ENVS 102

Section CN1

04/29/2008

Spring 2008 Passive Solar Water Heating Project

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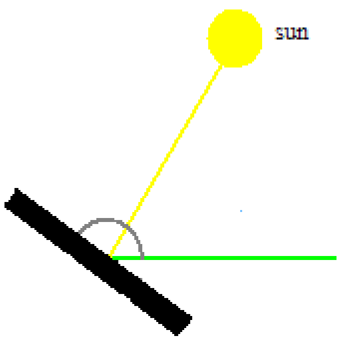
Introduction

The Challenge

The objective of our term project was to continue on the work of previous semesters and develop a functioning passive solar hot water heater. In addition to building a working project, we were asked to test a hypothesis about optimizing on facet of our solar heating system using a controlled experiment. We would be working in groups throughout almost the entire process, including the design, assembly, operation, and monitoring of the system. We were asked that the research required at the start of the semester be completed individually. We were also asked to evaluate our system, in both qualitative and quantitative terms, keeping in mind the requirement of optimizing the one parameter that our group selected in a well planned, controlled experiment. Finally, we were asked to present our results and describe our project in a detailed scientific report.

Our Hypothesis

In our hypothesis, we predict that by aligning our solar collector perpendicular to the sun at any given single point in the day, our solar water heating system will be able to achieve maximum operating efficiency. We intend to test the performance of our system by testing the relationship between the angle of our solar collector and the angle of the sun to the Earth's surface at mid-day, between 11:00 am and 2:00 pm. We chose this point because at this time the sun is at its highest point in the sky, and it is in general the hottest part of the day. We believe that by doing this we will be able to achieve the highest average temperatures in our water container.



**This illustration helps describe the basics of our hypothesis*

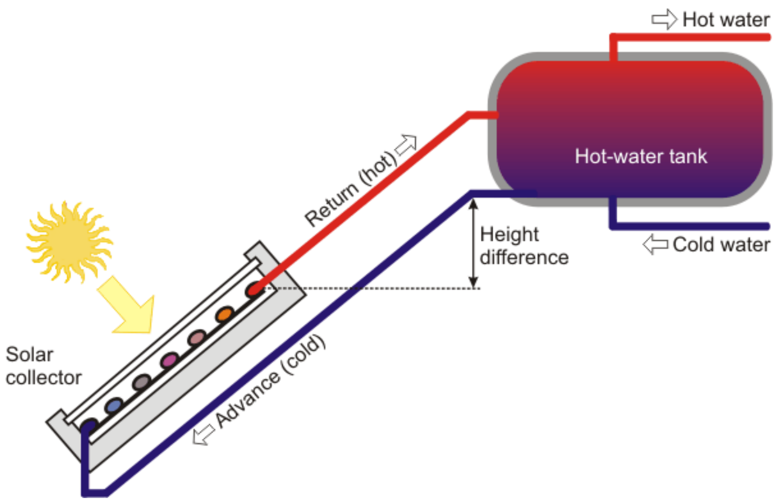
Background Research

Before we could begin the construction of our solar water heating system, we first had to be able to fully understand exactly how such a system works. During the beginning stages of our research, we were mainly focused on understanding the basic principles behind the construction and operation of passive solar water heaters. We would be using a thermosyphon system, so the dynamics of this type of system, including its construction, materials needed, and the basics principles of its function became our primary focus. The U.S. Department of Energy's website was particularly helpful with understanding this information.

Some useful background facts and terms that we found pertinent to our project are listed in the following:

- A passive solar heating system using no moving or mechanical parts. It functions solely on the sun's energy and the laws of physics.

- In thermosyphon passive solar heating systems, “Water flows through the system when warm water rises as cooler water sinks. The collector must be installed below the storage tank so that warm water will rise into the tank.”

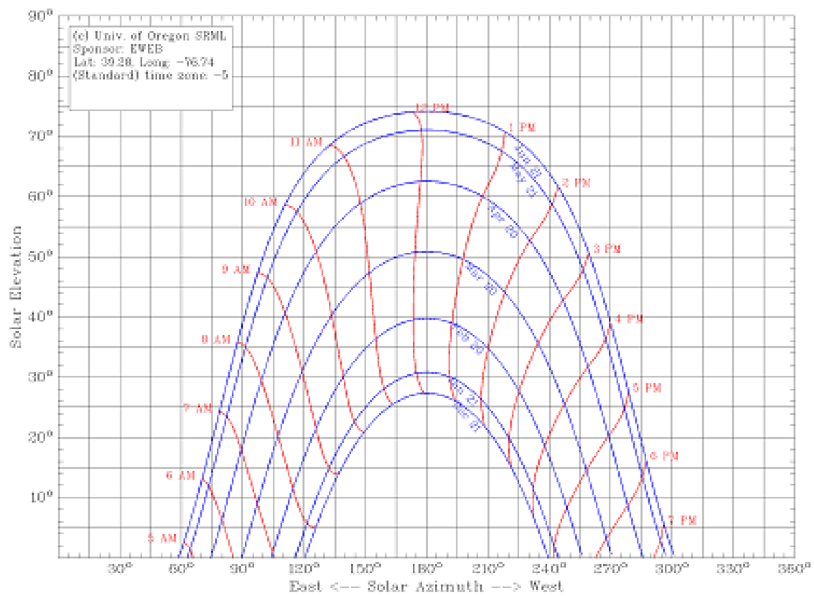


**This image, published in Renewable Energy World, shows how a thermosyphon passive solar water heater works*

In deciding which materials to use for the construction of our solar water heater, The Integral Passive Solar Water Heater Book was very useful. It provided complete instructions of do-it-yourself solar water heater designs. It also provided scientific research as to why certain materials were chosen over others, such as the importance of copper pipes in the collector and the use of flat black paint to absorb the sun’s energy more efficiently.

