Applicability Of Angstrom's And Hotel's Correlation Formulae: Nigeria

BY

Olufemi J. Okeneye

AUGUST; 1997

APPLICABILITY OF ANGSTROM'S AND HOTTEL'S CORRELATION FORMULAE: NIGERIA

BY

OLUFEMI J. OKENEYE

DEPARTMENT OF PHYSICS, SCHOOL OF SCIENCE AND SCIENCE EDUCATION

A. T. B. U.

BAUCHI

BAUCHI STATE, NIGERIA

APPLICABILITY OF ANGSTROM'S AND HOTTEL'S CORRELATION FORMULAE: NIGERIA

BY

OLUFEMI J. OKENEYE

PROJECT SUBMITTED TO SCHOOL OF SCIENCE AND SCIENCE EDUCATION

ABUBAKAR TAFAWA BALEWA UNIVERSITY OF TECHNOLOGY BAUCHI

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF B. TECH (HONS) PHYSICS IN PHYSICS PROGRAMME

AUGUST, 1997

CERTIFICATION

We certify that this work was carried out by OLUFEMI JAMES OKENEYE in the department of Physics, Abubakar Tafawa Balewa University Bauchi, and has been approved by the examiners.

MR. F. W. BURARI
(SUPERVISOR)

DATE: 7/10/ 1997

13/10/97.

MAL. S. ALI
(AG. HOD PHYSICS)

DATE: __________ 1997

PROFESSOR E.J.D. GA BA
(DEAN SCHOOL OF SCIENCE)

DATE: 13/10/ 1997

DEDICATION

This Project is dedicated to my parents, MR & MRS TIMOTHY OLUBAYO OKENEYE to whom I owe a great deal through the Lord Jesus Christ.

ACKNOWLEDGEMENT

I am first and foremost grateful to God the father of our Lord Jesus Christ, who has showered His blessing upon me through His guidance, provision and protection throughout my study.

This work would have been a futile exercise without the assistance, guidance and interest shown by my able Supervisor, Mr F. W. Burari, who in spite of his schedule, still found time to supervise me in the course of my project. He not only encouraged and gave me valuable advice as a friend and lecturer, but was also patient to go through the work making necessary corrections and offered useful suggestions. I am grateful to him.

I appreciate the academic assistance and patience provided to me by the Acting Head of Department of Physics Programme, Mal. S. Ali and other lecturers of the department. My thanks to my able and humble colleague Sayomi, G. O. For his company.

I wish to acknowledge the love and care shown to me by my dear ones, Olushina, Olusegun, Oluwarotimi, Iyabode, Afolashade, Olugbenga, Bunmi. Taiwo, Kehinde and the Abosade's (Jemima, Dorcas, Peace), who were ever near to encourage me morally, financially and willingness to listen to me. I am also grateful for bearing all the inconveniences I might have caused during the course of study.

I ever remember the joy these ones brought my way in the course of my study, Mrs M. A. Adegbola, Bro W. Oguntulo, the Dani's family, the A.G.B.C. family and the NIFES family ATBU they are a blessing indeed.

Finally, my appreciation goes to my loving roommates, J. S. Gushit, Sam Danladi and N. Buge, my twin brother, N. J. Chuktu and the final year brethren 96/97. With love from me to all of you.

To Christ be the glory forever. Amen

OLUFEMI J. OKENEYE
AUGUST, 1997.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The applicability of the Angstrom's correlation equation in the determination of the average global solar radiation using hours of bright sunshine data available for the four locations in Eastern, Western, Northern and southern part of Nigeria have been considered.

The applicability is in relation to the Hottel's correlation equation which uses only the latitude angle and altitude (sea level) of the location to estimate their total global solar radiation.

Both the Angstrom's and Hottel's correlation equation gave - satisfactorily results which are useful for solar energy devices application in Nigeria.

CHAPTER ONE

INTRODUCTION

The availability of solar energy over the earth surface is not uniform. It is more abundant in some areas than others. The sun's shinest region on the earth lies between Lat 20^0 - 30^oN and south of the equator.

Solar energy occupies one of the most important places among the various possible alternative energy sources. The information on the solar radiation characteristic and relevant meterological parameters at any place is of great importance to solar engineers and architects for providing them with an estimate of the available solar energy.

Its availability in any location in the world can be evaluated by two methods. The first been measured data from radiation monitoring network and the other is based on the use of physical empirical formula and constants. The Angstrom's and Hotel's type correlations have been used in this study to obtain the proper value for the regression coefficients a and b of equation (1.0) for four towns in Nigeria, and the total global radiation of equation (1.1) for the same locations.

However, owing to the high cost of equipment and difficulty in maintaining such equipment in rural areas serves as a limitation in the provision of radiation data of such areas.

The Angstrom correlation relate the ratio of monthly average total radiation to the monthly average radiation for a clear day H_o, and the ratio of sunshine hours to day length. The equation are:-

$H/H_o = a + b\, S/S_0$ .... (1.0)

$I_t = I_b + I_d$ .... (1.1)

through, many models have been devised for the prediction of the amount of solar energy incident on a horizontal plane of the earth's surface, the most important radiation data, which is often needed is the long term average daily global radiation on a horizontal surface. One of the simplest, which also gives the smallest; percentage error, for the estimation of the monthly average global radiation is well - known as Angstrom type correction (1.0).

The main reason in employing the Angstrom type correlation for predicting global radiation. is in obtaining the proper values for the regression coefficients a and b of equation (1.0) for a give location. The coefficients a and b are found to vary not only in different parts of the world but even for nearby locations in the same region having similar geographical and climatological conditions.

A designer of solar devices will primarily be interested in this values for a given location to determine maximum outputs. The designer must also know the total monthly, seasonal, or annual radiation to determine the long-time device output. If storage is included in a device design. the designer also needs to know about the frequency of cloudy and clear periods. by using clearness index equation (1.2) in order to optimize the device designed.

$$K = H/H_0 \quad \ldots\ldots (1.2)$$

The wider world requires that in as much a solar device is designed at a particular region it should work in another with similar constants and climatic condition. In

1.1.0 LITERATURE REVIEW

The world meteorological organisation (1968) has defined the properties required for different classes of instruments according to the accuracy and precision needed for different applications. The output from an instrument with uniform response will be proportional to the cosine of the angle between the incoming radiation and the normal to the sensor. Deviation from the cosine response are the main cause of uncertaining in the use of existing instruments. According to Gillet (1980) and McGregon the instruments used have an error of about ± 5%, rising to as much as ±15% for radiation coming from low latitudes.

Several equations based on empirical correction have been developed to cover the deficiencies in the records. The ratio of diffuse to global radiation has been correlated with the ratio of the global to extraterrestrial radiation by several authors. A commonly used correlation for estimating diffuse (hehce also the direct) radiation was proposed by page (1961). Powel (1979) and Leilotreported that page's equation gave better results. Other models have been proposed and Erbs(1980) has summarised and compared the various formula. Their accuracy decreases and their variance increase as the time interval is reduced. Thus the estimate of mean monthly diffuse radiation from the mean monthly global is quite accurate, but for hourly estimates large errors can occur. However since the long term average is good, the effect of such errors on the evaluation of system performance is not too serious.

Angstrom (1924) was the first to propose a correlation between the daily global radiation, the number of sunshine hours and the maximum values of these quantities. Igbal (1979) have also considered such correlations. It appears that the coefficient in the correlations vary from site to site. (4)

The importance of such empirical estimate is derived from the facts that the meteorological data are available for many locations in the country as they are easily measurable, and worked on by some individuals. Bamiro (1983) for Ibadan, Ezkwe and Ezeiko (1981) for Nsukka. Arunze and Obi (1983) for Zaria, Kano and Jos. By combining the measured and empirical data of radiation with theoretical model of estimation such as derived by Ezeilo (1983) and Bamiro (1981, 1983), a solar map of Nigeria in term of clearness index K was constructed. It is undoubtedly a very resource base for the entire country (2).

1.1.2 ENERGY FROM THE SUN

Solar energy is a very large, in-exhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW which is many thousands of time larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle energy needs of the world is on a continuing increase basis. This makes it one of the most promising of the unconvetional energy sources.

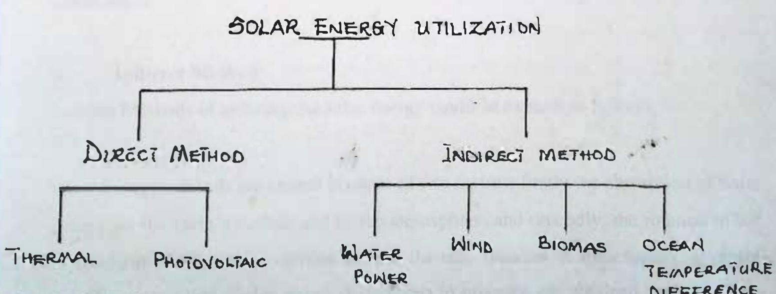
It has two other factors in its favour, firstly unlike fossil fuels and nuclear power, it is an environmentally clean source of energy. Secondly it is free available in adequate quantities in almost all parts of the world where people live.

However, there are some problems associated with its use. The main problem is that it is a dilute source of energy. Even in the hottest regions on earth, the solar radiation flow available rarely exceeds $1KW/M^2$, which is a low value for technological utilization. Consequently, large collection areas are required in many applications and these result in excessive costs.

One other problem associated with the use of Solar energy is that its availability varies widely with time. The variation in availability occurs daily because of the earth's orbit around the sun. In addition, variations occur at a specific location because of local weather conditions.

1.1.3 SOLAR ENERGY UTILIZATION

Solar energy utilization can be divided into direct and indirect methods. Direct method can be subdivided into two(2) and indirect into four (4)



i DIRECT METHOD

Thermal Collection: This is the mode of energy transfer for Solar devices which utilize the heating effect of solar radiation. The principle usually followed is to expose a dark surface to Solar radiation so that the radiation is absorbed. A part of the absorbed radiation is then transferred to a fluid like air or water. When no optical concentration is done, the device in which the collector is achieved is called a flat - plate collector. The flat-plate collector is the most important type of solar collector, because it is simple in design, has no moving parts and requires little maintenance. It can be used for a variety of applications in which temperatures ranging from 40^0c to about 100^0c are required.

Thermal applications are in the form; water heating, space heating, power generating, space cooling and refrigeration, Distillation and Drying.

