Justin Sanders
Kelly A. Thomas
Drew Fenlon
Professor Floyd
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ENVS 102/ Lab Report

Objective

The objective of this project was to develop a functioning passive solar water heating system, capable of heating to 105 degrees (Fahrenheit) ± 5 degrees. To this end, we worked in groups to research, design, build, monitor, and scientifically test the systems we constructed. The results of our monitoring and testing were recorded, analyzed, and presented in a final report of our procedures and results. Our procedures for design and testing were determined by the Scientific Method.

The Scientific Method

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

Research

The first part of this project involved the research of passive water heating systems. In this stage of the project we learned the difference between passive and active systems, the types of passive water heating systems (reviewed in summation below), and the necessary design features of a functional passive water heater. Approximately 50 pages of research per group member were done in order to obtain this knowledge *see bibliography, page 16.

Solar water heating systems overview

Solar water heating systems are distinguished as either passive or active as dictated by the presence of a pump to circulate the water. Passive solar water heaters are further classified as either thermosiphon or batch.

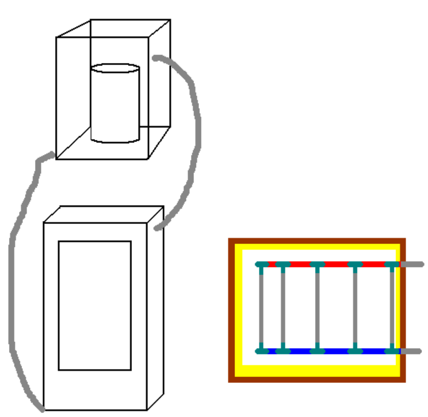
Thermosiphon systems rely upon convection (the natural circulation of warmer water over colder water) to circulate water between the collector and the reservoir tank.

Batch systems consist of one or more metal tanks painted with a heat absorbing black coating and placed in an insulating box. A glass cover that admits sunlight to strike the tank directly is then placed over the box. These systems will use can existing house pressure to move water through the system.

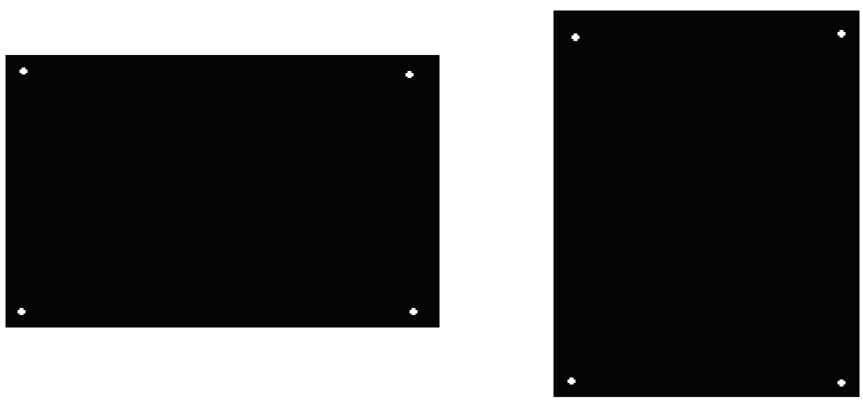
As there was no existing water pressure for these projects, we decided upon a thermosiphon system as the best design.

The Design Process

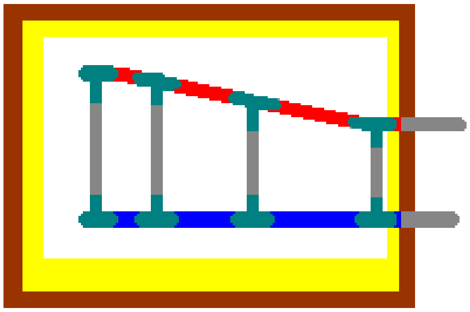
The design we used is a solar water heating core made of plastic tubing, sandwiched between metal sheeting, placed in a wooden box covered by plexi-glass. The plastic tubing lead to a 1 gallon holding tank where the water temperature was monitored. The holding tank was elevated so that the top hot tube would siphon the hot water to the top of the tank and the cold water would circulate to the bottom through convection.



The collector unit was made of a wood box measuring 11’ x 15’ in length and 3 inches deep. This made up the primary case of the collector. Inside the primary case, 2 sheets of aluminum measuring 10’ x 13’ sandwiched 6 clear plastic tubes, 11” in length and 3/8” in diameter, joined by 3/8” T-connectors. The tubes were arranged in a straight up-and-down network so as to promote convection throughout the system. The top tube, which siphoned the warm water back to the holding tank, was set at an angle. In concordance with the workings of convection, a cold water tube ran from the bottom of the collector to the bottom of the tank, and a hot water tube ran from the top of the collector to the top of the tank. Those tubes were also connected using T-connectors 3/8’ in diameter.



