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Measurements of Incoming Solar radiation: Comparison of Data obtained from a Constructed Reliable Model Pyranometer (RMP001) and a high Quality Pyranometer (CMP3) under Varying Climatic Condition at Mubi, Nigeria

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Abstract

This paper deals with the measurements of incoming solar radiation for a location in Mubi using a constructed Reliable Model Pyranometer (RMP001) and a high quality Pyranometer (CMP3). RMP001 was calibrated against CMP3 Pyranometer obtaining a calibration constant of $5230 \pm 0.02 Wm^{-2}$. *Measurements were taken at the same time for a period of fourteen months (1st November, 2008 to 31st December, 2009). The differences in results obtained are small enough to yield sufficiently accurate data for some purposes after averaging the measurement over a day. This reliable model pyranometer overcomes traditional problems in this type of device and offers similar characteristics to those of high quality pyranometers and, therefore, can be used in any installation where reliable measurement of solar irradiance is necessary, especially in those where cost is a deciding factor in the choice of a meter.*

Keywords: Solar radiation; Reliable Model Pyranometer; Calibration constant; Measurements.

INTRODUCTION

Solar radiation is the one and only energy source of the climate system of the Earth and, in total, more than 50% of the solar radiation irradiance at the top of the atmosphere reaches Earth's surface [1]. The amount of sunlight reaching Earth's surface is a source of practically all the energy in the biosphere. Sunlight is responsible, either directly or indirectly, for producing and maintaining the conditions required for supporting most life on this planet. For these reasons, and more, the study of what happens to sunlight as it passes through our atmosphere is crucial to many aspects of science and general knowledge.

Knowledge of solar radiation data is a necessary factor in many solar energy applications, including the design and analysis of energy conversion devices [2, 3]. The measurement of insolation requires costly equipment such as pyranometers. Unfortunately, this type of instrument is not easily available due to the cost, the required maintenance, and the calibration requirements of the measuring equipment [4]. In such situations where solar radiation data are scarce, the use of solar radiation models to estimate the data needed for solar energy applications is a common practice [5–7].

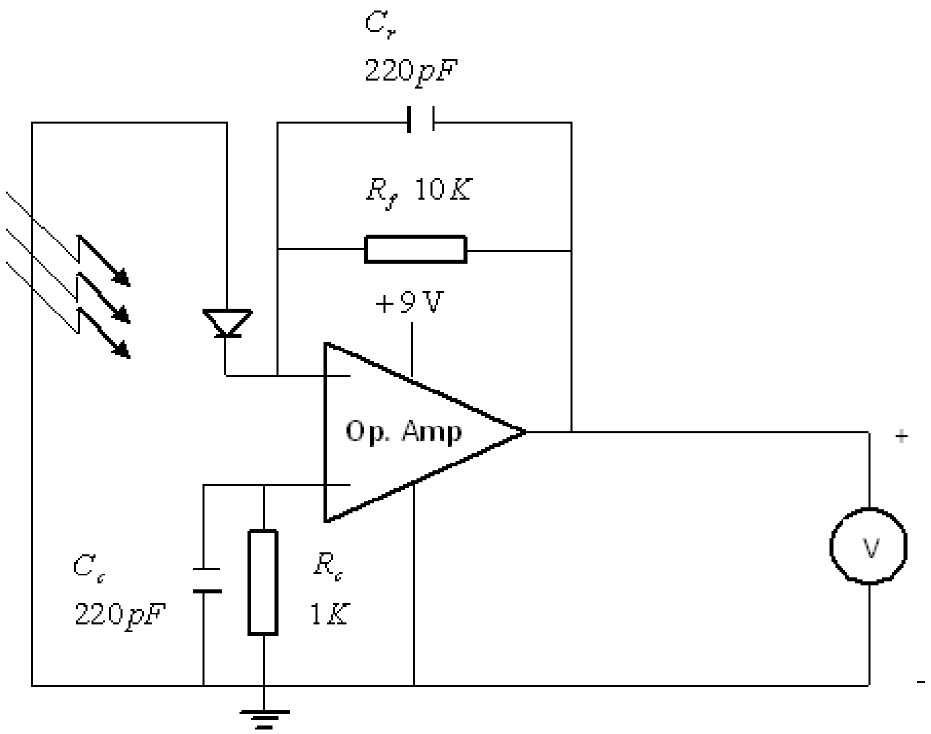

Figure 1: Pyranometer circuit diagram

This paper presents the measurement of solar radiation for a location in Mubi using a constructed Reliable Model Pyranometer (RMP001) and a high quality Pyranometer (CMP3). The need for radiation data covering entire areas led to the development of the Pyranometer. The sensing element of the constructed Reliable Model Pyranometer is a silicon photodiode which presents some characteristics and features to those of standard pyranometer at a price which is tens of times lower. The results obtained from the constructed Reliable Model Pyranometer will be compared to the results obtained from Standard Pyranometer to see whether it gives accurate measurements of daily solar radiation in the study area so that it can be used in any installation where reliable measurement of solar irradiance is necessary, especially in those where cost may be a deciding factor in the choice of a meter.

Design Implementation

The developed pyranometer is shown as a circuit diagram in Figure 1. The sensor element is a silicon diode, mounted on a plastic base, covered with a Teflon diffuser. The whole unit is placed on a base with a level control to ensure horizontality.

The developed pyranometer generates an electrical signal proportional to the irradiance received and converts the small current received from the detector to a voltage and amplifies it to a voltmeter.

Bearing cost, photodiode active-surface and signal-to-noise ratio in mind, we decided that the most suitable photodiode for this application was BPW21.

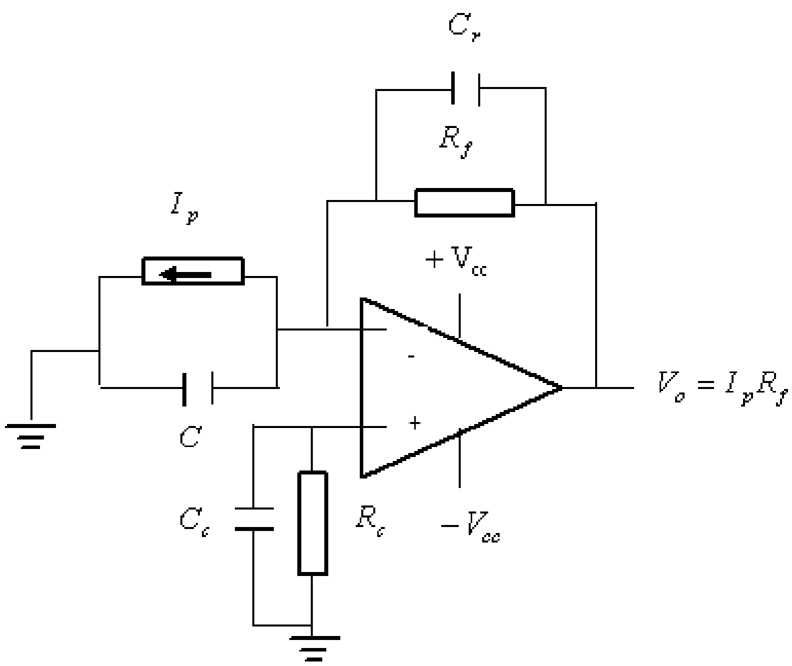

Figure 2: Transimpedance amplifier to condition the I_p signal provided by the photodiode

In the condition system, the transimpedance amplifier shown in Figure 2, configured around the LTC1051 operational amplifier (OPAM), was used for signal conditioning from the photodiode (see Figure 1). 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. Their value and function shall be seen later. 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_fa nominal irradiance of 1,000 W/m^2 is used. For this, the BPW21 photodiode produces the photocurrent I_p= 4.68 × 10^{-4}A. Therefore, the value of $R_f$implementedis 470Ω, to carry out precise adjustment. In order to correct the DC error due to polarization currents, a resistor (R_c) is connected to the non-inverting input of the OPAM. This resistor has a detrimental effect in terms of noise, which is amplified; this is why a 100*pF* compensation capacitor $C_c$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 $C_r$is connected in parallel with the feedback resistor R_f(see Figure 1). It is calculated that an appropriate value for the capacitor is 100 pF.

