Ozean Journal of Applied Sciences 3(2), 2010
ISSN 1943-2429

EXPERIMENTAL COMPARATIVE STUDY OF THE PERFORMANCES OF CONSTRUCTED RELIABLE MODEL AND STANDARD PYRANOMETERS

Medugu, D. W.*, Burari, F. W. ** and Bello, A. A.***
*Department of Physics, Adamawa State University, Mubi.
** Department of Physics, Abubakar Tafawa Balewa University, Bauchi.
*** Department of Mechanical Engineering, Abubakar Tafawa Balewa University, Bauchi.

*E- mail address for correspondence: dalemedugu@yahoo.com

Abstract: *A reliable model pyranometer, RMP001 was fabricated and calibrated against a reference commercial standard pyranometer, CMP3 obtaining a calibration constant of* $5230 \pm 0.024Wm^{-2}$. *Insolation data at 1 minute intervals was recorded under actual environmental conditions of Mubi, Adamawa State – Nigeria, using a data logger. The insolation was monitored for a period of 57 days. Results show that insolation is larger than on a dust-free day because dusts reflect sunlight off their sides. It is clear that the fabricated pyranometer (RMP001) performs about the same as the commercial standard pyranometer (CMP3). The differences in results obtained are so small enough to obtain sufficient accurate data especially when insolation is averaged over a day.*

Keywords: *Pyranometer, Calibration, Environmental, Insolation.*

INTRODUCTION

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

Solar radiation is becoming increasingly appreciated because of its influence on living matter and the feasibility of its application for useful purposes. It is a perpetual source of natural energy that, along with other forms of renewable energy, has a great potential for a wide variety of applications because it is abundant and accessible. Solar radiation is rapidly gaining ground as a supplement to the nonrenewable sources of energy, which have a finite supply.

Recent developments in the areas of photochemistry and photobiology have also helped in bringing attentions to solar radiations. The significant depletion of the stratospheric ozone layer, which shields the earth from much of the biologically injurious solar ultraviolet radiation (UVR), is apparently due to human activity and has now become a popular topic. Adverse biological effects of UVR on man include, among others, sunburn (erythema), conjunctivitis, and skin cancer (WHO, 1979). In contrast, the vital phenomenon of photosynthesis is an example of the beneficial effect of sunlight in the natural environment. Other beneficial and harmful effects on a variety of living beings, especially microorganisms, are well documented (Jagger, 1976; Chamberlin and Mitchell, 1978; Harms, 1980; Senger, 1980). Solar radiation has, therefore, a prominent ecological rule.

Many researchers derived radiation models by using sunshine hours, relative humidity, latitude and air temperature. Reddy, (1971) suggested the use of number of rainy days, sunshine hours, latitude and geographical factor as an input to his model. Using sunshine hours, maximum air temperature, latitude and relative humidity, Sabbagh et al (1977) estimated the global solar radiation at various places. Their method was not capable of predicting the direct and diffuse components of radiation. Paltridge and Proctor, (1976) employed cloud data and latitude in a model which could predict the direct and diffuse daily solar radiation at the earth's surface. In Nigeria, most researchers use available theoretical values of meteorological data to compute average insolation for different locations within Nigeria. They lack standard measured data obtained from reliable measuring instrument suitable for their local environment and therefore resorted to theoretical predictions using different models for the global daily sunshine radiation. Examples of such models in the Nigerian environment include that of Burari and Sambo (2001), Madekwe and Ogunmola (1997), Sambo and Doyle (1985) and Fagbenle (1983) to mention but a few. The need for developing a reliable model pyranometer for the collection of authentic insolation data for comparative study with a standard pyranometer becomes a necessity. This major reason among many others prompted the emergence of this study.

Instrumentation for Measuring Solar Radiation

There are two general categories of instruments used to measure solar radiation: Full – sky Instruments (instruments that measure radiation from the entire sky), and Direct Sunlight Instruments (instruments that measure only direct solar radiation) (Brooks, 2007).

Full – sky Instruments called pyranometers need an unobstructed view of the entire sky without much obstacles. Direct Sunlight Instruments are designed to view only light coming directly from the sun. They are called pyrheliometers.

Detectors used for Solar Radiation Measurements

The most common types of detectors used to measure radiation are thermoelectric and photoelectric.

Thermoelectric detectors measure temperature differences using a thermocouple or thermistor as a transducer to convert radiant energy to electrical energy. They are used mainly for solar and long wave radiation measurements and have the property of equal response over their wavelength range.

