Amanecer Solar Cookers Project

Engineers for a Sustainable World

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Solar Oven Team Members

Tim Bond
Team Advisor
Manager, Winter Lab
tkb2@cornell.edu

Nicholas Chisholm
Chemical Engineering
noc3@cornell.edu

Andrew Hart
Biological and Environmental Engineering
abh35@cornell.edu

Carmen Iao
Civil and Environmental Engineering
cni3@cornell.edu

Scott Johnson
Applied Engineering Physics
srj28@cornell.edu

Kevin Kircher
Applied Engineering Physics
kjk82@cornell.edu

Jocelyn Kluger
Environmental Engineering
jmk378@cornell.edu

Harrison Ko
Biological and Environmental Engineering
htk5@cornell.edu

Selina Lok
Electrical and Computer Engineering
sl449@cornell.edu

Rustom Meyer
Biological and Environmental Engineering
rlm56@cornell.edu

Akta Patel
Biological and Environmental Engineering
app37@cornell.edu

Shane Rothermel
Biological and Environmental Engineering
sdr25@cornell.edu

Vicky Tian
Operations Research and & Information Engineering
vlt8@cornell.edu

Chris Tilger
Civil and Environmental Engineering
cft6@cornell.edu

Hywel Wong
Environmental Engineering
hw282@cornell.edu

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Introduction

In developing regions, firewood is used as main the fuel source for cooking. Since wood cooking contributes to deforestation, causes respiratory illnesses, and creates a significant economic burden for its users, our motivation is to reduce consumption of wood fuel by providing solar ovens as a feasible alternative. The solar oven team seeks to improve the current oven design and our understanding of oven performance through controlled testing. From past projects' suggestions and outside contributions, the group decided to continue work testing the 1-D scale-up, constructing a 2-D scale-up, compiling past data into a condensed form, and optimizing parabolic concentrators. We believe this semester's activities will help further the mission of the Engineers for a Sustainable World.

Construction of the 2-D Scale-up Cooker

Design: Cooking Bigger Pots

The 2-D Expansion

The objective for this semester was to design an oven that was capable of fitting the larger pots that the Nicaraguan women wanted to use. The main issue with the larger pots (below) was that they were too tall to fit in the previous design of the oven.

Therefore, we decided to increase the height of the 1-D scale up version of the oven in order to fit the larger pots.

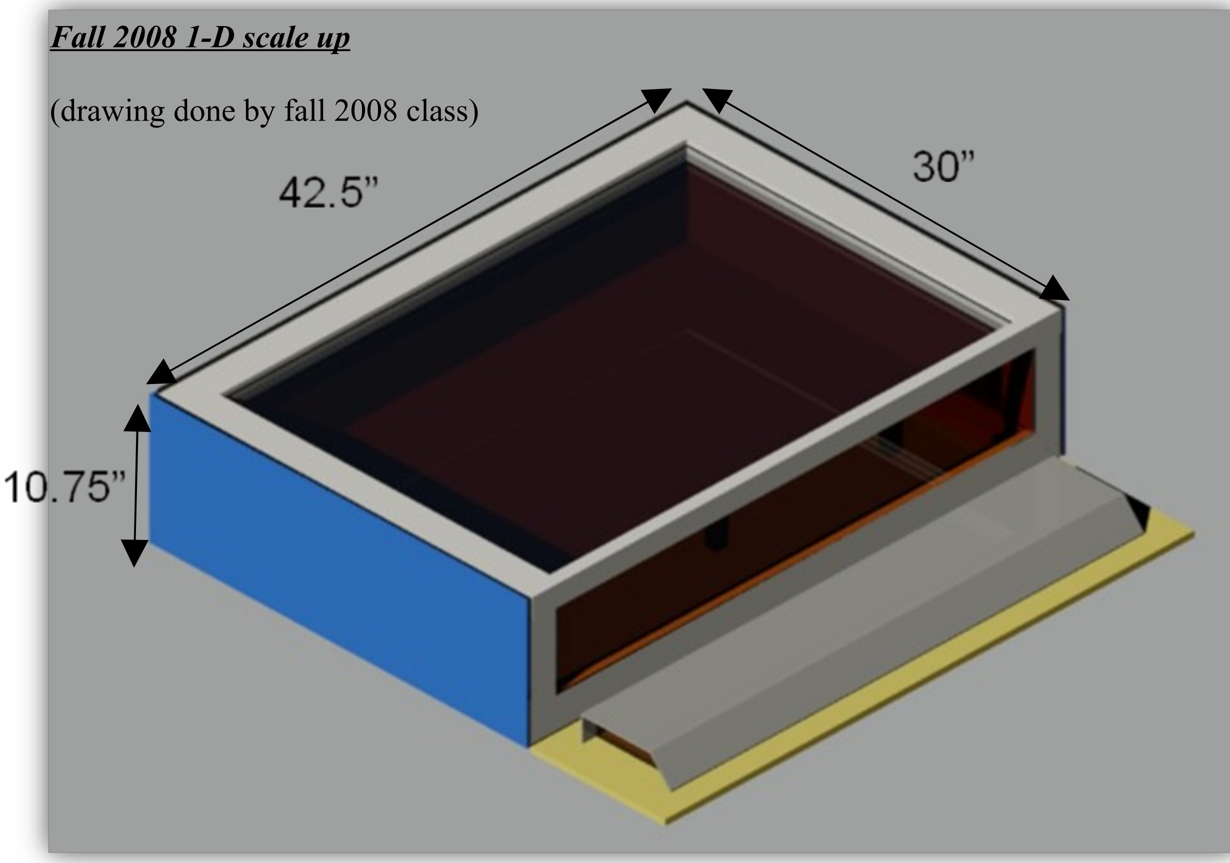

Figure 1: 1-D scale-up

The dimensions of the fall 2008 1-d scale up were 42.5” x 30” x 10.75”. We decided that in order to safely fit the larger pots, that we would increase the height dimension by four inches, resulting in the new dimensions of 42.5” x 30” x 14.75”.

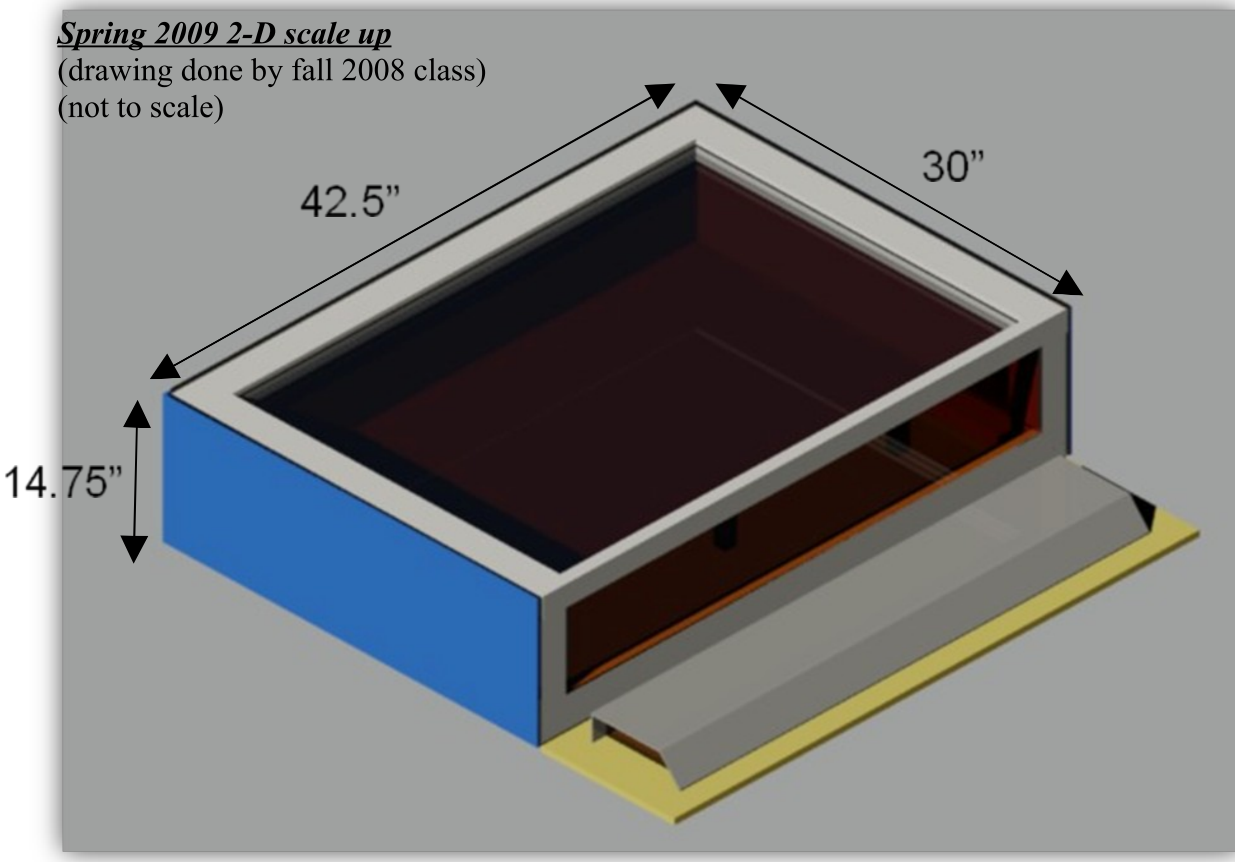

Figure 2: 2-D scale-up

We hope that by constructing and testing the larger ovens we can learn more about how sizing effects the cooking speed. While the original goal was simply to fit a larger pot inside the oven, we hope that this oven will also allow us to learn more about the heat transfer in the box cooker.