Photovoltaic Conversion:- In photovoltaic Conversion, the Solar radiation falls on devices called Solar cells which convert the sunlight directly into electricity. The principal advantages associated with solar cells are that they have no moving parts, requires little maintenance and work quite satisfactorily with beam or diffuse radiation. In the future, as costs of productions are reduced, it is possible that they may become one of the principal sources of electricity power for localized use.

Although costly, arrays of solar cells suitably mounted on panels are already being used extensively to supply electricity for many small commercial and agricultural applications in remote areas far from power generations. A typical application is the scientific calculations.

ii. Indirect Method

Indirect Methods of utilizing the solar energy could be explain as follows;

Wind Energy:- Winds are caused because of two factors, firstly the absorption of Solar energy on the earth's surface and in the atmosphere, and secondly, the rotation of the earth about it axis and its motion around the sun. Because of thesefactors, alternate heating and cooling cycles occur, differences in pressure are obtained, and the air is caused to move. The potential of wind energy as a sources of power is large. This can be judge from the fact that the energy available in the winds over the earth's surface is estimated to be $1.6x10^7$ MW. Which is of the same order of magnitude as the present energy available is free and clean.

Biomass:- Plant matter created by the process of photo-synthesis is called biomass. Photosynthesis is a naturally occurring process which devices its energy requirement from solar radiation. In its simplest form, the reaction of this process can be represented as follows:

$$H_20 + CO_2 + Energy \rightarrow CH_2 0 + 0_2$$

It is seen that in the process, water and carbon dioxide are converted into organic material.

The term "biomass" includes all plant life trees, agricultural plants, bush, grass and algae. Thus, it may be obtained from forecasts in a planned or unplanned fashion or from agricultural lands. By extension, the term is also understood to include livestock waste.

There are variety of ways of obtaining energy from biomass resources. The direct way if the biomass resource happen to be free or plant is to burn it as a fuel either for domestic or commercial purpose.

The indirect way of using biomass is transforming it into a convenient usable fuel in solid, liquid or gaseous form, by a process known as pyrolysis, the hydrogen and oxygen in wood can be eliminated and solid fuel in the form of charcoal is obtained. Others forms of biomass convertable are Biogas through the anaerobic fermentation of wet livestock waster to biogas. Liquid fuel through gasification of plant matter followed by chemical synthesis.

Ocean Thermal Energy Conversion:- The utilization of the temperature difference which exist naturally between the upper and lower level of water in the ocean. Tropical oceans collect and store very large amount of Solar energy. Utilization of this energy with its associated temperature difference and its conversion into work forms the basis of ocean thermal energy conversion (OTEC) systems.

1.1.4 ABUNDANCE OF SOLAR ENERGY IN NIGERIA

Nigeria lies between the latitude of $4^{0}00'$ North, longitude $2^{0}2'$ and $14^{0}30'$ East and has daylight or sunshine hour of not less than 11hours per day. The amount of the annual solar radiation varies from about 45% of the maximum possible value outside the earth's atmosphere in Niger Delta to over 70% in the extreme North-East in Lake-Chad basin. [9].

It receives 5.08×10^{2}KWh of energy with just 5% efficiency are used to cover only 1% of the country's surface area than 2.54×10^{6}MWh of electrical energy can be obtained from solar energy. This amount of electrical energy is equivalent to 4.66million barrels of oil per day [10].

1.1.5 SCOPE of work

The Angstrom's and Hottel's correlations have been used to carry out estimation for stations whose weather conditions are different from those in Nigeria. However, effort have been made in this study to apply equations [1.1] and [1.2] to limited data for four towns in Nigeria. The towns were picked as a measure to carry out an approximate test for these three regions in the country.

Further more a comparison was carried out to show which of the region has more solar radiation for enhancement.

CHAPTER TWO

EXTRATERRESTRIAL SOLAR RADIATION

2.1.0 THE ATMOSPHERE

The atmosphere is an amazingly thin shell of air surrounding the earth as can be seen by the layer of clouds. More than half of the atmosphere is contained in a layer extending upwards. Only 6km (3.7 miles) from the surface of the earth. The atmosphere is a compressible gas that exhibits pressure and volume changes as the temperature varies. The winds resulting from these changes may bring forth a damaging storm or cleanse the air of harmful contaminants.

A proper understanding of the atmosphere and the weather it generates is necessary for enjoyment of life as well as for dealing effectively with the weather related facts of our environment. However, much remains to be learned about the atmosphere. The weather cannot be forecast perfectly because both the solution method for the formulac and the observations describing the atmosphere are imperfect.

2.1.1 COMPOSITION OF THE ATMOSPHERE

The major constituents are nitrogen and oxygen. The third most abundant gas, argon, comprises less than 1% of the total, while the next carbon dioxide is present in even smaller quantities. In addition to these gases, numerous other constitute the reminder of the atmosphere. Thus the name homosphere is applied to this layer in contrast to the hetero sphere above 80km where the gases are more stratified according to their weights.

2.1.2 CHARACTERISTIC OF THE ATMOSPHERE

The atmosphere can be so band that we are unaware of its presence, or it can be so violent that we are literally blown off our feast, soaked with rain, bombard by hailstones or covered with snow. The basic difference in its behaviours is determined by the distribution of sunlight, temperature, pressure and moisture.

2.1.3 VERTICAL TEMPERATURE DISTRIBUTION

Temperature is defined as the degree of hotness or coldness of a substance and is actually a measure of the internal energy of the substance. Vertical change in atmospheric temperature is a critical factor in many weather producing processes. Measurement have been made to provide accurate information on the average temperature distribution through the atmosphere. The global average air temperature decrease with the freezing level at a height of only 2.3km (7000ft). Considering the source of heat for the atmosphere to explain these observation. This makes the earth's surface the primary absorber of heat from the sun. Some of this heat is transferred into the atmosphere.

2.1.4 HEAT IN THE ATMOSPHERE

The radiation from the sun (Solar radiation) can be regarded as the only heat source for the seas and atmosphere. Heat is also available from high temperature in the interior of the earth as well as from the friction of tides, but all these taken together account for about only 1/10,000 of the heat brought by solar radiation and are thus negligible. Some other celestial bodies in the universe (the moon of the earth, etc) also give radiations to the surface of the earth, but this portion equals only 1/100,000,000 of the sun's contribution and is thus more negligible. In our consideration of the heat source for the earth's atmosphere, therefore it is sufficient only to take into account the extraterrestrial solar radiation.

2.2.0 SOLAR RADIATION

Radiation is a mode of transfer of energy in the form of electromagnetic waves.

Solar radiation of course is a mode of transfer of energy, and for our earth it is the most important mode of transfer of energy.

Broadly speaking solar radiation at earth's surface consist of two components, direct and diffuse solar radiation.

Direct Radiation:- is the solar radiation received from the sun without change of direction. (I_b) (2.0)

$$I_b = I_{sc}[1+0.033\cos(360N/365)][a_0 + a_1\exp(-k(\cos(\theta_z))]\cos(\theta_z) \quad\text{................[2.0]}$$

Diffuse Radiation:- is that Solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere, I_d. [2.1]

$$I_d = [0.027\, I_{sc}(1+0.033\cos(360N/365)) - 0.2939 I_b]$$

$\cos(\theta_z)$ [2.1]

The combination of these two is referred to as total radiation I_T [2.2]

$$I_t = I_b + I_d \quad [2.2]$$

where:

$a_0 = r^0 \times a^1_0$ $a^1_0 = 0.4237 - 0.00821\,(6\text{-}A)^2$

$a_1 = r1 \times a^1 1$ $a^1_1 = 0.5055 + 0.001\,(6+a)^2$

$k = rk \times k^1$ $k^1 = 0.2711 + 0.01858(2.5 - A)^2$

ro, r1 and rk are the climate corrections which equal 0.95; 0.98 and 1.02 respectively.

2.2.1 THE SPECTRA OF ELECTROMAGNETIC RADIATION

The electromagnetic radiation is composed of waves of oscillating electric and magnetic fields. Each wave is characterized by magnetic fields. Each wave is characterized by wavelength λ and a frequency v. In free space all the waves travel at the same speed, c = 2.9979 x 10^8 (m/s) . The frequency, wavelength, and speed of each wave are related by the equation [2.3]

$c = v\lambda$ ....[2.3]

The equation can be written in energy form with h = planck constant (6.6×10^{-34} JS)

$E = hv$ ....[2.4]

Where $V = c/\lambda$

Equation [2.4] can be written in terms of the ratio of speed of light to the wave length form

$E = h^{*}c/\lambda$ ....[2.5]

The higher the frequency is the shorter the wavelength and vice versa equation [2.3] ν is inversely proportional to λ ($\nu = c(1/\lambda)$). The entire electromagnetic spectrum is shown in fig '2.1' below, only narrow band of wavelengths, those in the range 400nm $< \lambda <$ 700nm, are visible on the violet end ($\lambda <$ 400nm) are called ultraviolet. These wavelengths bordering on the the red ($\lambda >$ 700nm) are the infrared. As we will see approximately half of the solar radiation is in the infrared, the invisible components make-up less than 40 percent of solar energy.

When the electromagnetic radiation is incident on the surface of a body, it can either be transmitted, reflected, or absorbed. If the body is opaque no transmission is possible. The radiant energy per unit time, unit area per unit wave length incident on the

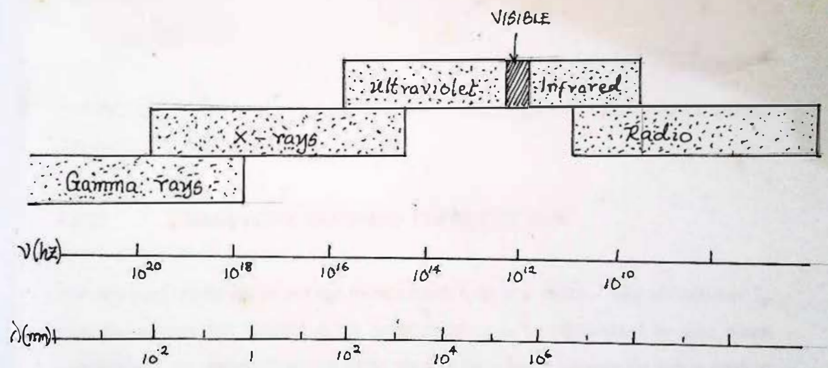


Fig 2.1: The electromagnetic Spectrum.

surface is called the incident spectra fluxe $F_\lambda^{(i)}$ similarly, the absorbed and reflected spectral fluxs are denoted by $F_\lambda^{(a)}$ and $F_\lambda^{(r)}$ respectively. The subscript n indicates that we are dealing with a single component wavelength. The total flux (f) in the distribution is

$$F = \int_0^\infty F_\lambda d\lambda \text{ .... [2.6]}$$

We will define the spectral absorptivity an and spectral reflectivity of a body's surface by

$$a_\lambda = \frac{F_\lambda^{(a)}}{F_\lambda^{(i)}} \quad \text{and} \quad \gamma_\lambda = \frac{F_\lambda^{(r)}}{F_\lambda^{(i)}} \text{ .... [2.7]}$$

We will define the spectral absorptivity an and spectral reflectivity of a body's surface by

$F = \int F\, n dn$ ....[2.6]

We will define the spectral absorptivity an and spectral reflectivity of a body's surface by

$$a_\lambda = \frac{F_\lambda^{(a)}}{F_\lambda^{(I)}} \quad \text{and} \quad r_\lambda = \frac{F_\lambda^{(r)}}{F_\lambda^{(I)}} \text{ ....[2.7]}$$

When the body is opaque, what is not reflected from the surface must be absorbed and we may write

$a_\lambda + r_\lambda = 1$ ....

