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EXPERIMENTATION OF A LOW COST ELECTRONIC SYSTEM FOR MEASUREMENT OF THE ULTRAVIOLET RADIATION INDEX TO THE CITY OF CAMPINA GRANDE, BRAZIL

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Abstract. Ultraviolet radiation represents approximately 7% of the electromagnetic spectrum emitted by the Sun. Due to the risks associated with sun exposure, the World Health Organization in collaboration with international organizations developed the Ultraviolet Index, using it to simplify the measurement of the level of ultraviolet radiation incident on the Earth's surface. Motivated by the large number of cases of skin cancer registered in Brazil this work aims to present the readings taken from a wireless system for measurement of ultraviolet radiation in format of Ultraviolet Index. Measurements were carried out in the city of Campina Grande (Brazil) for 76 days, where it was verified that the Ultraviolet Index reaches the Extreme Risk of exposure to the sun still early in the morning remaining until the beginning of the afternoon and that the daily maximum value occurs nearby noon.

Keywords: Instrumentation, Radiation Meter, Skin Cancer, Ultraviolet Index.

1. INTRODUCTION

Skin cancer is the most common of all types of cancer that occurs in humans. Its incidence has increased significantly throughout the world. In Brazil, according to INCA (2018), this is the most frequent type and corresponds to 30% of all malignant tumors registered in the country. The main cause for the development of skin cancer is exposure to ultraviolet radiation, which damages the deoxyribonucleic acid (DNA) of skin cells (INCA, 2016). The main source of ultraviolet radiation is the Sun, with the most intense incidence occurring in regions of tropical climate and at very high altitudes.

Due to the risks associated with sun exposure, the World Health Organization in collaboration with international organizations developed the Ultraviolet Radiation Index (UVI), using it to simplify the measurement of the level of solar ultraviolet radiation incident on the surface of the Earth, to make the public aware of the risks of excessive exposure to this radiation range and to alert people to the need to take photoprotection measures. The values of this index vary in ascending order from zero, as shown in Fig. 1, being presented in a dimensionless scale and of integers (Kirchhoff *et al.*, 2000), where each index corresponds to 25 mW.m^{-2} (Tiba and Leal, 2012). Figure 1 also shows the association of each index value with the level of risk it represents. The higher the index value, the greater the potential for damage to the skin and eyes, and the less time it takes for damage to occur. Indices 1 and 2, in green color, indicate a low risk of exposure to the Sun, where protection against ultraviolet radiation is not necessary. Indices 3 to 5 in yellow represent a moderate risk and 6 and 7 in orange indicate high risk. For these indices, radiation protection is required such as wearing a shirt and hat, putting on sunscreen and looking for shaded locations. Finally, indices of 8 to 10, in red, indicate a very high risk and greater than index 11, in the color purple, indicate extreme risk of exposure to the Sun. For these, it is necessary to resort to extra protections like avoiding going outside in addition to maintaining the

aforementioned protections. Thus, this article aims to present the results of the study conducted in the city of Campina Grande, Paraíba, Brazil, where daily measurements of UVI were performed using a low cost electronic equipment designed for this purpose.
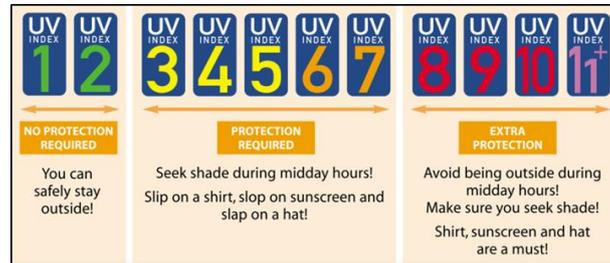

Figure 1. Diagram of index values with the respective recommendations of solar protection. Available from: WHO (2002)

2. EXPERIMENTAL PROCEDURE

According to WHO (2002), UVI is formulated using the spectrum of erythemic action induced by ultraviolet radiation on human skin. UVI is a dimensionless measure defined by WHO (2002) for a horizontal surface through Eq. (1) where: E_λ is the solar spectral irradiance for the terrestrial surface (Kirchhoff et al., 2000) expressed in $W.m^{-2}.nm^{-1}$ in the wavelength λ and $d\lambda$ is the wavelength range used in the sum; $s_{er}(\lambda)$ is the spectrum of erythemic reference action; and k_{er} is a constant equal to $40 \ m^2.W^{-1}$.

