Final Report

Engineers for a Sustainable World: Solar Ovens Team

Due Date: December 10, 2010
Team: Solar Lovin'
Class: CEE 4920 – Engineers for a Sustainable World

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Executive Summary

The solar box cookers currently used are known to have issues with performance after a year of operation due to the wood shaving insulation. The objective was to design an experiment that would be effective in comparing alternative materials that would not be prone to degradation. The experiment consisted of an insulated box with an internal heat source that forced heat transfer through one wall filled with the experimental insulation. The results suggest that the experimental method was successful and fiberglass insulation proved to be the most effective, while wood shavings and rice hulls appeared to be comparable, but less effective.

After previous parabolic cooker designs were researched, a new concentrated cooker was designed. The cooker's reflector was built along with a supportive wooden framework. Ideally, the cooker would effectively heat its focal point to 250 degrees centigrade (the temperature needed to fry tortillas, a staple food in Nicaragua). However, testing showed that the reflector reached 150 degrees centigrade, the equivalent temperature produced by the conventional box-cookers. Had the tape holding the temperature probe not melted, the cooker might have met the goal of 250 degrees centigrade. Future testing will need to occur to gain a more definitive conclusion.

Current solar oven designs only work in laboratory settings under artificial light. New small solar ovens were designed and constructed so the ovens could reach temperatures high enough to cook food using the sunlight at the Ithaca solar elevation. Though testing has not yet occurred, the team is confident that the oven will perform as expected. Additionally a side project was taken on to address the problem that prop rods on Nicaraguan ovens were breaking. Several designs were developed and will be used on new ovens and to retrofit old ovens.

Introduction

As this semester's Solar Oven team we have contributing to four years of research dedicated to designing, building, and testing solar ovens for use in the third world. Our team's mission was to improve and optimize solar oven designs in order to provide a cheap, sustainable, easy alternative to cooking with wood-burning stoves. The Solar Ovens Team is partnered with Grupo Fenix, an organization from the Universidad Nacional de Ingeneria in Nicaragua that works toward educating people in rural Nicaragua about the relevance of renewable energy sources. Solar Ovens reduce the need for women to spend hours of their day gathering resources that will later be burned, as well as reduce the health risks from smoke inhalation due to improper ventilation. The vast use of wood for cooking and other daily activities is a major cause of the current deforestation in this region.

The Solar Ovens Team also works with Las Mujeres Solares de Totogalpa, a women's organization in Sabana Grande, Nicaragua. We worked this semester to maintain our good relationship with these women. Through regular communication, they were able to provide feedback on our designs and the team was able to work to improve these designs to make the solar ovens more effective and easy to use.

Various members of the Solar Cooker group have traveled to Nicaragua five times since the project began in 2006. They have closely worked with Grupo Fenix and Las Mujeres Solares de Totogalpa and have helped build at least two new cookers on each trip. The trips have been very beneficial to the progression of the project because these cookers act as test beds for evolved design ideas from the members of Las Mujeres and the Solar Cooker group at Cornell University.

In the Fall of 2010, various tasks needed to be accomplished. In order to maximize productivity, the Solar Ovens group was split into separate subteams. Based on the interests of each individual team member, his/her relevant skills and background, and the various potential projects, three subteams were formed that worked independently. However, to promote overall group unity and to maintain communication, the entire team held one general meeting a week. This time was used to update each team member on the progress of other subteams and to give team members the opportunity to have input in all areas of the project. Additionally, in order for each team member to become accustomed to using a solar oven, a different member cooked dinner for the entire team using the oven each week. Learning how to operate the oven will gave each team member a better understanding of how to make design improvements that will help tobetter the "solar oven experience" for the Nicaraguan women.

The three subteams our team divided into were (1) Insulation (2) Concentrated Cooker and (3) Small Solar ovens. The Insulation Team's primary focus was to improve existing design and the longevity of the solar oven; the Concentrated Cooker Team looked to design a new oven that can reach higher temperatures and thus can be used for more applications; and the Small Solar Oven Team has worked to make a small scale oven suited for the Ithaca solar elevation so that the technology of the solar oven can be easily demonstrated to the Cornell and Ithaca community, promoting awareness. Together the Solar Oven Team has worked to increase Solar Oven usage by creating sustainable solutions that are culturally acceptable and desirable.

Team Members

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Delegation of Team Members to Tasks and Other Roles

1. Team Leader: Harrison Ko
2. Insulation Subteam: Sarah Clement, Harrison Ko, and Julianne Schwartz
3. Concentrated Cooker Subteam: Margaret Ding, and Catherine Hanna
4. Small Solar Oven Subteam: Joe Beaudette, Lauren Nielson, Leif Paulson, and Rachel Philipson
5. Webmaster: Julianne Schwartz

   https://confluence.cornell.edu/display/SolarCooker/Home+ESW+Solar+Ovens
6. Liaison with NGO: Sarah Clement
7. Report Compilation
   a. Weekly Report sent to Professor Richardson: Rotates each week
   b. Literature Review Presentation: Harrison Ko, Catherine Hanna, Lauren Nielson, and Julianne Schwartz
   c. Project Written Proposal: Rachel Philipson and Julianne Schwartz
   d. Project Proposal Presentation: Rachel Philipson
   e. Short Technical Update Written Report: Catherine Hanna and Margaret Ding
   f. Short Technical Update Presentation: Catherine Hanna and Margaret Ding
   g. Final Project Written Report: Rachel Philipson and Julianne Schwartz
   h. Final Project Presentation: Catherine Hanna and Margaret Ding
8. Meeting Minutes: Julianne Schwartz

Insulation Subteam

Description of Problem

The insulation in the solar box cookers plays a vital role in performance. The current insulation technique involves using wood shavings to fill the airspace in the side walls and in the bottom of the box cooker. This is done to reduce the convective heat transfer in the walls and floor of the oven. While this is currently the practiced technique for insulation, based on the experiences of the women in the Nicaraguan communities, the box ovens perform better during their first year of operation than in the years after. One of the theories associated with the diminished performance of the ovens over time is that the constant heat flow through the walls causes the insulation to settle to the bottom, and at that point the insulation would no longer be preventing convective heat transfer in the upper regions of the wall. With an expected life of 10-12 years, diminished operation after the first year is an issue that must be analyzed.

In the previous semester, the team devised a preliminary scheme for testing the insulation. The basic concept of the scheme was to isolate one wall of a solar oven. This would be accomplished by essentially insulating five faces of the solar oven significantly more than the sixth face (the experimental wall). Therefore, the vast majority of temperature change inside of the oven could be associated with the less insulated experimental wall. While the previous team established a basic concept for experimentation, our objective for this semester was to develop a concrete method for comparing insulation performance for use in the solar box cookers.

Methods

Experimental Design

In order to simplify the analysis of the experimental data, heat transfer was isolated to a single wall of a solar oven. As depicted in Figure 1, the experimental unit consisted of an insulated box with a heat source inside. In order to ensure that any significant amount of heat transfer only occurred through the experimental wall, five of the six sides of the experimental oven were designed to have a thermal resistivity roughly ten times greater than that of the experimental wall. This ensured that the heat inside the box would then travel through the path of least resistance, the less insulated experimental wall. The experimental wall was designed to mimic the walls of a conventional solar oven and allowed for interchangeable insulation types for testing.

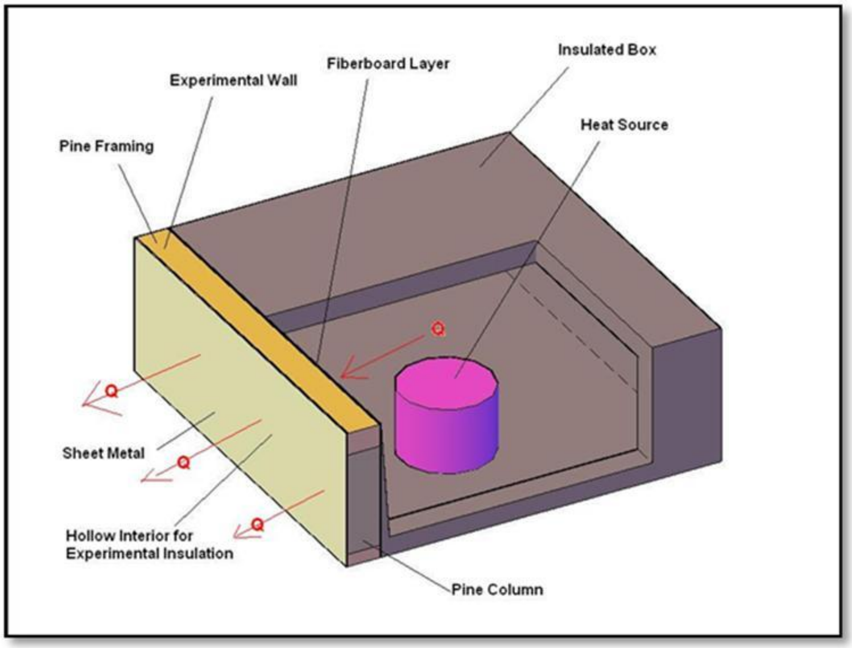

Figure 1: Concept Drawing

Construction

Ideally, the performance of experimental unit would closely resemble that of the real box ovens in terms of the relevant mechanisms for heat transfer out of the box. To mimic these conditions as closely as possible, an old 30in x 30in box cooker was used as an internal casing for the heat source. The old box cooker had one open face where the oven door used to be that was the location of the experimental wall. The old box cooker was then enclosed on five sides in an outer frame made of plywood and connected by metal brackets. The airspace in between the old box cooker and the five sides of the outer frame were filled with three inches of mineral wool. These faces served as the five overly insulated walls of the experimental unit. The final side, which replaced the door of the oven, was constructed using the same materials as an ordinary box oven wall, except that it was designed to allow for an easy change of insulation.