Finally, to be able to test our parameter, we needed to know the sun’s exact position in the sky during the months of May and April. This information was more difficult to find than we expected, but we eventually found a book titled Photovoltaics: Design and Installation Manual which provided a number of sun charts showing the angle of sun to the earth’s surface at various times throughout the day, based on longitude and latitude. Another useful resource that helped us confirm these angles was the sun path chart program retrieved from the University of Oregon’s Solar Radiation Monitoring

Laboratory website. This program allows you to input your zip code to generate a chart of the sun's path at any given dates of the year.



**Here is an example of the sun path chart we used for our experiment. This chart is for Catonsville, MD and is listed in local Eastern Time.*

Results

Materials and Building Design

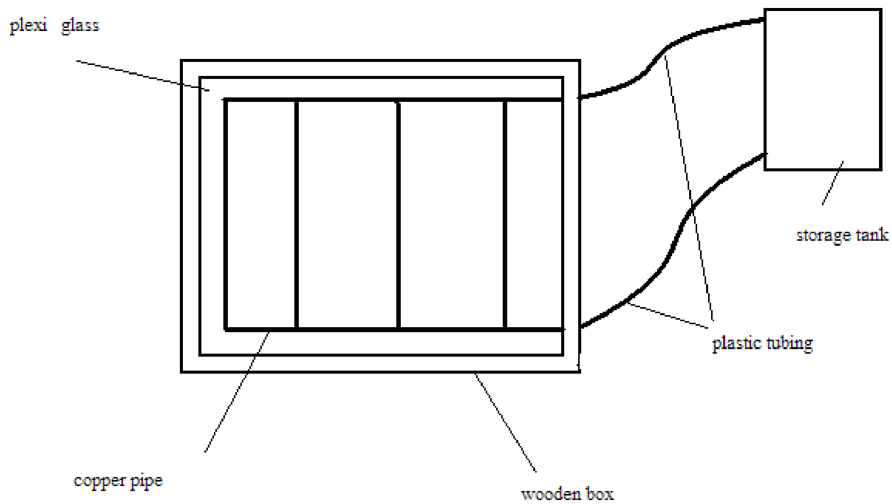
In building our system, we realized that we were not concerned with constructing a final marketable product, but rather an experimental one that could be used to accurately test our hypothesis. We also realized that our finished project did not have to be visually pleasing as long as it was functional. Cost was also an issue, and in a few instances we had to sacrifice the use of superior materials for ones that would fit into our budget. For example, if we had the funds, we would have used a better insulated storage tank, as well as thicker plexiglass. Nevertheless, we were very satisfied with our final product. The following is a breakdown of the materials used and the construction of the various parts of our solar heating system.

- *The solar collector* – The base of our solar collector was made from a plywood box that we were able to find. It measures approximately 30” x 26” x 3 ½ “, and the walls are about 1” thick. We used a saw to even out the edges of the collector. We then sealed the box with clear silicone because we wanted to keep air out of the collector. The entire inside of the box was painted flat black to better absorb the sun’s energy. We used ½ inch copper pipe, as well as 2 elbows and 6 T-fittings to create the plumbing in our collector. These pipes were soldered together to prevent leaks within our system, and they were painted flat black as well. We feel that this was a very important aspect in determining the success of our system. The intake and exit pipes both came out of the same side of our collector. A sheet of thin plexiglass was placed over the box, and securely fastened with screws.

- *Tubing* – We used ½ inch flexible black plastic tubing for the lines running from our collector to our storage tank. We used plastic fittings to connect these to the copper pipes as well as the collector. These fittings were wrapped in Teflon tape, and were sealed using silicone in a further effort to prevent leaks.

- *Storage Tank* – For our storage tank, we used a 5 gallon thick plastic cat litter bucket. The storage tank was positioned above the solar collector, allowing our thermosyphon system to function properly.

- *Temperature Sensors* – Using the LoggerPro program given to us in class, we were able to measure the temperature of our system at any given time in the day. In this experiment, we used two sensors – one placed inside the solar collector to measure its operating temperature, and the other placed at the top of the storage tank to measure the temperature of the hot water in our system. Both of these were recorded in Degrees Celsius. We used this program to record the temperature of our system every fifteen minutes for six weeks.



