Optimizing Solar Thermal Water Heaters for Low-Income Applications

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Executive Summary

With today’s growing energy crisis, it is more important than ever to develop sustainable, commercialized energy sources. Solar energy is a reasonable answer to many of the energy-consumption problems. It is a renewable source of energy that can be harvested and used for many basic functions. One such area of application is water heating. The average American uses 20-30 gallons of hot water a day. This intensive use reflects noticeably in utilities, reaching about 18% for a typical bill. Since most hot water goes toward everyday activities, such as showers, laundry, and cooking this money draining necessity seems unavoidable. Solar water heating, however, offers a cure for the malady. Systems that rely on solar radiation instead of natural gas or electricity significantly reduce hot water from utility costs; although, upfront expenses are still quite high. A typical solar hot water system takes 4-5 years to pay for itself through savings, making it an unreasonable option for many Americans.

The goal of our research is to make solar hot water a more practical option for domestic use. We aim to make existing technology more commercially available by reducing the cost of a small-scale solar system that can provide basic household hot water. Optics provided the most cost effective method for attaining this mark. A cheap Fresnel lens positioned above the solar collector will increase the area of usable sunlight by directing and focusing more radiation onto a collection surface. The resulting increase in solar irradiance will improve efficiency and let the system heat water more quickly. This effect allows a smaller collector with an integrated optical component to match the production of a larger collector. Since the collector is one of the most expensive elements of a solar water heating system, reducing its size puts a dent in the purchasing price and increases affordability.

Our team took several important steps towards accomplishing the long term project goals. The first portion of the semester was spent researching the key components required to build a solar hot water system, as well as various design options. After much investigation and guidance,
the team selected an active, indirect set-up with DC circulating pumps, an external plate heat exchanger, and an evacuated tube collector. The active, indirect arrangement mimics a popular design choice for many domestic systems, which allows our tests to more accurately reflect typical system output. DC pumps were chosen in an effort to potentially make the entire set-up solar powered. Since photovoltaic cells generate direct current, our pumps could be powered by a small array without involving an inverter. An external heat exchanger was opted for so that preexisting conventional water heaters can be easily outfitted with a solar system. In our case, an available electric water heater in the lab could be used as the system’s storage tank and secondary back-up heat supply. The most important decision was to use an evacuated tube collector. This collector is the most efficient product available to consumers. Its capability to produce adequate quantities of hot water during cloudy days extends our tests for measuring efficiency into low irradiance conditions.

The second half of the semester involved characterizing the storage tank and heat exchanger, while the system was under construction. Since the collector was not available until later in the semester, the electric heater inside the tank was used as an energy source. Temperature readings were taken by various thermocouples outfitted at various locations including, inside the tank and at the input and output of the heat exchanger. The devices were wired back to data acquisition hardware built by National Instruments, and the team wrote a program using NI LabVIEW to extract and export readings to a Microsoft Excel document. The data was then manipulated using principles from thermodynamics and physics, in order to produce accurate mathematical representations of component behavior. These equations were graphed to ease interpretation and in some cases assist in further manipulation.

Our results showed that if water was heated the recommended domestic hot water maximum (46 °C), then the system could remain inactive for 22 hours before reaching the recommended minimum temperature (35 °C). This means that a solar system is can withstand the duration of a night and retain the ability to supply hot water for morning usage. Tests run on the heat exchanger revealed that at large input temperature differences (large ΔT), the heat exchanger transferred the highest percentage of energy from one loop to the other. As the hot and cold loops approached the same temperature, energy loss grew exponentially. In order minimize this negative side effect, pumps can be shut off at low ΔT’s and turned back on at high ΔT’s.