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Modeling of Incident Radiation on a Solar Collector at Different Tilt Angles

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Abstract

A model was developed to predict the amount of solar radiation incident on a solar collector's surface. A Python based model tracked the sun's location and determined how much energy would strike a surface at any orientation. As a demonstration several fixed tilt angles and a tracking case were simulated for Schenectady, NY. Results followed the expected trends. Future goals for the model are to confirm its results numerically with experimental data and use it to determine optimal arrangements for bifacial solar collectors.

Introduction

Solar technology has the potential to provide power without burning fossil fuels, which emits greenhouse gasses leading to climate change. As such it is a growing area of interest. Solar collectors must be placed properly in order to produce their maximum power output. Determining the correct arrangement for new technologies would require much time consuming and expensive experimentation at many locations. Developing a model that can predict optimum outputs would simplify this process.

Methods

The model has two main functionalities, tracking the sun and calculating how much solar radiation strikes a surface. Sun tracking is accomplished by calculating two angles, the solar altitude angle (angle from the ground to a ray pointing towards the sun) and the solar azimuth angle (angle between a projection of the ray from the sun on the horizontal and a line pointing true south). These angles are calculated based on location and time of day and year. Results of the path of the sun across the sky for the model closely match existing published figures [1]. For calculating incident radiation on a collector surface, three components, beam, diffuse, and ground reflected, are calculated based on data from the National Solar Radiation Data Base (NSRDB) [2]. The components take into account the tilt of the collector, while for the beam component the sun's position is also considered.

As a demonstration of the model's capabilities, a simulation of insolation on four different arrangements of solar collector in Schenectady, New York was run for June and December. The four arrangements were fixed south facing collectors at 30^0, 45^0, and 60^0 tilt angles and a two-axis tracking system that keeps the collector always oriented normal to the beam radiation. Results here compared to confirm they qualitatively conform to previous experience. Numerical confirmation has not been performed as no experiments could be run this summer for comparison.

Results and Discussion

Plots of the calculated incident radiation on a collector in June are shown in figures 1-4. Generally the lower the tilt angle the more radiation is received for total and beam components due to beams striking from the sun (which is high in the sky) at a more normal angle. Ground reflected follows an opposite trend as the lower the tilt, the surface is pointed away from the ground. Tracking increases the amount of radiation in the morning and afternoon. Bear in mind that the tracking causes the tilt to be high in the morning and afternoon and low around midday. This causes the decrease in ground reflected for tracking near midday (Fig. 5).

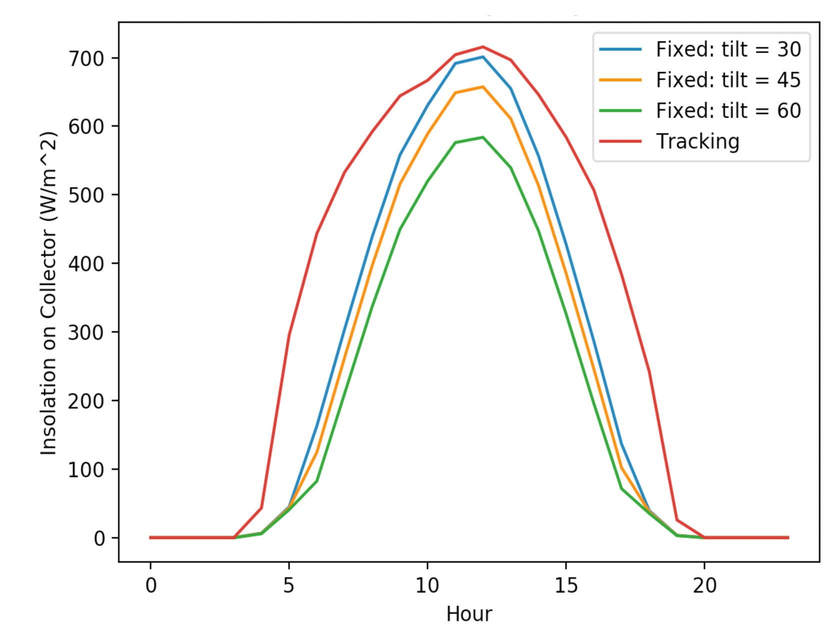

Figure 1 . Total insolation on a collector over a typical day of June in Schenectady.

