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Title: Effect of the angle of solar irradiance on the photo generation of a photovoltaic module

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PRESENTATION CONTENT

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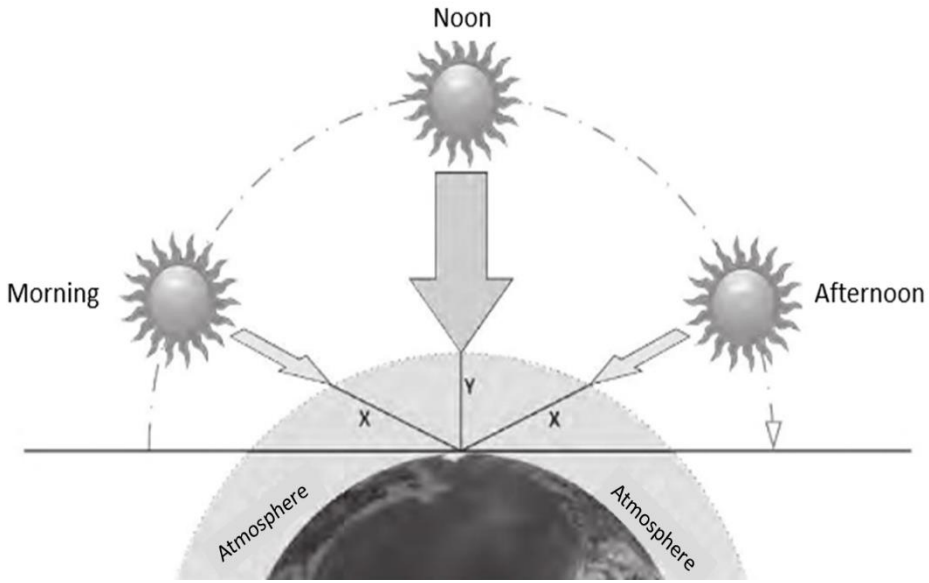
INTRODUCTION

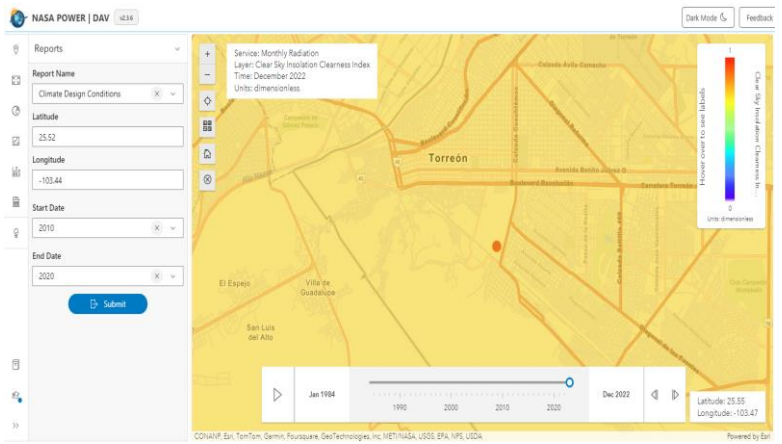
The angle of solar incidence is the angle at which a ray from the sun reaches a surface. Understanding the apparent motion of the sun, it follows that, being close to the zenith, the surface tends to receive a greater amount of energy. This is because the distance traveled by the sun's rays is shorter when the sun is at its maximum elevation, where the distances X are greater than the distance Y. From this derives the concept of irradiation, that is, the determined irradiance that reaches a surface in a given period of time. The hours of the day with the highest incidence of irradiance are called Hour Solar Peak, for its acronym HSP (Style, 2012).



METHODOLOGY

The steps followed for this experimental research were:

1. Determination of Peak Sun Hours in the region.
2. Measurement of irradiance throughout the day.
3. Measurement of short-circuit current and module efficiency by varying its tilt angle.
4. Determination of the power loss factor of the module due to variations in azimuth orientation and changes in the module's



