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### DEVELOPMENT AND TEST OF AN ELECTRONIC SUNSHINE DURATION MONITORING DEVICE

**Álvaro Barbosa da Rocha**

**Wanderley Ferreira de Amorim Júnior**

**Eisenhawer de Moura Fernandes**

Universidade Federal de Campina Grande, Department of Mechanical Engineering, R. Aprígio Veloso, 882 – CEP 58429140, Campina Grande - PB, Brazil

e-mails: [alvarobarbosa2@hotmail.com](mailto:alvarobarbosa2@hotmail.com), [engenheirowanderley@gmail.com](mailto:engenheirowanderley@gmail.com), [mourades@gmail.com](mailto:mourades@gmail.com)

**Emerson da Trindade Marcelino**

Universidade Federal do Pernambuco, Department of Mechanical Engineering, Av. da Arquitetura, s/n Cidade Universitária CEP: 50.740-550 Recife-PE, Brazil

e-mail: [emerson.t.m.eng@gmail.com](mailto:emerson.t.m.eng@gmail.com)

**Júlio Manuel Tavares Diniz**

Instituto Nacional do Semiárido (INSA), Av. Francisco Lopes de Almeida, Bairro Serrotão - CEP 58.434-700 - Campina Grande/PB

e-mail: [julio.tavares@insa.gov.br](mailto:julio.tavares@insa.gov.br)

**Abstract.** *From the 19th century, with the advent of instrumentation, it was possible to establish global scale monitoring for a specific set of climate variables, including daily sunlight or sunshine. Sunstroke is defined as the astronomical duration of the day or the number of hours of sunshine that appear outside the clouds, thus allowing the direct component of radiation to reach the Earth's surface. Daily sunlight measurement is performed using the Campbell-Stokes Heliograph, which, although a consolidated method over the past 100 years, is still performed directly using special instruments that make use of an operator's reading and interpretation to assess the duration, effective daytime. In order to improve the insolation monitoring, allowing its measurement in a wider range of locations was developed in the laboratory and tested an electronic device with logic Fuzzy. The device tested showed disparities of up to 11% compared to official data from the National Institute of Meteorology.*

**Keywords:** *Electronic instrumentation. Sunstroke duration. Heliograph.*

## 1. INTRODUCTION

The daily insolation is defined as the number of hours in the day to which the solar disk is not hidden due to the presence of atmospheric phenomena, like clouds or atmospheric disturbance, being visible to an observer on the terrestrial surface, where the horizon is free of obstructions (Almeida, 2016). Visible, obstruction-free sunlight allows the surface to receive a quantity of solar radiation per unit of time and area.

The quantification of energy transmitted in the form of electromagnetic spectrum is only dependent on body temperature (Freire et al, 2011), and can be emitted within spectra ranging from ultraviolet (1nm to 380nm) to visible (360nm to 760nm) and infrared (760nm to 2000nm).

Solar radiation, according to Almeida (2016) and Freire et al (2011), is transmitted in the form of electromagnetic radiation, measured based on its radiation flux density,  $W.m^{-2}$ , and derived from the blackbody theory, modeled according to the Plank equation. Sunshine tends to present a different amount of time between two regions because the area of the earth's surface on which the energy is distributed is a function of the inclination with which the sun's rays reach it. The angulation formed between the solar rays and the vertical one is called the angle of Zenith, caused by the inclination of the terrestrial orbit.

The heliographs, Fig. 01, consist essentially of a direct measurement device for sunshine, consisting of a glass sphere with a mean diameter of 96 mm concentrically mounted on a platform where the burning of the graduated paper strip occurs due to solar radiation levels greater than  $120 W.m^{-2}$ . Heliographs do not apply to the entire globe, covering only specific parts, such as latitudes between  $5^{\circ} N-45^{\circ} S$  and  $5^{\circ} S-45^{\circ} N$ , and a maximum measurement of 14 hours.

The tracks for recording the insolation are made in cardboard with printed markings that represent the hours. When the sun is clear of obstructions, the glass sphere, due to its focal image, converges the solar rays burning the cardboard

and leaving a drilling groove. Each time a cloud cloaks the solar circle, getting between the earth's surface and the sun, the furrow is interrupted for a proportionate period of time to break.

