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PERFORMANCE COMPARISON OF TRACKING AND NON-TRACKING SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEMS

by

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Summary:

Two identical 100 Watt solar water pumping systems were compared with passive tracking and non-tracking mounting frames. The passive tracker was interrupted by winds and did not always track the sun, but pumped enough additional water in early mornings, late evenings, and on calm days to average 159 L/day more than the fixed system; enough to water 2 additional cattle. Our conclusion was that this small amount of extra water was not warranted by the extra cost of the passive tracker.

Keywords:

Solar energy, water pumping, photovoltaic, solar power

PERFORMANCE COMPARISON OF TRACKING AND NON-TRACKING SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEMS[1]

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ABSTRACT

Two 100 Watt solar water pumping systems, each consisting of two 53 W photovoltaic panels and a diaphragm pump, were installed to provide water for livestock. The pumps were set at a depth of 30 m and the systems were identical except that one set of photovoltaic panels was mounted on a passive tracking device and the other set of panels was mounted in a fixed position. The passive tracking system was observed 'flipped over' out of the direct rays of the sun when the wind was gusting from the southwest. However, the passive tracking system pumped enough additional water during the early mornings, late afternoons, and days with low winds to average slightly more water pumped than the fixed system. Daily water volumes averaged 1,705 L/day for the system with the fixed solar panels and 1,864 L/day for the tracking system. Although the passive tracking system pumped slightly more water, the difference in average daily rates was not enough to warrant purchasing the tracker.

INTRODUCTION

An adequate year-round water supply is still a major stumbling block to livestock grazing in many arid and semiarid regions. Ranchers have found that if sufficient watering places are not provided, livestock do not move to areas of the pasture where grass may be abundant. Cattle will graze about one kilometer from a water supply; therefore, several water supplies are needed in most large pastures. It is recommended that water storage be provided to meet the livestock needs for 3 to 5 days.

One of the early uses of solar power was to harness the winds produced by uneven heating of the earth's surface. Windmills were used to pump water from shallow wells

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using bucket pumps [Fraenkel, 1986] and in the late 1800's, the American multibladed windmill was developed to pump water from deep wells. Many windmills have been in use for over 50 years and are simply worn out. Farmers and ranchers are seeking replacements for these windmills for remote water pumping. Additions of remote water pumps to the electrical grid are being discouraged by electric utilities because of the high maintenance cost of small, low capacity rural electric lines. A high connection fee often exceeds the cost of other fuel alternatives.

New developments with solar photovoltaic water pumping systems have provided a new potential for pumping water in remote areas. These pumping systems offer a compact package that is easily installed and can be easily moved from well to well when the pumping depth is less than 30 m. Several solar photovoltaic water pumping systems for remote areas have been evaluated by the USDA, Agricultural Research Service, Bushland, TX. The objectives of the evaluations were 1) to measure the performance of photovoltaic water pumping systems; 2) to determine the daily water pumping volumes at various pumping depths; 3) to evaluate the reliability of photovoltaic water pumping systems; and 4) to evaluate the effectiveness of passive tracking systems. This paper reports on the effectiveness of a passive tracking system as part of a remote shallow well pumping system.

DESCRIPTION OF PHOTOVOLTAIC PUMPING SYSTEM

The systems tested consisted of a photovoltaic (PV) panel array, mounting apparatus, controller, pump, and electric motor. A schematic of a pumping system with data acquisition is shown in Fig. 1. PV arrays are comprised of multiple panels containing 30 to 40 individual solar cells, rated at approximately 50 W; and usually wired in 12 or 24 V configurations. For this study, two 53-W panels were wired in series to produce a nominal output of 24 V. The panels were mounted on a tilting frame that allowed the surface to be rotated back and forth to keep the panel surface perpendicular to the sun. Two liquid filled cylinders were used to move the tracker by heating the fluid and causing the hot liquid-gas mixture to move from the hot side (toward the sun) to the cooler side (away from the sun). The manufacturer claims 55% more energy is collected with the tracker [Zomeworks[3], 1991].

The submersible motor was a DC electric motor rated for 24 V with a peak current draw of 3.1 A and was mounted directly to the pump. The pump was a diaphragm type pump constructed of marine bronze and stainless steel. The pump-motor combination weighed 6.4 kg (14 lbs) and the outside diameter was 96 mm (3.8 in).

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[3] The mention of manufacturer's names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

The pump-motor combination was 273 mm (10.75 in) long. The pump fits easily inside of a 102 mm (4 in) diameter pipe which is often used for small well casing.

A controller was used to boost the voltage to match the load requirements in low sunlight, boost the voltage for maximum pump output when the sunlight was good, and provide voltage regulation of the PV array around its maximum power point [Solarjack[3], 1992]. The controller increased the voltage in low sunlight to above 16 V so the pump would operate, thus providing small amounts of water. In excellent sunlight, the controller limited the voltage at 24 V and increased the current to increase the water flow.