2-D Scale up Construction

To construct the scaled up box cooker, we followed a manual given to us by Grupo Fenix titled "Solar Box Cooker Construction Manual". The manual includes measurements of the individual parts of the original 30"x30" ovens currently in use in Nicaragua. It also contains a detailed set of instructions for construction. Our team determined the dimensions for the 2-D scaled up version of the oven by first measuring the 1-D scaled up oven constructed during the Fall 2008 semester. Our team combined the measurements from the oven, and the dimensions given in the manual to determine the dimensions for the pieces for the 2-D scale up.

During the construction process we tried to follow the instructions outlined by the manual as closely as possible. We also tried to emulate the way in which the cookers were constructed in Nicaragua by drawing on the experience of team member who went to Nicaragua during Spring Break. There were some differences, however, in the construction of this oven in comparison to the previous ones. The differences included using a different wood sealant, using two pieces to form each L-shaped column, using different glass, using different hinges and attaching them differently, and putting fiberboard on top of the insulation in the door.

The use of a different wood sealant was the suggestion of our team's advisor Mr. Timothy Bond. The sealant we used was "Clear Multisurface Waterproofing Sealer" by Valspar; it claims to be for severe weather. We used two-piece L-columns because cutting L-shaped columns is rather difficult and piecing these columns together from two separate wood pieces makes the construction process much easier. The glass made in the United States of America is different than obtained in Sabana Grande, Nicaragua. The hinges we used were of a different variety; their design allowed the two different sides of the hinges to be completely folded within one another when the door is closed. Also, we decided to follow the directions in the manual that suggested chiseling out a recess for the hinges in the door. This technique was not used on the previous box cookers that were constructed in the lab. The fiberboard that was added on top of the insulation on the door was more for convenience since the wood pieces we used for the support means were just a little under the desired height. We decided to add another layer on top of the fiberboard to account for this difference.

The construction process for the 2-D scale up took almost the entire semester. The main problem in the construction process was the lack of construction meeting times. While we had increased the number of tests for the semester, we only had one meeting time for construction per week for most of the semester. We switched some of the testing times to construction times later in the semester when our team realized that we needed to get the construction done. In addition, since the entire team was taking this course for independent study, it was difficult to maintain a constant level of commitment from every member of the team. Fortunately, we were able to complete the new box cooker during this semester, although we have yet to run any tests on it.

Testing of the 1-D Scale-up Cooker

This semester, the solar oven team tried to determine the significance of several different parameters on cooking efficiency. The tests involved running several "standard" tests in the 1-D scale up of the original oven and comparing their results with those from non-standard tests. The standard test involves measuring the amount of time it takes to heat 5 pounds of water in a single black pot from 40°C to 95°C, and is a simplified adaptation of the procedure outlined in a report by the American Society of Agricultural Engineers, "Testing and Reporting Solar Cooker Performance" (1). The ultimate goal of these tests was to identify the important parameters that contribute to heat transfer to the water, optimize them, and provide suggestions for improvements for future cooker designs.

At the beginning of the semester, the team listed the following parameters as ones that could be of interest: total mass of water in the oven, oven volume, oven height, distance of black plate from the lights, area of the glass, area of the black plate, the effect of wind, number of pots, pot arrangement, pot size, ambient temperature change, and inside wall temperature. Of these, the group decided to focus on changing the number of pots used in the oven, the total mass of water in the oven, and pot arrangement. By testing various pot arrangements, we could determine the optimal arrangement for cooking.

Additionally, while not recognized as a major variable in the beginning of the semester, the group had the opportunity to test the effectiveness of silicone sealing around the glass in the presence of wind. This was done using the 1-D scale up of the original oven by running a standard test with two fans either off, or on at low or medium speeds both before and after the application of silicone. If silicone were determined to be insignificant, it could be a cost cutting measure for solar ovens construction.

To make the measurements for the experiments, the three major tools used were thermocouples to measure temperatures, strain gauges to measure the strain of the glass on the inside and outside of the oven, and an anemometer to measure wind speed. Additionally, a pyranometer was used to measure the insulation at each test, though this data was not actively used in the data analysis.

Data Analysis

Notes on terminology:
Small ovens: the ovens that were built prior to Fall 2008
Medium oven: "1-D scale-up" - the oven that was built in Fall 2008, scaled up length-wise
Large oven: "2-D scale-up" - the oven that was built this semester, Spring 2009, scaled up length-wise and height-wise

Compiling Data

We collected the data from Spring 2008, Fall 2008, and this semester (Spring 2009). The new light system was built during the Fall 2007 semester, and the data in this report only considers results from tests using that light system. When tests were run, thermocouples were placed in any of several locations in addition to the water in the pot(s), which include: inside air, inside wall, inside glass, black plate, outside air, outside wall, and outside glass. Not all of these locations had temperature data taken for a given test, so the available data is scattered over those sites with many gaps in data. The past tests have been run with certain experiments in mind, but the goals of the tests were not always well documented. We have collected all the data available into the spreadsheet below tracking all the important parameters, and have also compiled the raw data (.csv or .lmv files) in case future groups want to look more closely at the specific measurements. Data was taken from several folders on three of the computers in Winter Laboratory in Thurston Hall, and the test data was located in Excel files, with descriptions of the tests in Word documents. No efforts have yet been made to sort and catalog that information systematically, which could be an issue future solar oven teams could address.

Analyzing Data

The following variables were considered when analyzing the tests:

- Total mass of water in cooker
- Cooker volume
- Cooker height
- Area of glass
- Horizontal black area
- Number of pots
- Pot size
- Pot arrangement
- Wind speed
- Silicone caulking

The following data was also recorded for the tests when data was available:

- Inside wall temperature at water temperature 40°C
- Inside air temperature at water temperature 95°C

These variables were compared amongst the different tests to determine the effect each had on the time to heat water from 40°C to 95°C. For most tests, one of the above variables was varied while the others were maintained constant. We have collected and graphed sections of the data that reveal how cooking time varies as a function of some parameters.

Black Horizontal Surface Area

The effect of horizontal black area was determined by analyzing the tests that had changed the black area in some way. Different tests were: standard (black lid on pot, no area covered), half black plate, no black plate, in addition to silver lid on pot. These tests were run in Spring 2008 with the smaller cooker with 1 pot of 5lb water, centered. As hypothesized, increasing black area decreases time to cook.

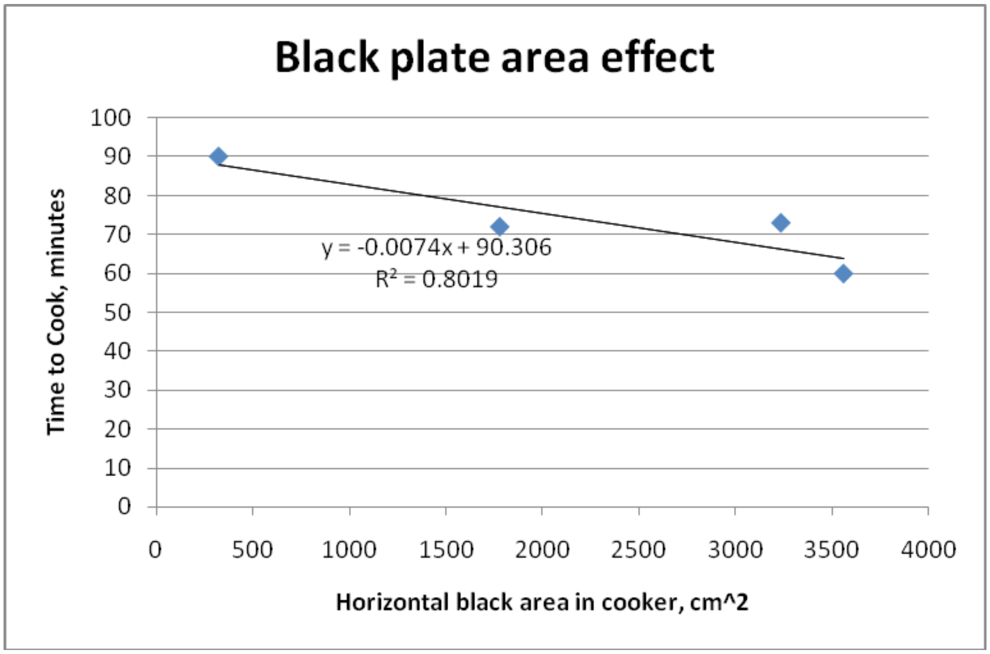

Figure 3: Effect of horizontal black area

Number of pots

This graph shows the effect of splitting up 5 pounds of water into one, three, and five pots. These tests were run with the smaller cooker. The time to heat up the water decreased as the water was distributed into more pots.