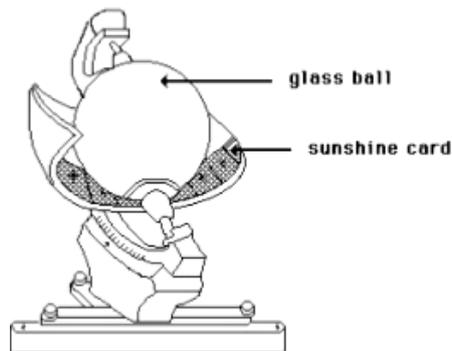


Figure 01. Campbell-Stokes heliograph. Available from: Institute of Astronomy, Geophysics and Atmospheric Sciences - USP.

The Campbell-Stokes heliograph, Fig. 01, presents a daily insolation measure, the average of 12 minutes and the model does not work on rainy days or higher, generating the absence of information about the days. From the nineteenth century, with the advent of instrumentation, it was possible to establish global monitoring for a specific set of variables of interest, allowing, according to the IPCC (2013), the ability to strictly measure the behavior of given variables in a complex panorama.

The main apparatus for measuring day-to-day insolation is the Campbell-Stokes heliograph which is configured to be used on flat roofs or on clean terrain so as to be well exposed to solar radiation throughout the day and a maximum measurement of 14 hours (Müller, 2017). This work aims to present the development of an instrumentation system aimed at monitoring the daily sunshine with technical and economic feasibility capable of providing data maximum error of 11% in relation to official data issued by the National Institute of Meteorology (INMet).

## 2. MATERIALS AND METHODS

In order to carry out this work, the methodology used was divided into two distinct phases, presented as: design of the instrumentation system to monitor the daily insolation and the experimentation with validation of the results obtained.

### 2.1 Instrumentation system design to monitor daily insolation

In this work we employed the use of design methodology (Back, 1983), Fig. 2, employing a sequence of steps in a chronological sequence.

- Stage 01 - Definition of the problem: survey of available requirements based on information obtained by conducting research related to the design of sensors and devices to measure daily sunshine;
- Stage 02 - Conceptual Project: presentation of sketches, diagrams and schemes aimed at the vision of idea that best meets the demands of the project established in the previous phase;
- Stage 03 - Preliminary design: equipment sizing based on calculations for the establishment of materials, thicknesses and design configurations;
- Stage 04 - Detailed Design: manufacturing processes according to the rules in force in the country, when the operational safety and reliability of the product, detailing its documentation for future construction;
- Stage 05 - Manufacturing: They use available resources for manufacturing and assembly, in relation to obtaining the concept established in the previous phases of the project;
- Stage 06 - Validation Test: tests performed to verify that the project specifications meet the initial requirements survey established and scaled in previous phases;
- Validation test: the proposed solutions are tested, mathematical analysis, compliance with current standards and verification of the existence of errors.