Actually, a_λ and r_λ for a real surface, depend on the wavelength of the incident flux and the direction of the incidence of the radiation.

2.2.2 RADIATIVE EMISSION FROM THE SUN

We now take the model of our sun to be a black body at a steady - state temperature $T_\odot$ then the radiant flux emitted at the solar surface can be represented by i.a.. plank distribution. The observed spectral differ slightly from $B_\lambda(T)$ because the sun is neither in radiative equilibrium nor even in steady state. Nevertheless, is a black body curve corresponding to a temperature of $T_\odot \sim 5800k$,

Using the equation

$\lambda_{max} = \alpha / T$ .... [2.8]

The characteristic of wavelength of solar spectrum is $\lambda_{max} = 500nm$

and from

$\int B_\lambda(T)\, d\lambda = \sigma T^4$ {stefan - Boltzmann law } [2.9]

where α and σ are universal constants.

$B_\lambda(a)$ = planck's function.

And T_θ = black body temperature

It is found from calculation that the total flux leaving the surface of the sun is 6.416 x 10^7 W/M².

This radiation is diffuse (travelling in all direction). when it leaves the surface of the sun. The total radiant power emitted from the sun is obtained by multiplying the flux above [2.0] by the surface area of the sun

$P_\theta = F_\theta 4\pi R_\theta^2$ ....[2.10]

$(6.42 \times 10^7 W/M^2) 4\pi (6.96 \times 10^8 m)^2$

$\approx 3.9 \times 10^{26}$ w

where R_θ (radius of sun) = 6.96 x 10^8m

F_θ = 6.42 x 10^7 W/m²

Since the sun emits radiation isotropically, this enormous power called luminosity is emitted equally in all directions of space. As the distance from the sun increases, this power is spread over spherical surface of increasing area. consequently, the intensity varies inversely as the square of the distance from the centre of the sun. At a distance r the surface area is $4\pi r^2$ so that radiant flux (F) crossing such a surface is

$$F = \frac{P_\theta}{4\pi r^2} = \frac{4\pi R_\theta^2 F_\theta}{4\pi r^2}$$

Or

$$= \frac{R_\theta^2 F_\theta}{r^2} \text{ ....[2.11]}$$

Because the earth's distance from the sun varies throughout the year, the total flux reaching the earth also changes .

The value of the flux is called the solar constant is not actually a constant but varies with season and somewhat with solar activity.

2.2.3 VARIATION OF EXTRATERRESTRIAL RADIATION

It has been determined from analysis of radiation data that the variations in total radiation emitted by the sun are less than ±1.5%. For purposes of thermal processes that use energy in large fractions of the total solar spectrum and where the transmittance of the atmosphere is a major uncertainty, the emission of energy by the sun can be considered as constant.

Variations in earth-sun distance do, however lead to variations of extraterrestrial radiation flux in the range of ±3%.

2.2.4 SOLAR CONSTANT

This is the total energy intensity of extraterrestrial solar radiation, measured just outside the earth's atmosphere and integrated over the entire solar spectrum.

The numerical value has been obtained by assuming the solar spectrum to be that of a black body at ~ 1352 w/m². the value of the solar constant has been measured by various investigator to range from 1352 to 1395 w/m². The discrepancy amounts to approximately 2 percent. The one used in this work is 1367 w/m². [2.11].

2.3.0 ATMOSPHERIC EFFECTS ON SOLAR RADIATION

Solar radiation is considerably altered in its passage through the earth's atmosphere. The two principal mechanism causing these atmospheric alterations are absorption and scattering.

Atmospheric absorption of solar radiation

There are several atmospheric constituents which absorb part of the incoming solar radiation. The first of these is usually called ozone absorption, although the actual absorption is by both oxygen and ozone molecules. This absorption removes nearly all of the ultraviolet solar radiation. So that very little solar radiation with wave lengths less than 0.3 microns reaches the earth's surface.

It is known how much the quantity of atmospheric ozone varies. However, these variations do not cause variations in the intensity of solar radiation at the earth's surface of sufficient magnitude to be of concern to solar energy system designers.

The other primary absorber of radiation in the atmosphere is water vapor. It absorbs solar radiation in quite specific wavelength bands in the infrared region. Consequently, the spectral distribution of Extraterrestrial radiation contains several pronounced dips and peaks in the infrared region as shown in the figure [2.2].

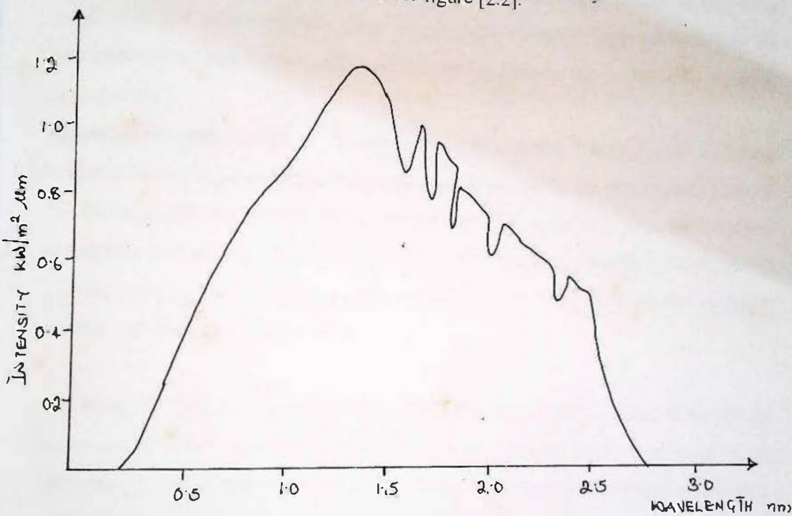


Fig 2.2 Approximate spectral distribution of solar radiation on earth with an air mass 2 atm.

The amount of water vapour in the atmosphere depends upon the local altitude, climate and season. The increased solar intensity at higher altitude locations is partly due to the smaller amounts of atmospheric water vapor at higher altitudes.

Atmospheric scattering of solar radiation: The atmospheric constituents primarily responsible for scattering are gas molecules, particulates, and water droplets. This scattering is fairly uniform with respect to direction. However, it is strongly wavelength dependent, and it affects short wavelength radiation moist. One consequent is that the scattered radiation eventually reaching the earth's surface from throughout the sky is characteristically blue.

Cloud effects on solar radiation: Clouds are a scattering agent of particular importance, clouds frequently reduce incoming radiation by as much as 80 - 90 percent by single and multiple scatterings thus effectively reflecting that amount of radiation back to space.

Because cloud distributions and types are highly variable, their effects on incoming radiation are also highly variable. Thus, clouds produce not only large reductions in the solar radiation available at the earth's surface, but in addition these reductions are quite unpredictable.

Atmospheric path length: The amount of atmospheric absorption or scattering affecting incoming solar radiation depends upon the length of the atmospheric path, or the thickness of the atmosphere, through which the radiation travels. Thus, the reduction in intensity of solar radiation at a location on the earth's surface depends not only on the varying composition of the atmosphere at that location, but also upon the locations altitude and upon the radiation angle.

Air Mass, M : The measure of the atmospheric path through which solar radiation must travel is called air mass M. An air mass value of (dimensionless) is assigned to an atmospheric path directly overhead at sea level. All other air mass values are assigned relative to this unit value.

The two factors which affects our mass for an atmospheric path are the direction of the path and the local altitude.

Solar Declination: The earth-sun vectors moves in the ecliptic plane, the angle between the earth-sun vector and the equatorial plane is called the solar declination angle, . By convention, is considered positive when the earth-sun vector points north-ward relative to the equatorial plane. The declination angle varies from -23.45 on Dec, the winter solstice, to +23.45 on June 22, the summer solstice.

Hour angle: In any time system, it is frequently convenient to express the time in degrees rather than hours. This is especially true for specifying the positions of bodies in space as function of time. The unit of angular measurement of time is the "hour angle". The basic convention is that 24 hours equals 360 hour angle degrees.

In solar energy, the solar hour angle is used extensively to express solar time, because it is directly related to the sun's position in the sky. The solar hour angle is measured from noon and is positive (-ve) before (after) solar noon.

Solar time varies with longitude, as well solar hour angles do also {2.12}.

Solar time = standard time + E + 4 (Lst - Loc) {2.12}

where E = the equation of time

Lst = the standard meridian for the local time zone

and Loc = the longitude of the location in question.

Solar incidence angles: The intensity of solar radiation on a surface depends upon the angle at which the sun's rays strike the surface. The intensity is proportional to the cosine of the angle between the rays and the surface. The intensity is proportional to the cosine of the angle between the solar rays and the surface normal.

2.40 ELEMENT OF ENERGY TRANSFER:

It is a law of nature (the 2nd law of thermodynamic) that the heat always tends to flow from the hotter to colder regions. There are three modes by which this transfer can occur, namely, conduction, convection and radiation.

Conduction is the transfer of heat through matter in which energy but not mass is transferred. The highly agitated atoms of warmer regions transfer some of their energy to their less agitated neighbours in cooler regions through atomic interactions. However, the atoms themselves are essentially fixed and cannot migrate through the material. The conduction process can be described as the diffusion of thermal energy in matter without the flow of mass.