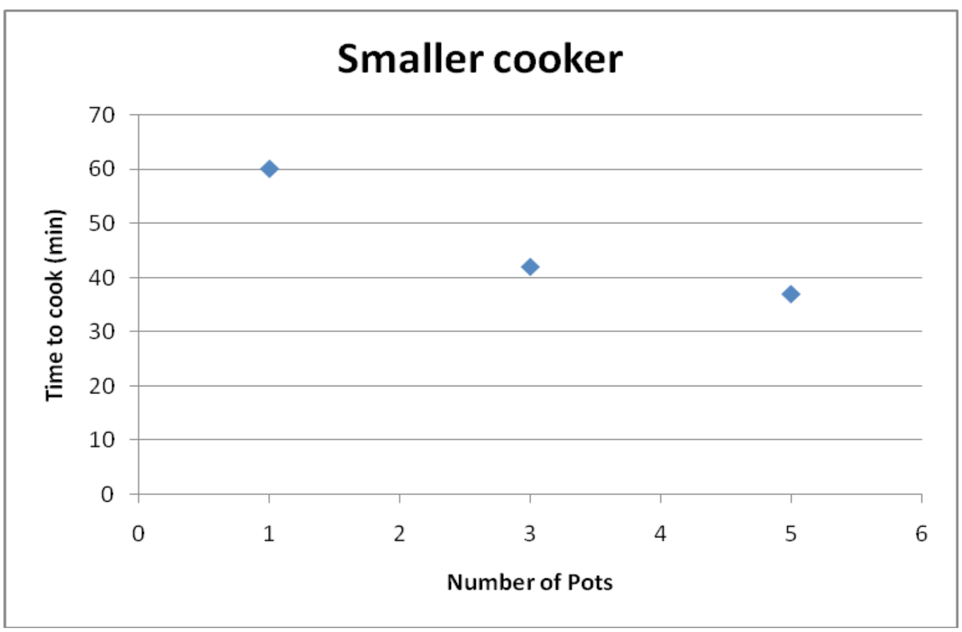

Figure 4: Effect of splitting a constant amount of water into multiple pots.

Silicone vs. No Silicone (No wind)

The tests were done with the medium cooker built in Fall '08. Each test had 5lb of water in 1 pot, centered. Tests were run to assess the significance of adding silicone caulking on the outside and inside glass panes.

The time it took to run a standard test without silicone is 51.9 minutes, which falls between the 95% confidence interval of the tests with silicone, between 50.16 and 52.89 minutes with a mean of 51.53 minutes. Therefore, there is no statistically significant difference at a 95% confidence level. However, we ran only one test in the without silicone no wind condition and this may contribute to the statistical insignificance.

Tests with Silicone, no wind	Time (min)
Average of the standard tests with silicone	51.525
Standard deviation of standard tests with silicone	1.391342
Significance level	0.05
Confidence	1.36349
Confidence interval	50.16-52.89

Wind Speed

The wind speed tests were conducted with the medium cooker built in Fall 2008. Each test had 5lb of water in 1 pot, centered. Theoretically, the water should take longer to heat when the fans are blowing across the oven. Unexpectedly, the water heated up faster on the medium fan setting than the low setting, although this is likely statistically insignificant and more tests are needed to arrive at more conclusive results.

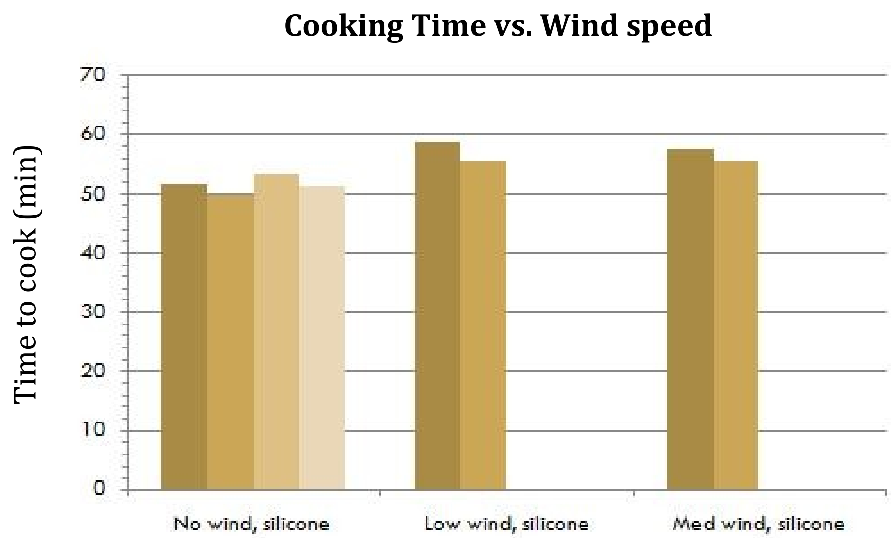

Figure 5: Effect of wind speed on cooking time

Oven Capacity

Oven capacity tests were conducted with the medium cooker built in Fall 2008. The pots each had 1lb of water in them and they were centered. Three tests were run: 1pot with 1lb of water; 2 pots with 1lb of water each; 3 pots with 1lb of water each.

The data indicated that more water takes longer to heat. However, for the tests that were run with 1, 2, and 3 pots, the results showed that they are still within the optimal range. If the mass of water is doubled, time to heat is not doubled. Diminishing marginal return has not taken effect yet. More tests are needed to determine the capacity function, and at what point it is faster to cook two quantities of food or water serially rather than at the same time.

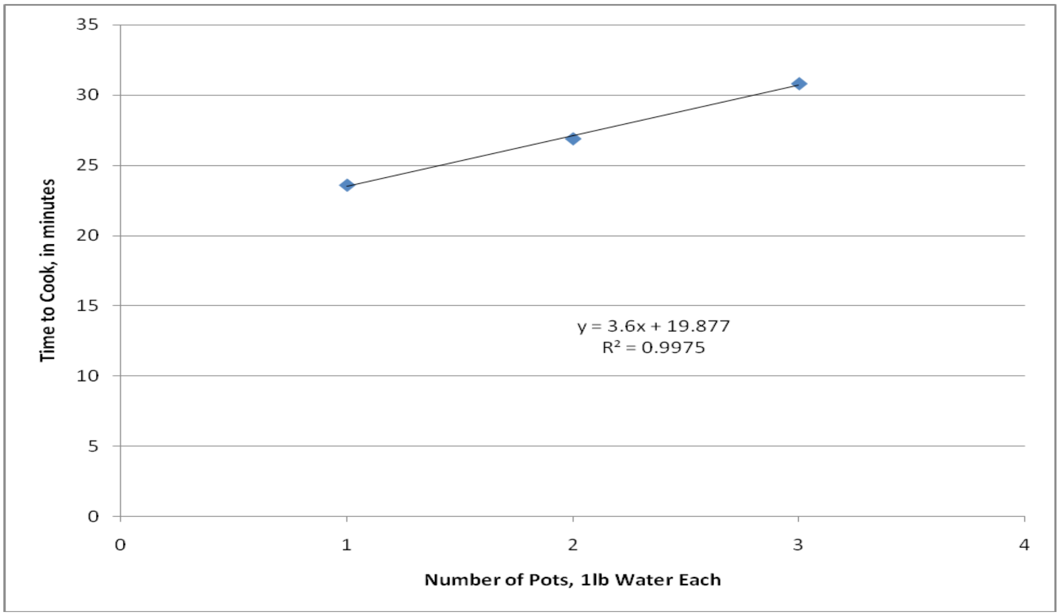

Figure 6: Effect of increasing volume of water in oven on time to cook (done by increasing number of pots with 1lb water each).

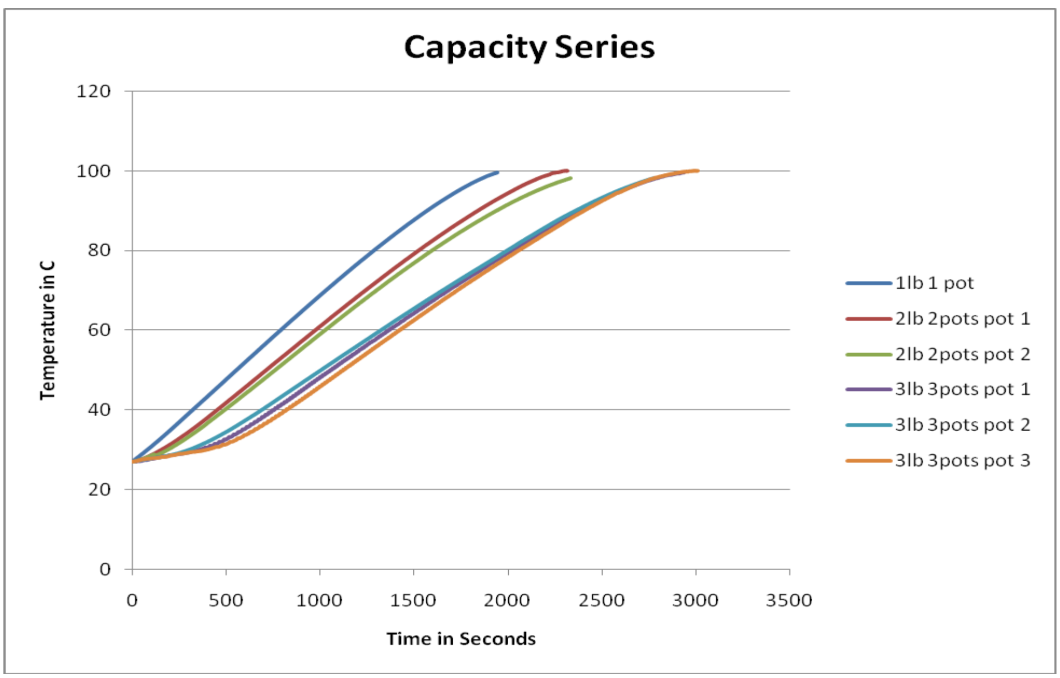

Figure 7: Time course of temperature change of water for three tests: one pot, two pots, and three pots. Each pot had 1lb of water.