In order to make the insulation inside of the experimental wall easily interchangeable, a decision was made to rotate the oven so the experimental wall sat on top of the oven as opposed to the side (Figures 2a and 2b). In the original orientation, the experimental wall would have to be secured to the side of the oven, making it inconvenient to change the insulation material. With the new orientation, the experimental wall does not have to be attached to the oven. Rather, weights were placed on top of the experimental wall to give it a tight seal.

Figure 2a: Old Oven Orientation

Figure 2b: New Oven Orientation

The heating system inside of the experimental oven was programmed to reach a user defined temperature differential. It consisted of four 500-Watt halogen light bulbs. All materials placed inside the oven were able to withstand the high temperatures during experimentation. The bulbs and wiring were attached to and held in place by two bricks, a material that could withstand high temperatures. All of the wiring from the lighting system ran out of the oven and was plugged into a controllable energy source.

The measuring and control system that was used was able to on power for the heating lamps until the air temperature inside the test box reached a specified number of degrees (Centigrade) greater than ambient air. The control system would then turn on and off the lights to maintain the desired temperature differential. The system was connected to a computer and used the program LabVIEW.

In order for LabVIEW to display the temperature at different locations throughout the experimental unit, seven thermocouples were places throughout the system (Figure 3).

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are needed to see this picture.

Figure 3: Diagram of Thermocouple Placement

Experiment

Due to the limiting time of one semester, the goal of the study was to develop an experimental set up that could be used by future teams to test various types of insulation materials. In order to determine the reliability and quality of the experimental set up described above, four types of insulation material were used. The materials used were: air, wood shavings, rice hulls, and fiberglass. Three trials were run for each type of insulation material.

Each type of insulation material was chosen for a specific reason. The first material, air, was chosen to obtain a standard set of data that could be used to compare the results of the other types of insulation material. Wood shavings were the second type of insulation material chosen for experimentation. Currently, the solar ovens that are used in Nicaragua utilize wood shavings for the insulation. In order to determine if an alternative material would be better suited for the ovens, the wood shavings and alternative material would need to be tested under the same conditions. The third type of insulation material chosen for testing was rice hulls. Rice hulls were suggested by our faculty advisor, Tim Bond, as they are an inexpensive material that would be readily available in Nicaragua. After some preliminary research, it was concluded that rice hulls would be a reasonable material to test. Finally, the fourth type of material that was tested was fiberglass. During correspondence with the

Nicaraguan women, it was mentioned that there was interest in using fiberglass to insulate the solar ovens. The Nicaraguan women stated that fiberglass is available in Managua, the capital of Nicaragua. If bought in bulk, the fiberglass would be relatively inexpensive. Therefore, at the request of the Nicaraguan women, fiberglass was tested.

The same testing procedure was followed for each of the three trials conducted for each type of insulation material. The insulation material used for the trial would be placed inside the experimental wall. Next, the experimental wall would be placed on the oven and two weights were placed on top; securing the wall in place. Using LabVIEW, the target differential temperature was set to 150 degrees Centigrade. This differential temperature is the difference between the ambient air temperatures and the air temperature inside the oven. The program would begin to collect data from the seven thermocouples every second. As a result of increasing the target differential temperature from zero, the heating system would turn on and heat the oven until the target differential temperature was achieved. Once this target differential temperature was reached, the experiment continued to run at this constant temperature differential. After ten minutes, the target differential temperature was set to zero, causing the heat source to turn off. At this point the data collection was stopped. The weights were lifted and the experimental wall was removed from the oven. The inside of the oven was allowed to cool. Once the differential temperature was 10 degrees Centigrade or smaller, the next trial was run. Three trials using air were conducted first, followed by three trials using wood shavings, then three trials using rice hulls, and finally three trials using fiberglass.

Results and Discussion

Figure 4 shows the typical data file acquired from running an experimental trial.

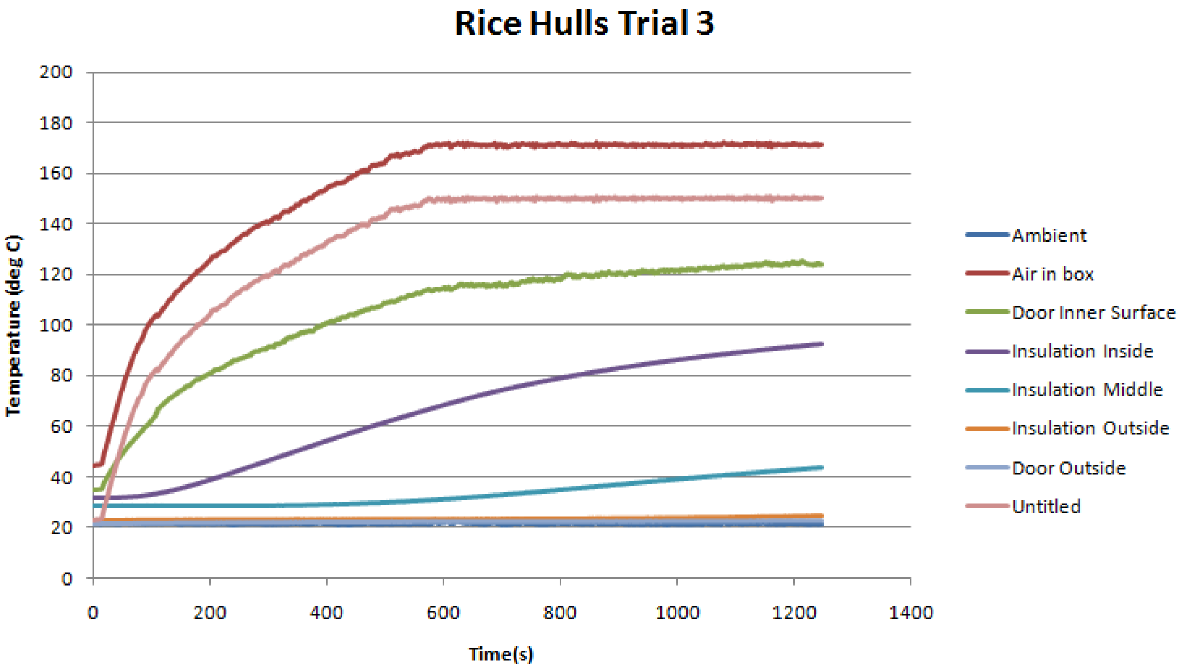

Figure 4: Data from Rice Hulls Trial 3

This study focused on the temperature readings from thermocouples 4 and 6 (Figure 5), representing the “insulation inside” and “insulation outside” respectively. These temperature readings were of particular interest due to the fact that these thermocouples flanked the insulation in the experimental wall. The difference between these thermocouples would in essence represent the thermal storage capability of the insulation.

