, as in column 1,($Wm^{-2}.micron^{-1}$).
3. OZONE CONS--- spectral absorption coefficient at corresponding wavelength.
4. WATER CONS ---- effective absorption coefficient for water vapour (cm^{-1}).
5. GAS CONS --- effective absorption coefficient for uniformly mixed gases(Km^{-1}).

WAVELENGTH	EXTT-COMP	OZONE CONS	WATER CONS	GAS CONS
0.290	482.0	38.000	0.000000	0.000000
0.295	584.0	20.000	0.000000	0.000000
0.300	514.0	10.000	0.000000	0.000000
0.305	603.0	4.800	0.000000	0.000000
0.310	689.0	2.700	0.000000	0.000000
0.315	764.0	1.350	0.000000	0.000000
0.320	830.0	0.800	0.000000	0.000000
0.325	975.0	0.380	0.000000	0.000000
0.330	1059.0	0.160	0.000000	0.000000
0.335	1081.0	0.075	0.000000	0.000000
0.340	1074.0	0.040	0.000000	0.000000
0.345	1069.0	0.019	0.000000	0.000000
0.350	1093.0	0.007	0.000000	0.000000
0.355	1083.0	0.000	0.000000	0.000000
0.360	1068.0	0.000	0.000000	0.000000
0.365	1132.0	0.000	0.000000	0.000000
0.370	1181.0	0.000	0.000000	0.000000
0.375	1157.0	0.000	0.000000	0.000000
0.380	1120.0	0.000	0.000000	0.000000
0.385	1098.0	0.000	0.000000	0.000000
0.390	1098.0	0.000	0.000000	0.000000
0.395	1189.0	0.000	0.000000	0.000000
0.400	1429.0	0.000	0.000000	0.000000
0.405	1644.0	0.000	0.000000	0.000000
0.410	1751.0	0.000	0.000000	0.000000
0.415	1774.0	0.000	0.000000	0.000000
0.420	1747.0	0.000	0.000000	0.000000
0.425	1693.0	0.000	0.000000	0.000000
0.430	1639.0	0.000	0.000000	0.000000
0.435	1663.0	0.000	0.000000	0.000000
0.440	1810.0	0.000	0.000000	0.000000
0.445	1922.0	0.003	0.000000	0.000000
0.450	2006.0	0.003	0.000000	0.000000
0.455	2057.0	0.004	0.000000	0.000000
0.460	2066.0	0.006	0.000000	0.000000
0.465	2048.0	0.008	0.000000	0.000000
0.470	2033.0	0.009	0.000000	0.000000
0.475	2044.0	0.012	0.000000	0.000000
0.480	2074.0	0.014	0.000000	0.000000
0.485	1976.0	0.017	0.000000	0.000000
0.490	1950.0	0.021	0.000000	0.000000
0.495	1960.0	0.025	0.000000	0.000000
0.500	1942.0	0.030	0.000000	0.000000
0.505	1920.0	0.035	0.000000	0.000000
0.510	1882.0	0.040	0.000000	0.000000
0.515	1833.0	0.045	0.000000	0.000000
0.520	1833.0	0.048	0.000000	0.000000
0.525	1852.0	0.057	0.000000	0.000000

WAVELENGTH	EXTT-COMP	OZONE CONS	WATER CONS	GAS CONS
0.530	1842.0	0.063	0.000000	0.000000
0.535	1818.0	0.070	0.000000	0.000000
0.540	1783.0	0.075	0.000000	0.000000
0.545	1754.0	0.080	0.000000	0.000000
0.550	1725.0	0.085	0.000000	0.000000
0.555	1720.0	0.095	0.000000	0.000000
0.560	1695.0	0.103	0.000000	0.000000
0.565	1705.0	0.110	0.000000	0.000000
0.570	1712.0	0.120	0.000000	0.000000
0.575	1719.0	0.122	0.000000	0.000000
0.580	1715.0	0.120	0.000000	0.000000
0.585	1712.0	0.118	0.000000	0.000000
0.590	1700.0	0.115	0.000000	0.000000
0.595	1682.0	0.120	0.000000	0.000000
0.600	1666.0	0.125	0.000000	0.000000
0.605	1647.0	0.130	0.000000	0.000000
0.610	1635.0	0.120	0.000000	0.000000
0.620	1602.0	0.105	0.000000	0.000000
0.630	1570.0	0.090	0.000000	0.000000
0.640	1544.0	0.079	0.000000	0.000000
0.650	1511.0	0.067	0.000000	0.000000
0.660	1486.0	0.057	0.000000	0.000000
0.670	1456.0	0.048	0.000000	0.000000
0.680	1427.0	0.036	0.000000	0.000000
0.690	1402.0	0.028	0.016000	0.000000
0.700	1369.0	0.023	0.024000	0.000000
0.710	1344.0	0.018	0.012500	0.000000
0.720	1314.0	0.014	1.000000	0.000000
0.730	1290.0	0.011	0.870000	0.000000
0.740	1260.0	0.010	0.061000	0.000000
0.750	1235.0	0.009	0.001000	0.000000
0.760	1211.0	0.007	0.000010	3.000000
0.770	1185.0	0.004	0.000010	0.210000
0.780	1159.0	0.000	0.000600	0.000000
0.790	1134.0	0.000	0.017500	0.000000
0.800	1109.0	0.000	0.036000	0.000000
0.810	1085.0	0.000	0.330000	0.000000
0.820	1060.0	0.000	1.530000	0.000000
0.830	1036.0	0.000	0.660000	0.000000
0.840	1013.0	0.000	0.155000	0.000000
0.850	990.0	0.000	0.003000	0.000000
0.860	968.0	0.000	0.000010	0.000000
0.870	947.0	0.000	0.000010	0.000000
0.880	926.0	0.000	0.002600	0.000000
0.890	908.0	0.000	0.063000	0.000000
0.900	891.0	0.000	2.100000	0.000000
0.910	880.0	0.000	1.600000	0.000000
0.920	869.0	0.000	1.250000	0.000000

WAVELENGTH	EXTT-COMP	OZONE CONS	WATER CONS	GAS CONS
0.930	858.0	0.000	27.000000	0.000000
0.940	847.0	0.000	38.000000	0.000000
0.950	837.0	0.000	41.000000	0.000000
0.960	820.0	0.000	26.000000	0.000000
0.970	803.0	0.000	3.100000	0.000000
0.980	785.0	0.000	1.480000	0.000000
0.990	767.0	0.000	0.125000	0.000000
1.000	748.0	0.000	0.002500	0.000000
1.050	668.0	0.000	0.000010	0.000000
1.100	593.0	0.000	3.200000	0.000000
1.150	535.0	0.000	23.000000	0.000000
1.200	485.0	0.000	0.016000	0.000000
1.250	438.0	0.000	0.000180	0.007300
1.300	397.0	0.000	2.900000	0.000400
1.350	358.0	0.000	200.000000	0.000010
1.400	337.0	0.000	1100.000000	0.000010
1.450	312.0	0.000	150.000000	0.064000
1.500	288.0	0.000	15.000000	0.000630
1.550	267.0	0.000	0.001700	0.010000
1.600	245.0	0.000	0.000010	0.064000
1.650	223.0	0.000	0.010000	0.001450
1.700	202.0	0.000	0.510000	0.000010
1.750	180.0	0.000	4.000000	0.000010
1.800	159.0	0.000	130.000000	0.000010
1.850	142.0	0.000	2200.000000	0.000140
1.900	126.0	0.000	1400.000000	0.007100
1.950	114.0	0.000	160.000000	2.000000
2.000	103.0	0.000	2.900000	3.000000
2.100	90.0	0.000	0.220000	0.240000
2.200	79.0	0.000	0.330000	0.000380
2.300	69.0	0.000	0.590000	0.001100
2.400	62.0	0.000	20.299999	0.000170
2.500	55.0	0.000	310.000000	0.000140
2.600	48.0	0.000	15000.000000	0.000660
2.700	43.0	0.000	22000.000000	100.000000
2.800	39.0	0.000	8000.000000	150.000000
2.900	35.0	0.000	650.000000	0.130000
3.000	31.0	0.000	240.000000	0.009500
3.100	26.0	0.000	230.000000	0.001000
3.200	22.6	0.000	100.000000	0.800000
3.300	19.2	0.000	120.000000	1.900000
3.400	16.6	0.000	19.500000	1.300000
3.500	14.6	0.000	3.600000	0.075000
3.600	13.5	0.000	3.100000	0.010000
3.700	12.3	0.000	2.500000	0.001950
3.800	11.1	0.000	1.400000	0.004000
3.900	10.3	0.000	0.170000	0.290000
4.000	9.5	0.000	0.004500	0.025000