Two identical solar photovoltaic water pumping systems were set at a pumping depth of 30 m; however, the passive tracker on one system was fixed in place and not allowed to track the sun. The pumping systems were operated for 18 months at the USDA Conservation and Production Research Laboratory, Bushland, TX. Only one calendar year of data is presented in this paper. The Laboratory is located at a latitude of 35°10' north and a longitude of 102°5' west, with an elevation of 1164 m (3819 ft). The PV arrays were set at an angle of 45 degrees from September 21 until March 21 and at 25 degrees from March 21 until September 21. Pumping depths were simulated using a back pressure regulating valve and pressure tank to maintain the desired pressure. Water pressure was measured with a pressure transducer and flow was measured with a turbine meter equipped with an electronic output. All data were sampled every 1 sec and the averaging interval was 1 min. Data were recorded with a data logger and the 1 min averages were stored for further processing.

RESULTS

Incoming solar irradiance was measured with a pyranometer mounted directly on the mounting apparatus so that the pyranometer was always at the same sun angle as the PV panels to insure that a correct measurement of incoming irradiance was recorded. The incoming irradiance for each system is shown in Fig. 2 for a clear day with a low wind speed. The wind speed average for March 31, 1996 was 2.8 m/s (Fig. 2). Figure 3 shows similar data collected on April 1, 1996 but with a moderate wind speed that averaged 8.3 m/s. Notice that the fixed tracking values are almost identical in Fig. 2 and 3, but the passive tracking system values fluctuated and are lower during the mid-day period on the day with the higher wind speeds (Fig. 3). The passive tracking system is unstable in gusty winds and flops to one side causing it to not maintain an optimum angle with the sun. In early morning and late evening, the tracker is turned toward its side (the sun) and is not affected by the wind as much as during mid-day. However, the tracking system was disadvantaged if there were strong early morning winds from the prevailing southwest direction since they tended to keep the panels from being able to reset to the rising sun.

Knowing that the tracker was affected during the mid-day period, we sought to determine the daily radiation lost by comparing the daily values for each month. We quickly saw that values were skewed because of the variation in radiation for 1996. Figure 4 shows the daily solar energy for the fixed tracker, the passive tracker, and an adjusted value determined from the horizontal solar radiation measurements made at a nearby weather station. The spring and summer values were corrected to fixed angles of 25 degrees and the fall and winter values were corrected to fixed angles of 45 degrees (Vick and Clark, 1996). The inclusion of this long term historical data and some knowledge of the radiation for 1996 clearly show these data are valid. The first six months of 1996 were months of low precipitation (19 mm), thus higher than normal radiation; followed by three months of excessive rainfall and cloudy days. About 75% of the annual average rainfall was received during this three month period. The period, October thru December, was near normal. The data presented in Fig. 4 clearly show that although the passive tracking system is tipped over away from the sun during mid-day when winds were moderate or high, the daily average radiation was always higher with the passive tracker. The passive tracker averaged 7.64 $kWh/m^2/day$ while the fixed tracking system averaged 6.49 $kWh/m^2/day$, an increase of 18% with the passive tracker.

Figure 5 contains the average flow curve for the submersible diaphragm pumps used in this study. This curve is the average of 24 monthly curves and was independent of the pump used, tracking system used, or the month in which the data were collected. Throughout the study period, a given amount of irradiance produced the same pumping rate at a 30 m pumping depth. The pumping rate increased with increased irradiance until the irradiance level reached 900 $Watts/m^2$ and then the pumping rate remained rather constant at 4 L/min. Thus, when the irradiance exceeded 900 $Watts/m^2$, no additional water was pumped. The daily water volumes pumped are shown in Fig. 6 for each month. The fixed tracking system averaged 1705 L/day and the passive tracking system averaged 1864 L/day during the calender year 1996; an increase of 9%. The greatest difference in pumping volumes occurred in the spring and fall months. (Further explanation will be given later.)

The efficiency of each pump is shown in Fig. 7 by months and shows that both pumps operated at the same efficiency during the year. The average pump efficiency was 37% and varied from a high of 44% to a low of 34%. With both pumps performing the same, any differences in system efficiency should be attributed to the tracking systems. Figure 8 shows the overall system efficiency which was determined by the energy in the pumped water divided by the total incoming energy to the PV panels. In all months, the passive tracking system had a lower overall efficiency than the fixed tracking system. Remember from Fig. 5 that the pump does not utilize irradiance intensities above 900 $Watts/m^2$; therefore, the passive tracking system receives more solar energy, but does not always pump more water. In this case, efficiency alone is not a good indicator of the performance of the systems.

Since the passive tracking system often receives incoming solar radiation that exceeds the amount that it can effectively use, we wanted to compare the average solar insolation for each season. Figures 9, 10, 11, and 12 show the average irradiance for the winter, spring, summer, and fall respectively. During the winter [Dec, Jan, & Feb] (Fig. 9), there is little difference in the amount of irradiance available due to tracking. Note that the passive tracker is lower during the mid-day time period indicating that the wind does interrupt the movement of the tracker. Also during this colder period, the passive tracker takes longer to react to the morning sun and it is delayed in turning toward the sun. Thus the tracking system provided little advantage during the winter months. Also, note that the daily values of water pumped (Fig. 6) are almost identical for both systems.

