Impact of Surface Ratio to Water Volume in a Passive Solar Hot Water System

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Environmental Science 102

Fall 2007

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Introduction

Challenge:

Work in groups to develop functioning solar water heating systems. Research, design, assemble, operate, and monitor the systems. Develop tests of the efficacy and efficiency on the system, and then run these tests on the systems. Evaluate the system, in both qualitative and quantitative terms, regarding its ability to supply a useful amount of hot water. Develop a hypothesis of how much hot water the system will be able to make, and then test this hypothesis to see if any improvements are necessary. Compile a Report describing the project and the results obtained.

Since functioning systems became operational last semester the primary objective now, is the continuation and extension of the work conducted by the students from last semester.

The Scientific Method:

1. Observe the situation or problem.
2. Formulate a Hypothesis that is testable and consistent to the observed situation.
3. Test the Hypothesis.
4. Gather Data from tests and analyze if the data disproves the Hypothesis.
5. Modify the Hypothesis and repeat 3 and 4 until a Hypothesis without discrepancies is reached.

Objective/goal:

Optimize the ratio of water volume to panel size so that the most amount of energy is transferred from sun to water with the least amount of energy waste.

Hypothesis:

In addition to the minimum amount of water required to cycle through the system, and testing the range of a 4.5-2.0 liters we predict that the system will lose efficiency (i.e.
drop below the optimum average of 110°-100°F) at higher water volumes as opposed to lower volumes. We can therefore be in a position to identify the most conducive amount of water per square footage of panel to maintain the target, optimum temperature range of 100-110°F. The amount of panel to be tested in this system will be 2 square feet (288 square inches—remaining constant) at a starting point of 4.5 liters (variable) which will then experience 5 total treatments (beginning at 4.5 liters minus an incremental decrease in water for the following 4 experimental units). We predict that the optimum ratio will be one square foot of panel per one liter of water, or (1 liter: 30.48^2 centimeter).

**Essential Terminology:**

**Passive Solar Hot Water System:** This type of heater requires no mechanical parts. The process that heats and cools the water is entirely based on the building of the system, and the heat from the sun.

**Active Solar Hot Water System:** This is the kind that is in most commercial units today, with a mechanical pump that pumps the water from the tank to the collector.

**Thermosyphon:** This is what causes a passive solar system to work. It is the process of how the hot water from the collector will travel to the tank and the cold water from the tank will go back into the collector to be reheated, “recycling” the water. Heat rises so the tank will have to be elevated from the collector. The collector will have the water in it that it is heating, the hot water will flow through the collector and come out the top and go up into the tank. The hot water will come into the top of the tank. As the water cools the cooler water will sink to the bottom and go out of the tank back down into the bottom of the collector to be reheated. Thermosyphon is based on the scientific principles of convection and conduction.
Research:

The breadth of our research related to construction details of the passive solar hot water system, the materials required to build such a system, background information including the science of how one of these systems work, and insights into possible innovations we could provide to supplement the dynamic field of solar hot water heater design.

1) For details pertaining to construction of a passive solar hot water system we used the Natural Resources of Canada website (citation included in bibliography). This very reliable, informative Canadian government website is designed for providing instructions for basic solar hot water heater construction. This site provides an overview of various solar hot water systems, benefits from solar hot water heating, and categories of solar hot water systems. The site contains very useful information concerning optimum position suggesting that for “best performance, install collectors between 18°-50° from the horizontal plate.” Furthermore, “solar collectors should be installed on a southeast to southwest orientation for maximum performance.” There has been no site I have looked at to this point, which provides such definitive and clear answers on the subject of panel orientation.

2) In regards to details in material lists we referenced the Chanconas and Jacobs lab report from the fall 2006 semester (citation included in bibliography). In the report we found materials lists, construction instructions, measurements (of tubing, collector, tank) and overall progress of their experiment. Highlights include the use of a flat foam insulator on the inside of the collector box and on the outside of the tank. Also, it is suggests using sheet aluminum (as the collector plate) and plastic tubes painted with flat-black paint. Our group regarded this report as reputable since according to their graphs, the team achieved desirable results maintaining a constant temperature of 102°F.

