Predictive Model of a Pool Solar Water Heater

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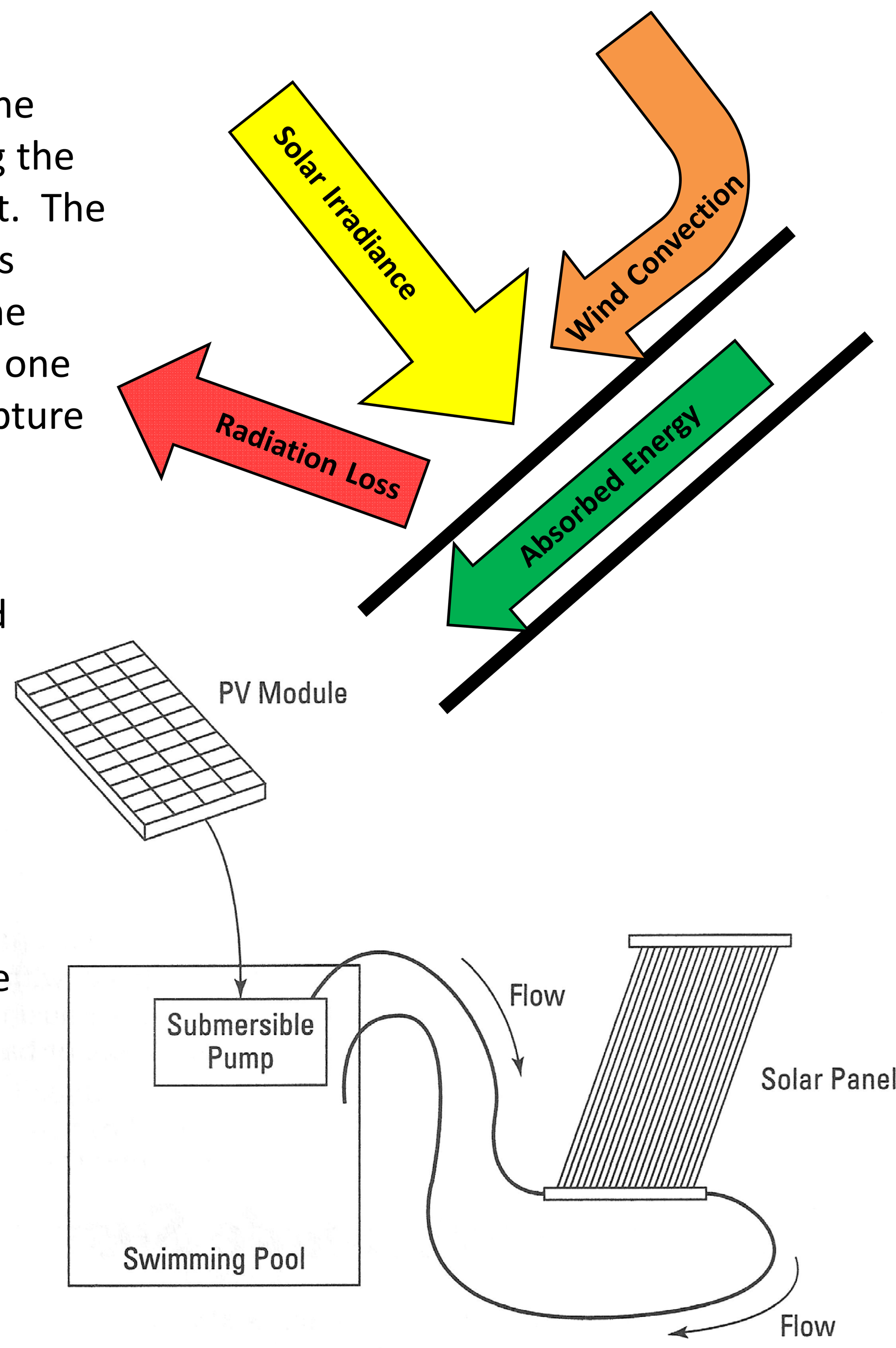
Background

Many outdoor pools are already "Solar Heated". The pool sits in the sun with the water absorbing the sun's energy during the day, and losing the heat during the night. The amount of energy gained from the sun is dependent on the top surface area of the pool. By incorporating a solar collector, one can extend the size of their pool and capture more energy.