**We did not have access to a camera during the lab, so we created this illustration to show the design of our system*

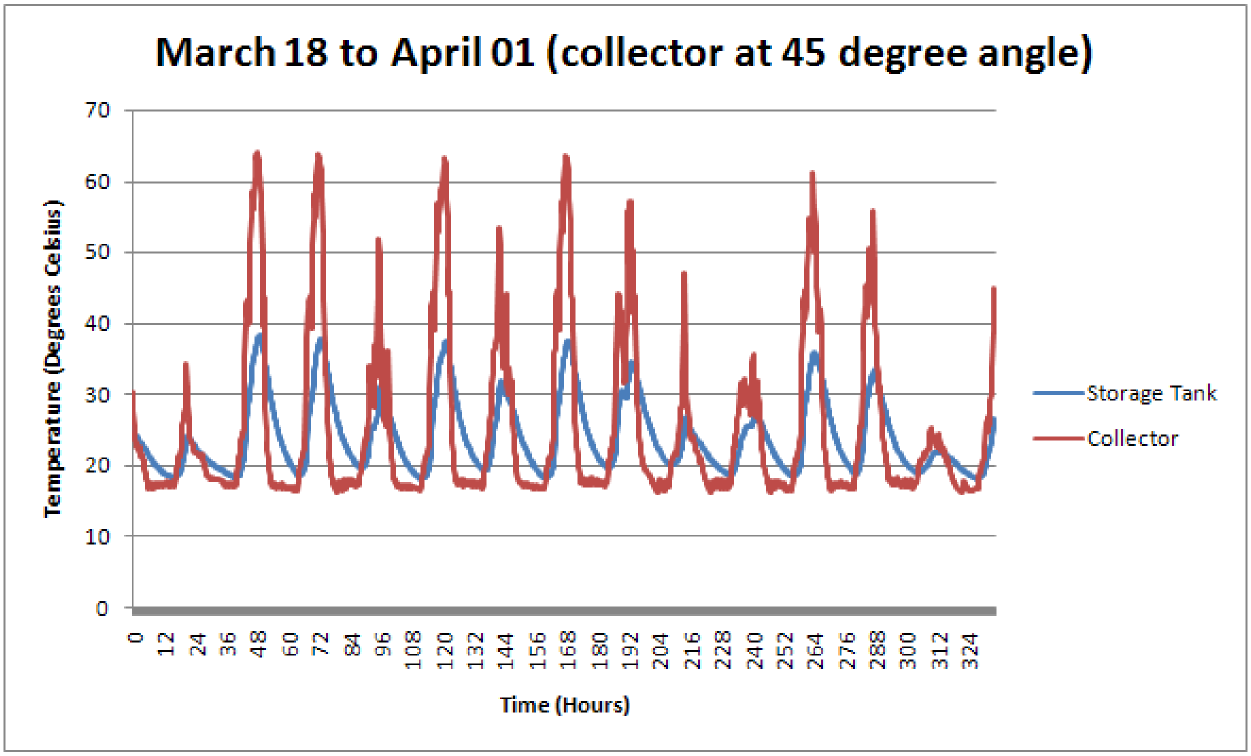
Summary of Lab Notes

The following page contains a summary of the notes we recorded throughout our lab experiment. They cover everything from the construction of our solar heating system to the last week of recorded data.

The pages following our lab notes are the graphs that we collected using the LoggerPro software. They indicate the temperature change in degrees Celsius for both the solar collector and the storage tanks for the dates listed above them. The angle of the collector was measured from the ground using a protractor. The time is listed in hours, and follows 6 or 12 hour increments to make it easier to understand the temperature change throughout the day. Due to their enormous size, the tables showing the individual data points we collected are not included in this report. Additional notes are listed below each graph.

Dates	*Progress and Observations*	*Angle of Solar Collector (Degrees, measured from the ground)*
19-Feb	All materials were purchased and we finally began construction of our system. The box used for the collector is evened out, and the corners and edges are sealed with silicone.	n/a
26-Feb	Construction continues. The pipes for the inside of the solar collector are cut and soldered, and the collector is painted flat black. Pipe fittings are secured on the storage tank.	n/a
4-Mar	We put the fininshing touches on our system, and secured the plexiglass on the collector. The final product is assembled and set up to ensure that it functions properly. LoggerPro and sensors are also installed.	n/a
11-Mar	There are no problems, and everything is functioning properly. We set the angle of the collector to 45 degrees and await results.	n/a
18-Mar	We begin collecting data from our system. The collector angle is set at 45 degrees, as we read in research that this is an optimum angle for overall performance of the system.	45
25-Mar	Lab was closed for this week, so no changes were made.	45
1-Apr	Results from the last two weeks are recorded, and the angle is changed to 50 degrees. We predicted that with a sharper angle, the collector would not be able to absorb as much sunlight and not perform as well.	50
8-Apr	Last weeks results are recorded, and we begin lowering the angle of the collector to observe changes in the data.	40
15-Apr	Last weeks results are recorded, and this time the angle is set at 30 degrees. We used the sun chart to ensure that, for this week, the collector would be perpendicular to the sun from 11 am to 2pm. We hoped that by concentrating on the sun's position during the hottest part of the day that our system would be able to reach maximum efficiency.	30
22-Apr	The results from last week were recorded, and we lowered the angle again to 25 degrees to observe the effects.	25
29-Apr	We gather the final data from our system.	n/a