2 Sheets
10 X 13 sheet aluminum, painted black



The front of the collector was a sheet of plexi-glass ¼ inch thick. The inside of the collector was painted with a flat-black paint. Foam-board insulation of an R-11 value provided a nest for the aluminum and tubing inside the primary case. The unit was then set at an angle towards the sun. The tank was a plastic reservoir with the capacity to hold 1 gallon of water. The tank was originally placed in a foam board box for insulation. Insulation was later added or adjusted after initial testing to ensure proper water temperature consistency. Once the unit was fully assembled, two temperature probes were inserted, one in the collector to record air temperatures and the other in the tank to record water temperatures. The results of this data collection are displayed in graph form below (see Data and Testing).

Hypotheses

Our initial hypotheses centered on the idea that getting heat into the water would prove less difficult than retaining that heat over a longer period of time. The hypotheses we tested were:

- The angle of solar collector plays a determining role in both heating the water and in retaining that heat for a longer period of time.
- Angling the intake/output tube promotes faster water circulation which would result in more efficient heating.

- Removing insulation from the sides of the collector will allow more hot air to flow around the sides of the tubes thus resulting in better water heating.
- Insulation of the intake/output tubes has a noticeable effect upon heat retention.
- The height and positioning, relative to each other, of the hot and cold intake/output tubes will affect the heating of the water temperature.

Data and Testing

The following results were recorded using the Logger Pro lab system.

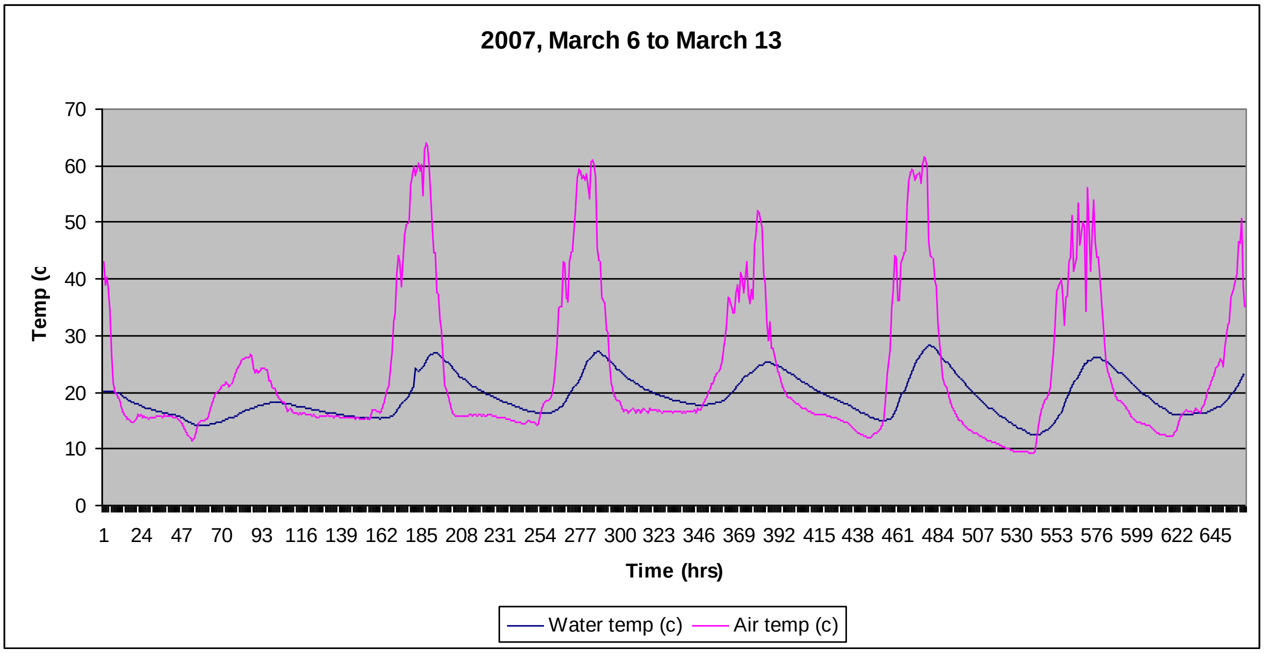
March 1, 2007

In order to get an idea of the base temperatures for day and night of the green house we ran sample test on the air and a beacon of water placed in the sun. Computer sampling worked upon set up but computer malfunction caused the data to not record correctly over the weekend.

March 8, 2007

- System is up and running
- Water temp. 29C = 84.2 F
- Air temperature 60C = 140 F

Upon arrival to the greenhouse we noticed a small leak in the storage tank. The leak was fixed and the system continued to run for the duration of the week. Air temperatures rose steadily, given appropriate weather conditions. Water temp had a delayed effect and did not rise in sync with the air. Circulation needed to be improved. Initial tests with out insulations showed steep water-cooling during night hours and therefore a need to insulate the storage tank.