$$UVI = k_{er} \int_{250\ nm}^{400\ nm} E_\lambda \cdot s_{er}(\lambda) \ d\lambda \tag{1}$$

The spectrum of reference erythemic action is defined by ISO 17166: 1999 as the spectral dependence of the ability of ultraviolet radiation to produce erythema on human skin. It is formed by a set of discrete values with an assigned weight, usually normalized between zero and one, for each wavelength according to its biological efficiency (Kirchhoff et al., 2000) as indicated by Eq. (2), (3) and (4).

$$s_{er}(\lambda) = 1.0 \qquad\qquad at \ 250 \leq \lambda \leq 298 \ nm \tag{2}$$

$$s_{er}(\lambda) = 10^{0.094(298-\lambda)} \qquad at \ 298 < \lambda \leq 328 \ nm \tag{3}$$

$$s_{er}(\lambda) = 10^{0.015(140-\lambda)} \qquad at \ 328 < \lambda \leq 400 \ nm \tag{4}$$

The determination of the UVI can be through measurements or numerical model calculations. Two measurement approaches can be taken according to WHO (2002): the first is to use a spectroradiometer and calculate the UVI using Eqs. (1) – (4). The second is to use a broadband detector that has been calibrated and programmed to provide the UVI directly. The prediction by numerical model of the UVI is obtained with a model of radiative transfer that requires the entrance of total ozone and the optical properties of the aerosol. A regression model is used to predict total ozone using the input of ground or satellite-based ozone spectroradiometers. Good cloud parametrization is also required unless only clear sky values are reported.

Following this second method of measurement, to develop this work a factory calibrated ultraviolet (UV) sensor was used to measure the UVI. This sensor has a GUVA-S10GD photodiode with a good blindness to visible light, allowing the emission of electrical signals that vary depending on the intensity of the incident ultraviolet radiation under its optical window. The sensor used covers 64.7% of the UV-A radiation range, 100% of the UV-B range and 44.4% of the UV-C range. This sensor also has an accuracy of ± 1 UVI, a long-term work stability (drift rate per year) of less than 5% and a response time of less than 0.5 seconds. Its spectral responsivity curve can be seen in Fig. 2. As a way of analyzing the accuracy of the obtained data, two sensors of the same model were used to carry out the measurements.
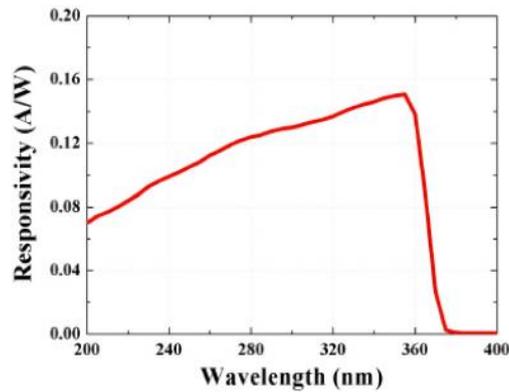
Figure 2. UV sensor spectral responsivity curve. Available from: http://www.epartshub.com.