During the spring [Mar, Apr, & May] (Fig. 10), the passive tracker collects intercepts more irradiance because it turns to the sun quickly in the morning and collects the maximum irradiance for 7 to 8 hours unless interrupted by the wind. The fixed tracker collects the maximum irradiance for only about 4 hours. This is reflected in the daily water volumes being much larger for the passive tracking system. Similarly, during the summer [Jun, Jul, & Aug] (Fig. 11), the passive tracker collects more insolation; however, in 1996, these months were extremely wet with the rainfall being equal to our annual amount. This is reflected in the irradiance averaging just above 800 Watts/m^2 instead of the almost 900 Watts/m^2 for the other seasons. The fall season [Sep, Oct, & Nov] (Fig. 12) has an irradiance more like the winter than the spring because of the sun angle. Except for the first part of September, most of the fall occurs after the fall equinox. However, because of the higher irradiance received in the late afternoons, the passive system pumps more water (Fig. 6).

The data from these seasonal comparisons indicate that the tracking system will provide more energy during all months of the year; although the pump may not be able to utilize all of the extra energy collected. Any irradiance collected above 800 Watts/m^2 did not contribute to the volume of water pumped and did not contribute to the usefulness of the system. The difference between the volume of water pumped would allow a rancher to water 2 to 3 more head, which probably would not be significant to most ranchers. The 1800 L/day would provide sufficient water for about 30 head of beef animals and if this was a cow-calf operation, the number of mother cows should be reduced to about 25. We doubt that the extra cost of a passive tracking system is warranted for these types of livestock water pumping systems.

SUMMARY

Two photovoltaic water pumping systems were operated for over a year at Bushland, TX, to determine the performance of the passive tracking system. Two identical 100 W systems with submersible diaphragm pumps were used to lift water from a

simulated 30 m depth. The systems began pumping water when the solar radiation intensity exceeded 200 W/m^2 and reached their maximum flow of 4.0 L/min at an intensity of 900 W/m^2. Daily water volumes pumped averaged 1,864 L/day for the unit with the passive tracker and 1,705 L/day for the unit with a fixed tracker. Irradiance measurements show that the system with the passive tracker often has intensity levels above 800 W/m^2 that do not produce additional amounts of water. Unless a pumping system is used that takes advantage of the extra irradiance, the passive tracker does not benefit the pumping systems.

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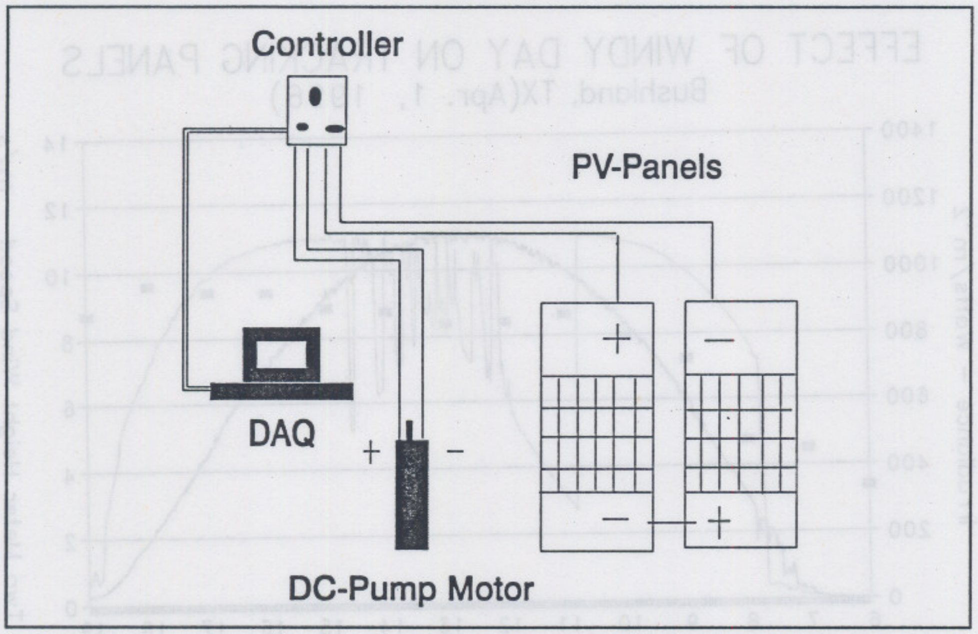

Figure 1 Schematic of photovoltaic water pumping systems as tested at Bushland, TX.