In contrast, convection is the transfer of heat through matter produced by the transport of mass.

Consequently, convection occurs only in fluids, that is in liquids and gases. When one region of a fluid is made hotter than another, pressure and density gradients result. These gradients generate convection cycles that carry warmer fluids to cooler regions and vice versa. When the source of heating is removed, the cycles continue to mix the fluid until a uniform temperature is achieved. Solids cannot convect heat. However, some liquids both conduct and convect heat well.

Radiative heat transfer is unique in that it does not require any matter to transfer heat from warmer to colder regions. In fact, a vacuum is the most efficient medium for radiative transfer. Radiative transfer is produced by travelling electromagnetic waves. Any medium that does not transmit these waves will not permit the transfer of heat by radiation.

All three modes of heat transfer play an important role in the operation of solar heating devices.

Conduction of Heat:

Two surfaces of arbitrary size and shape are maintained at different temperatures, T_1 and T_2. Assume the region between them is filled with a uniform insulating material. Heat will flow from the warmer to the cooler surface through the insulator in a rather complicated pattern (fig. 2.3). The heat flow at any point within the insulator can be represented by the heat flux vector J whose magnitude gives the heat energy per unit time crossing unit area. Like radiative flux, the units of J are typically watts/m², cal/sec-cm², or Btu/hr-ft².

The vector J is determined by the law of conduction.

$J = -k\, {}^{dT}/_{ds}\, \hat{n}$ (2.13)

Where the expression $dT/ds(\hat{n})$ is called the temperature gradient and is written formally as ∇T. Heat is said to flow along the relative temperature gradient.

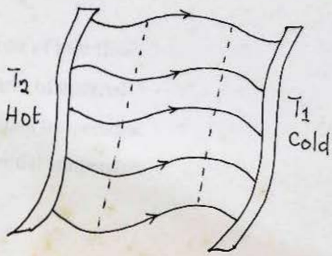


Fig.2.3 The steady - state heat flow pattern through a conductive medium.

Where n is a unit vector in the direction in which the temperature increases most rapidly, $dT/_{dx}$ is the rate of change of temperature with distance along that direction, and K is the interval conductivity of the insulator. The negative sign in Equation 2.13 suggests that heat flows in the direction in which the temperature decreases most rapidly with distance. Furthermore, the magnitude of the flow is proportional to the rate of decrease.

Two Surfaces within the insulator are considered as shown in fig (2.3) At the first surface: heat is entering the enclosed region while at the second is leaving. If more heat enters than leaves this region, temperatures at points within the interior will rise and vice versa. When the insulator is first inserted between the hot and cold surfaces the temperatures at points within the insulator do indeed change with time. However, eventually a steady state is reached in which the temperatures become constant in time. Hence, in the steady state, the rate heat flows crossing any set of surfaces which Completely enclose a region within an insulator must be zero.

The objective in conduction problems, is to compute the rate at which heat is being transferred from the hotter to the colder surface. The more complex the shape of the insulator is, the more difficult the solution. The Equation 2.14 can be properly written on considering some parameters.

$$J = \frac{Q}{A} = d\,(T_2 - T_1) \qquad 2.14$$

Where Q = rate of heat flow

A = area of material

T_2 = Final temperature

T_1 = Initial temperature.

CONVECTION

Convection plays a significant role in the transfer of heat from a solar panel to the surrounding air. It is important to distinguish between natural and forced convection. Natural convection occurs when the flow pattern are generated by instabilities produced by temperature gradients within the fluid. Forced convection is a mode of heat transfer that results from fluid flow produced by such external agents as pumps. or blowers.

Convection is a more complex phenomenon than conduction because of its dependence on the many parameters of the fluid involved in the heat transfer process due to its complexicity. a rigorous equation analogous to the conduction equation 2.13 is very difficult to establish. An attempt to obtain semiquantitative estimates for convective heat losses and establish those factors that affect convection coefficients.

The simplest case of natural convection is that which occurs from a large flat surface to an unbounded fluid such as still air. This process is particularly important in the heat transfer from the warm gazing of a solar heating panel to the cooler surrounding air. The amount of heat transferred from a heated surface to still air depends on the orientation of the surface and on such parameters as the density, humidity, viscosity, specific heat, and thermal conductivity of the air. Thus it is understandable why semiquantitative relationships obtained from experimental data are often the only expressions available to describe natural convection. It is always possible to express the heat flux leaving a surface to the cooler air using the relation.

$$J = Q/A = h_\infty (T - T_a) \quad \{2.15\}$$

Where T and T_a are the temperatures of the surface and the air, respectively, and h_∞ is called the open air convection or heat transfer coefficient. The subscript on h_∞ is used here to denote that the heat transfer is to an unbounded fluid. It is noted that Equation 2.15 does not suggest that the heat flux is strictly proportional to the temperature difference (T-Ta); h∞ itself depends on T and Ta, as well as on the other factors described. Based on experiments, it has been determined that the convection coefficient from a flat smooth surface to open air is approximately proportional to the fourth root of the temperature difference and can be estimated by

$$h_\infty \quad c(T-Ta)^{1/4} = c\Delta T^{1/4} \qquad 2.16$$

Where c = c(hor.) = 2.5w/m²-°c^{5/4} and c = c(vert) = 1.77 w/m²°c^{5/4} are constants for horizontal and vertical surfaces, respectively.

The dependence of h_∞ on ΔT for horizontal and vertical surfaces has been to vary from 3 to 5w/m²-°c^{5/4} and 4.5 to 7w/m²-°c^{5/4} respectively, over the temperature range ΔT = 10 to 60 °c.

With winds, the open air convection coefficients may be many times larger than those given for still air. Shielding collectors from winds will considerably reduce thermal losses and increase operating efficiency.

Radiative Heat Transfer from Heated Surfaces to the Sky

Whenever a surface is heated to some temperature T(in Kelvins), it will generally emit radiation to the environment. Furthermore, it will also absorb some thermal radiation from the surroundings. The net radiative flux from the surface can be expressed as the difference between the flux emitted and the flux absorbed.

$$J = J_{emit} - J_{abs}$$

The radiative flux emitted by a surface can be expressed as

$$J_{emit} = \epsilon\sigma T^4$$

where T is in Kelvins and ϵ is the average thermal emissivity of the surface over the thermal range of interest. Since T is typically ~ 300k, the thermal emissivity is represented by its average over the spectral region $2\mu m > \lambda < 20\mu m$ and must not be confused with the average for the solar spectrum ($0.3\mu m > \lambda < 2\mu m$). The absorbed flux is

$$J_{abs} = aJ_{inc}$$

where a is the thermal absorptivity of the surface and J_{inc} is the thermal flux falling on the surface. We can find the net radiative flux from the surface, on applying Kirchholff's relation and set $\epsilon = a$, we shall obtain 2.17.

$$J = \epsilon[\sigma T^4 - J_{inc}] \qquad 2.17$$

An application of this Equation 2.17 is that for a heated surface exposed to the open sky. The thermal flux incident on a surface from the sky, depends on both the temperature as well as on the capacity of the atmosphere to thermal radiation. The thermal flux from the sky can be expressed as $J_{inc} = \sigma T^4_{sky}$ where the sky temperature may be somewhat lower than the actual air temperature. Using this result in Equation 2.17, we obtained the net transfer of radiation from a heated surface to the sky is

$$J = \epsilon\sigma [T^4 - T^4_{sky}] \qquad 2.18$$

A similar result is obtained when a small heated object at a temperature T is placed in a large enclosure. The incident flux on the object becomes $J = \epsilon\sigma[T^4 - T^4_{inc}]$ 2.19

CHAPTER THREE

3.0 ESTIMATION, AND DATA ANALYSIS

3.1 INSTRUMENTS FOR MEASUREMENT

Solar radiation measurements are most often made of total (beam and diffuse) radiation, in energy per unit time per unit area, on a horizontal surface. Instruments for these measurements convert radiation to some other form of energy and provide a measure of the energy flux produced by the radiation. A brief reviews of such solar radiation instruments are discussed.

Barometers:- Are instruments used in determination of the atmospheric pressure.

Thermometer: Used for measuring the degree of hotness of an object.

Relative humidity: Is one out of the various ways in which the amount of water vapour in the atmosphere is measured. It is defined as the ratio of the actual vapour pressure to the saturation vapour pressure at the air temperature.

$$u = 100\ e/ew \quad (3.1)$$

where e = actual vapour pressure

ew = saturation vapour pressure

Sunshine recorders:- Are instruments designed to measure the duration of bright sunshine. The instrument fall into two main classes.

I. Those that utilize the heating power of the sun's radiation

ii. Those that utilize the chemical action produced by the visible and ultra - violet rays.

Solarimeters: Are instruments used in the determination of the radiation falling on a horizontal surface.

Actinometers: Are instruments used for the measurements of the direct solar radiation at normal incidence and for radiation from selected parts of the sky.

The solarimeter and actinometers are generally interpreted to be the same as pyranometer.

Pyranometer: An instrument for measuring total hemispherical solar (beam + diffuse) radiation, usually a horizontal surface. If shaded from the beam radiation by a shade ring, it measures diffuse radiation.

Pyrheliometer: An instrument for measuring direct solar radiation.

Cloud - cover observation: Which are made monthly at least hourly at weather observation stations around the world, different methods are involved in the measurement of cloud behaviours in space. Searchlight for cloud height is the most common method used in the most part of the world.

$$h = l \tan E \quad \text{----- (3.2)}$$

where E = angle of elevation in the vertical plane containing the searchlight

E' = observers point

$$h = l/\cot E + \cot E' \quad \text{----- (3.3)}$$

3.1.2 NOMENCLATURE

D = the day number

a . b = regression constants:

H = the monthly average of daily global radiation on a horizontal surface (w/m^2 - day)

Ho = the extraterrestrial solar radiation on a horizontal surface on an average day of each month (w/m^2 - day)

Ws - Sunset hour angle in degrees.

Ib = Direct radiation, w/m^2 - day

Id = Diffuse radiation, w/m^2 - day

It = total radiation, w/m² - day

del (δ) = Solar declination (degrees)

Lat (ϕ) = Latitude angle (degrees)

K = Clearness index (H/Ho)

n , n. = Day number at the start and end of a period.