March 13, 2007

- Large leak in reservoir tank (lost 1 liter of water over the weekend).
- Air temp: 50.5C = 122.9 F
- Water temp: 35C = 95 F

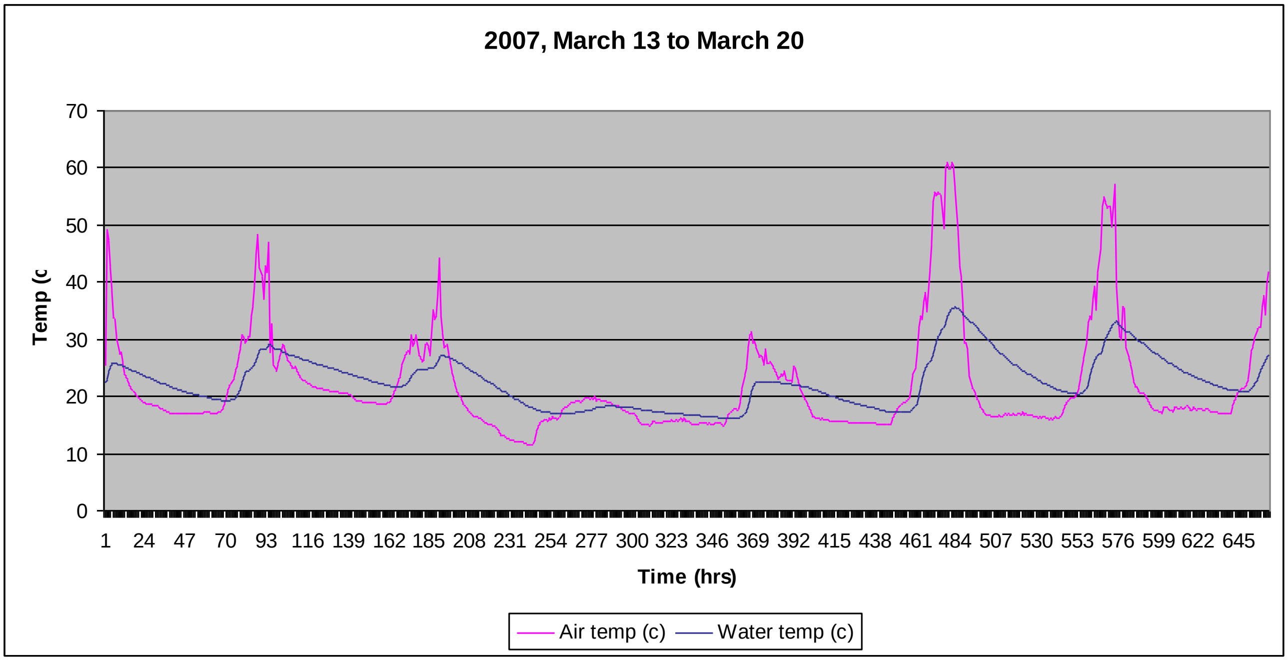
Built and installed a new reservoir and a container for the reservoir (cardboard box, lined with foam board insulation). Installed new gaskets and fittings (solved leakage problems) Spray painted the interior sides of the solar panel box black, removed insulation within box to test hypothesis, better air circulation will result in more efficient heating of the tubes.

After all leaks were fixed water temperature improved.

March 15, 2007

- Had extremely low readings due to leak and snow.

- Added insulation to hot water line, testing to see if it will help keep the hot water from cooling as it travels to the tank.