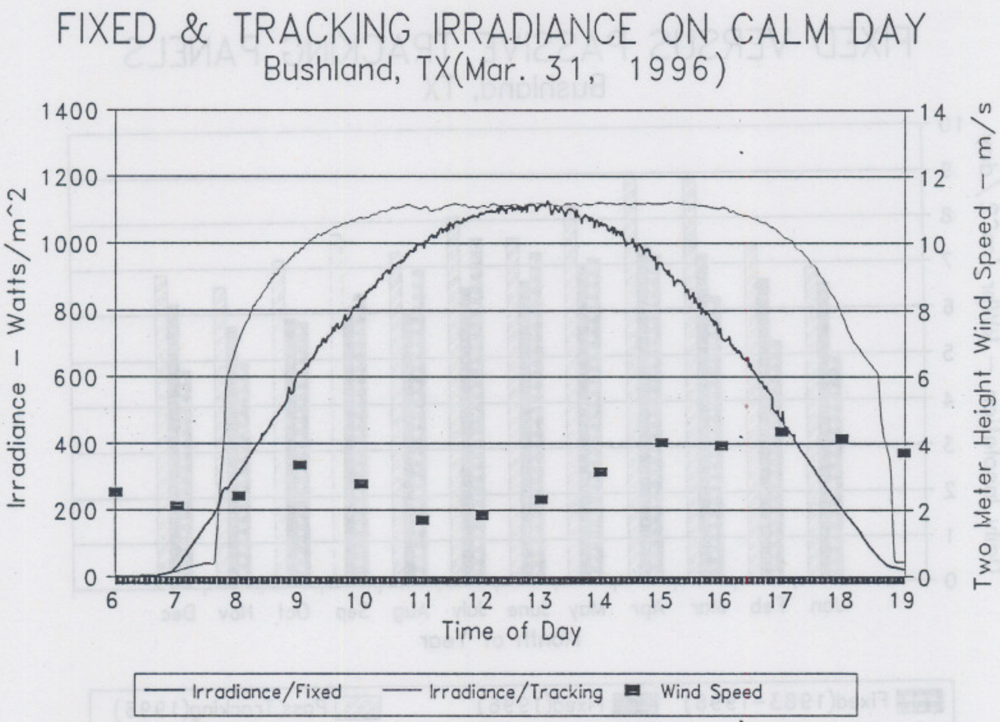

Figure 2 Fixed and tracking irradiance on a calm day (March 3, 1996, Bushland, TX).

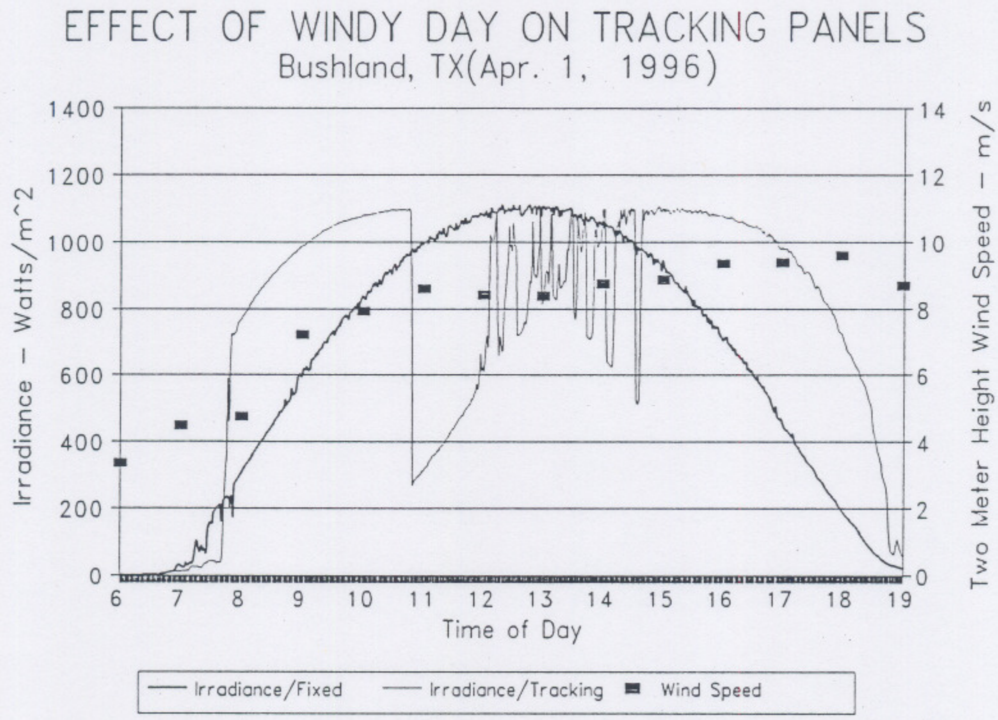

Figure 3 Fixed and tracking irradiance on a windy day (April 1, 1996, Bushland, TX).