Strain Gauges

This semester we decided to attach strain gauges to the large solar oven in order to characterize the strain of the glass over a range of temperatures. We used strain gauges from Vishay® Micro-Measurements. We want to characterize the glass, because the users in Nicaragua have had problems with glass cracking and breaking. The gauges come in pairs, with each pair measuring strain in perpendicular directions along the surface. We attached one of these pairs to the top glass outside the oven, one on the bottom glass inside the oven, and one on a piece of thermally neutral material. The purpose of the thermally neutral material is to calibrate the strain gauges for the strain of gauge itself due to thermal expansion. We can subtract the strain reading from the thermally neutral material, from the readings of the other surfaces to obtain measurements of the actual strain.

After several experiments, we believe the cycling of temperature changes caused the gauges to become detached from the surfaces. The strain gauges that were in the oven started producing data, which looked like it was from a strain gauge with a bad connection after two or three experiments. The strain gauge on the top of the oven continued to give good data for a few more experiments. This is probably because the temperature range on the outside glass is less than that of inside the oven. The adhesive we used was M-Bond 600 from Vishay®. We were able to collect some data, but we do not have enough data from the thermally neutral material to analyze the data from the inside and outside glass.

We have another adhesive we want to use to bond the gauges to the glass: Omega® OB-200. This adhesive is designed to go through thermal changes, so we think that it will last longer than the M-Bond 600. Next semester we plan to attach another strain gauge pair to the thermally neutral material, inside glass and outside glass and collect enough data to figure out what the strain of the glass is as a function of temperature.

The graphs below show some of the curves obtained from the strain gauge data before the gauges wore off:

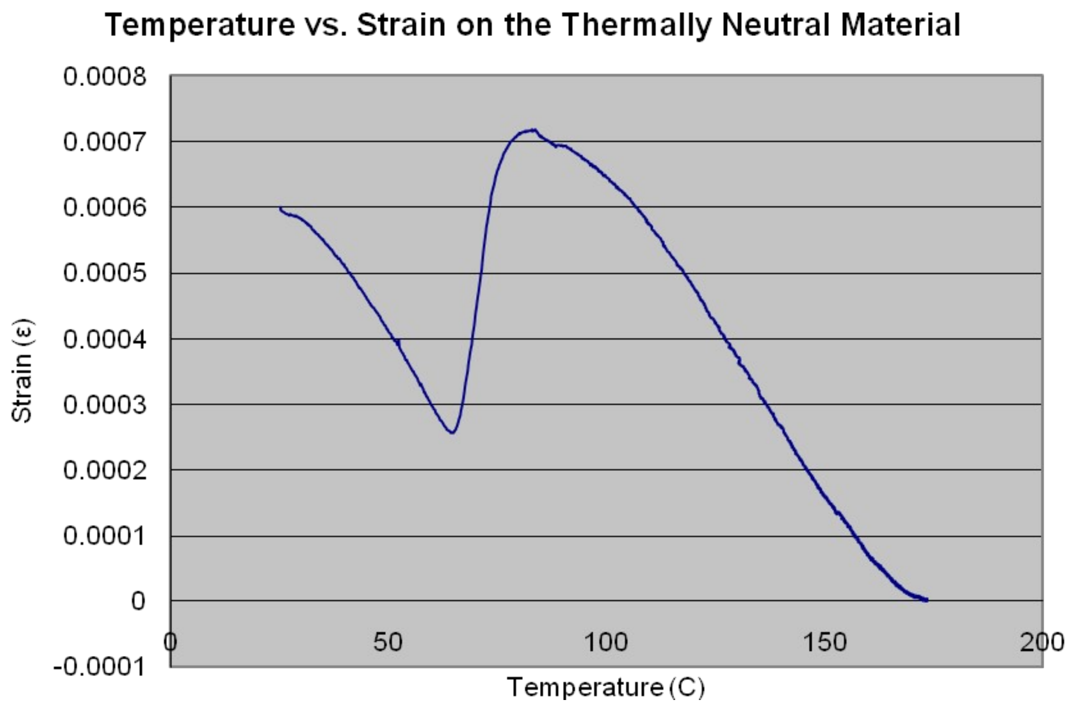

Figure 8: A curve of the strain reading of the thermally neutral material, which we could use to characterize the strain gauge over a wide temperature range. 2/6/09

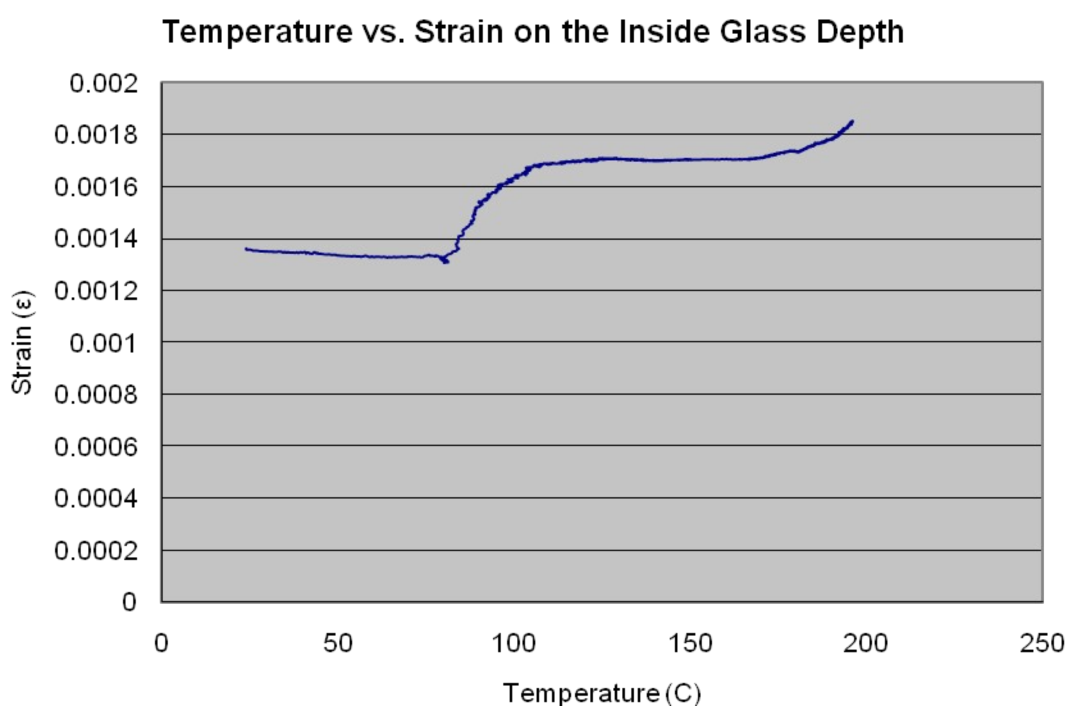

Figure 9: A graph of the strain of the inside glass in the depth direction. 2/6/09

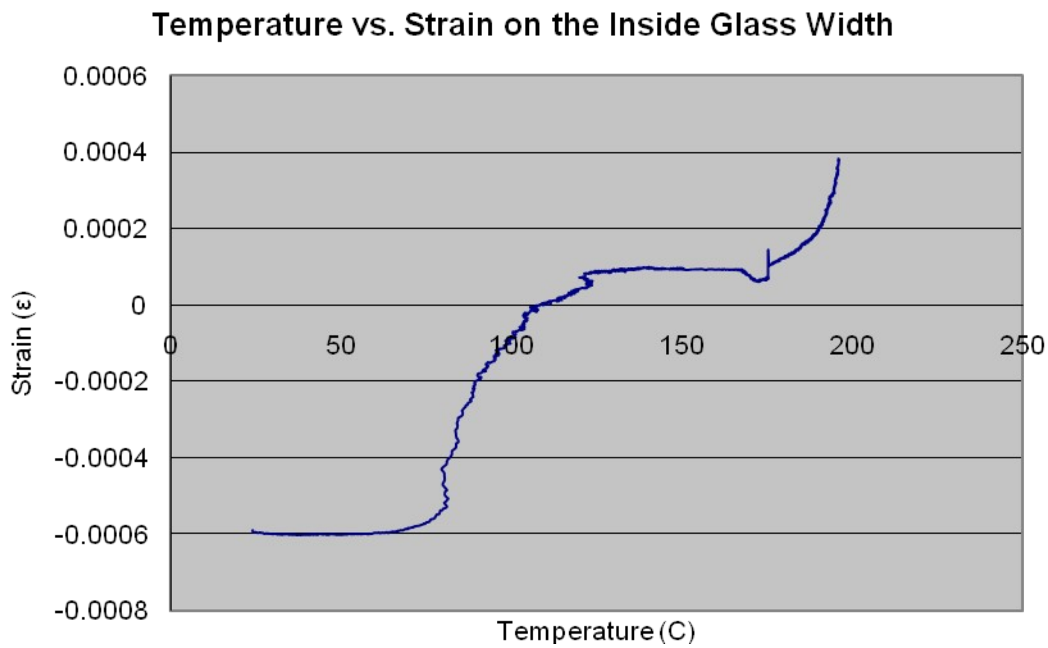

Figure 10: A graph of the strain of the inside glass in the width direction. 2/6/09

