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THE DETERMINATION OF SOLAR ENERGY RECEIVED IN MISAU TOWN BAUCHI STATE NIGERIA

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Abstract

The paper titled "Measurement of solar energy received in Misau, Bauchi state using calorimetric method" is an attempt to measure the solar energy and power collected per unit area (solar constant) in Misau. The solar constant is an important value for the studies of global energy balance and climate. The analysis of satellite data suggests a solar constant of 1366.10 Wm^{-2} with a measurement uncertainty of ±3 Wm^{-2} of the radiant energy emitted from the sun. in this study we used locally fabricated low cost devices of aluminium cylinder to evaluate the amount of solar energy received and solar constant and the values obtained was 2690.08J and 1160.43Wm^{-2} respectively from ground-based measurement of solar radiation, which turns out to be in close agreement with that suggested by satellite data measurement and those reported in many literatures. The observed slight deviation in our evaluated value is attributed to the fact that solar constant is not perfectly constant, but varies in relation to the solar activities and fluctuation in extraterrestrial radiation which is about 6.9% during the year (from 1412.0 Wm^{-2} in January to 1321.0 Wm^{-2} in July) due to the Earth's varying distance from the sun. The analysis further shows that the temperature of the sun's photosphere and the hours of daylight were 5545.24K and 12hours 38minutes respectively.

1. Introduction

To overcome the dependency on conventional fuels, researchers and many organizations are working on alternative fuels, which should be commercially viable, easy to use, less pollutant, and must be abundant in nature. In this direction, renewable energies, like solar energy, tidal energy, wind energy, biofuels and so forth, are more suitable than conventional sources of energy.

SOLAR ENERGY

Solar energy is radiant light and heat from the sun. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar technologies include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar technologies include orienting a building to the sun, selecting materials with favorable mass or light-dispersing properties, and designing spaces that naturally circulate air [1].

The large magnitude of solar energy available makes it a highly appealing source of electricity. In 2014, the International Energy Agency said that 'the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. As the market for solar power technologies grows, determining the amount of solar energy available at a given location is important for maximizing energy efficiency of solar technologies and determining if solar power is even a possibility for specific region. Engineers must understand the basics of solar energy and the earth in order to incorporate solar energy in to their designs.

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This study showed the usefulness and the amount solar energy received and also the amount of power collected per unit area in Misau, Bauchi state. This study is novel as there has been no record regarding this aspect of research in the area Monitoring Earth's atmosphere is a challenging task. In industrialized countries, there are well-established networks of instruments to monitor the atmosphere close to Earth's surface. Some stations are used for scientific purposes, but most serve a primary regulatory function-monitoring a specific set of air quality indicators as mandated by government agencies. (in U.S, the "criteria pollutants" on which the Air quality Index is based, as established by the Environmental protection Agency, are SO_2, NO_2, O_3, CO and particulate matter [2]. Although these quantities are certainly of scientific interest, they are only local measurements and represent only a small subset of important atmospheric components.

In order to understand how Earth/atmosphere system works, it's necessary to understand the entire atmosphere, not just the part within direct reach from Earth's surface. Typically, the total amount of gases and particles in a column of atmosphere cannot be determined from measurements just at Earth's surface by a single measurement essentially at the bottom of the atmosphere column.

The study was aimed at finding the amount of solar energy received, power collected per unit area (flux density), and the temperature of the sun's photosphere in the area (Misau, latitude 11.31^{o}N and longitude 10.47^{o}E). The amount of solar energy received serve as an important factor for maximizing energy efficiency of solar technologies and determining if solar power is even a possibility for specific region [3].