MATERIALS AND METHODS

Experiment Design

Calibration

Following construction of the pyranometer according to the specifications and methodology described, the next step was calibration of it. The pyranometer constructed was calibrated them against a reference high quality pyranometer, CMP 3 whose calibration was trusted (14.71±0.36 μV/W/m^2). The pyranometer was mounted beside the reference pyranometer and data was collected under open skies for a full three days. The process of calibrating the pyranometers constructed to the elements was carried out following the ISO 9847 standard (Solar Energy,1992), by comparison with a standard pyranometer (SP), specifically the Kipp&Zonen CMP 3 which belongs to the *secondary standard class*, or the best. The pyranometer took irradiance measurements during 2008, with the aim of testing the intensity of solar radiation.

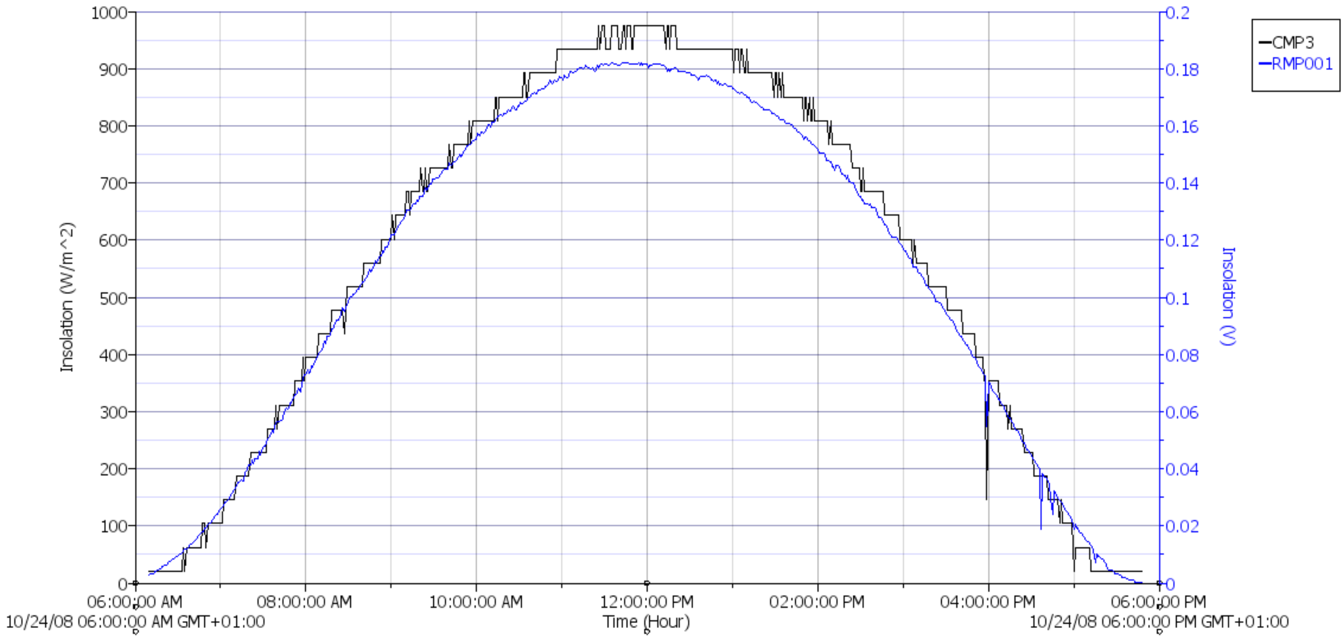

Figure 3: Graph of Solar Radiation measured with CMP3 and RMPs verses Time obtained on 24th October, 2008

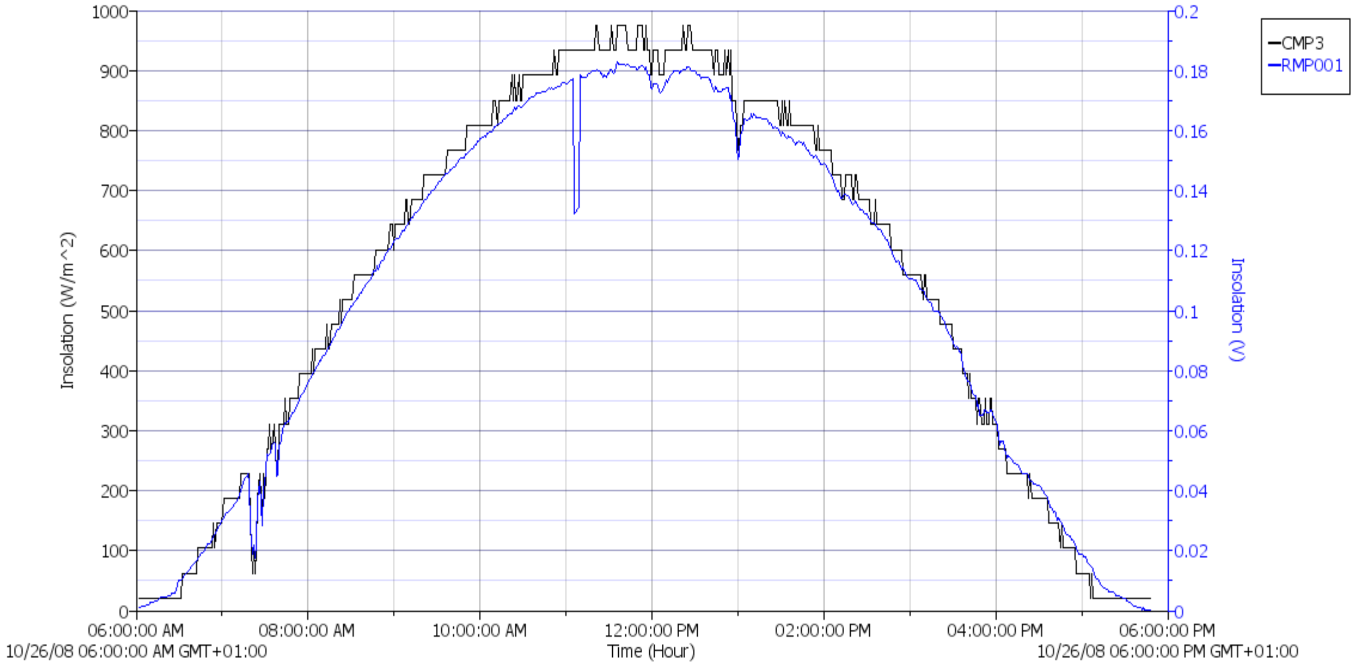

Figure 4: Graph of Solar Radiation measured with CMP3 and RMPs verses Time obtained on 26th October, 2008

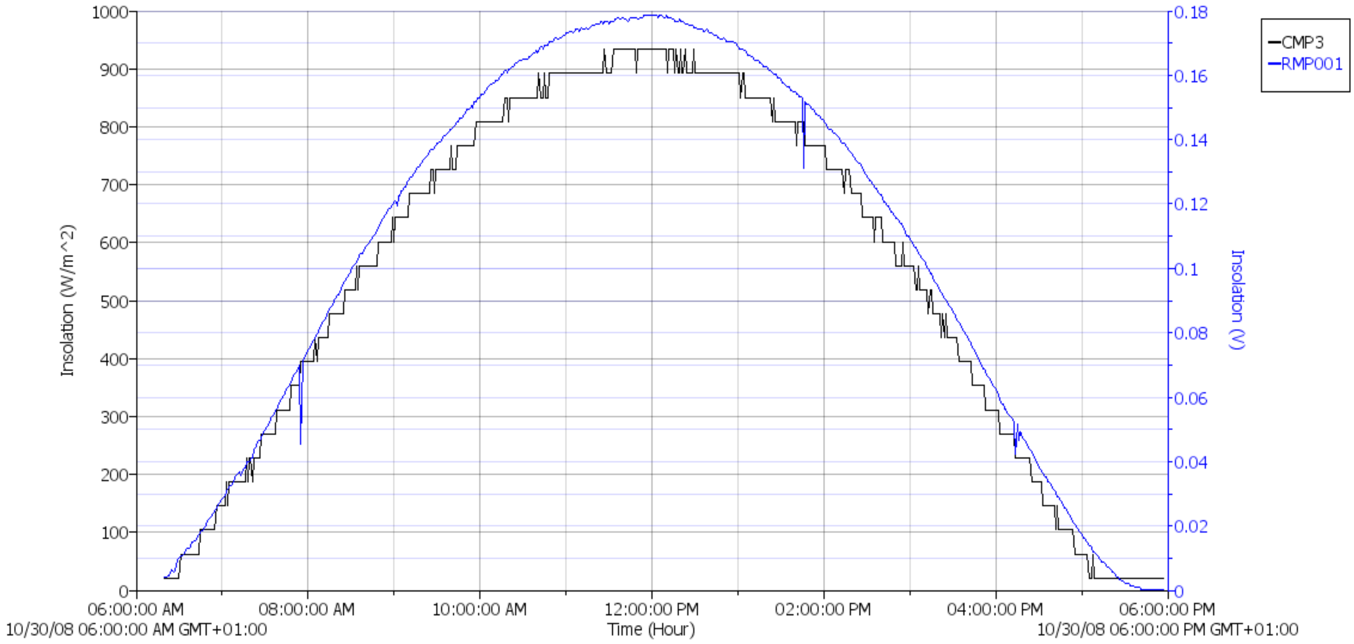

Figure 5: Graph of Solar Radiation measured with CMP3 and RMPs verses Time obtained on 30th October, 2008