APPENDIX —— B

A listing of the computer program, written for implementing the mathematical model described in chapter 3. The program, was initially developed on an ICL 1904 computer at ASTON UNIVERSITY. It was later transferred to a PRIME 500 computer at WOLVERHAMPTON POLYTECHNIC.

```
C          PROGRAM-------  SPECPR
$INSERT SYSCOM>A$KEYS
$INSERT SYSCOM>KEYS.F
C*      PROGRAM FOR CALCULATING THE HOURLY AND
C**     DAILY IRRADIATION COMPONENTS OF DIRECT,
C       DIFFUSE AND GLOBAL RADIATION.
C
C       THE SPECTRAL REGION FROM 0.29 TO 4.0
C*      MICRONS, HAS BEEN DIVIDED IN TO 144
C       INTERVALS.
C
C       STARTING POINT IS THE IRRADIANCE OUTSIDE
C       THE EARTH'S ATMOSPHERE.
C
C***************************************
      REAL LATITU,LONGI
      INTEGER SITE,AFIL1,BFIL1
C
      COMMON / /DAYN(12)
      DIMENSION WL(144),EXTT(144),AC1(144),AC2(144)
      DIMENSION AC3(144),AFIL1(7),BFIL1(7)
      DIMENSION HSPEC1(144),HSPEC2(144),HSPEC3(144)
      DIMENSION DSPEC1(144,24),DSPEC2(144,24),DSPEC3(144,24)
      DIMENSION HTOT1(20),HTOT2(20),HTOT3(20)
C
C
      DIMENSION SELE(24),SAZ(24),STIM(24),IHASH(20)
      DIMENSION RELE(20),RAZ(20),RTIM(20),RMASS(20)
      DIMENSION RMUL(20)
      DIMENSION WCON(12),TURB(12),SITE(8)
C
C
      DATA DAYN/0.0,31.0,59.0,90.0,120.0,151.0,181.0
     1          ,212.0,243.0,273.0,304.0,334.0 /
      DATA IHASH/20*'**'/
C************************
C         WL(X)----WAVELENGTH IN MICRONS.
C         EXTT-----EXTRATERRESTRIAL IRRADIANCE.
C         AC1 -----OZONE ABSORPTION CO-EFF.
C         AC2------WATER VAPOUR ABSORPTION CO-EFF.
C         AC3------GASES ABSORPTION CO-EFF.
C  ***********************************
C         HSPEC(1...2...3)--SPECTRAL DISTRIBUTION.
C         DSPEC(1...2...3)--DAILY IRRADIATION.
C         HTOT(1....2...3)--HOURLY TOTAL IRRADIANCE.
C         1-----DIRECT
C         2-----DIFFUSE
C         3------GLOBAL.
C   ***********************************
C    READ INITIAL CONSTANT VALUES
C    FOR WL,EXTT,AC1,AC2,AC3.
C    ALSO READ IN MONTHLY VALUES
C    FOR WATER VAPOUR CONTENT
C    AND TURBIDITY.
C********************************
      CALL OPEN$A(A$READ+A$SAMF,'CONDAT',6,5)
      CALL OPEN$A(A$READ+A$SAMF,'TUWCON',6,6)
```

```
C
C
      WRITE(1,400)
 400  FORMAT('+',2X,'SITE INFORMATION FILE/NAME....')
      READ(1,410) AFIL1
 410  FORMAT(7A2)
      IFILN1=NLEN$A(AFIL1,14)
      CALL OPEN$A(A$READ+A$SAMF,AFIL1,IFILN1,3)
C
      WRITE(1,420)
 420  FORMAT('+',2X,'ENTER DATA OUTPUT FILE/NAME.....')
      READ(1,410) BFIL1
      IBFIL1=NLEN$A(BFIL1,14)
      CALL OPEN$A(A$WRIT+A$SAMF,BFIL1,IBFIL1,8)
      DO 1150 J=1,144
      READ(9,1100) WL(J),EXTT(J),AC1(J),AC2(J),AC3(J)
 1100 FORMAT(1X,5(F12.6))
 1150 CONTINUE
C    **************
      READ(10,1160) (WCON(I),I=1,12)
 1160 FORMAT(12(F3.1))
      READ(10,1170) (TURB(J),J=1,12)
 1170 FORMAT(12(F4.3))
C   ********************
      READ(7,1200,END=5700) YEAR,MONTH,DATE,LATITU,LONGI,
     +      HEIGHT,SITE

 1200 FORMAT(F6.1,I2,F4.1,F6.3,F6.2,F5.0,8(A2))
      ICOUNT=1
C   *************
C   PRINT DATE AND LOCATION
C   INFORMATION.
C
      WRITE(12,1250)IHASH,IHASH
1250  FORMAT(1H1,15X,20A2,/,16X,'*',38X,'*',/,16X,
     1  '*',7X,'--POSITION OF THE SUN--',8X,'*',/,16X,'*',
     2     38X,'*',/,16X,20A2)
      WRITE(12,1300) SITE,HEIGHT,LATITU,LONGI
 1300  FORMAT(1H ,///,9X,'SITE--',8(A2),2X,'HEIGHT = ',F5.0,
     1  2X,'METRES A.S.L.',//,10X,'LATITUDE = ',F6.3,3X,'DEG'
     2     ,3X,'LONGITUDE = ',F6.3,2X,'DEG')
      WRITE(12,1350) YEAR,MONTH,DATE
 1350 FORMAT(1H ,/,9X,'YEAR = ',F6.0,2X,'MONTH = ',I2,2X
     1         ,'DATE = ',F4.0,//)
C*******
C
      IF(ICOUNT.EQ.1) GO TO 1480
 1400 READ(7,1450,END=5700) YEAR,MONTH,DATE
 1450 FORMAT(F6.1,I2,F4.1)
      IF(MONTH.GT.12) GO TO 5700
      WRITE(12,1350) YEAR,MONTH,DATE
C      TEST FOR END OF DATA.
C
C      CORRECTIONS FOR SITE HEIGHT ABOVE
C      SEA LEVEL.
C      CORRECTION FACTOR FOR SUN-EARTH DISTANCE
C
C      SVAT--ELEVATION OF SUN AT SUNRISE AND SUNSET
```

```
C
C***********************************
 1480 H=HEIGHT*3.281
      SVAT=(-0.833-0.0214*SQRT(H))
      BND1=1.0/(0.9555*(20.67*ANC1))-0.047121
      BNC=ANC1+0.0083*BND1
      SVAT=ACOSX(BNC)
      DAY=DAYN(MONTH)+DATE
      LEAPY=IFIX(YEAR/4.0)
      IF(LEAPY*4.NE.YEAR) GO TO 1500
      IF(MONTH.LT.3) GO TO 1500
      DAY=DAY+1
 1500 SOLCON=1370.0
C*********
C    SOLCON---SOLAR CONSTANT
C
      CALL DISTAN(SOLCON,DAY,CORR)
      WRITE(12,1550) CORR
 1550 FORMAT(1H ,15X,'CORRECTION FOR SUN-EARTH  '
     1           ,'DISTANCE','= ',F7.4,/)
C
      W=WCON(MONTH)          /*WATER CONTENT
      W1=W*10.0              /* W1----IN MILIMETERS
      BETA=TURB(MONTH)         /* BETA---TURBIDITY
      WRITE(12,1570) W1
 1570 FORMAT(1H ,15X,'ATMOSPHERIC WATER VAPOUR  '
     1          ,'CONTENT ','=',F4.1,'MM')
      WRITE(12,1580) BETA
 1580 FORMAT(1H ,15X,'ATMOSPHERIC TURBIDITY =',F6.3,///)
C*************************************
C     CALCULATE ELEVATION OF SUN AND
C     AZIMUTH FOR A GIVEN TIME.
C*************
      WRITE(12,1600)
 1600 FORMAT(1H ,9X,'TIME ',5X,'ELEVATION OF',5X,
     1       'AZIMUTH')
      WRITE(12,1650)
 1650 FORMAT(1H ,9X,'(HOURS)',3X,'SUN (DEGREES)',5X,
     1          '(DEGREES)',/)
      I=1
      HOUR=1.0
 1700 CALL SOLAR(YEAR,MONTH,DATE,HOUR,LATITU,LONGI,A,E)
      WRITE(12,1750) HOUR,E,A
 1750 FORMAT(1H ,9X,F5.1,7X,F8.2,5X,F10.2)
      STIM(I)=HOUR
      SELE(I)=E
      SAZ(I)=A
      HOUR=HOUR+1.0
      I=I+1
      IF(HOUR.LT.25.0) GO TO 1700
C
C*******************************************
C    SUNRISE AND SUNSET TIMES EVALUATED.
C
C    STORE--AIR-MASS
C           ELEVATION
C           AZIMUTH
C       AND HOURLY MULT. FACTOR
```

```
C******************************
C
      J=1
 2100 IF(SELE(J).GT.SVAT) GO TO 2150
      J=J+1
      GO TO 2100
 2150 FACTOR=SELE(J)-SELE(J-1)
      SUNRIS=STIM(J)-(SELE(J)-SVAT)/FACTOR
      WRITE(12,2200)
 2200 FORMAT(1H1,/)
      WRITE(12,2250) SUNRIS
 2250 FORMAT(1H ,9X,'TIME OF SUNRISE = ',F6.3,
     1            2X,'HOURS')
      COUNT=STIM(J)-SUNRIS
      IF(COUNT.LT.0.5) GO TO 2300
      K=1
      RMUL(K)=COUNT-0.5
      RTIM(K)=(SUNRIS+STIM(J)-0.5)*0.5
      HOUR=RTIM(K)
      CALL SOLAR(YEAR,MONTH,DATE,HOUR,LATITU,LONGI,A,E)
      RELE(K)=E
      RAZ(K)=A
      K=K+1
      RMUL(K)=1.0
      RTIM(K)=STIM(J)
      RELE(K)=SELE(J)
      RAZ(K)=SAZ(J)
      GO TO 2350
C******
C      TOATL HOURLY VALUES CALCULATED.
C      DURING THE HOURS OF SUNRISE AND
C      SUNSET WHEN THE HOURLY TIME MAY
C      NOT BE UNITY,MULTIPLY BY APPROPRIATE
C      TIME INTERVAL.
C **************************
 2300 K=1
      RMUL(K)=STIM(J)+0.5-SUNRIS
      RTIM(K)=(SUNRIS+STIM(J)+0.5)*0.5
      HOUR=RTIM(K)
      CALL SOLAR(YEAR,MONTH,DATE,HOUR,LATITU,LONGI,A,E)
      RELE(K)=E
      RAZ(K)=A
 2350 K=K+1
      J=J+1
 2400 IF(SELE(J).LT.SVAT) GO TO 2450
      RMUL(K)=1.0
      RELE(K)=SELE(J)
      RAZ(K)=SAZ(J)
      RTIM(K)=STIM(J)
      K=K+1
      J=J+1
      GO TO 2400
C*********************
 2450 FACTOR=SELE(J-1)-SELE(J)
      SUNSET=STIM(J-1)+(SELE(J-1)-SVAT)/FACTOR
      DHOUR=SUNSET-SUNRIS
      WRITE(12,2500) DHOUR
 2500 FORMAT(1H ,24X,'NO OF DAY-HOURS = ',F6.3)
```

```
      WRITE(12,2550) SUNSET
 2550 FORMAT(1H ,9X,'TIME OF SUNSET = ',
     1   2X,F7.3,2X,'HOURS',//)
      COUNT=SUNSET-STIM(J-1)
      IF(COUNT.LT.0.5) GO TO 2600
      RMUL(K)=SUNSET-STIM(J-1)-0.5
      RTIM(K)=(SUNSET+STIM(J-1)+0.5)*0.5
      HOUR=RTIM(K)
      CALL SOLAR(YEAR,MONTH,DATE,HOUR,LATITU,LONGI,A,E)
      RELE(K)=E
      RAZ(K)=A
      GO TO 2650
 2600 K=K-1
      RMUL(K)=SUNSET-STIM(J-1)+0.5
      RTIM(K)=(SUNSET+STIM(J-1)-0.5)*0.5
      HOUR=RTIM(K)
      CALL SOLAR(YEAR,MONTH,DATE,HOUR,LATITU,LONGI,A,E)
      RELE(K)=E
      RAZ(K)=A
 2650 KIM=K
      WRITE(12,2700) KIM
 2700 FORMAT(1H ,24X,'NO OF HOUR-UNITS = ',2X,I2,//)
C
C***************************************
C
      WRITE(12,2750)
 2750 FORMAT(1H ,9X,'TIME-HOURS',4X,'ELEVATION',
     1     2X,'AZIMUTH',2X,
     2          'AIRMASS',2X,'MUL-FACTOR',/)
      DO 2900 L=1,KIM
      ELE=RELE(L)
      CALL AMASS(ELE,H,AM)
      RMASS(L)=AM
      WRITE(12,2850)RTIM(L),ELE,RAZ(L),RMASS(L),RMUL(L)
 2850 FORMAT(1H ,11X,F6.1,5X,F6.1,2X,F10.1,2X,F6.2,4X,
     1          F6.2)
 2900 CONTINUE
C
C***********************************
      DTOT1=0.0
      DTOT2=0.0
      DTOT3=0.0
      DO 4100 K=1,144
C     DSPEC1(K)=0.0
C     DSPEC2(K)=0.0
C     DSPEC3(K)=0.0
 4100 CONTINUE
C*****
C         HOURLY REGISTERS ARE SET TO ZERO.
C
      DO 4500 L=1,KIM
      DO 4150 N=1,144
      HSPEC1(N)=0.0
      HSPEC2(N)=0.0
      HSPEC3(N)=0.0
      DSPEC1(N,L)=0.0
      DSPEC2(N,L)=0.0
      DSPEC3(N,L)=0.0
```

```
 4150 CONTINUE
      TOT1=0.0
      TOT2=0.0
      TOT3=0.0
      HTOT1(L)=0.0
      HTOT2(L)=0.0
      HTOT3(L)=0.0
      OZ=0.35
      ALPHA=1.3
      Z3=1000.0
      HZ=HEIGHT
      PREP=EXP((HZ/Z3)*(-0.1174-0.0017*(HZ/Z3)))
      XW=0.795*W
C
C**********************
C        P---ACTUAL PRESSURE
C        P1--STANDARD AIR PRESSURE AT SEA-LEVEL.
C        OZ--AMOUNT OF OZONE (CMS).
C        ALPHA--WAVELENGTH EXTINCTION CO-EFFICIENT.
C        BETA---TURBIDITY CO-EFFICIENT.
C        W---WATER VAPOUR CONTENT IN A VERTICAL
C            COLUMN.
C       TC1,TC2,TC3,TC4 ANT TC5 ARE TRANSMITTANCE
C       CO-OFFICIENTS DUE TO RAYLEIGH SCATTERING,
C       OZONE ABSORPTION,AEROSOL EXTINCTION,WATER
C       VAPOUR ABSORPTION AND ABSORPTION DUE
C       TO GASES,RESPECTIVELY.
C************************
C
      AR=RMASS(L)
      DO 4200 J=1,144
      AL=WL(J)
      TC1=EXP(-0.008735*PREP*AR*(AL**(-4.08)))
      TC2=EXP(-AC1(J)*AR*OZ)
      TC3=EXP(-AR*BETA*(AL**(-ALPHA)))
      TC4=EXP((-0.3*XW*AR*AC2(J))/
     1   ((1+25.25*AC2(J)*AR*XW)**(0.45)))
      TC5=EXP((-1.41*AC3(J)*AR)/
     1      ((1.0+118.3*AC3(J)*AR)**(0.45)))
C
C     COMPUTE THE DIRECT COMPONENT OF
C     IRRADIANCE.
C************
      ATT=EXTT(J)*10.0*CORR
      TR=ATT*TC1*TC2*TC3*TC4*TC5
      HSPEC1(J)=TR*(1/AR)
      GK=0.5
      TD=ATT*TC2*TC4*TC5
      HSPEC2(J)=GK*(TD-TR)*(1/AR)
      HSPEC3(J)=HSPEC1(J)+HSPEC2(J)
C*******
      DSPEC1(J,L)=HSPEC1(J)
      DSPEC2(J,L)=HSPEC2(J)
      DSPEC3(J,L)=HSPEC3(J)
 4200 CONTINUE
C*********************
C       HOURLY TOTAL VALUES ARE CALCULATED
C       BY INTEGRATING THE AREA UNDER THE
```

```
C       SPECTRAL CURVE.THIS IS CARRIED OUT
C       USING TRAPEZIUM RULE.
C
C****
      DO 4450 M=1,144
      IF(M.GT.1) GO TO 4300
      HOR=(WL(M+1)+WL(M))*0.5-WL(M)
      GO TO 4400
 4300 IF(M.LT.144) GO TO 4350
      HOR=(WL(M)+WL(M-1))*0.5-WL(M)
      GO TO 4400
 4350 HOR=(WL(M+1)+WL(M))*0.5-(WL(M)+WL(M-1))*0.5
 4400 TOT1=TOT1+HSPEC1(M)*HOR
      TOT2=TOT2+HSPEC2(M)*HOR
      TOT3=TOT3+HSPEC3(M)*HOR
 4450 CONTINUE
      TOT1=TOT1*RMUL(L)
      TOT2=TOT2*RMUL(L)
      TOT3=TOT3*RMUL(L)
C*******
C       DAILY TOTALS CALCULATED FROM HOURLY
C       TOTALS.
C       RMUL----HOURLY MULTIPLICATION FACTOR
C               HAS BEEN USED.
C***
      DTOT1=DTOT1+TOT1
      DTOT2=DTOT2+TOT2
      DTOT3=DTOT3+TOT3
      HTOT1(L)=TOT1
      HTOT2(L)=TOT2
      HTOT3(L)=TOT3
 4500 CONTINUE
C
      DTOT1=DTOT1*3.6
      DTOT2=DTOT2*3.6
      DTOT3=DTOT3*3.6
C*******************************************************
C     PRINT DAILY VALUES OF DIRECT,DIFFUSE AND
C     TOTAL IRRADIATION.
      WRITE(12,5050)
 5050 FORMAT(1H ,///,19X,'DAILY RADIATION TOTALS....',//)
      WRITE(12,5100) DTOT1
 5100 FORMAT(1H ,15X,' DIRECT'
     1     ,' RADIATION = ',F10.0
     2    ,2X,'KW*(M**-2)',/)
      WRITE(12,5150) DTOT2
 5150 FORMAT(1H ,15X,'DIFFUSE ',
     1    'RADIATION = ',F10.0,
     2   2X,'KW*(M**-2)',/)
      WRITE(12,5200) DTOT3
 5200 FORMAT(1H ,15X,'GLOBAL  ',
     1         'RADIATION = ',F10.0,
     12X,'KW*(M**-2)',///)
C********
C    PRINT HOURLY VALUES FOR DIRECT,DIFFUSE
C    AND TOTAL IRRADIATION.
      WRITE(12,5250)
 5250 FORMAT(1H ,11X,'TIME-HOURS ',2X,'DIRECT COMP',6X,
```

```
     1'DIFF-COMP',6X,'TOTAL RAD')
      DO 5400 M=1,KIM
      WRITE(12,5300) RTIM(M),HTOT1(M),HTOT2(M),HTOT3(M)
 5300 FORMAT(1H ,13X,F7.2,5X,F8.1,7X,F8.1,7X,F8.1)
 5400 CONTINUE
C
C***************
C       THE MEAN DAILY VALUES OF SPECTRAL DISTRIBUTION
C       OF SOLAR RADIATION ARE PRINTED.
C********
      WRITE(12,5445)
 5445 FORMAT(1H1,15X,'MEAN SPECTRAL DISTRIBUTION',//)
      WRITE(12,5450)
 5450 FORMAT(1H ,//,9X,'WAVE LENGTH',6X,'DIRECT COMP',3X,
     1  'DIFFUSE COMP',3X,'GLOBAL RAD',/)
      AKIM=KIM
      DO 5600 K=1,KIM
      WRITE(12,5499) K
 5499  FORMAT(1H ,///,'HOUR NUMBER = ',I2,//)
      DO 5600 N=1,144
C     SEC1=DSPEC1(N)/AKIM
C     SEC2=DSPEC2(N)/AKIM
C     SEC3=DSPEC3(N)/AKIM
C     WRITE(12,5500) WL(N),SEC1,SEC2,SEC3
      WRITE(12,5500) WL(N),DSPEC1(N,K),DSPEC2(N,K),DSPEC3(N,K)
 5500 FORMAT(1H ,11X,F8.4,6X,F7.1,7X,F7.1,8X,F7.1)
 5600 CONTINUE
C
 5700 CALL CLOS$A(5)
      CALL CLOS$A(6)
      CALL CLOS$A(3)
      CALL CLOS$A(8)
      CALL EXIT
      END
```

```
C*****************************************
      SUBROUTINE DISTAN(SOLCON,DAY,CORR)
C
C**********
C         AS THE DISTANCE BETWEEN THE EARTH AND
C        THE SUN VARIES THROUGHOUT THE YEAR,
C         IT MEANS VARYING VALUE OF IRRADIATION
C         REACHING OUTSIDE THE EARTH'S ATMOSPHERE.
C         THE IRRADIANCE VALUES TABULATED IN LITERATURE
C         ARE FOR MEAN SUN-EARTH DISTANCE.
C      INPUTS-------
C         SOLCON--THE VALUE OF SOLAR CONSTANT AT MEAN
C         SUN-EARTH DISTANCE.
C         DAY----THE DAY OF THE YEAR,I.E. 15 FOR 15TH
C                 JAN OR 51 FOR 20TH FEB.
C       AS THE DISTANCE BETWEEN THE SUN AND EARTH
C       VARIES THROUGHOUT THE YEAR,SO THE
C       RADIATION REACHING OUTSIDE THE EARTH'S
C       ATMOSPHERE VARIES.
C       A CORRECTION FACTOR HAS TO BE APPLIED
C       TO THE SOLAR CONSTANT VALUE TO ALLOW
C       FOR ABOVE.
C
C      INPUT-----
C           SOLCON-SOLAR CONSTANT.
C           DAY--DAY OF THE YEAR I.E. 15
C                FOR 15TH JAN AND 51 FOR 15TH FEB.
C      OUTPUT-------
C         CORR-CORRECTION FACTOR.
C**************
      DIMENSION A(3),B(3)
      DATA TWOPI/6.283185/
      DATA A/45.326,0.88018,-0.00461/
      DATA B/1.8037,0.09746,0.18412/
      W=TWOPI/360.0
      J=DAY
      CS=SIN(3*W*J)
      SCS=COS(3*W*J)
      D1=(A(1)*COS(W*J)+A(2)*COS(2*W*J)+A(3)*SCS)
      D2=(B(1)*SIN(W*J)+B(2)*SIN(2*W*J)+B(3)*CS)
      CORR=1.0+(D1+D2)/SOLCON
      RETURN
      END
```

```
C*********************************************
      SUBROUTINE AMASS(ELE,H,AM)
C      THIS SUBROUTINE CALCULATES THE AIR-MASS
C      FOR A GIVEN ELEVATION OF THE SUN.
C
C      WHEN THE ELEVATION OF THE SUN IS LESS
C      THAN 10 DEGREES, THE PROCEDURE USED
C      HAS BEEN AFTER J.K.PAGE.
C
C      AIR-MASS VALUES ARE ALSO ADJUSTED
C      FOR HEIGHT ABOVE SEA-LEVEL.
C*********
C    -INPUTS----
C        ELE---ELEVATION OF THE SUN IN DEGREES.
C        H--- SITE HEIGHT ABOVE SEA LEVEL IN FEET.
C    -OUTPUT---
C        AM----AIRMASS.
C
C**********
      DIMENSION A(7)
      DATA A/3.67985,-24.4465,154.017,-742.181,
     1    2263.36,-3804.89,2261.05/
      DATA RAD/0.0174533/
      CAR=EXP((H/1000.0)*(-0.1174-0.0017*(H/1000.0)))
      IF(ELE.LT.10.0) GO TO 7410
      ANG=ELE*RAD
      AM=1/SIN(ANG)
      GO TO 7430
 7410 ANG=ELE*RAD
      S=SIN(ANG)
      POL=0.0
      DO 7420 J=2,7
      K=J-1
      PIL=(A(J)*S**K)
      POL=POL+PIL
 7420 CONTINUE
      PAL=A(1)+POL
      AM=EXP(PAL)
 7430 AM=AM*CAR
      RETURN
      END
```

```
      SUBROUTINE SOLAR(YEAR,MTH,DATE,HOUR,LAT,LONG,A,E)
C
C*****************************************************
C       THIS SUBROUTINE CALCULATES THE LOCAL
C       AZIMUTH AND ANGLE OF ELEVATION OF THE
C       SUN. ALGORITHM IS AS GIVEN BY
C       WALRAVEN(1978) AND LATER MODIFIED BY
C       WILKINSON(1981).
C***************
C    -INPUT PARAMETERS----
C       -THE YEAR E.G. 1985.
C       -MONTH---OF THE YEAR---
C       -DATE-OF THE MONTH---
C       -HOUR-THE TIME OF THE DAY---
C       LAT-LOCAL LATITUDE(NORTH IS +VE)
C       LONG--LOCAL LONGITUDE IN DEGREES WEST OF
C             GREENWICH.
C    -OUTPUTS-----
C     A---AZIMUTHAL ANGLE(+VE IS EAST OF SOUTH).
C     E---SUN ELEVATION( DEGREES).
C
C***********
      REAL LAT,LONG
      COMMON / /DAYN(12)
      DATA TWOPI,RAD/6.283186,0.0174533/
      DELYR=YEAR-1980.0
      LEAP=IFIX(DELYR/4.0)
      T=HOUR
      DAY=DAYN(MTH)+DATE
      IF(DELYR.NE.LEAP*4.0) GO TO 7505
      IF(MTH.GT.3) GO TO 7505
      DAY=DAY-1.0
 7505 TIME=DELYR*365.0+LEAP+DAY-1.0+T/24.0
      IF(DELYR.EQ.LEAP*4.0) GO TO 7510
      IF(DELYR.GT.0.0) GO TO 7520
      IF(DELYR.EQ.LEAP*4.0) GO TO 7520
 7510 TIME=TIME-1.0
 7520 THETA=(360.0*TIME/365.25)*RAD
      G=-0.031271-4.53963E-7*TIME+THETA
      A9=(0.033434-2.3E-9*TIME)
      EL=4.900968+3.67474E-7*TIME+A9
     1*SIN(G)+0.000349*SIN(2*G)+THETA
      EPS=0.409140-6.2149E-9*TIME
      SEL=SIN(EL)
      A1=SEL*COS(EPS)
      A2=COS(EL)
      RA=ATAN2(A1,A2)
      IF(RA.GT.0.0) GO TO 7530
      RA=RA+TWOPI
 7530 DECL=ASINX(SEL*SIN(EPS))
      A9=(TIME/365.25-DELYR)
      ST=1.759335+TWOPI*A9+3.694E-7*TIME
      IF(ST.LT.TWOPI) GO TO 7540
      ST=ST-TWOPI
 7540 S=ST-LONG*RAD+T*15.0*RAD
      IF(S.LT.TWOPI) GO TO 7550
      S=S-TWOPI
 7550 H=RA-S
```

```
      PHI=LAT*RAD
      A9=COS(PHI)*COS(DECL)*COS(H)
      E=ASINX(SIN(PHI)*SIN(DECL)+A9)
      A=ASINX(COS(DECL)*SIN(H)/COS(E))/RAD
      PIT=SIN(DECL)/SIN(PHI)
      IF(SIN(E).GE.PIT) GO TO 7570
      IF(A.LT.0.0) GO TO 7560
      A=180.0-A
      GO TO 7570
 7560 A=A+360.0
      A=180.0-A
 7570 E=E/RAD
      RETURN
      END
```