S = Daily number of hours of bright sunshine (hr)

So = Maximum possible hours of bright sunshine (or day length) (hr)

Isc = Solar Constant, w/m² - day (1367)

A = distance above sea level, m

a + b = atmosphere transparency index

3.2.0 DATA AND DATA ANALYSIS

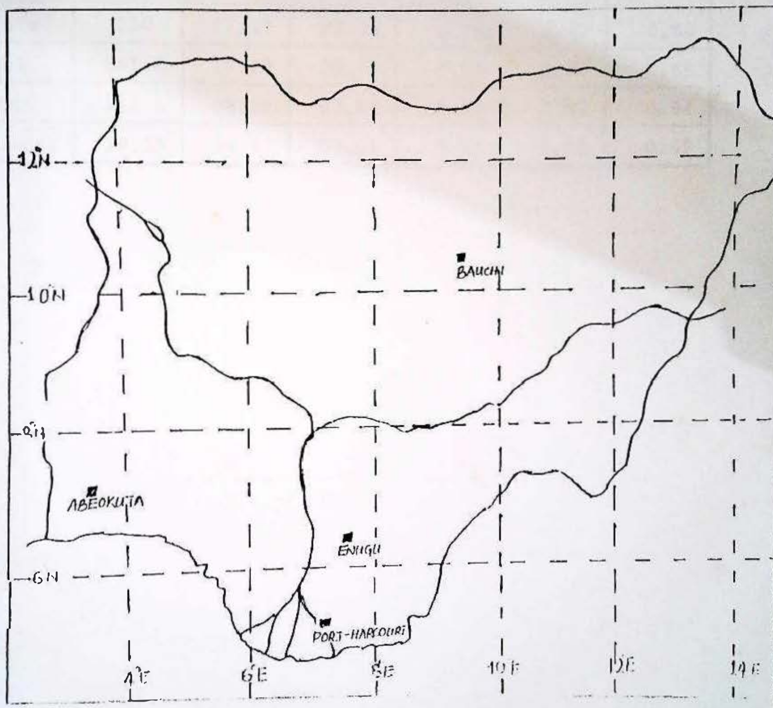
3.2.1 DATA USED

This study covers four different stations located in the East, North, South and West of Nigeria as shown in fig (3.1). The latitude, longitude and altitude of each of these stations used are given in table (3.1).

Climatological data which include sunshine hours (s), temperature (T), and relative humidity (R) for one of the station obtained from the Department of Metrological Services, Bauchi and had been used in the study tables (3.2 - 3.6).

The sunshine hours (s) for the remaining three stations were obtained from {2}.

Fig 3.1: Map of Nigeria showing four states in study.



;LE:-3.1

Geographical coordinates and regression parameters for four towns in Nigeria

Town	Geographical coordinates			Regression coefficients		
	Alt (m)	Lat.N	Long.E	a	-b	a+b
Abeokuta	150	07.17	03.33	0.19	0.41	0.60
Bauchi	661.0	10.28	09.75	0.25	0.43	0.68
Enugu	141.5	06.28	07.55	0.22	0.42	0.64
/hartcourt	19.55	04.77	07.02	0.18	0.41	0.59

MEASURED DATA OF GLOBAL SOLAR RADIATION IN BAUCHI TOWN
Monthly average insolation, Monthly average sunshine, Temperatue and Relative humudity
(1991 - 1995)

ABLE:-3.2 1991

Month	Radiation (mlt)	Sunshine (hrs)	TEMPERATURE		REL.HUMUDITY(%)	
			Max.	Min.	Max.	Min.
Jan	14.1	7.8	30.5	14.7	50	11
Feb	16.3	9.0	36.1	18.5	70	9
Mar	15.4	7.5	36.8	21.7	92	7
Apr	15.3	7.3	36.8	24.8	98	11
May	13.4	5.9	32.3	22.9	98	37
Jun	14.5	7.3	32.5	22.5	96	41
Jul	13.6	6.3	30.3	21.2	99	50
Aug	12.8	5.5	28.7	20.7	100	51
Sept	16.0	7.6	32.1	21.5	98	40
Oct	16.1	7.6	33.7	20.5	97	17
Nov	16.8	8.7	33.7	16.1	91	08
Dec	13.7	7.6	29.9	13.7	57	12

LE:-3.3 1992

onth	Radiation (mlt)	Sunshine (hrs)	TEMPERATURE		REL.HUMUDITY(%)	
			Max.	Min.	Max.	Min.
an	14.2	6.0	27.9	13.6	53	11
eb	17.2	8.0	31.9	15.0	48	07
ar	17.4	5.6	36.5	21.5	90	05
pr	17.4	6.6	37.4	23.4	97	03
ay	17.2	7.7	35.4	23.3	94	19
Jun	13.7	7.3	32.1	21.7	99	42
Jul	14.5	6.7	29.9	20.7	98	46
Aug	13.5	4.9	28.3	19.3	98	55
Sept	15.5	6.3	29.9	20.3	99	50
Oct	18.1	8.9	32.9	19.5	96	19
Nov	16.0	7.5	31.5	16.1	92	14
Dec	16.7	9.5	31.3	13.0	68	19

TABLE:-3.4 1993

Month	Radiation (mlt)	Sunshine (hrs)	TEMPARETURE		REL.HUMUDITY(%)	
			Max.	Min.	Max.	Min.
Jan	14.7	7.4	28.3	12.7	63	15
Feb	18.4	9.4	33.5	15.1	54	11
Mar	18.0	7.5	36.5	20.5	72	06
Apr	18.7	7.3	38.6	23.3	90	08
May	17.4	8.1	36.7	24.1	92	16
Jun	17.1	8.0	32.9	22.3	97	36
Jul	14.8	6.8	30.3	21.0	98	37
Aug	14.8	xx	29.3	20.6	98	52
Sept	16.3	7.5	31.3	20.7	98	41
Oct	17.9	7.6	33.3	20.7	93	19
Nov	17.8	9.4	34.7	16.9	86	15
Dec	14.9	xx	30.9	14.6	63	15

TABLE:-3.5 1994

Month	Radiation (mlt)	Sunshine (hrs)	TEMPERATURE		REL.HUMUDITY(%)	
			Max.	Min.	Max.	Min.
Jan	15.9	xx	30.9	14.5	59	12
Feb	16.4	xx	32.9	16.2	50	07
Mar	20.4	8.0	38.2	20.5	45	07
Apr	16.4	4.9	xx	24.1	76	16
May	17.1	7.5	xx	23.3	xx	xx
Jun	14.9	7.0	xx	21.7	93	34
Jul	13.4	5.5	xx	20.7	97	43
Aug	12.5	4.4	xx	20.0	97	56
Sept	15.0	5.9	xx	20.4	97	47
Oct	16.8	7.9	xx	20.7	96	24
Nov	17.5	9.4	xx	15.2	86	14
Dec	15.5	6.6	xx	12.5	57	16

TABLE:-3.6 1995

Month	Radiation (mlt)	Sunshine (hrs)	TEMPERATURE		REL. HUMUDITY (%)	
			Max.	Min.	Max.	Min.
Jan	15.3	8.2	31.6	12.5	49	13
Feb	17.8	8.9	32.5	14.4	61	16
Mar	19.0	8.2	38.3	xx	72	06
Apr	19.5	6.4	38.9	xx	95	06
May	16.9	7.9	36.3	xx	92	15
Jun	16.8	7.5	34.1	xx	95	24
Jul	15.4	6.3	31.3	xx	95	48
Aug	14.9	6.0	30.3	20.6	98	54
Sept	17.2	6.7	30.7	20.8	98	50
Oct	19.5	7.4	33.2	21.2	98	26
Nov	18.2	9.2	33.0	15.7	92	19
Dec	17.5	10.2	33.2	14.4	88	21

TABLE:-3.7
Relevant meteorological data and solar radiation data for

Bauchi, "LAT.10.28N , LONG.09.75E and Alt.661m"

Month	S	So	Ho	S/So	REG.COEFF.		H	H/Ho	K(%)
					a	b			
Jan	7.35	11.47	9857.04	0.64	0.25	0.43	5224.24	0.53	53
Feb	8.83	11.67	10196.57	0.76	0.28	0.44	6219.91	0.61	61
Mar	7.36	11.94	10334.42	0.62	0.25	0.43	5373.90	0.52	52
Apr	6.50	12.23	10040.89	0.53	0.23	0.42	4518.40	0.45	45
May	7.42	12.47	9496.49	0.60	0.24	0.43	4748.25	0.50	50
Jun	7.42	12.58	9148.08	0.59	0.24	0.43	4482.56	0.49	49
Jul	6.32	12.53	9275.87	0.50	0.22	0.42	3988.25	0.43	43
Aug	5.20	12.33	9758.54	0.42	0.20	0.41	3610.66	0.37	37
Sept	6.80	12.05	10163.76	0.56	0.23	0.42	4776.97	0.47	47
Oct	7.88	11.76	10176.52	0.67	0.26	0.43	5597.09	0.55	55
Nov	8.84	11.52	9892.11	0.77	0.28	0.44	6133.11	0.62	62
Dec	8.48	11.40	9698.59	0.57	0.28	0.44	5916.14	0.61	61

TABLE:-3.8

Relevant meteorological data and solar radiation data for Abeokuta, "LAT.07.17N , LONG.03.33E and Alt.150m"

Monht	S	So	Ho	S/So	REG. COEFF		H	k	k(%)
					a	b			
Jan	5	11.6	9958	0.43	0.2	0.41	3784	0.38	38
Feb	5.35	11.8	10291	0.45	0.21	0.42	4116	0.4	40
Mar	5.53	12	10422	0.46	0.21	0.42	4377	0.42	42
Apr	5.55	12.2	10125	0.46	0.21	0.42	4050	0.4	40
May	5.9	12.3	9580	0.48	0.22	0.42	4024	0.42	42
Jun	4.3	12.4	9232	0.35	0.18	0.41	2954	0.32	32
Jul	3.03	12.2	9359	0.24	0.16	0.4	2443	0.26	26
Aug	2.15	12.2	9841	0.18	0.14	0.39	2067	0.21	21
Sept	3.05	12	10249	0.25	0.16	0.4	2665	0.26	26
Oct	4.15	11.8	10267	0.35	0.18	0.41	3286	0.32	32
Nov	5.73	11.7	9990	0.49	0.22	0.42	4296	0.43	43
Dec	6	11.6	9801	0.52	0.22	0.42	4313	0.44	44