The photoelectric types, here referred to as photodiodes, are solid-state devices that convert light energy (photons) to electrical current (Pearcy 1989; Hamamatsu Corp. 1995). Photoelectric detectors are particularly useful for measuring the light required by plants for photosynthesis, because they respond to the photon flux over the photosynthetically active wavelengths.

The accepted wavelength band for photosynthetically active radiation measurement is 400–700 nm, and is commonly referred to as the visible light spectrum. Several types of photodiode are suitable for light measurement in the visible range. These include silicon (Si), selenium, cadmium sulfide, lead sulphide, lead selenide, and gallium arsenide phosphide (GaAsP) photodiodes (Unwin 1980; Pearcy 1989). Of these, Si and GaAsP photodiodes are the most useful (Pearcy 1989).

Description of a Reliable Model Pyranometer

The Reliable Model Pyranometer (RMP001) developed is shown in Figure 1. The pyranometer is shown as a circuit diagram in Figure 2. The transimpedance amplifier shown in Figure 3, configured around the LTC1051 operational amplifier (OPAM), was used for signal conditioning from the photodiode (see Figure .2). In this circuit I_p is the photocurrent from the diode and C its parasitic capacitor. C_c, R_c and C_r are compensation, correction and stabilization elements respectively. Finally, R_f is the feedback resistor which fixes the DC gain in the circuit, so the output from this is $V_0 = I_p R_f$.

To calculate the value of R_f a nominal irradiance of 1,000 W/m^2 is used. For this, the BPW21 photodiode produces the photocurrent $Ip = 4.68 \times 10^{-4}$A. Therefore, the value of Rf implemented is 470Ω, to carry out precise adjustment. In order to correct the DC error due to polarization currents, a resistor (Rc) is connected to the non-inverting input of the OPAM. This resistor has a detrimental effect in terms of noise (Graeme, J.,1996), which is amplified; this is why a 100*pF* compensation capacitor Cc is connected in parallel with it. The parasitic capacitor on the photodiode BPW21, C, is 580*pF*. This capacitor has to be taken into consideration, as it can influence the stability of the assembly (reducing its phase margin, and therefore, its relative stability). To improve the stability of the amplifier, finally, a capacitor Cr is connected in parallel with the feedback resistor Rf (see Figure 2). It is calculated that an appropriate value for the capacitor is 100 pF.