Figures 3 – 5 show the graphs obtained on three random days within October, 2008. The readings of insolation obtained were in Wm^{-2} and V for the CMP3 pyranometer and RMP001 respectively. The conversion of the output from RMP001from V to Wm^{-2} was done to obtain the calibration constant of 5230 ± 0.02 Wm^{-2} [8].

Measurement

The measurement of solar radiation for a location in Mubi, Adamawa State - Nigeria was conducted with both RMP001 and CMP3 for a period of fourteen months from 1st November, 2008 to 31st December, 2009. Insolation data at 1 min intervals was recorded using a HOBO data logger. The logger has a USB interface with proprietary software for communicating with a computer. The data was stored in a proprietary binary format and latter saved as a text file that was imported into excel. The measurements were averaged every day. The instruments were set outside Physics laboratory (Figure 6).

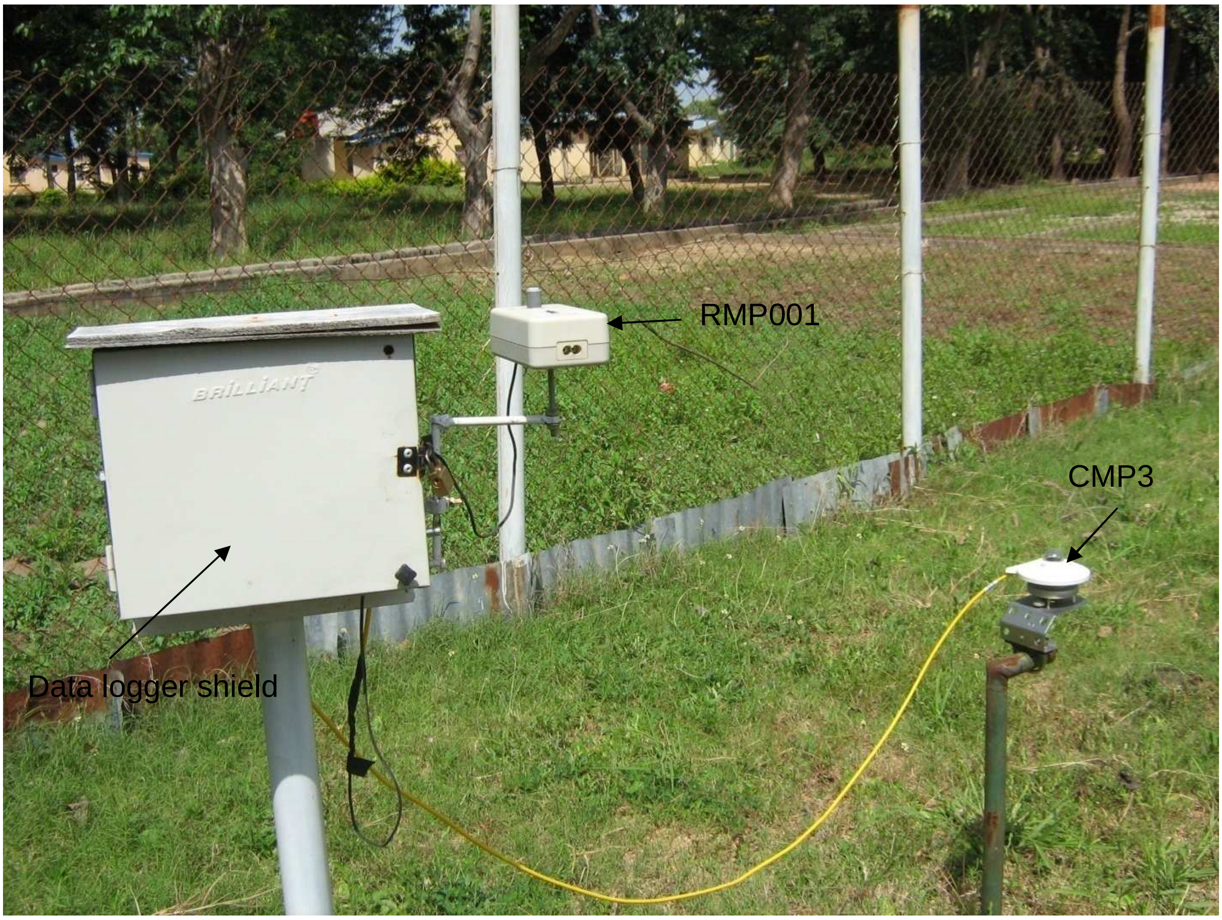

Figure 6: Picture of the instruments installed in Mubi

Methods of Analysis

The accuracy of RMP001 is tested by calculating the mean bias (MBE), root mean square (RMSE) and the mean percentage (MPE) errors. The MBE (Wm^{-2}), RMSE (Wm^{-2}) and MPE (%) are defined as follows:

$$MBE = \left[\sum (\bar{H}_{i,CMP\backslash} - \bar{H}_{i,RMP}) \right] / n \tag{1}$$

$$RMSE = \left\{ \left[\sum (\bar{H}_{i,CMP} - \bar{H}_{i.RMP})^2 \right] / n \right\}^{1/2} \tag{2}$$

$$MPE = \left\{ \sum \left[(\bar{H}_{i,CMP} - \bar{H}_{i,RMP}) / \bar{H}_{i,CMP} \right] x100 \right\} / n \tag{3}$$

Where $\bar{H}_{i,CMP}$ and $\bar{H}_{i,RMP}$ is the ith insolation measured with CMP3 and RMP001 respectively; and n is the total number of observations.

MBE and MPE tests provide information on the long-term performance. A low MBE and MPE are desired. Positive values give the average amount of over-insolation in the value measured with RMP001 and vice-versa. The drawback of these tests are that over-insolation of an individual observation will cancel under-insolation in a separate observation.

The RMSE test provides information on the short-term performance of the correlations by allowing a term by term comparison of the actual deviation between the values measured with RMP001and the value measured with CMP3; the smaller the value, the better the RMP001 performance. However, a few large errors in the sum can produce a significant increase in RMSE. In general, a low RMSE is desirable.

The t – statistic is defined as

$$t = \left[(n-1) MBE^2 / (RMSE^2 - MBE^2) \right]^{1/2} \tag{4}$$

The t-statistic allows pyranometers to be compared and at the same time it indicates whether or not a pyranometer's measurement is statistically significant at a particular confidence level. The smaller the value of t, the better is the pyranometer's performance.

RESULTS AND DISCUSSION

The results of insolation obtained from RMP001 and CMP3 for each day under consideration are presented in figures 7 – 20. The Monthly Mean Daily Insolation Measured with RMP001 and CMP3 are presented in Table1 while Table 2 contains the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and t – statistics.