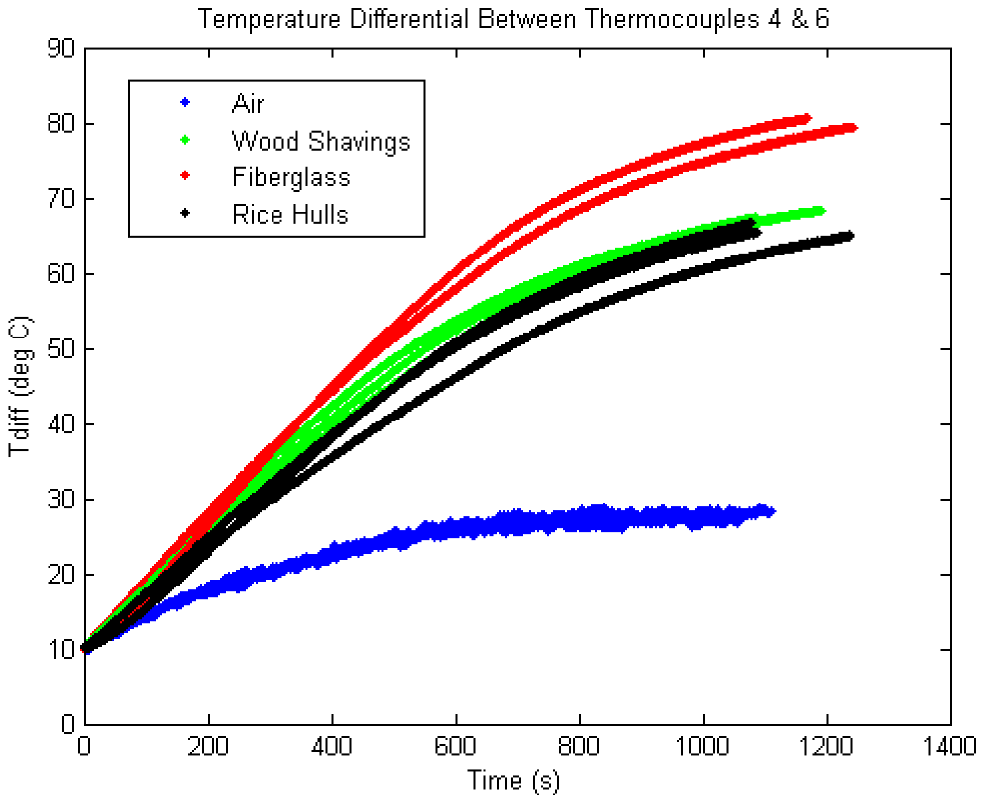

Figure 5: Temperature Differential vs. Time for Thermocouples 4 and 6

To analyze this data, Matlab was used to isolate the temperature differences between the two desired thermocouples for all of the trials. These differences were analyzed from a specific start point and an endpoint. The start point was defined as the time when the difference in temperature between thermocouples 4 and 6 was 10 degrees Centigrade. The start point was used to essentially normalize the data to make more appropriate comparisons. The value of 10 degrees Centrigrade was chosen based on the data files themselves, the difference of 10 was a value that was available in all data files and occurred early on in experimentation. The endpoint was defined as the end of the experimental trial; 10 minutes after the difference of 150 degrees Centigrade between thermocouple 1 (ambient air) and thermocouple 2 (inside air) was achieved as previously specified in the methods. The overall results are displayed in Figure 5. It should be noted that there were three trials conducted for each type of insulation, however one of the fiberglass trials was not recorded in this report because of its radical and inconsistent behavior.

The results from Figure 5 indicate that there is a clear separation between the temperature differences of the insulations and the air. The air trials are all consistent and are lower than those of any of the other insulation types. This is to be expected since air is the control and is known to be a poor insulator due to the convective currents in the air during heating. The two fiberglass trials appear to have the greatest temperature difference between thermocouples 4 and 6 and that indicates that fiberglass has the greatest heat storage capacity and is therefore the best insulator. Wood shavings and rice hulls appear to be fairly comparable in their temperature differences, with wood shavings appearing to perform slightly better.

There is observable variation among the insulation trials; however this variation is not seen among the air trials. This suggests that there may be an issue with the way that the experiments were conducted. It was speculated that the effectiveness of the insulation materials may be sensitive to density changes in the insulation. Due to the fact that no system was developed for maintaining any constant density of the insulation in the experimental wall, it can be surmised that this could be the cause of the variation in insulation test trials.

Aside from the issue with density, the results from this study indicate that the experimental setup is effective and highly repeatable. The observable differences in the temperature gradient across the insulation and the consistency with the air trials indicates that the experimental method is quite successful and could be used for further experimentation in the future.

Criteria Review

Prior to testing, technical, social, economic, and environmental criteria were selected to determine the success of the team. The work accomplished this semester was assessed in comparison to these criteria.

Technical

The technical criterion used to assess the study was that prior to suggesting an alternative insulation material to the women in Nicaragua, it would be thoroughly tested in order to be confident that the material was indeed equal or superior to the currently used wood shavings. The results from the study conducted this semester did not provide concrete evidence that the rice hulls or fiberglass had equal or superior insulation capabilities than the wood shavings. Although the fiberglass appeared to produce a larger temperature differential than the wood shavings, inconsistency was evident between the fiberglass trials and therefore a conclusion could not be made with confidence. While the study conducted this semester did not produce the necessary results to claim with confidence that an alternative insulation material was superior, the work accomplished provides a basis for future testing on the new experimental unit.

Social

The Nicaraguan women accepting a suggestion for an alternative insulation material was the social criterion used to assess the study. If a superior insulation material was found, the benefits of using the new material would need to be effectively communicated to the Nicaraguan women. Since the women discovered current material for insulation, it is important for them to understand the advantages of using a new material instead of the wood shavings. This semester, upon request by the Nicaraguan women, the insulation capabilities of fiberglass in a solar oven were tested. Therefore if the results from the study had proved that fiberglass was superior, the Nicaraguan women would have already accepted this material and the social criterion would have been achieved. However, no confident conclusions were able to be drawn from the testing any of the alternative insulation materials, and thus this semester the challenge to meet the social criterion was not encountered. Although the social criterion was not applicable to the work accomplished this semester, it is important for future teams to consider.

Economic

The low cost and availability of the insulation materials in Nicaragua was the economic criterion determined to assess the insulation study. This semester, rice hulls were chosen to be tested as an insulation material because they are inexpensive and are readily available in Nicaragua. Also this semester, the insulation capability of fiberglass was tested upon the request of the Nicaraguan women. The women stated that fiberglass is available in large cities and is relatively inexpensive. Although no conclusion was reached on the insulation ability of rice hulls or fiberglass, the insulation materials that were selected for testing did meet this economic criterion.

Environmental

Two environmental criteria were selected based upon Paul T. Anastas and Julie B. Zimmerman's Twelve Principles of Green Engineering. First, all material and energy inputs and outputs utilized during this test would be as inherently nonhazardous as possible. Secondly, an attempt would be made to design products, processes and systems that include integration and interconnectivity with available energy and material flows. None of the materials used or the energy inputs and outputs associated with the insulation material testing were hazardous. In an attempt to design products, processes, and systems that include the integration and interconnectivity with available material flow, only materials that are readily available in Nicaragua were used for this study.

Recommendations for Future Teams

This semester, the insulation team has worked to design and construct a successful experiment. An experimental oven was built and connected to a computer controlled heating system. This allows for the testing and comparison of different insulation materials. However, since the problem with insulation only appears after a year of use, the insulation used for experimentation must be exposed to the same conditions. The experimental unit was designed to create a method to test and analyze this issue. It is assumed that a typical solar oven goes through one heating and cooling cycle a day. In order to expose the tested insulation to the same amount of use, the computer system can be set to run the experimental oven through several heating and cooling cycles automatically. This will essentially speed up time and allow any degradation to appear after a shorter testing period.

Due to the fact that some of the original materials used could not handle the high temperatures inside the oven, it was decided that the experimental unit must successfully run through many testing cycle before it could be left to run automatically. This caused experimentation to take a lot more time than expected. Given the time constraints of one semester, the insulation team was not able to implement the use of an automatic system. Therefore, insulation could not be tested for an equivalent of one year's use.

However, this semester, the insulation team was able to conclude that the experimental unit is a safe and effective way for testing insulation. Using the experimental unit constructed and tested this semester, future teams will be able to implement the automatic testing scheme to provide further insight on the capabilities of different insulation materials after long-term use.

Conclusion

Based on the results from this study, the following conclusions can be concluded that this experimental method is an effective way to test and compare various insulation materials. The results indicate that using fiberglass as insulation material results in the greatest temperature differential across the insulation. Although they have a smaller temperature differential than fiberglass, wood shavings and rice hulls appear to be comparable. Air, however, proved to be worse than all other forms of insulation used in this study. Further experimentation with density control will be necessary to draw more concrete conclusions. An optimum insulation cannot be suggested to the women in Nicaragua until performance over time is investigated.

Concentrated Cooker Subteam

Description of Problem

The Solar Oven team here at Cornell has continuously collaborated with organizations in Nicaragua to improve upon the implemented solar box cooker design. The box cookers currently used by the women in Nicaragua reach temperatures up to 180 degrees Centigrade (350 Fahrenheit), which is high enough to cook food, but falls short of the temperatures required to fry food. This becomes a relevant issue when considering the typical Nicaraguan meal, which incorporates tortillas as a staple food. Tortillas must be fried, and this requires a cooking surface that reaches temperatures of at least 250 Centigrade.

Because the solar box ovens cannot fry these tortillas, they are presently being cooked on wood-burning stoves indoors. Typical Nicaraguan housing does not provide proper ventilation for such methods. This causes harmful particles and toxins (including carbon monoxide) to be dispersed into the air within housing units. If inhaled, these toxins can trigger asthma attacks and in some cases, cause cancer from long-term exposure. According to the Minnesota Pollution Control Agency, breathing air containing wood smoke can also "irritate eyes, lungs, throat and sinuses, reduce lung function (especially in young children), increase severity of existing lung diseases such as asthma, emphysema, pneumonia and bronchitis, increase risks of heart attacks, and trigger headaches and allergies." [1]

Additionally, the manual labor required to gather and cut wood to fuel the stoves is a large time commitment. The surrounding environment consists mainly of forested areas, which means the Nicaraguans are both depleting their dwindling natural resources and further enabling soil erosion. Since the year 1990, Nicaragua has lost 20.6 percent of its forests. Currently, deforestation is occurring at rate of 1.3 percent annually [2]. The primary threat to Nicaragua's forests is illegal logging; this is in part contributed to by wood demand for fueling stoves.

With this cultural context, the Solar Oven team started pursuing the concept of a concentrated parabolic cooker. The goal is to create a design that works well enough to be a possible alternative to wood-burning stoves. The concentrated cooker utilizes the geometry of the parabola in the reflector to focus sunrays at a single focal point; this gathers heat more rapidly and efficiently than a solar box cooker, and can reach the frying temperatures of 250 Centigrade. In consideration of its potential use in Nicaragua, the cooker design must be conscientious of the building materials available in the area and take into account the windy conditions outdoors.