APPENDIX ---- C

A typical output from the computer program **SPECPR**, written in the FORTRAN programming language.

```
****************************************
*                                      *
*       --POSITION OF THE SUN--        *
*                                      *
****************************************
```

SITE--BIRMINGHAM HEIGHT = 100. metres a.s.l.

LATITUDE = 52.500° LONGITUDE = 1.916°

YEAR = 1981. MONTH = 9 DATE = 15.

CORRECTION FOR SUN-EARTH DISTANCE= 0.9914

ATMOSPHERIC WATER VAPOUR CONTENT = 15.0 mm.

ATMOSPHERIC TURBIDITY = 0.184

TIME (HOURS)	ELEVATION OF SUN (DEGREES)	AZIMUTH (DEGREES)
1.0	-33.09	162.95
2.0	-29.16	146.04
3.0	-23.12	130.75
4.0	-15.55	117.03
5.0	-7.04	104.44
6.0	1.97	92.44
7.0	11.05	80.44
8.0	19.81	67.81
9.0	27.77	53.91
10.0	34.33	38.16
11.0	38.78	20.31
12.0	40.45	0.94
13.0	39.03	-18.50
14.0	34.80	-36.51
15.0	28.38	-52.44
16.0	20.51	-66.47
17.0	11.79	-79.17
18.0	2.69	-91.19
19.0	-6.37	-103.14
20.0	-14.99	-115.63
21.0	-22.70	-129.23
22.0	-28.97	-144.37
23.0	-33.16	-161.19
24.0	-34.74	-179.18

TIME OF SUNRISE = 5.646 HOURS

NO OF DAY-HOURS = 12.785

TIME OF SUNSET = 18.432 HOURS

NO OF HOUR-UNITS = 13

TIME-HOURS	ELEVATION	AZIMUTH	AIRMASS	MUL-FACTOR
6.1	2.6	91.6	16.13	0.85
7.0	11.1	80.4	5.02	1.00
8.0	19.8	67.8	2.84	1.00
9.0	27.8	53.9	2.06	1.00
10.0	34.3	38.2	1.71	1.00
11.0	38.8	20.3	1.54	1.00
12.0	40.4	0.9	1.48	1.00
13.0	39.0	-18.5	1.53	1.00
14.0	34.8	-36.5	1.69	1.00
15.0	28.4	-52.4	2.02	1.00
16.0	20.5	-66.5	2.75	1.00
17.0	11.8	-79.2	4.71	1.00
18.0	3.0	-90.8	14.77	0.93

DAILY RADIATION TOTALS....

DIRECT RADIATION = 10283. KWm^{-2}.
DIFFUSE RADIATION = 5475. KWm^{-2}.
GLOBAL RADIATION = 15759. KWm^{-2}.

HOURLY MEAN RADIATION(Wm^{-2}).

TIME-HOURS	DIRECT COMP	DIFF-COMP	TOTAL RAD
6.07	1.7	22.4	24.1
7.00	44.8	79.7	124.5
8.00	143.1	117.8	260.9
9.00	252.0	139.9	391.9
10.00	345.4	152.9	498.4
11.00	408.0	159.9	567.9
12.00	431.0	162.2	593.2
13.00	411.6	160.3	571.8
14.00	352.1	153.7	505.9
15.00	260.7	141.3	402.0
16.00	152.2	120.1	272.3
17.00	51.5	83.7	135.2
17.97	2.4	26.9	29.3

MEAN DAILY SPECTRAL DISTRIBUTION($Wm^{-2}.micron^{-1}$).

WAVELENGTH	DIRECT COMP	DIFFUSE COMP	GLOBAL RAD
0.290	0.0	0.0	0.0
0.295	0.0	0.0	0.0
0.300	0.0	0.3	0.3
0.305	0.5	5.8	6.3
0.310	2.2	22.8	24.9
0.315	5.9	58.3	64.2
0.320	9.9	90.5	100.4
0.325	16.7	141.5	158.3
0.330	23.0	180.1	203.1
0.335	27.4	195.4	222.8
0.340	30.6	198.4	229.1
0.345	33.9	199.5	233.4
0.350	38.0	204.5	242.6
0.355	41.0	202.3	243.3
0.360	43.7	197.9	241.6
0.365	49.8	208.0	257.8
0.370	55.7	215.1	270.8
0.375	58.2	208.9	267.1
0.380	59.9	200.5	260.4
0.385	62.3	194.7	257.0
0.390	65.9	193.0	258.8
0.395	75.2	207.0	282.2
0.400	95.0	246.5	341.5
0.405	114.7	280.9	395.6
0.410	127.8	296.3	424.1
0.415	135.2	297.3	432.6
0.420	138.8	290.0	428.8
0.425	140.0	278.3	418.3
0.430	140.7	266.8	407.6
0.435	148.1	268.1	416.2
0.440	166.9	288.9	455.8
0.445	182.8	303.0	485.8
0.450	197.0	313.2	510.2
0.455	208.2	317.7	525.9
0.460	215.1	315.4	530.4
0.465	219.0	309.0	528.0
0.470	223.2	303.5	526.7
0.475	230.0	301.3	531.3
0.480	239.0	302.2	541.2
0.485	232.8	284.4	517.2
0.490	234.6	276.9	511.5
0.495	240.5	274.6	515.2
0.500	242.8	268.3	511.1
0.505	244.3	261.5	505.8
0.510	243.6	252.7	496.3
0.515	241.2	242.7	483.9
0.520	245.3	239.7	485.1
0.525	251.0	238.0	489.0

MEAN DAILY SPECTRAL DISTRTIBUTION($Wm^{-2}.micron^{-1}$).

WAVELENGTH	DIRECT COMP	DIFFUSE COMP	GLOBAL RAD
0.530	253.1	233.2	486.3
0.535	253.0	226.6	479.6
0.540	251.5	219.2	470.6
0.545	250.6	212.6	463.2
0.550	249.5	206.3	455.7
0.555	250.9	202.0	452.9
0.560	249.6	195.8	445.4
0.565	253.6	194.0	447.5
0.570	256.5	191.3	447.8
0.575	260.7	190.0	450.7
0.580	263.8	188.2	452.0
0.585	267.0	186.5	453.5
0.590	268.9	184.1	453.0
0.595	268.4	179.7	448.1
0.600	268.1	175.7	443.8
0.605	267.2	171.4	438.6
0.610	269.9	170.2	440.1
0.620	272.7	166.2	438.9
0.630	275.4	162.4	437.8
0.640	278.1	158.7	436.7
0.650	279.3	154.5	433.8
0.660	281.4	151.0	432.3
0.670	282.0	146.9	428.9
0.680	283.1	143.4	426.4
0.690	281.6	138.4	420.0
0.700	279.2	133.3	412.5
0.710	280.1	130.3	410.4
0.720	251.5	111.8	363.4
0.730	252.6	109.5	362.2
0.740	270.5	115.9	386.5
0.750	274.0	115.0	389.0
0.760	178.6	68.2	246.7
0.770	245.0	96.0	341.0
0.780	267.6	104.5	372.1
0.790	262.3	99.9	362.2
0.800	257.6	95.7	353.2
0.810	243.6	87.7	331.3
0.820	221.9	77.0	298.9
0.830	230.4	78.9	309.3
0.840	238.6	80.8	319.3
0.850	243.6	81.4	325.0
0.860	240.6	78.8	319.5
0.870	237.3	76.2	313.5
0.880	233.4	73.4	306.8
0.890	226.1	69.4	295.5
0.900	193.7	56.7	250.4
0.910	197.1	56.9	254.0
0.920	199.5	56.7	256.3

MEAN DAILY SPECTRAL DISTRIBUTION($Wm^{-2}.micron^{-1}$).

WAVELENGTH	DIRECT COMP	DIFFUSE COMP	GLOBAL RAD
0.930	115.1	29.6	144.7
0.940	99.7	24.8	124.5
0.950	95.8	23.4	119.1
0.960	113.5	27.7	141.2
0.970	175.5	45.0	220.4
0.980	184.8	47.2	231.9
0.990	201.2	51.6	252.8
1.000	203.7	51.8	255.4
1.050	186.9	44.0	230.9
1.100	137.6	28.8	166.4
1.150	84.3	15.5	99.7
1.200	143.1	27.3	170.4
1.250	130.7	23.5	154.2
1.300	99.7	16.2	115.9
1.350	15.1	2.0	17.1
1.400	0.7	0.1	0.8
1.450	17.1	2.0	19.1
1.500	56.5	7.1	63.6
1.550	85.4	11.2	96.6
1.600	76.4	9.5	86.0
1.650	73.2	8.8	82.0
1.700	62.4	7.1	69.5
1.750	47.6	5.0	52.6
1.800	10.9	0.9	11.9
1.850	0.0	0.0	0.0
1.900	0.1	0.0	0.2
1.950	4.7	0.4	5.1
2.000	18.9	1.5	20.4
2.100	26.9	2.2	29.2
2.200	26.3	2.1	28.4
2.300	22.5	1.7	24.2
2.400	12.3	0.8	13.1
2.500	1.6	0.1	1.6
2.600	0.0	0.0	0.0
2.700	0.0	0.0	0.0
2.800	0.0	0.0	0.0
2.900	0.3	0.0	0.3
3.000	1.2	0.1	1.3
3.100	1.1	0.0	1.1
3.200	1.7	0.1	1.8
3.300	1.1	0.0	1.2
3.400	2.7	0.1	2.8
3.500	4.1	0.2	4.3
3.600	4.1	0.2	4.2
3.700	3.8	0.1	4.0
3.800	3.7	0.1	3.8
3.900	3.3	0.1	3.5
4.000	3.5	0.1	3.6

APPEXDIX ----- D

Listings of computer programs written in the BASIC programming language and run on a COMMODORE 2000 series microcomputer. These programs performed the functions of; collecting, analysing and plotting the measured solar radiation data for Birmingham, under different experimental conditions. A brief description of each program is given in **chapter 6, section 5.**