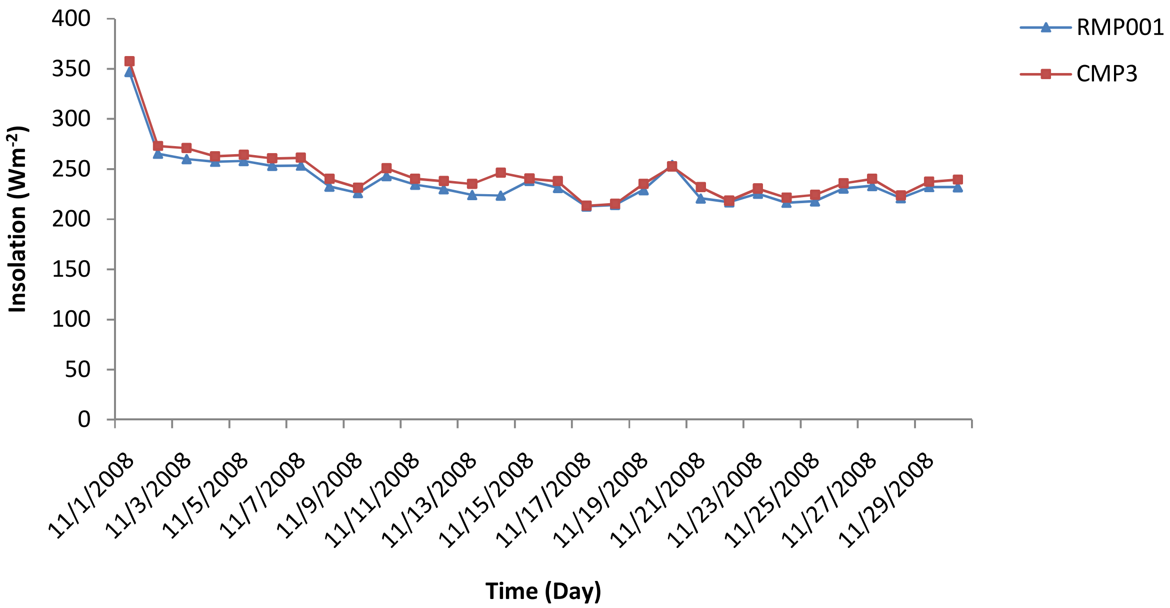

Figure 7: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for November, 2008.

The measurements are taken for fourteen months (November, 2008 to December, 2009). Looking at figures 7 – 20, it can be observed that the RMP001 faithfully follows the CMP3 curves at everyday of the month. It reveals quite similar behavior throughout each month. It could be seen from figure 7 that for the period of November, 2008 the CMP3 value are little higher than that of RMP001, except for 17th, 18th and 20th in which they are almost the same.

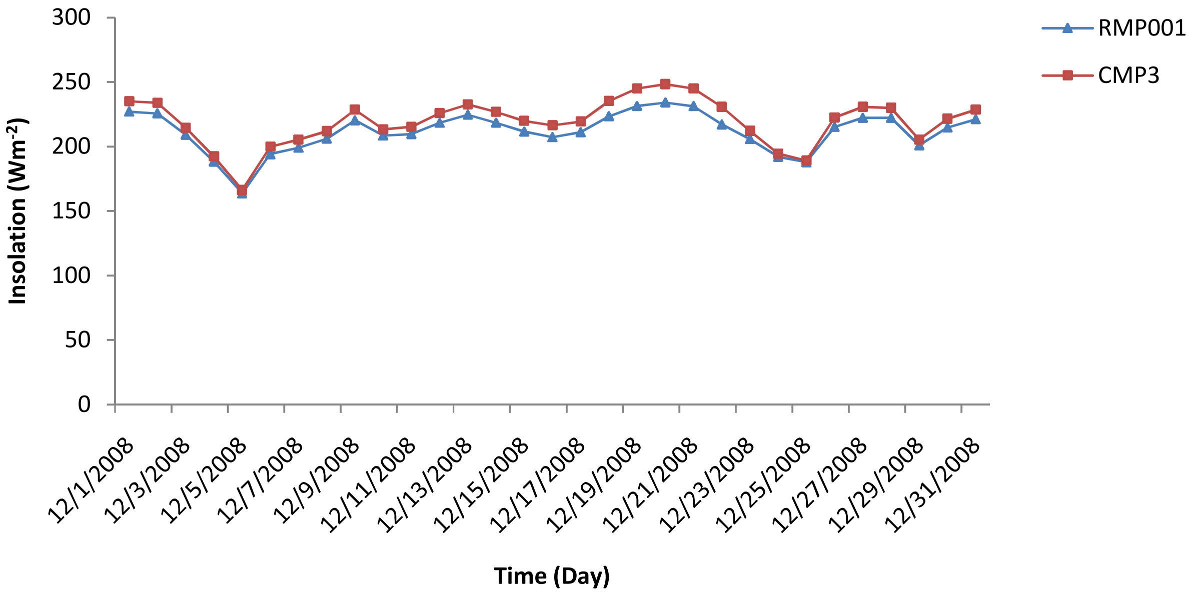

Figure 8: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for December, 2008.

Similarly, in December, 2008, there was no rain but dusty harmattan wind and Figure 8 indicates higher insolation measured CMP3 than the one measured with RMP001 except on the 5th, 24th, 25th and 29th where they are almost the same.

Also, in January, 2009, there was no rain. A look at Figure 9 shows a very little difference in both measurements with an exception on 14th, 15th, 16th, 17th and 31st.

The values obtained from RMP001 and CMP3 are almost the same throughout February, 2009 (Figure 10) except on 1st – 11th in which RMP values are lower than that of CMP3 and vice versa on 25th and 28th.

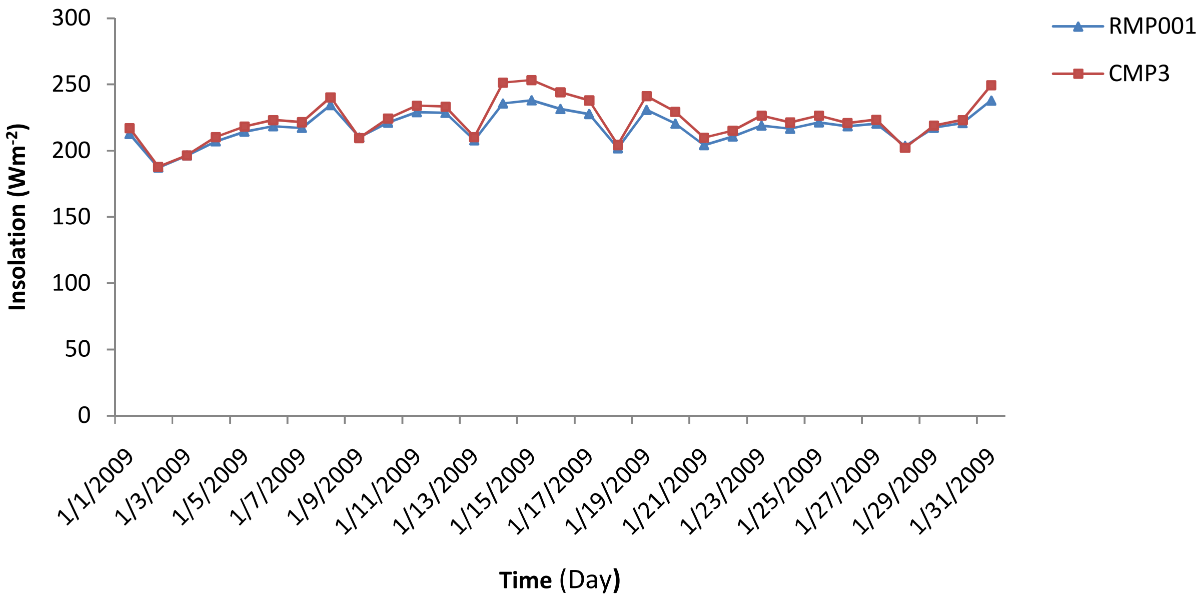

Figure 9: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for January, 2009.

