

## Variation in Direct Solar Irradiation with Relative Humidity and Atmospheric Temperature

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### ABSTRACT

A class first Pyranometer was used to measure the direct solar irradiation and the obtained results were analyzed. Separate sensors were used to measure the relative humidity and the atmospheric temperature (RH/AT sensors). The measurements were conducted for the whole year of 2013. The author analyzed the collected solar data during one day, month, and year. The maximum, minimum, average, and accumulative solar irradiation (SR) were calculated and analyzed with connection to relative humidity and atmospheric temperature. The author found that April was characterized by the average maximum solar irradiation ( $SR = 1112 \pm 1 \text{ W/m}^2$ ), May had the maximum SR accumulation ( $13276552 \pm 1 \text{ W/m}^2$ ). The maximum average percentage relative humidity found in July ( $\% RH = 97 \pm 3\%$ ), while the minimum average  $\% RH$  is in December ( $\% RH = 25 \pm 3\%$ ). In May, the maximum average atmospheric temperature was  $36.0 \pm 0.6^\circ\text{C}$ , while the average minimum was in January ( $AT = 19.1 \pm 0.6^\circ\text{C}$ ). The total accumulation of solar flux during the year 2013 is  $222 \pm 1 \text{ MW/m}^2$ .

**Keywords:** solar irradiation, pyranometer, relative humidity, atmospheric temperature, accumulative solar flux

### INTRODUCTION

Solar energy is one of the most essential resources of renewable energy. It is clean, safe, and non-pollutant for the environment. One hour of the solar energy reaching the surface of the Earth is equivalent to all needs of energy for all humans on the Earth for one year. The solar energy data is vital for conducting the feasibility studies for solar energy systems. The solar data is essential in many applications like designing PV systems, solar collectors, solar dryers, and in buildings [Ertekin & Yaldiz, 1999] [Sabziparver & Shetaee, 2007]. The solar data values of direct normal irradiance allow one to derive precise information on the performance of solar energy systems [Lopez, Rubio & Batlles, 2000]. There are different techniques and devices used to measure the solar radiation. The received solar energy depends on the time during a day and during the season. In addition, it depends on the geographical place [Scharmer & Greif, 2000]. For a country like Oman,

the economical and efficient application of solar energy is dependent on the solar data. Different types of devices are used to measure the solar flux, like pyrheliometer, Pyranometer [Paulescu, et al., 2012]. The collected solar data is very important for researchers or any person working in the solar field. There are many scientists who used different models to predict solar flux.

Several scientists measured the solar irradiation as a reference [Lee, Yoo, & Levermore, 2013] measured the global solar irradiation on a horizontal surface for major cities of South Korea during the period (1986–2005). In North Mexico City, Matsumoto [Matsumoto et al., 2014] measured the global-horizontal solar radiation from 1999 until 2012 [Perez, Bilbao & De-Meguel, 2014] measured the monthly mean hourly values of direct irradiance for different locations in Spain characterized by different climatic conditions. The study carried out during the period (2002–2012) [Gairaa & Benkacali, 2011] performed hourly measurements of global and diffuse radiant fluxes

at Ghardaia in southern Algerian peninsula from January 1, 2005, to December 31, 2008. The collected data are very important in the design of building energy systems. In Saudi Arabia, they made Solar Atlas in February 2014, which provides live data recorded from 41 stations across the country [AlYahya & Irfan, 2016].

In our study, solar irradiation was measured for the first time at Dhofar University (North Al-Saadah-Salalah) to have a data bank for utilizing solar energy for different purposes. Al-Saadah-Salalah is at 17.0167° N, and 54.0929° E. This study was carried out in the period from January 1, 2012, until December 31, 2013 [Wazwaz & Salmi, 2010]. The Automated Weather Station (AWS) was constructed at the roof of the Chemical Engineering Department. The AWS composed of the first-class Pyranometer, along with the RH/Temperature sensors. There are different models used to calculate the solar irradiance (direct and diffuse) by connecting it with humidity and ambient temperature [Jimenez, Barrionuevo & Rodriguez, 2016] [Loutfi et al., 2017].