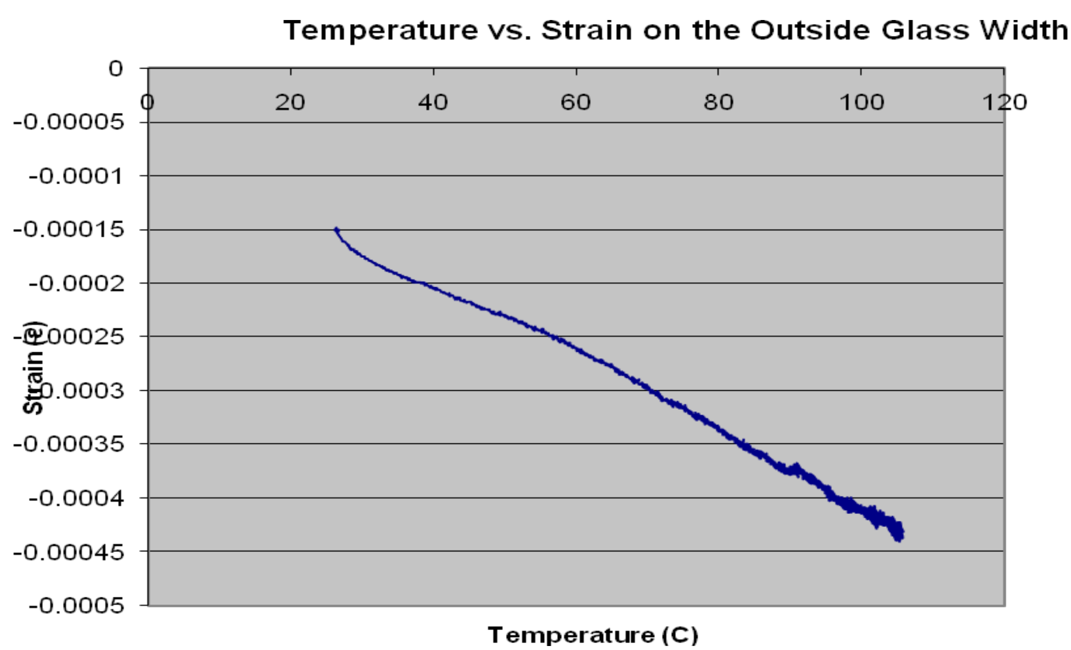

Figure 11: A graph of the strain of the outside glass in the width direction. 2/6/09

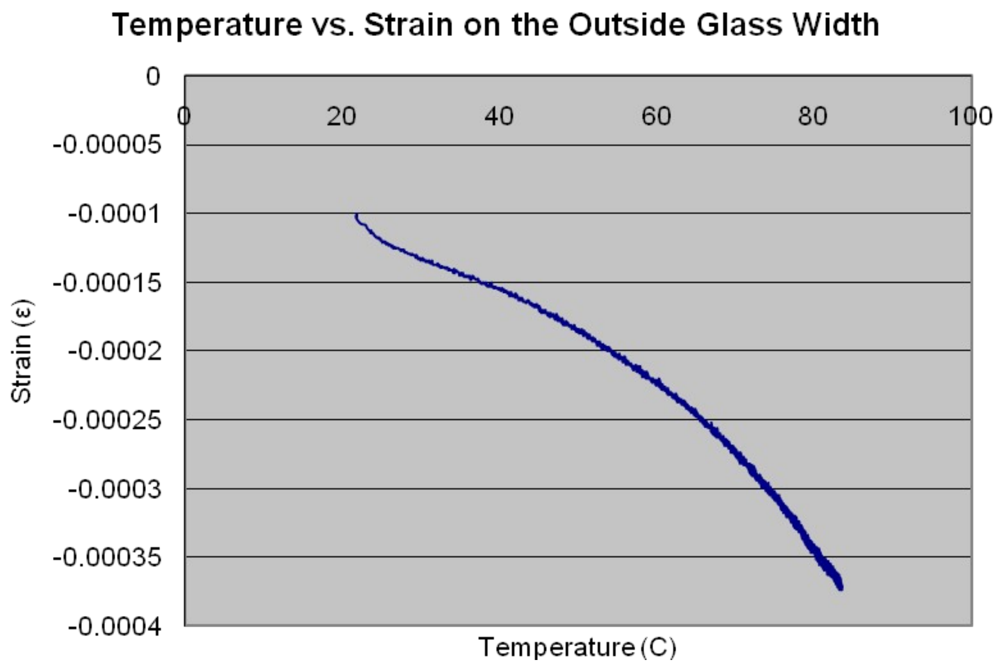

Figure 12: Another graph of the strain of the outside glass in the width direction. 2/8/09

Paint Test Repeat

In the Fall of 2008, the Solar Ovens team performed a test aimed at discovering an appropriate and effective means of preventing paint from peeling off the steel framing of the box ovens. While this test led to interesting and useful results, it was done with a U.S. variety of oil paint that differs slightly from the paint used by las Mujeres Solares. Having procured a sample of the Nicaraguan paint, the Spring 2009 Solar Ovens team repeated the paint test.

The procedure from the Fall 2008 test was followed as closely as possible; please see the Fall 2008 report for exact details. The differences between the Spring 2009 paint test and that of the Fall 2008 were:

1) Use of Nicaraguan paint in place of U.S. oil paint

2) Use of ammonia in place of baking soda as neutralizing agent

3) Use of different roll of duct tape (possible variation in adhesive properties)

In addition to corroborating the Fall 2008 results, the Spring 2009 team sought to determine the effect of hand oils on paint adhesion. To do the hand oil tests, we prepared 8" by 1" columns of the surface with one of the pretreatments considered (control, sanding, and phosphoric acid) as described in the Fall 2008 procedure, and then rubbed our fingers (neither recently washed nor particularly oily) on each column for approximately two minutes.

Results of the Fall 2008 and Spring 2009 paint tests are summarized below. The error bars on both charts represent 95% confidence intervals.

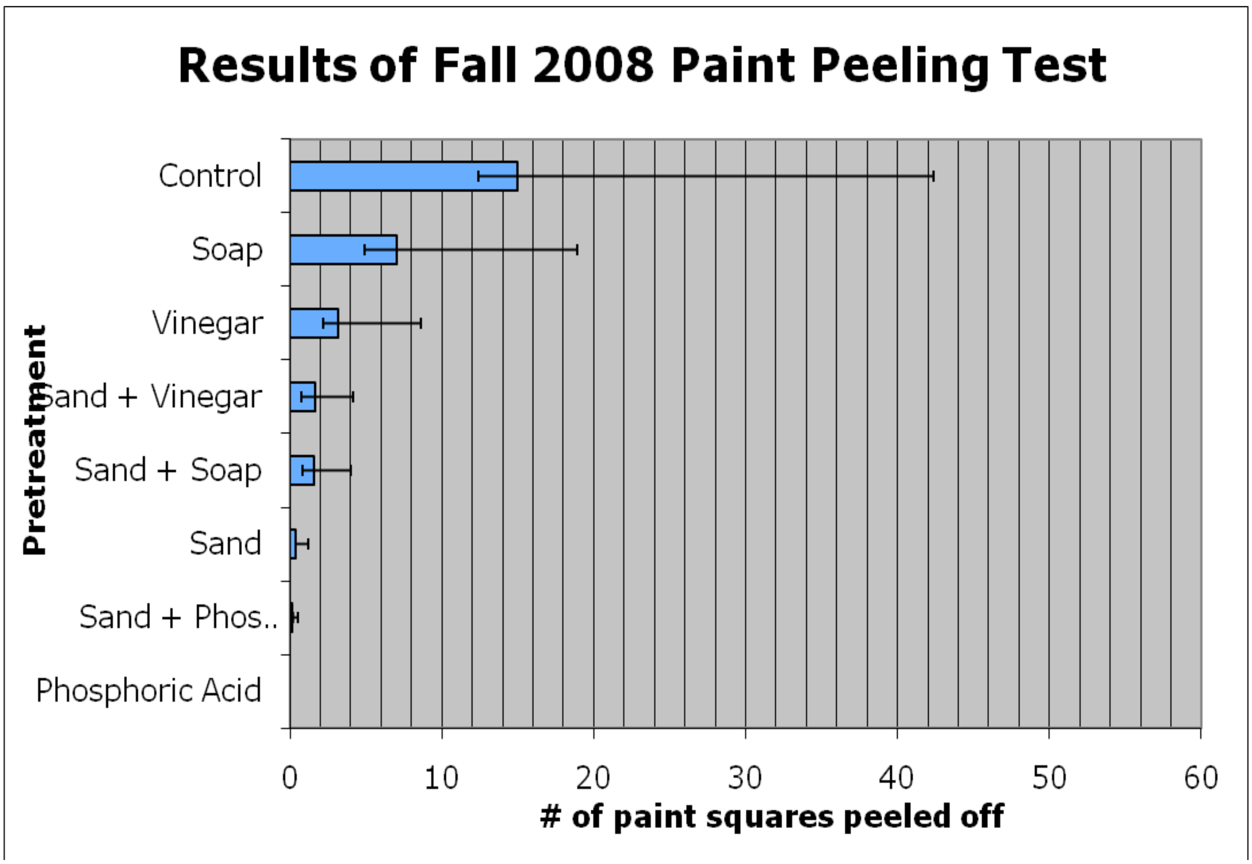

Figure 13: Adhesion of paint with different pretreatments.