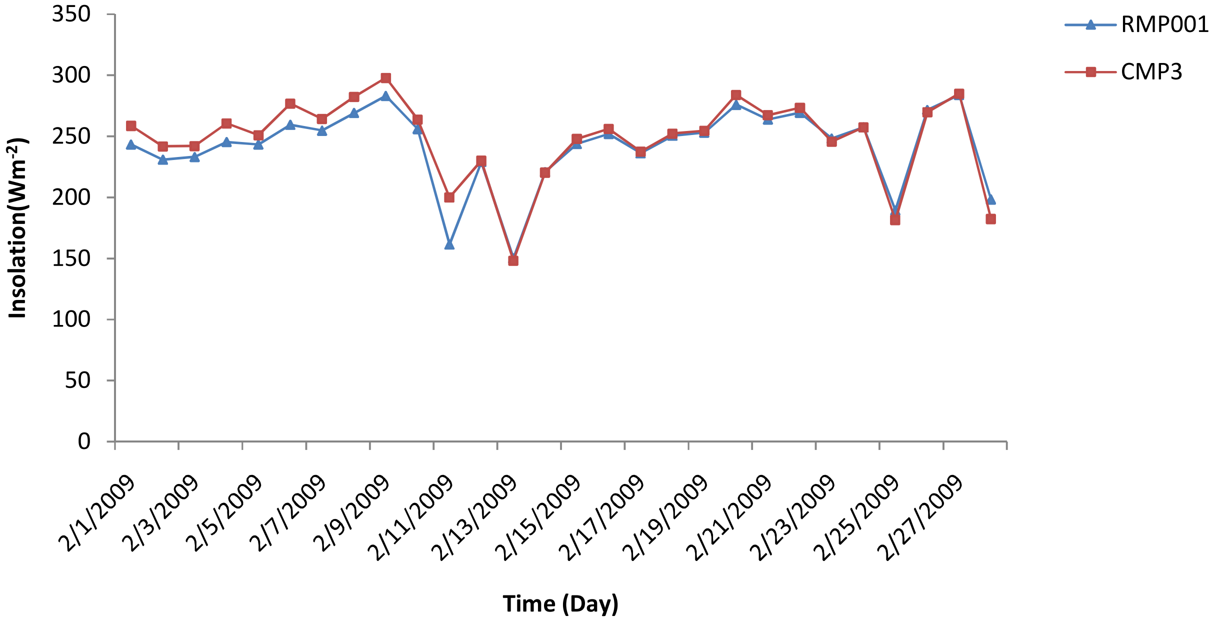

Figure 10: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for February, 2009.

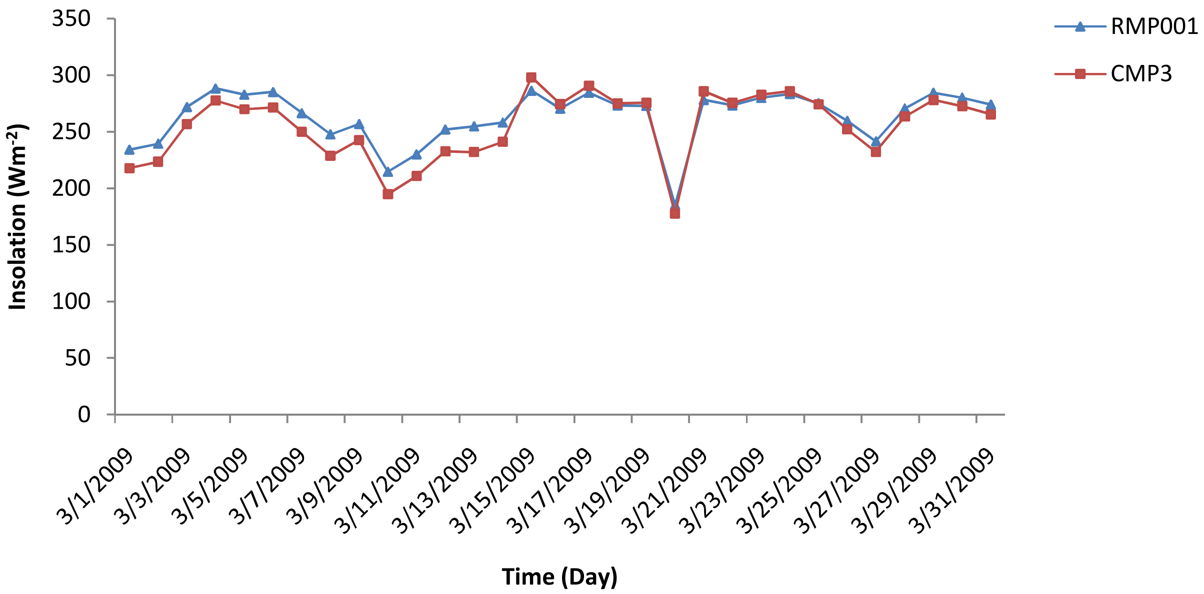

Figure 11: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for March, 2009.

In March, 2009, the values of RMP001 are significantly higher than CMP3 throughout the month except for few days where they are almost the same (18th, 19th, 22nd, 23rd, 24th and 25th) as can be seen in Figure 11.

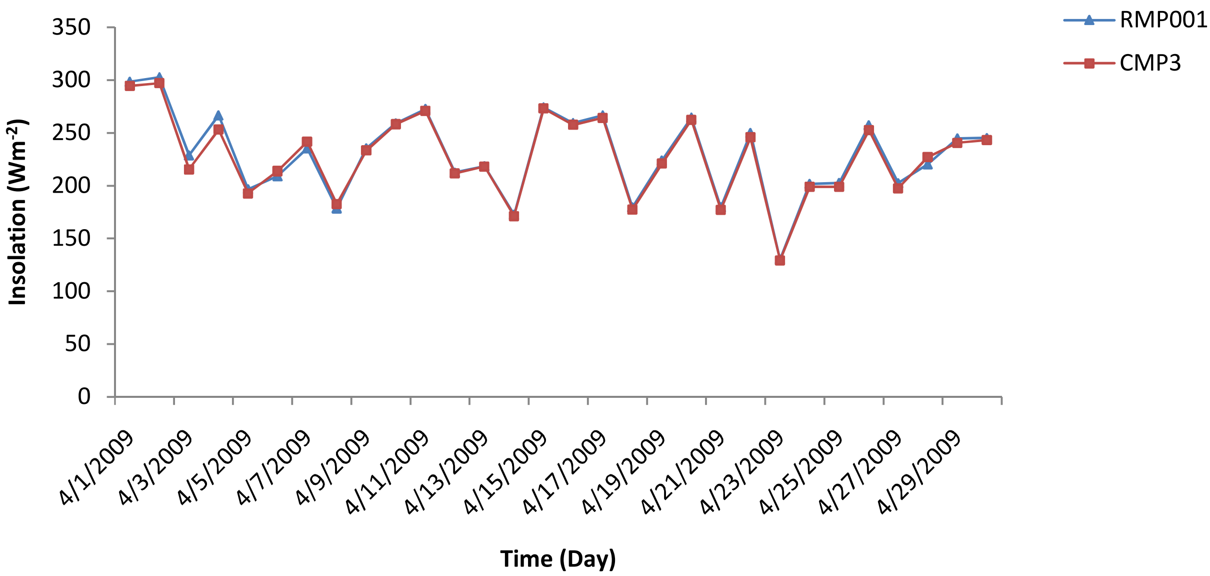

Figure 12: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for April, 2009.

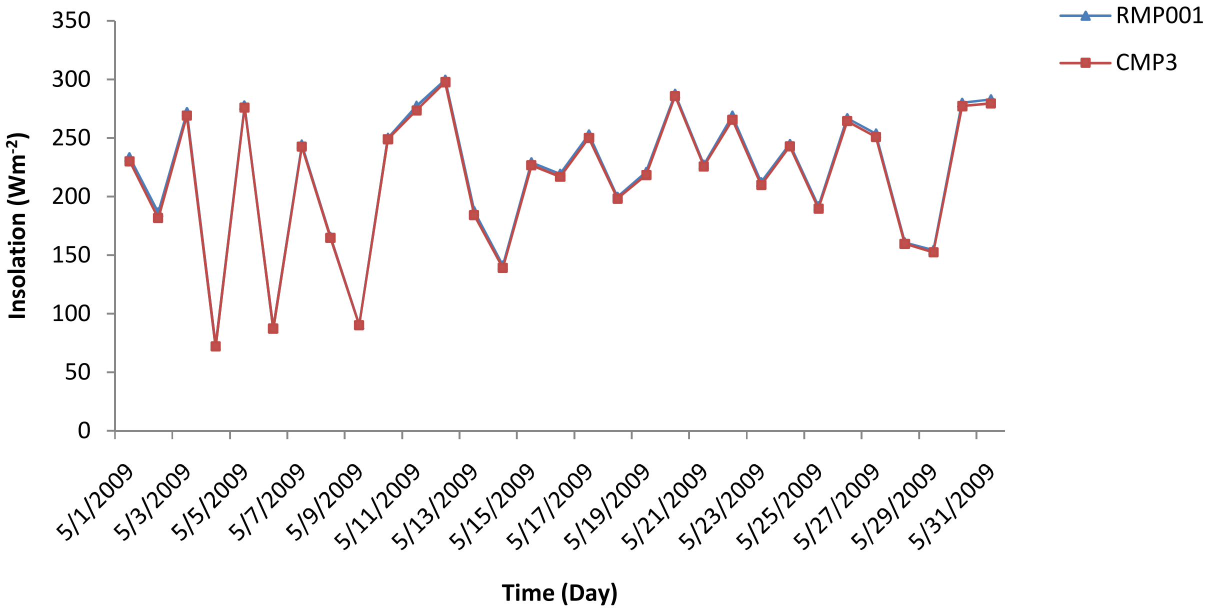

Figure 13: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for May, 2009.