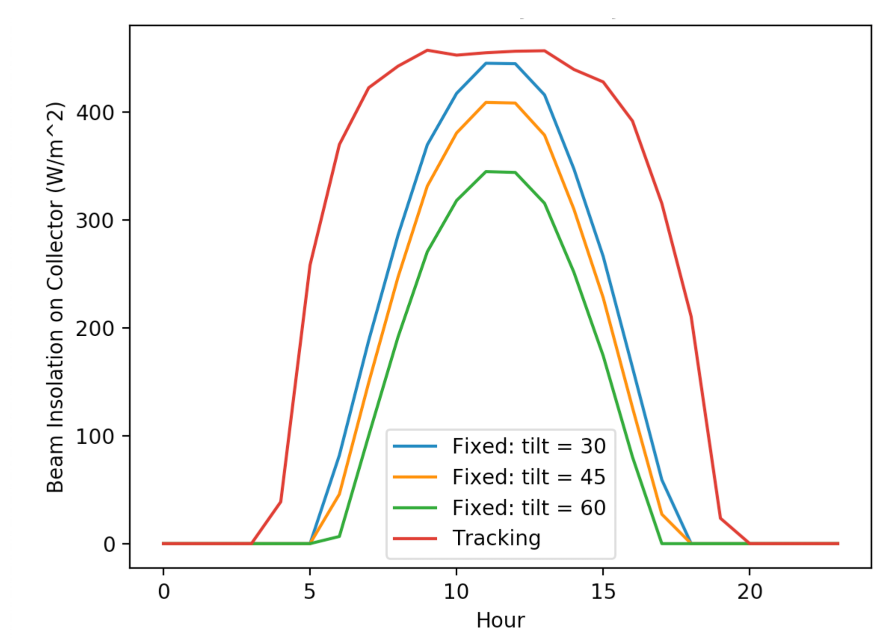

Figure 2. Beam insolation on a collector over a typical day of June in Schenectady.

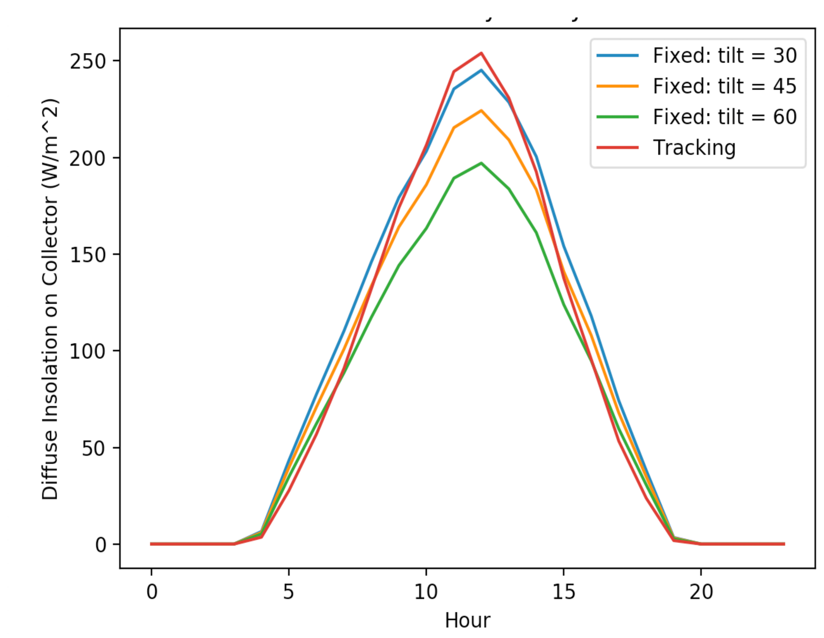

Figure 3. Diffuse insolation on a collector over a typical day of June in Schenectady.