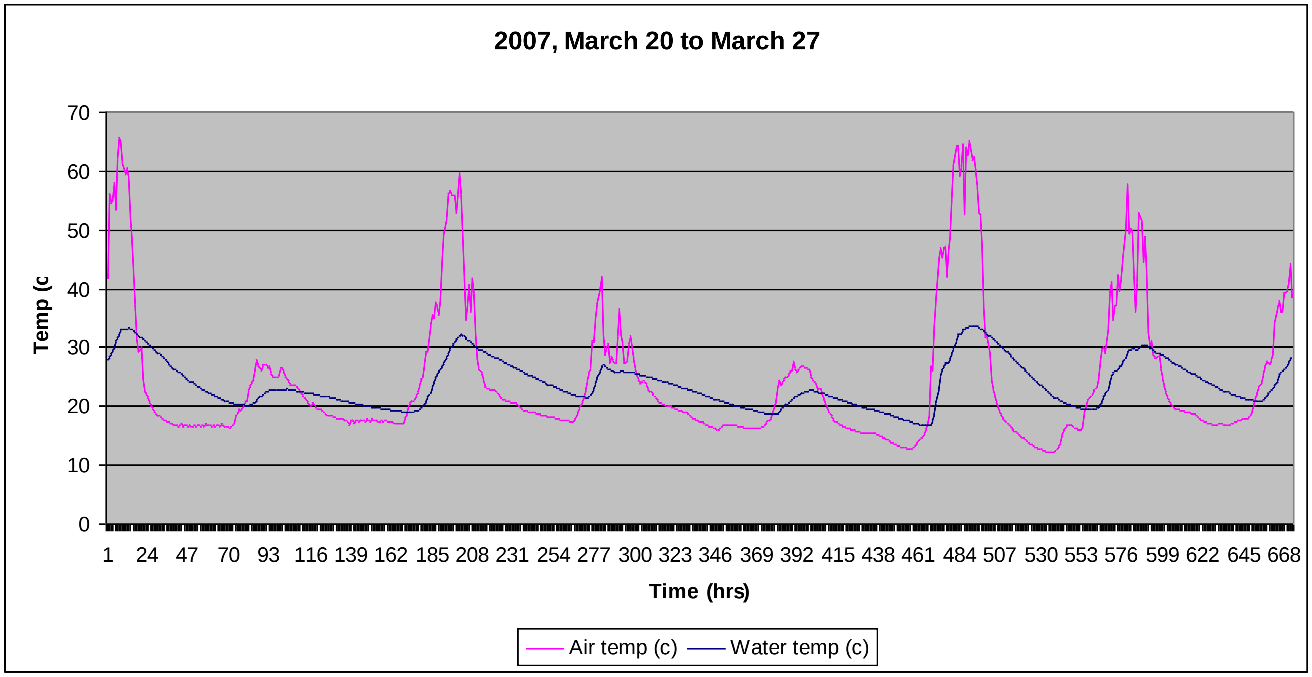


High water temperature of the week was 36 (c) – March 18, 2007

March 20, 2007

- No leaks.
- Plexi-glass had fallen off collector therefore causing insufficient heating of tubes.
- Air-51.5 C = 124.7 F (high temp. of 66 C = 150.8 F)
- Water- 27.7 C = 81.8 F (high temp. of 33 C = 91.4F)

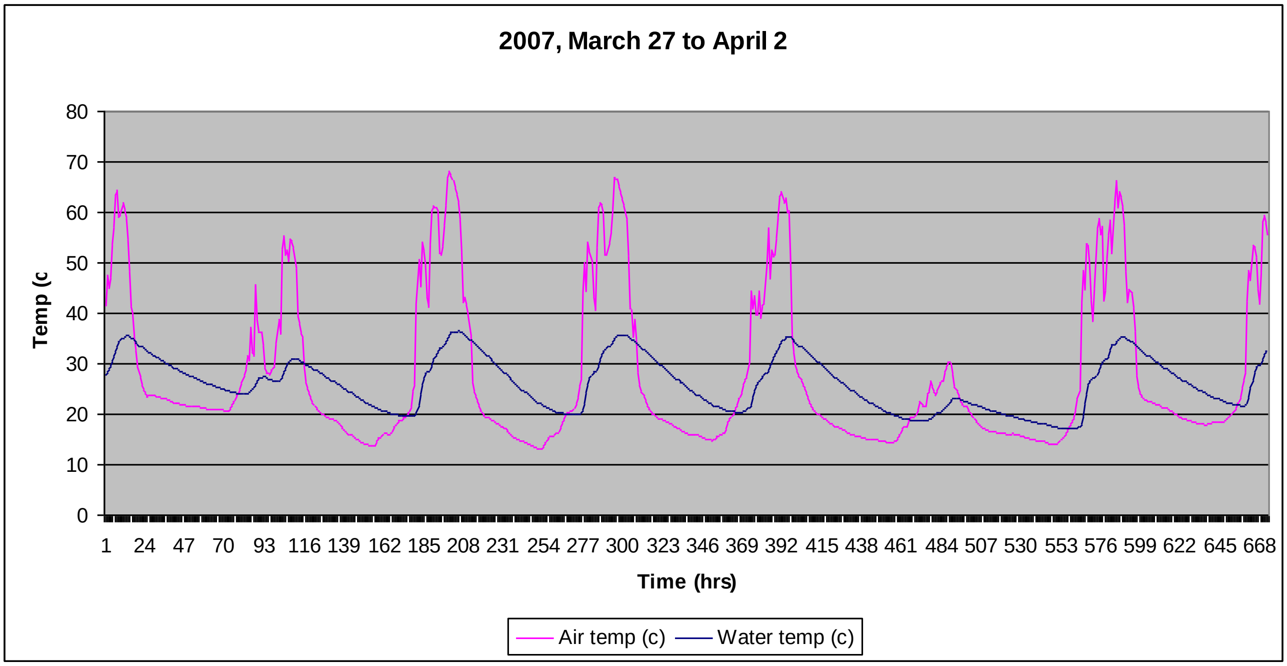
We removed the insulation on the hot water line. Insulating the tube had shown no significant improvement in the heat retention of the water. Data did not support our original hypothesis.



March 27, 2007

- Found that the hot water tube flowing from the collector to the tank was pinched causing a cut off of circulation.
- Air: 45.1C = 113.2 F (high temp. of 68 C = 154.4 F)
- Water: 29C = 84.2 F (high temp. of 35 C = 95 F)

We began testing our angle hypothesis. The collector was moved from facing west, parallel to the wall, to face the south wall of the green house in order to collect the morning and early after noon sun. We also reapplied insulation to the intake/output tubing to test the hypothesis once more.



April 3, 2007

- Water: 32.5C = 90.5 F (high temp. of 37C = 98.6 F)
- Air: 57.8C = 136.2 F (high temp. of 68C = 154.4 F)

We decided to change our tank again. We chose a larger tank and put bricks inside to cause the water column to rise higher, effectually using more space with the same amount of water (1 gallon). The intake/output tubes were placed closer together to test a second water circulation hypothesis. Our theory was that the hot water would enter the tank and then rise causing a greater water temperature differential between the cold and hot water. The solar collector was then turned upside down to see if our slanted tube design would affect the water temperature with the cold water coming in and going out at an angle. Continuing with our test of the angle hypothesis we then positioned the collector to the noon to 3pm sun. We also replaced insulation in the collector. The data did not support our hypothesis that increased airflow around the tubes would result in better water heating.