Figure 12 indicates very few days in which RMP values are little higher than CMP3 values (1st, 2nd, 3rd and 4th) and vice versa on the 6th and 7th. The values are almost the same for the remaining days.

May, 2009 marked the beginning of rainy season of the year. The insolations from both instruments are the same throughout the month (Figure 13)

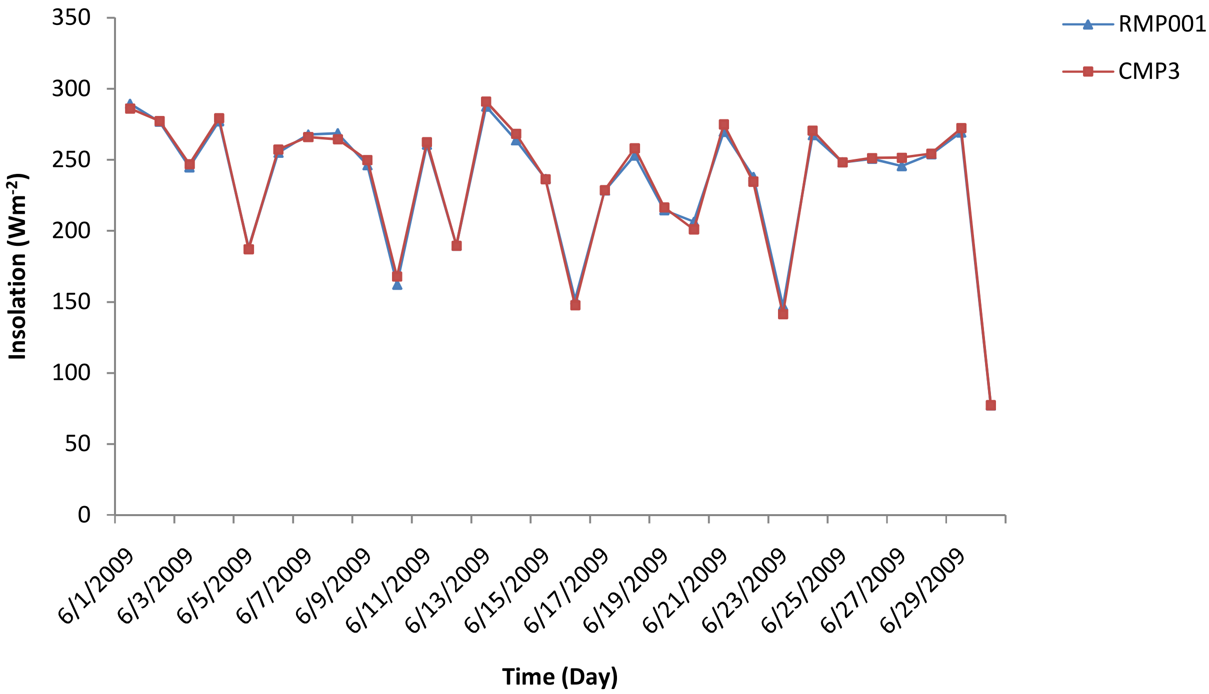

Figure 14: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for June, 2009.

Similarly, the values of insolation measured with the instruments are almost the same throughout June, 2009 as seen in Figure 14.

The values obtained from both instruments are the same throughout July, 2009 except for few days where the values obtained with RMP001 higher (16th, 18th, 19th and 20th) and lower (6th, 10th, 22nd, 23rd and 25th) as shown in Figure 15.

In August, 2009, the period is characterized by heavy clouds with almost daily rain. It could be seen from Figure 16 that the values are the same throughout the month with the exception on 2nd, 5th, 22nd and 23rd where the values measured with RMP001is lower.

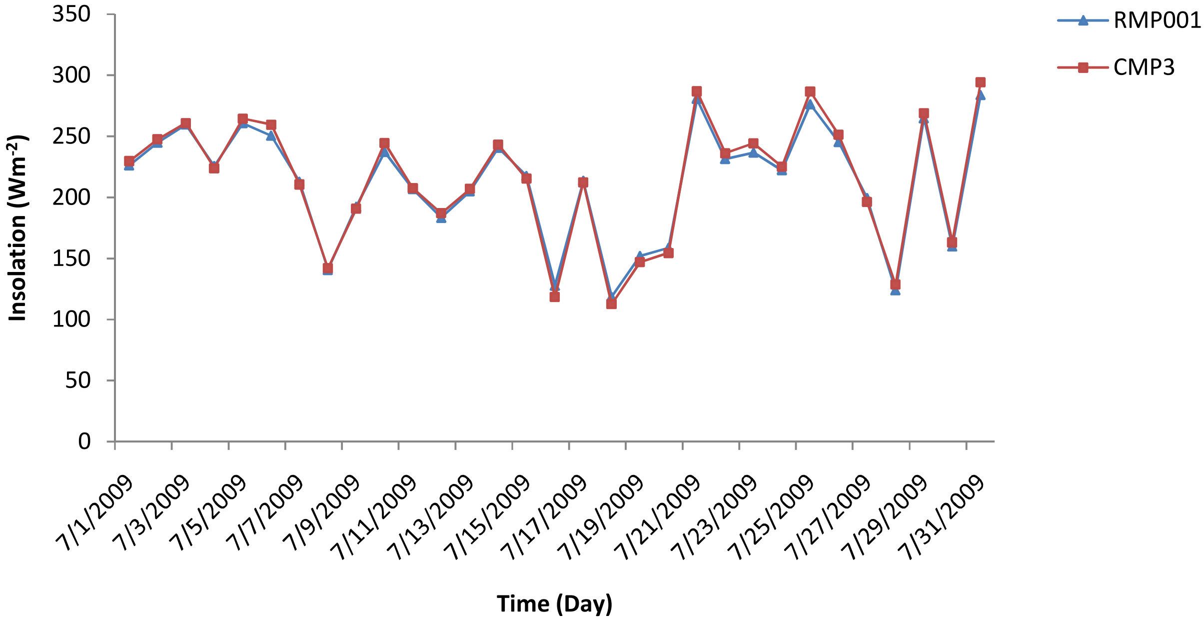

Figure 15: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for July, 2009.

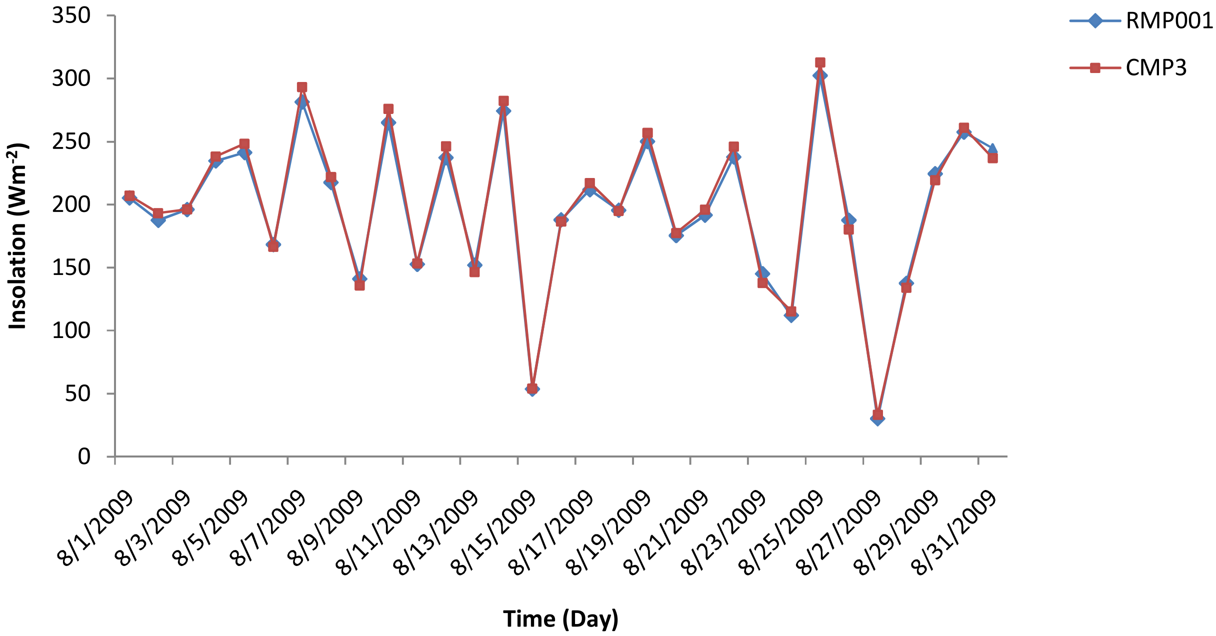

Figure 16: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for August, 2009.