N.B. In these program listings, screen layout and cursor control characters are not printed.

```
10    REM--PROGRAM(DAT1)-23.05.1981(P.S.A)
20    REM---FOR RECORDING SOLAR RADIATION
30    REM---DATA ON A CASSETTE.
40    REM----*********------
50    REM
60    B1=243:B2=122:B3=244:B4=2
70    X1=5180000
80    DIMV(16),C$(16)
90    DIMY(16),P(16),P$(16)
100   DIMB(16)
110   REM-----**********-------
120   REM
130   OPEN1,0
140   GOSUB970:REM-STARTING DATE AND TIME
150   POKEB1,B2:POKEB3,B4
160   OPEN2,1,1,"DATSUN"
170   PRINT£2,D$
180   GOSUB1120:REM--INPUT CHANNELS
190   GOSUB540:REM--SCANNING AND RECORDING
200   REM.....       TIMES IF DIFFERENT!
210   IFJ1=1THENN2=1:GOTO230
220   N2=INT(T2/T)
230   REM-----**********------
240   REM
250   N1=0
260   IFJ1=1THEN280
270   GOSUB510:REM--REGISTERS SET ZERO
280   A=TI
290   GOSUB1370:REM--DATA ACQUISITION
300   IFJ1=1THEN360
310   GOSUB1540:REM--INCREMENT REGISTERS
320   REM----************
330   REM
340   REM--PRINT ON SCREEN
350   IFJ1=1THENGOTO390
360   IFN1<N2THENGOSUB2150:GOTO410
370   GOSUB1590:REM--AVE. VALS. TO STRING FORM
380   IFJ1=2THENGOTO400
390   GOSUB1800:REM-INTS. VALS TO STRING
400   N1=0:GOSUB1970:REM--STORE ON CASSETE
410   PRINT"  IF YOU WISH TO TERMINATE THE PROGRAM"
420   PRINT"   AT THIS STAGE PRESS "CHR$(34)"E"CHR$(34)"
430   GETA$:IFA$="E"THEN2240
440   REM----**********---------
450   REM
460   IFA+T>X1THENGOSUB2200:REM--TIME SET AT MIDNIGHT
470   IFA+T>TITHEN430
480   PRINT"""
490   GOTO280
500   REM--------*******--------
510   FORJ=1TOM1:N=B(J)
520   P(N)=0:NEXTJ:RETURN
530   REM--------*******--------
```

```
540   PRINT"""
550   PRINT"    SCAN TIME INTERVAL ?"
560   PRINT"    02 10 SECONDS"
570   PRINT"    12 30 SECONDS"
580   PRINT"    22  1 MINUTE"
590   PRINT"    32  2 MINUTES"
600   PRINT"    42  5 MINUTES"
610   PRINT"    52 10 MINUTES"
620   PRINT"    SELECT THE NUMBER YOU REQUIRE"
630   GETA$:IFA$="0"THEN T=600:GOTO740
640   IFA$="1"THENT=1800:GOTO740
650   IFA$="2"THENT=3600:GOTO740
660   IFA$="3"THENT=7200:GOTO740
670   IFA$="4"THENT=18000:GOTO740
680   IFA$="5"THENT=36000:GOTO740
690   GOTO630
700   DA$=STR$(INT(T/60))
710   PRINT£2,DA$
720   REM**********
730   IFJ1=1THEN950
740   PRINT"    DATA RECORDING INTERVAL?"
750   PRINT"    02 2 MINUTES"
760   PRINT"    12 5 MINUTES"
770   PRINT"    22 10 MINUTES"
780   PRINT"    32 15 MINUTES"
790   PRINT"    42 30 MINUTES"
800   PRINT"    52  1 HOUR"
810   PRINT"    62  1 MINUTE"
820   PRINT"    72  30 SECONDS"
830   PRINT"  SELECT THE NUMBER YOU REQUIRE"
840   GETA$:IFA$="0"THENT2=7200:GOTO930
850   IFA$="1"THENT2=18000:GOTO930
860   IFA$="2"THENT2=36000:GOTO930
870   IFA$="3"THENT2=54000:GOTO930
880   IFA$="4"THENT2=108000:GOTO930
890   IFA$="5"THENT2=216000:GOTO930
900   IFA$="6"THENT2=3600:GOTO930
910   IFA$="7"THENT2=1800:GOTO930
920   GOTO840
930   DS$=STR$(INT(T2/3600))
940   PRINT£2,DS$
950   RETURN
960   REM--------*******--------
970   PRINT"  TYPE IN DATE FORMDD.MM.YY2":GOSUB1940
980   D$=E$
990   IFLEN(D$)<>8THENGOTO970
1000  PRINT"  TYPE IN TIME FORMHH.MM.SS.(G.M.T)"
1010  GOSUB1940
1020  IFLEN(E$)<>8THENGOTO1000
1030  D$=D$+E$
1040  A$(1)=LEFT$(E$,2):A$(2)=MID$(E$,4,2)
1050  TI$=A$(1)+A$(2)+A$(3)
1060  PRINT"""
1070  PRINT"INSERT DATA TAPE IN DECK £1 AND PRESS"
1080  PRINT"SPACE WHEN READY"
```

```
1090  WAIT59410,4,4
1100  RETURN
1110  REM--------*******--------
1120  B$=""
1130  PRINT""""
1140  PRINT"    HOW MANY INPUTS? IN FORM NN"
1150  GOSUB1940
1160  IFLEN(E$)<>2THENGOTO1140
1170  B$=E$:M1=VAL(E$)
1180  PRINT"    TYPE IN CHANNEL NO FORM NN2"
1190  FOR J=1TOM1
1200  PRINT"    "J"CHANNEL NO=":GOSUB1940
1210  IFLEN(E$)<>2THENGOTO1200
1220  B$=B$+E$:B(J)=VAL(E$)
1230  NEXTJ
1240  REM************
1250  PRINT"" DATA TYPE FOR STORAGE TO CASSETTE?"
1260  PRINT" PRINT NUMBER"
1270  PRINT"    INTS.VALUES ONLY  12"
1280  PRINT"    MEAN VALS ONLY    22"
1290  PRINT"    BOTH VALUES       32"
1300  GETA$:IFA$=""THEN1300
1310  SM=VAL(A$):IFSM>3THEN1250
1320  B$=B$+A$
1330  J1=VAL(E$)
1340  PRINT£2,B$
1350  RETURN
1360  REM--------*******--------
1370  POKE59459,0
1380  PCR=59468:ADR=59426
1390  POKE PCR,PEEK(PCR)AND31OR224
1400  FORJ=1TOM1:N=B(J)
1410  POKEADR,N
1420  POKEPCR,PEEK(PCR)AND31OR192
1430  POKEPCR,PEEK(PCR)AND31OR224
1440  POKEPCR,PEEK(PCR)AND31OR192
1450  X=PEEK(59471)
1460  POKEPCR,PEEK(PCR)AND31OR224
1470  Y=PEEK(59471)AND15
1480  Z=(16*X)+Y
1490  V(N)=INT(1000*(Z/819)+.5)
1500  PRINT"    CHANNEL"N"="V(N)"MILLIVOLTS"
1510  NEXTJ
1520  RETURN
1530  REM--------*******--------
1540  FORJ=1TOM1:N=B(J)
1550  P(N)=P(N)+V(N):NEXTJ
1560  N1=N1+1
1570  RETURN
1580  REM--------*******--------
1590  FORJ=1TOM1:N=B(J)
1600  IFN1=0THEN1640
1610  Y(N)=INT(P(N)/N1)
1620  NEXTJ
1630  GOSUB510
```

```
1640  GOSUB1670
1650  RETURN
1660  REM--------*******--------
1670  FORJ=1TOM1:N=B(J)
1680  P$(N)=STR$(Y(N)):GOSUB1720
1690  NEXTJ
1700  GOSUB1750:RETURN
1710  REM--------*******--------
1720  B=LEN(P$(N))
1730  IFB<5THENFORK=1TO5-B:P$(N)="0"+P$(N):NEXTK:RETURN
1740  IFB=5THENRETURN
1750  REM--------*******--------
1760  S$=""
1770  FORJ=1TOM1:N=B(J)
1780  S$=S$+P$(N):NEXTJ:RETURN
1790  REM--------*******--------
1800  FORJ=1TOM1:N=B(J)
1810  C$(N)=STR$(V(N)):GOSUB1860
1820  NEXTJ
1830  GOSUB1900
1840  RETURN
1850  REM--------*******--------
1860  B=LEN(C$(N))
1870  IFB<5THENFORK=1TO5-B:C$(N)="0"+C$(N):NEXTK:RETURN
1880  IFB=5THENRETURN
1890  REM********
1900  R$=""
1910  FORJ=1TOM1:N=B(J)
1920  R$=R$+C$(N):NEXTJ:RETURN
1930  REM--------*******--------
1940  E$="":INPUT£1,E$:IFE$=""THEN1940
1950  RETURN
1960  REM--------*******--------
1970  IFJ1<>1THEN2050
1980  FORJ=1TOM1:N=B(J)
1990  IFV(N)>0THEN2020
2000  NEXTJ
2010  GOTO2150
2020  PRINT£2,TI$
2030  PRINT£2,R$
2040  GOTO2150
2050  FORJ=1TOM1:N=B(J)
2060  IFY(N)>0THEN2090
2070  NEXTJ
2080  GOTO2150
2090  PRINT£2,TI$
2100  IFJ1=2THENGOTO2130
2110  PRINT£2,R$
2120  IFJ1=1THENGOTO2150
2130  PRINT£2,S$
2140  REM***************
2150  PRINT"    T$---="TI$
2160  PRINT"    R$---="R$
2170  PRINT"    S$---="S$
2180  RETURN
```

```
2190  REM--------*******--------
2200  IFTI<>0THEN2200
2210  IFTI=<7200THEN2210
2220  TI$="000000":A=TI:RETURN
2230  REM----------*******--------
2240  IFJ1=1THEN2270
2250  GOSUB1540:REM-INCREMENT VALS.
2260  GOSUB1590:REM-MEAN VALS. TO STRING
2270  IFJ1=2THEN2290
2280  GOSUB1800:REM-INTS. VALS. TO STRING
2290  GOSUB1970:REM-WRITE TO CASSETTE
2300  CLOSE1:CLOSE2
2310  PRINT"----*****END OF PROGRAM---**"
```

```
10    REM--PROG(PRO1)-20.05.81(P.S.A)
20    REM--PROGRAM FOR TRANSFERRING SOLAR RADIATION
30    REM--DATA FROM A CASSETTE TO DISK
40    REM====
50    PRINT""IF YOU WISH TO MODIFY ANY LINE OR ADD"
60    PRINT"  LINE PLEASE DO SO UP TO LINE NO. 210"
70    PRINT" THEN PRESS RUN 90"
80    REM. 110-210
90    DIMA1$(16)
100   REM****************
110   A1$(1)="CH(10)-DIFFUSE COMP-EPPLEY (9.77)"
120   A1$(2)="CH(11)-GLOBAL COMP ON HORIZONTAL "
130   A1$(2)=A1$(2)+"-EPPLEY(9.69)"
140   REM----
150   A1$(3)="CH(12)-EPPLEY SOUTH FACING INCLINE "
160   A1$(3)=A1$(3)+" 40 DEG.(10.4)"
170   A1$(4)="CH(13)-SOUTH FACING AT 40 DEG-"
180   A1$(4)=A1$(4)+"KIPP C.M.5(11.1)"
190   A1$(5)="CH(14)-GLOBAL COMP AT HORIZONTAL-KIPP "
200   A1$(5)=A1$(5)+"C.M.7  S-N THERM(11.16)"
210   REM***************
220   OPEN1,0
230   Z$=CHR$(13)
240   REM-----********----
250   PRINT"""
260   PRINT"TYPE IN DATA DESTINATION F/N"
270   INPUT£1,E$
280   PRINT"IF FILE NAME CORRECT?"
290   PRINT" TYPE 1 FOR YES"
300   PRINT" TYPE 0 FOR NO"
310   GETA$:IFA$=""THEN310
320   IFA$="0"THEN260
330   OPEN5,8,12,E$+",SEQ,WRITE"
340   REM-----********----
350   PRINT""        READY TO READ DATA TAPE"
360   PRINT"        ======================="
370   PRINT"ENSURE TAPE IS FOR THE CORRECT PERIOD,
380   PRINT"IS REWOUND, AND IS READY IN CASSETTE £1
390   PRINT"PRESS SPACE BAR WHEN READY
400   WAIT59410,4,4
410   REM-----********----
420   OPEN2,1,0,"DATSUN"
430   INPUT£2,H$,P$
440   PRINT"""
450   PRINT"350-H$="H$,"P$="P$
460   H2=VAL(MID$(H$,9,2))-1
470   H2$=RIGHT$(STR$(H2),2)
480   H3$=LEFT$(H$,8)+H2$+RIGHT$(H$,6)
490   H$=H3$
500   PRINT£5,H$;Z$;P$;Z$;
510   REM-----********----
520   M1=VAL(LEFT$(P$,2))
530   FORJ=1TOM1
```

```
540   IFA1$(J)<>""THEN570
550   PRINT"PLEASE CHECK THE CHANNEL LABELLING"
560   GOTO850
570   PRINT£5,A1$(J);Z$;
580   NEXTJ
590   J1=VAL(RIGHT$(P$,1))
600   INPUT£2,DA$ :PRINT£5,DA$;Z$;
610   IFJ1=1THEN650
620   INPUT£2,DS$
630   PRINT£5,DS$;Z$;
640   REM*************
650   PRINT"  DATA BEING TRANSFERRED"
660   PRINT"  ======================"
670   PRINT"  FROM CASSETTE TO DISK"
680   PRINT"  ====================="
690   INPUT£2,T$:IFST=64THEN850
700   H1=VAL(LEFT$(T$,2))-1
710   H1$=STR$(H1)
720   R$="0"
730   IFLEN(H1$)<3THENH1$=R$+RIGHT$(H1$,1)
740   T1$=H1$+RIGHT$(T$,4)
750   T$=T1$
760   INPUT£2,R$:IFST=64THEN850
770   IFJ1<>3THENGOTO790
780   INPUT£2,S$:IFST=64THEN850
790   IFJ1<>3THEN820
800   PRINT£5,T$;Z$;R$;Z$;S$;Z$;
810   GOTO830
820   PRINT£5,T$;Z$;R$;Z$;
830   GOTO690
840   REM-----********----
850   CLOSE5:CLOSE2
860   CLOSE1
870   PRINT"  **-END OF DATA-**"
880   PRINT"***END OF PROGRAM***"
```

```
10    REM---PROGRAM(PRO2)-20/05/1981(P.S.A)
20    REM-TO MODIFY DATA FOR ANY
30    REM-CORRECTIONS TO ORIGINAL DATA
40    REM-IT MAY BE DIFFUSE MULTIPLIER OR
50    REM-A FILTER FACTOR
60    PRINT"" IF YOU WISH TO MODIFY ANY LINE"
70    PRINT"DO SO THEN TYPE RUN 90"
80    REM   650-750
90    DIMB(16),A2(12),Z(12),A1$(16)
100   REM*****************
110   L1=2       :REM-INPUT DISK FILE
120   L2=3       :REM--O/P DISK FILE
130   A$=CHR$(13)
140   REM******************
150   DATA 1.07,1.1,1.14,1.18,1.2,1.2
160   DATA1.2,1.19,1.15,1.11,1.08,1.06
170   REM-DIFFUSE MONTHLY MULTIPLIER
180   FORI=1TO12:READA2(I):NEXTI
190   REM
200   REM----*********-------
210   PRINT"""
220   PRINT"  DATA INPUT FILE NAME "
230   INPUTF$
240   PRINT"IF FILE NAME CORRECT TYPE 12 OTHERWISE 02"
250   GETZ$
260   IFZ$="0"THEN220
270   IF Z$="1"THEN290
280   GOTO250
290   OPENL1,8,14,F$+",SEQ,READ"
300   PRINT" DATA OUTPUT FILE NAME"
310   INPUTF$
320   PRINT"IF FILE NAME CORRECT TYPE 12 OTHERWISE 02"
330   GETZ$
340   IFZ$="0"THEN300
350   IFZ$="1"THEN370
360   GOTO330
370   OPENL2,8,12,F$+",SEQ,WRITE"
380   REM----*********-------
390   PRINT"""
400   PRINT"  PROGRAM RUNNING"
410   REM-READ DATA FROM DISK FILE
420   INPUT£L1,H$:IFST=2THEN820
430   INPUT£L1,P$:IFST=2THEN820
440   PRINT£L2,H$;A$;P$;A$;
450   PRINT"H$="H$,"P$="P$
460   J1=VAL(RIGHT$(P$,1))
470   M1=VAL(LEFT$(P$,2)):REM-NO OF CHANNELS
480   FORJ=1TOM1:B(J)=VAL(MID$(P$,J*2+1,2)):NEXTJ
490   GOSUB720:REM-LABELS AND RECORD TIME
500   REM------
510   INPUT£L1,T$
520   IFST=2THEN820
530   INPUT£L1,R$:IFST=2THEN820
```

```
540    S1=LEN(R$)
550    IFS1<M1*5 THENR$="0"+R$
560    GOSUB660
570    PRINT£L2,T$;A$;F$;A$;
580    IFJ1<>3THEN510
590    INPUT£L1,R$:IFST=2THEN820
600    S2=LEN(R$)
610    IFS2<M1*5THENR$="0"+R$
620    GOSUB660
630    PRINT£L2,F$;A$;
640    GOTO510
650    REM== CORRECTION ROUTINE ====
660    C1=VAL(LEFT$(R$,5))
670    C8=INT(C1*1.2)
680    C1$=STR$(C8):C2=LEN(C1$)
690    IFC2<5THENFORK=1TO5-C2:C1$="0"+C1$:NEXTK
700    F$=C1$+RIGHT$(R$,20)
710    RETURN
720    REM************
730    FORJ=1TOM1
740    INPUT£L1,A1$(J)
750    PRINT£L2,A1$(J);A$;
760    NEXTJ