The Solar Oven teams from previous years have made several attempts at achieving an effective concentrated cooker design. One team made a shallow, modular three-dimensional parabolic reflector, which was too small and inexactly executed to achieve any results. The most recent team built a large two-dimensional parabolic trough reflector, which failed to effectively focus the light at a single point. (See Appendix A for images of past projects.) After careful consideration, we decided to pursue a new three-dimensional (3D) parabolic design, which will conserve material and allow for a more compact, efficient concentrated cooker. Our main goal was constructing a functioning reflector that focuses light at a single focal point and heats the point up to 250 Centigrade.

Methods

In order to make informed design decisions, we needed to thoroughly research 3D parabolic cookers and their construction processes. We split up the concentrated cooker design-build process into two stages: (1) the parabolic reflector and (2) the framework for the reflector/cooking surface. After testing the reflector and confirming that it indeed had a single focal point and was able to rapidly gather heat, we went on to building its framework.

The Parabolic Reflector

Design:

Our research found that many of the existing 3D parabolic cookers are not parabolic, but in fact spherical. A spherical reflector is much easier to construct, but is not as effective as a parabolic reflector due to a phenomenon called *spherical aberration*. The diagram below (Figure 1) demonstrates the effects of spherical aberration in part (a) and its elimination with the parabolic reflector geometry in part (b), when considering light rays of parallel incidence.

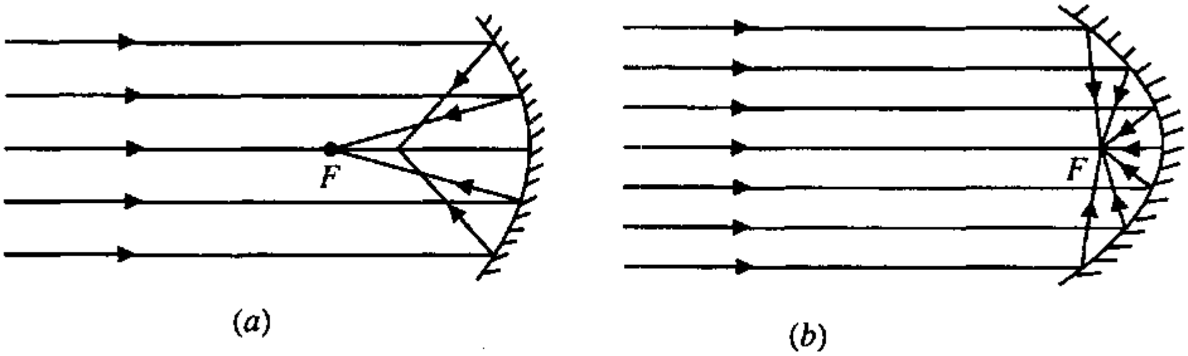

Figure 1: Spherical Reflector and Parabolic Reflector [3]

The spherical reflector is unable to focus light at a single focal point; rays that hit the surface further from the optical axis (the horizontal centerline) focus in tighter, and vice versa. The parabolic reflector remedies this problem by focusing all rays to a single focal point (as long as there is parallel incidence). We therefore decided to construct a true parabolic reflector, not a spherical one.

We also needed to determine whether to construct a shallow or deep paraboloid. Most 3D parabolic cookers utilize shallow parabola geometry. Shallow reflectors are more mobile and easily manipulated to the angles needed to receive direct sunlight. This also leaves more flexibility for the design of the cooking surface in relation to the reflector.

Lastly, we needed the dimensions of the shallow parabolic reflector we wanted to construct. Many of the reflectors we researched had a diameter of approximately one meter. We consulted with Tim Bond (the Manager of Civil Infrastructure Complex, including Winter Lab), and he said he had 3’ by 4’ aluminum sheeting, which was close to this dimension.

Construction:

The construction of a 3D parabolic shape is not trivial. We quickly realized the impracticalities of molding sheet metal to the desired shape, and researched methods to build the paraboloid from petals. Figure 2 details how the flat sheet would look with the appropriate partitions, before assembly.

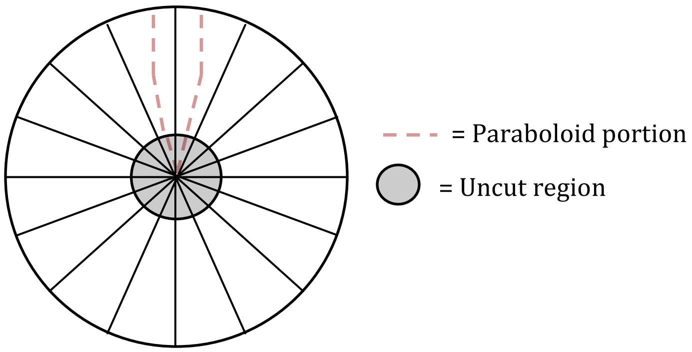

Figure 2: Sketch of Metal Flat Sheet with Partitions

Because Tim provided us with a thin 3’ by 4’ aluminum sheet, we decided not to cut out a circle and retain as much reflective surface area as possible. We first cut the sheet into 16 sections as shown, and then plotted the paraboloid points needed for a shape with a focal length of 25 cm. A center circle of diameter 3 cm was left uncut to preserve structural stability. Instead of cutting along the paraboloid petals and adhering them edge-to-edge, we folded the slices up and overlapped them to give us room for error. We used reflective tape to keep the petals in place and complete our 3D parabolic reflector. Below is the finished product in Figure 3. Appendix B Table 1 contains the points we used to create these petals, all dimensions in cm. Appendix B Figure 1 details how to plot the points in Table 1.

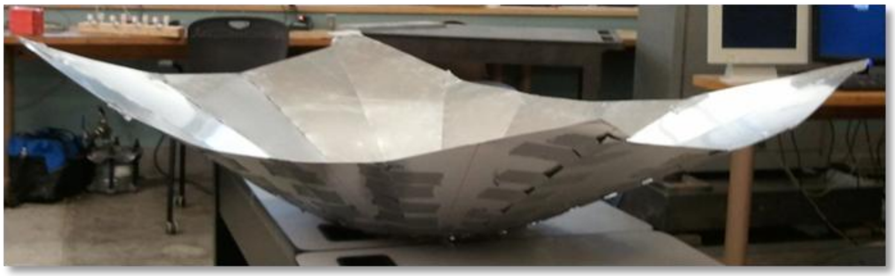

Figure 3: Finished 3D Parabolic Reflector

The Framework for the Reflector / Cooking Surface

Design:

The framework of the reflector has a cross-shaped support system, with measured parabolic geometry to properly maintain the reflector's shape. It also accommodates the tilting of the reflector to receive sunlight at different angles corresponding to its position in the sky due to time of day. Bolts and nuts tightened appropriately prevent the reflector from further rotating when the desired angle is achieved. The entire system is on wheels for greater mobility and braced for structural stability. Unfortunately, we were unable to start the design and construction of the cooking surface.

Construction:

Refer to our finished results shown in Figures 4 and 5.

Figure 4: Reflector and Framework

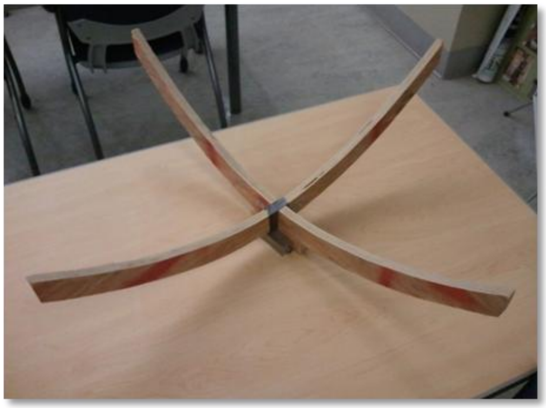

Figure 5: Reflector Support System

Results

The theoretical focal point (based on our petal design and construction) was calculated to be 9.8 inches. The actual focal point of our reflector was measured to be 10 inches, which is a mere two percent difference from the theoretically calculated point.

When we tested our system, the wooden framework had not been constructed. Therefore, our experimental setup involved a propped wheelbarrow that served as a support for the reflector and allowed us to easily shape and tilt our prototype. Two tripods were used to support a wooden rod that was placed directly across the reflector (Figure 6). Attached to the rod with black duct tape was a small metal corner that could easily absorb heat, and attached to this metal piece was a thermal couple used to record temperatures (Figure 7). This metal piece and thermal couples were placed directly at the paraboloid's focal point.