The storage of data collected by the sensors was done in real time for an application (API) platform for archiving and viewing data in the cloud over the worldwide computer network. The transmission of data occurred by wireless communication through a wireless module ESP-12E, which allows TCP/IP type connection to a local wireless network based on the IEEE 802.11b/g/n standard. The UV sensor was connected to the analog input of this wireless module which has 10-bit resolution. Fig. 3 shows the block diagram representing the apparatus.
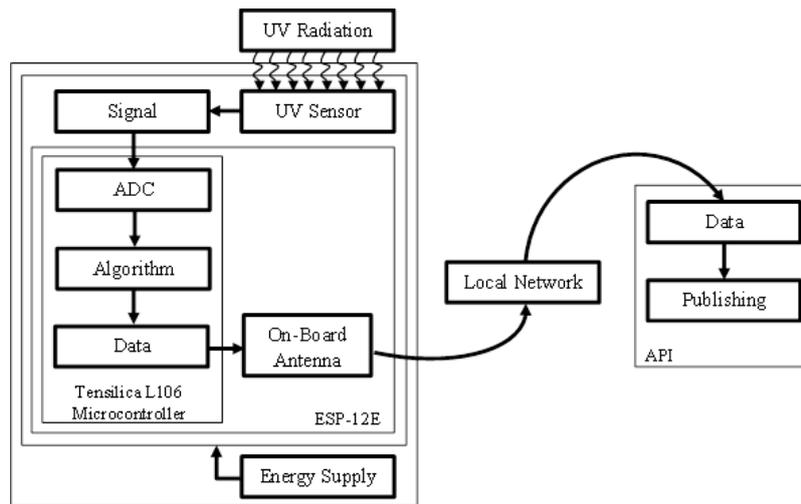

Figure 3. Block diagram representing the apparatus of measurement of UVI.

Figure 4. Image of UVI measuring equipment installed at a high point of the ground such as on a roof.

This measurement system was installed in the city of Campina Grande, Paraíba, Brazil, installed in a high point of the ground and distant of objects that provoke shade as shown in Fig. 4. The electronic circuit was placed inside a polypropylene shield, keeping only the UV sensor on the outside, fixed in horizontal position, for direct contact with UV radiation.

With an altitude of approximately 573 m above sea level, the exact location of the installation point was 7°11'55" South and 35°53'51" West. Measurements began on September 20th, 2018 and lasted 76 calendar days. Qualitative information was also collected by direct observation in relation to the observed climatic situation near the measurement point during the days of experimentation.

This device remained on for 24 hours each day automatically capturing the information about the ultraviolet radiation of the environment and publishing this data to a platform only during the photoperiod of the day when there was the presence of ultraviolet radiation equivalent to UVI 1 or higher. Collecting 60 readings at 5000 milliseconds intervals, the device performs an arithmetic average of these readings at the end of the loop which is after each 5 minutes. Then, this average was transmitted over the network by HTTP Post protocol to an API platform as the momentary UVI of the location.

It was decided to perform an arithmetic average due to the oscillations of the ultraviolet radiation incident on the terrestrial surface that occur constantly throughout the day. The intensity and the spectral and directional distributions of solar radiation including the ultraviolet spectrum that reaches the terrestrial surface are influenced by astronomical, geographic, environmental and atmospheric factors (Balogh et. al., 2011; ICNIRP, 2004; Incropera and Witt, 2008). If the measuring equipment performed only a single reading, instead of the average of 60 readings, it could pick up a lower value than the actual one if it coincided with the moment of the passage of some cloud or the high concentration of aerosols in the atmosphere, for example. Thus, it is expected that these variations that occur in the atmosphere for a short time do not affect the capture of the real value by the sensor.