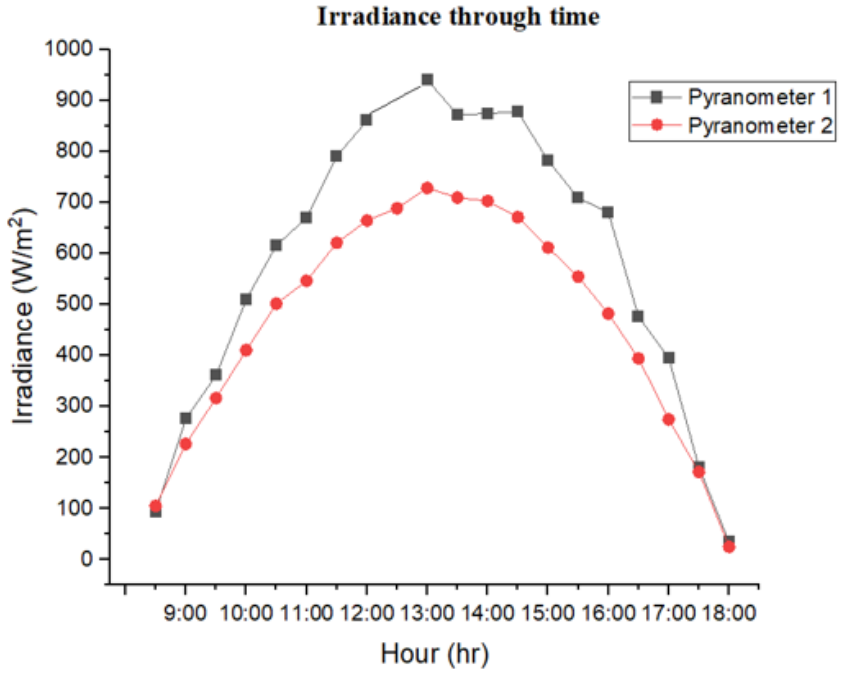
RESULTS

In the first test, the curves obtained from measurements taken with each pyranometer were compared. This comparison is illustrated in Graph 1, where "Pyranometer 1" refers to the Tenmars handheld pyranometer and "Pyranometer 2" refers to the sensitive Kipp & Zonen pyranometer.

This observation confirms that peak solar hours occur around noon, when the sun's rays travel the shortest distance to reach the surface. In both cases, irradiance measurements exceeding 700 W/m² were obtained.

Graph 1

Irradiance over time.



[Own elaboration in OriginLab]

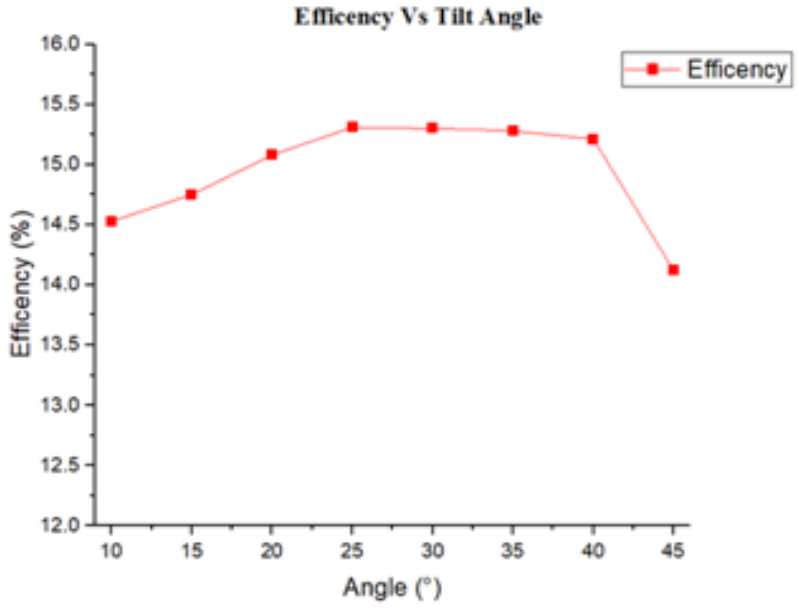
RESULTS

From Graph 2, it can be observed that the highest efficiency from the module occurs at inclination angles between 25° and 35°. This aligns with the latitude of the test area, which is 25.54389°. If the module's inclination is adjusted by more than 10° from this range, a decrease in photo generation occurs due to the adverse effects on the angle of solar incidence.

This observation confirms that peak solar hours occur around noon, when the sun's rays travel the shortest distance to reach the surface. In both cases, irradiance measurements exceeding 700 W/m² were obtained.

Graph 2

Efficiency of the module against the angle of inclination.



[Own elaboration in OriginLab]

RESULTS

Similarly, Graph 3 illustrates the behavior of the short-circuit current (Isc) generated by the module in relation to the inclination angle, while the module received an average irradiance of 874 W/m².

In Graph 3, it is evident that the highest short-circuit current values occur at inclination angles between 20° and 35°. In contrast, at other inclination angles, the short-circuit current decreases significantly. This phenomenon occurs because inclinations closer to the region's latitude enhance the reception of direct irradiance, allowing for more effective conversion of solar energy into electrical energy.