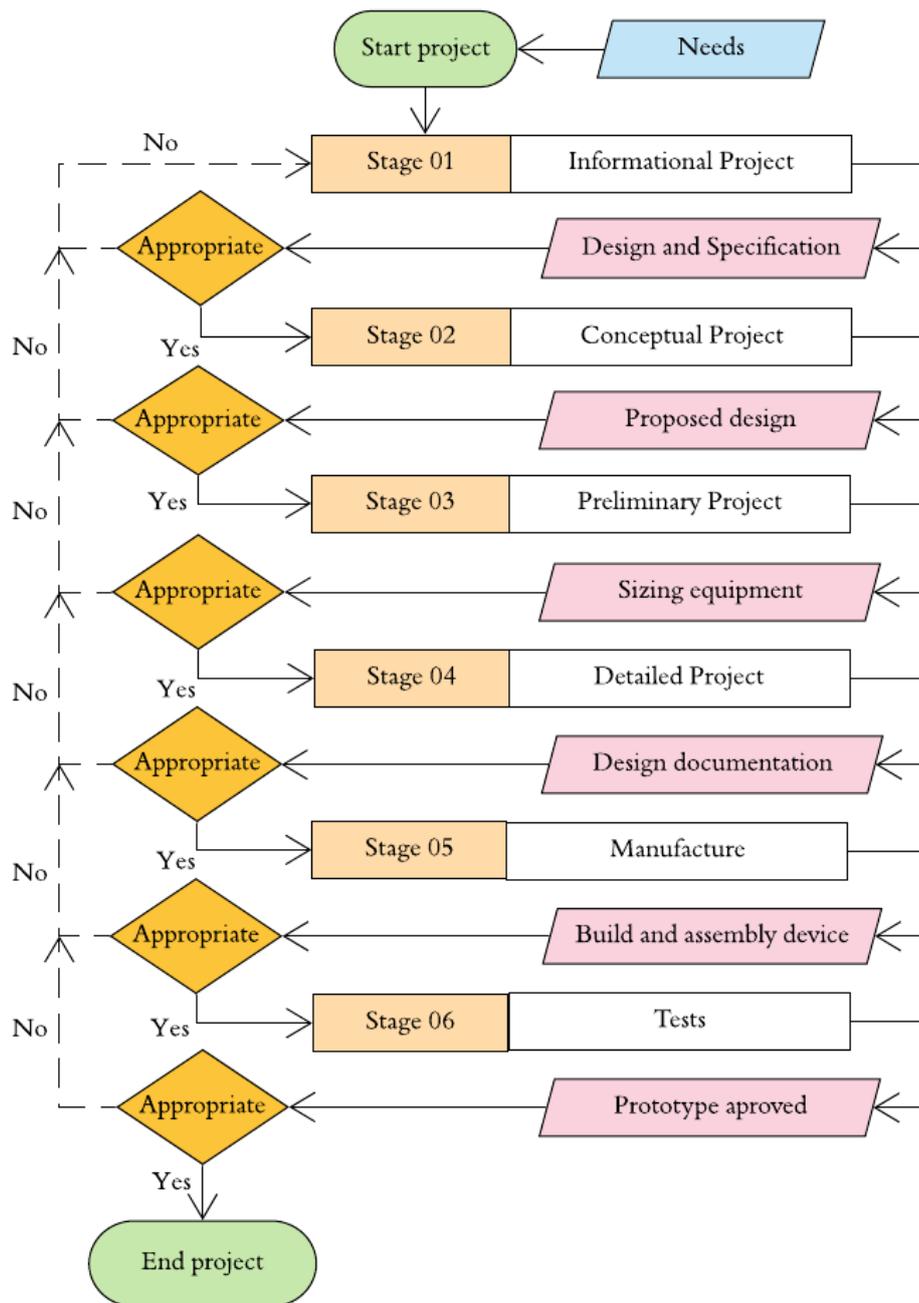


Figure 2. Flowchart of the project methodology adopted in the work.

## 2.2 Experimentation with validation of the results obtained

The experiments carried out with the Prototype occurred in the period from October 2017 to January 2018 near the Federal University of Campina Grande (UFCG), in an area free from interference, with no formation of shadows throughout the day. The device began to operate at 5:00 AM and withdrawn at 18:30 PM. The validation of the data was obtained by the direct comparison between the data obtained by the experiment and the official INMet data.

## 3. DISCUSSION

### 3.1 Characteristics of the developed equipment

Two concepts were developed by the authors, being the concept of instrumentation system modeled as a flat plate the concept approved, manufactured and tested. Table 1 presents the technical characteristics of the approved project.

Table 1. Basic specifications established for the instrumentation system by project methodology.

FEATURES	VALUES
Maximum measurement capacity (hours)	14
Energy autonomy (hours)	20
Number of sensors	4
Measurement principle	Light Dependent Resistor - LDR
Brightness reading range (lux)	0 - 100000
Output voltage range (mV)	0 - 5000
Spectral sensitivity range (nm)	350-950
Signal conditioning system	Wheatstone bridge
Microcontroller	ATmega328p
Datalogger	Internal
Minimum operating temperature (°C)	0
maximum operating temperature (°C)	65
Power supply	Lithium battery 18650
Internal power supply voltage (Volts)	5 DC
Energy dissipation (Watts)	5
Capacity of battery bank (mAh)	5000
External structure	High Density Polyethylene (HDPE)

### 3.2 Description of the system

The instrumentation system aimed at monitoring the daily developed sunshine is shown in block diagram, Fig. 3. The sensor element is Light Dependent Resistor, mounted in signal conditioner. The ATmega328P microcontroller features a 10-bit digital analog converter (ADC), converting the voltage levels into digital signals, and is employed by fuzzy logic in calculating daily sunshine. The microcontroller also promotes datalogger control, display and data format, as well as other aspects of the instrumentation system.