3. RESULTS AND DISCUSSION

In most measurements, variations in cloudiness over the location of measurements greatly decreased the UVI recorded by the measurement system. This can be observed, for example, when comparing the records of day 20/Oct (Fig. 6), which was a sunny day without cloud cover, with that of 07/Oct (Fig. 5), which was many clouds and showers of rain in the morning, followed by sun with a few clouds in the afternoon. During the day with many clouds, there is a delay in the change in the levels of risks, i.e. in the values of UVI, as the day progresses when compared to the start times of these risks on a clear day. Comparing day 07 with day 20, in the morning, we observed a delay of 22 min for the record of the beginning of the Low Risk, 57 min for the Moderate Risk, without perceived variation for the High Risk, for the Very High Risk was of 17 min and to the Extreme Risk was 7 min. Already in the afternoon, due to the few clouds of the day 07, the difference was in average of 10 min.
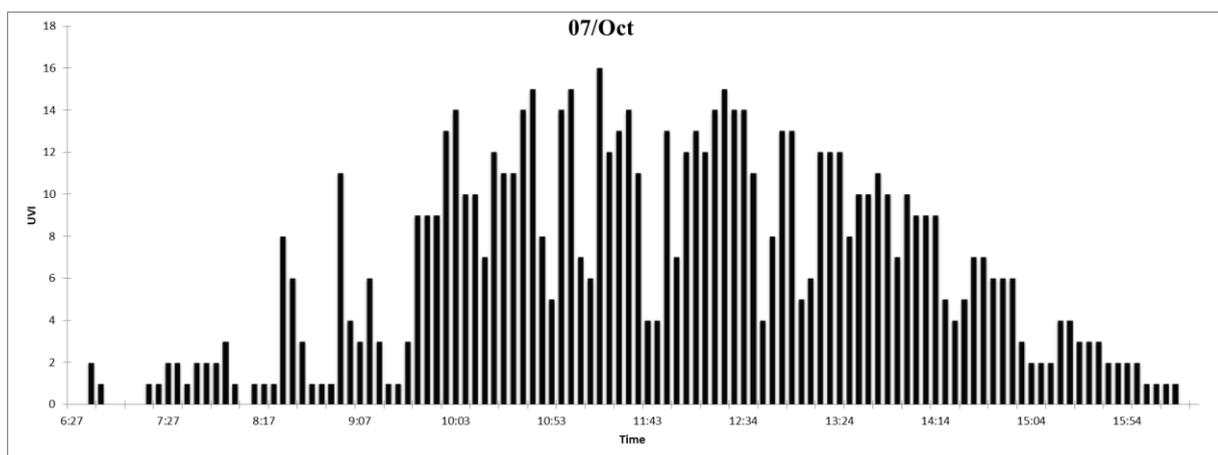

Figure 5. Variation of UVI values registered throughout the day 07/Oct.
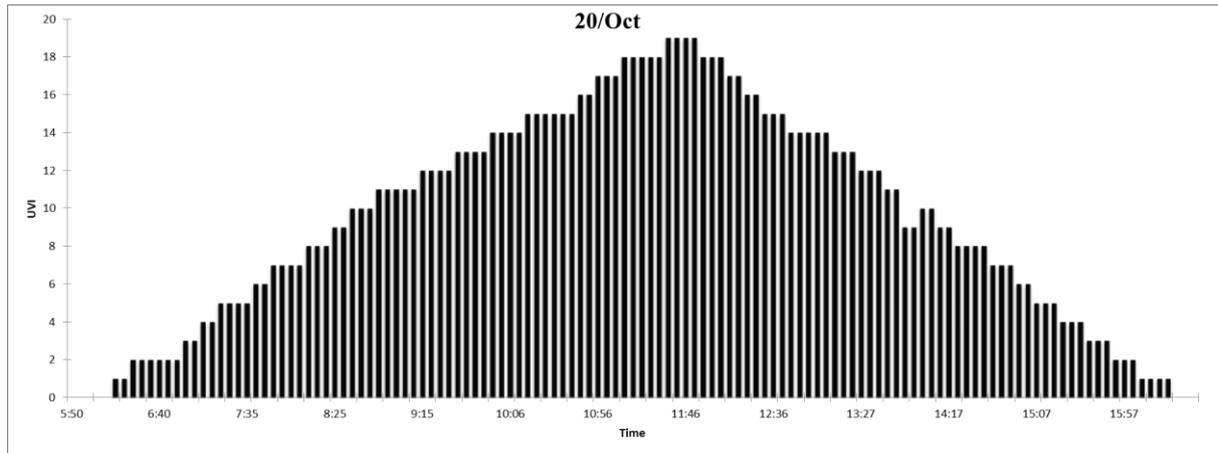
Figure 6. Variation of UVI values registered throughout the day 20/Oct.

To evaluate the daily repetitiveness of the start time of each risk level, the average value and standard deviation of the sampling times of ten days were calculated for each fist value of risks recorded. This information was organized in Tab. 1. This table provides an alarming finding as to the period of risk of exposure to ultraviolet radiation. It was found that the UVI reaches the High level between 07:21 and 08:17, then the Very High level between 08:06 and 8:44 and the Extreme level between 08:27 and 09:31, which remains until the early afternoon, when the UVI returns to the Very High level between 13:24 and 14:06. For such times of the day, WHO (2002) recommends extra protection such as avoiding sun exposure, looking for shadows, wearing shirts that protect arms, sunglasses, hat and sunscreen. In the afternoon, the UVI reaches the Low Risk level between 15:36 and 15:48.