Data Collected Using LoggerPro Software

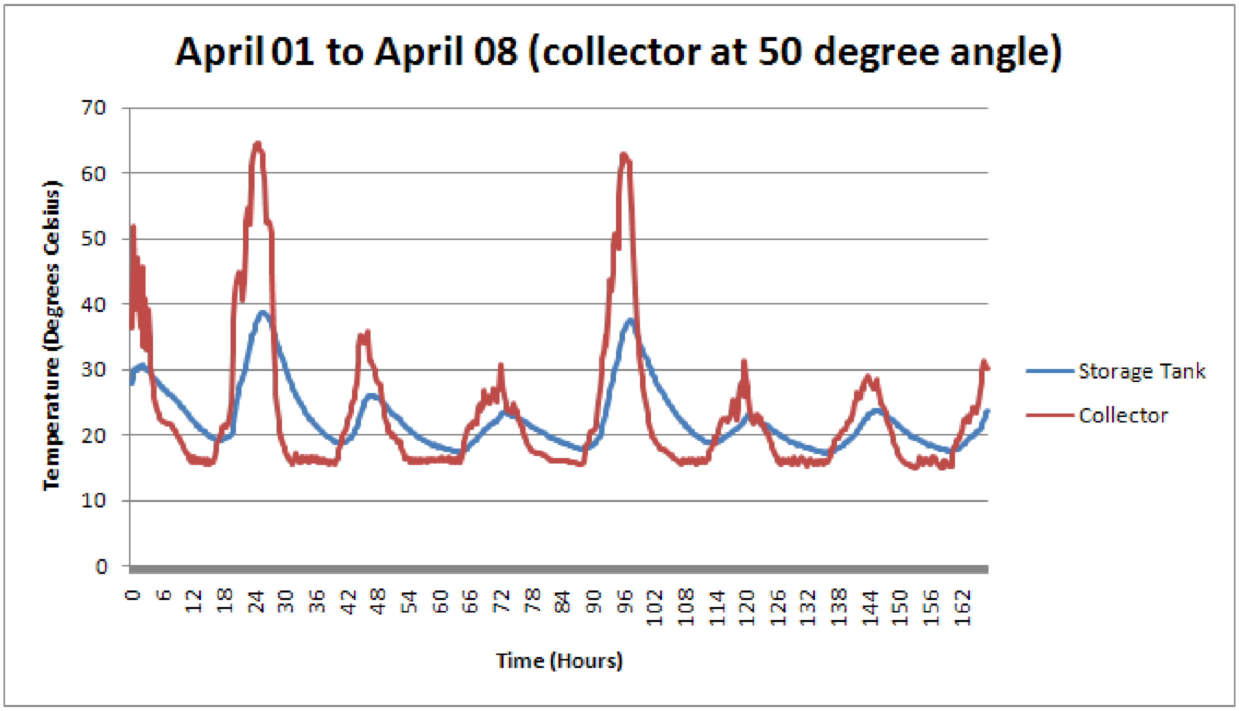


This chart represents the first two weeks of our experiment. We chose to position our collector at a 45 degree angle because we learned from our research that this would be acceptable for overall performance. We also chose to do this because we did not at this time have access to a sun path chart for the Catonsville, MD area. Upon arriving to the greenhouse, we observed that the water in our storage tank was very warm, as well as the tubing running from our collector to the tank. We saw through our data that our system performed very well during this time period, and there were only a few bad days where our temperature remained unsatisfactory.

<u>Two highest temperatures reached in the storage tank</u> – 38.3 and 37.8 degrees Celsius

<u>Weather conditions for these two weeks</u> – While I could not find an actual weather report for the month of March, both the performance of our solar heating system and the conditions we observed indicate

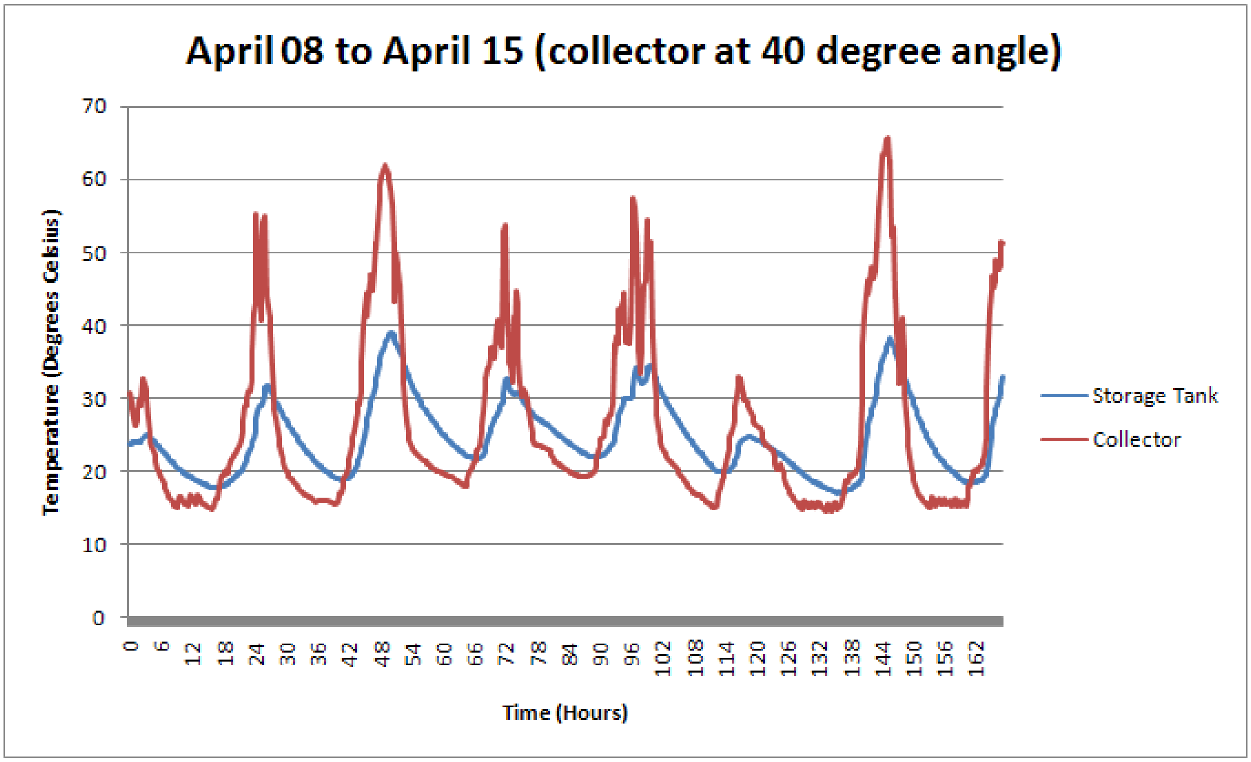
that these two weeks were fairly sunny with only a few days of rain. The average high for the month is 54 degrees Fahrenheit.



This chart represents the third week of our experiment. We chose to position our solar collector at 50 degrees this time to see if we could observe a difference in efficiency with a slightly sharper angle. When observing our experiment in class after this week, we noticed that the water in the storage tank was not as hot as before, but this was expected as it was not a very sunny day. We observed that our slight change of the collector angle did not noticeably affect the highest temperatures we achieved, but made us aware that a much more drastic change would be needed to reach the results we wanted.

