CONSTRUCTION OF PYRANOMETER FOR MEASURING GLOBAL SOLAR RADIATION

BY

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FEBRUARY, 2017

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Submitted to the Department of Physics, Abubakar Tafawa Balewa University Bauchi, Bauchi State Nigeria.

In Partial Fulfillment of the award of Bachelor of Technology B.Tech (Hons), Degree in Applied Physics

Supervisor: Prof F.W. Burari

2017

Declaration

I hereby declared that this work is the product of my own research effort undertaken under the supervision of Prof. F.W Burari, and has not and will not be presented elsewhere, for the award of degree certificate; all the sources have been dully acknowledged.

Name: BASHIR GARBA

REG. NO. 11/26011/U/1

SIGNATURE______ 9/2/2017.

CERTIFICATION

This is to certify that this research work meets the requirement and regulation governing the award of a degree of Bachelor of technology in Applied Physics of Abubakar Tafawa Balewa University Bauchi.

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Signature: ------------

Date --08/02/17---

External Examiner

Name: Prof. Osita C. Meludu

Signature: -----------

Date --08/02/17---

Dedication

I dedicate this research work to my Father Mal. Garba Zailani, my Mother Asma'u Garba and the rest of my family members.

Acknowledgement

All praises be to Allah (SWT), the beneficial, the most merciful, WHO gave me the life and health to carry out this research project throughout the period.

To my beloved parent, thanks a lots for all supports and encouragements they gave me at all times, which without their support, may be difficult for me to make it.

I would like to thanks my supervisor, Prof. F.W Burari for his continuous supervision, useful advices for the successful research completion.

Special thank goes to my entire lecturer at Physics Department and my coach, Mal Abubakar Salihu, for his special assistance, encouragement and guidance to make this research project a successful one.

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Abstract

The construction of pyranometer for measuring global solar radiation was done in Abubakar Tafawa Balewa University, Bauchi State Nigeria; the main characteristic of the sensor used is low-cost of all its components. The design of the device is based on using TEFT4300 silicon phototransistor and covered with a protective wood case. The device has better sensitiveness to solar irradiance, allowing an excellent response of the sensor in a range from approximately 875 to 1000nm. The calibration was done within four days: 29th, 30th, 31st December 2016 respectively and 2nd January 2017. The maximum irradiance of 100.92W/m^2 was obtained on 29th December 2016 at around 12pm to 1pm. While the minimum irradiance of 22.0W/m^2 was obtained on 31st December 2016 at early hour of the day (7am).

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

The efficient utilization of the solar energy for the system design and selection of components for Agriculture, Industries, Telecommunications and House hold applications require the knowledge of the actual solar radiation reaching the earth surface at a location of interest. It warms our planet and gives us our everyday wind and weather. Without solar radiation, the earth would gradually cool in time becoming encased in layers of ice.

The term solar energy refers to energy from the sun which comes to the earth in the form of direct, diffuse or reflected rays, (Doyle and Sambo, 1985). Solar energy is free, natural and non-pollinating energy that man can capture for a variety of purposes, (Onah and Osoji, 2007). Measurement of solar radiation per unit of surface (W/m^2) is called the irradiance. The solar radiation intensity (irradiance), is a measure of quantity of electromagnetic radiations which are transmitted from the sun to the earth surface to another.

However, due to the average distance of the sun from the earth (about 150million kilometers), the quality and the intensity of the solar radiation change considerably on its journey through the earth atmosphere. These changes are usually conditioned by solar constant, transparency of the atmosphere, length of the daily sunlight, and the angle at which the sun's rays strike the earth. The average distance of 150million kilometers is equivalent to the earth astronomical unit (1.0au). Due to the shape of the earth orbit, the sun is closer to the earth in January at a distance of about 147million kilometer, and the sun is far away in July at a distance of about 152million kilometer. Thus amount of solar radiation received on the earth surface depends on the year, time of the day and season (O. Ojo 1982).

The term global solar radiation is the total amount of solar energy received by the earth surface, usually expressed as W/m^2. About 99% of global solar radiation has wavelength between 300 and 3000nm. This includes ultra-violet (300 to 400nm), visible (400 to 700nm), and infrared (700 to 3000nm) radiation. Global solar radiation is the sum of direct, diffuse and reflected solar radiation. Direct solar radiation passes directly through the atmosphere to the earth surface, diffuse solar radiation reaches a surface and is reflected to adjacent surfaces.

The visible portion of the solar radiation spectrum provides energy for photosynthesis, which is primarily gate way for inorganic carbon to become organic or support life on the earth. Infrared light heat the ground and maintains an ideal environmental for life. Global solar radiation drives the global water cycle and weather patterns. In fact, about the half of the solar radiation absorbed by the earth surface is consumed by evapotranspiration on a global scale. Solar radiation is also used to generate electricity.

The global irradiance is the short wave energy that actually reaches a horizontal surface after all the absorption and scattering process. This amount is influenced by the path length through the atmosphere; clarity of the atmosphere, and the amount and type of cloud cover. This interaction of solar radiation with the atmosphere involves a series of quite complex processes. In order to simplify understanding of the atmosphere, the energetic equilibrium between the atmosphere, the surface of the earth and incoming solar radiation can be operated into three processes.

1. Solar radiation entering the atmosphere being absorbed and scattered before reaching the ground.
2. Thermal (long wave) radiation originated from the surface of the earth and the atmosphere above.

3. Non-radiative heat and energy transport processes in the atmosphere and between the soil and the atmosphere.

This atlas deals primarily with the processes which belong to the first category concerning the short wave radiation in the wave band 0.2 to 4.0μm. The incoming extraterrestrial irradiation enters the atmosphere and interacts with atmospheric components, which are the various gases, (including wave vapor) and the condensed water droplets and other aerosols.

Some of these absorb short wave radiant energy, and others scattered it in broad terms:

1. Absorption by gas molecules, aerosol and condensed water accounts for 20% of energy loss. This results in a heating of the atmosphere.
2. Back scattering and back reflection mainly from clouds sends 23% of the incoming solar energy directly back to space.
3. Averaging over the globe, only 57% of the primary incoming solar energy directly back to space.
4. 30% of the incident extraterrestrial energy reaches the ground as beam radiation.
5. 27% of the incoming extraterrestrial energy reaches the ground as beam radiation.