Table 1. Averages and standard deviations of the recorded times (in the format of hour:minute) at the beginning of each level of risk.

		AVERAGE	STANDARD DEVIATION
	Beginning of Records	5:59	0:12
	End of Records	16:37	0:03
RISK START IN THE MORNING	Low	6:17	0:16
	Moderate	7:08	0:22
	High	7:49	0:28
	Very High	8:25	0:19
	Extreme	8:59	0:32
RISK START IN THE AFTERNOON	Very High	13:45	0:21
	High	14:37	0:09
	Moderate	15:03	0:11
	Low	15:42	0:06

In order to monitor the increase of ultraviolet radiation incidence, the maximum daily values of UVI (UVI_{max}) recorded by the measuring system during all the days of experimentation. These maximum values can be visualized in Fig. 7. With the proximity of the summer solstice of the southern hemisphere we noticed that the tendency of the obtained data was an intensification of ultraviolet radiation on the terrestrial surface, since an increase of daily UVI_{max} was observed during the 76 days of tests, where all these values were within the Extreme Risk classification. Okuno and Vilela (2005) explain that in almost all Brazilian territory the UVI values are quite high during most of the year and at latitudes lower than 9º the UVI reaches High and Extreme Risk levels throughout the year.
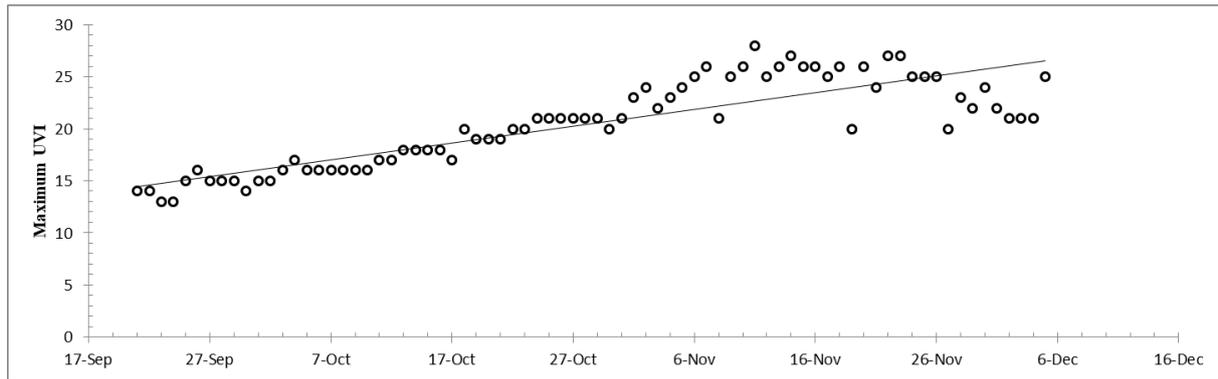
Figure 7. Record of maximum daily UVIs during the measurement period and tendency line.

For the purpose of comparison of the results, the analysis of the data of two UV sensors of the same model positioned next to each other with the same data collection and recording configurations was carried out. This test occurred from 21/Sep to 25/Sep. Table 2 shows the averages and standard deviations of the recorded times of change of the risk levels for each sensor during the five days of tests and in the last column are the differences between the calculated averages. Figures 8, 9, 10 and 11 present the comparisons of the UVIs recorded by the two sensors over four consecutive days. For day 22/Sep (Fig. 8) the weather was partly cloudy in the morning, then sunny afternoon with few clouds. For both days 23/Sep (Fig. 9), 24/Sep (Fig. 10) and 25/Sep (Fig. 11) it was predominantly sunny day with some clouds during all the day.