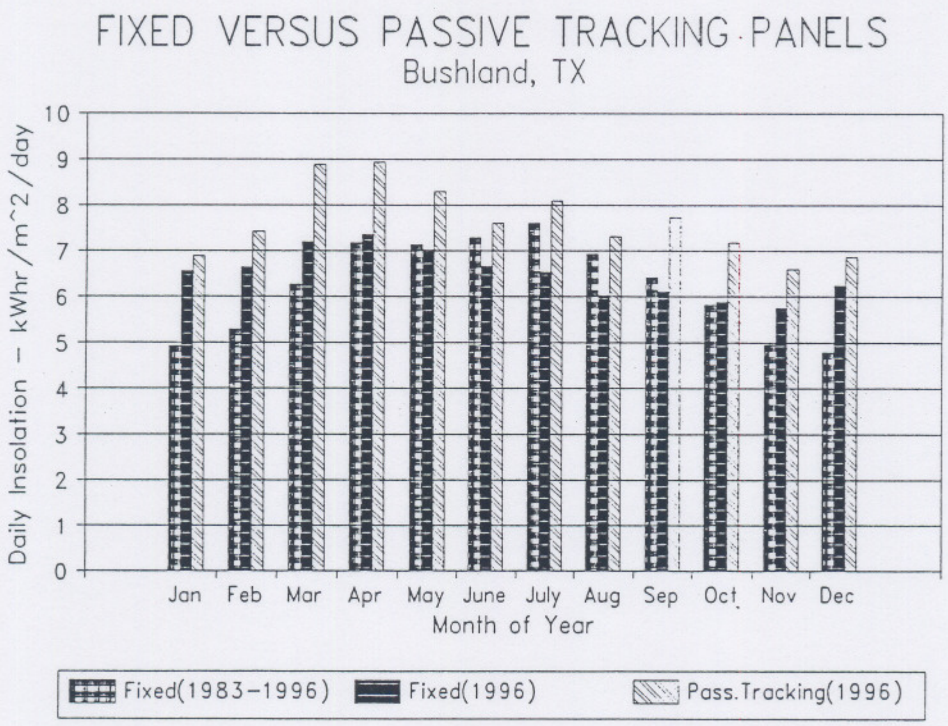

Figure 4 Daily insolation at Bushland, TX.

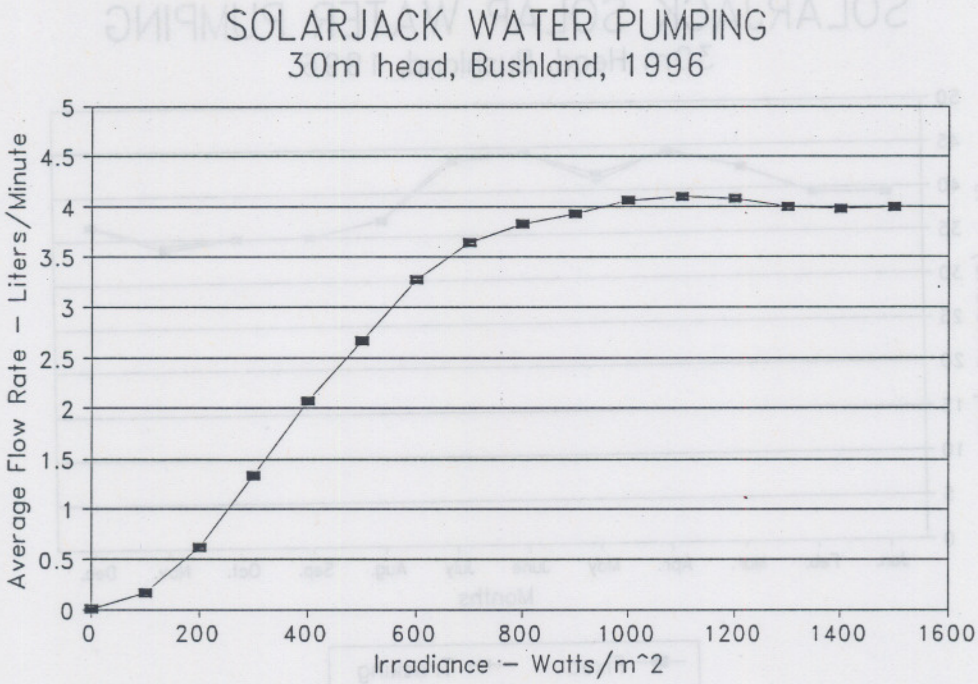

Figure 5 Average flow rates of Solarjack submersible pumps measured at Bushland, TX (1996).