3) Ideas into possible innovations (and eventually the variable we decided to test) lend inspiration to Ken Olson from the Arizona Solar Center (citation included in bibliography). Ken Olson, the author, conveys a detailed summary of the most popular and successful systems while supplementing his overview with quantitative information with the purpose of giving instructions on how to get started and how to avoid common errors. For example, in the Atlantic states, Olson suggests to use 1 square foot of collector per 1.0 gallons of tank capacity. Olson goes into detail concerning flat-plate collectors recommending using them for low(er) temperature applications (below 140°F; 60°C). He concludes with advice on (temperature) stratification of the tank. The reliability of this information is fairly certain although it is a “.com” since their references include non-profit and credible government sponsored organizations. In addition, this information is quite pertinent and useful to the cause since its contents only include novice, fact-based instructions.
Results:

Materials and Process:

Our group based our bench model design off of the passive solar hot water heater from the previous group—Chanconas and Jacobs—who were successful with their initial design.

The basic process and components of the system are as follows:

Collector: First we built our collector; the idea behind building a collector was to get the inside of it as hot as possible. This was how we were going to trap the heat/energy from the sun, and heat the water.

We had to set up the inside of our collector so we could transfer the water. We used plastic tubing to create the pathway for our water to travel through, and we had to make it so the water was inside our collector long enough so it could have enough time to be properly heated up.

We couldn’t just have the tubing from the bottom of the collector reach to the top of the collector in a straight line because there wouldn’t be enough time for the water that was inside to heat up properly, so we laid out our tubing like this:

![Tubing Diagram]

The water that is coming into the collector is cold water and it will then take some time (notice the black spots that are forcing the water to continue in the correct path) to pass through the system, enabling it to heat up to the hottest possible temperature it can before exiting the collector.

Tubing: We used $\frac{1}{2}$ inch clear, plastic tubing in our entire system. The tubing was used inside the collector and to attach both ends of the collector to the tank.

Tank: The criteria we need for our tank was, namely that is should be big enough to hold the amount of water that we were going to be putting into it. It had to have flat sides so we could firmly put our connections without having to worry about any leaks.

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1 The unforeseen impact of this aspect will be elaborated upon in the “discussion” section of this report.
**Insulation:** We used foam insulation for the entire product. When we finished building and attaching our tank we wrapped it in insulation foam. We used insulation tubes to cover our plastic tubing, and we lined the inside of our collector with more insulation foam. The foam was an added defense against heat loss.

The tank we used was a cat litter container; we used plastic tube connectors to attach the tubes to our system:

The one on the left is what we used to attach the tubes to our tank and the one on the right is what we used to connect our tubes inside the collector.

Our final tank with the connections looked like this:
The tank with the foam insulation:

The final product with the collector:
Table of Raw Data with weekly Analysis:

<table>
<thead>
<tr>
<th>Dates</th>
<th>Laboratory observations, Predictions &amp; Progress</th>
<th>Water Volume (Liters)</th>
<th>Modifications Improvements and plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/02-10/09</td>
<td>Began Construction of collector. Assembled tubes and measured the desired distance between the tanks and collector. We then drilled numerous ½” holes, Insulated the box, secured plexi glass and overall finished the collector. Attached fittings to tank #1. Installed last fixtures to tank and hooked up system added water for test run.</td>
<td>*n/a</td>
<td>Obtain a square tank since a round tank will inevitable leak because it will not foster gaskets on the curvature surface.</td>
</tr>
<tr>
<td>10/09-10/16</td>
<td>Installed LoggerPro probes on the tank, the collector and the base control tank: Also discovered leakage from tank. Which we decided to monitor.</td>
<td>0</td>
<td>This week: Finished insulating tank and collector as shown(left) Monitor leak to see how significant above observation was. Consider the square tank idea more seriously by this point.</td>
</tr>
<tr>
<td>10/16-10/23</td>
<td>On 10/16, our group discovered that the Tank had leaked the entire water volume causing invalid data around hour number 116. As a result, we changed the circular leaking tank to a square tank and installed rubber gaskets. We placed rocks into tank to stabilized and compensate for water.</td>
<td>4.5</td>
<td>Placed rocks into tank to stabilized and compensate for water.</td>
</tr>
</tbody>
</table>
intend to disqualify previous weeks data due to water loss and interruption of collection. However we predict that these improvements will counter the leak so we will retest the previous weeks volume. Please note* since we will be decreasing water over the coming weeks below levels needed to run the system (minimum water in the tubes estimated at 1 ½ liters) we intend to compensate for low water levels by adding rocks into the tank. One last thing to note: we account for the unexplained dip in all three temperatures around hour 24 as a data error caused by LoggerPro. The results of this week with the fixed problem are as follows:

<table>
<thead>
<tr>
<th>Time (Hours)</th>
<th>Temp C</th>
<th>Tank °C</th>
<th>Collector °C</th>
<th>Base Tank °C</th>
</tr>
</thead>
</table>

4.5 Liters October 16-23
Another sunny week. The peak temperature from previous week was 37° C and although close to desired range, we still decided to make modifications (shown right). On 10/23, the beginning of this week’s data, Labpro displayed: experimental tank at 28.9° C, the collector at 35.9° C, and the control tank at 23.8° C. The results of this week are illustrated in the graph below:

Removed an additional 1 liter of water, Professor Floyd informed us the possibility that the rock may be effecting the heat transfer in tank. From our discussion, we conclude that air is the best insulator and will need to figure out a way to still take up water volume but with air instead of dense mater like rocks. Our modification is presented in the next column and our graph is presented below:

Final addition of insulation. Moved the collector more flat 14’ off table at far end and 9’ closer to the wall. We expect an improvements.

We use a bucket that is hollow and weighted down at the top rim by rocks.
Decreased water depletion increment by .5 liter since even with volume compensator in place, the water level would drop below the hot water flow valve. Therefore we removed the ½ liter and proceeded as planned. It appears from the extended 7-day forecast that we were going to get a cloudy (problematic) week of weather which was confirmed when we retrieved the graph on 11/13. The results are shown below with a noticeable decrease in energy input (we will discuss the implications and impact this week's weather had in relation to our hypothesis and data trend in the “discussion” section of this report).

<table>
<thead>
<tr>
<th>Date Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/6-11/13</td>
<td>Decreased water depletion increment by .5 liter since even with volume compensator in place, the water level would drop below the hot water flow valve. Therefore we removed the ½ liter and proceeded as planned. It appears from the extended 7-day forecast that we were going to get a cloudy (problematic) week of weather which was confirmed when we retrieved the graph on 11/13. The results are shown below with a noticeable decrease in energy input (we will discuss the implications and impact this week's weather had in relation to our hypothesis and data trend in the “discussion” section of this report).</td>
</tr>
<tr>
<td>2.0</td>
<td>Took at 1/3 liter. Left bucket in tank.</td>
</tr>
</tbody>
</table>
11/13-20  Tank cracked in half. Consulted Professor Floyd who agreed with us that we had enough data to show a trend so therefore we ended the experiment one trial early. No graph.

*na  Ended the experiment early due to technical difficulties.
Further Analysis:

<table>
<thead>
<tr>
<th>Strong points of design/implementation</th>
<th>Weak Points of design/implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The size of the panel was sufficient</td>
<td>• The diameter of the tube (1/2 inch)</td>
</tr>
<tr>
<td>• The square tank we used-no leaks</td>
<td>• The placement of the top fitting</td>
</tr>
<tr>
<td>• The copper fittings-no leaks</td>
<td>• Tubes inside collector should be</td>
</tr>
<tr>
<td>• The aluminum for panel</td>
<td>copper instead of plastic</td>
</tr>
<tr>
<td>• The plexi glass instead of glass for</td>
<td>• Stronger tank to avoid breakage</td>
</tr>
<tr>
<td>safety</td>
<td>• Cost of materials</td>
</tr>
<tr>
<td>• The elevation of tank</td>
<td>• Laptop power failures resulting in</td>
</tr>
<tr>
<td>• The direction of panel</td>
<td>LoggerPro data loss.</td>
</tr>
</tbody>
</table>

Important Aspects:

Initially, when we began the construction of our system we were pretty well versed in the proper materials and design we were going to follow. Although alterations were made like deciding to reverse our hypothesis and use a square tank, our intention and goal was always addressed. Our hypothesis, for example, changed mid-semester from adding water to taking water away to ease the construction process, but ultimate goal was little affected: test ratio of panel area to water volume.

Indeed, as with our objectives, the material list consisted mostly of what we intended to buy outright although we had to accept some minor differences. For example, the tank we used was a cat litter container and we suggest using a more durable plastic pail or bucket. Furthermore, we strongly encourage using ¼ inch hose instead of what we used, ½ inch hose because the tubing diameter difference actually means that there will be 2 times as much surface area to heat. This of course, accounts for a far more efficient model and thus, hotter water, perhaps by almost twice as much.