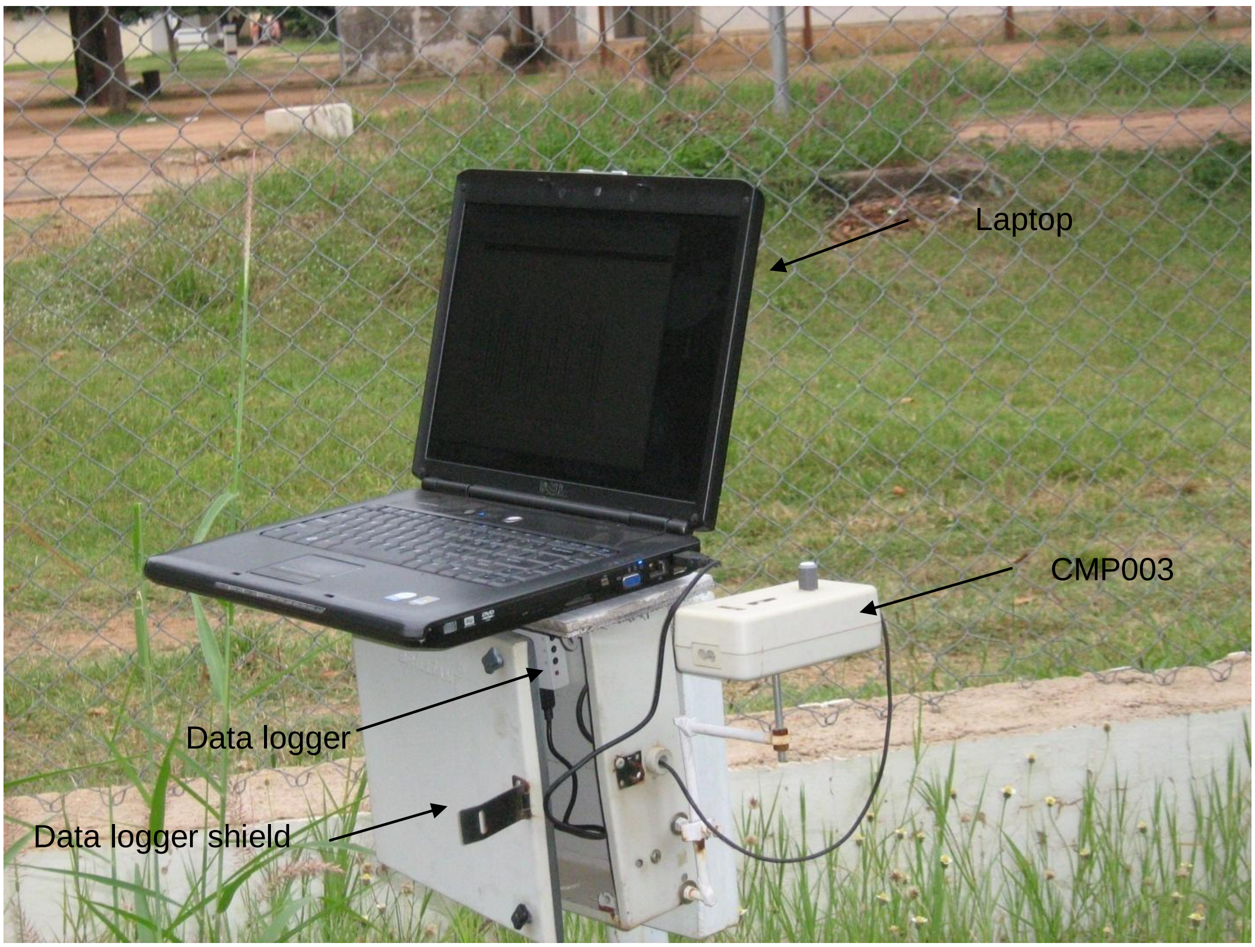


Figure 1: Picture of the Constructed Reliable Model Pyranometer undergoing Measurements

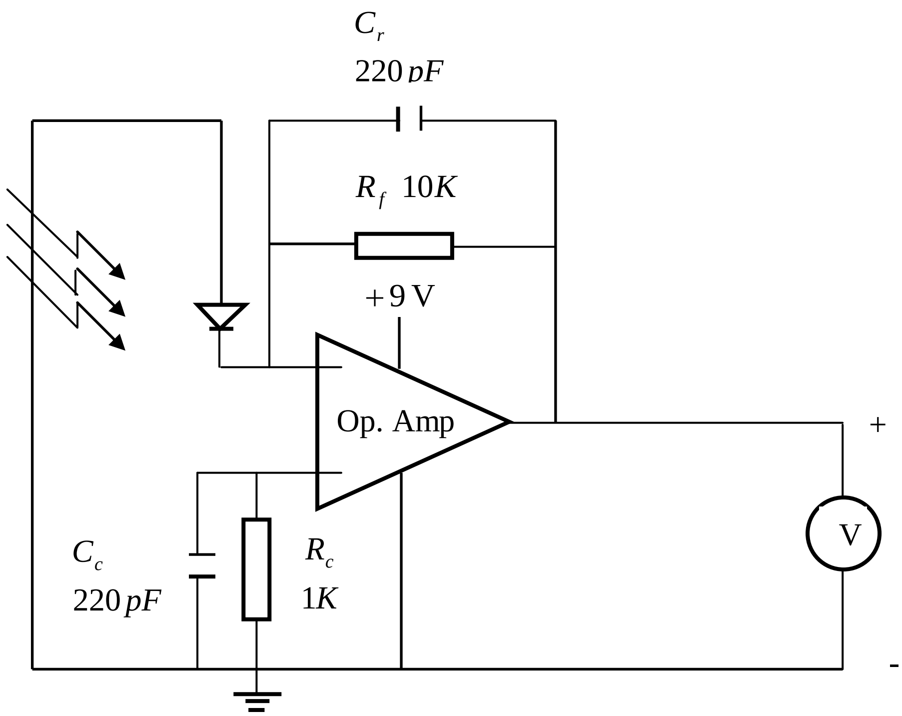


Figure 2: Pyranometer circuit diagram.