Depending on the reflectance of ground for solar radiation (the albedo), 8% of the short wave radiation is reflected back to space from the ground. This occurs with only minor spectral degradation. 49% of the extraterrestrial flux is absorbed at the surface and is transformed in to sensible heat or converted chemically into bound energy form like biomass, or transformed in to other renewable energy (wind and water).

The second path of heat loss to space is through thermal radiation in the band 4.0 to 100μm. The thermal radiation resulting from the absorption of short wave radiation complements the thermal radiation to space resulting from the earth's internal geological processes and radioactive decay. The proportion attributes to the solar budget is 49%. There is an added contribution to the outgoing long wave radiation to space from the short wave energy absorbed in the clouds and in the atmosphere. This brings the absorbed short wave contribution to the outgoing thermal radiation to 69% of the incoming shortwave radiation.

This project research is based on the construction of device for measurement of global solar radiation (pyranometer). The work started with brief introduction to solar radiation. Interaction between solar radiation and the atmosphere are important, because they provide a way to study atmosphere processes that influence air quantity, weather and climate.

Pyranometer is an instrument used for measuring solar radiation on a horizontal surface. Pyranometers are widely used in meteorology, climatology, and agriculture and solar energy studies among others. Solar radiation is detected by interception and subsequent analysis of the effects of interception on a receiver. (Asogwa and Okeke, 1995). Based on a theoretical data, the tropical Nigeria have an average insolation of about 3.7kWh/m²day along the coastal areas, and to about 7.0kWh/m²day along a semi-arid areas of the North. The country however on the average, receives solar radiation level of about 5.3kWh/m²day, (ECN, 2005).

Most researchers within the country use these available theoretical values of metrological data to compute average irradiance of solar radiation for different location within Nigeria, they lack standard measured data obtained from reliable measuring instrument suitable for their local environment and therefore resorted to theoretical prediction using different models for global daily sunshine's radiation.

1.2 Solar Radiation outside the Atmosphere

The spectrum of the radiation emitted by the sun is close to that of a black body at a temperature of 5,900K. About 8% of the energy is in the ultra-violet region, 44% is in the visible region, and 48% is in the infra-red region.

The solar constant I_0 is the beam solar radiation outside the Earth's atmosphere when the sun is at its mean distance from the Earth. Its value is

$$I_0 = 1.37 \pm 0.02 kW/m^2.$$

Variations in the distance of the sun from the Earth due to the ellipticity of the Earth's orbit cause the actual intensity of solar radiation outside the atmosphere to depart from I_0 by a few percent. Allowance for these variations can be made by means of the factor

$$F = 1 - 0.0335 \sin 360(n_d - 94)/365,$$

Where n_d is the day of the year (on 1 January $n_d = 1$; on 31 December $n_d = 365$); the argument of the sine function is in degrees. All the values of solar radiation intensity given below, which are for the sun at its mean distance from the Earth, must be multiplied by F to obtain the actual values on day n_d. When the Earth is nearest the sun in January the solar radiation in clear weather is 3% greater than the average; when the Earth is farthest from the sun in July the solar radiation is 3% less than the average.

1.3 The Effects of Atmosphere and the Earth

The processes affecting the intensity of solar radiation that are important in solar energy work are scattering, absorption, and reflection. Reflection occurs in the atmosphere and on the Earth's surface.

The scattering of solar radiation is mainly by molecules of air and water vapor, by water droplets, and by dust particles. This process returns about 6% of the incident radiation to space, and about 20% of the incident radiation reaches the Earth's surface as diffuse solar radiation.

Air molecules scatter sunlight with an intensity proportional to λ^{-4}, where λ is the wavelength of the radiation. This is called Rayleigh scattering; it is important for particles with radius less than $\lambda/10$. This wavelength effect can be seen in the blue color of the clear sky and the red color of the setting sun. The sky appears blue because the shortest wavelength blue light is scattered more strongly than the longest wavelength red light. The setting sun appears red because much of the blue light has been scattered out of the direct beam. Scattering from large particles with radius greater than 25λ is independent of the wavelength. As a result, sunlight scattered from the water droplets in mist and cloud, and from the dust particles in haze, is white.

The absorption of solar radiation is mainly by molecules of ozone and water vapor (Fig. 1). Absorption by ozone takes place in the upper atmosphere at heights above 40 km. It occurs mainly in the ultra-violet region of the spectrum, where it is so intense that very little solar radiation of wavelength less than 0.3μm reaches the Earth's surface. About 3% of the solar radiation is absorbed in this way.

At low levels in the atmosphere about 14% of the solar radiation is absorbed by water vapor, mainly in the near infra-red region of the spectrum. Clouds absorb very little solar radiation, which explains why they do not evaporate in sunlight. The effect of clouds on solar radiation is mainly scattering and reflection.

There is a small amount of absorption of solar radiation by oxygen. The absorption of solar radiation by carbon dioxide is also slight, although the absorption and emission of long-wave atmospheric radiation by carbon dioxide is important in the greenhouse effect.

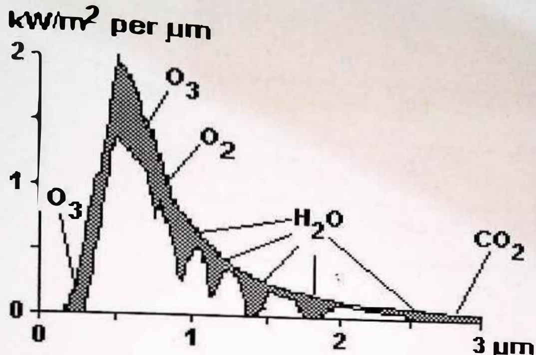


Fig.1.1 The solar spectrum.

The upper graph is for radiation outside the atmosphere; the lower graph is for radiation received at the earth's surface under a clear sky. Absorption bands by gases in the atmosphere are indicated by chemical formulas.

The reflection of solar radiation depends on the nature of the reflecting surface. The fraction of the solar irradiation that is reflected from the surface of the Earth is called the albedo of the surface. The total albedo, which includes all wavelengths, is closely related to the visible albedo, which includes only light in the visible region of the spectrum. Table 1 shows some typical albedo values for the sun overhead. When the sun is low in the sky (with a large zenith angle z) the albedo of a water surface is much greater than the value tabulated. The albedo of clouds depends on how thick they are.