TABLE:-3.9

Relevant meteorological data and solar radiation data for Enugu "LAT.06.28N, LONG.07.55E and Alt.141.50"

Month	S	So	Ho	S/S o	REG.COEFF		H	K —	K (%)
					a	b			
Jan	6.90	11.7	9980	.59	.24	.43	4890	.49	49
Feb	6.70	11.8	10312	.57	.24	.43	5053	.49	49
Mar	5.25	12	10441	.44	.21	.42	4072	.39	39
Apr	5.83	12.1	10143	.48	.22	.42	4260	.42	42
May	5.94	12.3	9598	.48	.22	.42	4031	.42	42
Jun	5.37	12.4	9250	.43	.20	.41	3481	.38	38
Jul	4.15	12.3	9377	.34	.18	.41	2997	.32	32
Aug	3.72	12.2	9859	.30	.17	.40	2759	.29	29
Sept	3.71	12	10267	.31	.17	.40	3018	.29	29
Oct	5.36	11.9	10288	.45	.21	.42	4174	.40	40
Nov	7.23	11.7	10012	.62	.25	.43	5177	.52	52
Dec	7.20	11.6	9824	.62	.25	.43	5077	.52	52

BLE:-3.10
Relevant meteorological data and solar radiation data for

Port-harcourt "LAT.4.77N, LONG.07.02E and Alt.19.55m"

onth	S	So	S/So	Ho	REG.COEFF.		H	k	K(%)
					a	b			
Jan	4.79	11.8	.41	10012	.20	.41	3805	0.38	38
Feb	5.00	11.9	.42	10341	.20	.41	3826	0.37	37
Mar	4.15	12	.35	10469	.18	.41	3350	0.32	32
Apr	4.58	12.1	.38	10169	.19	.41	3559	0.35	35
May	4.5	12.2	.37	9623	.19	.41	3271	0.34	34
Jun	3.13	12.3	.26	9275	.16	.40	2112	0.26	26
Jul	2.09	12.2	.17	9402	.14	.39	1974	0.21	21
Aug	2.59	12.2	.21	9884	.15	.40	2273	0.23	23
Sept	2.2	12	.18	10294	.14	.39	2162	0.21	21
Oct	3.14	11.9	.26	10316	.16	.40	2682	0.26	26
Nov	4.7	11.8	.40	10044	.20	.41	3616	0.36	36
Dec	5.3	11.7	.45	9857	.21	.42	3943	0.40	40

3.2.2 DATA ANALYSIS AND RESULTS

Equations 1.0 and 1.1 have been used in this study for the first and second method to evaluate the So, Ho, w2, (Del) in tables (3.11 - 3.14), and Ib, Id and It tables (3.15 - 3.18) in both cases using a Computer program in quick basic {APPENDIX A AND B}.

The values of the regression coefficients a and b in equation [1.0] were evaluated from values of H/Ho and S/So. The clearness index which is k(H/Ho) as in table (3.7 - 3.10). Using the following equations (3.4 and 3.5)

$$a = 0.1 + 0.24\ S/So \quad (3.4) \quad [12]$$

$$b = 0.38 + 0.08\ S/So \quad (3.5) \quad [12]$$

The graphs of the percentage clearness index were drawn for the four towns, as to determine the atmospheric transparency of these stations (fig 3.2 - 3.5) and that of the total global solar radiation (fig. 3.6 - 3.9).

3.3 DISCUSSION OF RESULTS

The annual regression coefficient a and b were calculated table (3.1). The regression coefficient a represents the fraction of H reaching the groundon a completely cloudy day. It essentially depends on local climatic conditions. The coefficient b represents the part of H_o absorbed by clouds when the sky is completely covered. It depends on the thickness of the cloud. High values of b correspond to strong diffusion by cloud cover. The more humid the atmosphere is and the suspended solid and liquid particles, the least light reaches the ground as a result of increased attenuation.

For the lower value of b, the amount of diffused radiation by cloud is minor. The sum of the regression coefficients (a+b) is defined as the atmospheric transparency cloudiness index for global radiation under perfectly clear sky conditions. The higher the values of a + b (about 1), the lower the liquids and solids particles content and the less the absorption of the incident energy. Conversely, the lower the values of a + b (about 0), the less transparent the atmosphere is due to high concentration of liquids and solids particles. Fig 3.2 - 3.5. The higher the value of sunshine duration, the higher the value of H/Ho (K), the clearer the atmosphere.

Fig 3.6 - 3.9. show the mean monthly total global radiations for the four towns. The pattern of fluctuations of radiation is the same for all the locations. Peak total global solar radiation occurs in December and January. It is observed that Bauchi has the highest total global solar radiation of 472690 w/m² - day and Port Harcourt with lowest 2431.77 w/m² - day. In this case, the Hottel's correlation method (1.1) is useful to calculate solar radiation when no measured data are available. The data required in applying this method is Latitude angle and altitude above sea level.

ABLE:-3. 11 ABEOKUTA: LAT. 7.17N

Month	Ho	Ws2	So	del2
Jan	9957.65	87.23	11.63	-20.84
Feb	10290.66	88.28	11.77	-13.31
Mar	10422.06	89.7	11.96	-2.37
Apr	10124.93	91.21	12.16	9.51
May	9580.06	92.44	12.33	18.82
Jun	9232.04	93.04	12.41	23.08
Jul	9359.22	92.76	12.37	21.09
Aug	9841.35	91.7	12.23	13.27
Sept	10248.7	90.25	12.03	1.97
Oct	10267.31	88.74	11.83	-9.88
Nov	9990.4	87.49	11.66	-19.07
Dec	9801.34	86.9	11.59	-23.10

TABLE:-3.12 BAUCHI: LAT. 10.28N

Month	Ho	Ws2	So	del2
Jan	9857.04	85.99	11.47	-20.84
Feb	10196.57	87.52	11.67	-13.31
Mar	10334.42	89.57	11.94	-2.37
Apr	10040.89	91.74	12.23	9.51
May	9496.49	93.51	12.47	18.82
Jun	9148.08	94.37	12.58	23.08
Jul	9275.87	93.96	12.53	21.09
Aug	9758.54	92.44	12.33	13.27
Sept	10163.76	90.36	12.05	1.97
Oct	10176.52	88.17	11.76	-9.88
Nov	9892.11	86.36	11.52	-19.07
Dec	9698.59	85.51	11.40	-23.10

LE:-3.13 ENUGU: LAT. 06.28N

Month	Ho	Ws2	So	del2
Jan	9980.22	87.58	11.68	-20.84
Feb	10311.68	88.50	11.80	-13.31
Mar	10441.46	89.74	11.97	-2.37
Apr	10143.33	91.06	12.14	9.51
May	9598.21	92.14	12.29	18.82
Jun	9250.22	92.67	12.36	23.08
Jul	9377.29	92.42	12.32	21.09
Aug	9859.42	91.49	12.20	13.27
Sept	10267.43	90.22	12.03	1.97
Oct	10287.54	88.89	11.85	-9.88
Nov	10012.44	87.80	11.71	-19.07
Dec	9824.41	87.29	11.64	-23.10

BLE:-3.14 PORT-HARCOURT: LAT. 04.77N

Month	Ho	Ws2	So	del2
Jan	10012.17	88.17	11.76	-20.84
Feb	10341.30	88.86	11.85	-13.31
Mar	10468.59	89.80	11.97	-2.37
Apr	10168.78	90.80	12.11	9.51
May	9623.11	91.62	12.22	18.82
Jun	9275.07	92.03	12.27	23.08
Jul	9402.03	91.84	12.24	21.09
Aug	9884.32	91.13	12.15	13.27
Sept	10293.52	90.16	12.02	1.97
Oct	10315.99	89.16	11.89	-9.8
Nov	10043.6	88.34	11.78	-19.07
Dec	9857.10	87.95	11.73	-23.10

E: -3.15 ABEOKUTA: LAT.07.17N, LONG.03.33E, ALT.150m

Month	Ib	Id	It
Jan	228590.8	38.067	228628.9
Feb	226768.1	37.764	226805.9
Mar	223630.1	37.241	223667.3
Apr	219877.5	36.616	219914.1
May	216601	36.071	216637.1
Jun	2146774.5	35.75	214710.3
Jul	214632.9	35.743	214668.7
Aug	216516.7	36.057	216552.7
Sept	219762.7	36.597	219799.3
Oct	223515.9	37.222	223553.1
Nov	226764.9	37.763	226802.6
Dec	228625.1	38.073	228663.2

E:-3.16 BAUCHI: LAT.10.28N, LONG.09.75E, Alt.661.50m

Month	Ib	Id	It
Jan	4725545	38.067	4725582
Feb	4687864	37.764	4687903
Mar	4622994	37.241	4623030
Apr	4545419	36.616	4545455
May	4477685	36.071	4477722
Jun	4437860	35.75	4437894
Jul	4436998	35.743	4437035
Aug	4475941	36.057	4475978
Sept	4543045	36.597	4543081
Oct	4620633	37.222	4620670
Nov	4687797	37.763	4687835
Dec	4726253	38.072	4726290

E:-3.17, ENUGU: LAT.06.28, LONG.07.55, Alt.141.50m

Month	Ib	Id	It
Jan	202465.9	38.067	202503.9
Feb	200851.5	37.764	200889.3
Mar	198072.1	37.241	198109.3
Apr	194748.4	36.616	194785
May	191846.4	36.071	191882.5
Jun	190140.1	35.750	190175.8
Jul	190103.2	35.743	190139
Aug	191771.6	36.0565	191807.7
Sept	194646.7	36.597	194683.3
Oct	197970.9	37.222	198008.1
Nov	200848.7	37.763	200886.4
Dec	202496.3	38.073	202534.3

LE:-3.18, P/HARCOURT: LAT.04.77N, LONG.07.02E,Alt.19.55m

Month	Ib	Id	It
Jan	2589.41	38.067	2627.48
Feb	2568.77	37.76	2606.53
Mar	2533.22	37.24	2570.46
Apr	2490.71	36.62	2527.33
May	2453.60	36.071	2489.67
Jun	2431.77	35.75	2467.52
Jul	2431.30	35.74	2467.04
Aug	2452.64	36.06	2488.70
Sept	2489.41	36.60	2526.01
Oct	2531.93	37.22	2569.15
Nov	2568.73	37.76	2606.49
Dec	2589.80	38.07	2627.87