Two highest temperatures reached in the storage tank – 38.5 and 37.5 degrees Celsius

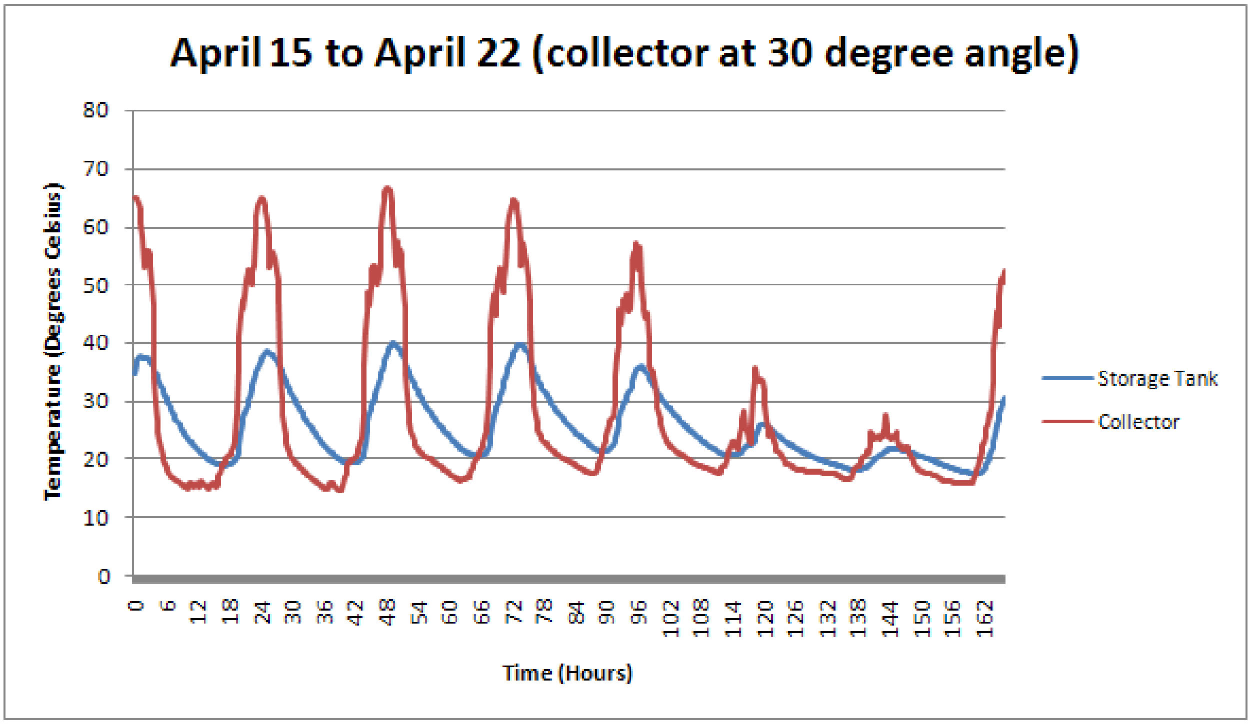
Weather conditions for these two weeks – The high temperatures for the days where we attained peak performance from our system were 61 degrees Fahrenheit and 63 degrees Fahrenheit. This was a terrible week for our experiment, with lots of precipitation and cloudy days.



This chart represents the fourth week of our experiment. For this week, we chose to set the angle of the solar collector at a 40 degree angle. We did this for two reasons. First, we wanted to move closer towards our hypothesis by positioning our collector closer to perpendicular with the sun. Second, we wanted to confirm the results we discovered last week by checking to see if the results we found would be equally similar to weeks one and two. When we examined our system in class, we noticed that our water was very warm, and would be suitable for bath or shower water. Our performance was slightly improved this week, with highest temperature marginally better than previous tests.

Two highest temperatures reached in the storage tank – 38.9 and 38.1 degrees Celsius

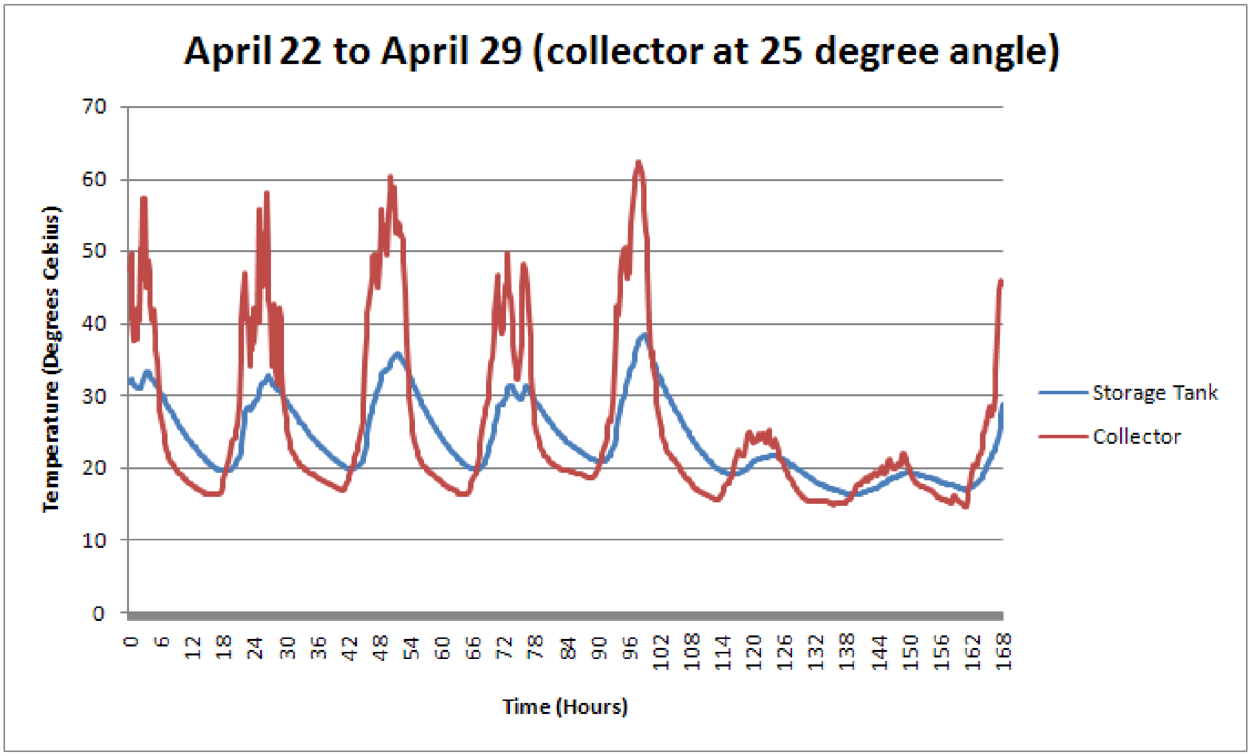
Weather conditions for these two weeks – The high temperatures for the days where we attained peak performance from our system were 72 degrees Fahrenheit and 55 degrees Fahrenheit. This was a better week than last week for our system, even though it too was not very sunny. We attribute the wavy lines representing mediocre days on the graph to fog which was present on those days, which probably resulted in hours of interrupted sunlight.