## EXPERIMENTAL

### Installation of the Automated Weather Station (AWS)

We installed the Automated Weather Station (AWS) on the roof of the Chemical Engineering Department – College of Engineering- Dhofar University- North of AlSaadah-Salalah Oman. The station consisted of a pyranometer (first class), and relative humidity/atmospheric temperature (RH/AT) sensors. The specifications of the Pyranometer and the RH/AT illustrated in Table 1 and 2, respectively. The AWS was bought from Coastal Environmental Systems, Inc.

The utilized pyranometer used is first class (S80124, coastal Environmental Systems). This solar radiation sensor is applied in scientific grade solar radiation observations. It complies with the “first class” specifications within the latest ISO and WMO standards. It serves to measure the solar radiation flux that is incident on a plane surface in W/m<sup>2</sup> from a 180 degrees field of view (also called “global” solar radiation). Working completely passive, using a thermopile sensor, the sensor generates a small output voltage proportional to this flux. Employing two glass domes, certain measurement errors are reduced; in

**Table 1:** Specifications of pyranometer

Item	Specification
ISO classification	First Class
Spectral range	305 to 2800 nm
Sensitivity (nominal)	15 $\mu\text{V}/\text{Wm}^2$
Temperature range	-40 to +80 °C
Range	0 to 2000 $\text{Wm}^2$
Temperature dependence	< 0.1%/°C
Calibration traceability	WRR

particular, thermal offsets, so that high measurement accuracy can be attained. The sensor can be directly connected to most commonly used data logging systems. It used for scientific meteorological observations, building physics, climate- and solar collector testing. A common application is for outdoor solar radiation measurements as part of a meteorological station. This application requires horizontal leveling; leveling feet and a level are included. The cable can be installed or replaced by the user. The applicable standards are ISO 9060 and 9847, WMO (World Meteorological Organization), and ASTM E824–94. It used for stability estimations according to EPA.

The relative humidity and air temperature sensor (RH/AT sensors) is compact and easy to use. The relative humidity element is a hygroscopic capacitive type. It is interchangeable. These elements never need calibration. Instead, the elements are easily replaced without the expense and inconvenience sometimes associated with the calibration process. The membrane filter/mechanical housing of the sensor protects it from dust and dirt.

The AWS connected to a PC and controlled by software (INTERCEPT V1.17.62). The AWS is working day and night, continuously recording the readings every minute. The collected data are

**Table 2:** Specifications of RH/AT sensors.

Item	Specification
RH Accuracy	+/- 3%
RH Resolution	0.1%
RH Range	0 – 100% RH
Operational Temperature Range	-30°C to +60°C
Storage Temperature	-80°C to +80°C
AT Accuracy	+/- 0.6°C
Time Constant, Max	1 sec in well-stirred oil. 15 sec in still air
Shield	Gill multi-plate naturally ventilated shield
Typical Error In Full Sunlight	0.5°C

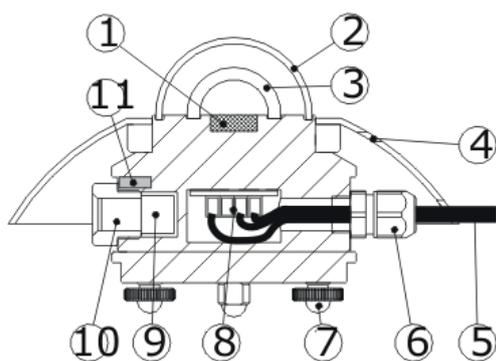


Figure 1: Solar radiation sensor

processed, analyzed and plotted. Figure 1 shows all parts of the first class Pyranometer and RH/AT sensors, respectively. The numbers inscribed in Figure 1 are describes as follows:

1. Detector
2. Outer glass dome.
3. Inner glass dome.
4. Sun shield.
5. Cable.
6. Connector.
7. Adjustable feet.
8. Smart interface.
9. Humidity indicator.
10. Desiccant.
11. Bubble level.

Figure 2 shows the installed automated weather station installed on the roof of the Chemical Engineering Department at Dhofar University.