However, the sun is not the only factor in this system. The air temperature and wind level can add energy to the system during warm days or can remove energy during cool days. The collector acts as a black body object and will radiate away a portion of the energy . The portion of energy absorbed by the collector must then be conducted through the pipe walls to the water inside. The system can be summarized as:

$$q_{sun} = q_{air} + q_{rad} + q_{ground} + q_{h20}$$



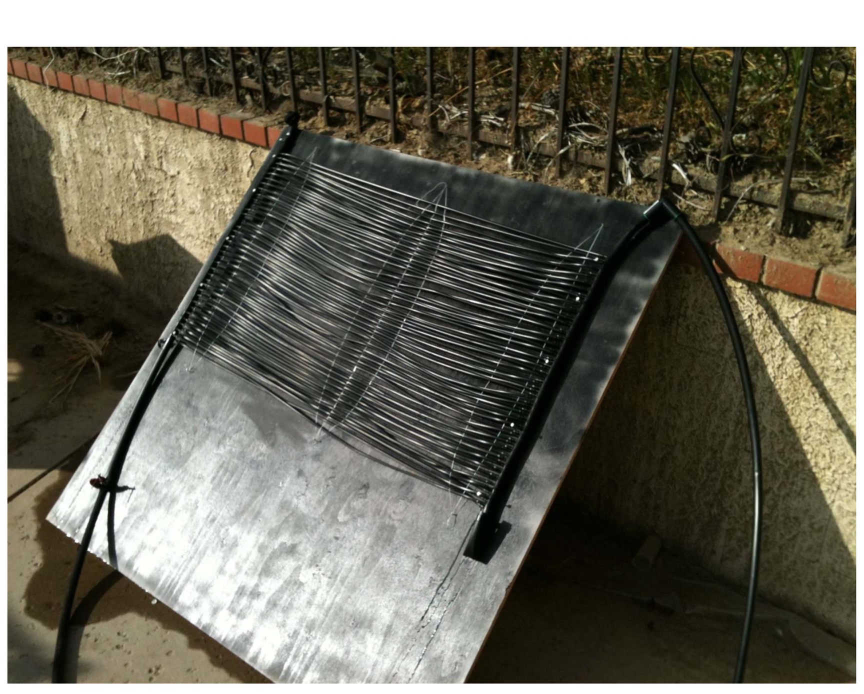
Objective

The objective of this project was to model the solar collector system in Microsoft Excel taking into account all the energy gains and losses within the system. The Excel model was to be designed to be useful to a do-it-yourself homeowner in order to determine the proper solar collector size needed for their pool using easy to construct, off the shelf components. The creation of the model would use theoretical relationships drawn from fluid dynamic, thermal dynamic, and heat transfer studies, and assumptions were to be used as needed. Testing with a small scale collector would be performed and the results compared to determine the accuracy of the model.

Building

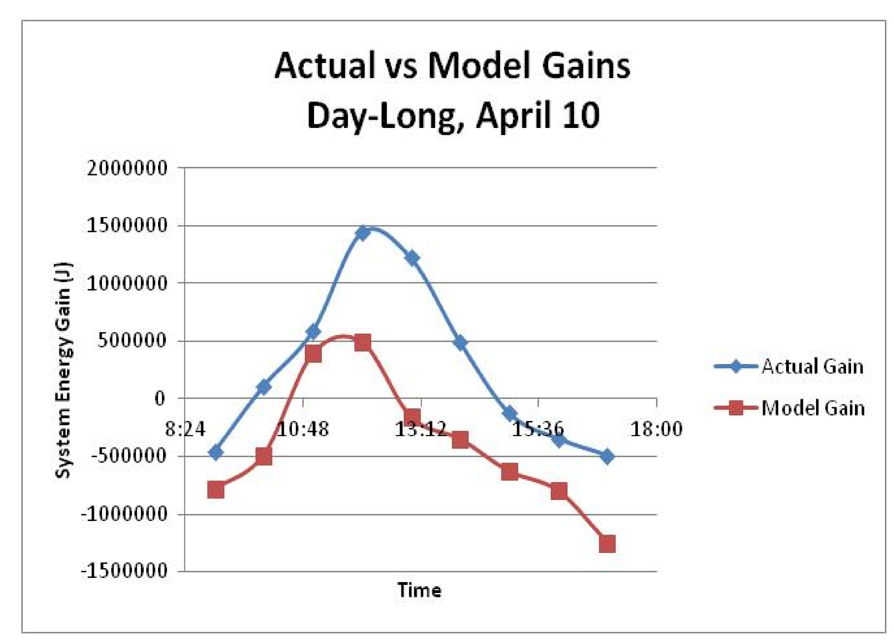
The predictive Excel model was compiled using mathematical relationships to track the flow of energy in and out of the system. This can be thought of as "Energy Accounting". The effects of air temperature, wind speed, radiation loss, and ground loss (assumed to be negligible) were subtracted from the solar irradiance input to determine the amount of energy entering the system. Due to the interdependence of pipe surface temperature, air temperature, and heat transfer, some VBA programming was used to provide iterative results.