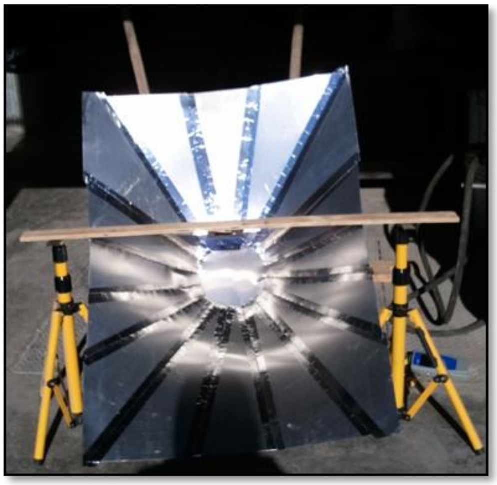

Figure 6: Reflector Sitting on Wheelbarrow

Figure 7: Thermal Couple Attached to Metal

The testing showed very promising results (see Figure 8). The peak temperature achieved within minutes was 145 degrees Celsius, with ambient temperature around 11 Celsius. However, testing was not completely conclusive because of the fact that half-way through testing, the tape holding the black metal piece to the wooden rod melted. Hence, the thermal couple fell out of the reflector's focal point and began reading ambient air temperatures instead. The sudden drop in temperature, at around 784 seconds into the trial, is the point where this event occurred.

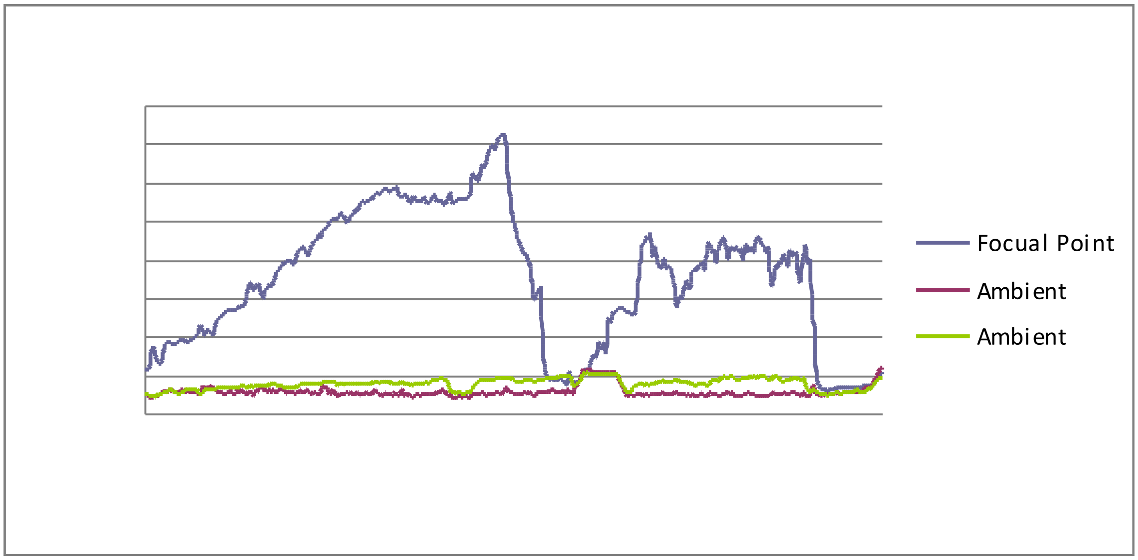

Figure 8: Data from Most Successful Testing

The small spikes and bumps in the recorded data are due to gusts of wind that struck our reflector and constant adjustments that were made to the reflector support system, including tilting of the reflector, movement of the tripods, and adjusting the wooden rod. The adjustments occurred because of the fact that the sun's position is always changing and must be tracked in order to optimize the amount of sunlight focused at the paraboloid's focal point.

No other successful attempts at testing occurred due to time constraints and lack of sufficiently sunny days.

Criteria Review

The following section asserts a critical review of our parabolic solar cooker. We discuss the technical, social, economic, and environmental implications of our prototype.

Technical

Our goal was to create a user-friendly design such that the appropriate components could be removed and/or replaced accordingly. In addition, the oven as a whole should be relatively mobile in order to successfully track the path of the sun. Most importantly, the final prototype should be able to meet the temperature requirements for frying foods (250 Centigrade), and be efficient, durable, and practical enough for everyday use.

Our design is user-friendly in that the reflector, reflector support system, and reflector framework can be easily separated for replacement of any given part. The reflector is mobile (on wheels) and able to tilt to track the sun. Although we did not obtain official test data reaching 250 Centigrade, we have test results yielding temperatures of approximately 140 Centigrade in very little time, which indicates that such temperatures should be possible. Our concentrated cooker as a whole is not finished, lacking a separate cooking surface.

Social

Our social criteria stated that the constructed concentrated cooker should provide concrete results that demonstrate its ability to fry food. These results and their implications were to be communicated to the proper organizations in Nicaragua, as well as to local restaurant owners who previously expressed curiosity towards solar frying. Communication and feedback on the cooker design/implementation would develop greater interest in eventually introducing concentrated cookers to Nicaragua.

We maintained communication with the organizations in Nicaragua over the semester, and informed them that we were working on a parabolic reflector. We received positive feedback, and recommend further informing them about the possibilities of concentrated cookers once concrete temperature testing data reaching 250 Centigrade is achieved.

Economic

We felt that materials in the final design should be available, in terms of both location and cost, to residents in Nicaragua. This would increase the ease with which these ovens could be implemented and built. Ideally, the materials needed should be able to be purchased from local Nicaraguan businesses in order to generate revenue for the local economy.

Our reflector and framework are made of aluminum and wood. Both of these materials are already currently being used in the solar box cookers in Nicaragua.

Environmental

According to Zimmerman's 12 Principles of Green Engineering, materials and energy inputs should be as renewable as possible; the use of a concentrated cooker in favor of a wood-burning stove implements sunlight as an energy source instead of wood. Concurrently, our solar reflector uses sunlight only as a renewable source of heat to bring its focal point area to high temperatures.

Discussion

For much of the design of our reflector and wooden framing, we used materials already found in Winter Lab. Therefore, construction could be carried out almost immediately after design versus waiting two weeks for material shipments to arrive. We designed and built generally at the same time. We found this was easiest since problems cannot always be predicted beforehand. Some ideas that had been originally planned were found to be more difficult to construct than anticipated. Therefore, we tended to design while we were building at some moments (especially for the framework).

Our two attempts at testing revealed that a better support system was needed instead of the makeshift wheelbarrow system. Given the portion of the successful data that we have, we can conclude that our prototype has definite potential to reach temperatures of 250 Celsius. The temperature at the focal point was steadily increasing at the time of failure due to the melted tape. Had failure not occurred, the linear trend shown in Figure 9 estimates that a temperature reading of 250 Celsius may have occurred after approximately 25 minutes, and may even occur faster in non-windy, winter conditions. Specific future tasks include finding a better way to attach the thermal couple to the metal corner, i.e. find a supportive material that will not melt at high temperatures.

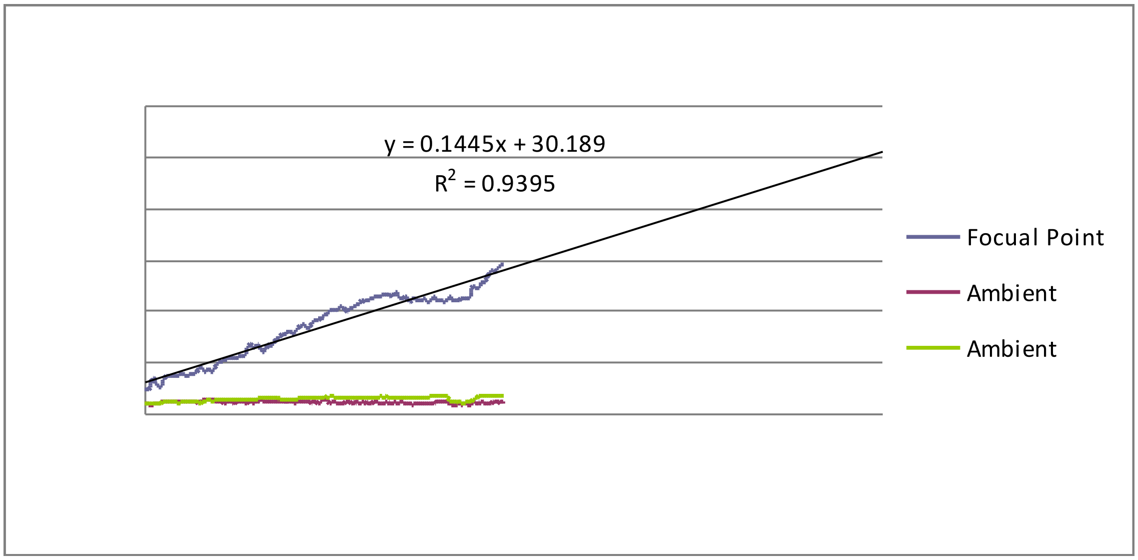

Figure 9: Predicted Trend in Temperature Reading (had failure not occurred)

In addition, this past semester allotted no time to build the cooking surface upon which a pot can be placed. Next semester's work on this project should prioritize this task along with another attempt at successful testing.

Recommendations for Future Teams

There are many suggestions for further improvements that may be research more thoroughly next semester as well. One subject our team was very interested in for future design involved the compound parabola shown in Figure 10. For parabolas, light only focuses on a single point, known as the focal point, when shinned normal to its surface. In order to allow for greater light concentration at the focal point when light is directed at an angle, a compound parabola is needed. The compound parabola basically involves overlapping two parabolas to form one. Properly designed compound parabolas can focus sunlight from many angles. This would mean that the reflector could also focus rays hitting at an angle of 30 degrees, which subsequently means that the compound parabolic cooker could concentrate rays at a focal point for at least 2 hours without adjustment. See Appendix C for further diagrams of the compound parabola.