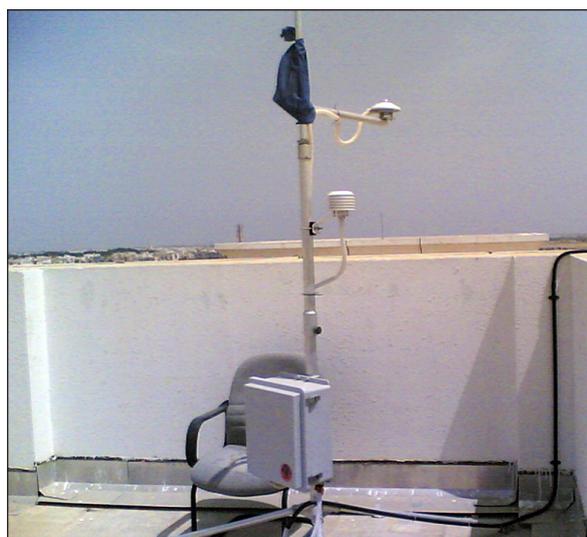


Figure 2: Automated weather station on the roof of the Chemical Engineering Department at Dhofar University

## RESULTS AND DISCUSSION

### Calculations during the day

The Automated Weather Station (AWS) collects the solar data, Relative Humidity (RH) and Atmospheric Temperature (AT) during the day per minute and sends it via the data logger to be saved on the PC. The collected data was analyzed using Excel. Figure 3 below shows the data collected during the first day of January 2013 where SR represents the solar flux (solar irradiation).

The time of measurement started at 12:00 AM mid night until 11:59 PM next day (working 24 hours).

Figure 3 indicated the following parameters during that day: 1. SR: Maximum of SR =  $846 \pm 1 \text{ W/m}^2$ , Average of SR =  $506 \pm 1 \text{ W/m}^2$ , Accumulative of SR =  $338718 \pm 1 \text{ W/m}^2$ . 2. RH: Maximum of RH=  $42 \pm 3\%$ , Average of RH=  $29 \pm 3\%$ , Minimum of RH=  $16 \pm 3\%$ . 3. AT: Maximum of AT =  $28.4 \pm 0.6^\circ\text{C}$ , Average of AT=  $22.5 \pm 0.6^\circ\text{C}$ , Minimum of AT=  $17.8 \pm 0.6^\circ\text{C}$ . We did the same calculations for all days of all months of the year 2013.

### Calculations during the month

During each month of the year 2013, the author performed the calculations to find the Maximum of SR, Average of SR, Accumulative of SR, Maximum of RH, Average of RH, Minimum of RH, Maximum of AT, Average of AT, and Minimum of AT as seen in Figure 4. Figure 4 shows that during January 2013: The Average of Maximum SR =  $901 \pm 1 \text{ W/m}^2$ , Average of SR =  $470 \pm 1 \text{ W/m}^2$ , The Average Accumulation of SR =  $319984 \pm 1 \text{ W/m}^2$ , The Accumulation of SR =  $9599519 \pm 1 \text{ W/m}^2$ . In the same way, the calculations for RH and AT were performed (see Figures 5 and 6). Figure 5 shows the calculations of RH for January 2013.

Figure 5 shows that: Average of the Maximums of RH =  $61 \pm 3\%$ , Average of RH =  $48 \pm 3\%$ , Average of Minimums of RH =  $31 \pm 3\%$ . From Figure 6, we found that: Average of Maximums of AT =  $28.8 \pm 0.6^\circ\text{C}$ , Average of AT =  $23.2 \pm 0.6^\circ\text{C}$ , Average Minimums of AT =  $19.1 \pm 0.6^\circ\text{C}$ . During January 2013, it was found that: The Maximums of SR=  $1282 \pm 1 \text{ W/m}^2$  (In January 29), The Maximums of RH =  $75 \pm 3\%$  (In January 9, 30), The Maximums of AT=  $32.3 \pm 0.6^\circ\text{C}$  (In January 3). The investigation was carried out in the same way for the rest of the months of the year 2013. The summary of all months is shown in Table 3.