770    INPUT£L1,DA$:PRINT£L2,DA$;A$;
780    IFJ1=1THEN800
790    INPUT£L1,DS$:PRINT£L2,DS$;A$;
800    RETURN
810    REM***************
820    CLOSEL1:CLOSEL2
830    PRINT""
840    PRINT"   END OF CURRENT FILE"
850    PRINT" IF YOU WISH TO END PROGRAM TYPE 1  "
860    PRINT"  AND TYPE 0 TO READ ANOTHER FILE"
870    GETZ$
880    IFZ$="1"THEN920
890    IFZ$="0"THEN210
900    GOTO870
910    PRINT""
920    PRINT"   END OF PROGRAM"
```

```
10    REM---PROGRAM(PRO3)--20/05/1981(P.S.A)
20    REM-PROGRAM FOR FINDING HOURLY
30    REM-MEAN VALUES OF IRRADIANCE(W/M*M)
40    REM-AND DAILY TOTAL IRRADIATION
50    DIMX(16),X$(16),X1(16),X2(16)
60    DIMD1(16),D2(16),G1(16),G2(16)
70    DIMB(16),A1(12),Z(12),A1$(16)
80    DIMY1(16),Y2(16)
90    REM****************
100   X9=1100:   REM--IRRADIATION RANGE TEST
110   D6=99  :REM-END OF DAY MARKER
120   R7=90  :REM-END OF RUN
130   DZ=95
140   P9=30      :REM--CENTRAL TIME VALUE
150   HD=3
160   A4=1.0     :REM--HOURLY INCREMENT
170   L1=2       :REM-INPUT DISK FILE
180   L2=3       :REM--O/P DISK FILE
190   A$=CHR$(13)
200   REM*****************
210   REM-INSTRUMENT CALIBRATIONS
220   Z(1)=5.570125:Z(2)=24  :REM-CH(10)
230   Z(3)=5.689852:Z(4)=23  :REM--CH(11)
240   Z(5)=5.9293  :Z(6)=22  :REM--CH(12)
250   Z(7)=6.32839 :Z(8)=21  :REM--CH(13)
260   Z(9)=6.362599:Z(10)=21  :REM--CH(14)
270   Z(11)=4.79308:Z(12)=25 :REM--CH(15)
280   REM****************
290   REM-DAYS OF MONTHS
300   DATA 31,28,31,30,31,30,31,31,30,31,30,31
310   FORJ=1TO12:READA1(J):NEXTJ
320   REM
330   REM----*********-------
340   PRINT"""
350   PRINT"  DATA INPUT FILE NAME "
360   INPUTF$
370   PRINT"IF FILE NAME CORRECT TYPE 12 OTHERWISE 02"
380   GETZ$
390   IFZ$="0"THEN350
400   IF Z$="1"THEN420
410   GOTO380
420   OPENL1,8,14,F$+",SEQ,READ"
430   PRINT" DATA OUTPUT FILE NAME"
440   INPUTF$
450   PRINT"IF FILE NAME CORRECT TYPE 12 OTHERWISE 02"
460   GETZ$
470   IFZ$="0"THEN430
480   IFZ$="1"THEN500
490   GOTO460
500   OPENL2,8,12,F$+",SEQ,WRITE"
510   REM----*********-------
520   PRINT"""
530   PRINT"  PROGRAM RUNNING"
```

```
540   REM-READ DATA FROM DISK FILE
550   INPUT£L1,H$:IFST=2THEN2700
560   INPUT£L1,P$:IFST=2THEN2700
570   PRINT£L2,H$;A$;P$;A$;
580   PRINT"H$="H$,"P$="P$
590   J1=VAL(RIGHT$(P$,1))
600   M1=VAL(LEFT$(P$,2)):REM-NO OF CHANNELS
610   FORJ=1TOM1:B(J)=VAL(MID$(P$,J*2+1,2)):NEXTJ
620   GOSUB1070:REM-LABELS AND RECORD TIME
630   D5=VAL(LEFT$(H$,2)):M5=VAL(MID$(H$,4,2))
640   Y5=VAL(MID$(H$,7,2))
650   REMY5=YEAR--M5=MONTH--D5=DATE
660   H5=VAL(MID$(H$,9,2))
670   REM  H5=TIME(G.M.T)-HOURS
680   REM--ALL REGISTERS SET ZERO
690   GOSUB1030
700   REM----*********-------
710   N2=0:N1=0:FS=1:F1=1
720   REM------
730   INPUT£L1,T$
740   TL=LEN(T$)
750   G$="0"
760   IFTL<6THENT$=G$+T$
770   IFST<>2THENN1=1:GOTO800
780   IFST=2ANDN1=0THEN2700
790   IFST=2ANDN1=1THEN2580
800   H2=VAL(LEFT$(T$,2))
810   IFF1=1THENH3=H2:F1=0
820   IFH2>=(H5-HD)THENGOTO860
830   H2=H3+1
840   GOSUB2470:REM=DAILY TOTALS
850   H2=VAL(LEFT$(T$,2)):H5=H2
860   INPUT£L1,R$:IFST=2THEN2580
870   V1=LEN(R$)
880   IFV1<M1*5THENR$="0"+R$
890   N2=N2+1:GOSUB63999:REM-IRRADIATION CONVERSION
900   IFJ1<>3THEN950
910   INPUT£L1,S$:IFST=2THEN2580
920   V2=LEN(S$)
930   IFV2<M1*5THENS$="0"+S$
940   GOSUB63999:REM-IRRADIATION CONVERSION
950   T5=VAL(MID$(T$,3,2))
960   IFABS(P9-T5)<=P3THEN980
970   GOTO720
980   IFJ1=3THENGOSUB1800:GOTO1000
990   GOSUB1520
1000  N2=0:H5=H5+1
1010  GOTO720
1020  REM-----ALL REGISTERS SET ZERO
1030  FORJ=1TOM1:N=B(J)
1040  X2(N)=0:X1(N)=0:D1(N)=0:G1(N)=0
1050  Y2(N)=0:D2(N)=0:G2(N)=0:Y1(N)=0
1060  NEXTJ:RETURN
1070  REM************
1080  REM-LABELS AND CENTRAL-CONTROL VAL.
```

```
1090  FORJ=1TOM1
1100  INPUT£L1,A1$(J)
1110  PRINT£L2,A1$(J);A$;
1120  NEXTJ
1130  INPUT£L1,DA$:PRINT£L2,DA$;A$;:P2=INT(VAL(DA$)/60)
1140  IFJ1=1THEN1160
1150  INPUT£L1,DS$:PRINT£L2,DS$;A$;:P2=INT(VAL(DS$))
1160  REM************
1170  IFP2>0AND((INT(P2*.5))*2)=P2THEN1200
1180  P3=INT(P2*.5)
1190  RETURN
1200  P9=P9-.5:P3=INT(P2*.5-.5)+.5:GOTO1190
1210  RETURN
1220  REM***************
1230  FORJ=1TOM1:N=B(J)
1240  K=J-1
1250  X$(N)=MID$(R$,K*5+1,5)
1260  IFN=<9THENX(N)=INT((VAL(X$(N))/47.619-5)*10)/10
1270  IFN=10THENX(N)=INT(VAL(X$(N))/Z(1)+Z(2))
1280  IFN=11THENX(N)=INT(VAL(X$(N))/Z(3)+Z(4))
1290  IFN=12THENX(N)=INT(VAL(X$(N))/Z(5)+Z(6))
1300  IFN=13THENX(N)=INT(VAL(X$(N))/Z(7)+Z(8))
1310  IFN=14THENX(N)=INT(VAL(X$(N))/Z(9)+Z(10))
1320  IFN=15THENX(N)=INT(VAL(X$(N))/Z(11)+Z(12))
1330  IFX(N)>X9THENX(N)=INT(X(N)/10)
1340  X1(N)=X1(N)+X(N)
1350  NEXTJ:RETURN
1360  REM---**********------
1370  FORJ=1TOM1:N=B(J)
1380  K=J-1
1390  X$(N)=MID$(S$,K*5+1,5)
1400  IFN=10THENX(N)=INT(VAL(X$(N))/Z(1)+Z(2))
1410  IFN=11THENX(N)=INT(VAL(X$(N))/Z(3)+Z(4))
1420  IFN=12THENX(N)=INT(VAL(X$(N))/Z(5)+Z(6))
1430  IFN=13THENX(N)=INT(VAL(X$(N))/Z(7)+Z(8))
1440  IFN=14THENX(N)=INT(VAL(X$(N))/Z(9)+Z(10))
1450  IFN=15THENX(N)=INT(VAL(X$(N))/Z(11)+Z(12))
1460  IFX(N)>X9THENX(N)=INT(X(N)/10)
1470  Y1(N)=Y1(N)+X(N)
1480  NEXTJ:RETURN
1490  REM-----*********-------
1500  REM= FIND HOURLY MEAN===
1510  REM=INCREMENT DAILY AND RUN TOTALS
1520  FORJ=1TOM1:N=B(J)
1530  IFN2=0THEN1590
1540  X2(N)=INT(X1(N)/N2)
1550  D1(N)=D1(N)+X2(N)
1560  G1(N)=G1(N)+X2(N)
1570  NEXTJ
1580  GOSUB1620
1590  RETURN
1600  REM**********
1610  REM= PRINT HOURLY VALUES=
1620  FORJ=1TOM1:N=B(J)
1630  IFX2(N)>0THEN1660
```

```
1640  NEXTJ
1650  GOTO1710
1660  GOSUB2420
1670  FORJ=1TOM1:N=B(J)
1680  PRINT£L2,X2(N);A$;
1690  NEXTJ
1700  GOSUB1730
1710  RETURN
1720  REM************
1730  REM---HOURLY TOTALS SET ZERO
1740  FORJ=1TOM1:N=B(J)
1750  X1(N)=0:X2(N)=0
1760  NEXTJ
1770  RETURN
1780  REM************
1790  REM= FOR INSTANTANEOUS AND MEAN IRRADIANCE
1800  FORJ=1TOM1:N=B(J)
1810  IFN2=0THEN1900
1820  X2(N)=INT(X1(N)/N2)
1830  D1(N)=D1(N)+X2(N):G1(N)=G1(N)+X2(N)
1840  NEXTJ
1850  FORJ=1TOM1:N=B(J)
1860  Y2(N)=INT(Y1(N)/N2)
1870  D2(N)=D2(N)+Y2(N):G2(N)=G2(N)+Y2(N)
1880  NEXTJ
1890  GOSUB1910
1900  RETURN
1910  REM----***********----
1920  FORJ=1TOM1:N=B(J)
1930  IFX2(N)>0THEN1970
1940  IFY2(N)>0THEN1970
1950  NEXTJ
1960  GOTO2020
1970  GOSUB2420
1980  FORJ=1TOM1:N=B(J)
1990  PRINT£L2,X2(N);A$;Y2(N);A$;
2000  NEXTJ
2010  GOSUB2040
2020  RETURN
2030  REM----***********----
2040  FORJ=1TOM1:N=B(J)
2050  Y1(N)=0:Y2(N)=0:X1(N)=0:X2(N)=0
2060  NEXTJ:RETURN
2070  REM---DAILY VALUES PRINTED
2080  IFJ1=3THENGOSUB1800:GOTO2100
2090  GOSUB1520
2100  N2=0
2110  FORJ=1TOM1:N=B(J)
2120  IFD1(N)>0THEN2190
2130  IFJ1<>3THEN2150
2140  IFD2(N)>0THEN2190
2150  NEXTJ
2160  PRINT£L2,DZ;A$;
2170  REM-END OF DAY MARKER=DAILY TOTALS ZERO
2180  GOTO2270
```

```
2190  IFFS=0THEN2210
2200  PRINT£L2,D6;A$;:REM-END OF DAY
2210  FORJ=1TOM1:N=B(J)
2220  PRINT£L2,D1(N);A$;
2230  IFJ1<>3THENGOTO2250
2240  PRINT£L2,D2(N);A$;
2250  NEXTJ
2260  GOSUB2290
2270  RETURN
2280  REM---DAILY REGISTERS SET ZERO
2290  FORJ=1TOM1:N=B(J):D1(N)=0
2300  D2(N)=0
2310  NEXTJ
2320  RETURN
2330  REM----***********----
2340  REM--RUN TOTALS PRINTED
2350  FORJ=1TOM1:N=B(J)
2360  PRINT£L2,G1(N);A$;
2370  IFJ1<>3THENGOTO2390
2380  PRINT£L2,G2(N);A$;
2390  NEXTJ:RETURN
2400  REM----***********----
2410  REM-PRINT AND RESET TIME-HOUR
2420  REM=
2430  PRINT£L2,H2;A$;:H3=H2
2440  RETURN
2450  REM*********
2460  REM--DATE CHANGE ROUTINE
2470  REM====
2480  GOSUB2080:REM-DAILY VALUES PRINTED
2490  D5=D5+1
2500  IFD5>A1(M5)THEND5=1:M5=M5+1
2510  D$="":R$="."
2520  E$=STR$(D5):D$=D$+RIGHT$(E$,2)+R$
2530  E$=STR$(M5):D$=D$+RIGHT$(E$,2)+R$
2540  E$=STR$(Y5):D$=D$+RIGHT$(E$,2)
2550  PRINT£L2,D$;A$;
2560  RETURN
2570  REM----***********----
2580  H2=H3+1
2590  IFJ1=3THENGOSUB1800:GOTO2610
2600  GOSUB1520
2610  FS=0
2620  PRINT£L2,R7;A$;
2630  GOSUB2110
2640  GOSUB2350:REM-RUN TOTALS
2650  REM= DATE AND TIME OF LAST READING
2660  DL=LEN(D$):R$="0"
2670  IFDL<8THEND$=R$+D$
2680  Q$=D$+T$
2690  PRINT£L2,Q$;A$;
2700  CLOSEL1:CLOSEL2
2710  PRINT""
2720  PRINT"   END OF CURRENT FILE"
2730  PRINT" IF YOU WISH TO END PROGRAM TYPE 1  "
```

```
2740  PRINT"  AND TYPE 0 TO READ ANOTHER FILE"
2750  GETZ$
2760  IFZ$="1"THEN2800
2770  IFZ$="0"THEN340
2780  GOTO2750
2790  PRINT""
2800  PRINT"   END OF PROGRAM"
```

```
10    REM--PROG(PRO4)--15/05/1981(P.S.A)
20    REM-PROG FOR READING HOURLY,DAILY
30    REM-AND RUN VALUES OF RADIATION
40    REM-FROM A DISK FILE AND PRINTING
50    REM-ON THE PRINTER
60    DIMB(16)
70    DIMX2(16):DIMD1(16):DIMG1(16)
80    DIMY2(16),D2(16),G2(16)
90    DIMB1$(16)
100   DZ=95
110   D6=99     :REM---END OF DAY MARKER
120   R7=90     :REM--RUN TERMINATED
130   L3=7
140   OPEN1,0:OPEN2,4
150   A1$="SOLAR RADIATION DATA RECORDED IN PHYSICS "
160   A2$="DEPT. OF ASTON UNIVERSITY (1981)"
170   PRINT£2,A1$;A2$
180   REM-----*******--------
190   PRINT""
200   PRINT"  TYPE IN DATA INPUT FILE NAME"
210   INPUTF$:PRINT
220   PRINT"  IF FILE NAME CORRECT TYPE"
230   PRINT"   12 OTHERWISE 02"
240   GETA$
250   IF A$="1"THEN280
260   IFA$="0"THEN200
270   GOTO240
280   OPENL3,8,10,F$+",SEQ,READ"
290   E$=RIGHT$(F$,6)
300   PRINT£2,SPC(8)E$
310   PRINT£2,
320   PRINT""
330   PRINT"  ******PROGRAM RUNNING*********"
340   REM------*********-----
350   REM===
360   INPUT£L3,H$:IFST=2THEN1810
370   A$=LEFT$(H$,8)
380   B$=RIGHT$(H$,8)
390   INPUT£L3,P$
400   J1=VAL(RIGHT$(P$,1))
410   M1=INT(VAL(LEFT$(P$,2)))
420   FORJ=1TOM1:B(J)=INT(VAL(MID$(P$,J*2+1,2)))
430   NEXTJ
440   REM-----*********-------
450   GOSUB1610:REM-LABELS AND SCAN DETAILS
460   PRINT£2,
470   XX$="DATA SURVEY STARTED AT "
480   PRINT£2,SPC(4)XX$;A$" TIME "B$
490   PRINT£2,SPC(24)"-------------------------"
500   PRINT£2,
510   REM----PRINT HEADINGS--
520   XX$="HOURLY MEAN VALUES(W/M*M)-TIME G.M.T-HOURS"
530   PRINT£2,SPC(4)XX$
```

```
540   FS=0
550   INPUT£L3,H5:IFST=2THENGOTO1890
560   IFH5=DZTHENGOSUB1430:GOTO550
570   IFH5=D6THENGOSUB1240:GOSUB1430:GOTO550
580   IFH5=R7THENGOSUB1490:PRINT"RUN TOTALS":GOTO1810
590   GOSUB800:GOTO550
600   REM----PRINT HEADING
610   REM----**********-------
620   PRINT£2,
630   X$="    CH("
640   Y$=")"
650   E$="":D$="":R$=""
660   E$="    TIME"
670   FORJ=1TOM1:N=B(J)
680   R$=STR$(N)
690   D$=X$+R$+Y$
700   E$=E$+D$
710   D$="":R$=""
720   NEXTJ
730   PRINT£2,E$
740   A$="":D$="-"
750   N9=LEN(E$)-4
760   FORI=1TON9:A$=A$+D$:NEXTI
770   PRINT£2,SPC(4)A$
780   RETURN
790   REM------*********------
800   IFFS=0THENGOSUB620:FS=1
810   IFJ1=3THEN1010
820   E$=""
830   B$="   "
840   C$=STR$(H5)
850   V1=LEN(C$)
860   IFV1=2THENR$="     ":GOTO880
870   R$="   "
880   E$=B$+C$+R$
890   FORJ=1TOM1:N=B(J)
900   INPUT£L3,X2(N)
910   R$="    "
920   D$=STR$(X2(N))
930   V1=LEN(D$)
940   IFV1=4THENB$="    ":GOTO960
950   B$="    "
960   E$=E$+R$+D$+B$
970   D$=""
980   NEXTJ
990   PRINT£2,E$
1000  RETURN
1010  E$="":B$="       "
1020  C$=STR$(H5):V1=LEN(C$)
1030  IFV1=2THENR$="     ":GOTO1050
1040  R$="   "
1050  E$=B$+C$+R$
1060  FORJ=1TOM1:N=B(J)
1070  INPUT£L3,X2(N):D$=STR$(X2(N)):V1=LEN(D$)
1080  INPUT£L3,Y2(N):H$=STR$(Y2(N))
```

```
1090  H$=RIGHT$(H$,LEN(H$)-1):V2=LEN(H$)
1100  V3=V1+V2:B$="":U$=" "
1110  K1=9-V3
1120  FORN=1TOK1:B$=B$+U$
1130  NEXTN
1140  V$="[":U$="]"
1150  E$=E$+D$+V$+H$+U$+B$
1160  NEXTJ
1170  PRINT£2,E$
1180  RETURN
1190  REM-----**********-----
1200  REM------********------
1210  REM-----DAILY TOTALS PRINTED
1220  REM