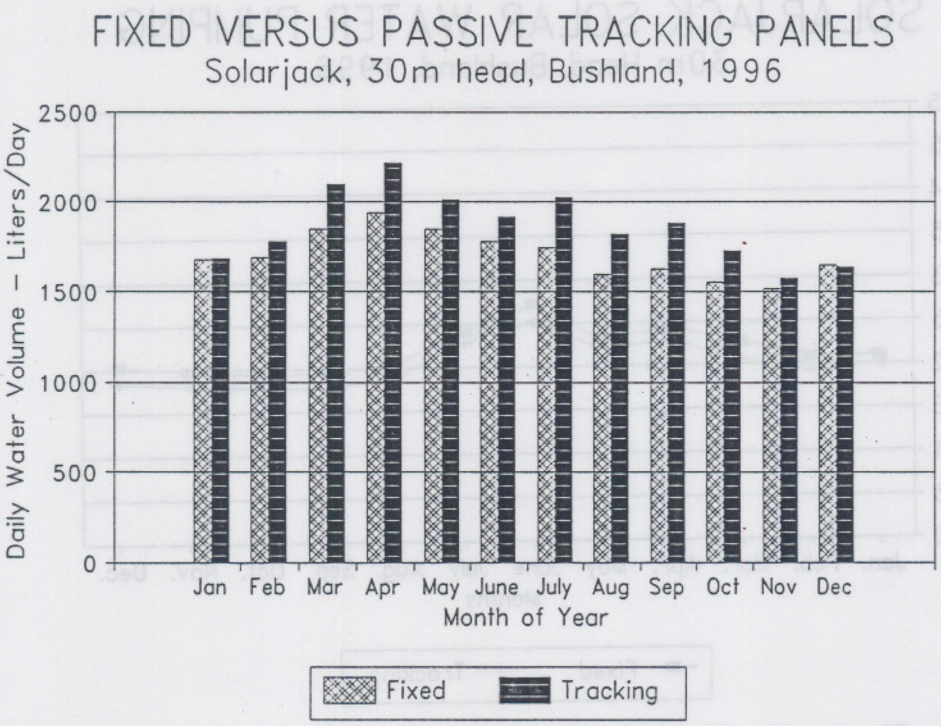

Figure 6 Daily water volume pumped at Bushland, TX (1996) with a Solarjack submersible pump.

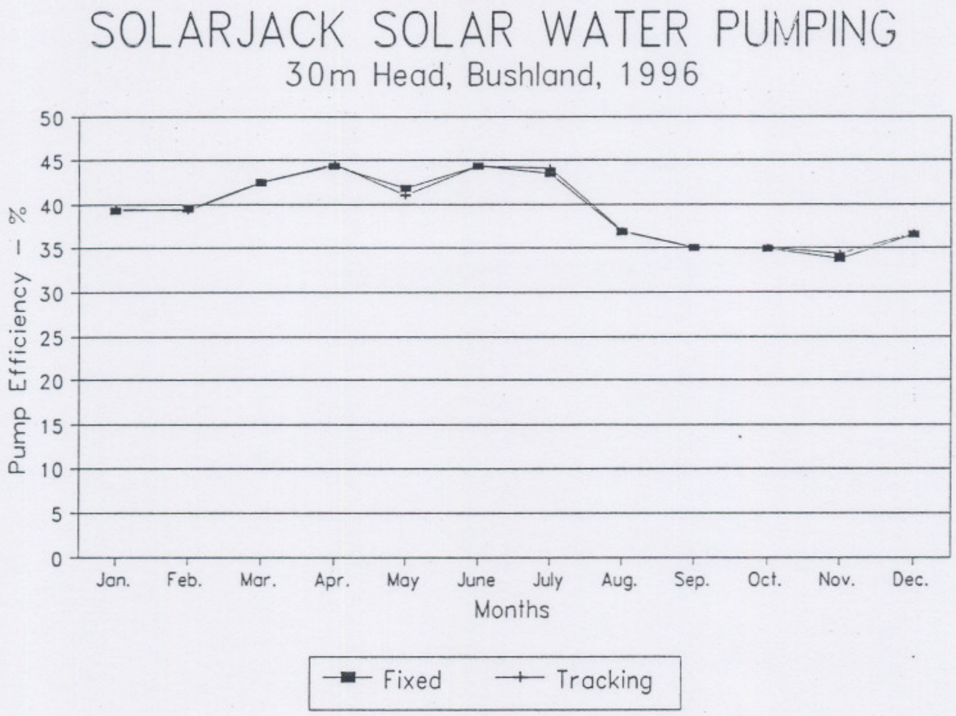

Figure 7 Fixed and tracking Solarjack pump efficiency at Bushland, TX (1996).