Table1.1. Surface Albedos

Surface	Albedo
Vegetation	0.2
Pale soil	0.3
Dark soil	0.1
Water	0.1
Clouds	0.5-0.9

1.4 Solar Radiation under a Clear Sky

A simplified presentation of the solar radiation at the earth's surface applicable in tropical Asia is given in this section.

The main parameters affecting the intensity of solar radiation are the zenith angle z of the sun, the water vapor content w of the atmosphere, and Schuepp's turbidity coefficient B.

The water vapor content w is given in centimeters of perceptible water. Exact determinations of w require the use of upper air data. If upper air data are not available, approximate estimates can be made with the help of the formula

$$w = 0.18e,$$

Where 'e' is the vapor pressure in the atmosphere at the Earth's surface in millibars. In a tropical wet and dry climate w typically varies from 2cm in the dry season to 5cm or more in the wet season.

The turbidity coefficient B is zero in a dust-free atmosphere, and increases in value as the air becomes more turbid. Direct determinations of B require measurements of beam solar irradiance in different ranges of the spectrum using colored filters. In a tropical wet and dry climate B typically varies from near zero in the wet season to about 0.2 during the dry season. If there is smoke in the air B can be greater. Inland in Thailand the equation

$$B = 0.25 - 0.017V,$$

Where V is the mean visibility in kilometers, gives estimates of the mean values of B with an accuracy ±0.02.

The values of beam solar irradiance I_b at sea level are given in Table 2 for several values of the water content w of the atmosphere, the zenith angle ζ of the sun, and the turbidity coefficient B. Small corrections for variations in the ozone content of the atmosphere, and for variations in the surface air pressure, are ignored. Since the tabulated values are for application at sea level, they underestimate the beam solar irradiance at elevated mountain sites. The correction factor F for variations in the Earth-sun distance mentioned earlier should be applied.

Table1.2. Beam Solar Irradiance at Sea Level

w(cm)	**z(degrees)**	**I_b(kW/m^2)**		
		B = 0	**B = 0.1**	**B = 0.2**
2	0	1.047	0.879	0.768
2	60	0.879	0.684	0.524

2	70	0.810	0.530	0.384
2	80	0.628	0.314	0.181
5	0	0.977	0.838	0.698
5	60	0.838	0.628	0.475
5	70	0.740	0.489	0.349
5	80	0.572	0.286	0.161

Diffuse solar irradiance is determined mainly by the solar zenith angle z the turbidity B, and the albedo of the ground around the site. Table 3 gives values of the diffuse solar irradiance I_d for several values of z and B when the albedo of the ground is 0.25. For albedos 0.1, 0.2, and 0.3 multiply the tabulated values of I_d by the correction factors 0.90, 0.96, and 1.04 respectively.

Table1.3. Diffuse Solar Irradiance

	I_d(kWm^2)		
z(degrees)	**B = 0**	**B = 0.1**	**B = 0.2**
0	0.063	0.133	0.202
60	0.045	0.087	0.119

70	0.034	0.063	0.084
80	0.018	0.034	0.039

Table 4 gives the daily total global solar irradiation under clear skies in tropical latitudes on the 15th day of the critical months March, June, September, and December. The tabulated values are for water vapor content w = 2cm and turbidity B = 0. For water vapor content w = 5cm multiply the tabulated values by the correction factor 0.93; for turbidity B = 0.1 and 0.2 multiply the tabulated values by 0.90 and 0.84 respectively.

Table1.4. Daily Global Solar Radiation under Clear Skies

	Daily Global Solar Irradiation (MJ/m²)		
Latitude ϕ:	**0°**	**10°**	**20°**
March	28.8	28.1	26.3
June	25.4	28.2	30.2
September	28.3	28.2	27.3
December	26.9	23.3	18.9

1.5 AIM AND OBJECTIVES

The project is aimed at constructing Pyranometer for the measurement of global solar radiation.

The key objectives of this project include:

- To measure the amount of solar radiation received, in Yelwa campus ATBU Bauchi.
- To evaluate the performance of the constructed pyranometer when compared with readings obtained via a standard pyranometer.

1.6 JUSTIFICATION OF STUDY

The construction of the device was aimed at finding the amount of solar radiation received. That is power collected per unit area in the area of Yelwa campus ATBU Bauchi, latitude 10°17'0 ''N and longitude 9°47'0"E. The amount of solar received serves as important factor for maximizing energy efficiency of solar technologies.

1.7 LIMITATION OF STUDY

The research is based on construction of pyranometer and measurement of solar radiation intensity received at ATBU Bauchi Yelwa campus.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

While solar radiations data are not utilized as frequently as other climatic variables, researchers nevertheless understand that as the primary driving force for all atmospheric processes, solar radiation is an important factor for a complete understanding of the workings of many of the earth's systems. This chapter contains different literature reviews which are important for the study and construction of pyranometer for irradiance measurement.

Medugu, et al. (2009) constructed a reliable model pyranometer for irradiance measurement. They constructed the pyranometer using a silicon photodiode held with protective plastic case. They obtained a calibration constant of 5230±0.02W/m² at Mubi Adamawa state of Nigeria. They used the constructed pyranometer as a standard for calibration and comparison, where the stability of the reference model pyranometer compared favorably with the constructed pyranometer during a day open- sky test given an irradiance of 20.76 and 21.7W/m² for the reference and the constructed pyranometers respectively, at 5:25pm.

Samuel, (1881) Langley scaled Mt Whitney to get as much of earth's atmosphere as possible and measure the solar constant. Traveling to the thin high altitude atmosphere was an attempt to minimize the corrections needed for the amount of solar constant absorbed by the atmosphere. (http://suite101.com/abbotand-the-solarconstant-a63100).Langley invented bolometer, an instrument used to very accurately measure the radial energy at all wavelengths. Langley bolometer was the first instrument needed for this first attempt to measure the solar constant.

Nwankwo, et al. (2011) constructed a pyranometer using locally available materials for global solar radiation measurement, where they obtain a calibration constant of $6.58 \times 10^5 VW/m^2$ and the maximum irradiance of $895.W/m^2$ on 6/09/2011 at Ebonyi state university, Abakaliki. They compared the calibration constant of the constructed and reference pyranometer (Eistrain Lungs pyranometer) on a clear sky day. The calibration of the constructed and reference pyranometer was $6.58 VW/m^2$ and $7.3 \times 10^5 VW/m^2$ respectively. And the maximum irradiance was $895.70 W/m^2$ and $1043.83 W/m^2$ for the constructed and reference pyranometers respectively.