SOLAR RADIATION

Stars generate huge amount of energy through the process of nuclear fusion. Our own sun, an unremarkable medium-sized star, produce a total power E of about 3.910^{26} W. This power is radiated into space uniformly in all directions. Fundamental physical laws tell us that the intensity of this radiation decreases as the inverse square of the distance from the sun. The solar constant (S_o) is defined as the average power per unit area of solar radiation falling on the surface of an imaginary sphere of radius R around the sun $S_o = \frac{E}{4\pi R^2} = 1370 Wm^{-2}$

Where, R is the average earth/sun distance, about 1.49610^8 km. The solar "constant" actually fluctuates a little and, the energy Earth receives varies with the seasonal change in the Earth/sun distance. If one astronomical unit (AU), is the average Earth/sun distance, then the amount of solar radiation reaching Earth varies according to:

$$S_{max} = \frac{S_o}{(1-e)^2} = \frac{1370}{(0.983)^2} = 1417 Wm^{-2}$$

$$S_{min} = \frac{S_o}{(1+e)^2} = \frac{1370}{(1.0717)^2} = 1324 Wm^{-2}$$

Where, e is the eccentricity (a measure of departure from a circle) of Earth's orbit around the sun. Earth's eccentricity varies slowly (with periods of hundreds of thousands of years). The current value is about 0.017. The maximum and minimum vary a little more than 3% from the mean. Earth is closest to the sun in early January (yes, really), so this is when maximum solar radiation reaches Earth. The minimum amount of radiation is received about six months later [4].

Visible and ultraviolet light and heat are obvious components of solar radiation, but solar radiation is much more complicated than that. The sun's energy, like that generated by other stars, is distributed over a broad range of the electromagnetic spectrum, following well – known physical laws. It behaves approximately like a "blackbody" radiating at a temperature of about 5800 K. its maximum output is in the green – yellow part of the visible spectrum, around 500 nm. Not surprisingly, this is near the maximum sensitivity of the human eye [5].

SOLAR RADIATION ENTERING THE EARTH SYSTEM

In order to study the effects of solar radiation on the Earth system, it is necessary to determine the amount of energy reaching the Earth's atmosphere and surface [6]. Once the surface irradiance of the Sun is determined the amount of energy reaching the top of the Earth's atmosphere can be calculated using the Inverse Square Law. The average amount of energy received on a surface perpendicular to incoming radiation at the top of the atmosphere is the solar constant. (While this calculation can lead to a better student understanding of the Inverse Square Law, the accepted value is a yearly average from NASA satellite measurements.)

Solar Radiation Striking the top of the Earth's Atmosphere. The Inverse Square Law is used to calculate the decrease in radiation intensity due to an increase in distance from the radiation source.

Inverse Square Law:

$$I = E \times \frac{(4 \times R^2)}{4 \times r^2}$$

I = Irradiance at the surface of the outer sphere

E = Irradiance at the surface of the object (Sun)
4 x R^2 = surface area of the object (sun)
4 x r^2 = surface area of the outer sphere
In order to calculate the solar constant the following equation is used:

$$S_o = E \times \frac{R^2}{r^2}$$

S_o = Solar Constant
E = Surface Irradiance of the Sun
R= 6.96 x 10^5 km (Radius of the Sun)
r = 1.496 x 10^8 km (Average Sun- Earth Distance)

REQUIRED MATERIALS
For the measurement of solar energy, the materials required for the construction the instrument to be use are as follows:

- A 5cm diameter, 2cm thick aluminium (or brass) cylinder with a hole drilled along one of its diameter.
- A 5cm diameter PVC sleeve (the kind used in construction for down pipes
- A U-shaped clamp collar.
- A short length of PVC piping, the kind used by electricians.
- A thermometer.
- A protractor with a bob line [3]

But some of the actual dimension and size of the material mentioned above were not available within the immediate environment, which led to local construction of similar material (in size and dimension) that substitute the above mentioned. Therefore, the materials used are as follows:

- An aluminium cylinder block of 4.4cm in diameter, 2.5cm thick with a drilled hole along one of its diameter.
- A 5.0cm in diameter PVC sleeve (the kind used for down pipes)
- A U-shaped clamp collar.
- A short length of PVC piping, the kind used by electricians.
- A thermometer
- A protractor with a bob line.