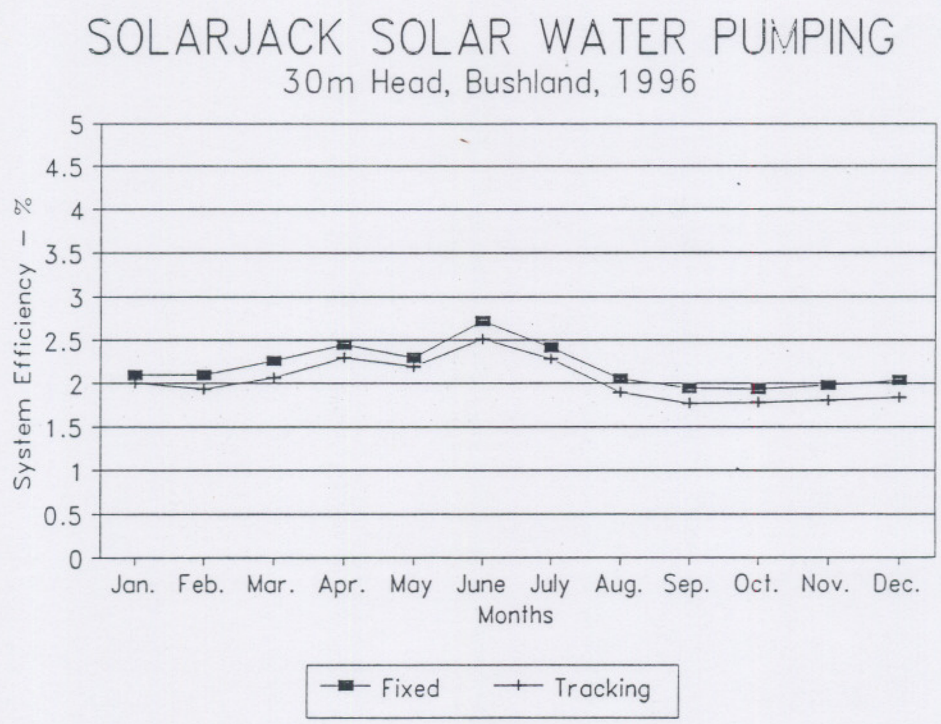

Figure 8 Fixed and tracking Solarjack system efficiency at Bushland, TX.

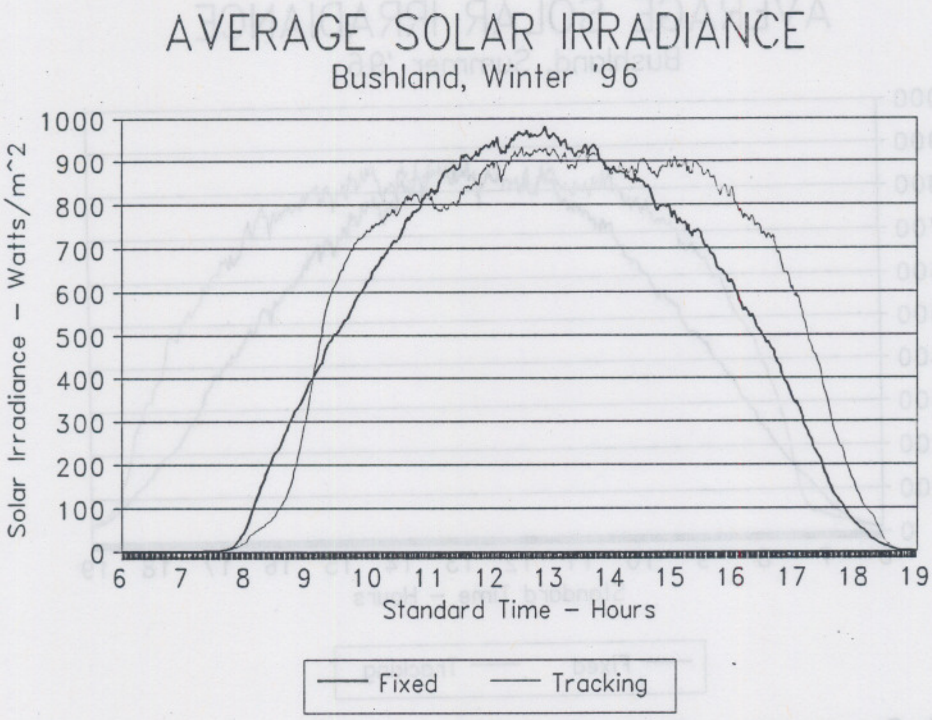

Figure 9 Winter season fixed and tracking solar irradiance at Bushland, TX.

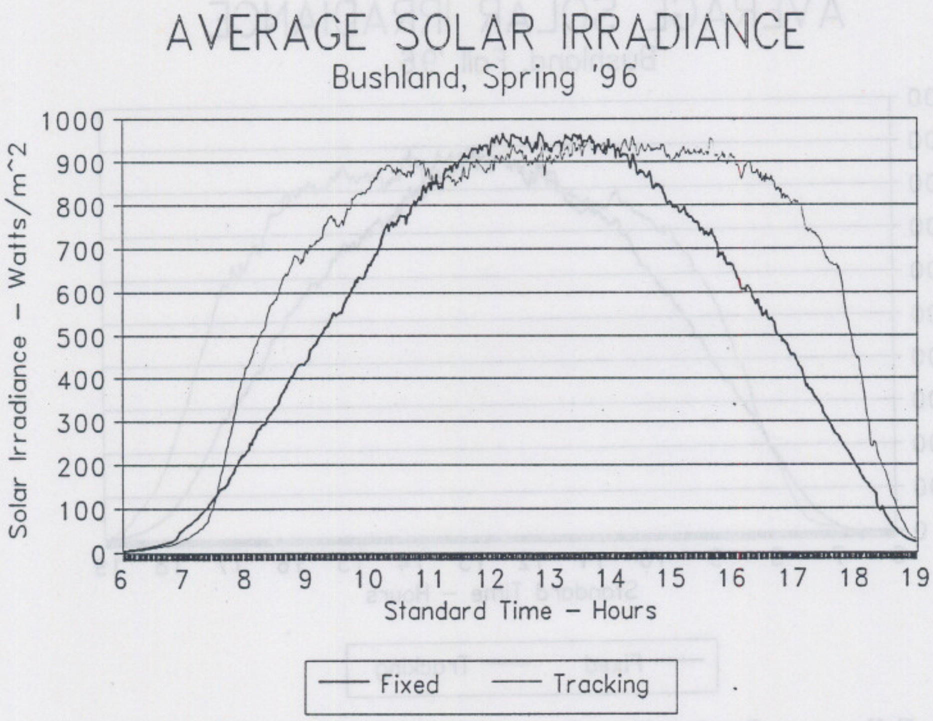

Figure 10 Spring season fixed and tracking solar irradiance at Bushland, TX.