- Previous water temperature before adjustments: 38C = 100.4 F.

- New temperature after adjustments: 21C = 69.8 F.

April 5, 2007

- Water: 31.5C = 88.8 F
- Air: 38C = 100.4 F

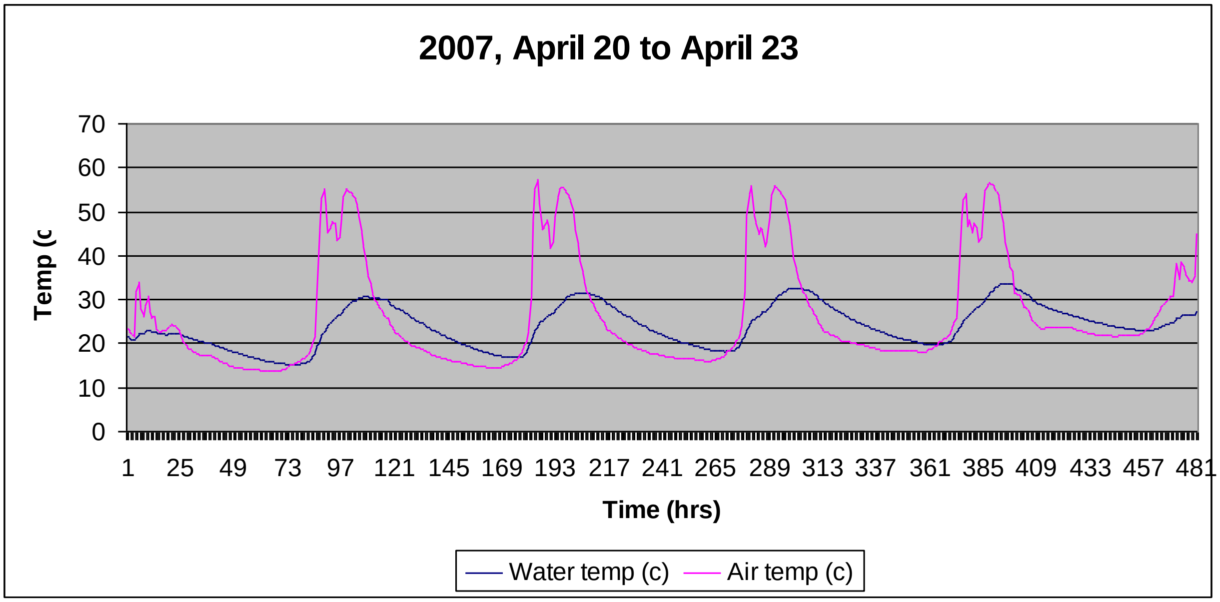
The computer malfunctioned causing us to lose data and a graph. After much tampering and rebooting the problem seems to be fixed. The water temperature rose steadily and in sync with the air temperature.

- Water: 23C = 74.6 F
- Air: 37.6C = 99.6 F

-- Spring break and a class cancellation --

April 19, 2007

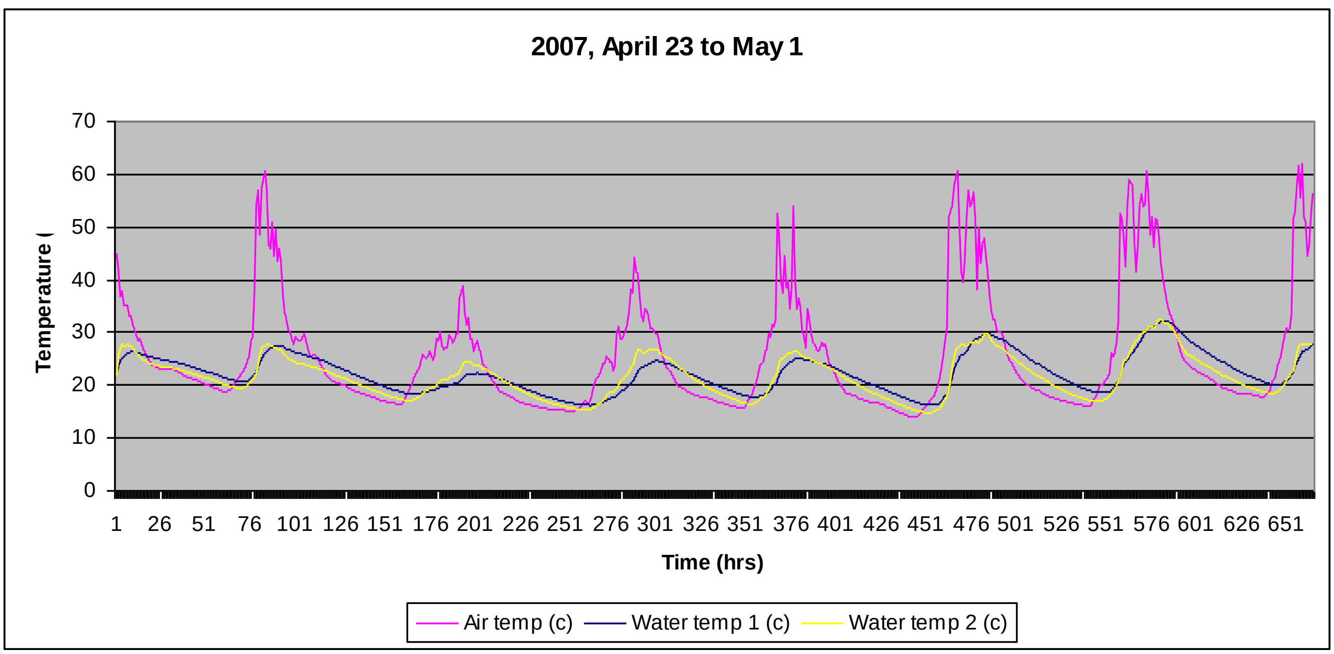
A Power outage in the greenhouse caused 2 weeks worth of data loss. Reset the computer, fixed our system and resumed data monitoring for the following days.