Medugu (2011) constructed a three pyaranometers using a silicon photo-detector (BPW21) mounted on a plastic base, covered with a Teflon diffuser. The housing is placed on a base with a level control to ensure horizontal. He used a developed pyranometer which generates an electrical signal proportional to irradiance received and converts the small current received from a detector to voltage and amplifies it to a voltmeter. The measurement was conducted over Mubi, Maiduguri and Bauchi with the aid of reliable model pyranometers RMP001, RMP002 and RMP003 respectively. The reliable model pyranometers were then calibrated against a reference high quality pyranometers, Kipp and Zonen CMP3 whose calibration constant was trusted ($14.71 \pm 36 \mu V/W/m^2$), obtaining a calibration constant of 5134 ± 19, 4550 ± 23 and $5120 \pm 25 W/m^2$ for RMP001, RMP002 and RMP003, respectively. The calibration constant obtained for the pyranometers produce the best fit with calibration output.

Fernando, et al. (2011) designed and constructed a low-cost sensor (pyranometer) and measured the amount of solar radiation receïved in the Northern Chile. The design of the sensor was based on using a PT202C phototransistor. The phototransistor device has better sensitiveness to solar irradiance, allowing an excellent response of the sensor in a range from approximately 300 and 1200nm. The experimental results were compared with data obtained from the CM11ISO9060 secondary standard pyranometer. He measured the maximum irradiance received at Northern Chile to be 1350W/m^2

2.2 SOLAR RADIATION

Solar radiation is radiant energy emitted by the sun from nuclear fusion reaction that creates electromagnetic energy. It is the dominant, dirèct energy input in to the terrestrial ecosystem; and it affects all physical, chemical, and biological processes. The sun provides a natural influence on the earth atmosphere and climate (Austin, 1999).

The radiation arriving outside the earth's atmosphere is referred to as extra-terrestrial solar radiation. The flux density of extra-terrestrial radiation is given by the solar constant Isc, which is defined as the rate at which total solar energy of wavelengths fall on a unit horizontal surface normal to the solar beam at the mean-earth distance. The solar constant is not accurately known constant. It has been estimated at 1375W/m^2 (Fygelson, 1977), while Miller (1981) gives a range of 1368W/m^2 to 1377W/m^2 and *Hickey et al.* (1982) gives an average value of 1376W/m^2. A frequently quoted value of the solar constant is 1353W/m^2 (Kondratyev, 1969). But, according to the World Radiometric Reference (WRR), the present and most reliable value of the solar constant is 1370±6W/m^2 (WHO, 1981). The solar flux at the top surface of the earth's atmosphere can be assumed to be equal to the solar constant.

The solar constant is related to the extra-terrestrial solar spectral irradiance E_λ by:

$$I_{sc} = \int_0^\infty E\lambda \, d\lambda$$

Since the distance between the sun and the earth varies during the year, the value of the solar radiation flux, I_o outside the atmosphere is in general different from Isc. Applying an eccentricity correction factor ε_o for the earth's orbit with R_o as the mean sun-earth distance and R the sun earth distance at the given moment in time.

$\varepsilon_o = (R_o/R)^2$ which is approximately $1 + 0.033\cos(2\pi d_n / 365)$.

It follows that:

$I_o = \varepsilon_o I_{sc}$

Where d_n is the day number of the year, is used by Duffie and Beckman (1980).

2.3 COMPONENTS OF SOLAR RADIATION IN THE ATMOSPHERE

Solar radiation is redistributed as it transverses the earth's atmosphere. It is therefore necessary to look at the radiation according to its distribution.

1. **Direct Solar Radiation**

The solar radiation arriving on the ground directly in line from the solar disk is called the direct or beam of radiation.

2. **Diffused Solar Radiation**

Due to scattering of radiant energy in the atmosphere, the short-wave solar radiation reaching the earth surface is not only direct but also scattered or diffused radiation. In clear sky, the magnitude of the diffused solar radiation is dependent upon solar height, atmospheric transparency, and the albedo of the underlying surface.

3. Global Solar Radiation

The total radiation is termed global solar radiation; and is the sum of the direct and diffused solar radiation. In case of a horizontal surface proposed by Igbal (1983), the total radiation F^{H}_{Global} is the sum of vertical component of the direct beam I_m and the diffused horizontal radiation $F^{H}_{Diffused}$:

$$F^{H}_{Global} = I_m \cos\theta_z + F^{H}_{Diffused}$$

Where θ_z is the angle between the direct beam and the normal to the surface.

2.4 SOME SOLAR RADIATION MEASUREMENT INSTRUMENTS

An instrument for measuring irradiance is called a **radiometer**. It is usually desirable for radiometers to respond equally to equal amounts of energy at all wavelengths over the wavelength range of the radiation to be measured. Most radiometers therefore work by using a thermopile to measure the temperature rise of a sensitive element whose receiving surface is painted dull black. Instruments for measuring solar irradiance using a photovoltaic cell as the sensitive element have a non-uniform spectral response.

1. The Pyrheliometer

A **pyrheliometer** is an instrument for measuring beam solar irradiance at normal incidence. It is so designed that it measures only the radiation from the sun's disk (which has an apparent diameter of ½°) and from a narrow annulus of sky of diameter 5° around the sun's disk.

2. The Pyranometer

A **Pyranometer** is an instrument for measuring solar irradiance from the solid angle 2π onto a plane surface. When mounted horizontally facing upwards it measures global solar irradiance. If it is provided with a shade that prevents beam solar radiation from reaching the receiver, it measures diffuse solar irradiance.

3. The Pyrgeometers

The pyrgeometers are type of solar measurement instrument designed for infrared radiation (IR) measurement, for both atmospheric and material testing research applications.

4. The Sun Trackers

The sun trackers are all-weather, reliable and affordable tracking and positioning instruments. Either as a dedicated sun tracker or as computer based positioner.

5. The Sunshine Duration Sensors

The sunshine radiation sensors are radiometers for the measurement of the sunshine duration. Sunshine duration is defined by the World Meteorological Organization (WMO) as the time during which the direct solar radiation exceeds the level of $120 W/m^2$.

These radiometers must be calibrated periodically against a standard. An accuracy of about 3% is then obtainable in good instruments.