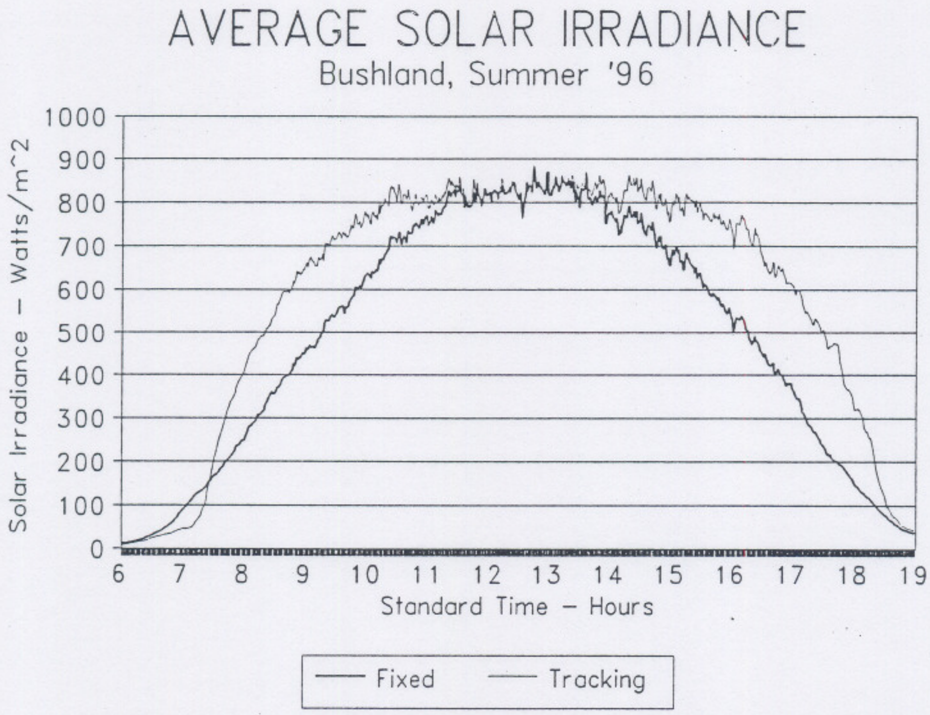

Figure 11 Summer season fixed and tracking solar irradiance at Bushland, TX.

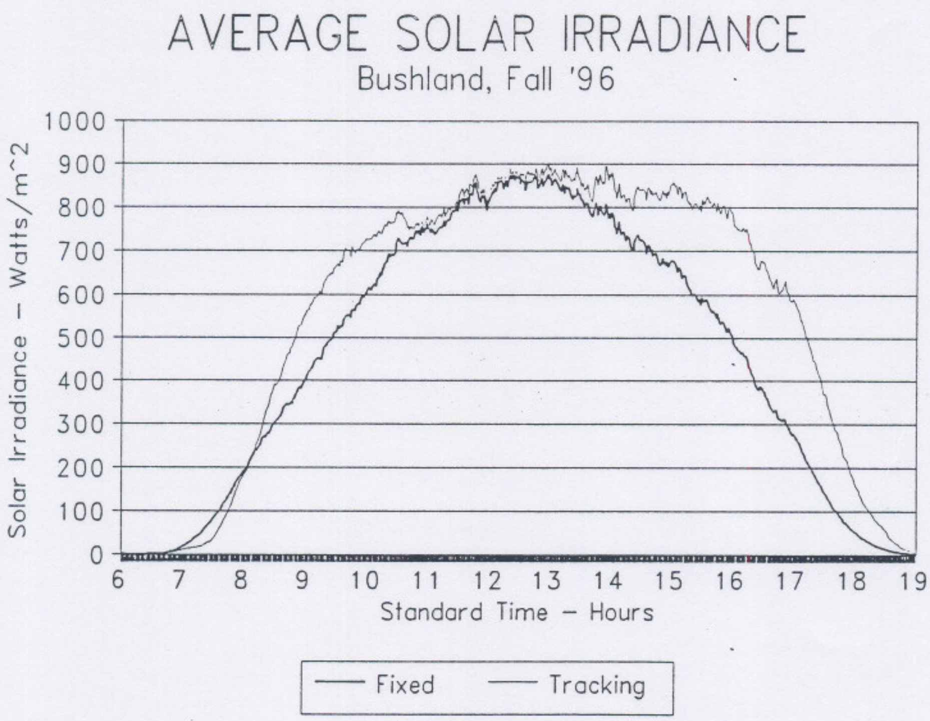

Figure 12 Fall season fixed and tracking solar irradiance at Bushland, TX.