This chart represents the fifth week of our experiment. We calculated that for this week, the sun would be at a 60 degree angle from the earth's surface between 11 am and 2 pm, so in order to position our solar collector perpendicular it, we would need to align our collector on a 30 degree angle from the ground. This allowed us to fully test our hypothesis, and we were very excited to see that we had attained very high temperatures in our storage tank this week. When we felt the water in the storage tank, it was once again very warm and comfortable. It finally felt as if we had made some progress.

Two highest temperatures reached in the storage tank – 39.9 and 39.6 degrees Celsius

Weather conditions for these two weeks – The high temperatures for the days where we attained peak performance from our system were 77 degrees Fahrenheit and 84 degrees Fahrenheit. Most of the week was very sunny, and provided great conditions for testing our system.



This chart represents the sixth and final week of our experiment. This week we wondered what would happen if we reduced the angle of our solar collector by a mere 5 degrees. We wondered if the results would be similar to last week, and if so how close. After reaching the greenhouse, we detected that the water in our storage tank did not feel as warm as in earlier weeks. We were disappointed to see that the peak temperatures for the week were very low compared to other tests. However, we believe that these results could be somewhat misleading, and that certain factors may have played a role in limiting our performance. This will be described later in the report.

Two highest temperatures reached in the storage tank – 38.3 and 35.7 degrees Celsius

Weather conditions for these two weeks – The high temperatures for the days where we attained peak performance from our system were 76 degrees Fahrenheit and 80 degrees Fahrenheit. This looks like it should have been a much better week for our testing, with a few good sunny days. Surprisingly, our highest temperature was reached on a day that was recorded as foggy.