After comparison between these two UV sensors, it was observed that Sensor 1 presented a greater variability than Sensor 2 in the registry of changes in Low, Moderate, High, Very High and Extreme risk levels in the morning and Very High in the afternoon. However, the difference between the averages was very low, except for the Very High (morning) and Extreme risks, which presented values of difference considered. Even if new sensors, same manufacturer, same installation and code configurations were used, these differences are possibly due to the inherent uncertainties of the component. This may be caused by some impurity present in the photodiode that reduces the sensor's visibility to some wavelengths. Despite this, it was attested that both sensors have the same behavior at times when there is oscillation, increase or decrease in the incidence of ultraviolet radiation. For more precise calibration, a reference sensor such as a spectroradiometer should be use.

Table 2. Averages and standard deviations of the recorded times (in the format of hour:minute) during the test with the two UV sensors.

|		SENSOR 1		SENSOR 2		Difference between averages
		Average	Standard Deviation	Average	Standard Deviation	
	Beginning of Records	6:06	0:14	6:03	0:07	0:03
	End of Records	16:34	0:01	16:39	0:03	0:05
RISK START IN THE MORNING	Low	6:32	0:38	6:23	0:18	0:09
	Moderate	7:41	0:45	7:41	0:22	0:00
	High	8:50	1:30	8:49	0:15	0:01
	Very High	9:05	1:22	8:45	0:08	0:20
	Extreme	10:33	0:58	9:56	0:45	0:37
RISK START IN THE AFTERNOON	Very High	13:50	0:44	13:58	0:10	0:08
	High	14:28	0:15	14:40	0:02	0:12
	Moderate	14:51	0:14	15:06	0:05	0:15
	Low	15:38	0:06	15:44	0:08	0:06
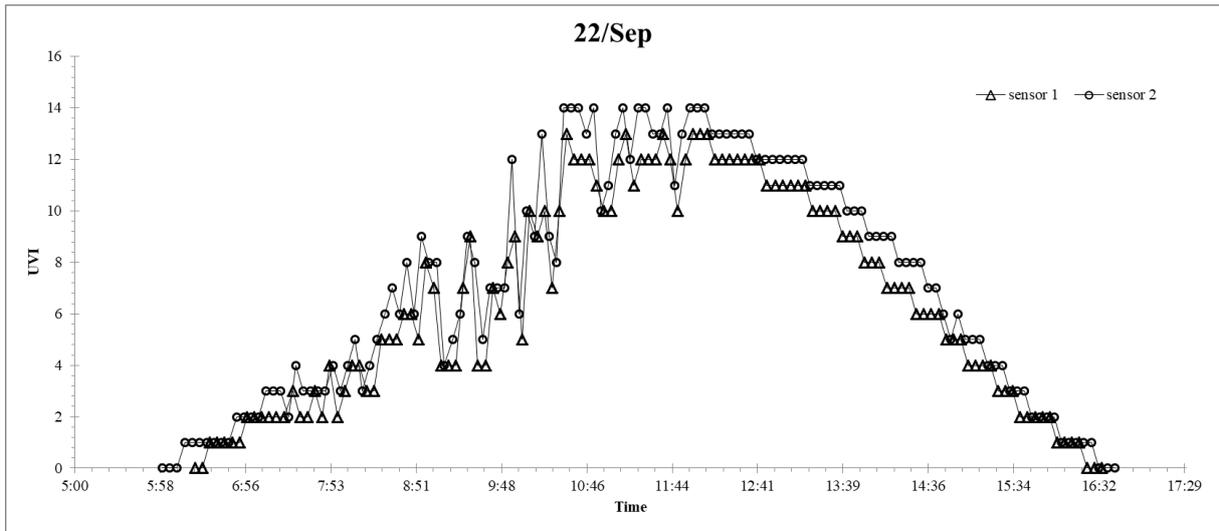
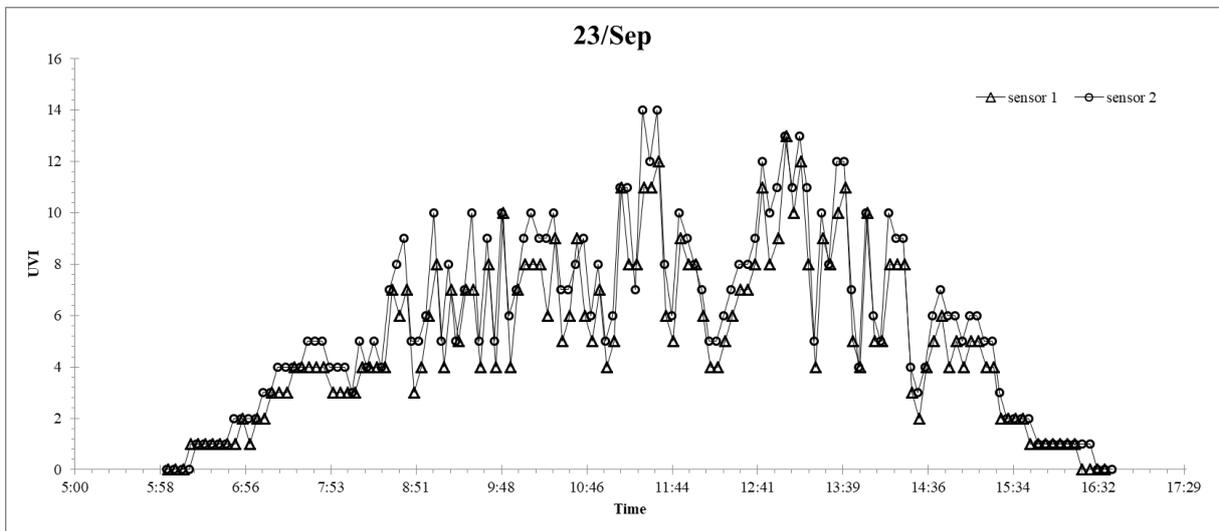Figure 8. Day 22/Sep test records with both UV sensors.