Great care is needed when choosing a site for these radiometers, especially when the measurements are required for climatological studies in conjunction with measurements by other instruments over a large area. It is surprisingly difficult to find sites that have an uninterrupted view of the sky from the zenith to the horizon in all directions. Objects that stand above the horizontal plane of the instrument obscure part of the sky and influence the diffuse solar irradiance measured. Such objects may even obscure the beam solar irradiance for part of the day at some time in the year. It should also be remembered that a good site chosen at one time may become unsatisfactory later because nearby trees have grown taller, or because new buildings have been constructed.

2.5 THE SOLAR SPECTRUM

The Sun's radiation is a good approximation of black body radiation (a continuous distribution of wavelengths with no wavelengths missing) with wavelengths in the range of about 0.2 µm to 2.6 µm (Figure 2.5). The solar spectrum consists of ultra -violate rays in the range of 200 to 400 nm, visible light in the range 390 nm (violet) to 740 nm (red) and the infra-red in the range 700 nm to 1mm. Table 2.1 shows the subdivisions of the Ultra Violate range and Table 2.2 shows the distribution of extraterrestrial solar radiation.

Table 2.1: Ultra Violates Radiation.

UV-A	320-400 nm	Not harmful in normal doses, vitamin D production.
UV-B	290-320 nm	Tanning, can burn.
UV-C	230-290 nm	Causes skin cancer.

Table 2.2: The distribution of extraterrestrial solar radiation.

Ultra Violet	200-400 nm	8.7%
Visible	400-700 nm	38.3%
Near Infra- Red	7003-500nm	51.7%

2.6 ROUGH ESTIMATE OF SOLAR ENERGY AVAILABLE AT THE EARTH SURFACE

The solar constant is the average extraterrestrial insolation at the edge of the atmosphere:

$$G_{sc} = 1367 W/m^2$$

The Earth presents a disc of area πR^2 to the sun; therefore the total amount of extraterrestrial insolation incident on the Earth is $G_{SC} \times \pi R^2$. This value is then divided by half the surface areas of the Earth, $4\pi R^2/2$, which gives 684 W/m^2, the average insolation incident on unit area of the Earth facing the Sun (Figure 2.9). Note that solar panels are calibrated assuming that there is 1000 W/m^2 available.

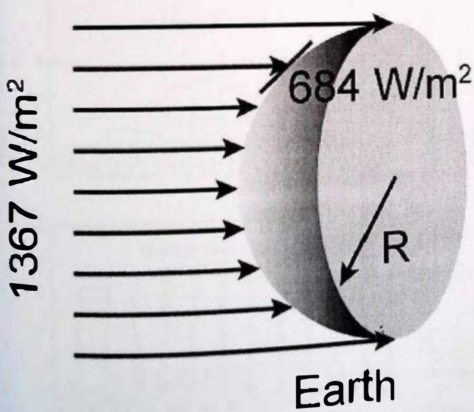


Figure 2.1: Radiation estimation.

A rough estimate of the irradiation incident per unit area (H) of the Earth's surface can be made if we assume that 30% of the Sun's energy is lost in the atmosphere and that a day is an average of 12 hours long at any location.

$$H = 0.7 \times 684 \times 12 = 5.75kWh/day$$

Or if we assume that the Sun is only at an appreciable strength for an average 6 hours in the day (as is likely in more northerly latitudes):

$$H = 0.7 \times 684 \times 6 = 2.88kWh/day$$

Figure 2.10 shows the yearly profile of mean solar radiation for different locations around the World. The solid grey line show the value of 5.75kWh/day and the dashed grey line shows 2.88kWh/day.

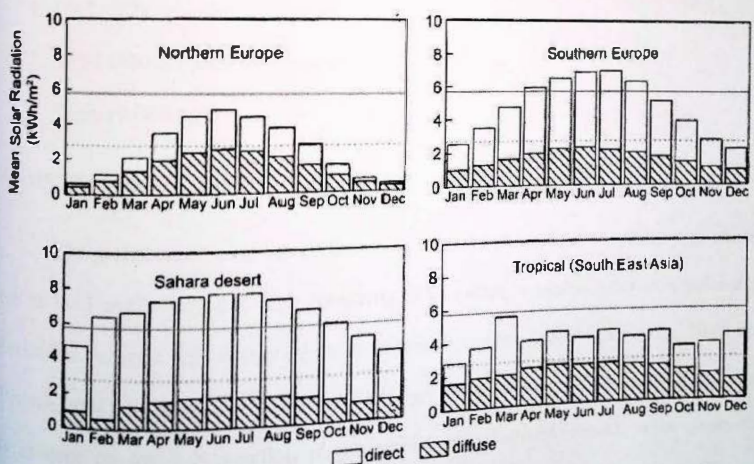


Figure 2.2: The yearly profile of mean solar radiation for different locations around the world. http://www.itacanet.org/the-sun-as-a-source-of-energy/part-1-solar.

CHAPTER THREE

3.0 MATERIALS AND METHOD

This chapter describes the materials used and method of construction.

3.1 MATERIALS USED

The materials used in the construction of the pyranometer includes are as follows:

1. A wood case, 16cm x 12cm x8cm with thickness of 1cm.
2. 1k, 10k, 10k, 220, and 4.7k ohm resistors.
3. Light emitting diode.
4. Switch.
5. 9V battery.
6. UA741CN operational amplifier.
7. TEFT4300 Silicon Phototransistor.
8. Digital Multimeter

3.2 METHOD OF CONSTRUCTION

The pyranometer was constructed using a silicon phototransistor which was chosen for its local availability and high sensitivity. This silicon phototransistor is a solid-state device that converts light energy (photons) to electric current, (Agbo and Nweke, 2007) and (Nweke, 2008). When radiation at a specific energy level that is capable of ionizing the atoms is incident on the P-N junction phototransistor, an electrical current arises from the continuous movement of excess electrons and holes. According to (Brooks, 2012), this electric current produced by the phototransistor is directly proportional to the amount of global solar radiation reaching its surface. The photo sensor element is mounted on the top of a wooden case, covered with a transparent plastic material to protect the photo sensor from absorbing dirt. The developed pyranometer generates an electrical signal proportional to the irradiance received, (Medugu, el al, 2010).