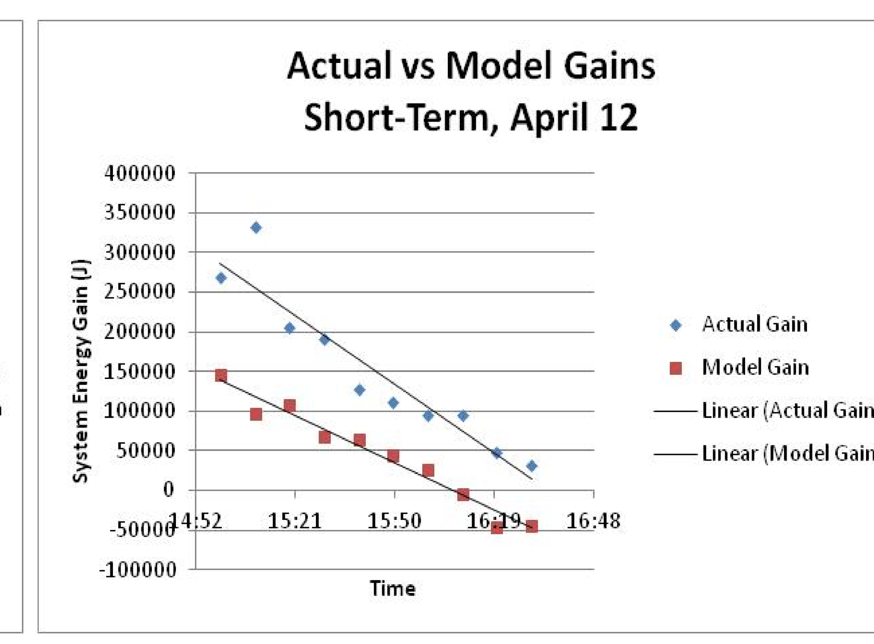
The prototype collector was built using polyethylene plastic drip-irrigation tubing and connectors. The collector was 3.5 ft wide by 2 ft high and mounted on a black board to maximize solar energy absorption. It was set at a 45˚ angle facing south-west to maximize sun exposure. The system pumped water from either the pool or a 10 gallon insulated cooler.