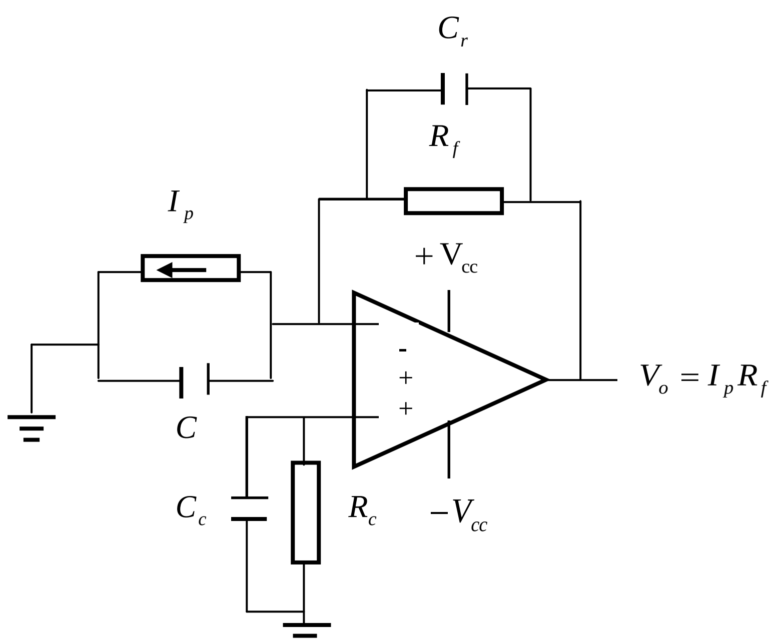


Figure 3: Transimpedance amplifier to condition the I_p signal provided by the photodiode

System Fabrication

A hole was drilled about one quarter distance from one end in the top of the plastic case. A plastic LED holder was inserted into the hole and super glued. The photodetector was inserted into the LED holder. Another two holes were also drilled opposite to where photodetector was placed. These holes are for the purpose of inserting level gauges to ensure horizontality and verticality of the instrument. A small hole was also drilled in the center of the opposite end of the enclosure from the hole (on the side of the enclosure, not the top). This hole is large enough for a grommet, through which a connecting cable is passed. Several centimeters of the cut end of the plug and cable assembly were assembled through the grommet, from the outside to the inside of the case. The transimpedance amplifier configured around the LTC1051 operational amplifier (OPAM), was then fixed into the case. The photodiode and the connecting cable were soldered to the input and output of the OPAM respectively.

The Teflon diffusing disk was finally carefully mounted over the photodetector assembly (Brooks, 2007). When convinced that the pyranometer was working properly, the bottom of the case was attached with the screws.

Instrumentation and Test Procedure

This reliable model pyranometer fabricated (RMP001) was then calibrated against a reference high quality CMP3 pyranometer whose calibration was trusted ($14.71 \pm 0.36 \mu V^{-1} Wm^{-2}$). RMP001 was mounted beside CMP3 and data was collected under open skies for a full day, 6.00 a.m. to 6.00 p.m. and stored at an interval of 1 minute. The readings of insolation obtained were in Wm^{-2} and V for the CMP3 pyranometer and RMP001 respectively as shown in Fig. 4.

The output from this instrument is about 0.17853 V near noon in full sunlight, for insolation of roughly 933.37 Wm^{-2}. The conversion of the output from RMP001 from volts to Wm^{-2} was done to obtain the calibration constant as follows:

$$0.17853V = 933.37Wm^{-2}$$

$$1V = \frac{933.37}{0.17853} = 5228.084916 \approx 5230 \pm 0.024Wm^{-2}$$

This calibration constant obtained for RMP001 produces the best fit with the calibrated output.