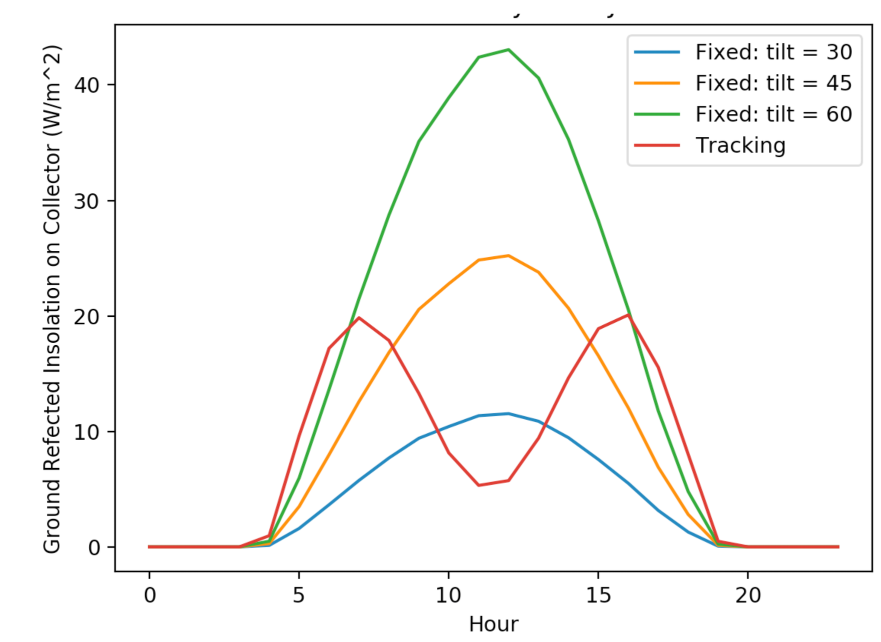

Figure 4. Ground reflected insolation on a collector over a typical day of June in Schenectady.

Figure 5 compares the total daily insolation in June to that in December. In December with the sun being lower to the horizon, the higher tilt angle gets more radiation striking them it. Days are also shorter and have less radiation in general. The misalignment of the daily peaks between June and December originates in the NSRDB data.

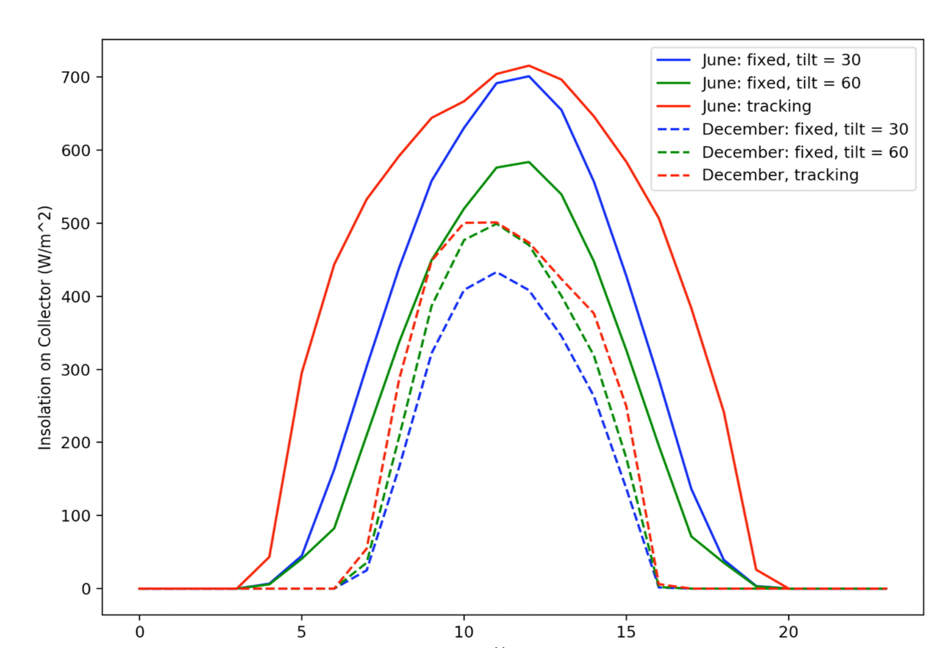

Figure 5. Comparison of total insolation on a collector over a typical day in June and December for Schenectady.

Future Work

Ultimately this model is to be used for studies of bifacial solar collectors, which can collect light on both sides. These have the potential to increase the amount of energy that can be generated in the same geographic footprint if used right. How best to arrange bifacial collectors to get maximum power output has not been determined. The goal is to use to the model to predict optimum tilt angle of bifacial panels. This will be confirmed with experimental results.

Acknowledgments

- Professor Richard D. Wilk

References

[1] Duffie, J.A. and Beckman, W.A. *Solar Engineering of Thermal Processes* , 4th. edition, Wiley, Hoboken, NJ (2013).

[2] nsrdb.nrel.gov