HOW TO ASSEMBLE THE DEVICE

- Set the aluminium cylinder block inside the sleeve and drill a hole through both sleeve and aluminium cylinder block. The diameter of the hole should be the same as that of the thermometer.
- Weight the cylinder and paint it matt black.
- Glue the cylinder inside the PVC sleeve, making sure the holes are correctly aligned.
- Fill the bottom of the sleeve with a polystyrene foam block.
- Glue the sighting tube on the side of the device, 90^o from the thermometer hole, and the protractor with its bob line (that will be used for the measurement of the sun's zenith distances, that is the angle between the local vertical and the direction of the sun)
- Place the completed device on the clamp collar as shown in figure 1 below [7].

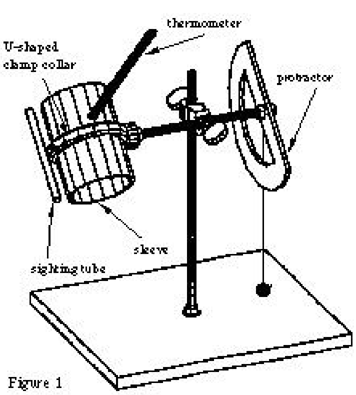


Figure 1

PROCEDURE OF OBTAINING DATA

Place the device in a refrigerator, merely a few minutes will do the cooling needed.

With the help of the sighting tube fitted with a screen, adjust the device so that the angle of incidence of light from the sun should be normal to the flat base of the cylinder. While adjusting the device, make sure that the cylinder does not receive any light from the sun. To make a measurement of initial temperature wait for the device to reach 17 to 18 ^{O}C.

Then remove the polystyrene mask and expose the cylinder for 5 to 10 minutes. Make current measurement of the cylinder temperature as a function of time.

Finally make a measurement of the sun's zenith distance (Z) (unit, degrees). During the whole experiment, make sure that the cylinder remains perpendicular to the direction of the sun (if Z changes, take an average value)

PRESENTATION AND DATA ANALYSIS

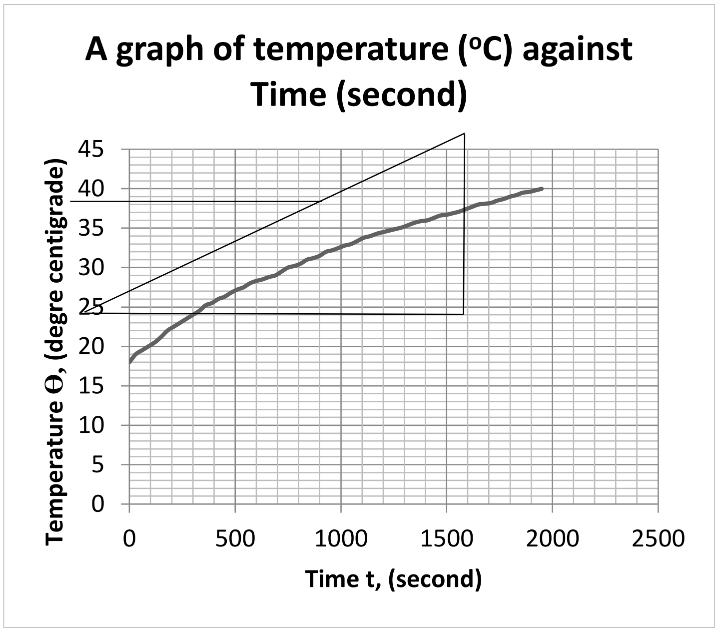
4.1 RECORD OF MEASUREMENTS

- Diameter of aluminium block cylinder 2r = 4.4cm
- Mass of aluminum block cylinder M =172 g =0.172 Kg
- Air temperature T_{air} =33.0^{O}C