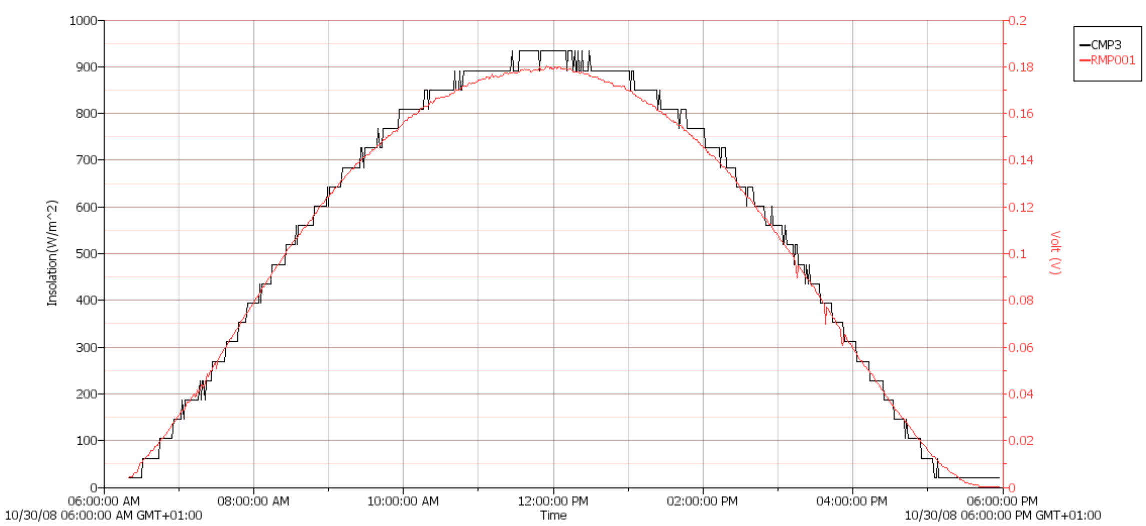


Figure 4: Graph of Solar Radiation measured with CMP3 and RMP001verses Time on 30th October, 2008.

EXPERIMENTAL RESULTS AND DISCUSSION

In order to test the pyranometer, its output needed to be recorded. Insolation data at 1 minute intervals was recorded for Mubi, Adamawa State – Nigeria, using a data logger. The logger has a USB interface with proprietary software for communicating with a computer. The data was stored in a propriety binary format and later saved as a text file that was imported into excel. The plot of insolation against time for both pyranometers is displayed in Fig.5. From Fig.5, it is seen that at the initial time, that is 6:21a.m., the insolation taken with the constructed pyranometer (RMP001) and the standard reference pyranometer (CMP3) are 23.94Wm^{-1} and 21.07 Wm^{-1} respectively. The highest insolation occurred at 11:52a.m. with insolation of 923.80 Wm^{-1}and 933.37 Wm^{-1}for RMP001 and CMP3 respectively. At 5:25 p.m., the insolations are 20.76 Wm^{-1}and 21.7 Wm^{-1} for RMP001 and CMP3 respectively.