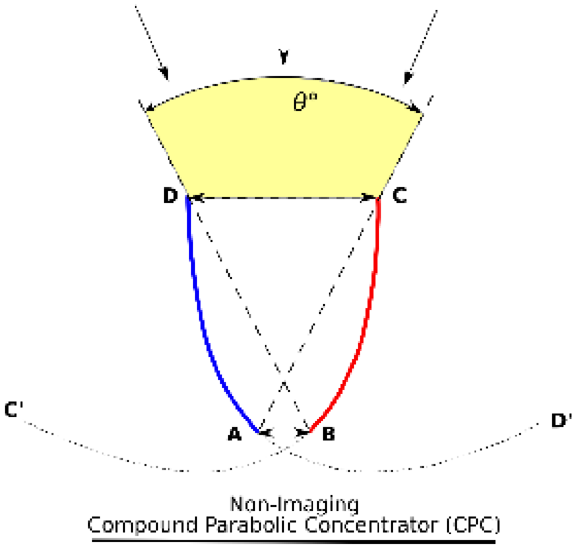

Figure 10: Diagram showing a Compound Parabolic Concentrator [4]

Other suggestions for improvement involve making the current concentrated cooker more aesthetically pleasing. This can include painting the wooden framework black to absorb more sunlight.

Conclusion

The prototype constructed this semester shows great potential in its ability to reach high temperatures to fry tortillas. Because of this potential, a wooden framework has already been constructed. This will allow for increased stability in further testing that will occur next semester.

Most women in Nicaragua fry tortillas for their families every morning before the sun rises and before their children walk to school and husbands head to work. Therefore, they would not be able to use our cooker for their needs. However, restaurants need to be able to provide freshly made tortillas throughout the day and would therefore, have great need for our cooker. Hence, we are targeting the production of our cooker toward Nicaraguan restaurants.

Once the cooker has been successfully tested and proven to reach temperatures of 250 centigrade, the prototype can then be introduced to Nicaragua. Constant communication with Groupo Fenix has informed us that they are extremely interested in the concentrated cooker. The group is currently working on the construction of a restaurant to sell solar foods. If our cooker operates well enough to fry tortillas, the group would love to use our prototype. The goal is for introduction to occur in the coming March during spring break.

Small Solar Cooker Subteam

Description of Problem

Currently, the only solar ovens available to the solar oven team at Cornell are exactly the same as those used in Nicaragua. These ovens work well and are invaluable for tests aimed to improve the efficiency and effectiveness of the Nicaraguan ovens. However, these ovens only work under the solar oven team's overhead lighting array in a laboratory setting. In order to demonstrate the usefulness of solar ovens without using artificial lighting, the team decided to design an oven compatible with the Ithaca climate and location. The new oven was to be scaled down in order to transport more easily and the window was angled to allow maximum solar gain, sized to be carried by one person and fit through a doorway, and constructed of locally available materials.

A side project that was undertaken at the beginning of the semester: the development of a new method for propping the lids (which act as reflectors to increase the incident radiation into the oven) open on the ovens in Nicaragua. Some of the Nicaraguan women affiliated with an organization dedicated to the promotion and production of solar cooking devices called Grupo Fenix had asked for several years for help in the design of prop rods. These rods would be able to prop the lids stably and securely during wind and that could be infinitely adjusted, as opposed to the one-sided flimsy wood board design with a series of drilled holes that act as settings (which operates as the current design).

Methods

The design of the small solar oven was based on the team's existing Nicaraguan oven designs and on another small oven previously built by the solar oven team, which is frequently used by Professor Francis Vanek. The new design for the small solar ovens incorporated the best elements of each of these ovens, eliminated elements that do not work well, and created solutions to produce an elegant and functional design.

The first step of the design process was to design the frame of the oven. This included determining the angle of the glass window. Research suggested that a solar collector (in our case, the glass surface) should be angled off from horizontal by a value approximately equal to its latitude. Ithaca sits at a latitude of 42°26' North. The team decided to modify this value and use an angle of 45° two reasons: first, a 45° angle simplifies the design and improves constructability, and second, 45° allows us to capture more solar energy in the fall and winter when the sun does not rise as high.

The team then determined dimensions for an oven that one person can carry, while accommodating three pots. Professor Vanek's oven proved useful for this task, as it can hold three pots and be transported by one person. The interior of the oven was sized such that a small pot could be pushed to the front of the oven and not be impeded by the angled glass cover. A design was produced in AutoCAD to which the team referred throughout construction (Figure 1).

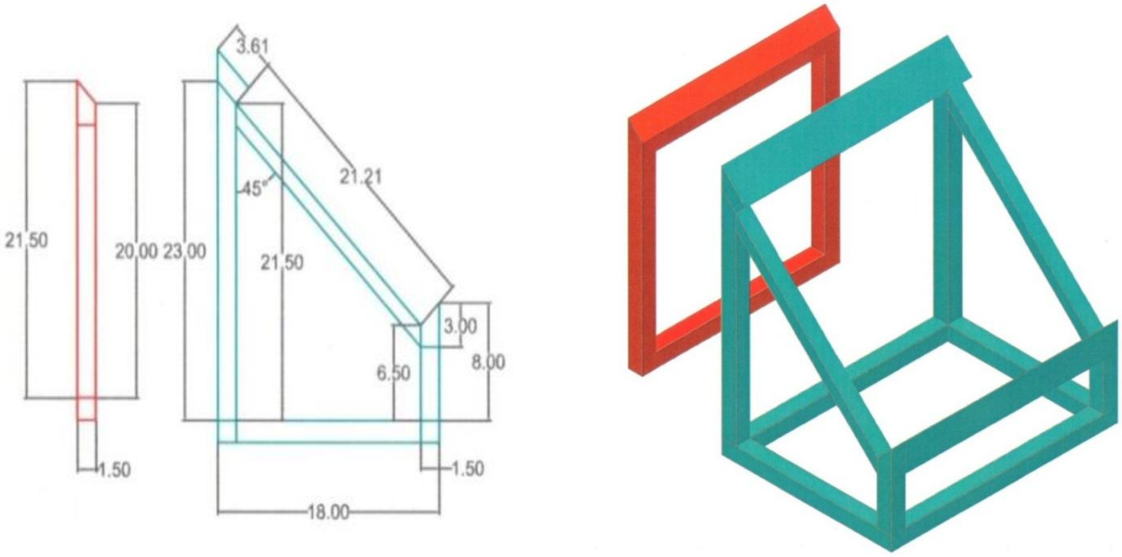

Figure 1: AutoCAD Drawings of the Oven Frame

After the dimensions for the oven were determined and the frame was designed, the team needed to determine the essential materials used in the oven. Since this oven will only be used in Ithaca, the team decided to ignore the limitations on materials to those only available in Nicaragua. Materials were chosen that are readily available locally, rather than imitating the materials used in Nicaraguan ovens

The team used 2x4 lumber that was split in half lengthwise to construct the oven's frame. This lumber is easy to come across locally, and happened to be stocked in surplus in the lab. The framing was all connected with coated wood screws available in any hardware store. Fiberglass insulation was used in the cavities of the oven because of its good insulation properties, its compatibility with high temperatures, and its local availability. The inside of the oven is covered with a thin fiberboard which offers some insulating properties as well as structural support for the thin, reflective, metal film attached to the inside of the oven. The team had originally decided to use aluminum sheeting to line the interior of the oven, but a roll of the film was presented to the team and we decided that it would most likely perform better. Double pane glass is used for the oven cover to maximize heat gains and provide better thermal resistance. The small solar oven is depicted in Figure 2 during and after construction.

Figure 2: Oven Frame During Construction and Completed Oven

In addition to designing and building the small solar oven, the team was also working to develop a new design for the prop rods on the ovens currently used in Nicaragua. The current prop rod design consists of a single wooden bar with holes so that the user can select the height and angle of the solar oven's lid. The method for determining a new prop rod design mainly consisted of discussion. There were a variety of factors to consider when designing a new prop rod. Such factors included availability of materials, ease of construction and retrofitting and if the new design would have any impact on how Nicaraguan women used the oven. The final design selected was based off of a prop rod design used on one of the power tools in the Winter Lab (Figure 3).

Figure 3: Prop Rod

Results and Discussion

This semester, the small solar oven team set about designing and building two smaller box ovens. We set a tentative schedule as a group, as to when we thought we'd finish each phase of our project, and began work. Looking back at our progress throughout the semester, our team was able to successfully follow our schedule upon completion of each milestone, except for a few instances. The design process took a little longer than expected, but producing a well-thought design before beginning construction proved to be very beneficial down the road, as we did not encounter any major setbacks, or unforeseeable factors. Since we were confident of our design, to make up for the extra time added to the design process, we were able to use the services of a few interested ESW chapter students, who were keen on helping us out. We were able to give them clear instructions on various tasks, while we continued construction and this reduced construction time noticeably. At the end of the semester, we successfully completed one of the ovens, while the other is nearly complete. The second oven will be completed during study week, or by the students in the ESW chapter as the oven is being built for their use.