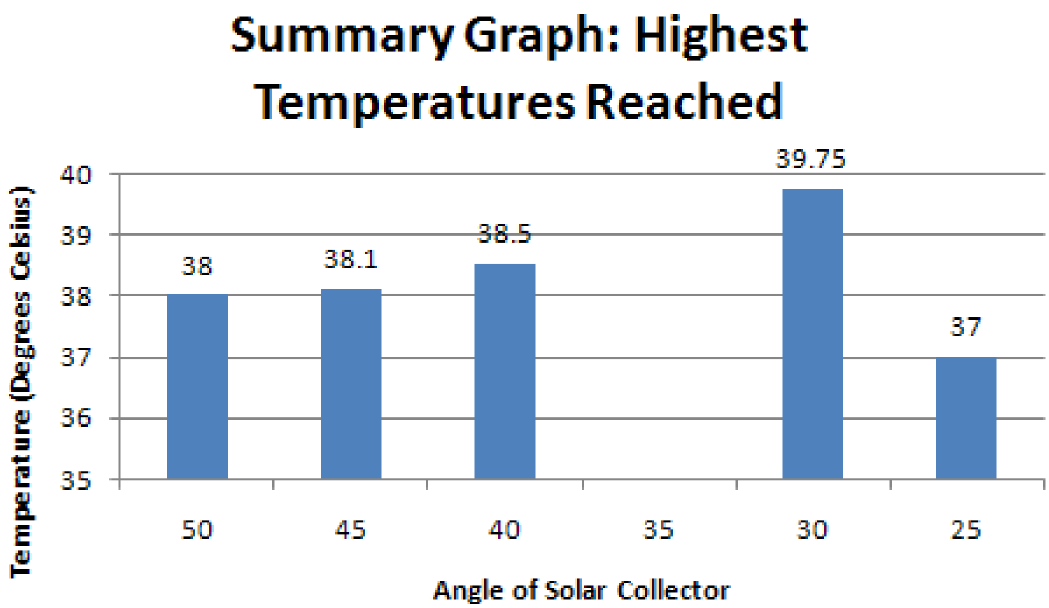
Discussion

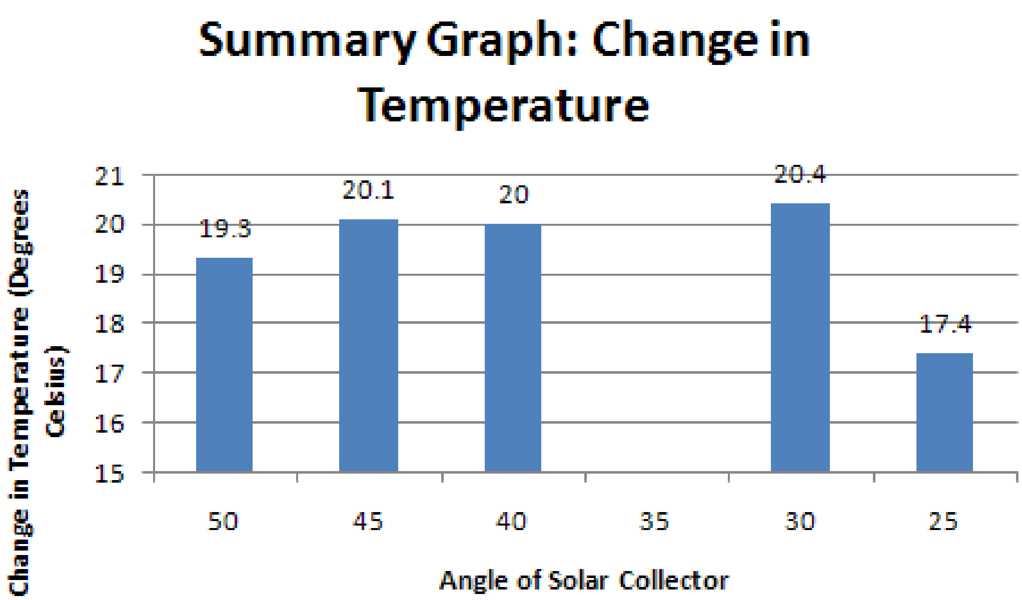
Was Our Hypothesis Proven?

Our hypothesis stated, in a bit more detail, that we believed our solar heating system would perform most efficiently if the solar collector was positioned perpendicular to the sun during the hottest part of the day. To support our conclusion and discoveries we made throughout the semester, we have included two summary graphs, which help to better understand our data.

The first graph shows the highest temperatures obtained with our system. These numbers are averages of the highest temperatures reached in the storage tank for each angle we tested. These were stated in the results section of the report. We chose to average the peak temperatures in order to present a more general way to measure the performance of our system.

For the second graph, we decided to show the temperature difference between the highest temperatures reached in our storage tank and the low temperatures preceding them. These values were calculated by taking the highest temperature reached in the storage tank and subtracting the lowest temperature prior to it. We chose to show this graph as a way to measure the direct energy input of our solar heating system.


Summary Graph: Highest Temperatures Reached
Temperature (Degrees Celsius)
40
39
38
37
36
35
38
38.1
38.5
39.75
37
50
45
40
35
30
25
Angle of Solar Collector


Summary Graph: Change in Temperature
Change in Temperature (Degrees Celsius)
21
20
19
18
17
16
15
19.3
20.1
20
20.4
17.4
50
45
40
35
30
25
Angle of Solar Collector

At the end of our experiment, after thoroughly analyzing our results, we found our hypothesis to be supported. We saw that when our solar collector was placed perpendicular to the sun, we achieved higher temperatures in our storage tank as opposed to when the collector was positioned at other angles. We also found through analyzing the change in the temperature of the water in the storage tank that our hypothesis was supported. With our collector perpendicular to the sun, our solar heating system was able to absorb more energy than during other trials.

We find it important to note that, while our hypothesis was supported, we did not see a huge difference in any of the data collected. While our solar heating did perform slightly better during the fifth week of our experiment, these results lead us to believe that our experiment will do little to aid the advancement of state of the art solar heating systems. However, further research conducted after the experiment's closure proposes that the data collected during this experience might be able to assist in the success of local applications. We learned that professionals who install solar water heaters focus more on the specific angle during the winter months because of the amount of sunlight is less during these months. During the summer months the angle does not make as much of a difference because the heat of the sun is greater and the amount of sunlight exposure is longer. This information helps us to better understand the results of our experiment, and also suggests that we might have been able to measure much more varying data had our solar heating system been tested during the winter months.

Another detail which we judged might have influenced the results of our experiment was the outside air temperature and weather conditions. We knew that rainy or cloudy days would present favorable results, but we wondered if the outside temperature might have had some effect on the efficiency of our solar heating system. We did not think this would be the case, since we were testing in the greenhouse, a climate controlled environment. However, we decided that it would be appropriate to determine if this guess might be wrong. We have included a chart, which shows the observed weather conditions for the month of April. This was the only recent data we were able to find, so for the weeks in March the weather is mostly unknown. This is shown on the following page for reference, and was obtained from The Weather Channel Interactive, Inc. website.

After analyzing this, and matching it with our own graphs and data, we found that the outside temperature did not affect the performance of our system in the greenhouse. While our best day for data happened to be warmer than other days, we were also able to produce very positive results on much colder days. Likewise, on some warmer days our solar heating system failed to produce the same favorable results.

One final issue which we feel is important to discuss is the data recorded during our sixth week of the experiment. During this week, our solar collector was positioned 25 degrees from the ground. As you can see from our results section and summary graphs our system performed much worse on this week than any other week tested. We realize that these may be accurate data, one aspect discourages us from thinking this. We did not realize it at the time, but during this week about ¼ of our collector was shadowed by the cement wall of the greenhouse. We believe since the collector was not receiving as much sunlight as during other tests, this may have limited the efficiency of our system. Other than this issue, we did not encounter any problems with our solar heating system. Throughout the entire testing period, we did not discover any leaks in our system. Both our experiment and the software used to monitor it functioned flawlessly during the semester.