1230  XX$="DAILY TOTALS OF RADIATION (WH/M*M) FOR;"
1240  PRINT£2,SPC(4)XX$
1250  FORJ=1TOM1:N=B(J)
1260  IFJ1=3THEN1300
1270  INPUT£L3,D1(N)
1280  PRINT£2,SPC(16)"CH("N")="D1(N)
1290  GOTO1320
1300  INPUT£L3,D1(N),D2(N)
1310  PRINT£2,SPC(16)"CH("N")="D1(N)"["D2(N)"]"
1320  NEXTJ
1330  IFH5=D6THEN1350
1340  PRINT"RUN TOTALS"
1350  PRINT£2,
1360  PRINT"IF YOU WISH TO ADJUST ";
1370  PRINT"PAPER DO SO THEN PRESS SPACE"
1380  WAIT59410,4,4
1390  PRINT""
1400  PRINT"  ******PROGRAM RUNNING***"
1410  RETURN
1420  REM-------*******-------
1430  INPUT£L3,D$
1440  PRINT£2,SPC(10)"DATE= "D$
1450  PRINT£2,SPC(10)"============="
1460  GOSUB620:FS=1:RETURN
1470  REM-----*********-------
1480  REM----RUN TOTALS******
1490  GOSUB1240
1500  PRINT£2,SPC(4)"RUN TOTALS (WH/M*M) FOR;"
1510  FORJ=1TOM1:N=B(J)
1520  IFJ1=3THEN1560
1530  INPUT£L3,G1(N)
1540  PRINT£2,SPC(12)"CH("N")="G1(N)
1550  GOTO1580
1560  INPUT£L3,G1(N),G2(N)
1570  PRINT£2,SPC(12)"CH("N")="G1(N)"["G2(N)"]"
1580  NEXTJ
1590  RETURN
1600  REM*************
1610  FORJ=1TOM1:N=B(J)
1620  INPUT£L3,B1$(J)
1630  PRINT£2,SPC(4)B1$(J)
```

```
1640  NEXTJ
1650  REM**********
1660  IFJ1<>1THEN1710
1670  INPUT£L3,DA$
1680  PRINT£2,
1690  XX$="DATA RECORING INTERVAL= "
1700  PRINT£2,SPC(4)XX$;DA$" SECONDS":GOTO1790
1710  INPUT£L3,DA$,DS$
1720  PRINT£2,
1730  XX$="DATA AVERAGING AND RECORDING INTERVAL= "
1740  PRINT£2,SPC(4)XX$;DA$" SECONDS"
1750  XX$="DATA AVERAGING AND RECORDING INTERVAL= "
1760  PRINT£2,SPC(4)XX$;DS$" MINUTES"
1770  XX$="MEAN RECORDED DATA IN BRACKETS,E.G.-[***]-"
1780  IFJ1=3THENPRINT£2,SPC(4)XX$
1790  RETURN
1800  REM****************
1810  INPUT£L3,Q$
1820  QL=LEN(Q$):G$="0"
1830  IFQL<14THENQ$=G$+Q$
1840  E$=LEFT$(Q$,8)
1850  F$=MID$(Q$,9,2)+"/"+MID$(Q$,11,2)+"/"+RIGHT$(Q$,2)
1860  PRINT£2,
1870  XX$="DATA RECORDING FINISHED ON "
1880  PRINT£2,SPC(4)XX$;E$;" AT ";F$
1890  CLOSEL3:CLOSE1:CLOSE2
1900  PRINT""
1910  PRINT"    *****END OF PROGRAM******"
```

```
10     REM---PROGRAM(PLOT1)--07/06/1981(P.S.A)
20     REM-PROGRAM FOR CONVERTING SOLAR
30     REM-RADIATION RECORDED DATA TO
40     REM-EQUIVALENT IRRADIANCE VALUES
50     REM-DATE FOR EACH DAY RECORDED
60     REM=PRECEDING THE DAILY DATA
70     REM==  **  ====
80     PRINT""INSERT DATA I/P DISK IN DRIVE 1"
90     PRINT" DATA O/P DISK IN DRIVE 0 "
100    PRINT"  WHEN READY PRESS RUN 120"
110    STOP
120    REM===========
130    D6$="99":REM-END OF DAY MARKER
140    X9=1100
150    L1=2       :REM-INPUT DISK FILE
160    L2=3       :REM--O/P DISK FILE
170    A$==(13)
180    DIMX(16):DIMX$(16):DIMX1(16)
190    DIMB(16):DIMA1(12)
200    DIMZ(12),A1$(16)
210    REM-INSTRUMENT CALIBRATIONS
220    Z(1)=5.570125:Z(2)=24  :REM-CH(10)
230    Z(3)=5.689852:Z(4)=23  :REM--CH(11)
240    Z(5)=5.9293  :Z(6)=22  :REM--CH(12)
250    Z(7)=6.32839 :Z(8)=21  :REM--CH(13)
260    Z(9)=6.432587:Z(10)=21  :REM--CH(14)
270    Z(11)=4.79308:Z(12)=25 :REM--CH(15)
280    REM== MONTHLY DAYS =====
290    DATA 31,28,31,30,31,30,31,31,30,31,30,31
300    FORJ=1TO12:READA1(J):NEXTJ
310    REM
320    REM----*********-------
330    PRINT"""
340    PRINT"  DATA INPUT FILE NAME"
350    INPUTF$:PRINT
360    PRINT"IF FILE NAME CORRECT TYPE 12 OTHERWISE 02"
370    GETZ$
380    IFZ$="0"THEN340
390    IF Z$="1"THEN410
400    GOTO370
410    OPENL1,8,14,F$+",SEQ,READ"
420    REM----*********-------
430    REM-READ DATA FROM DISK FILE
440    INPUT£L1,H$:IFST=2THEN1340
450    INPUT£L1,P$:IFST=2THEN1340
460    PRINT"""
470    PRINT"  PROGRAM RUNNING"
480    R1$="T":R2$==(H$,2):R3$==(H$,4,2)
490    R4$==(H$,7,2)
500    R5$==(F$,5)
510    R6$=""
520    R6$= R1$+R2$+R3$+R4$+R5$
530    FL$="0:"+R6$+",SEQ,WRITE"
```

```
540   OPENL2,8,12,FL$
550   REM=* * * * * * *
560   PRINT£L2,H$;A$;P$;A$;
570   J1==(((P$,1))
580   M1==(((P$,2)):REM-NO OF CHANNELS
590   FORJ=1TOM1:B(J)==(((P$,J*2+1,2)):NEXTJ
600   D5==(((H$,2)):M5==(((H$,4,2))
610   Y5==(((H$,7,2))
620   REMY5=YEAR--M5=MONTH--D5=DATE
630   H5==(((H$,9,2))
640   REM  H5=TIME(G.M.T)-HOURS
650   GOSUB1150
660   REM----*********-------
670   D$==(H$,8)
680   PRINT£L2,D$;A$;
690   INPUT£L1,T$:IFST=2THEN1340
700   H2==(((T$,2))
710   IFH2>=H5THEN750
720   PRINT£L2,D6$;A$;
730   GOSUB1230
740   PRINT£L2,D$;A$;
750   H5=H2:V$=T$
760   PRINT£L2,V$;A$;
770   INPUT£L1,R$
780   W1==(R$):IFW1<M1*5THENR$="0"+R$
790   IFJ1<>3THENGOSUB840:GOTO830
800   INPUT£L1,S$
810   W2==(S$):IFW2<M1*5THENS$="0"+S$
820   GOSUB1000
830   GOTO690
840   REM**********
850   FORJ=1TOM1:N=B(J)
860   K=J-1
870   X$(N)==(R$,K*5+1,5)
880   IFN=<9THENX(N)=INT((((X$(N))/47.619-5)*10)/10
890   IFN=10THENX(N)=INT(((X$(N))/Z(1)+Z(2))
900   IFN=11THENX(N)=INT(((X$(N))/Z(3)+Z(4))
910   IFN=12THENX(N)=INT(((X$(N))/Z(5)+Z(6))
920   IFN=13THENX(N)=INT(((X$(N))/Z(7)+Z(8))
930   IFN=14THENX(N)=INT(((X$(N))/Z(9)+Z(10))
940   IFN=15THENX(N)=INT(((X$(N))/Z(11)+Z(12))
950   IFX(N)>X9THENX(N)=INT(X(N)/10)
960   PRINT£L2,X(N);A$;
970   NEXTJ
980   RETURN
990   REM************
1000  GOSUB850
1010  FORJ=1TOM1:N=B(J)
1020  K=J-1
1030  X$(N)==(S$,K*5+1,5)
1040  IFN=10THENX(N)=INT(((X$(N))/Z(1)+Z(2))
1050  IFN=11THENX(N)=INT(((X$(N))/Z(3)+Z(4))
1060  IFN=12THENX(N)=INT(((X$(N))/Z(5)+Z(6))
1070  IFN=13THENX(N)=INT(((X$(N))/Z(7)+Z(8))
1080  IFN=14THENX(N)=INT(((X$(N))/Z(9)+Z(10))
```

```
1090  IFN=15THENX(N)=INT(((X$(N))/Z(11)+Z(12))
1100  IFX(N)>X9THENX(N)=INT(X(N)/10)
1110  PRINT£L2,X(N);A$;
1120  NEXTJ
1130  RETURN
1140  REM-----*********-------
1150  FORJ=1TOM1
1160  INPUT£L1,A1$(J)
1170  NEXTJ
1180  IFJ1<>1THEN1210
1190  INPUT£L1,DA$
1200  GOTO1220
1210  INPUT£L1,DA$,DS$
1220  RETURN
1230  REM----***********----
1240  REM--DATE CHANGE ROUTINE
1250  D5=D5+1
1260  IFD5>A1(M5)THEND5=1:M5=M5+1
1270  D$="":R$="."
1280  E$==(D5):D$=D$++(E$,2)+R$
1290  E$==(M5):D$=D$++(E$,2)+R$
1300  E$==(Y5):D$=D$++(E$,2)
1310  H5=H2
1320  RETURN
1330  REM----***********----
1340  PRINT"END OF FILE"
1350  PRINT£L2,D6$;A$;
1360  CLOSEL1:CLOSEL2
1370  PRINT"   END OF PROGRAM"
```

```
10      REM---PROGRAM(PLOT2)--20/05/1981(P.S.A)
20      REM-PROGRAM FOR READING IRRADIANCE
30      REM-DATA AND SELECTING DATA FOR A
40      REM-GIVEN DATE THEN STORING IT
50      REM-SEPARATELY FOR EACH CHANNEL NO.
60      REM=== ** ===
70      D6$="99":REM-END OF DAY MARKER
80      L1=1      :REM-INPUT DISK FILE
90      A$=CHR$(13)
100     DIMX1(16),X2(16)
110     DIMW1(300,6),W2(300,6),T(300)
120     DIMB(16)
130     REM
140     REM----*********-------
150     PRINT"TYPE IN DATE IN FORM DD.MM.YY2":INPUTB$
160     D9=VAL(LEFT$(B$,2)):M9=VAL(MID$(B$,4,2))
170     Y9=VAL(RIGHT$(B$,2))
180     PRINT"  DATA INPUT FILE NAME"
190     INPUTF$:PRINT
200     PRINT"IF FILE NAME CORRECT TYPE 12 ";
210     PRINT"OTHERWISE 02"
220     GETZ$
230     IFZ$="0"THEN180
240     IF Z$="1"THEN260
250     GOTO220
260     OPENL1,8,14,F$+",SEQ,READ"
270     REM----*********-------
280     PRINT""
290     PRINT"  PROGRAM RUNNING"
300     REM-READ DATA FROM DISK FILE
310     INPUT£L1,H$:IFST=2THEN1260
320     INPUT£L1,P$:IFST=2THEN1260
330     J1=VAL(RIGHT$(P$,1))
340     M1=VAL(LEFT$(P$,2)):REM-NO OF CHANNELS
350     FORJ=1TOM1
360     B(J)=VAL(MID$(P$,J*2+1,2))
370     NEXTJ
380     REM----*********-------
390     REM= DATE TEST =
400     INPUT£L1,D$
410     D5=VAL(LEFT$(D$,2))
420     IFD5=99THEN520
430     IFD5<>D9THEN1150
440     M5=VAL(MID$(D$,4,2))
450     IFM5<>M9THEN1150
460     Y5=VAL(RIGHT$(D$,2))
470     IFY5<>Y9THEN1150
480     REM******************
490     REM=OPEN DATA O/P FILES====
500     D1$=LEFT$(B$,2):D2$=MID$(B$,4,2)
510     D3$=MID$(B$,7,2):GOTO540
520     D1$=LEFT$(D$,2):D2$=MID$(D$,4,2)
530     D3$=MID$(D$,7,2)
```

```
540   E1$="M":E2$="I":E3$="P"
550   IFJ1=2THENU$=E1$:GOTO590
560   IFJ1=1THENU$=E2$:GOTO590
570   IFJ1=3THENU$=E2$:V$=E1$
580   REM******************
590   REM==STORE DATA ARRAYS====
600   I=0
610   INPUT£L1,T$:IFST=2THEN810
620   I=I+1
630   IFT$=D6$THEN810
640   FORJ=1TOM1:N=B(J)
650   INPUT£L1,X1(N)
660   W1(I,J)=X1(N)
670   NEXTJ
680   IFJ1<>3THEN730
690   FORJ=1TOM1:N=B(J)
700   INPUT£L1,X2(N)
710   W2(I,J)=X2(N)
720   NEXTJ
730   C1=VAL(LEFT$(T$,2))
740   C2=(VAL(MID$(T$,3,2)))/60
750   C3=VAL(RIGHT$(T$,2))/3600
760   C4=INT((C2+C3)*100)/100
770   C5=C1+C4
780   T(I)=C5
790   GOTO610
800   REM*************************
810   REM==PRINT DATA O/P FILES==
820   FORJ=1TOM1:N=B(J)
830   N$=RIGHT$(STR$(N),2)
840   C1$="":C1$=N$+U$+D1$+D2$+D3$+E3$+U$
850   FL$="0:"+C1$+",SEQ,WRITE"
860   N1=N
870   OPENN1,8,N1,FL$
880   IFJ1<>3THEN950
890   N$=RIGHT$(STR$(N),2)
900   C1$="":C1$=N$+V$+D1$+D2$+D3$+E3$+V$
910   EL$="0:"+C1$+",SEQ,WRITE"
920   L2=N-6
930   OPENL2,8,L2,EL$
940   REM==========**
950   K1=I:IFW1(K1,J)=0ANDT(K1)=0THENK1=K1-1
960   PRINT£N1,K1;A$;
970   FORK=1TOK1
980   PRINT£N1,T(K);A$;
990   PRINT£N1,W1(K,J);A$;
1000  NEXTK
1010  CLOSEN1
1020  REM**********
1030  IFJ1<>3THEN1110
1040  N2=I:IFW2(N2,J)=0ANDT(N2)=0THENN2=N2-1
1050  PRINT£L2,N2;A$;
1060  FORK=1TON2
1070  PRINT£L2,T(K);A$;
1080  PRINT£L2,W2(K,J);A$;
```

```
1090  NEXTK
1100  CLOSEL2
1110  NEXTJ
1120  GOTO1260
1130  REM*******************
1140  REM==READ DATA FOR A DAY=====
1150  INPUT£L1,T$:IFST=2THEN1260
1160  IFT$=D6$THEN400
1170  FORJ=1TOM1:N=B(J)
1180  INPUT£L1,X1(N)
1190  NEXTJ
1200  IFJ1<>3THEN1240
1210  FORJ=1TOM1:N=B(J)
1220  INPUT£L1,X2(N)
1230  NEXTJ
1240  GOTO1150
1250  REM----***********----
1260  CLOSEL1
1270  PRINT""
1280  PRINT"   END OF PROGRAM"
```

```
10     REM-PLOT3 -(23.05.1981)-P.S.A
20     REM-PROGRAM FOR PLOTTING DATA ON A
30     REM-GRAPH PLOTTER
40     REM-DATA INPUT FROM A DISK FILE
50     REM-OPTION FOR VERTICAL OR HORIZONTAL
60     REM- X-AXIS
70     REM-CHOICE OF ONE , TWO OR THREE GRAPHS
80     REM-ON A GIVEN A4 SIZE PAPER
90     REM*****
100    OPEN 1,5
110    OPEN2,4
120    DIMX(300),Y(300)
130    C1=600  :REM=C1-MARGIN START X-AXIS
140    HL=10200  :REM-HORZ MARGIN LENGTH
150    C2=600    :REM-MARGIN START Y-AXIS
160    VL=6000   :REM-VERTICAL MARGIN LENGTH
170    GOSUB2450:REM-DRAW OUTLINE
180    PRINT"" HORIZONTAL GRAPH X-AXIS PARALLEL ";
190    PRINT"TO LONG-SIDE OF A4 SHEET"
200    PRINT" FOR VERTICAL- X-AXIS PARALLEL ";
210    PRINT "TO SHORT-SIDE OF A4"
220    PRINT"TYPE OF GRAPH REQUIRED?"
230    PRINT"  TYPE 12 FOR HORIZONTAL"
240    PRINT"  TYPE 22 FOR VERTICAL"
250    GETA$:IFA$=""THEN250
260    E$=A$:ZY=VAL(E$)
270    IFA$="1"THEN3750
280    IFA$="2"THEN320
290    GOTO220
300    REM===VERTICAL  GRAPHS=========
310    REM=NO OF GRAPHS ON ONE SHEET
320    GOSUB1270
330    IFA$="1"THEN370
340    IFA$="2"THEN550
350    IFA$="3"THEN850
360    GOTO320
370    REM===ONE VERTICAL GRAPH =====
380    A1=2500:A2=6000
390    HX=6000:HY=4800
400    W1=10000:W2=5800
410    SX=1.0:SY=1.0
420    PRINT£1,"PU;SI .15,.2"
430    GOSUB1370
440    GOSUB1450
450    IFA$="0"THEN510
460    IFA$="1"THEN480
470    GOTO440
480    GOSUB2530
490    GOSUB2240
500    GOTO440
510    GOSUB2800
520    GOSUB2450
530    END
```

```
540   REM===TWO VERTICAL GRAPHS****  ====
550   A1=1000:A2=5900
560   HX=3600:HY=4000
570   W1=5300:W2=5500:W3=W1
580   SX=.8 :SY=.8
590   PRINT£1,"PU;SI .14,.19"
600   VD=INT(HL*.5)
610   GOSUB1370
620   GOSUB1450
630   IFA$="0"THEN690
640   IFA$="1"THEN660
650   GOTO620
660   GOSUB2530
670   GOSUB2240
680   GOTO620
690   GOSUB2800
700   A1=A1+VD:W1=W3+VD
710   REM ==========