Concerning the small ovens, the semester proved to be a success. Our team worked through the design and build process without leaving out important details of the oven's design. The team had spoken with Professor Vanek, who has been using a small solar oven for a few years, before the start of the design process. We discussed ways in which the oven could be improved, and were able to incorporate all of these suggestions into our design to produce a cooker that is both more comfortable to use and more robust. Such suggestions included a better system to secure the oven door. Originally, a bungee cord had been used to close the door; this did not allow for a very tight fit and was somewhat dangerous. Also, the oven was made slightly taller to accommodate larger pots and the glass cover was made removable. We were able to keep a good balance of staying with a proven design, while making changes to improve performance and intuitiveness in the design.

The primary objectives of the small solar oven team were to design and construct a solar oven that is smaller than the conventional design that could work in Ithaca, which were achieved. Underlying these goals was the pursuit of promoting solar oven technology in the Cornell and Ithaca communities. Due to the interest in alternative energy of the populace in Ithaca, it seemed only fitting to translate the technology of solar cooking from ovens designed to work in Nicaragua to ones that would work in Ithaca. If anything, raising awareness in the Cornell community was definitely achieved through conversation regarding the project between the team members and their friends and acquaintances. This project even attracted younger prospective engineers, who volunteered their time to aid in construction; this further suggests that the project was indeed successful.

With regards to the prop rod project, the team developed a simple design using materials present in the lab. A 3/8-inch diameter steel rod fitted with a brass tee to be attached to an oven that was threaded for a bolt to screw in and apply pressure on the rod to hold it in place. The team is confident that the new prop rod will solve the problem of the tops coming loose, but time constraints prevented the group from conducting tests to evaluate their performance.

Criteria Review

Technical

The technical criteria for the construction of the small solar oven were relatively straightforward. First, the oven needed to be small enough so that one person could easily carry and transport the oven. Current designs used in Nicaragua are large, bulky, heavy and impossible to be carried by one person. The new oven is much smaller in size and can easily be carried by one person. Though the size was significantly decreased, the oven is still large enough to fit three medium sized pots comfortably in the oven. Additionally, the oven design was altered to accommodate for the solar elevation in Ithaca. The glass window in Nicaraguan ovens is flat, but the oven designed for Ithaca had to be tilted in order to maximize sun exposure. Construction of the oven was completed, however a set of reflector panels has not yet been constructed. Therefore, we have not tested the oven to see what temperature it can reach. However, since the design was closely based off of Professor Vanek's fully functional oven, we are extremely confident that with the addition of reflector panels, the oven will reach high temperatures necessary for cooking. Materials used for constructing the oven were mostly available in the Winter Lab and similar to those used in construction of the Nicaraguan ovens. Though the materials the team used were not exactly what is used in Nicaraguan ovens, they are not drastically different and will give people a good representative of the materials a Nicaraguan oven is made of. Overall, the technical criteria proposed at the beginning of the project were fully maintained.

Though the prop rod project was not mentioned in the original proposal, there are also applicable criteria for this project. The prop rod design needed to be easy to use and robust, considering current designs were not holding up in heavy winds. Though we have not devised a way to test the current design, the team believes that it will hold up better than the wooden prop rods since it is made of metal. An additional benefit to the new prop rod design is that there aren't discreet places that the prop rod must be at (the old design consisted of a series of holes in a wooden rod), but rather the user can slide the metal rod along the hydraulic fitting to get the desired height of the oven lid.

Social

The social characteristics of this project vary slightly from those of the other solar oven subteams. While we are all working towards the same cause- providing an inexpensive way for women in Nicaragua to prepare food, the small solar oven team is more concerned with outreach rather than improving the design of the ovens used in Nicaragua. The construction of the small solar oven will enable us to effectively demonstrate how solar ovens work and how well they work in Ithaca. Because the design was altered for the Ithaca solar elevation, the demonstration will be more meaningful because the oven will be able to reach higher temperatures and not require artificial lighting. Promoting the solar oven project will help the team get recruits and also make the general public more aware of the cause. Promotion of solar ovens may even convince people to get their own solar oven to use instead of traditional ovens. This helps promote the use of green energy in Ithaca.

Since the women from Nicaragua put in a specific request for the team to address the prop rod problem, there aren't any concerns as to whether the new design will be accepted among users of the oven. The design change will be welcomed, as it solved a problem with the current ovens.

Economic

In our proposal, we planned to use mostly materials available locally in Nicaragua so that our demonstration oven would accurately represent ovens used in Nicaragua. However, we did not limit ourselves to using only materials used in Nicaraguan ovens. We constructed the frame and siding using wood, as Nicaraguan ovens are constructed. Fiberglass was more readily available and is a better insulation material than wood chips, which are traditionally used in Nicaraguan ovens, so the team opted to use fiberglass instead. Additionally, reflective sheeting was used for the reflective inside. It was readily available in the lab and did not need to be purchased; therefore it was a cheaper option than sheet metal. Overall, since the team was able to utilize many materials available in the Winter Lab, the cost of construction of the oven was extremely low, which upheld the original criteria outlined in the beginning of the semester.

Additionally, the prop rod also needed to be made of cheap, locally available materials. Hydraulic fittings and metal rods are inexpensive and thus fill the economic criteria for this section of the project. Also, because the new design is more robust, prop rods will not have to be replaced as often, thus saving money for the Nicaraguan women using the ovens.

Environmental

The primary focus of the solar oven project has been to minimize energy consumption. By using the sun's energy to cook food, we directly reduce the amount of nonrenewable energy (specifically wood) that Nicaraguan women use to cook. The small solar oven's purpose is to help promote the project so that we can optimize designs and make solar ovens more available to Nicaraguan women. Additionally, we wanted to make the oven as robust as possible so that it has a long lifetime, without overdesigning the oven. The longer the lifetime of the ovens, the less often they must be replaced and less resources will be used in construction of the ovens. The team believes that the design for the small solar oven is robust enough to have a lifetime of at least five years. Designs were based off of a small solar oven that has been in use for five years. Improvements on the old oven's design should increase the lifetime of the new small solar oven.

Recommendations for Future Teams

This semester, the small solar oven team had planned to construct two fully functional solar ovens to be used for demonstration purposes in Ithaca. Due to time constraints, the team was not able to complete these tasks. Future teams should finish the construction of the second small solar oven. Additionally, a reflector panel system must be designed in order to maximize the oven's sun exposure to reach desired temperatures. This system can be based off of the reflector panels currently used with Professor Vanek's oven, adjusted to improve ease of constructability and oven temperature. Additionally, future teams should work towards developing an experiment to test the robust-ness of the new prop rod designs and perhaps taking them to Nicaragua on the spring break trip to retrofit current ovens with the new prop rod.

Conclusion

Overall, the small solar oven team had a very productive semester. Our original goals were to design a solution to the prop rod problem and design and build a small solar oven for demonstration purposes in Ithaca. We devised several feasible new prop rod designs, all which would be easily integrated into the current Nicaraguan solar oven design. Additionally, ovens already in use would be easily retrofitted to incorporate the new designs. We were not able to come up with a way to test these designs, so we do not know how well they work, but the team is confident that the new prop rods are much more robust than the previous prop rods.

The majority of the semester focused on the design and construction of the small solar oven. The team was fortunate enough to have an oven to base designs off of, but we still had to consider how the frame would fit together, the best way to assemble the oven, and how to construct the oven to maximize insulation.

In estimating the timeline for completion of the project, the team underestimated how long construction of the small solar oven would take. Most team members were inexperienced with construction and had minimal knowledge to estimate how long the project would take. Additionally, we were not able to test the effectiveness of the prop rod designs because work in the latter half of the semester was heavily focused on completing construction of the oven. Fortunately, the solar oven project is an ongoing one, so the Spring 2011 team will be able to complete the work that time constraints prevented us from finishing.

Personal Reflections

Joe Beaudette

Working for the solar oven team this semester has been a delightful and fulfilling experience. I am very interested in passive solar design and harnessing the power of the sun in simple but creative ways. Being part of the solar oven team has allowed me to learn about this topic and apply my knowledge to produce a valuable and useful end result. Through the solar oven team I have learned a great deal about the global uses of solar energy and the implications of solar oven use. I have also come to understand the demand for simple and cost effective solar technology.

As a member of the small solar oven sub group this semester, I researched how our oven should be designed to produce the best results in Ithaca. We decided on solar collection angle and designed our oven around this angle and the size and material constraints that we imposed. Working on a project from the initial concept phase through to its completion has been a valuable experience. I have come to appreciate the complexity involved in almost any engineering project. I have learned that close attention to detail must be paid from project scheduling down the smallest detail of how each part of the oven connects to the rest.

I have appreciated being able to escape from the grind of normal academics and work in the shop to build the oven that I helped design. I learned how to use tools I have never used before and how to come up with innovative solutions to problems that arise throughout a project. I enjoyed getting dirty and constructing our project from scratch.