April

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1 OBSERVED Hi **75°F** Lo **50°F** Precip (in) **0.55in.**	**2** OBSERVED Hi **61°F** Lo **39°F** Precip (in) **0in.**	**3** OBSERVED Hi **50°F** Lo **29°F** Precip (in) **0.92in.**	**4** OBSERVED Hi **62°F** Lo **40°F** Precip (in) **0.51in.**	**5** OBSERVED Hi **63°F** Lo **49°F** Precip (in) **0in.**
6 OBSERVED Hi **51°F** Lo **45°F** Precip (in) **0.84in.**	**7** OBSERVED Hi **47°F** Lo **42°F** Precip (in) **0.05in.**	**8** OBSERVED Hi **53°F** Lo **41°F** Precip (in) **0in.**	**9** OBSERVED Hi **62°F** Lo **40°F** Precip (in) **0.04in.**	**10** OBSERVED Hi **72°F** Lo **50°F** Precip (in) **0in.**	**11** OBSERVED Hi **78°F** Lo **53°F** Precip (in) **0.29in.**	**12** OBSERVED Hi **77°F** Lo **57°F** Precip (in) **0.09in.**
13 OBSERVED Hi **58°F** Lo **46°F** Precip (in) **0.03in.**	**14** OBSERVED Hi **55°F** Lo **36°F** Precip (in) **0.06in.**	**15** OBSERVED Hi **59°F** Lo **40°F** Precip (in) **0in.**	**16** OBSERVED Hi **66°F** Lo **36°F** Precip (in) **0in.**	**17** OBSERVED Hi **77°F** Lo **36°F** Precip (in) **0in.**	**18** OBSERVED Hi **84°F** Lo **44°F** Precip (in) **0in.**	**19** OBSERVED Hi **82°F** Lo **50°F** Precip (in) **0in.**

20	21	22	23	24	25	26
OBSERVED	OBSERVED	OBSERVED	OBSERVED	OBSERVED	OBSERVED	OBSERVED
Hi **72°F**	Hi **61°F**	Hi **72°F**	Hi **74°F**	Hi **76°F**	Hi **76°F**	Hi **80°F**
Lo **57°F**	Lo **56°F**	Lo **53°F**	Lo **51°F**	Lo **53°F**	Lo **47°F**	Lo **57°F**
Precip (in)	Precip (in)	Precip (in)	Precip (in)	Precip (in)	Precip (in)	Precip (in)
0.68in.	**0.96in.**	**0in.**	**0in.**	**0in.**	**0in.**	**0.37in.**

27	28	29	30
OBSERVED	OBSERVED	OBSERVED	OBSERVED
Hi **57°F**	Hi **63°F**	Hi **61°F**	Hi **58°F**
Lo **51°F**	Lo **48°F**	Lo **46°F**	Lo **35°F**
Precip (in)	Precip (in)	Precip (in)	Precip (in)
0.34in.	**1.91in.**	**0.04in.**	**0in.**

Conclusion

Afterthoughts

In the end, we found this experiment to be very informative, as well as a fun experience. None of us had ever thought about creating a solar heating system, and at the beginning of the semester the idea seemed very intimidating. Now we have a much better understanding about the design and operation of these systems, and we would feel very confident explaining these aspects to others who are interested. This experience proved to be a great deal more challenging than we figured from the beginning, but it was beneficial overall. We had a great time building the system, and learned a few new skills during the process, such as soldering. This class also gave us a chance to work in groups, which is a nice change from other classes offered at CCBC. Finally, we have all become experts at using Microsoft Excel to make graphs and tables.

Energy Saved

In order to fully evaluate this experiment we need to calculate the BTUs that our system generated during a given time. We know that a BTU is the quantity of heat required to raise the temperature of one pound of water 1 degree Fahrenheit. We had 5 gallons in our storage tank, and one gallon of water is equal to 8.34 lbs. For this calculation, we used the temperature change of our best day of data, which was 20.4 degrees Celsius. We used a conversion tool to convert this to Fahrenheit. The equation used to calculate the BTUs stored by our system in that one day is shown below.

68.7 degrees F x 41.7 lbs = 2865 BTUs

Change in Temp x Lbs of Water = BTUs

We used this number to calculate that our system would generate 28650 BTUs a day if it was 10 times larger, and provided that it always functioned at maximum efficiency. We learned in Part II of our energy audit for ENVS 101 that the average American uses 3,340 Therms of natural gas a year, which is the equivalent of 334,000,000 BTUs. We can divide this by 365 to get the approximate BTUs used in one day, which is 915,068. This alone shows us that we would need to make significant changes to our solar heating system in order to use it as our only source of energy. We can go a step further than this by calculating the amount of money that would be saved by using a 10 times bigger solar heating system than the one in our experiment. If we assume that the cost of one Therm of natural gas is $0.90, then we can see that an average American spends about $8 a day for energy. By converting the BTUs generated by our system to Therms (28,650/100,000) and multiplying this by $0.90, we can see that a person would save about $0.26 a day using a solar heating system. Given the cost to build the system, it is obvious that it would take a very long time for this approach to save money. However, it is very environmentally friendly, which is a benefit.

It must be noted that these numbers are estimates, and that much more complicated math would have to be used to get a truly accurate representation of the energy used and money saved. This approach assumes that all of the water in the storage tank experienced the same change in temperature, which is unlikely given the design principles of a thermosyphon system. It also assumes that our system would function flawlessly, and reach peak operating performance every day, regardless of weather conditions. However, we feel that these calculations still help in evaluating the practical uses of our system.

Recommendations

The most important recommendation that we would make to future students is to research effectively. Even during our experiment, we felt the need to find research which better supported the idea that we were studying, and we feel that with better research we might have been able to produce better results. We also recommend that future students use all of the resources around them, such as the school's library and computers, and also not be afraid to ask for help when they need it. Yes, this project turned out to be much more challenging than anticipated, but if you stay motivated and patient it will be very rewarding.

We also recommend to society to evaluate the energy supply and consumption processes that we live by. We have learned that solar heating systems may not be able to provide enough energy by themselves in most parts of the country, and that we should work on balancing different sources of energy until we find something that works, both for the environment and for our wallets.

One final recommendation to anyone enrolled in Environmental Science is to always remember Barry Commoner's first law of Ecology – "Everything is connected to everything else." This will help a lot throughout the semester.

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