Despite some minor snafus we experienced with the tank and the tubing, the experiment did in fact, show a trend and so by definition was successful. We held the reliability, reproducibility, and validity most important above all through out the experiment—this of course, proved most wise indeed. We will discuss the validity of our hypothesis in detail in the next section, discussion.


**Discussion**

**Hypothesis proven? A critical approach:**

This of course is the real essence of any scientific endeavor which all data, experiments and subsequent conclusions are dependent upon. As a reminder, a condensed version of our hypothesis is provided here for clarity:

Test various volumes of water in order to determine the optimum ratio of panel to water volume as illustrated by temperature. This optimum is believed to be the least amount of water since simply put, there is less to heat.

To support our conclusion, our group complied a summary graph of the greatest temperature differences between the coldest and hottest temperature of each week. We utilized this method because it would more accurately measure pure energy input as opposed to other factors out of our control. The graph is as follows:

As can be seen above, our hypothesis was supported to a certain extent by clearly showing a trend of lesser amounts of water facilitating greater temperature differences and/or energy.
However, the data from the 2.0 liters (our final week) clearly stands alone from this apparent trend but we account for this by the severe weather of the week of November 6-13, 2007—thunderstorms and clouds—with only one truly sunny day.

Another implication of the impact weather has on these systems is air temperature. Since the system is located in a non-temperature controlled greenhouse, the tank can then therefore be heated or cooled depending on the temperature. This means that as the seasons change so too will your temperature read outs on LoggerPro. As can be seen below, the air in the collector never changed because solar energy is constant all year. However, the control tank (yellow line) and the unit tank are positively correlated meaning that as the control tank temperature raises so does the unit tank temperature. This could also account for the sharp difference between 2.5 liters and 2.0 liters from week data point.

Also important to note, is that although we changed the contents of volume compensator from rocks to essentially air, we did not see any noticeable differences in the data. Therefore, based off of data our group has gathered and analyzed, we can move on to the submission of a recommendation for future researchers:
Recommendation and insight:

Through the testing of our hypothesis and based on the data derived from our system, our system concludes that the optimum panel to water volume ratio is 1 square foot of panel to 1 liter of water.

Indeed, we are confident that this information will aid future researchers when constructing and determining collector and tanks and sizes. Conversely, the most valuable information to take from certain flaws in our experiment is consideration of tube size, which will greatly impact your heat transfer; the size of our tubes were simply too big, and that caused the water to sit too long in the tubes and it lost heat as it was moving from the collector to the tank. If we had used smaller tubes we would have not lost nearly as much heat between the collector and tank. The bigger the tube, the more water will fill. The more water that fills it, the more water that will be sitting waiting to cycle through the system, and the longer it takes to cycle through the more heat it is going to lose. Further, the larger the diameter of tube the more surface area to heat—this of course severely impacts efficiency. In sum

Conclusion:

At the start of this class we were instructed to not only make a passive solar hot water heating system but also choose an area of the system and make improvements on the system. We were to test the changes that we made and record the effects of the changes. Our group decided to study the effect of changing the water volume to panel ratio. That is we did not change the panel ratio, which was two feet by two feet. We did on the other hand change the water volume. Four times in fact, we set the water volume at 2, 2.5, 3.5, and 4.5 liters. Our hypothesis was that the higher the water volume and colder the temperature would be. So as the water volume goes down the temperature of the tank water will go up. We tested this by creating a passive solar hot water heating system. Once the system was leak free, then we started to collect data, and then all we had to do was to change the water volumes. We would change the water volumes, collect data, and make any changes needed to the system.

Dan Clark’s Afterthoughts:

This project was a good real life experience in problem solving and actually doing experimental work. This project taught me how to think scientifically and actually get my hands dirty. Personally, I’m not really an engineering kind of guy. This project made find that side of me. The strength of this project was the collector. It did not fail once throughout the semester. The collector got heat into the system. The hoses were the weakness of the project because they did not keep the heat in and the hoses themselves were too big. The heat did not heat the water up fully and keep the heat all the way to the tank. I think using the same collector with smaller hoses we could have gotten much higher temperatures in the tank. Another thing not to do is to use
metal nuts on the back of the tank connections because they are harder than the bucket and just
tare right through the bucket.