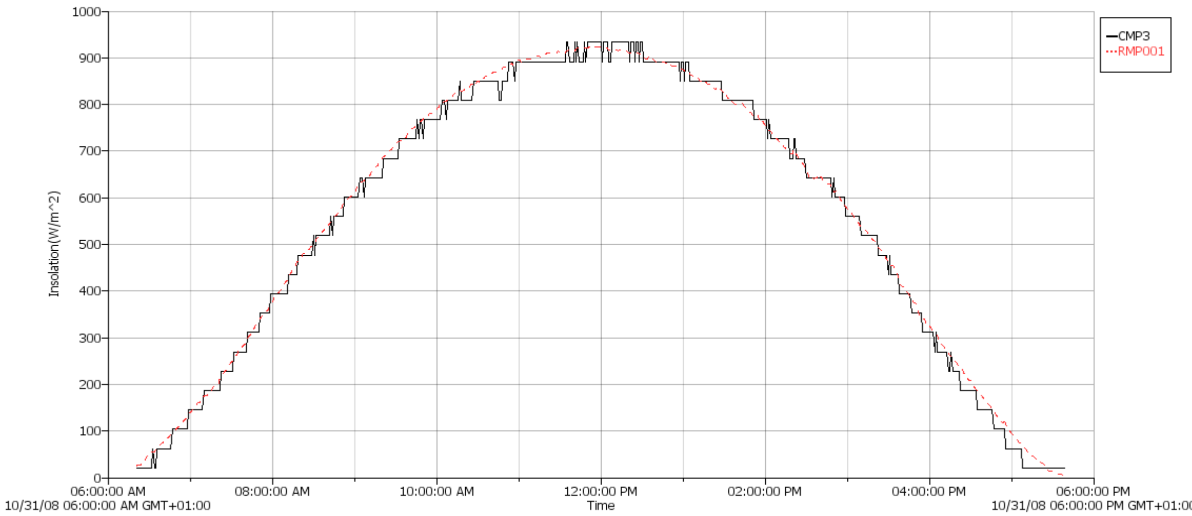
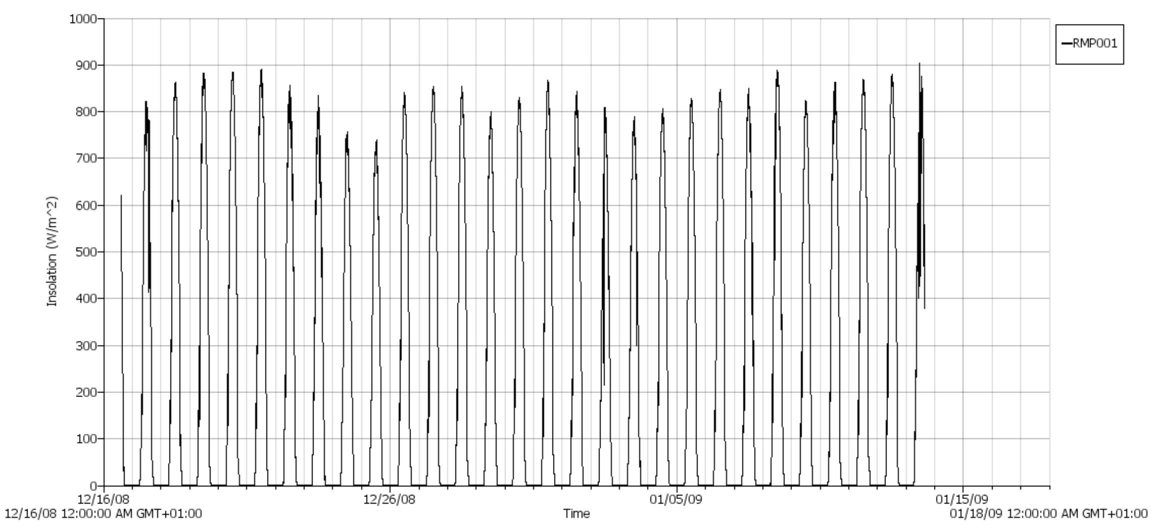
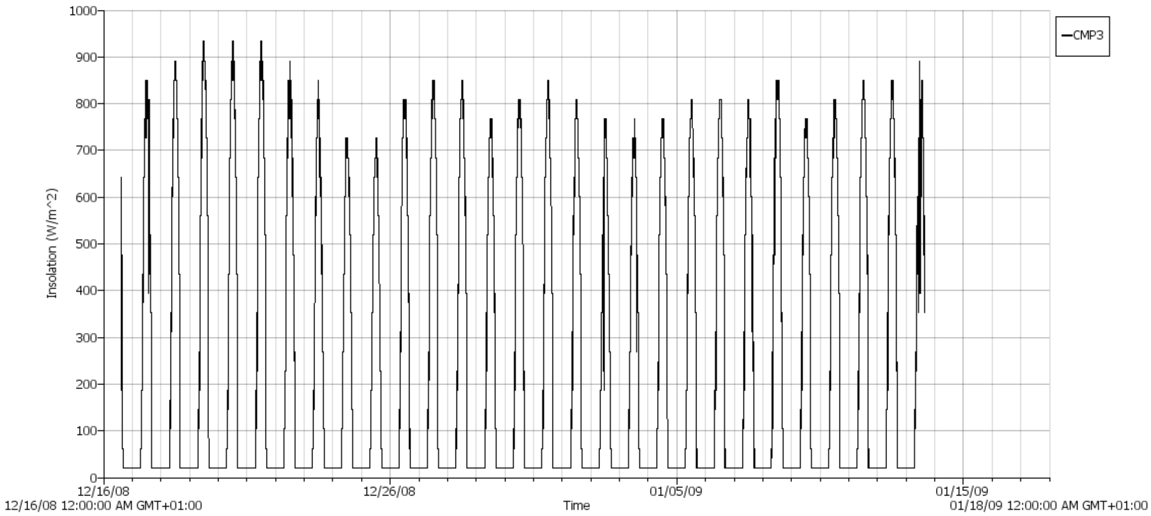


Figure 5: Insolation graph covering 31st October, 2008 at Adamawa State University, Mubi using both CMP3 and RMP001 after calibration, adjustments and model maximum values of insolation have been entered.