3.3 Processes of Construction

The pyranometer was constructed in parts and then assembled. A hole was drilled at the top of a wood case of 1cm thickness with a dimension of 16cm by 12cm by 80cm where a diode holder was inserted and glued. The photo detector was inserted into the diode holder. The exposed surface of the phototransistor was covered with a transparent plastic material in order to protect it from dust and other weather attacks; the radius of the exposed surface is 0. 25cm. And therefore the area of the surface is π r^2 which is 1.96375m^2. A pair of wires was soldered to the anode and cathode terminals of the phototransistor which was then connected to the terminals of a digital multi-meter through which the output readings indicating the amount of solar radiation was obtained in volt (V).

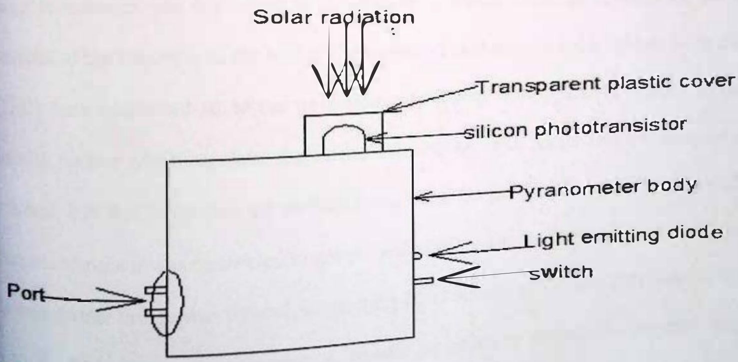


Fig. 3.1 Pyranometer block diagram

3.4 PYRANOMETER CIRCUIT DIAGRAM

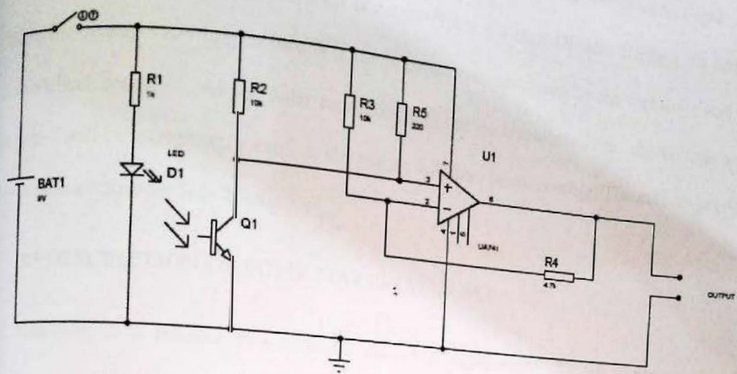


Fig. 3.2 Pyranometer circuit diagram

The figure above is the circuit diagram of the pyranometer in which a 9V battery is used as a power source. The positive terminal of the battery was connected to Vcc while the negative terminal was connected to the ground. A switch was used between the positive terminal of the battery and the Vcc of the circuit. A 1kΩ resistor and a light emitting diode (LED) were connected to serves as indicator for power supply, the 1k resistor serve as limiting resistor which regulates the current entering the LED. An IC base was mounted and soldered, UA741CN operational amplifier was used. On pin 2 of the operational amplifier, the phototransistor was connected to ground and 10kΩ resistor to the Vcc. On pin 3, a simple voltage divider bridge was formed, connecting 10kΩ resistor to Vcc and 220Ω resistor to the ground which serves as a correction resistor in order to correct the dc error due to polarization, and as a reference input to the operational amplifier. Pin 4 was connected to the ground with the aid of a jumper wire. A feedback resistor of 4.7kΩ was connected from the output to the pin 2, which was the non-inverting input of the operational amplifier. Pin 7 was also connected to Vcc.

The IC acts as comparator which compares the potentials from its two terminals (pin 2 and pin 3). The potential at pin 3 was kept constant (from Voltage Divider Bridge). In order to obtain the output, $V_O = I_p R_f$, where I_P is the photocurrent produced by the transistor and R_f is the feedback resistor . As the solar radiation falls on the phototransistor, the voltage across the pin 2 will be increasing, therefore the output will also be increasing. The current produced by the phototransistor I_P is 3.2A.

3.5 DESCRIPTION OF SOME MATERIALS USED

Resistor: Is a passive two terminal electrical component that implements electrical resistance as a circuit element. In electronic circuit, resistors are used to reduce the current flowing in the circuit, adjust signal levels, and divide voltages, bias active elements and terminal transmission line among other uses. The behavior of the ideal resistor is dictated by the relation specified by Ohm's law:

V = IR, Ohm's law states that, the voltage V across a resistor R is proportional to the current I flow, where the constant of proportionality is the resistance R. The ohm (Ω), is the SI unit of electrical resistance named after George Simon Ohm, which is equivalent to volt per ampere. Resistors are arranged either in parallel or in series.

If we have resistors for example R1, R2 and R3 connected in series or in parallel, there equivalent resistance is: $R_{eq.} = R1+R2+R3$ and $1/R_{eq} = 1/R1 + 1/R2 + 1/R3$ for resistors in series and in parallel respectively.

Light Emitting Diode (LED): This is a two lead semiconductor light source. It is a p-n junction diode, which emits light when activated. When a suitable voltage is applied to the leads, electrons are available to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy photon) is determined by the energy band gap of the semiconductor.

Phototransistor: This is similar to normal transistor. The difference the base is that sensitive to the light. In other words, a light excitation in its base will generate a current between its collector and emitter, which is proportional to the incident radiation. In contrast to photodiodes, phototransistor include (due to their intrinsic characteristics) amplifier stage. For this reason, they present more sensitivity and higher response irradiance than photodiodes.

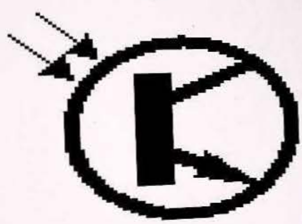


Fig 3.3 phototransistor.

Operational Amplifier: Is basically a three terminal device which consists of two higher impedance inputs, one called the inverting input, marked with a negative or minus sign, (−) and the other is called the non-inverting input, marked with a positive or plus sign, (+). The third terminal represents the operational amplifier's output port which can both sink source either voltage or current. In a linear operational amplifier, the output signal is the amplification factor, known as amplifiers gain (A) multiplied by the value of the input signal depending on the nature of their output and the output signals.

There are four different classifications of operational amplifier:

i. Voltage "in" and voltage "out".

ii. Current "in" and current "out".

iii. Transconductance voltage "in" and current "out".

iv. Transresistance current "in" and voltage "out"

Digital Multimeter (DMM): Is a test tool that measures two or more electrical values, principally voltage (Volts), currents (Amps) and resistance (Ohms). It combines the testing capabilities of single task meters, the voltmeter (for measuring voltages "volts"), the ammeter (for measuring currents "amps") and the ohmmeter (for measuring resistances "ohms").