720   GOSUB1340
730   GOSUB1370
740   GOSUB1450
750   IFA$="0"THEN810
760   IFA$="1"THEN780
770   GOTO740
780   GOSUB2530
790   GOSUB2240
800   GOTO740
810   GOSUB2800
820   GOSUB2450
830   END
840   REM====  ******  ===
850   REM==THREE VERTICAL GRAPHS ====
860   A1=950 :A2=5500
870   HX=2300 :HY=3300
880   W1=3800:W2=4000:W3=W1
890   SX=.6:SY=.6:VD=INT(HL*.33)
900   PRINT£1,"PU; SI .12,.17"
910   GOSUB1370
920   GOSUB1450
930   IFA$="0"THEN990
940   IFA$="1"THEN960
950   GOTO920
960   GOSUB2530
970   GOSUB2240
980   GOTO920
990   GOSUB2800
1000  REM ==========
1010  A1=A1+VD:W1=W3+VD
1020  GOSUB1340
1030  GOSUB1370
1040  GOSUB1450
1050  IFA$="0"THEN1110
1060  IFA$="1"THEN1080
1070  GOTO1040
1080  GOSUB2530
```

```
1090  GOSUB2240
1100  GOTO1040
1110  GOSUB2800
1120  REM ==========
1130  A1=A1+VD:W1=W3+VD*2
1140  GOSUB1340
1150  GOSUB1370
1160  GOSUB1450
1170  IFA$="0"THEN1230
1180  IFA$="1"THEN1200
1190  GOTO1160
1200  GOSUB2530
1210  GOSUB2240
1220  GOTO1160
1230  GOSUB2800
1240  GOSUB2450
1250  END
1260  REM======  ****  =========
1270  PRINT"" NUMBER OF GRAPHS REQUIRED?"
1280  PRINT"  FOR ONE2 TYPE     1"
1290  PRINT"  FOR TWO2 TYPE     2"
1300  PRINT"  FOR THREE2 TYPE   3"
1310  GETA$:IFA$=""THEN1310
1320  RETURN
1330  REM====   **   =====
1340  PRINT""   * NEXT GRAPH *"
1350  RETURN
1360  REM==PLOTTING ROUTINES ===
1370  GOSUB2530
1380  GOSUB1540
1390  GOSUB1680
1400  GOSUB1760
1410  GOSUB2010
1420  GOSUB2240
1430  RETURN
1440  REM===  *****  =========
1450  REM====  ***  ===
1460  PRINT"" IF ANOTHER PLOT REQUIRED ";
1470  PRINT"ON THE SAME GRAPH"
1480  PRINT" TYPE  12 FOR YES"
1490  PRINT" TYPE  02 FOR NO"
1500  GETA$:IFA$=""THEN1500
1510  PRINT"""
1520  RETURN
1530  REM==================
1540  REM=FIND MAX/MIN
1550  A=X(1):B=X(1):P=Y(1):Q=Y(1)
1560  FOR I=1 TON
1570  IF X(I)>A THENA=X(I)
1580  IF X(I)<B THENB=X(I)
1590  IF Y(I)>P THENP=Y(I)
1600  IFY(I)<Q THENQ=Y(I)
1610  NEXT
1620  PRINT"" FROM INPUT DATA"
1630  PRINT"MINIMUM-X="B,"MAXIMUM-X="A
```

```
1640  PRINT"MINIMUM-Y="Q,"MAXIMUM-Y="P
1650  PRINT"***************"
1660  RETURN
1670  REM================
1680  REM= AXES DETAILS ===
1690  INPUT "XMIN,XMAX";MX,XM
1700  INPUT "YMIN,YMAX";MY,YM:PRINT
1710  INPUT"X STEP LENGTH";S1
1720  INPUT"Y STEP LENGTH";S2:PRINT
1730  JX=HX/(XM-MX):PRINT"JX="JX
1740  KY=HY/(YM-MY):PRINT"KY="KY
1750  RETURN:REM=================
1760  REM= FOR VERTICAL GRAPHS =
1770  IF S1<>0THENB=S1:REM B=STEPLENGTH
1780  M=INT((XM-MX)/B)
1790  Y=INT(MY*KY)
1800  AX=A2
1810  PRINT£1,"DI1,0"
1820  PRINT£1,"PU;PA "A1","A2";XT"
1830  X=INT(B*JX):REM****************
1840  FOR I=1TOM
1850  PRINT£1,"PD;PR "X",0;XT"
1860  NEXT
1870  Y=INT(A2+200*SY)    :REM***************
1880  PRINT£1,"PU;PA"A1","Y""
1890  FOR I=0TOM
1900  PRINT£1,"PA"A1-100*SX+I*X","Y"":REM*********
1910  PRINT£1,"LB"MX+I*B;CHR$(3)
1920  NEXT
1930  REM**************
1940  X$="MEAN IRRADIANCE(W/M*M)":GOTO1960
1950  INPUT"X-AXIS LABEL?";X$
1960  L=INT(LEN(X$))
1970  X=INT(A1+HX*.5-50*SX*L)
1980  Y=INT(A2+400*SY)
1990  PRINT£1,"PU;PA"X","Y";LB"X$;CHR$(3)
2000  RETURN:REM========
2010  REM*****Y AXIS INSTRUCTIONS****
2020  Y$="TIME-HOURS(G.M.T)":GOTO2040
2030  INPUT"Y-AXIS LABEL?";Y$
2040  L=INT(LEN(Y$))
2050  X=INT(A1-400*SX)
2060  Y=INT(A2-HY*.5+50*L*SY)
2070  PRINT£1,"PU;PA"X","Y";DI0,-1;LB"Y$;CHR$(3)
2080  REM****************
2090  IFS2<>0THENB=S2:REM B=STEPLENGTH
2100  M=INT((YM-MY)/B)
2110  X=A1
2120  PRINT£1,"PU;PA "X","A2";YT"
2130  Y=-(INT(B*KY))
2140  FOR I=1TOM
2150  PRINT£1,"PD;PR0,"Y";YT"
2160  NEXTI
2170  PRINT£1,"PU;PA"X-200*SX","A2""
2180  FOR I=0TOM
```

```
2190  PRINT£1,"PA"A1-200*SX","A2+50 +I*Y""
2200  PRINT£1,"LB"MY+I*B;CHR$(3)
2210  NEXTI
2220  RETURN
2230  REM=================
2240  PRINT£1,"DI1,0;"
2250  PS=1:GOTO2310
2260  PRINT"DO YOU WISH THE POINTS TO BE JOINED
2270  PRINT:PRINT"    YES     KEY   1":PRINT
2280  PRINT:PRINT"     NO     KEY   2":PRINT
2290  GETP$:IFP$=""THEN2290
2300  PS=VAL(P$)
2310  PRINT"CHOOSE PLOTTING SYMBOL"
2320  GETSM$:IFSM$=""THEN2320
2330  L5=10:NX=0
2340  FOR I=1TON
2350  NX=NX+1
2360  X=INT((X(I)-MX)*JX+A1)
2370  Y=INT(A2-(Y(I)-MY)*KY)
2380  IFNX<L5THENPRINT£1,"PA"X","Y";PD":GOTO2420
2390  NX=0:IFPS=1THEN2410
2400  PRINT£1,"SM"SM$";PA"X","Y";SM;":GOTO2420
2410  PRINT£1,"SM"SM$";PA"X","Y";SM;PD;"
2420  NEXTI
2430  PRINT£1,"PU;":RETURN:REM*******
2440  REM==============
2450  REM-DRAW THE OUTLINE
2460  PRINT£1,"PU;PA"C1","C2""
2470  PRINT£1,"PD;PA"C1+HL","C2""
2480  PRINT£1,"PD;PA"C1+HL","C2+VL""
2490  PRINT£1,"PD;PA"C1","C2+VL";PU"
2500  PRINT£1,"PD;PA"C1","C2";PU"
2510  RETURN
2520  REM====================
2530  REM==DATA INPUT FROM DISK==
2540  PRINT"INPUT DATA FILE NAME?"
2550  INPUTF$:PRINT
2560  PRINT"IF FILE NAME CORRECT TYPE 12OTHER WISE 02"
2570  PRINT""
2580  GETZ$
2590  IFZ$="0"THEN2540
2600  IFZ$="1"THEN2620
2610  GOTO2580
2620  OPEN7,8,11,F$+",SEQ,READ"
2630  PRINT£2,"FILE NAME="F$
2640  INPUT£7,N
2650  FORL=1TON
2660  INPUT£7,P1
2670  INPUT£7,P2
2680  IFZY=1THENX(L)=P1:Y(L)=P2:GOTO2700
2690  X(L)=P2:Y(L)=P1
2700  NEXTL
2710  CLOSE7
2720  RETURN
2730  REM=============
```

```
2740  REM=ARRAY SET ZERO ==
2750  FORL=1TO300
2760  X(L)=0:Y(L)=0
2770  NEXTL:RETURN
2780  REM****************
2790  REM==================
2800  REM==GRAPH HEADINGS===
2810  PRINT£1,"PU;PA "W1","W2""
2820  PRINT""  TYPE HEADING LINE?"
2830  INPUTA1$:PRINT
2840  PRINT£1,"DI0,-1;LB"A1$;CHR$(3)
2850  PRINT"IF ANOTHER LINE TYPE  12 OTHERWISE 02"
2860  GETZ$:IFZ$=""THEN2860
2870  IFZ$="0"THEN2920
2880  W1=W1-200*SX
2890  A1$=""
2900  PRINT£1,"PU;PA"W1","W2""
2910  GOTO2820
2920  PRINT£1,"PU;DI1,0"
2930  RETURN
2940  REM======*****=====
2950  IF S1<>0THENB=S1:REM B=STEPLENGTH
2960  M=INT((XM-MX)/B)
2970  Y=INT(MY*KY)
2980  PRINT£1,"PU;PA "A1","A2";XT"
2990  X=INT(B*JX):REM*****************
3000  FOR I=1TOM
3010  PRINT£1,"PD;PR "X",0;XT"
3020  NEXT
3030  Y=INT(A2-200*SY)    :REM***************
3040  PRINT£1,"PU;PA"A1","Y""
3050  FOR I=0TOM
3060  PRINT£1,"PA"A1-100*SX+I*X","Y"":REM*********
3070  PRINT£1,"DI1,0;LB"MX+I*B;CHR$(3)
3080  NEXT
3090  X$="TIME-HOURS(G.M.T)":GOTO3110
3100  INPUT"X-AXIS LABEL?";X$
3110  L=INT(LEN(X$))
3120  X=INT(A1+HX*.5-50*L)
3130  Y=INT(A2-400*SY)
3140  PRINT£1,"PU;PA"X","Y";LB"X$;CHR$(3)
3150  RETURN:REM========
3160  REM*****Y AXIS INSTRUCTIONS****
3170  Y$="MEAN IRRADIANCE(W/M*M)":GOTO3190
3180  INPUT"Y-AXIS LABEL?";Y$
3190  L=INT(LEN(Y$))
3200  X=INT(A1-400*SX)
3210  Y=INT(A2+HY*.5-50*L)
3220  PRINT£1,"PU;PA"X","Y";DI0,1;LB"Y$;CHR$(3)
3230  IFS2<>0THENB=S2:REM B=STEPLENGTH
3240  M=INT((YM-MY)/B)
3250  X=A1
3260  PRINT£1,"PU;PA "X","A2";YT"
3270  Y=INT(B*KY)
3280  FOR I=1TOM
```

```
3290  PRINT£1,"PD;PRO,"Y";YT"
3300  NEXT
3310  PRINT£1,"PU;PA"X-200*SX","A2""
3320  FOR I=0TOM
3330  PRINT£1,"PA"A1-200*SX","A2-100*SY+I*Y""
3340  PRINT£1,"LB"MY+I*B;CHR$(3)
3350  NEXT
3360  RETURN
3370  REM=================
3380  REM-
3390  PS=1:GOTO3460
3400  PRINT£1,"DI1,0;"
3410  PRINT"DO YOU WISH THE POINTS TO BE JOINED
3420  PRINT:PRINT"    YES     KEY   1":PRINT
3430  PRINT:PRINT"     NO     KEY   2":PRINT
3440  GETP$:IFP$=""THEN3440
3450  PS=VAL(P$)
3460  PRINT"CHOOSE PLOTTING SYMBOL"
3470  GETSM$:IFSM$=""THEN3470
3480  L5=10:NX=0
3490  FOR I=1TON
3500  NX=NX+1
3510  X=INT((X(I)-MX)*JX+A1)
3520  Y=INT((Y(I)-MY)*KY+A2)
3530  IFNX<L5THENPRINT£1,"PA"X","Y";PD":GOTO3570
3540  NX=0:IFPS=1TTHEN3560
3550  PRINT£1,"SM"SM$";PA"X","Y";SM;":GOTO3570
3560  PRINT£1,"SM"SM$";PA"X","Y";SM;PD;"
3570  NEXT
3580  PRINT£1,"PU;":RETURN:REM*******
3590  REM==============
3600  REM==GRAPH HEADINGS===
3610  PRINT£1,"DI1,0"
3620  PRINT£1,"PU;PA "W1","W2""
3630  PRINT"TYPE HEADING LINE?"
3640  INPUTA1$:PRINT
3650  PRINT£1,"LB"A1$;CHR$(3)
3660  PRINT"IF ANOTHER LINE TYPE 12 OTHERWISE 02"
3670  GETZ$:IFZ$=""THEN3670
3680  IFZ$="0"THEN3730
3690  W2=W2-200*SY
3700  A1$=""
3710  PRINT£1,"PU;PA"W1","W2""
3720  GOTO3630
3730  RETURN
3740  REM================
3750  REM===HORIZONTAL GRAPHS ====
3760  GOSUB1270
3770  IFA$="1"THEN3810
3780  IFA$="2"THEN3990
3790  IFA$="3"THEN4300
3800  GOTO3760
3810  REM== ONE HORIZONTAL GRAPH ==
3820  A1=1500:A2=1200
3830  HY=4600:HX=6000
```

```
3840  W1=2000:W2=6400
3850  SX=1.0:SY=1.0
3860  PRINT£1,"PU;SI .15,.2"
3870  GOSUB4740
3880  GOSUB1450
3890  IFA$="0"THEN3950
3900  IFA$="1"THEN3920
3910  GOTO3880
3920  GOSUB2530
3930  GOSUB3380
3940  GOTO3880
3950  GOSUB3600
3960  GOSUB2450
3970  END
3980  REM=== ****  =====
3990  REM=== TWO HORIZONTAL GRAPHS ==
4000  A1=1200:A2=1200
4010  HX=4000:HY=4000
4020  W1=1100:W2=6300:W3=W2
4030  SX=.8:SY=.8
4040  PRINT£1,"PU;SI.14,.19"
4050  HD=INT(HL*.5)
4060  GOSUB4740
4070  GOSUB1450
4080  IFA$="0"THEN4140
4090  IFA$="1"THEN4110
4100  GOTO4070
4110  GOSUB2530
4120  GOSUB3380
4130  GOTO4070
4140  GOSUB3600
4150  REM ==========
4160  A1=A1+HD:W1=W1+HD:W2=W3
4170  GOSUB1340
4180  GOSUB4740
4190  GOSUB1450
4200  IFA$="0"THEN4260
4210  IFA$="1"THEN4230
4220  GOTO4190
4230  GOSUB2530
4240  GOSUB3380
4250  GOTO4190
4260  GOSUB3600
4270  GOSUB2450
4280  END
4290  REM== *** ======
4300  REM==THREE HORIZONTAL GRAPHS ==
4310  A1=1000:A2=2000
4320  HX=2500:HY=3000
4330  W1=800:W2=6000:W3=W2
4340  HD=INT(HL*.33)
4350  SX=.7:SY=.7
4360  PRINT£1,"PU;SI .12,.17"
4370  GOSUB4740
4380  GOSUB1450
```

```
4390  IFA$="0"THEN4450
4400  IFA$="1"THEN4420
4410  GOTO4380
4420  GOSUB2530
4430  GOSUB3380
4440  GOTO4380
4450  GOSUB3600
4460  REM ==========
4470  A1=A1+HD:W1=W1+HD:W2=W3
4480  GOSUB1340
4490  GOSUB4740
4500  GOSUB1450
4510  IFA$="0"THEN4570
4520  IFA$="1"THEN4540
4530  GOTO4500
4540  GOSUB2530
4550  GOSUB3380
4560  GOTO4500
4570  GOSUB3600
4580  REM ==========
4590  A1=A1+HD:W1=W1+HD:W2=W3
4600  GOSUB1340
4610  GOSUB4740
4620  GOSUB1450
4630  IFA$="0"THEN4690
4640  IFA$="1"THEN4660
4650  GOTO4620
4660  GOSUB2530
4670  GOSUB3380
4680  GOTO4620
4690  GOSUB3600
4700  GOSUB2450
4710  END
4720  REM=================
4730  REM== HORZ ROUTINES ====
4740  GOSUB2530
4750  GOSUB1540
4760  GOSUB1680
4770  GOSUB2950
4780  GOSUB3160
4790  GOSUB3380
4800  RETURN
4810  REM ===   ===
```

```
10      REM-PROG..(ADC TEST)..
20      REM***SINGLE CHANNEL TEST***
30      PRINT"""
40      PRINT  "                   ADCTEST"
50      PRINT""
60      PRINT"CONNECT PRECISION MILLIVOLT SOURCE ";
70      PRINT"TO   APPROPRIATE CHANNEL."
80      PRINT"INJECT MILLIVOLTS CORRESPONDING TO";
90      PRINT" 25 W/M2 AND ADJUST ZERO POT ";
100     PRINT"SO THAT DISPLAY  FLICKERS BETWEEN 0 AND 1."
110     PRINT""
120     PRINT"INJECT MILLIVOLTS CORRESPONDING TO ";
130     PRINT"1000 W/M*M AND ADJUST GAIN POT ";
140     PRINT"SO THAT DISPLAY SHOWS BETWEEN ";
150     PRINT" 4995 AND 5000"
160     PRINT"REPEAT UNTIL ZERO AND GAIN ";
170     PRINT"CORRECTLY    ADJUSTED."
180     PRINT""
190     PCR=59468:ADR=59426
200     POKEPCR,PEEK(PCR)AND 31 OR 224
210     PRINT"CHANNEL";:INPUTN
220     IFN>15THENGOTO210
230     PRINT"""
240     PRINT "        PRESS SPACE TO RESET"
250     POKEADR,N
260     POKEPCR,PEEK(PCR)AND 31 OR 192 :X=PEEK(59471)
270     POKEPCR,PEEK(PCR)AND 31 OR 224:Y=PEEK(59471)AND15
280     Z=(16*X)+Y
290     V=INT(1000*(Z/819))
300     PRINT"                 "N"               "
310     PRINT"          CHANNEL"N"="V
320     FORI=OTO 250:NEXT:PRINT ""
330     GETA$
340     IFA$=" "THEN360
350     GOTO260
360     PRINT""":GOTO210
```