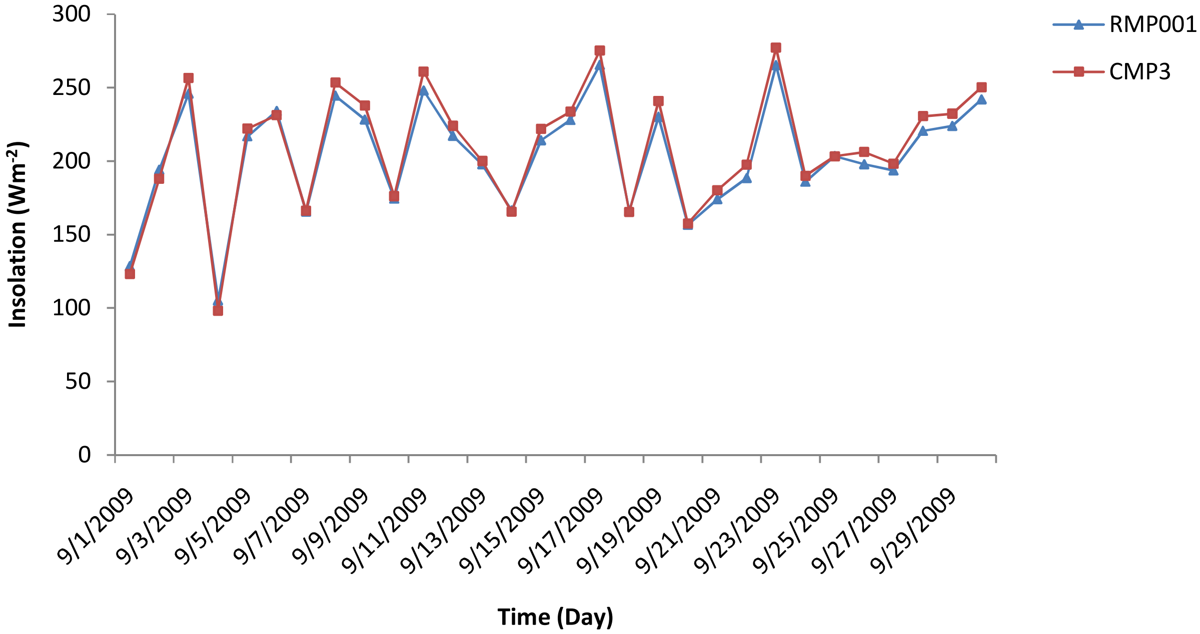

Figure 17: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for September, 2009.

In September, 2009, the weather was characterized by mostly diurnal rain. As from 8^{th}, 9^{th}, 11^{th}, 12^{th}, 17^{th}, 18^{th}, 19^{th}, 21^{st} – 30^{th}, RMP001 measured lower insolation as portrayed in Figure 17.

In October, 2009, the period had very little diurnal rain unlike September. A look at Figure 18 shows that the graph of insolation measured with RMP001 are lower throughout with exception of 6^{th}, 7^{th}, 20^{th} 28^{th} and 29^{th} in which they are almost the same.

For the period of November, 2009, they were no rain. Figure 19 reveals that throughout the period, insolation obtained with RMP001 was lower except on 4^{th}, 6^{th}, 16^{th}, 17^{th}, 18^{th}, 24^{th}, 25^{th} and 27^{th} where the values are almost the same.

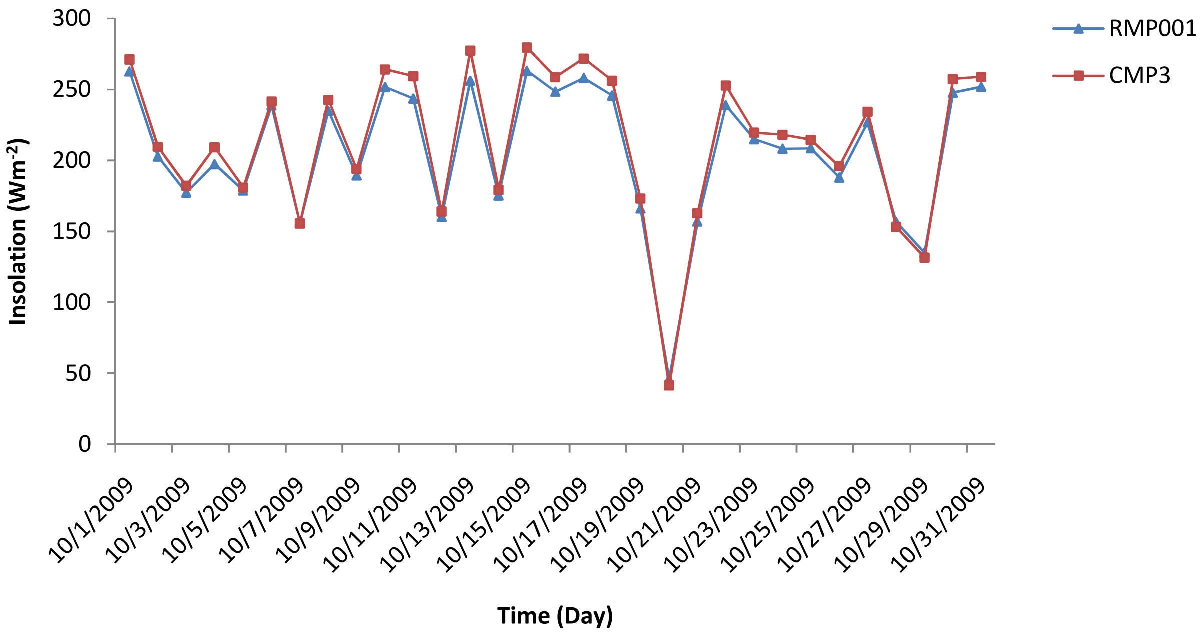

Figure 18: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for October, 2009.

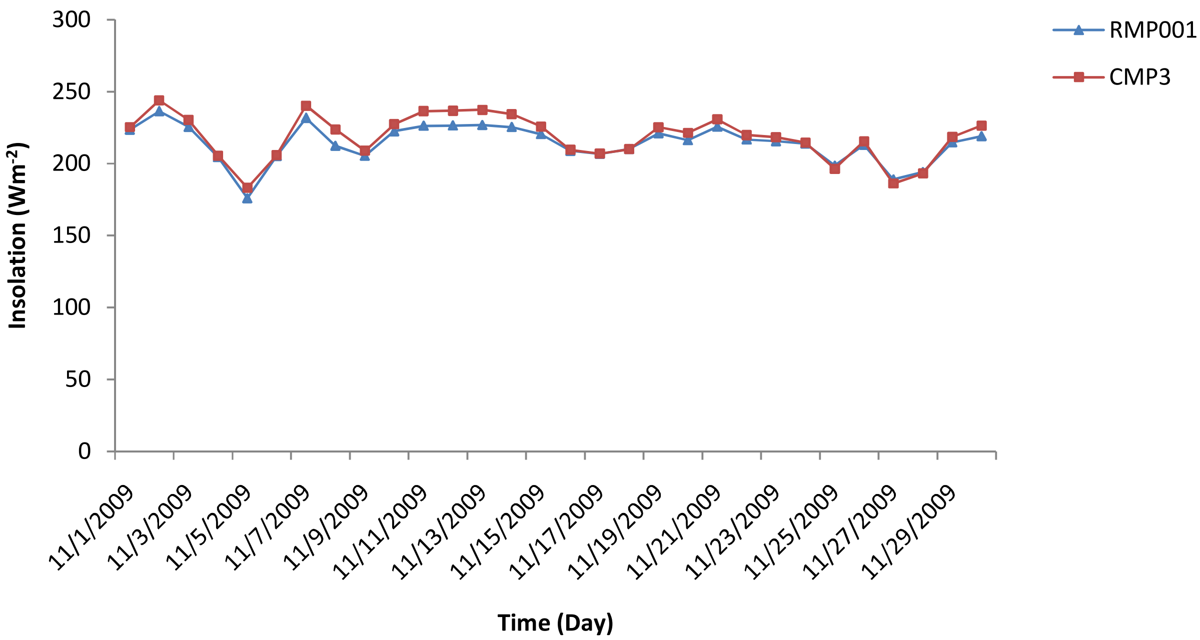

Figure 19: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for November, 2009.