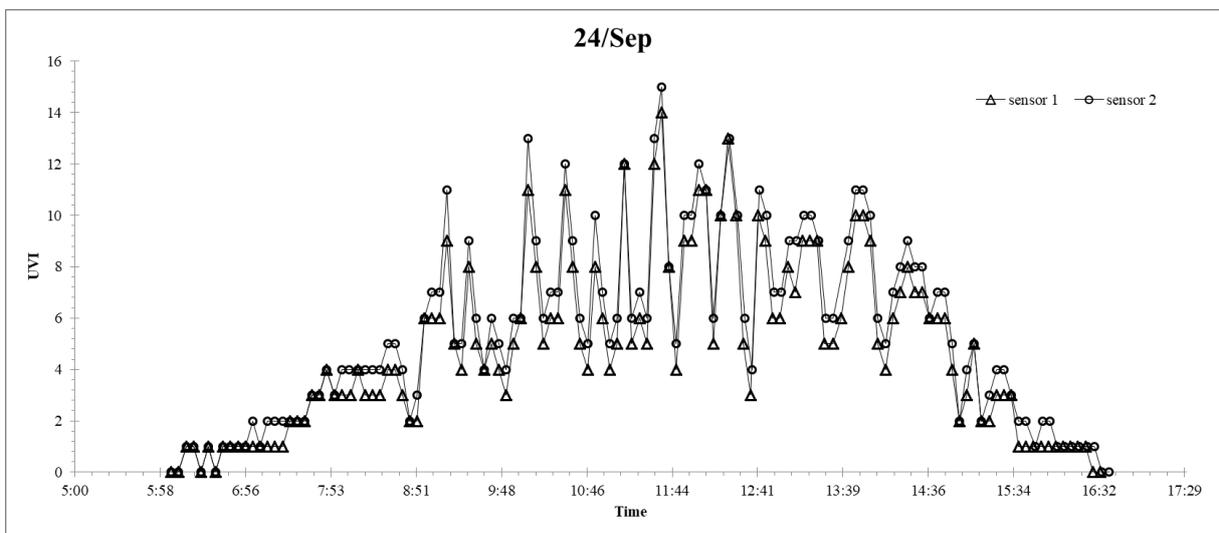Figure 9. Day 23/Sep test records with both UV sensors.