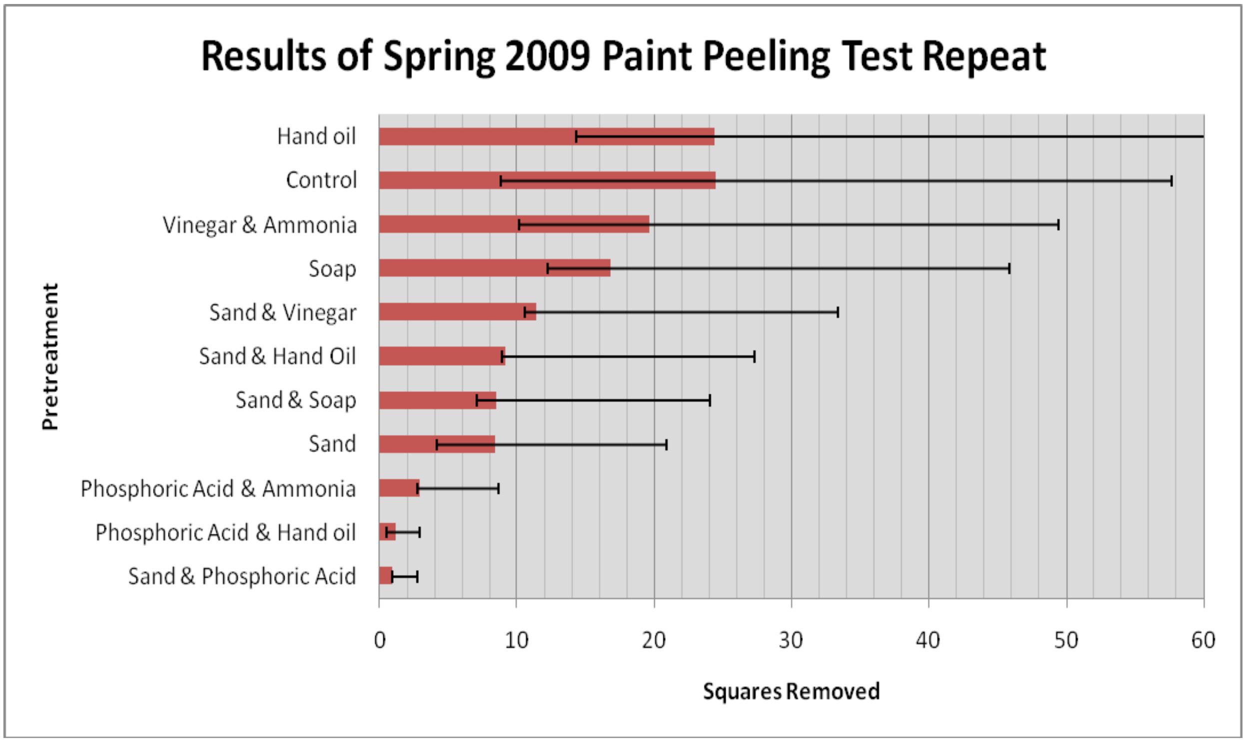

Figure 14: Adhesion of paint with different pretreatments.

Table 1 compares the results of the 2008 and 2009 paint tests. Here we define adhesion, *a*, as

$$a = 1 - N_{removed}/N_{total}$$

where $N_{removed}$ is the number of squares removed, and N_{total} is the total number of squares in our grid (64 in this experiment).

Table 1: Comparison of paint test results

Pretreatment	2008 Adhesion	2009 Adhesion	Variation
Control	76.6%	61.8%	14.7%
Soap	89.1%	73.7%	15.3%
Vinegar	95.0%	69.3%	25.7%
Sand & Vinegar	97.3%	82.2%	15.1%
Sand & Soap	97.5%	86.7%	10.8%
Sand	99.4%	86.9%	12.5%
Sand & Phosphoric Acid	99.8%	98.5%	1.2%
Phosphoric Acid	100.0%	95.4%	4.6%

It can be seen that the general trends of the 2008 test were reproduced: phosphoric acid performed the best, with no statistically significant difference between the trials with and without sanding. Although sanding did not perform as well in the 2009 experiment as it did in 2008, it was still the second best pretreatment with an adhesion 25% better than the control group.

It is worth noting that all pretreatments in the 2009 experiment displayed significantly poorer adhesion values than they did in 2008, with an average downward shift in adhesion of 12.5%. This is likely due to the change in tape; the 2009 duct tape, of which we ran out, was noticeably stickier than its 2008 counterpart was.

Finally, the experiment was inconclusive as to the result of hand oil on adhesion. In the case of no pretreatment, hand oil had no discernable impact on adhesion. In the case of phosphoric acid, hand oil increased the adhesion by three percent. In the case of sanding, hand oil decreased the adhesion by one percent. None of these differences are statistically significant; however, as they all lie well within the confidence intervals of their respective treatments. It appears that a more sensitive test would have to be developed to detect the effect of hand oil on paint adhesion.

Parabolic Trough

Objectives

The idea behind a solar trough system is multifaceted, but hinges on the concept of concentrating solar radiation with a minimum amount of effort required by the user when the device is in operation. A trough design utilizes the planar path of the sun and does not have to be adjusted every few minutes if it is oriented in the east-west direction. Therefore, a parabolic trough system could prove beneficial to families that have other obligations throughout the day and cannot continually monitor another type of device.

The trough could be set up to perform a variety of tasks including:

- Heating a thermal transfer fluid in a hot plate cooking device with a continuous heat transfer loop.
- Providing thermal energy to a continuous pasteurizer of water.
- Providing the energy input to a heat engine coupled to one of a variety of useful devices.
- Concentrating ultraviolet radiation on water, thereby irradiating pathogens.

The majority of the work this semester was performed on a system that exploits the energy absorptive properties of a black pipe at the focal line of a trough to heat water to a high enough temperature to enable pasteurization. Throughout the semester tests were run to compare the theoretical and observed values of energy absorption to assess the operating efficiency of a rather basic system. A thermostatic valve was also constructed and incorporated into the trough system to monitor the temperatures at the completion of the pasteurization process.

Trough Description and Construction

The parabolic trough (shown in Figure 15) that was used as a testing apparatus throughout the semester was constructed in the Fall 2008 semester as a side project to the solar oven team. From the onset, the trough was designed to have an incident area of one square meter, which would provide enough energy to power a water pasteurizer targeted for family use. In order to determine the length and width of the system, a quick optimization was performed to minimize the usage of materials. Dimensions of the trough that was constructed are displayed in Figure 16. A longer, narrower trough uses less structural and reflective material but more pipe and will not reach as high a temperature as a short, wide trough. The materials used in construction include: plywood, 2x4 boards, aluminum sheets, reflective Mylar, a steel pipe threaded on both ends, and a variety of highly available fasteners.

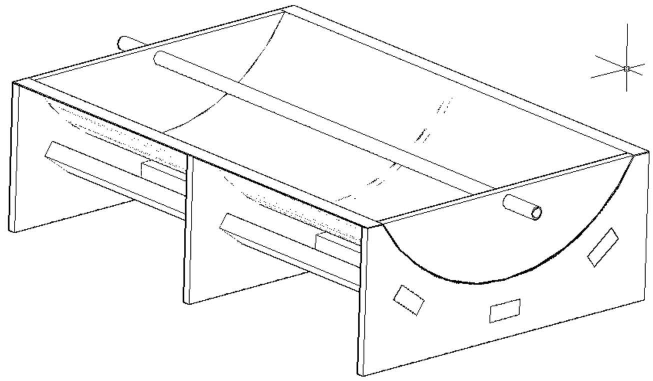

Figure 15: Parabolic Trough Isometric View

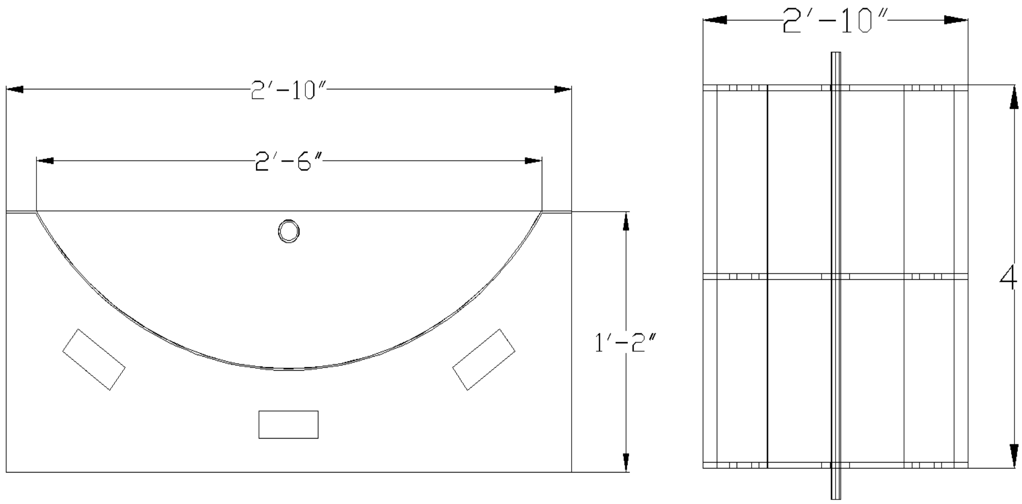

Figure 16: Parabolic trough dimensions.