APPENDIX ——— E

A typical printout of the output as given by program PRO4.(in section 6.5.5).

SOLAR RADIATION DATA RECORDED IN PHYSICS DEPARTMENT
UNIVERSITY OF ASTON IN BIRMINGHAM...(1981)

CHANNEL(10)-DIFFUSE HORIZONTAL..EPPLEY(9.77)
CHANNEL(11)-GLOBAL HORIZONTAL..EPPLEY(9.69)
CHANNEL(12)-GLOBAL 52 DEG INCLINE..EPPLEY(10.4)
CHANNEL(13)-GLOBAL HORIZONTAL-KIPP C.M.5 S-N THERM(11.1)
CHANNEL(14)-GLOBAL HORIZONTAL-KIPP C.M.7 E-W THERM(11.16)

DATA CHANNEL(S) SCANNING INTERVAL= 30 SECONDS
DATA AVERAGING AND RECORDING INTERVAL= 5 MINUTES
MEAN RECORDED DATA IN BRACKETS,E.G.-[*****]-

DATA SURVEY STARTED AT 11.03.81 TIME 19.30.00

HOURLY MEAN VALUES(W/M*M)-TIME G.M.T-HOURS
DATE= 12. 3.81

TIME	CH(10)	CH(11)	CH(12)	CH(13)	CH(14)
7	35[33]	33[32]	27[26]	35[33]	36[34]
8	103[107]	100[105]	106[116]	107[112]	109[115]
9	153[152]	161[151]	187[168]	172[162]	175[165]
10	187[180]	205[184]	246[206]	218[195]	223[199]
11	227[230]	238[253]	295[322]	257[272]	260[277]
12	417[424]	494[497]	718[698]	529[532]	541[544]
13	406[390]	373[360]	527[521]	402[387]	404[392]
14	134[135]	122[124]	137[142]	131[134]	131[135]
15	291[276]	263[250]	391[367]	311[293]	281[267]
16	131[151]	119[134]	142[167]	130[147]	132[147]
17	41[43]	38[39]	41[43]	41[43]	41[43]

DAILY TOTALS OF RADIATION (WH/M*M) FOR;
CH(10)= 2125 [2121]
CH(11)= 2146 [2129]
CH(12)= 2817 [2776]
CH(13)= 2333 [2310]
CH(14)= 2333 [2318]

DATE= 13. 3.81
==============

TIME	CH(10)	CH(11)	CH(12)	CH(13)	CH(14)
7	26[25]	25[24]	22[22]	27[24]	28[25]
8	47[47]	44[44]	35[36]	46[46]	47[47]
9	80[80]	74[74]	59[58]	78[77]	78[78]
10	122[114]	111[103]	89[83]	117[110]	118[111]
11	119[122]	108[112]	82[87]	115[118]	115[118]
12	68[67]	63[62]	50[48]	66[65]	66[66]
13	175[174]	158[157]	144[144]	171[170]	172[170]
14	112[118]	102[108]	86[88]	110[114]	111[114]
15	44[43]	41[41]	34[33]	44[43]	45[44]
16	63[64]	58[59]	50[51]	63[63]	63[64]

DAILY TOTALS OF RADIATION (WH/M*M) FOR;
CH(10)= 856 [854]
CH(11)= 784 [784]
CH(12)= 651 [650]
CH(13)= 837 [830]
CH(14)= 843 [837]

RUN TOTALS (WH/M*M) FOR;
CH(10)= 2981 [2975]
CH(11)= 2930 [2913]
CH(12)= 3468 [3426]
CH(13)= 3170 [3140]
CH(14)= 3176 [3155]

DATA RECORDING FINISHED ON 13. 3.81 AT 16/29/47

SOLAR RADIATION DATA RECORDED IN PHYSICS DEPARTMENT
UNIVERSITY OF ASTON IN BIRMINGHAM...(1981)

CHANNEL(10)-CLEAR ..EPPLEY(9.77)-EPPLEYS AT 40 DEG
CHANNEL(11)-FILTER RG715 C/F 707NM..EPPLEY(9.69)
CHANNEL(13)-GLOBAL HORIZONTAL-KIPP C.M.5-(11.1)
CHANNEL(15)-FILTER RG630 C/F 623NM..EPPLEY(10.4)

DATA CHANNEL(S) SCANNING INTERVAL= 10 SECONDS
DATA AVERAGING AND RECORDING INTERVAL= 10 MINUTES

DATA SURVEY STARTED AT 12.08.81 TIME 18.23.00

HOURLY MEAN VALUES(W/M*M)-TIME G.M.T-HOURS

TIME	CH(10)	CH(11)	CH(13)	CH(15)
18	46	23	60	27
19	29	23	34	22

DAILY TOTALS OF RADIATION (WH/M*M) FOR;
CH(10)= 75
CH(11)= 46
CH(13)= 94
CH(15)= 49

DATE= 13. 8.81

TIME	CH(10)	CH(11)	CH(13)	CH(15)
6	36	23	39	23
7	59	27	70	34
8	213	110	239	138
9	242	121	281	154
10	188	91	223	117
11	285	142	325	181
12	418	214	442	271
13	340	172	372	219
14	401	209	417	265
15	181	85	214	111
16	184	90	220	115
17	111	53	133	68
18	47	26	56	30
19	34	23	46	23

DAILY TOTALS OF RADIATION (WH/M*M) FOR;
CH(10)= 2739
CH(11)= 1386
CH(13)= 3077
CH(15)= 1749

DATE= 14. 8.81
=============

TIME	CH(10)	CH(11)	CH(13)	CH(15)
5	24	23	31	22
6	63	30	105	38
7	207	104	227	131
8	351	182	358	229
9	428	218	401	275
10	250	121	287	156
11	142	64	157	84
12	192	92	241	118
13	232	112	254	145
14	110	50	137	65
15	146	69	194	89
16	54	30	72	35
17	78	39	92	48
18	34	23	42	23
19	24	23	27	22

DAILY TOTALS OF RADIATION (WH/M*M) FOR;
CH(10)= 2335
CH(11)= 1180
CH(13)= 2625
CH(15)= 1480

DATE= 15. 8.81
=============

TIME	CH(10)	CH(11)	CH(13)	CH(15)
6	39	23	47	23
7	108	54	133	68
8	249	132	289	166
9	357	186	361	233
10	684	368	594	457

DAILY TOTALS OF RADIATION (WH/M*M) FOR;
CH(10)= 1437
CH(11)= 763
CH(13)= 1424
CH(15)= 947

RUN TOTALS (WH/M*M) FOR;
CH(10)= 6586
CH(11)= 3375
CH(13)= 7220
CH(15)= 4225

DATA RECORDING FINISHED ON 15. 8.81 AT 10/25/08

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MEASUREMENT OF SPECTRAL DISTRIBUTION OF SOLAR RADIATION AND MATHEMATICAL MODEL VALIDATION

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