Troy Albert’s Afterthoughts:

Ah, the close of the semester. Nothing sweeter than the omnipresent anxiety of faculty and
student alike, frantically scrambling for the glory of the last grade or assignment like a pack of
furry squirrels—so coined as CCBC’s unofficial mascot--squandering about making the last
additions for winter. This is a good time, this is our time. So too, comes the end of our project and
subsequent lab report. But before I get lost in some sort of quasi-nostalgic rant, let me give kudos
to you, Professor Floyd for making me think more like a scientist as well as use Microsoft Excel.
Indeed, this project has taught me a great deal of things and without doubt made me fully
appreciate the famous Emerson quote; “Science is 99% perspiration and 1% inspiration”—a
lesson learned all too well and in due time.

To next semester’s students: pick you group carefully, pick your goal even more carefully
and don not be modest when it comes to your ideas or aspirations; science depends on it! Also do
not be intimidated by this project! Even if you do not come out with a good grade, the most
positive I personally have ever got out of school was from the challenging classes. Follow his
directions and guidance and you will grow as a student.

Gavi Zeitlin’s Afterthoughts:

This project was a real eye-opener to me, the idea that the sun’s energy could actually be tapped
by a regular person, using everyday items you buy at a hardware store. At first this project seemed
rather intimidating, isn’t this type of project for professionals? But, as we learned, it is possible to
tap into the awesome power of the sun, and channel it into a renewable energy source that does no
harm to the environment and can be quite effective.
We have unfortunately been molded by a society that’s looking for a quick fix to every problem,
even if the fix is only temporary, once it’s done the thought of the problem will leave our minds
until it resurfaces from underneath out superficial covering.
I’m reminded of a rather humorous incident that happened over the semester, when our professor
brought out a solar powered water sprinkler, for one’s garden. One of the groups was trying to
figure out how it worked and without thinking asked “Where do you plug it in?”
If this class thought me one thing (besides how to make graphs in Excel) it’s that hard work and
really thinking a problem through are much more satisfying compared to looking for a quick fix
for a problem. Because in that situation you’re simply covering up the problem, you’re not fixing
it.
So when the student of Spring 2008 reads this, know that, yes, you will (horrors!) have to put in
some effort, but the reward will be much more satisfying then if you try to get by with as little
work as possible, “just to get a grade.” Sweat, think, and be challenged.
This guy wrote a book about how to build a big enough active water heating system for an entire house. He did not put the entire book on the website but he did provided a pretty good plans on how to build one. Also what insulation to use on the collection tank, so that the system does not lose all of its heat.

Science Direct, 2007, Dong Won Lee, Atul Sharma, 

This website was about a research project about how to reduce the fossil fuel needs for South Korea. They were mainly using active solar water heating systems so I did not really pay attention to the site. The one thing I got from it was they said at the end that this kind of water heating is feasible if the occupants of the house only draw water in the evening. They would have hot water only in the evening.


This website had a study that was done by an Australian college on trying to find a way round using fossil fuels for heating water. The website wrote that in passive systems, where natural convection and direct solar absorption by the water body are the principle heat transfer mechanisms, greenhouses are the main technology used. They concluded that passive and active solar technologies could reduce conventional energy requirements for water heating in recirculation aquaculture systems. However, no studies are available to indicate the potential annual energy savings for different configurations in different climates.


This website in curtsey of a non-profit organization that is based out of El Paso, Texas. This website is out there to help people build a passive solar water heater for their house. They say to start out with a 40-gallon tank, preferably a water heater tank, and paint it black with barbecue paint or engine enamel. Then put it into a box that is big enough and use a glass that big enough. The website said 1 sq. ft. per every 2 to 2 1/2 gallons of water. They said for a 40-gallon tank a sliding glass door glass would work perfectly. They said to insulate the box with the highest r-valued insulation you could find. Then they said to put the box where it will face the sun for 9am to 4pm.
This website informed me about the properties of insulation. They define insulation as those materials or combinations of materials, which retard the flow of heat energy. The website goes through the different types of insulation as well as the forms of insulation. Then the site went through the thermal properties of insulation: temperature limits, thermal conductance, thermal conductivity, emissivity, thermal resistance, and thermal transmittance. The website also gives you tips on what type of insulation to use in certain applications.

www.greenbuilder.com/sourcebook/heatcool.htm

This website gave me a lot of information about how to build specifically a passive water heating system especially for a pool or a spa etc. This site gave me the pros and cons about having a system for a pool. This website had a few pictures and diagrams showing the flow of the water and where everything included in the system goes and what order they have to go in.

**Further Reading:**


  http://www.backwoodshome.com/articles/hackleman65.html