The sensors used are inserted in Wheatstone bridges. The sensor features individual passive filters for each sensor. The variation of the LDR resistance generates a signal with signal resolution in mV.

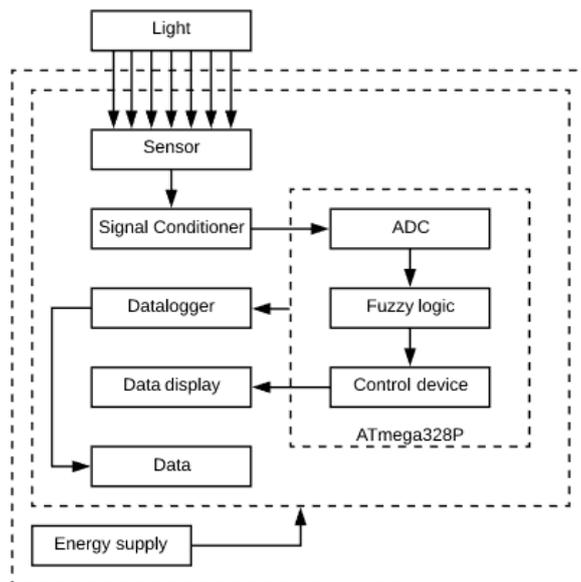


Figure 3. Supervision software operating flowchart.

Each of the 4 LDR sensors has an independent individual conditioning system consisting of a Wheatstone bridge with 3 resistors with 0.5% accuracy and an LDR. The system allows to accurately measure decimal variations in the resistance value of the LDR in the order of tenths of Ohm, generating, according to the variation of the ambient light, signal levels are given by Eq. (1). The individual signal conditioning circuit features passive low-pass filter with a cut-off frequency of 700kHz.

$$V_m = \left( \frac{-\Delta R}{4R} \right) \cdot V \quad (1)$$

The wheatstone bridge, Fig. 4, shows the same resistors R1, R2, R3, while the resistor R4 corresponds to the LDR. The output voltage of the sensor (Vm), in the order of mV, passes through the low-pass passive filter, and is later directed to a 10-bit analogue-digital converter (ADC) that converts it to insulation through the Fuzzy algorithm

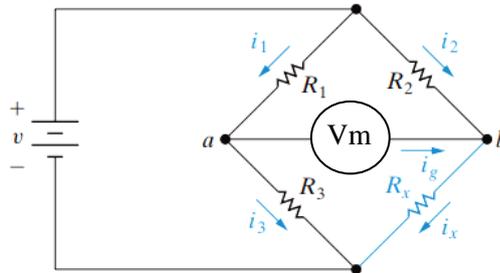


Figure 4. Schematic of a wheatstone bridge. Available from: NILSSON & RIEDEL (2015).

The behavior of the developed sensor has as particularity the wavelength range that it operates, 350nm to 950nm, and its best capacity of operation occurs in 550nm. Although the wavelength detectable by LDR is between 350nm to 950nm, its resistance to current flow ranges between 0 and 1M ohm for this range.

### 3.3 Fuzzy algorithm

The application of multivariate logic in the determination of the sunshine condition by means of a specialist model capable of distinguishing sunny periods from cloudy without the need for mathematical formulation (Gomide, 1994).

The construction of the Fuzzy model, built in C language, uses the values of the voltages of the sensors and, through the microcontroller Atmega328P, makes a scheduling by transforming the input values into fuzzy sets, by means of inference rules, creating a scale for to match the input values with the values of the speech universes of the real variables.

The existence of 04 light sensors acts in redundancy to evaluate the repeatability of the samples collected for 30 second time intervals, thus establishing a mean and a standard deviation of the data read. The mean and standard deviation of the voltage readings are entered into the fuzzy logic algorithm. The structure of the fuzzy logic algorithm is presented in Fig. 5, indicating the processes used to convert the input signals into linguistic parameters and, subsequently, used in the mathematical model of daily sunshine measurement.