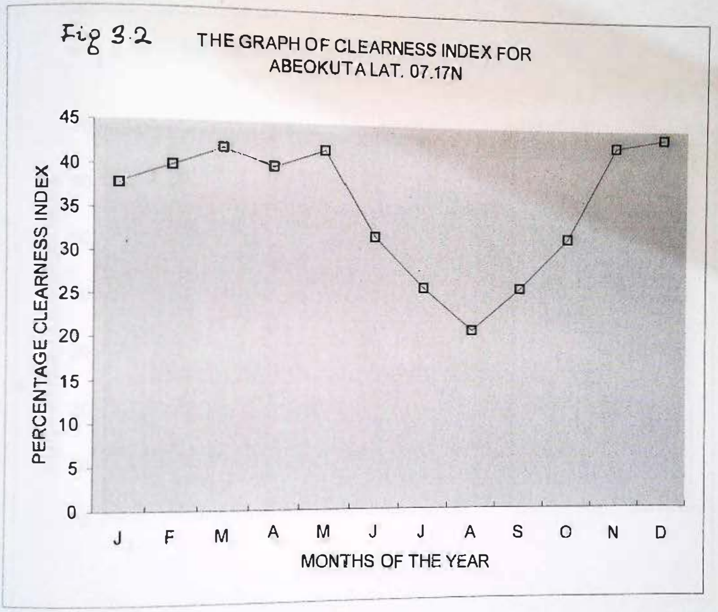
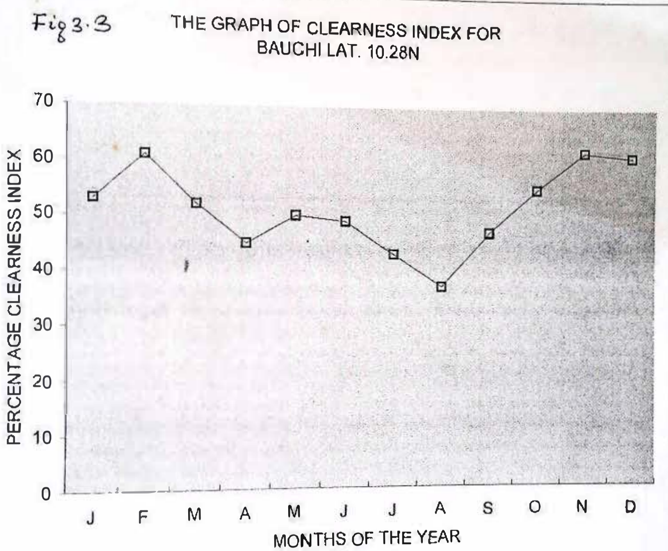


Fig 3.2
THE GRAPH OF CLEARNESS INDEX FOR
ABEOKUTA LAT. 07.17N
PERCENTAGE CLEARNESS INDEX
45
40
35
30
25
20
15
10
5
0
J F M A M J J A S O N D
MONTHS OF THE YEAR

Fig 3.3


THE GRAPH OF CLEARNESS INDEX FOR
BAUCHI LAT. 10.28N
PERCENTAGE CLEARNESS INDEX
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS OF THE YEAR

THE GRAPH OF CLEARNESS INDEX FOR
ENUGU LAT. 06.28N

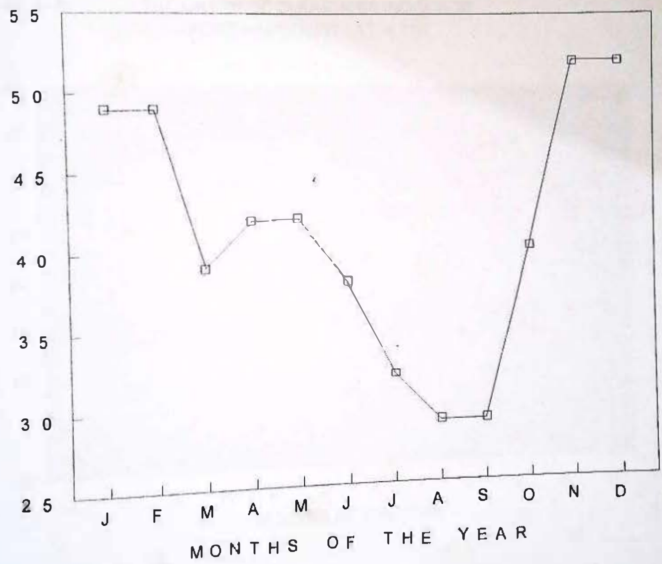


Fig 3.4

Fig 3.5

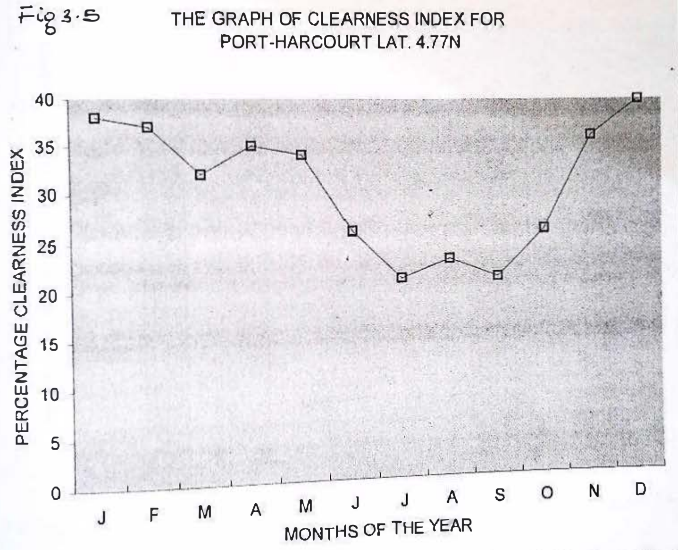

THE GRAPH OF CLEARNESS INDEX FOR
PORT-HARCOURT LAT. 4.77N
PERCENTAGE CLEARNESS INDEX
40
35
30
25
20
15
10
5
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS OF THE YEAR

Fig 3.6

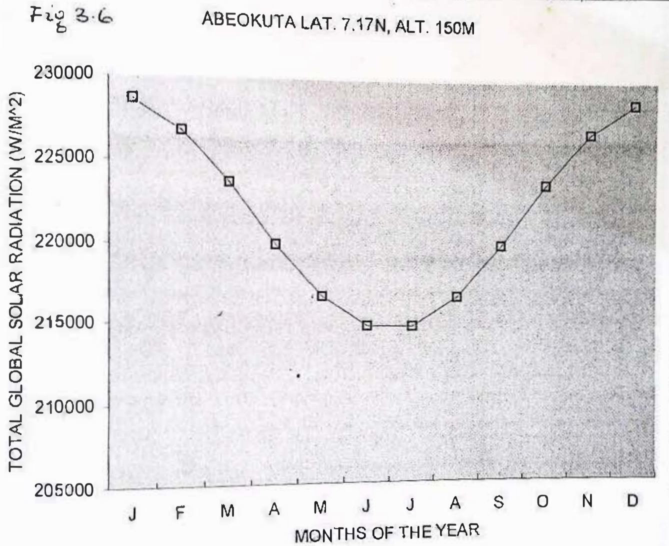

ABEOKUTA LAT. 7.17N, ALT. 150M
TOTAL GLOBAL SOLAR RADIATION (W/M^2)
230000
225000
220000
215000
210000
205000
J F M A M J J A S O N D
MONTHS OF THE YEAR

Fig 3.7

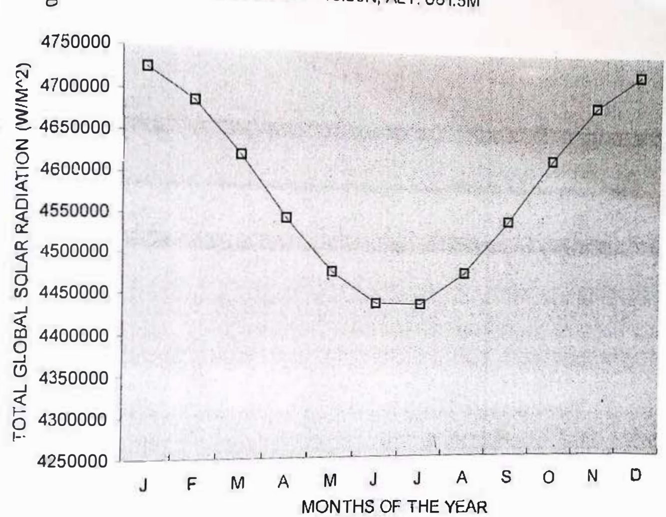

BAUCHI LAT. 10.28N, ALT. 661.5M
TOTAL GLOBAL SOLAR RADIATION (W/M^2)
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
J F M A M J J A S O N D
MONTHS OF THE YEAR

Fig 3.8

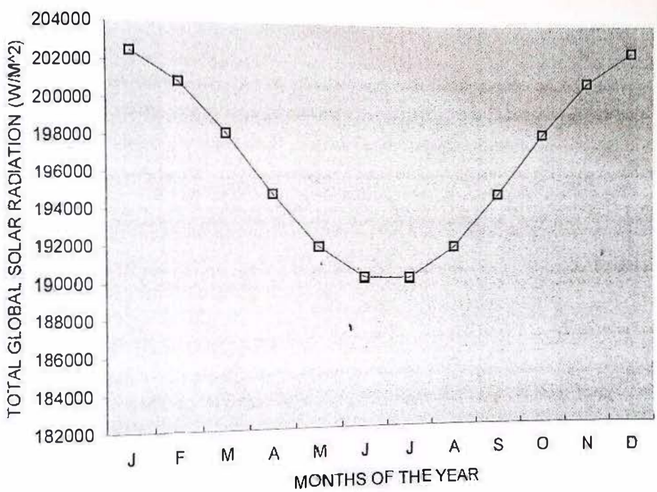
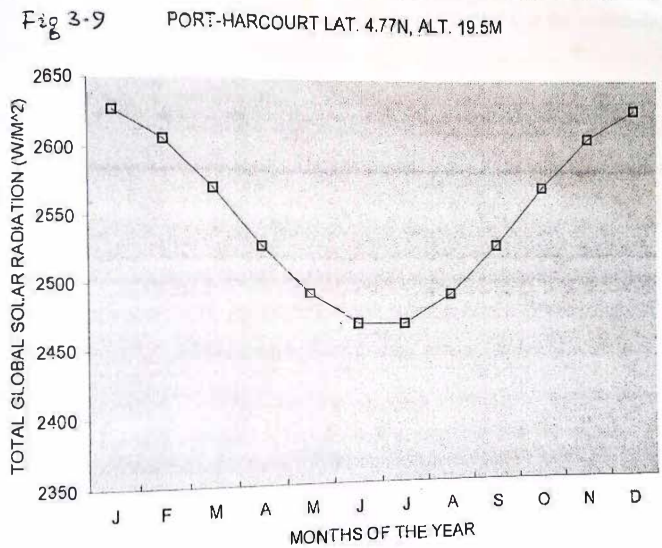

ENUGU LAT.06.28, ALT 141.5M
TOTAL GLOBAL SOLAR RADIATION (W/M^2)
204000
202000
200000
198000
196000
194000
192000
190000
188000
186000
184000
182000
J F M A M J J A S O N D
MONTHS OF THE YEAR

Fig 3-9


PORT-HARCOURT LAT. 4.77N, ALT. 19.5M
TOTAL GLOBAL SOLAR RADIATION (W/M^2)
2650
2600
2550
2500
2450
2400
2350
J F M A M J J A S O N D
MONTHS OF THE YEAR

CHAPTER FOUR

4.0 CONCLUSION

The Computation of monthly mean daily global radiation on a horizontal surface from Angstrom's correlation for four different locations in Nigeria, which have been proved the most simple and accurate correlation formulae. Provided that the meteorological parameter (sunshine duration) is available.