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 CALIBRATION RESULTS

The measurements were carried out within four days; on 29/12/2016, 30/12/2016, 31/12/2016 and 2/01/2017. The readings of the insolation obtains were in volts (mV), the conversion of this volt to watt per meter square was done. The mean outputs of this instrument were 100.92W/m^2, 97.30 W/m^2, 92.13 W/m^2 and 94.91 W/m^2 for these four days respectively.

TABLE 4.1: READINGS FOR 29/12/2016.

SERIAL NUMBER	TIME (HOUR)	VOLTAGE (mV)	IRRADIANCE (W/m^2)
1	7am	160.0	26.07
2	8am	580.0	94.13
3	9am	650.0	105.20
4	10am	730.0	118.96
5	11am	750.0	112.21
6	12pm	785.0	127.92
7	1pm	780.0	127.10
8	2pm	770.0	125.47
9	3pm	740.0	120.58
10	4pm	710.0	115.70
11	5pm	680.0	110.80
12	6pm	165.0	26.80

TABLE 4.2: READINGS FOR 30/12/2016.

SERIAL NUMBER	TIME (HOUR)	VOLTAGE (mV)	IRRADIANCE (W/m^2)
1	7am	140.0	22.81
2	8am	540.0	88.00
3	9am	630.0	102.66
4	10am	700.0	114.07
5	11am	740.0	120.58
6	12pm	765.0	124.66
7	1pm	740.0	120.58
8	2pm	730.0	118.96
9	3pm	700.0	114.07
10	4pm	680.0	110.80
11	5pm	640.0	104.29
12	6pm	160.0	26.07

TABLE4.3: READINGS FOR 31/12/2016.

SERIAL NUMBER	TIME (HOUR)	VOLTAGE (mV)	IRRADIANCE (W/m^2)
1	7am	120.0	19.55
2	8am	520.0	84.74
3	9am	610.0	99.40
4	10am	698.0	113.74
5	11am	710.0	115.70
6	12pm	745.0	121.40
7	1pm	674.0	109.83
8	2pm	660.0	107.55
9	3pm	650.0	105.20
10	4pm	630.0	106.66
11	5pm	600.0	99.77
12	6pm	135.0	22.00

TABLE 4.4: READINGS FOR 2/01/2017.

SERIAL NUMBER	TIME (HOUR)	VOLTAGE (mV)	IRRADIANCE (W/m^2)
1	7am	134.0	21.84
2	8am	560.0	91.25
3	9am	640.0	104.25
4	10am	684.0	111.46
5	11am	696.0	113.42
6	12pm	720.0	117.43
7	1pm	712.0	116.02
8	2pm	706.0	115.05
9	3pm	680.0	110.80
10	4pm	640.0	104.29
11	5pm	608.0	99.08
12	6pm	150.0	24.44

Fig. 4.1: Graph of Irradiance (W/m^2) against local time for 29/12/2016.

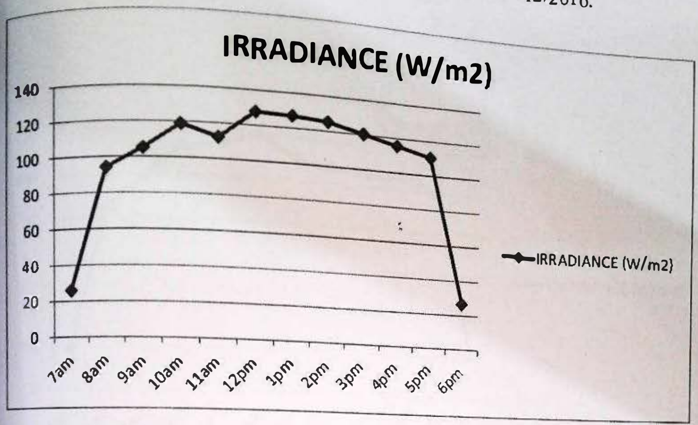


Fig. 4.2: Graph of Irradiance (W/m^2) against local time for 30/12/2016.

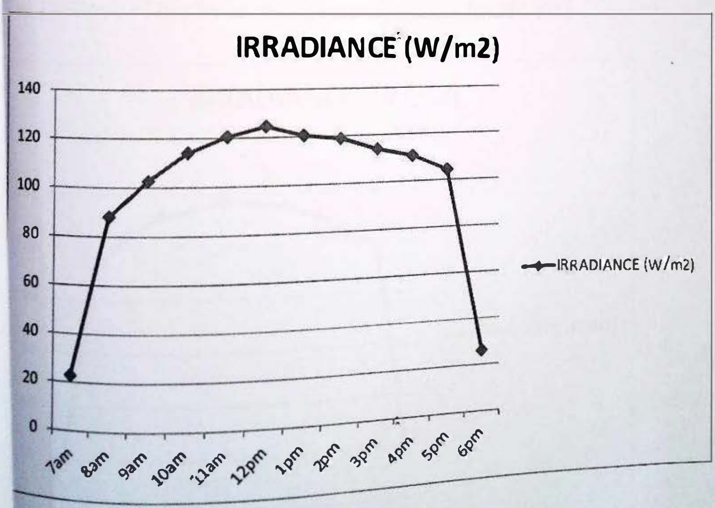


Fig. 4.3: Graph of Irradiance (W/m²) against local time for 31/12/2016.