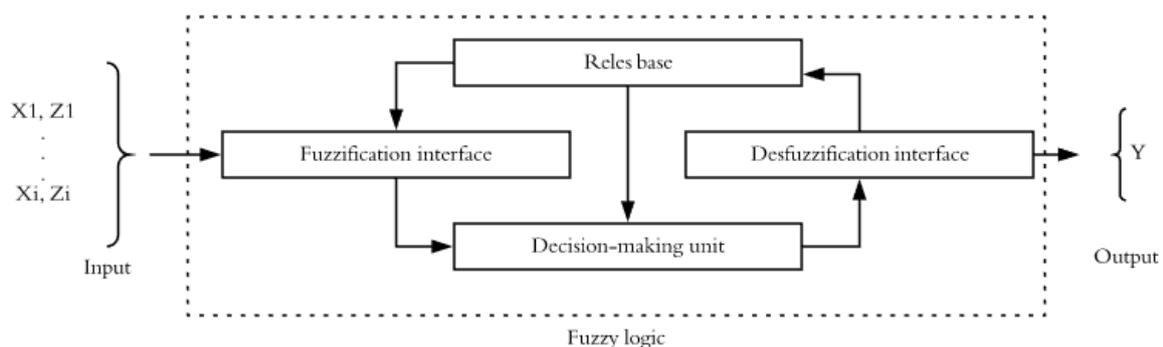


Figure 5. Structure of the fuzzy logic.

The fuzzy algorithm used, Fig. 5, is of the trapezoidal type defined by a membership function  $\mu_A: [0; 1]$  associated to each element  $x$  of the fuzzy set  $A$  a degree of pertinence  $\mu_A(x)$  (SANDRI & CORREA, 1999).

- $\mu_A(x) = 1$  indicates that  $x$  is completely compatible with  $A$ ;
- $\mu_A(x) = 0$  indicates that  $x$  is completely incompatible with  $A$ ;
- $\mu_A(x) > 0$  and  $\mu_A(x) < 1$  indicates that  $x$  is partially compatible with  $A$ , with degree  $\mu_A(x)$ .

The fuzzy algorithm used makes use of trapezoidal function, modeled by Eq. (2), converting the input signals of the sensors into gradual transition between cloudy, partly cloudy and sunny states. The gradual transition between the states allows the calculation model used to measure the insolation can be modified according to the input signals.

$$trampmf(x; a; b; c; d) = \max \left\{ \min \left( \frac{x-a}{b-a}; 1; \frac{d-x}{d-c}; 0 \right); 0 \right\} \quad (2)$$

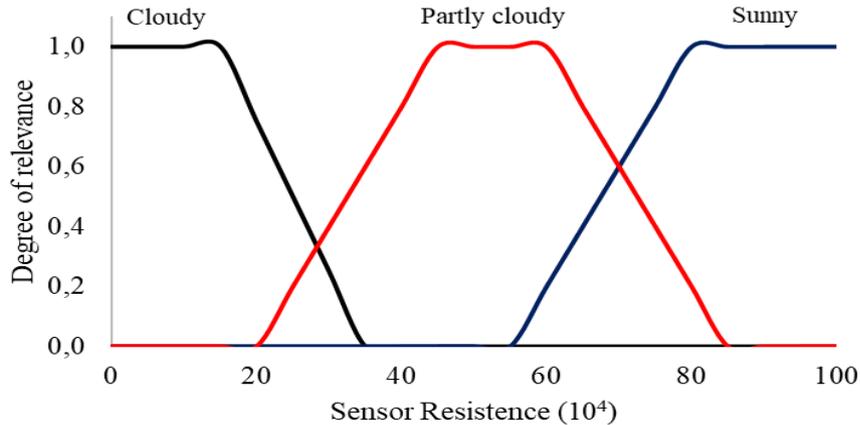


Figure 6. Rules of the fuzzy logic algorithm.

The rules used in the action-condition mechanism, Fig. 6, graphically represent the rules used in the fuzzy logic algorithm to determine the daily insolation, allowing a modeling of a system by relational or differential equations, the scheduling of the input values to condition the output values.