The cylinder temperature as a function of time on June 30, 2016

TABLE OF VALUES

Time (seconds)	Temperature ^{O}C	Time (seconds)	Temperature ^{O}C
0.00	18.00	990.00	32.50
30.00	19.00	1020.00	32.80
60.00	19.50	1050.00	33.00
90.00	20.00	1080.00	33.40
120.00	20.50	1110.00	33.80
150.00	21.20	1140.00	34.00
180.00	22.00	1170.00	34.30
210.00	22.50	1200.00	34.50
240.00	23.00	1230.00	34.70
270.00	23.50	1260.00	34.90
300.00	24.00	1290.00	35.10
330.00	24.50	1320.00	35.40
360.00	25.20	1350.00	35.70
390.00	25.50	1380.00	35.90
420.00	26.00	1410.00	36.00
450.00	26.30	1440.00	36.30
480.00	26.80	1470.00	36.50
510.00	27.20	1500.00	36.70
540.00	27.50	1530.00	36.90
570.00	28.00	1560.00	37.10
600.00	28.30	1590.00	37.40
630.00	28.50	1620.00	37.70
660.00	28.80	1650.00	38.00
690.00	29.00	1680.00	38.10
720.00	29.50	1710.00	38.20
750.00	30.00	1740.00	38.50
780.00	30.20	1770.00	38.70
810.00	30.50	1800.00	39.00
840.00	31.00	1830.00	39.20
870.00	31.20	1860.00	39.50
900.00	31.50	1890.00	39.60
930.00	32.00	1920.00	39.80
960.00	32.20	1950.00	40.00



SLOPE OF TH GRAPH

The slope S, of the graph = $\frac{\Delta\theta}{\Delta t} = \frac{39-22}{1600-0}$

$= \frac{17}{1600}$

= 0.011 K/s

CALCULATING THE POWER COLLECTED BY DEVICE.

The amount of heat (Q) collected by the aluminium cylinder is given by:

$Q = Mc(\theta_2 - \theta_1$

Where;

M = 0.172kg (mass of aluminium block)

C = 0.92×10^3Jkg^{-1}k^{-1} (specific heat capacity of aluminium)

$\Theta_2 - \Theta_1 = \Delta\Theta$ = 17k (change in temperature)

∴ $Q = 0.172\times0.92\times10^3\times17 = 2690.08$J

The power collected per unit area by device that is flux density (solar constant, E_s) is given by:

$$E_s = \frac{Q}{A\Delta t}$$

Where;

A = area of aluminium cylinder exposed to the sun. We use πr^2 because it is the circular part of the cylinder that was exposed to solar radiation.

Δt = change in time

But $Q = Mc\Delta\theta$

$$\therefore E_s = \frac{Mc\Delta\theta}{A\Delta t} = \frac{Mc}{A} \times \frac{\Delta\theta}{\Delta t}$$

Where;

$$\frac{\Delta\theta}{\Delta t} = \text{slope, s}$$

$\therefore E_s = \frac{Mc}{A} \times s$

$A = \pi r^2$

$$r = \frac{\text{diameter of the cylinder}}{2} = \frac{4.4}{2} = 2.20\text{cm}$$

$r = 2.2\text{cm} = 2.20 \times 10^{-2}\text{m}$

$\therefore A = \pi \times (2.20\times10^{-2})^2 = 1.5\times10^{-3}\text{m}^2$

Now,

$$E_s = \frac{0.172 \times 0.92 \times 10^3}{1.50 \times 10^{-3}} \times 0.011$$

$\therefore E_s = 1160.43\text{Wm}^{-2}$

DETERMINIG THE TOTAL POWER RADIATED BY A UNIT AREA OF THE PHOTOSPHERE

The power E_s is collected on a unit area which is situated at a distance d_{es} = 1.496×10^8Km (average Sun – Earth distance). P, the whole power radiated by the sun is received on a sphere of area $4\pi d_{es}^2$

Therefore,

$$P = 4\pi d_{es}^2 \times E_s \qquad (1)$$

E, the total power emitted per unit area is given by;

$$E = \frac{P}{4\pi R_s^2} \qquad (2)$$

Substituting equation (1) in (2) we get

$$E = \frac{d_{es}^2}{R_s^2} \times E_s \qquad (3)$$

Where; $R_s = 6.96\times10^5$Km, $d_{es} = 1.496\times10^8$Km, and E_s= 1160.43 Wm^{-2}

$$E = \frac{(1.496 \times 10^8)^2}{(6.96 \times 10^5)^2} \times 1160.43$$

$\therefore E = 5.3612 \times 10^7\text{Wm}^{-2}$

DETERMINING THE TEMPERATURE OF THE SUN'S PHOTOSPHERE

The temperature, T of the sun's photosphere can be obtained from Stefan's – Boltzmann law:

$$E = \sigma T^4$$

Where;