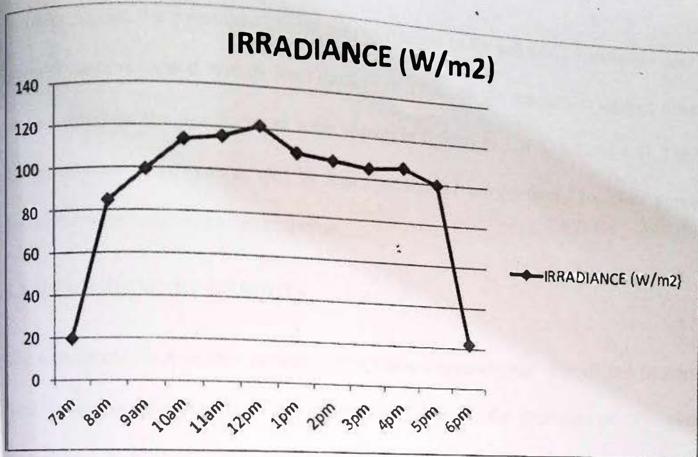
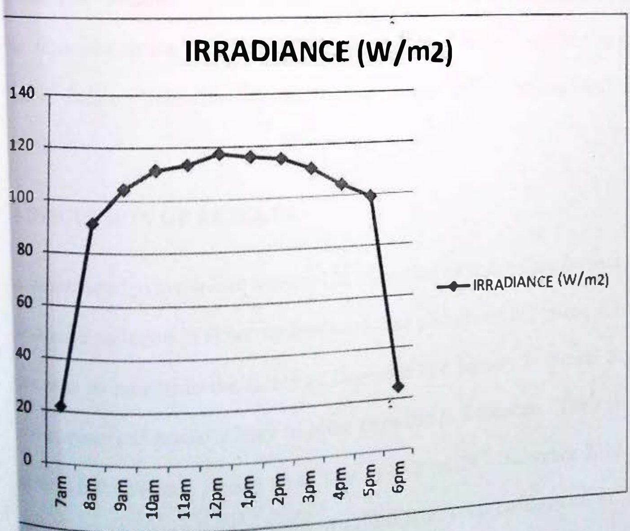


Fig. 4.4: Graph of Irradiance (W/m²) against local time for 2/01/2017



4.2 TESTING OF THE PYRANOMETER

In order to test the pyranometer, its output needed to be recorded. Insolation data at 1hour interval were recorded within four days. The plots of the insolation against time (voltage against time) for the pyranometer were shown in figures (4.1, 4.2, 4.3 and 4.4). The values of the constructed pyranometer will be less than that of a commercial (original pyranometers) due to the difference in cosine response.

4.3 MEASUREMENT RESULTS

The instrument used in this project is constructed pyranometer. The digital Multimeter was used to display the amount of solar radiation falling on the pyranometer. The pyranometer was placed in secured place which is not blocked by land scape features, such as trees, buildings, hills, or mountains that may otherwise shade the instrument during the calibration. The choice of the locations were based on the requirements that for the optimum amount of global solar radiation to be received, the field of the view of the pyranometer sensor must be free from obstructions at all time. The readings were taken from 7am to 6pm at Abubakar Tafawa Balewa University Bauchi, Yelwa campus behind International secondary school ATBU.

4.4 DISCUSSION OF RESULTS

The constructed pyranometer was used in measuring solar radiation for four days. The plot of global solar radiation in W/m^2 against local time was shown in figures; 4.1, 4.2, 4.3 and 4.4. There was no rainfall in the month of December and January in Bauchi State; therefore the sky was clear and partially hazy in some days due to harmattan. The maximum irradiance received (100.92W/m^2) among these four days is on 29th December 2016 as shown in the graph, while the minimum irradiance of (22.00 W/m^2) was obtained on 31st December 2016.

From the graphs, is shown that on 29th and 30th December 2016 the sky was clear, while on 31st December 2016and 2nd January 2017, the sky was a bit hazy due to harmattan, which attenuates the radiation falling on the earth. The highest irradiance occurred between 12pm to 2pm as shown in the graph and its peak values were at 12pm. The World Energy Center (ECN 2005), in their measurements obtained the minimum and maximum solar irradiance at 6am and 2pm respectively, which they concluded that it is in accordance with the global solar radiation pattern. This is almost agreed with measurement made on this project in which the minimum and the maximum irradiance received occurred at 7am and 12pm, which is also in accordance with global solar radiation pattern.

When comparing the values obtained in this project (using silicon phototransistor) and those obtained by others in the literature review that uses silicon photodiode as their sensor element, it is found that phototransistor is about 100times sensitive than photodiode. *Medugu, et al.* (2011) measures solar radiation at ATBU using silicon photodiode and recorded a maximum of 178.5mV at 12pm, while in this project; we recorded the maximum 785mV at 12pm. This shows that the phototransistor used in this project is about 60% times more sensitive than the photodiode he used.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

The summary of this research project (construction of pyranometer for measuring global solar radiation) is as follows:

i. The project was limited on construction and measurement of solar radiation received in ATBU.

ii. The measurement of solar radiation was conducted behind international secondary school, Abubakar Tafawa Balewa University Bauchi Yelwa campus, with the aid of constructed pyranometer.

iii. Phototransistor is the sensor element used mounted on a top of a wooden case, and covered with a transparent plastic material to prevent it from absorbing dust.

iv. The generated electrical signal is proportional to the irradiance received, converts the current received from the detector to voltage and amplifies them to digital multi-meter with the aid of operational amplifier.

v. Insolation data at one hour interval were recorded for four days; 29th, 30th, 31st, December 2016 respectively and 2nd January 2017.

vi. The maximum and minimum values obtained were 100.92W/m^2 on 29th December 2016 at around 12pm to 1pm and 22.00 W/m^2 on 31st December 2016 at the early hour of the day (7am) respectively.

vii. The average irradiance received within these four days is 96.31W/m^2.

viii. The graphs of irradiance (W/m^2) against local time were shown in figure: 4.1, 4.2, 4.3 and 4.4 in chapter four (4) of the project.

5.2 CONCLUSION

At any given moment, the amount of solar energy received at a location on the earth surface depends on the condition of the atmosphere; the calibration was conducted on; 29th, 30th, and 31th, of December, 2016, 2nd January, 2017 from 7am to 6pm. The calibration was carried out at Yelwa campus, north eastern Nigeria (Latitude $10^0 17'0''$, Longitude $9^0 47'0''$) ,for four days. Silicon phototransistor was used as the sensor in this research project, and obtained an average value of 96.31 W/m^2 from ground base measurement of solar radiation, which compared with those reported from literature reviews who used photodiode as their detector and found that phototransistor is very sensitive to light than photodiode, (of about 100 times) .

5.3 RECOMMENDATION

As the project is concerned, construction of pyranometer for measuring global solar radiation using silicon phototransistor, the project can be improved by using reference or commercial pyranometers to compare the output of the constructed pyranometer.

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Onah, D.U and Osuji, R.U., (2007). Design, construction and characterization of a pyranometre for measuring global solar radiation. Nigeria Journal of Solar Energy vol18 p 81. Fig. 4.4: Graph ofIrradiance (W/m^2) against local time for 2/01/2017

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