### 3.4 Calibration and results obtained

Calibration of the light sensor and devices occurred using a calibrated pressure gauge to obtain a reference value, subjecting the developed luxmeter and sensor to the same intensity of light simultaneously at different light intensity intensities. The LDR has its responsiveness at 550nm, with an efficiency of 98% in measured values, coinciding with the employee describing the 5800K.

The calibration of the sensors, Fig. 7, was performed in the laboratory by monitoring the variation of the output voltage of the sensors as a function of the variation of the resistance (ohms) for levels of luminosity, generating Fig. 6 were used as input parameters in the fuzzy logic algorithm.

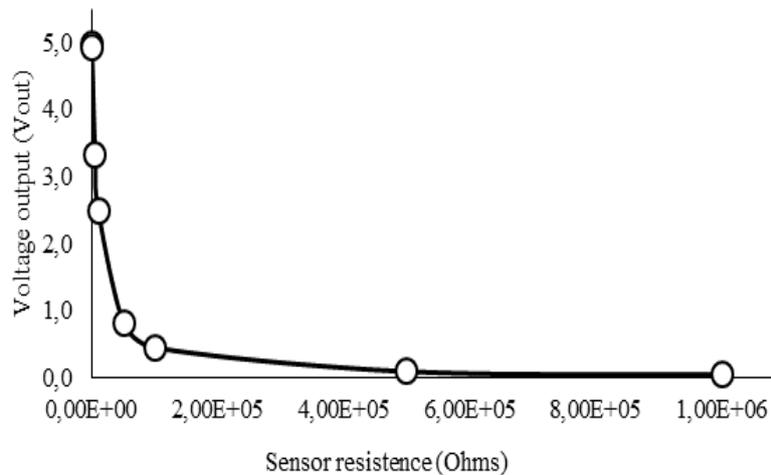


Figure 7. Calibration curve of the light sensor: Resistivity vs Output Voltage.

The calibration curve obtained by means of Fig. 7 shows the relation between Resistivity (ohms) Output voltage (mV), allowing the establishment of a recurrence equation. The calibration curve is dependent of the output of the

fuzzy logic algorithm. The Eq. (3) shows the calibration curve obtained with coefficient of determination ( $R^2$ ) of 0.999, Where V is voltage (mV) and R is resistance (Ohms).

$$V = 12300.R^{-0,341} \quad (3)$$

The redundancy of sensors allows to establish the average daily insolation. The developed device allows, indirectly, to obtain the amount of minutes that the solar disk appears in the sky without being clouded by the cloud cover. Tab. 2 and Tab. 3 show the amount of sun minutes for the daytime intervals in test 09 and test 21, respectively.

Table 2 – time of insolation per period of the day - Test 09/out.

Period	Sun Minutes				Result	
	Sensor 01	Sensor 02	Sensor 03	Sensor 04	Average	Standard deviation
5	12	12	12	11	11,75	0,50
6	32	30	32	32	31,50	1,00
7	41	41	41	43	41,50	1,00
8	40	40	41	41	40,50	0,58
9	47	47	44	47	46,25	1,50
10	52	52	51	52	51,75	0,50
11	42	42	42	41	41,75	0,50
12	33	32	33	33	32,75	0,50
13	21	21	22	21	21,25	0,50
14	32	31	32	32	31,75	0,50
15	22	22	22	22	22,00	0,00
16	25	25	25	25	25,00	0,00
17	5	5	5	4	4,75	0,50
18	0	0	0	0	0,00	0,00
Total amount of hours					6,71	0,13

Table 3 – time of insolation per period of the day - Test 21/out.