$E = 5.3612\times10^7$ Wm^{-2} (radiant emittance)

$\sigma = 5.67\times10^{-8}\text{Wm}^{-2}\text{K}^{-4}$ (Boltzmann constant)

$$\therefore T = \sqrt[4]{\frac{E}{\sigma}}$$

$$T = \sqrt[4]{\frac{5.3612 \times 10^7}{5.67 \times 10^{-8}}}$$

$\therefore T = 5545.24\text{K}$

DETERMINING THE DAY LENGTH HOUR

The day length hour (sunrise to sunset) is given by:

$$\text{hours of daylight} = \frac{2h}{15} \text{ (hours)}$$

Where,

$h = \cos^{-1}(-\tan\beta \times \tan\delta)$. (Hour angle)

Also

$\beta = 11.31^o$N (latitude of Misau)

$\delta = 23.45 \times \sin\left[\frac{248+N}{365} \times 360\right]$. (Declination angle)

N = 30+152 (day number 30 June, 2016)

$$\therefore \delta = 23.45 \times \sin\left[\frac{248+182}{365} \times 360\right]$$

$\delta = 23.12^o$

$\therefore \mathrm{h} = \cos^{-1}(-\tan 11.13 \times \tan 23.12)$.

$\therefore$h = 94.82°

$$\therefore \text{hours of daylight} = \frac{2 \times 94.82}{15} \text{ (hours)}$$

$$\text{hours of daylight} = 12.64 \text{ (hours)} = 12\text{hours } 38\text{minutes}$$

CONCLUSION

The project is based on measuring the solar energy received in Misau, Misau Local Government Bauchi State using calorimetric method.

The experiment was carried out on 30th June 2016 around 11:30am to 12:30pm and the result obtained from the experiment shows that the amount of solar energy received in Misau on Thursday, 30th June, 2016 was 2690.08J. And the power collected per unit area (flux density, E_s) was 1160.43 Wm^{-2} and also the hour of daylight was 12hours 38minutes.

This project has provided an introduction to earth's atmosphere, how it affects transmission of sunlight to the surface and how to design relatively simple instrument to measure solar radiation and indirectly, some important atmospheric constituents.

The project described how to construct an instrument for measurement of solar constant received in a given area using local materials, from the required materials, procedure for assembling the constructed device. This show the important and value of data collection with relatively inexpensive constructed instrument described in the project. If the instrument is carefully constructed, properly calibrated and used under appropriate condition this instrument can produced scientifically useful data.

The project also described how to determine the solar constant received in a given area and the temperature of the sun's photosphere from measurement of the sun's radiation at ground level.

At any given moment, the amount of solar radiation received at a location on the Earth's surface depends on the state of the atmosphere, the location's latitude, and the time of day. This present research work was carried out at Misau, Misau local Government, Bauchi State, Northern Nigeria (Latitude 11.31°N, Longitude 10.47°E, Altitude 406m above the sea level) on Thursday, 30th June, 2016. This is one of the months of the period of semi rainy season in this region, as such; appreciable high sunshine duration and clearness index due to solar radiation are recorded. In this study, we used locally fabricated low cost devices of aluminium cylinder to evaluate the amount of solar energy received and the solar constant, the value obtained was 2690.08J and 1160.43Wm^{-2} respectively from ground-based measurement of solar radiation

As this paper concerned measurement of energy using calorimetric method. It can be improved upon and modified in different ways. since the instrument used for data collection is neither mechanical nor electrical. Therefore, it can be improved by constructing an instrument that can be use electrically or mechanically for data collection.

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