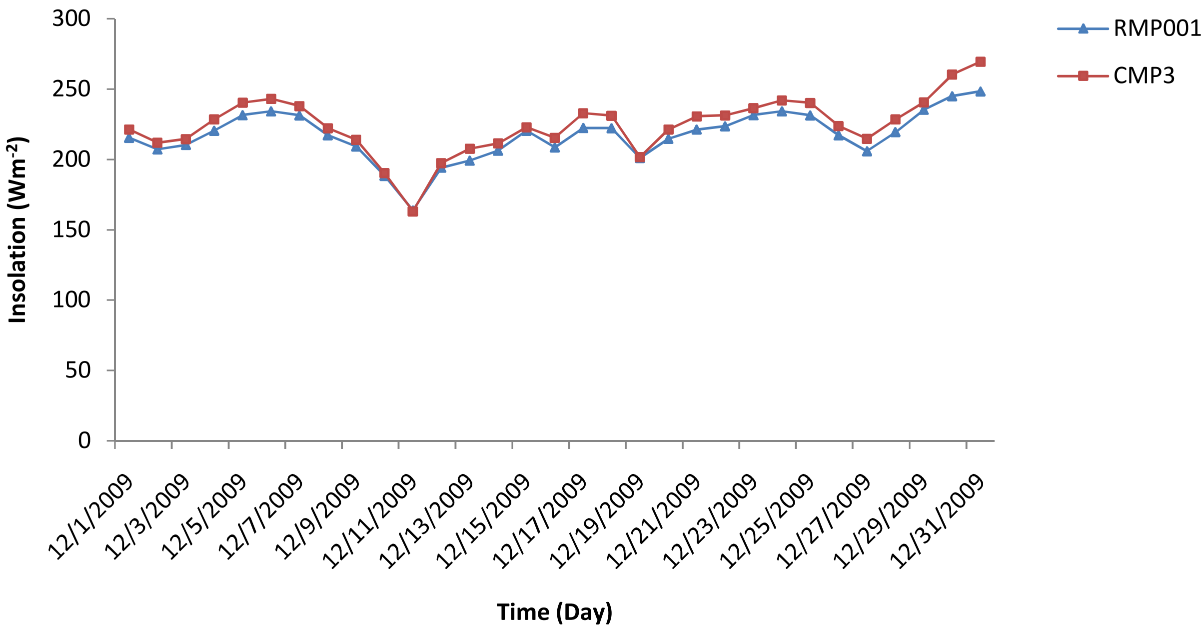

Figure 20: Graph of Daily Insolation Measured with RMP001/CMP3 verses Time for December, 2009.

Similarly as presented in Figure 20 the values obtain with the aid of RMP001 in December, 2009 were lower throughout but almost the same on 10th, 11th and 12th.

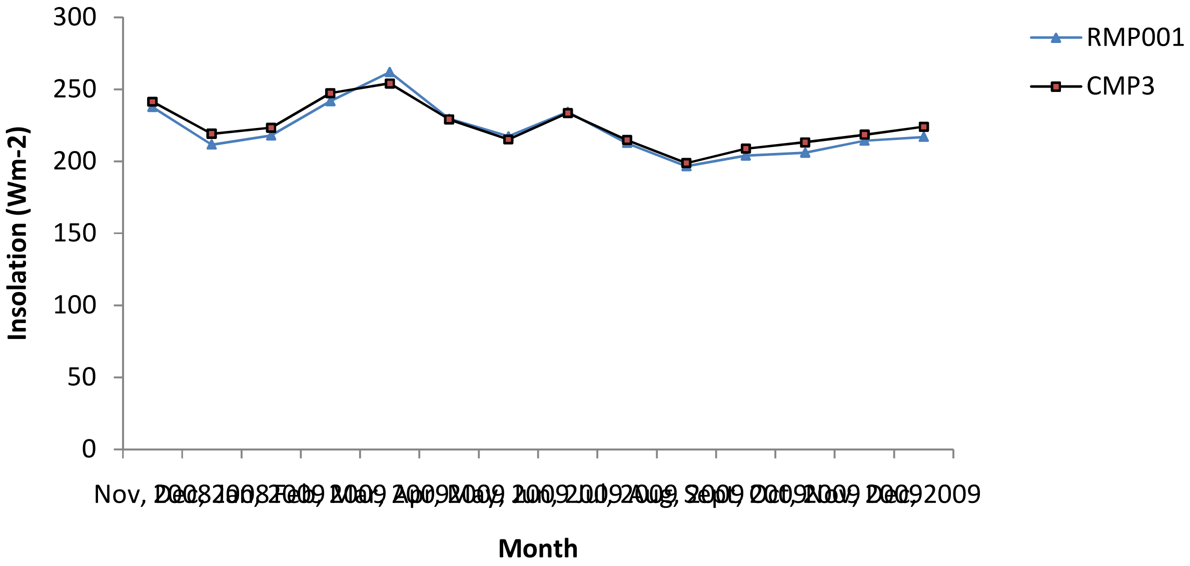

Figure 21: Graph of Monthly Insolation Measured with RMP001/CMP3.

Figure 21 shows the graph of monthly mean daily insolation measured with both instruments. In general, insolation values using RMP001 is less prevalent in dry season months, November, 2008, December, 2008, January, 2009, February, 2009, September, 2009, October, 2009, November, 2009 and December, 2009; and is more prominent in pre wet and wet season months (March, 2009 through August, 2009).

Table 1: Comparison of Monthly Mean Daily Insolation Measured with RMP001 and CMP3

Month	*Insolation*(Wm^{-2})		*MPE* %
	*RMP*001	*CMP*3	
Nov, 2008	237.78	241.45	-1.52
Dec, 2008	211.68	219.18	-3.42
Jan, 2009	218.04	223.39	-2.39
Feb, 2009	241.84	247.45	-2.27
Mar, 2009	262.03	254.15	3.10
Apr, 2009	229.51	229.13	0.17
May, 2009	217.4	215.21	1.02
Jun, 2009	234.45	233.57	0.38
Jul, 2009	212.83	214.8	-0.92
Aug, 2009	196.73	198.83	-1.06
Sept, 2009	204.04	208.75	-2.26
Oct, 2009	206	213.24	-3.40
Nov, 2009	214.37	218.54	-1.91
Dec, 2009	217.03	224.02	-3.12

Table 2: statistical Test Results

MBE (Wm^{-2})	*RMBE* (Wm^{-2})	*t*
-0.19	0.72	1.04

The RMP001 performance examined using Mean Bias Error (MBE) and Root Mean Square Error (RMSE).The test RMSE provides in for motion on the short term performance of the RMP001 as it allows a term –by term comparison of the actual deviation between both measured values. A Zero value for MBE is ideal and low RMSE is very desirable [9 – 12]. According to these supposition and from Table 2 we can considered that the values of MBE, RMSE and t-statistics are -0.19Wm^{-2}, 0.72Wm^{-2} and 1.04 respectively. These low values clearly prove that the Constructed Reliable Model Pyranometer can be used for measurement of global solar radiation on a horizontal surface at any location on earth especially in those where cost may be a deciding factor in the choice of a meter.

CONCLUSION

The measurements of incoming solar radiation for a location in Mubi using a constructed Reliable Model Pyranometer (RMP001) and a high quality Pyranometer (CMP3) were presented and investigated. The overall results indicate a good agreement between the values obtained from both instruments. The Constructed Reliable Model Pyranometer can then be used in any installation where reliable measurement of solar irradiance is necessary, especially in those where cost may be a deciding factor in the choice of a meter.

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