Testing and Results

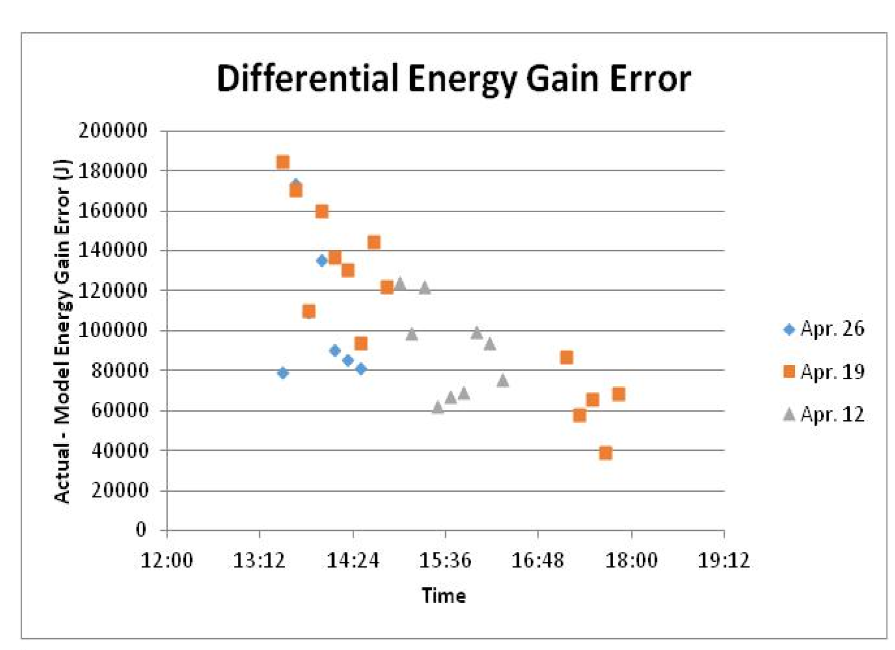
Both Open-Loop and Closed-Loop testing was performed. Open-Loop testing sourced water from the pool, thus keeping the inlet water temperature near constant. However, this set-up resulted in temperature gains smaller than the accuracy of the sensors and resulted in un-reliable data. Closed-Loop testing used a insulated cooler for holding water, thus reducing outside influences and generating larger temperature gains for measuring. While this was less representative of normal use conditions, it provided a better analysis of the energy gains and losses. Both Day-Long (9 hour) and Short-Term (1.5 hour) tests were performed and a n example of each test's actual and predicted energy gain is shown below. The difference between the two was much larger than expected, but the data did follow similar trends.