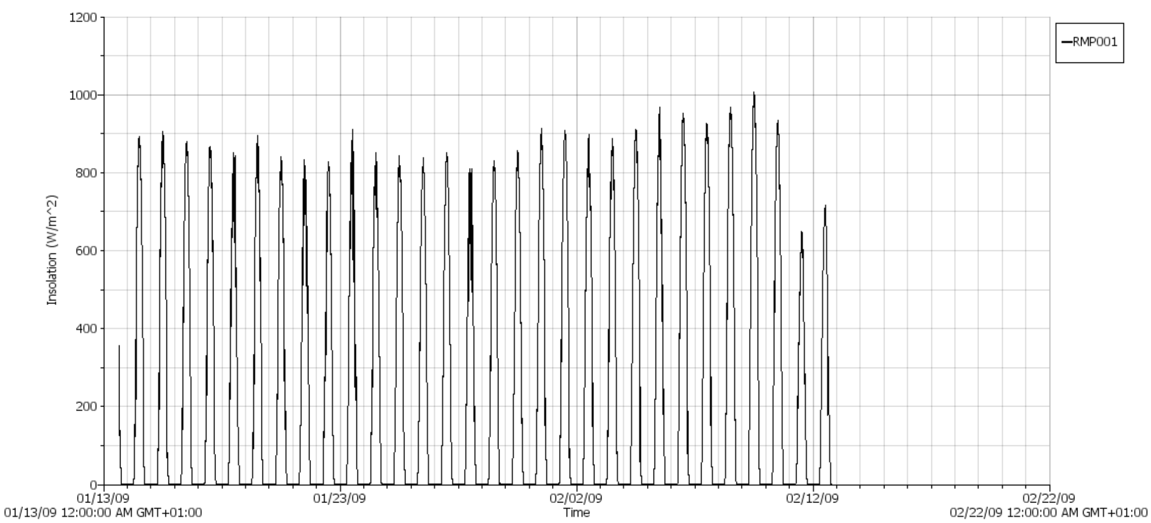


(a)

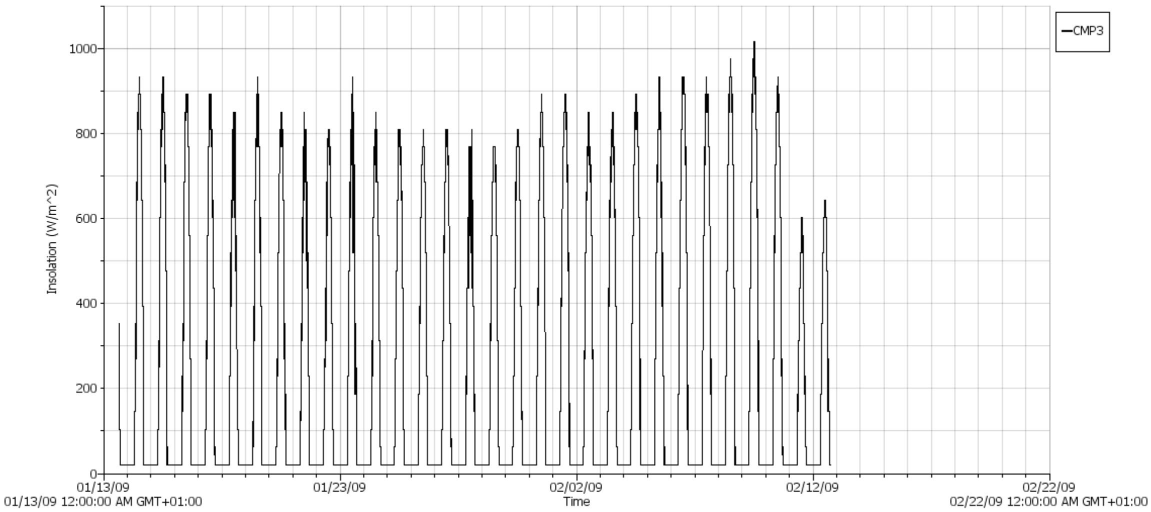


(b)

Figure 6: Solar insolation comparisons with (a) RMP001 and (b) CMP3 pyranometers taken from 16th December, 2008 to 13th January, 2009.



(a)



(b)

Figure 7: Solar insolation comparisons with (a) RMP001 and (b) CMP3 pyranometers taken from 14th January, 2009 to 12th February, 2009.

The results of insolation taken from 16th December, 2008 to 12th February, 2009 during harmattan period with the aid of RMP001 and CMP3 are shown in Figures 6 and 7. The graphs show a mixture of clear and dusty days. It is shown that on dusty days, the insolations are higher than on a clear day. The reason is the dusts reflect sunlight falls on them and the maximum daily insolation occurs on the dust-free days, as shown in the figures. Figures 6 and 7, (a) and (b) also gives similar results. It is finally concluded that the fabricated pyranometer (RMP001) performs almost the same as the commercial standard pyranometer (CMP3).