April 23, 2007

- Water: 28C = 82.4 F
- Air: 47.3C = 117.14 F

Despite good weather, our system did not perform as well as we had hoped for. At this point we had tested all our previous hypotheses and while the data did support our hypothesis that the angle of the collector was essential to its heating of the water, our overall temperatures were still consistently too low. It seemed as those our water was only being heated by the ambient heat of the greenhouse and not by circulating through the collector. Under the assumption that the problem was not with our collector but with our reservoir, we took down our whole system and began a side-by-side comparison test with another system. We placed our old collector with our old reservoir tank and our current reservoir tank with the solar collector from previous group. We tested both over the following week to see which setup was the most effective.



Water temp 1 is our old collector and tank. Water temp 2 is our new tank and comparison collector.

May 1, 2007

Final data collection date

System 1: Old collector with old reservoir tank.

Air: Week's high temperature was 60.8C = 141.4 F

Water: Week's high temperature was 31C = 87.8 F

System 2: Previous group's collector with our new reservoir tank.

Air: Week's high temperature was 60.8C = 141.8 F

Water: Week's high temperature was 31C = 87.8 F

Both systems performed with the same effectiveness. This data supports our hypothesis that the inability to heat the water is not a product of our collector. In examining system 2 a minor breakthrough occurred when we noticed that the water flowing between the collector and the reservoir was carrying organic matter with it. This may have caused a blockage inside the intake/output tubes which then prevented the water from circulating. We removed the blockage and setup a half and hour monitoring period, in which we noticed a drastic change in the performance of the system. It is our concluding hypothesis that an organic matter blockage inside the reservoir tank was the reason why our system did not function as planned.

A point of interest still remains in why system 1 did not function. Both system 1 and comparison system 2 were based on similar designs. However, system 1 did not suffer the organic matter blockage in the reservoir tank that system 2 did. Ultimately, we did not have the time to perform further tests so as to solve this anomaly. Perhaps later groups will be able to recreate our system and conditions and provide answers to this question.

Data Analyses

Analysis of the data we collected shows that of our five hypotheses, one was supported by the data and four were unsupported by the data.

Our hypothesis that the angle and positioning of the collector unit would affect how effectively that water heated and circulated was supported by the data. We noticed a change in temperatures from the beginning of testing collector angles. Our collector was originally set parallel to the west wall of the greenhouse. The temperatures we recorded were in the mid to high twenties (highest recorded temperature before angling the collector was 33C or 91.4 F). The first angle we tested was to move the collector to a southern facing position (exactly 55 degree pitch and 20 degree angle yaw to collect the morning and afternoon sun). Baring leaks in our system, temperatures recorded afterwards were consistently in the thirties, with a high temperature of 35C or 95 F. The following week we ran a short sampling period where we repositioned the collector, parallel to the west wall. We noticed that temperatures were again recording in the mid to high twenties. We reset for a week's worth of data and again repositioned the collector to catch the afternoon and setting sun (from 3'o clock on exactly 85 degree pitch and 33 degree yaw). From this point on, again baring leaks and other system malfunctions, recorded temperatures were consistently above 35C. We noticed that the more the collector is optimally angled towards the sun, the higher air and water temperatures we recorded. It was during this period that we recorded our highest temperature of 38C or 100.4 F.

The hypothesis that constructing our collector with one of the intake/output tubes at angle would result in faster and more effective water circulation was unsupported by the data. We began the testing with the angled tube located on the top and acting as the hot water intake/output tube. We tested the system this way for three weeks, recording temperatures ranging from 25C to 36C. On April 3, 2007 we inverted our collector and used the angled tube as the cold water intake/output tube. We ran the system like this for the remainder of the tests. Baring leaks and other system malfunctions, we recorded no noticeable temperature changes between the two methods of operation. Recorded temperatures for duration of time in which the system ran inverted ranged from 23C to 31C, giving us a 3 degree difference in temperatures between the two methods of operation. We have no data to support that this difference was due to the inversion of the system and not the result of other hypotheses (or malfunctions) being tested within the system.