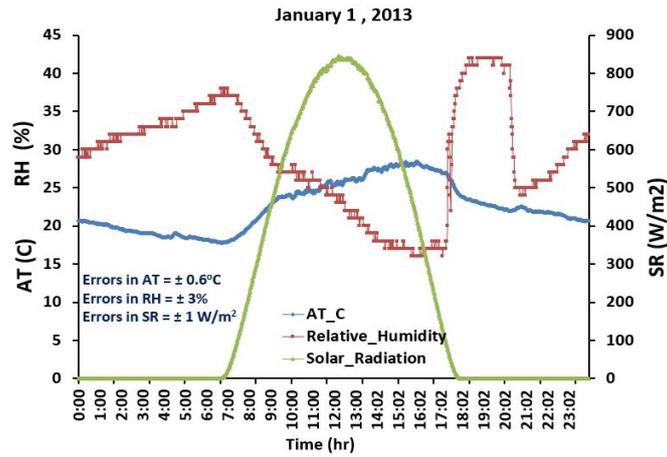


Figure 3: The collected data of SR, RH and AT

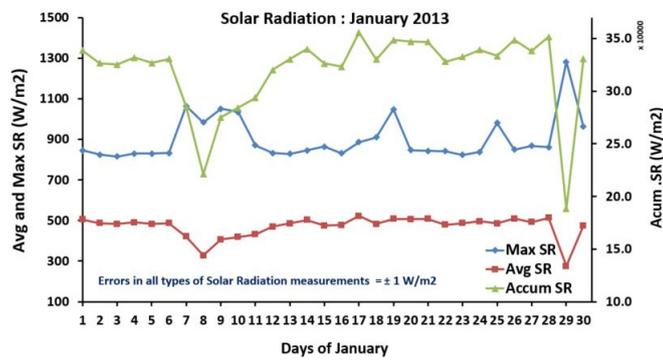


Figure 4: Solar irradiation for January 2013

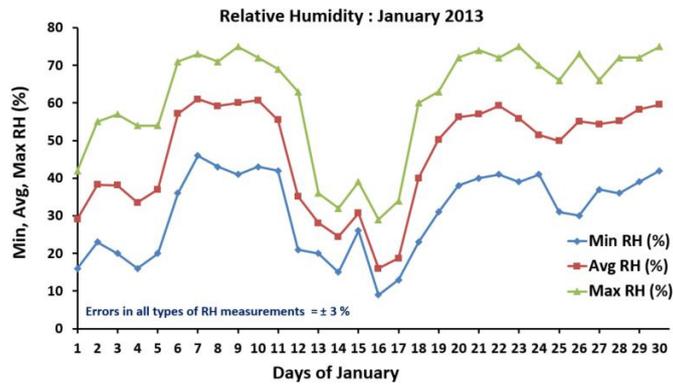


Figure 5: Relative humidity for January 2013

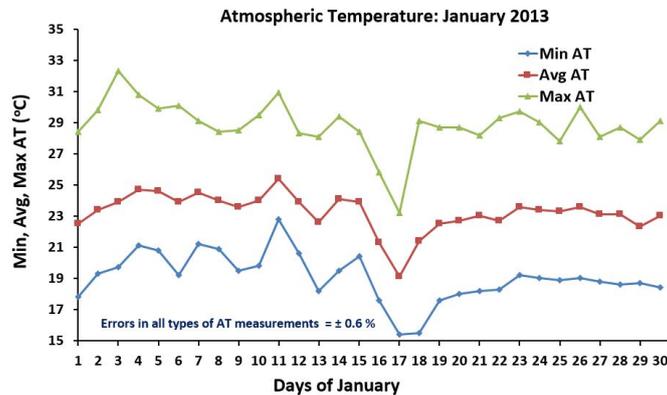


Figure 6: Atmospheric temperature for January 2013

**Table 4:** The maximum SR, RH, and AT found in the year 2013 at Dhofar University

Month	Max SR( $\pm 1W/m^2$ ) (Day/s number)	Max RH ( $\pm 3\%$ ) (Day/s number)	Max AT ( $\pm 0.6^\circ C$ ) (Day/s number)
January	1282.00 (29)	75.00 (9.30)	32.30 (3)
February	1249.00 (12)	88.00 (3)	32.20 (15)
March	1360.00 (26)	88.00 (26)	36.40 (8)
April	1362.00 (5)	90.00 (3,4)	38.80 (2)
May	1280.00 (7)	87.00 (31)	41.80 (19)
June	1149.00 (24)	94.00 (29)	37.10 (10)
July	1027.85 (13)	95.6 (1–11, 15–31)	29.5 (9)
August	1034.22 (15)	94.00 (20–30)	28.9 (21)
September	1062.20 (18)	88.20 (4–8,20–25)	34.50 (20)
October	1144.79 (5)	95.00 (10)	37.75 (15)
November	980.00 (16)	83.00 (22)	36.70 (7)
December	1022.00 (13)	81.00 (8)	34.90 (4)

**Table 3:** Summary of the measured and calculated SR, RH and AT for all months of the year 2013

Month	Avg. Max SR ( $\pm 1W/m^2$ )	Avg.SR ( $\pm 1W/m^2$ )	Avg. Accum SR ( $\pm 1W/m^2$ ) x 1000	Accum ( $\pm 1W/m^2$ ) x 10,000	Avg.Max RH ( $\pm 3\%$ )	Avg.RH ( $\pm 3\%$ )	AvgMin RH ( $\pm 3\%$ )	AvgMax AT ( $\pm 0.6^\circ C$ )	Avg AT ( $\pm 0.6^\circ C$ )	AvgMin AT ( $\pm 0.6^\circ C$ )
January	900.77	469.93	319.0	959	61.20	47.57	30.60	28.84	23.24	19.07
February	991.57	542.95	331.0	1067	65.25	49.79	32.28	29.38	24.06	19.66
March	1100.97	558.54	406.0	1258	72.03	50.57	31.06	32.24	26.82	22.35
April	1111.68	540.97	422.0	1264	80.52	63.27	41.48	33.91	28.99	25.56
May	1058.71	547.55	428.0	1327	81.65	66.09	44.27	36.00	30.93	27.40
June	966.60	425.25	336.0	1010	87.13	75.62	56.60	33.89	29.39	26.95
July	864.68	380.41	301.7	9039	97.40	86.4	77.60	28.90	26.35	23.80
August	870.04	382.77	303.2	909	96.80	87.40	80.00	26.70	25.72	23.75