Energy Absorption

Although the constructed parabolic trough system intercepted one square meter of solar radiation, there are complications associated with assuming the widely accepted sunlight irradiance of 1000 W/m^2 being perfectly converted to thermal energy at the black collecting pipe. The tests for energy absorption were performed over a series of days with differing sunlight intensity levels, all being less than the 1000 W/m^2 as measured by a pyranometer on the trough. New Mylar can be assumed to perfectly reflect the incoming light to the focus of the trough; however, the parabolic shape is not absolutely perfect and scatters a significant portion of the incoming light, in addition to the fact that the Mylar has been slightly degraded due to mechanical and ultraviolet wear throughout its life. When the sunlight finally reaches the pipe, the black paint coating can be assumed to convert the light to heat, but also reflects a significant portion to the surroundings. Because of these inefficiencies, it was necessary to test the overall solar energy to thermal energy conversion properties of the system.

Description of Test and Results

The black collecting pipe was filled with water and capped at both ends. In order to make a variety of measurements of the system, thermocouples were placed at four locations on the steel pipe and three locations within the water, leaving the last of eight channels on the computer for the pyranometer described before. The steel pipe thermocouples were placed mid-pipe and the water thermocouples were placed at the quarter length, mid-span, and three-quarter length inside the pipe. The tests were run on mostly sunny days, where the likeliness of a cloud disturbing the measurements was insignificant. In order to determine the temperatures of the steel and water for the energy equations, the four measurements for the steel and three measurements for the water were averaged using an arithmetic mean. Care was taken to isolate the steel pipe thermocouples from the wind, which was noticed to greatly affect temperature readings. The water thermocouples were also checked to verify that they were not touching the steel pipe before each test, as that would lead to overestimation of the water temperature.

The following results average five of nine tests that had enough sunlight to heat the water in the system to boiling and no equipment or experimental failures were observed. The excluded tests had variety of setbacks including clouds blocking the sun, thermocouples becoming unattached, and data logger problems that prevented proper recording of data.

Table 2: Measurements and values used.

Mass of Water	0.793 kg
Mass of Steel:	4.669 kg
Average Irradiance:	918 W/m^2
Heat Capacity of Steel:	500 J/kg^0C
Heat Capacity of Water:	4180 J/kg^0C

The time versus temperature curves for heating water from 30 °C to 100 °C along with the surrounding steel heat absorber pipe are plotted in Figure 17.

Since the pasteurizing device will be operating in the full range of temperatures tested, a first-order slope approximation was fitted to both the water and steel curves in order to determine the temperature change over time.

Table 3: Summary of test results

Initial Temperatures	**Final Temperatures**	**Time Period**
Water: 30.13 °C	Water: 95.05 °C	1125 seconds
Steel: 36.54 °C	Steel: 96.78 °C	
Slopes	**Heating Power**	
Water: .0577 °C/second	Water: 191.3 watts	
Steel: .0535 °C/second	Steel: 124.9 watts	

These calculations yield a total realized heating power for our system of 316.2 watts, a 34% efficient conversion of sunlight to thermal energy. With this conservative estimate of power, the estimated water pasteurization ability of the device was 4.19 liters/hour. Since these tests were run during winter days with low ambient temperatures, this value likely represents the lower estimate of the power of the device.

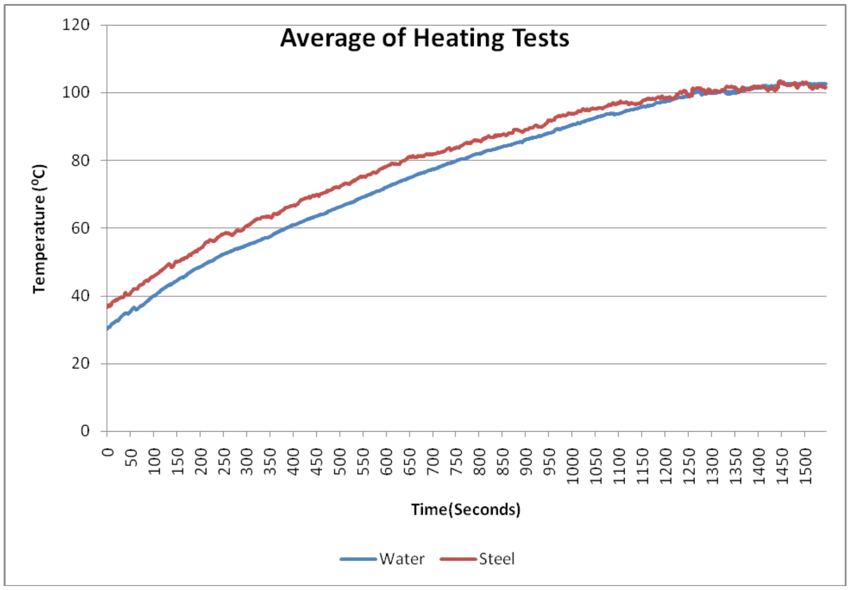

Figure 15: Temperature curve for trough absorber

Valve

Throughout the design process of the parabolic trough system, different options for a thermostatic valve to control the temperature and flow of water from the terminal end of the device were investigated. The initial idea of constructing a novel design using the properties of bimetallic materials as a thermometer was largely abandoned after it was realized that widely available automobile thermostats would provide a similar function. A manufacturer of thermostatic valves was also contacted for a quote, $112, which turned out to be prohibitively expensive for the application of this project.

A quick water tightness check of the thermostat purchased at the local automotive parts store showed that the device leaked around a metal on metal contact point within the device. Since the thermostatic valve needs to be absolutely watertight to avoid allowing unpasteurized water into the pasteurized water reservoir, a modification was needed to prevent this leak. The application of the silicone used to seal the box cookers formed a quasi gasket that prevented any water from leaking around the internal parts of the thermostat.

The thermostat purchased is rated at 91°C, which was later verified to be the temperature the device begins to open at. In the system, the valve remains shut during periods when the water has not reached a high enough temperature to be considered safe. However, once the water reaches 91°C, well above the pasteurization temperature, the valve begins to allow the flow of water into the clean reservoir. If the system falls below this temperature, the valve closes again, and the water will not pass until the system heats back up. With the thermostatic valve and the geometry of the trough, this device can be completely passive, and purify water throughout the day without human intervention.

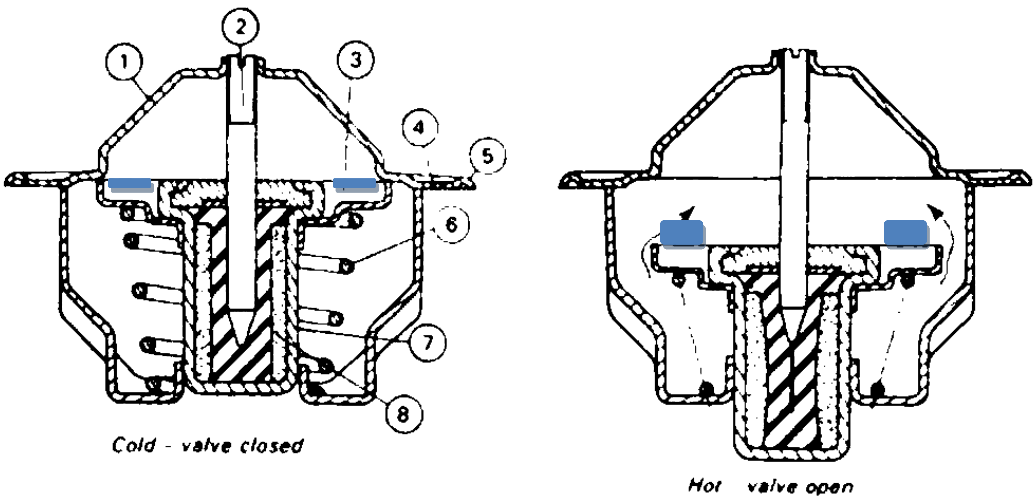

Figure 18: Schematic of Modified Thermostat. The blue blocks represent the silicone "gasket" addition to the thermostat.

Water Flow and Temperature

In order to verify the functionality of the parabolic trough as a pasteurizer, it was necessary to determine the temperature of water released from the system and the steady state flow rate that could be realized by the system. It is important that the temperature within the absorber is maintained at a high enough temperature to destroy pathogens contained in the water flowing through the absorber pipe.

Using the calculations discussed in the section above, the conservative estimation of the steady state water flow rate is about 4.2 liters per hour. Figure 19 displays temperature data recorded and plotted as temperature versus time. Initially the absorber was not purged with water resulting in a high temperature recorded for the air in the absorber. Since the thermal conductivity of air is significantly lower than water, it took approximately 30 minutes for the valve to open even though the valve is rated to open at 91 °C; the air temperature near the valve was near 110 °C.

Once the valve opened, the back pressure of the system needed to be adjusted in order to reach steady state. If the pressure on the outlet side of the valve is not adjusted, the temperature of the water near the valve rises to approximately 102 °C, the valve opens and the water is rapidly expelled from the system, and then the valve closes. The system operating in this fashion does not reach steady state. In order to reach a continuous flow, the pressure on the outlet side of the valve must be adjusted to reach steady state and a continuous flow rate. When this was done, a sustainable flow was achieved around 52 minutes into the experiment and was maintained until the end of the experiment at 75 minutes. Constant flow would have been maintained as long as solar irradiance was maintained at a similar level. The flow rate was calculated to be 465mL over a five-minute time span, which is equivalent to 5.58 L per hour. In addition, water was calculated to be at sufficient pasteurization temperature for a period of approximately 81 seconds before exiting the system.