The hypothesis that a collector without insulation around the sides would allow for hot air to flow around the tubes and result in better water heating was unsupported by the data. We ran our system from March 1 to March 13 with the inside of the collector, tightly packed on all sides with insulation. Temperatures were recorded ranging from 51C to 61C (air), and 25C to 29C (water). On March 13 we removed insulation from the front of the collector to allow hot air to circulate around the tubes. Temperatures rose drastically over the next week (highest recorded temperatures were 66C air and 33C water). We continued to run the system without insulation in the collector until April 3 when we replaced the insulation in the collector as a final test.

Temperatures were recorded ranging from 30C to 65C air, and 21C to 38C water. The data shows that insulation in the collector had no noticeable effect upon the temperatures, neither did we notice any substantial change in the operation of the system with or without insulation.

Our hypothesis that insulating the intake/output tubes would have a noticeable effect upon the heat retention capabilities of our system, was unsupported by the data. We began testing this hypothesis incrementally. On March 15 we covered the hot water intake/output tube with foam insulation of an R-11 value. We ran the system and recorded the temperatures. Prior to insulating the tube, the average time of heat loss was approximately 1 degree every 3 hours. After insulating the tube, the average time of heat loss was approximately 1 degree every 4 hours. It should be noted that other areas of our system, such as the reservoir tank, were insulated and thus a great deal of heat retention and loss prevention is attributable to that. This test dealt solely with any added retention of heat provided by insulating the intake/output tubes. We ran the system with the hot water intake/output insulated until March 20 when we removed the insulation from the hot water tube. After another week of data was recorded we noticed that the average rate of heat loss was still approximately 1 degree every 4 hours. We would try insulating the cold water intake/output tube and eventually both intake/output tubes, but neither test showed any change in heat retention.

Our final hypothesis that the height and position of the intake/output tubes relative to each other would affect the temperatures recorded was unsupported by the data. We built 2 different reservoir tanks, each with the intake/output tubes positioned at different heights. One tank had them separated 3 inches apart, while the other had them separated 1 ½ inches apart (for brevity's sake we will designate them Tank A and Tank B). Tank A was run from March 8 to April 3. During that time water temperatures were recorded ranging between 21C and 35C, with the average high water temperature at 30C. Tank B ran from April 3 until May 1. During that time water temperatures ranging between 21C and 38C were recorded with the average high water temperature at 29.2. The temperature difference between the highest recorded water temperatures in Tank A and Tank B is negligible (less than 1 degree of difference). The recorded data does not support this hypothesis.

Calculations

A BTU is practically defined as the amount of energy used to raise one pound of water one-degree F. Our system used 1 gallon of water. 1 gallon of water is approximately 8.34 lbs. Therefore, to raise 1 gallon of water 1 degree F, our system would use 8.34 BTUs per gallon per degree. Operating at peak levels, our system heated water from 11C (51.8 F) to 38C (100.4 F), or 48.6 (F) degrees of temperature. Heating 1 gallon of water 48.6 degrees would then use 405.32 BTUs (operating at peak efficiency). Our system ran for approximately 60 days (from March 8, 2007 to May 1, 2007). Assuming that our system operated at peak efficiency for 60 days, it would have used 24,319 BTUs.

Applied in a more practical sense, this data can be viewed as dollar savings in terms of water heating bills. Most of the fuels used for water heating are measured and sold in therms. 1 therm is 100,000 BTUs. Below are the most common sources of fuel used for home water heating, their average cost, and the amount of BTUs contained within:

Oil – 142,000 BTUs per gallon. $2.20 per Gallon

Natural Gas – 100,000 BTUs per therm. $1.34 per therm.

Electricity – 3,412 BTUs per KwH. 11.9¢ per KwH.

Due to fuel costs being determined by the amount of fuel use, a degree of assumption is necessary for the following cost savings calculations.

According to the EIA, in 2004 the per capita energy consumption for the aforementioned fuels was

Oil – 2373.24 gallons

Natural Gas – 3,370 therms

Electricity – 98764.99 KwH

This would then mean that the approximate cost of dollars per year for the above fuels would be:

Oil - $5,221.13

Natural Gas - $4,515.80

Electricity - $10,864.14

The caveat to those numbers is that they represent the total amount of money spent on the total amount of energy used and not solely the money and energy used for water heating.

According to the Department of Energy's home energy calculator, water heating accounts for 8 percent of the total home energy used. Taking the above totals for energy use and multiplying them by .08 would then give us:

Oil – 189.85 gallons at $2.20 per gallon = $417.67

Natural Gas – 269.6 therms at $1.34 per therm = $361.26

Electricity – 7,901.19 KwH at $.12 per KwH = $948.14

This number again needs to have a caveat placed upon it. The above dollar amounts represent the money saved if a passive solar water heater was used to heat the water for an entire house. This project focused specifically on a passive solar water heater as a means to heat a hot-tub.

Figures on the average hot-tub's energy use were unavailable. However, hot tub owners may find that information somewhere with the documentation for their hot tub. The calculations at that point are simply a matter of dividing the above numbers by the energy used by their specific hot tub.