September	893.58	393.13	311.5	934	94.25	84.34	65.20	29.50	26.15	22.80
October	963.06	423.70	335.0	1006	87.45	74.80	46.56	31.00	26.80	22.60
November	896.27	4489.98	336.0	1008	68.70	53.63	34.70	32.83	27.49	23.53
December	831.77	481.99	325.0	1007	55.76	38.76	24.83	30.35	24.80	20.64

It can see (from Table 3) that: 1. In SR calculations: April gave the maximum average SR, March gave the best average, May month gave the best average accumulative of SR, and May is the best accumulation of SR among all months of the year 2013. In RH calculations: July gave the average maximum of RH, December gave the average minimum of RH, and August gave the best average value. In AT calculations: May gave the average maximum of AT, January gave the average minimum of AT, and May gave the highest value of the average of AT. Among all maximums in all months, we found that: the maximum SR found in April, the maximum RH found in July, and the maximum value of AT found in May. The accumulative SR for the whole year of 2013 is  $222 \pm 1 MW/m^2$ .

## CONCLUSIONS

The AWS installed was composed of first-class pyranometer and the RH/AT sensors. The measured values of the SR, RH, and AT are for the year 2013. The measured values of all parameters used to make several calculations such as average, accumulative, average maximums, average minimums, average among all data measured. It can be concluded that May is the best for collection of solar irradiation, while July is the worst one of collection solar irradiation because of the presence of thick layers of clouds in the sky during this month, which prevented some of the solar radiation from reaching the surface of the earth. This can be seen clearly in the average maximum RH values which are found in July ( $97 \pm 3\%$ ).

Generally, most of the year is very good for the collection of solar radiation at Dhofar University (Dhofar Region). This makes Dhofar University (Dhofar Region) an excellent place for the Photothermal and Photovoltaic applications.

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