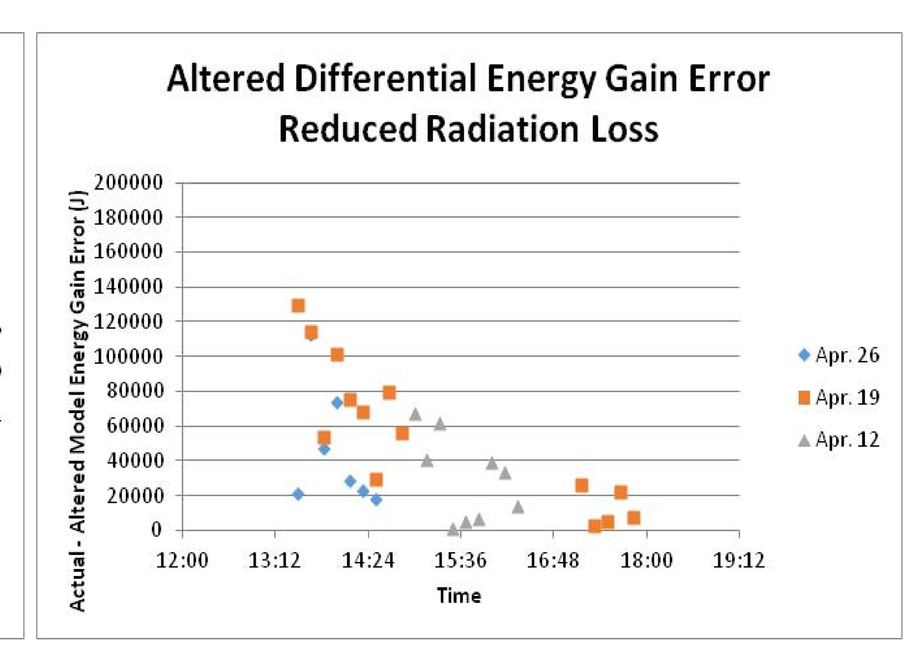


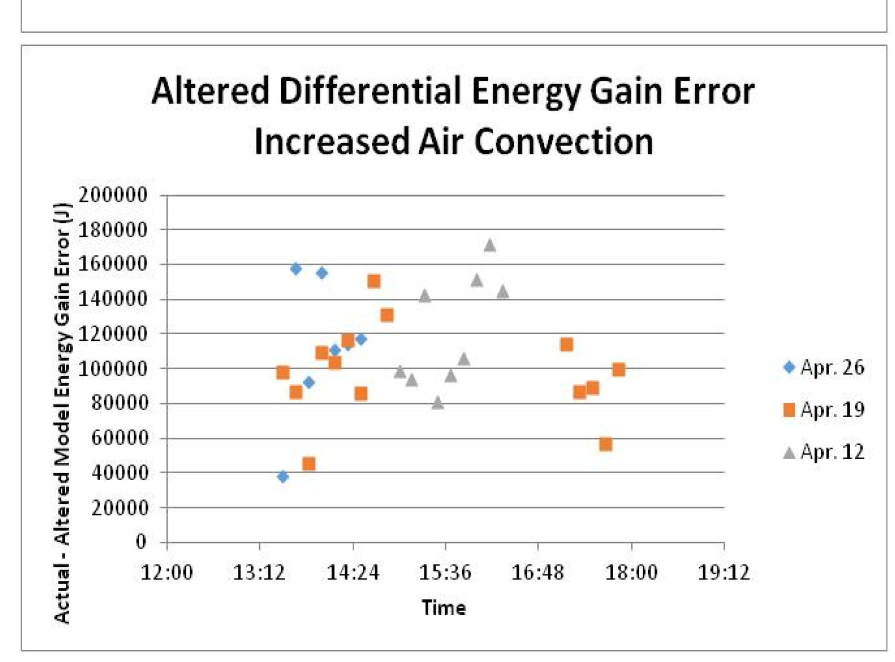


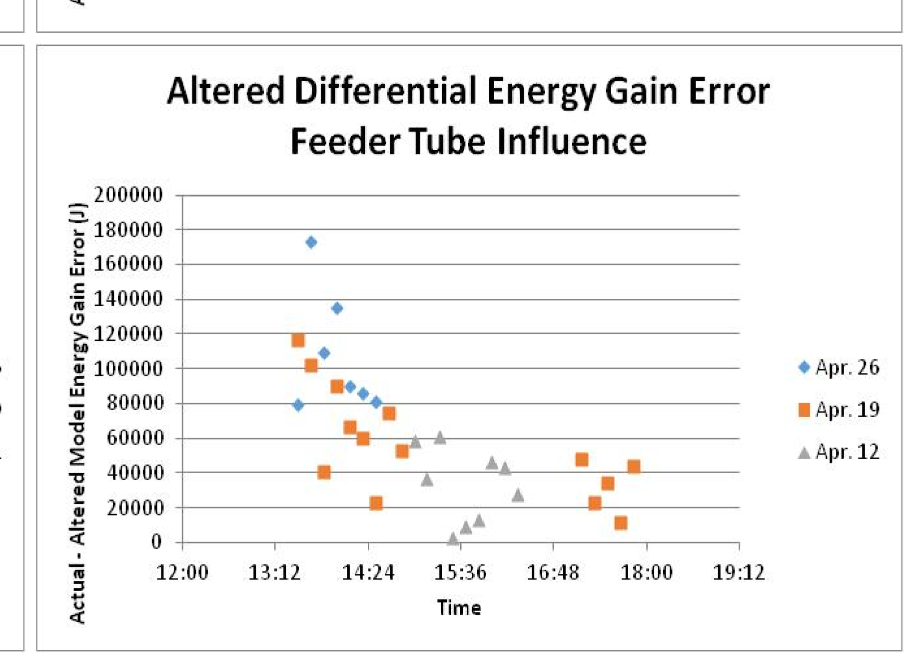
Due to the nature of the data, the difference between the actual and model predicted energy gain was a better basis of analysis than percent error. Three Short-Term tests were performed and the differential energy gain error is shown in the top left plot below. The errors are scattered and decrease with time of day.

The most likely sources for this error were an overestimation of radiation loss, an underestimation of the influence of air convection, and the lack of isolation of the collector from the feeder tubes. The influence of each of these sources was tested by altering the model and observing the change in the differential energy gain error, shown in the graphs below.









Conclusion

The largest contributors to the error were the assumptions around radiation loss, air convection, and influence of the feeder tubes. Additional sources of error could include heat generated by the submersible pump or by friction of the water passing through the system. Further testing is required to improve the accuracy of the model and testing set-up and correct for previous assumptions. It was also determined that while the drip irrigation tubing worked for a small scale solar collector, leaking issues related to the water pressure would limit the size of a functional collector.