The Angstrom's correlation was used in obtaining the actual values for the regression coefficient a and b for a location. The coefficients a and b are found to vary for the locations.

Among the four locations, Bauchi has been found to have the highest total global solar radiation per annum. For any location where no measurement of solar radiation are available Hottel's Correlation can be used to some extent, Provided the latitude and altitude of the location is known.

It can be concluded from this work that attempt has been made to provide information about accurate solar radiation data for these locations.

4.1.0 SUGGESTION

Carrying out this study on four locations in four different region in the country, it could as well be carried out on locations within a region since it is possible that there could be variations in their regression coefficients in the same region.

The estimation of the total global solar radiation is important to be carried out in some locations in a particular region.

These are also necessary because there can't be much dependency on the measuring instrument for measured data which were found to have errors, costly in maintenance or to provide them in a location is such expensive.

At the time of this work Bauchi meteorological service has no any record on daily global solar radiations.

REFERENCES

1. Sukhatme, S. P (1984). Solar Energy: Principle of Thermal Collection and Storage. Tata Mcgraw-Hill New Delhi.

2. Energy Development and Utilization in Nigeria. Edited by Ayodele, A.S (1987) Nigeria Institute of Social & Economic Research: Ibadan

3. Duffie, J. A. & Beckman, W. A. (1974) Solar Energy Thermal Processes. John Wiley: Canada

4. Sol. W (1982): An Introduction to Solar Energy for Scientists and Engineers. John Wiley: Canada

5. Stine. W. B. And Horrigan, R. W. (1985) Solar Energy Fundamental and Design with Computer Applications. John Wiley: Canada

6. Kreider, J. F. And Kreith, F. (1981) Solar Energy Handbook. Mc Graw - Hill

7. McVeigh J. C. (1983) Sun Power: An Introduction to the Application of Solar Energy. Pergamon. UK

8. Campbell, I. M. (1977) Energy and the Atmosphere: A physical - chemical Approach. John Wiley

9. Ibrahim, M. (1994) Design, Construction and Performance Evaluation of Portable box-type solar energy cooker. A.T.B.U.

Bauchi, B. Tech Thesis

10. Veeran, P. K. And Kumar, S. (1993). Analysis of monthly average daily global radiation and monthly average sunshine duration at two tropical locations.

11. Massaqudi, J. G. M. (1987) Global solar radiation in Sierra-leone (West Africa)

12. Rietveld, M. R. (1978) A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine pg. 243 - 252.

APPENDIX A

```
REM
REM
REM
REM
REM
0 REM **** COMPUTATION FOR ESTIMATION OF GLOBAL ****
0 REM ****     SOLAR RADIATION           ****
0 REM ****     ANGSTROM'S CORRELATION TYPE        ****
0 DEF fnr (x) = x * 3.142 / 180
0 DEF fnd (x) = x * 180 / 3.142
5 DEF FNACS (x) = 3.142 / 2 - (x + x ^ 2 / 6 + 3 * x ^ 5 / 40 + 15 * x ^ 7 / 336)
0 DIM Ws(366), Ho(366), del(366), So(366), Ws2(366), del2(366)
00 REM *** declare constants
10 pi = 3.142
20 lat = fnr(4.77)
30 Isc = 1367
40
150 REM *** accept input
160 INPUT "ENTER THE VALUE OF D:"; d
170
180
190 REM *** start the iterative calculations
193 CLS
196 PRINT " day", "   Ho", "   Ws", "   So", "   del"
198 PRINT "--------------------------------------------------------"
200 FOR day = d TO 365
210    del(day) = fnr(23.45) * SIN(fnr(360 / 365 * (284 + day)))
   del2(day) = fnd(del(day))
220    x = -TAN(del(day)) * TAN(lat)
230    Ws(day) = FNACS(x)
   Ws2(day) = fnd(Ws(day))
240    So(day) = 2 / 15 * Ws2(day)
250    Ic = COS(lat) * COS(del(day)) * SIN(Ws(day))
   Ib = Ws(day) * 2 * pi / 360 * SIN(lat) * SIN(del(day))
255    Id = Ic + Ib
260    Io = 24 / pi * Isc * (1 + .033 * COS(fnr(360 / 365 * day)))
270    Ho(day) = Id * Io
280    PRINT day, Ho(day), Ws2(day), So(day), del2(day)

290 NEXT day
300
310 REM *** start monthly computations
320
330 n2 = 0
333 CLS
```

```
PRINT "MONTH", "AVERAGE Ho", "AVERAGE Ws2", "AVERAGE So",
VERAGE del2"
PRINT "-----", "----------", "----------", "----------", "-----------"
FOR month = 1 TO 12
n1 = n2 + 1
READ mth$, max
n2 = n1 + max - 1
sumHo = 0
sumWs2 = 0
sumSo = 0
sumdel2 = 0
FOR day = n1 TO n2
    sumHo = sumHo + Ho(day)
    sumWs2 = sumWs2 + Ws2(day)
    sumSo = sumSo + So(day)
    sumdel2 = sumdel2 + del2(day)
NEXT day
aveHo = sumHo / max
aveWs2 = sumWs2 / max
aveSo = sumSo / max
avedel2 = sumdel2 / max
PRINT mth$, aveHo, aveWs2, aveSo, avedel2
NEXT month
END
DATA
NUARY,31,FEBRUARY,28,MARCH,31,APRIL,30,MAY,31,JUNE,30,JULY,31
DATA
GUST,31,SEPTEMBER,30,OCTOBER,31,NOVEMBER,30,DECEMBER,31
```

```
EM          APPENDIX B
EM
EM
EM
EM
REM  *** COMPUTATION FOR ESTIMATION OF TOTAL GLOBAL ****
REM  ***          SOLAR RADIATION              ****
REM  ***       HOTTEL'S CORRELATION TYPE              ****
DEF fnr (x) = x * 3.142 / 180
DEF fnd (x) = x * 180 / 3.142
DEF FNACS (x) = 3.142 / 2 - (x + x ^ 2 / 6 + 3 * x ^ 5 / 40 + 15 * x^ 7 / 336)
DIM Ws(366), Ib(366), del(366), Id(366), It(366), del2(366), Ws2(366), zen(366)
0 REM * ** declare constants
0 altitude = 150
0 lat = fnr(7.17)
0 Isc = 1367
0 ro = .95
2 rl = .98
5 rk = 1.02
7 ao = ro * (.4237 + (.00821 * (6 - altitude) ^ 2))
8 al = rl * (.5055 + (.001 * (6 - altitude) ^ 2))
9 k = rk * (.2711 + (.01858 * (2.5 - altitude) ^ 2))
50 REM *** accept input
60 INPUT "ENTER THE VALUE OF D:"; d
70
80
90 REM  *** start the iterative calculations
93 CLS
96 PRINT " day", "   Ib", "   Id", "   It", "   del2"
98 PRINT "-------------------------------------------------------"
00 FOR day = d  TO 365
10    del(day) = fnr(23.45) * SIN(fnr(360 / 365) * (284 + day))
      del2(day) = fnd(del(day))
20    x = -TAN(del(day)) * TAN(lat)
30    Ws(day) = FNACS(x)
      Ws2(day) = fnd(Ws(day))
      zen(day) = COS((COS(lat) * COS(del(day)) * COS(Ws(day))) + (SIN(lat) *
SIN(del(day))))
240   Ib(day) = Isc * (1 + .033 * COS(fnr((360 / 365) * day))) * (ao + al * EXP(-k *
zen(day))) * zen(day)
250   Id(day) = (.027 * Isc * (1 + .033 * COS(fnr((360 / 365) * day))) - .2939 * Ib) *
zen(day)
      It(day) = Ib(day) + Id(day)
260
```

```
280   PRINT day, Ib(day), Id(day), It(day), del2(day)
290 NEXT day
300
310 REM  *** start monthly computations
320
330 n2 = 0
333 CLS
336 PRINT "MONTH", "AVERAGE Ib", "AVERAGE Id", "AVERAGE It",
"AVERAGE del2"
338 PRINT "-----", "----------", "----------", "----------", "----------"
340 FOR month = 1 TO 12
350 n1 = n2 + 1
360 READ mth$, max
370 n2 = n1 + max - 1
380 sumIb = 0
383 sumId = 0
386 sumIt = 0
388 sumdel2 = 0
390 FOR day = n1 TO n2
400    sumIb = sumIb + Ib(day)
410    sumId = sumId + Id(day)
420    sumIt = sumIt + It(day)
425    sumdel2 = sumdel2 + del2(day)
430 NEXT day
440 aveIb = sumIb / max
450 aveId = sumId / max
460 aveIt = sumIt / max
465 avedel2 = sumdel2 / max
470 PRINT mth$, aveIb, aveId, aveIt, avedel2
480 NEXT month
490 END
500 DATA
JANUARY,31,FEBRUARY,28,MARCH,31,APRIL,30,MAY,31,JUNE,30,JULY,31
510 DATA
AUGUST,31,SEPTEMBER,30,OCTOBER,31,NOVEMBER,30,DECEMBER,31
```