Since solar energy is a free resource, a hot tub owner would effectively save that entire dollar amount, minus the price of parts and installation of the passive solar hot water heater.

Conclusions and Recommendations

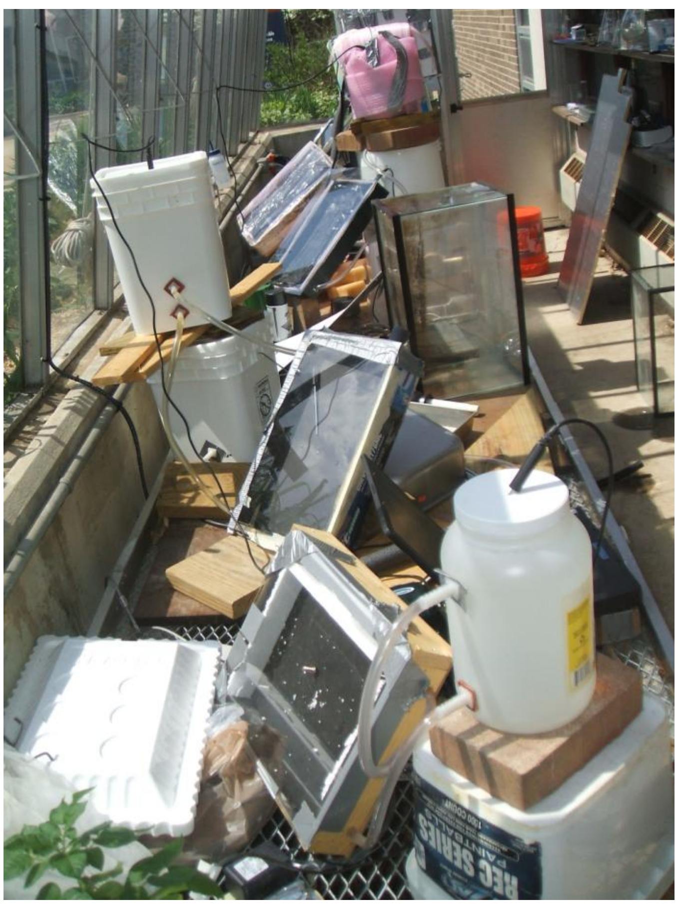
While the initial task may seem daunting, building a passive solar hot water heater is not as challenging as it may appear. Through our tests we learned that these systems have the potential to be a very effective alternative to conventional water heating methods. We would recommend that anyone attempting to follow our work and improve upon the design utilize the following information:

Placement of the system is a crucial factor in its effectiveness. Towards the end of our tests we began to notice the significant affect that even minor shadow coverage of the collector caused on the temperature of the water.

Incorporate some system of water purity control. Organic matter, even in small amounts, can build up inside the system and cause blockages.

Photos


REC SERIES
PAINTBALLS


REC SERIES
PAINTBALLS


REC SERIES
PAINTBALLS
1500 COUNT

References

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http://scithon.terc.edu/catchingsunshine/step1/WhatDo.cfm
-This article was extremely helpful explaining the details of creating a solar system and even talked about different supplies needed and why some products may be better suited for different projects.

Science Direct, “Methodology for estimation of potential for solar water heating in target Area”. (2007) Retrieved on Jan. 30, 2007 from,
http://0-www.sciencedirect.comlibrary.ccbcmd.edu/science
- Explains the thermosyphon effect, gives great detail and a good picture for a reference model. Talks about the differences between small models, such as ours, and larger systems.

Science Direct, “Thermal modeling of passive and active solar stills for different depths of water by using the concept of solar fraction”. (2006). Retrieved Jan. 30, 2007, from
http://0-www.sciencedirect.com.library.ccbcmd.edu/science
-very long article, included a lot of statistics, helpful when comparing depths of water and explaining the results of convection heat transfer coefficient.

The New York Times, “A Philosophy Built It; Solar Logic Keeps It Warm” (1993) Retrieved Jan. 30, 2007, from
http://0-proquest.umi.com.library.ccbcmd.edu/pqdweb?index=2&sid
-this article mostly talked about using solar power in ones home but some of the information was interesting and insightful. Perhaps not very useful for this particular project but was informative.

The New York Times, “ Solar Heat Unit in Use At a Pole”. (1994) Retrieved Jan. 30, 2007 from http://0-proquest.umi.com.library.ccbcmd.edu/pqweb
- This article from the newspaper, was great in explaining about the way they made their units. They used a similar design as the solar collector we are creating. Temperatures during their study were a low of (-41.6) and a high of (-14.4) degrees.

The New York Times, “Plugging Into The Sun”. (2007) Retrieved Jan. 30, 2007 from,
http://0-proquest.umi.com.library.ccbc.edu/pqdweb?index=1&sid
- Talked about the cost of installing a solar system in a house. Interestingly they also mentioned using one in a swimming pool which sparked my interest due to the nature of this project. A little helpful but not much.

Photos courtesy of Professor Jim Floyd (2007). Retrieved May 3, 2007 from,
http://student.ccbcmd.edu/envproj/jfloyd/index.htm

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