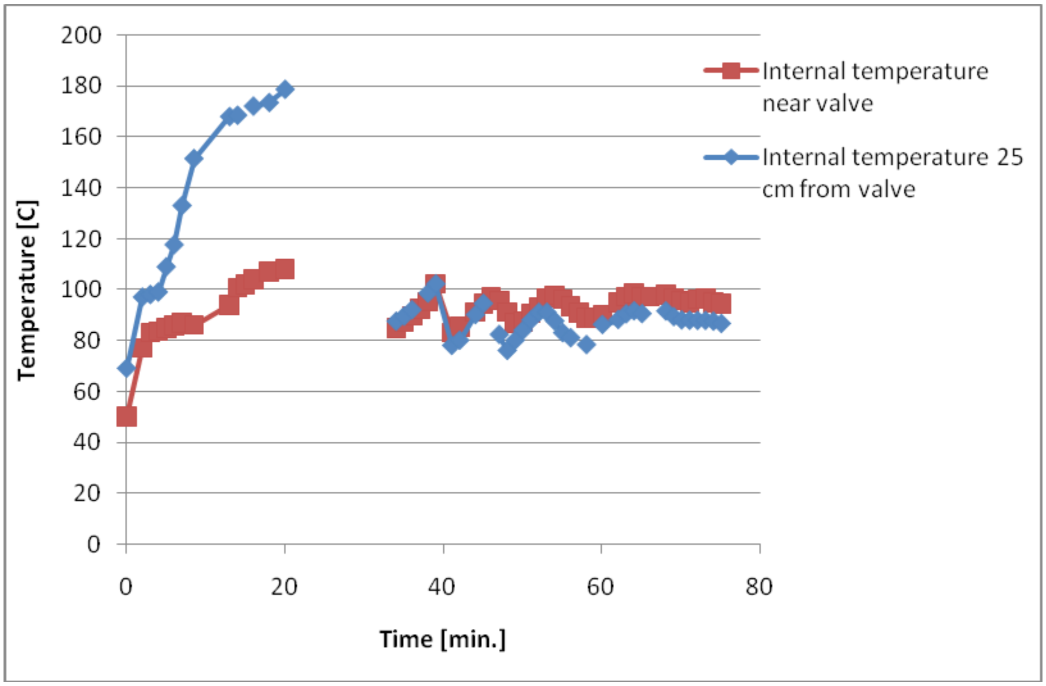

Figure 19: Plot of temperature versus time for the water pasteurization trough system. The red data points indicate internal temperature near valve and blue data points correspond to temperature readings 25 cm from the valve.

Power Cycle

We started our exploration of creating a thermal to mechanical energy system by analyzing the model Rankine cycle. The only design parameter that we could determine was the energy input due to the parabolic trough. We needed to find a way to convert the thermal energy to mechanical energy. We began with a few centrifugal pumps that we thought might spin if we applied a pressurized vapor through them, thus acting as a turbine. The pumps that we found were too large for any practical design for our system scale. For example, we analyzed a submersible well pump, but found that it required too great of a mass flow for use to consider it as a viable option. It was also determined that it is difficult to find a small scale turbine to used on a small system, and that a turbine may not be the best conversion device for a system of our scale. This led us to consider a standard reciprocating engine or a steam engine as the thermal to mechanical conversion device for a small system. We are currently in need of a reciprocating engine to test this type of design. Perhaps a two stroke weed-whacker engine would suffice, which we will determine in the next few months.

Recommendations

In response to the suggestions made by the previous team, we have successfully completed the construction of a 2-D scaled model and conducted numerous tests on the 1-D scaled oven. In spite of the substantial progress made, there are definitely areas for improvement as well as new ideas that are worthy of future consideration as project goals. In addition, our trip to Nicaragua over Spring Break proved to an invaluable opportunity for knowledge transfer, as members of both sides exchanged ideas and talked about problems with the oven that can be addressed by future project teams.

Improving the Reflector Prop Rods

While in Nicaragua, we discussed possible problems that the women might be having with their ovens. They happened to mention a problem with a component of the oven that we have worked very little with at Cornell, the reflector prop rods. The women mentioned that they could not use their box cookers during higher levels of wind since the wind would blow their reflectors shut, rendering the box cookers useless. Since we do most of our testing in the lab, we do not usually need to even construct the reflector since the lighting system is directly above the oven that is being tested. However, we feel that it is important to tackle this problem as a future project. It will be very important not only to come up with new designs for the prop rods, but also to devise a method for testing their ability to support the reflector during increased wind levels.

Testing

More testing on the 1-D scaled oven should be run to determine the oven capacity. Number of pots and mass of water in each pot could be varied for these tests. Similar tests should be run to determine the oven capacity for the smaller oven and the 2-D scaled oven.

Wind speed tests should be performed on the large oven to better determine the effect of wind speed, and wind speed with or without silicone caulking. A good number of tests should be run without wind to get standard data. Then wind speed could be varied to low, medium, and high, as indicated on our fan, before silicone caulking. Then with silicone caulking, wind tests should be performed again on no wind, low wind, medium wind, and high wind.

When not doing the oven capacity testing, water less than the standard 5 lb should be used to reduce cooking time, and hence to speed up testing.

Thermocouples

New thermocouples should be purchased, as many of the current ones are malfunctioning.

Additional Glass Strain Testing

The problem with breaking glass persists even with the bigger grooves in the new design. A possible future goal would be to get the strain gauges to adhere to the glass properly for data collection. We have another adhesive we want to use to bond the gauges to the glass: Omega® OB-200. This adhesive is designed to go through thermal changes, so we think that it will last longer than the M-Bond 600. Next semester we plan to attach another strain gauge pair to the thermally neutral material, inside glass and outside glass and collect enough data to figure out what the strain of the glass is as a function of temperature.

Lighting System with Parallel Rays

As mentioned in the previous final report, a lighting system with parallel rays would be desirable for testing the parabolic cookers. Adding lenses onto the halogen lamps seems to be a reasonable option for now. It would be a potential project for the future teams to look into adjusting the lighting system.

Parabolic Trough

There are countless areas of small-scale solar capture that could use a parabolic trough to provide their input energy. In order to keep this project targeted on a few specific goals, the following topics of future research are suggested:

- Further refine the water pasteurization system to a degree where its operation is straightforward and intuitive.

- Investigate the coupling of the water pasteurization system to a UV irradiating system that first passes the water and highly concentrated sunlight through a clear pipe that does not attenuate a significant amount of UV rays. The water and majority of the initial light then could continue to the pasteurization system noted above for an enhanced purifying effect.
- Research the solar to mechanical energy transfer device further to determine whether a feasible device could be constructed and whether its complexities are too burdensome for the Solar Oven Group.

Conclusions

This semester the ESW solar oven team worked on quite a few projects, and increased the solar cooking knowledge base. We completed construction of a larger box cooker, which is scaled up in two dimensions from our standard model. This cooker is a prototype for a new model of cooker, which Mujeres Solares can use, with larger pots of food. The cooker is also useful as research equipment, which will allow future teams to better understand the interplay of factors such as convection in the transfer of thermal energy to food.

Using the indoor lighting system, we tested the effects of silicone sealer, wind, and pot arrangement on cooking time in the 1-D scale-up cooker, as well as running a large number of ‘standard’ tests to determine standard deviation of a ‘standard’ test.

Through analysis of all the tests which have been run on solar box cookers in the Spring 2008, Fall 2008, and Spring 2009 semesters, we determined the following; increasing black plate area decreases cooking time, splitting food into more pots makes it cook faster, there was no statistical difference between time to cook with and without silicone sealer around the glass in the cooker, and tests of the effect of wind on cooking time gave inconclusive results. Additionally, it takes much less than twice as much time to heat twice as much volume of water in a cooker. Similarly, it took much less than three times as long to heat three times as much water. This suggests that cooking multiple dishes at once is a more efficient use of time than cooking them serially.

Our strain gauges malfunctioned, and our results for the measured strain in the glass are inconclusive.

We repeated the Fall 2008 tests on the effects of pretreatment on paint adhesion to galvanized steel, which is the kind of metal used on the exteriors of the ovens. The new test used the exact kind of paint, which Mujeres Solares uses on their ovens. We found results similar to the Fall 2008 test; namely, phosphoric acid is best, sanding is second best. Sanding is a more available and cheaper pretreatment than phosphoric acid, so we will continue to recommend sanding the ovens prior to painting them. However, our tests found no statistically significant difference in the effects of hand oil, applied by touching the metal after pretreatment and prior to painting, so we should probably revise our recommendation that the Mujeres Solares be careful not to touch the metal prior to painting, since effects of hand oil seem to be negligible.

A parabolic trough, which was constructed last semester, was tested for its capacity to pasteurize water. It is capable of pasteurizing at least 4.19 L/hr of water, which makes it practical as a small-scale supplier of drinking water. The feasibility of using the solar trough to power an engine was also investigated.

Much progress has been made this semester; however, what we know about solar cooking is still dwarfed by what we do not know. Our research has uncovered many new questions (see recommendations section) which can be investigated by future teams.

Bibliography

American Society of Agricultural Engineers. *Testing and Reporting Solar Cooker Performance.* s.l. : American Society of Agricultural Engineers, 2003.

http://images.brighthub.com/40/4/40492773A15DA9BFA73EC78A48046AC352135A39_small.jpg (Image for Figure 18).