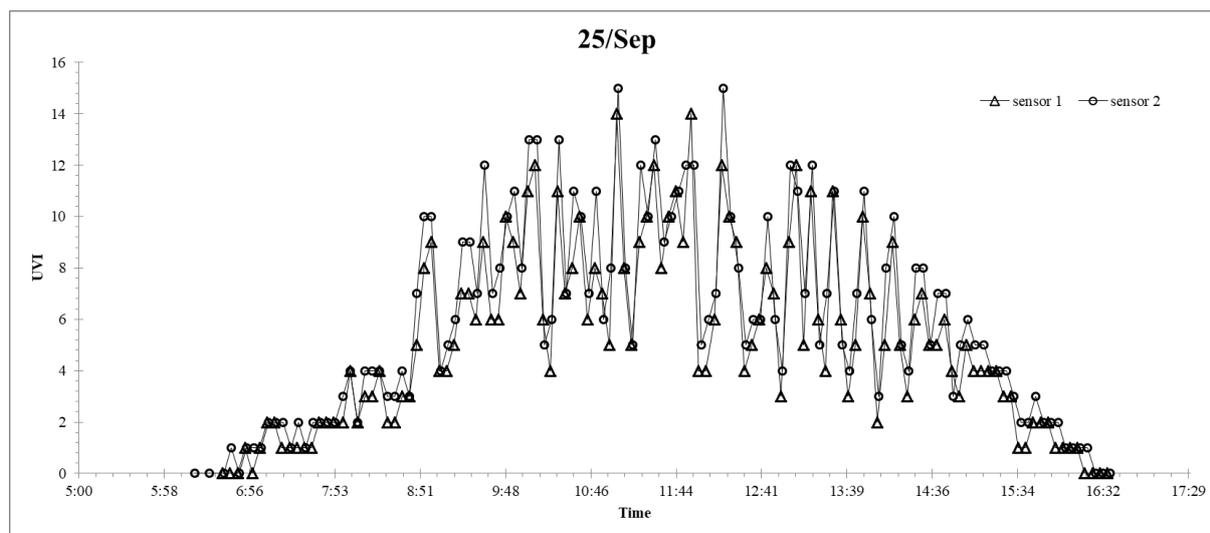Figure 10. Day 24/Sep test records with both UV sensors.

Figure 11. Day 25/Sep test records with both UV sensors.

4. CONCLUSION

The UVI was an important vehicle created by the WHO to educate people about the risks of excessive exposure to solar ultraviolet radiation and to warn them about the need to adopt means of protecting their health. Encouraging people to reduce exposure to the sun during times of high incidence can reduce harmful health effects and significantly reduce health care costs. It was with this objective that a low-cost UVI measurement equipment was designed and tested.

76 days of tests were performed with the UVI measurement equipment in the city of Campina Grande, Brazil. From these tests, a 10-day sample was selected to analyze the accuracy of the instrument in the recording of UVIs when there is an increase or decrease of risk levels throughout the day. The average of these records indicated that the UVI reaches the High, Very High and Extreme risk levels well before noon, meaning that extra protections for the skin and eyes should be taken from this early in the morning.

Also, from this sample, daily observations of the local cloudiness conditions were made to relate the occurrence of clouds with the recorded UVI readings. When comparing these days, delays considered in the registry of changes in the level of risk were observed in situations of high cloudiness and little delay on days with clear sky.

The erratic behavior presented by the data during the days with cloud record compared to the days without this record is well known to be influenced by the different daily conditions of atmospheric transparency associated with the variability in the ozone layer, aerosol concentration and type and cloud cover, factors that are determinant for the intensity of solar ultraviolet radiation arriving at the earth's surface according to Kirchhoff et al. (2000) and Balogh et. al. (2011).

Throughout the test, the maximum value of the UVI and the start and end times of registration were recorded, where an increase of the UVI_{max} was observed throughout the test days. This behavior was already expected, since the test period occurred during the transition from the spring season to the summer season in the southern hemisphere.

Taking into account that the UV sensor used in this study had a spectral sensitivity of 56.7% for the total range of ultraviolet radiation, and within this it allowed to perceive 64.7% of the UV-A band, 100% of the UV-B and 44.4% of UV-C, we conclude that the data of the measurements performed by the system represent the situation of the solar irradiance in this spectrum over the region where the equipment was installed.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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