CONCLUSION

A solar cell – based type model pyranometer, RMP001 was fabricated and calibrated against a reference commercial standard pyranometer, CMP3 whose calibration was trusted obtaining a calibration constant of $5228.084916 Wm^{-2}$.Both instruments were finally studied under actual environmental conditions of Mubi, Adamawa State of Nigeria. The data obtained show a typical mixture of clear and cloudy days. The result reveals that maximum daily insolation occurs on the clear days.

Also, the data obtained clearly reveals that the fabricated pyranometer (RMP001) performs about the same as the commercial standard pyranometer (CMP3). The differences in results obtained may be small enough to yield sufficiently accurate data for some purposes, especially when insolation is averaged over a day.

ACKNOWLEDGEMENT

The authors would like to thank Dr. David Brooks from the Institute for Earth Science Research and Education Energy Research Institute, Norristown, PA USA, for his great help in providing us the necessary materials.

REFERENCES

Austin, J., Driscoll, C.M.H., Farmer, F.G. and Molyneux, M.J. (1999): Late Spring Ultraviolet Levels over the United Kingdom and the Link to Ozone. *Annals Geophysical, Vol. 17, pp 1999 – 1209.*

Brooks (2007): Measuring Sunlight at Earth's Surface: Build Your Own Pyranometer. Institute for Earth Science Research and Education.

Burari, F.W. and Sambo, A.J. (2001): Models for the Predictions of Global Solar Radiation for Bauchi using Meteorological Data. *Nig. Journal of Renewable Energy, Vol. 9, pp 30 – 33.*

Chamberlin, C.E. and Mitchell, R. (1978): A Decay Model for Enteric bacteria and Natural Waters. Water pollution Microbiology, John Wiley and sons, New York, U.S.A.,Vol. 2. pp 325 – 348.

Fagbenle, R.O. (1983): Estimation of Total Solar radiation In Nigeria using Meteorological Data. Paper presented at the 3rd National Solar Energy Forum (NASEF), Bidda.

Graeme, J. (1996): *Photodiode amplifiers. Op amp solutions*. Mc-Graw Hill: New York, NY, USA,; pp. 24-59.

Hamamatsu, Corp. (1995): Photodiodes. Cat. No. KPD 0001E04 (Product Cataloque), Hamamatsu city, Japan.

Harms, W. (1980): Biological Effects of Ultraviolet Radiation. Cambridge University Press, Cambridge, U.K. pp 216.

Holben, B.N. (1998): A Federated Instruments Network and Data Archive for Aerosols Characterization. Remote Sensing of the Environment, Vol. 66. pp 1 – 16.

Jagger, J. (1976): Effects of Near – Ultraviolet Radiation on Microorganisms. Photochemistry and Photobiology, Vol. 23, pp 451 – 454.

Madekwe, A.A.L. and Ogunmola, A. (1997): Estimation of the Monthly Average Atmospheric Perceptible Water Vapor and its Relationship with Global Solar Radiation. *Nig. Journal of Physics, Vol. 9, pp20 – 26.*

Paltridge, G.W. and Proctor, D. (1976): Monthly Mean Solar Radiation Statistics for Australia. *Solar Energy, Vol. 18, no. 3, pp 325 – 243.*

Pearcy, R.W. (1989): Radiation and Light Measurements in Plant Physiological Ecology: Field Methods and Instrumentation. Chapmand and Hall, London, U.K. pp 97 –116.

Reddy, S.J. (1971): An Empirical Method for the Estimation of Total solar Radiation.*Solar Energy, Vol. 13, no. 2 pp 289 – 290.*

Sabbagh, J.A., Sayigh, A.A.M. and El – Salam, E.M.A. (1977): Estimation of the Total Solar Radiation from Meteorological Data. *Solar Energy, Vol. 19, no. 3, pp 307 –311.*

Sambo, A.S. and Doyle, M.D.C. (1985): Estimation of the Global and Diffuse Components of Solar Radiation for some Nigerian cities. *Nigerian Journal for Solar energy, Vol, 5 pp 16 – 22.*

Senger, H. (1980): The blue Light Syndrome. Springer – Verlag, Berlin, FRG. pp 665 –690.

Unwin, D.M. (1980): Microclimate Measurement for Ecologists. Academic Press, London, U.K., pp17 – 35.

World Health Organization (WHO) (1979): Environmental Health Criteria 14: Ultraviolet Radiation, Geneva, Switzerland, pp 110 – 138.