Period	Sun Minutes				Result	
	Sensor 01	Sensor 02	Sensor 03	Sensor 04	Average	Standard deviation
5	0	0	0	0	0,00	0,00
6	0	0	0	0	0,00	0,00
7	0	0	0	0	0,00	0,00
8	0	0	0	0	0,00	0,00
9	2	2	2	2	2,00	0,00
10	5	5	5	5	5,00	0,00
11	10	10	10	10	10,00	0,00
12	8	8	8	8	8,00	0,00
13	3	3	3	4	3,25	0,50
14	3	3	3	3	3,00	0,00
15	15	15	15	15	15,00	0,00
16	8	8	8	7	7,75	0,50
17	0	0	0	0	0,00	0,00
18	0	0	0	0	0,00	0,00
Total amount of hours					0,90	0,02

The results presented in Tab. 2 and Tab. 3 represent tests on different days. Table 2 shows the results obtained on a given day where the device considered it, according to the fuzzy logic algorithm, as partly cloudy with insolation of 6.71 hours, equivalent to 6 hours and 42 minutes, while the National Meteorological Institute indicated the occurrence of 6 hours. For Table 3 the results obtained are 0.90 hours of sunshine, equivalent to 54 minutes, while the National Institute of Meteorology presented an insolation of approximately 1 hour and 20 minutes.

This analysis presented in Tab. 2 and Tab. 3 is not presented directly to the user, and it is necessary to analyze the collected data in a thorough way.

The results obtained by the instrumentation system to monitor the daily insolation are shown in Fig. 8 representing the test period from October 2017 to January 2018. The data show that the system, post-calibration, showed a maximum relative error of 11% from official INMet data. The cost of the system was estimated at US \$ 70.00, presenting a mass of 0.78kg and occupying an area of 330cm<sup>2</sup>.

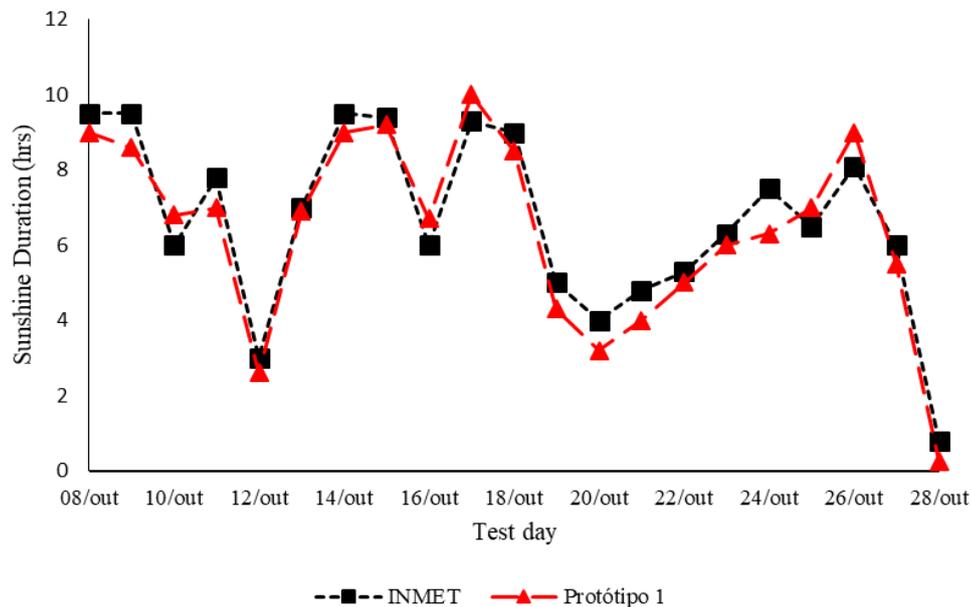


Figure 8. comparison of the results between the values obtained by the Prototype and INMet.

#### 4. CONCLUSIONS

Daily sunshine is an extremely important index for many sectors such as energy, health, architecture and agriculture. 120 days of testing were performed in the city of Campina Grande-PB, with only 21 of them exposed and used in the analysis due to the need for correction of parameters and algorithms.

The insolation values may vary greatly during the day, and it is not necessary that the period of greatest insolation occurs close to 11 to 13 hours, because the phenomena of the upper atmosphere have a direct influence on this phenomenon. The development of the equipment, although simple compared to the equipment widely used in the measurement of daily insolation by meteorological stations, has dimensions of 280 mm in length, 180 mm in width and 90 mm in height, with a mass of 780 g and an error of 11%.

The modeling of the developed device, although presented as a flat plate, presents itself as a device capable of measuring daily insolation with minimum acceptable accuracy and at a lower cost. Therefore, it is concluded that the measurement method can be applied to measure the duration of sunlight, within the stipulated margin of error, and plausible for application in other regions of Brazil.

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