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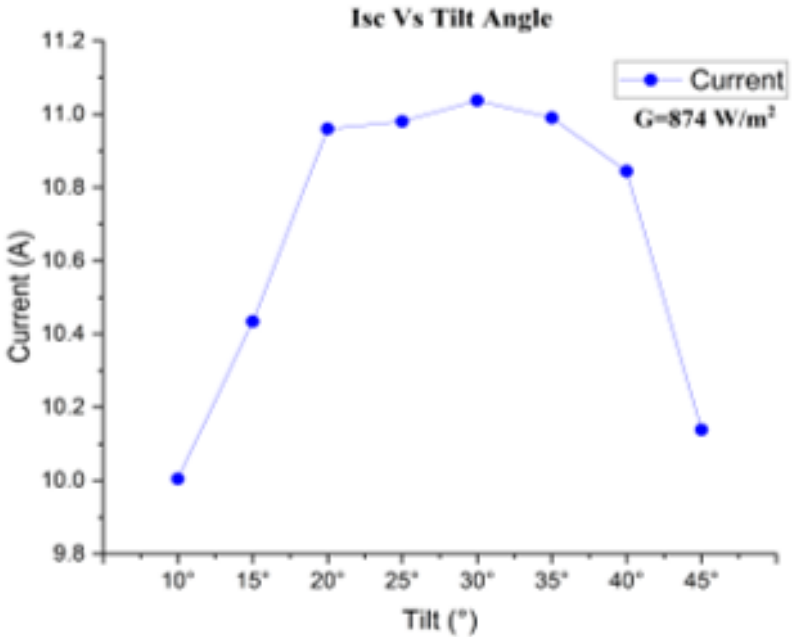
Graph 3

Short circuit current of the module against the angle of inclination.



[Own elaboration in OriginLab]

RESULTS

Through the third test, Table 1 presents the values of the maximum power point of the module at various orientations in the azimuth plane and different inclination angles.

Table 1 highlights the value of 378 W, the maximum power output obtained from all measurements, achieved at an inclination of 25° with a direct orientation to the south (0° in the azimuth plane). This result confirms that this orientation is optimal for the region, as it aligns with the correct positioning for solar modules in the northern hemisphere.

Table 1

Power of the module according to orientation

(°)	Inclination							
γ_s	10	15	20	25	30	35	40	45
90	140	195	213	256	244	277	222	138
75	168	254	255	284	268	252	243	192
60	225	267	276	309	292	286	267	262
45	240	268	290	332	323	308	293	263
30	248	280	298	341	326	315	299	280
15	272	282	307	362	336	324	307	287
0	289	310	321	378	367	328	311	299
-15	183	231	282	351	321	313	307	229
-30	136	212	276	344	319	302	297	220
-45	156	165	228	325	311	267	252	145
-60	140	161	218	304	288	232	224	130
-75	94	135	213	289	268	202	152	89
-90	77	129	139	248	224	144	123	50

[Own elaboration]

RESULTS

Using the values in Table 1, it is possible to calculate the power loss factor corresponding to each orientation and inclination.

Table 2 illustrates that to minimize the loss factor, the module should be oriented as closely to the south as possible, ideally within the range of -30° to +30°. Additionally, the inclination of the module should be maintained between 25° and 35°. Deviations from these angles tend to result in a higher power loss factor for the module.

Table 2

Loss factor according to orientation.

(°)	Inclination							
γ_s	10	15	20	25	30	35	40	45
90	-6.2	-4.8	-4.3	-3.2	-3.5	-3.9	-4.1	-6.3
75	-5.5	-3.2	-3.2	-2.4	-2.9	-3.3	-3.5	-4.9
60	-4.0	-2.9	-2.6	-1.8	-2.2	-2.4	-2.9	-3.0
45	-3.6	-2.9	-2.3	-1.2	-1.4	-1.8	-2.2	-3.0
30	-3.4	-2.5	-2.1	-0.9	-1.3	-1.6	-2.0	-2.5
15	-2.7	-2.5	-1.8	-0.4	-1.1	-1.4	-1.8	-2.3
0	-2.3	-1.8	-1.5	0.0	-0.2	-1.3	-1.7	-2.0
-15	-5.1	-3.8	-2.5	-0.7	-1.4	-1.7	-1.8	-3.9
-30	-5.6	-4.3	-2.7	-0.9	-1.5	-2.0	-2.1	-4.1
-45	-5.8	-5.6	-3.9	-1.4	-1.7	-2.9	-3.3	-6.1
-60	-6.2	-5.7	-4.2	-1.9	-2.3	-3.8	-4.0	-6.5
-75	-7.4	-6.4	-4.3	-2.3	-2.9	-4.6	-5.9	-7.6
-90	-7.9	-6.5	-6.3	-3.4	-4.0	-6.1	-6.7	-8.6

[Own elaboration]

CONCLUSIONS

This research investigates the impact of solar incidence angles on the electrical parameters of a photovoltaic module in Torreón, Coahuila. The findings indicate that the optimal configuration for the module is a southward orientation at 0° in the azimuth plane and a 25° inclination. This alignment maximizes efficiency during peak solar hours, averaging 6.34 hours. The study recorded a 0% power loss factor at the optimal settings and an -8.6% loss factor at suboptimal angles. These insights can guide other installations where ideal positioning is challenging, helping to enhance module performance.

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