At the beginning of the semester I had few goals beyond learning about local and global sustainability efforts and working on a project that could contribute to these efforts. I soon learned the importance of communication within our subteam and through the solar oven team as a whole. I have been held accountable for my own share of effort and have worked to produce a high quality product by the end of the semester. I even made homemade macaroni and cheese for the first time ever, in a solar oven nonetheless. The team atmosphere has made this semester a rewarding experience.

Sarah Clement

As a member of the Solar Oven Team this semester, I had the opportunity to collaborate and work with a group of other engineers to improve a current technology that has already been proven to have a positive impact upon society. Using the resources and technology available to us at Cornell, we were able to help a community in Nicaragua. Through communicating with the women in Nicaragua, our team was able to address specific issues that they felt were the most important. The team was able to be respond to the needs of the community.

At the beginning of the semester, the Solar Oven Team split into three subgroups. I was most interested in the testing of alternative materials for the insulation in a solar oven. The women in Nicaragua asked the Solar Oven Team to test the effectiveness of fiberglass as an insulation material. Our sub-team also chose to test the insulation capability of rice hulls. As a member of the Insulation

Sub-team, I was able to work hands on with the construction and development of an experimental set up and procedure. I was satisfied by the work that the sub-team accomplished this semester, as the experimental unit that was constructed provides tangible evidence of the achievements that were made. I am also pleased with the work that the entire Solar Oven Team achieved. Every member worked diligently throughout the semester to accomplish each sub-teams' individual goals.

Upon joining the Solar Oven Team, I set personal goals for the semester. Since I was aware of what I wanted to personally accomplish from the start, I was able to take the necessary steps to achieve my goals. Similarly, the Solar Oven Team set goals for the semester. The team worked well together; supporting and collaborating with one another. The dynamics of the Solar Oven Team this semester lead to the various achievements made by the team as a whole.

Margaret Ding

Personal Goals:

Working in a subgroup of two within a larger team was a unique experience. I believe as a group of two, my teammate and I had a well-balanced dynamic in which I was not hesitant to make suggestions or changes to our work. We constantly communicated and made sure we were on the same page. I was able to carefully consider criticism from Tim and the professors, and make changes in accordance to my conclusions. I was careful to be proactive and constantly continue this project, even though we did not end up achieving everything we had hoped. I participated more in class than I might normally, but I could have made a greater effort. I learned a lot about alternative energies and the great uncertainties they currently present to society. The Solar Oven team taught me that a simple idea with simple improvements focused on utility can be invaluable to those that use it (the women in Nicaragua).

Professional Goals:

I was able to apply my construction skills from my previous work experience with Tim Bond in building our solar reflector. As for writing, I believe my team's revision process taught us a lot about the value of clear technical writing. When addressing criteria, one should realize the scope of the project instead of putting out general "world peace" type goals. Technical writing should be persuasive without acting as propaganda. I have made an effort to incorporate proper flow into our reports and editing out the unnecessary. Our oral reports have also improved, and we have realized that powerpoint slides should *aid* your presentation, not *be* your presentation. As for the entire design-build process, I have learned about the value of detailed scheduling and designating appropriate time to other activities.

Catherine Hanna

I had originally wanted to be on the Solar Oven team because I knew this project would require loads of research, design-work, and construction; I wanted to take part in a project that would be completely hands-on and very interactive. My specific subteam (the Concentrated Cooker Subteam) fulfilled my requests since it required a maximum amount of time and effort, as we basically had to start from scratch when working on our parabolic cooker. This past semester, our group has seen a lot accomplished in terms of progress with this project. With our specific subgroup's cooker completed, I can say with certainty that my time spent working in Winter Lab was extremely fulfilling and worthwhile.

I believe I have accomplished all of my earlier stated professional goals for the semester. As a summary, I had wanted to fully comprehend how to design and develop solar ovens, I had wanted to apply previously learned knowledge to the project in order develop a strong basic engineering foundation, and I had wanted to improve my ability to work on projects with team members. Because I successfully built a solar oven from scratch by effectively finding solutions for anticipated problems with a partner, I would consider these goals completed. Though, I am still not quite comfortable speaking in large groups. I think this specific goal will require many years of effort to overcome, if at all.

In terms of personal goals, I do not quite know if I accomplished them to their fullest potential. I think working as a team helped me to gain a slightly better work ethic in that I always try to get work done as efficiently as possible since my work ethic reflects on the entire team. This fact forced me to put as much effort as possible into graded assignments. However, I think that time constraints caused our team to struggle with getting as many things completed as possible toward the end of the semester. Because we rushed many last-minute tasks, I think that these items were not finished in as well a manner as they could have been if more time was allotted. I know especially that my subteam was rushing to finish the wooden frame before the semester ended, and this caused our framework to be slightly less aesthetically pleasing than it could have been.

This project turned out to be more or less what I hoped it would. I learned that designing a prototype takes a lot of time and effort, more so than what I had imagined it would. I do wish I had more time to spend on this project this past semester; a few things could be improved with our cooker design. But what has not been finished this semester can always be done next semester, as I definitely plan to continue working with the Solar Oven Team and hopefully travel to Nicaragua over the coming spring break.

Harrison Ko

As my third semester working with this group, I found it to be a very different semester than the previous two. My goal for this semester was to take on more of a leadership position and to accomplish work that would have a long term effect on the Solar Oven Team's future. Based on these goals, I feel very proud of the work that I helped to accomplish this semester. Never before had a led a research effort; and it certainly was challenge to design and construct a successful experiment. I was fortunate enough to have very good teammates and of course Tim as the advisor; and as such our collective effort created an experimental method that appears to have vast potential for future use. I felt that the experience of coming up with an experiment with limited faculty intervention was a great experience for me, and it is something that I felt has helped me develop as a researcher.

The work that I accomplished this semester I feel is the finest that I have done since being on this team. It was thrilling to see everything come together and to watch concepts become reality. I do plan on continuing work with this project next semester, so I am positive that the work accomplished this semester will be built upon. Overall I thoroughly enjoyed this experience and I am proud of everyone on my team.

Lauren Nielson

During my time as part of the solar oven team, I gained great deal of experience, mostly in areas I did not expect to acquire knowledge. I developed practical skills in addition to project management skills and practice with team coordination. Since I had had only minimal exposure to power tools before embarking on the small solar oven project, the construction work that I contributed required that I learn how to properly use the necessary equipment. I am now familiar with tools (and the respective safety measures) such as power drills, as well as the bits, and saws like the band and table saws.

In terms of project management, my team worked well in coordinating times to meet for tasks that required multiple people and we learned how to time tasks that could be performed simultaneously and those with prerequisite accomplishments. I gained valuable experience in learning to allocate sub-tasks based on individual expertise, while at the same time learning the skills myself through observation and relevant questions. Furthermore, throughout the semester I was continually impressed with the innovativeness that my teammates and I exhibited whenever we encountered any type of setback or confusion. Overall, I enjoyed the sessions I had with my team and I am proud of what we have accomplished.

Rachel Philipson

In the beginning of the semester I had hoped that our team would make a significant contribution to the solar oven project. By designing and constructing a small solar oven, I believe that I, along with the team, have done so. The small solar oven will be used to promote the 'solar oven cause,' which is a very important aspect of keeping a project running. Additionally, I wanted to learn more about the engineering design process. Designing the small solar oven really did help me with this. After dimensioning the frame, I thought that the bulk of our work was done, however when we started to assemble the oven, new issues (such as the best way to screw the pieces together) arose, which taught me how design and construction isn't as simple as determining dimensions. This is a very important lesson that will certainly affect any future projects I work on.

Although working in the lab constructing the oven ended up not a direct application of my engineering skills, it was definitely a fun, interesting experience. I had never worked with power tools, and I feel that this is a skill that will be useful later in life, even if it never comes up in my professional career. Though I was not using knowledge learned in engineering classes, the hands-on experience of building the oven will help me be more considerate of construction constraints when working on other design projects in the future.

In the classroom, I found the lectures to be very interesting. Many of the topics discussed are not mentioned in other classes. I now feel more confident in my knowledge of the subject (and the other subjects we discussed in class), and would be comfortable discussing sustainable systems in an interview or other professional setting.

On a personal note, this semester I had also hoped to improve my teamwork and time management skills. I had never worked on a team with the size and structure of the solar oven team and I think that it was definitely a strengthening experience. Most of the construction required at least two people to be in the lab so this was a good way to prevent the team from putting tasks off until the very end of the semester. Though we did not finish everything we set out to do, I feel like we put a lot of time into the project, and that it wasn't all at the end of the semester. Our time was very well managed and I hope that I can continue to work like this on other projects in future semesters.

Julianne Schwartz

Throughout this semester in CEE 4290, I have worked towards fulfilling the goals I have set for myself, as well as making sure to be a valuable member to my team. I had no to previous knowledge or experience working with solar energy, and being a part of the solar oven team allowed me to contribute to helping others while also gaining knowledge in an exciting field of research.

In the beginning of the semester I set a goal for my team to come up with a reasonable objective within the timeframe that would result in a completed product by the end of the semester. However, since we were working to develop a new experiment, there were sometimes unforeseen obstacles that slowed the process. Originally we had planned to let the insulation experimental unit run through many heating cycles automatically, however, do to the extremely hot lighting system inside, we decided that we did not feel comfortable letting the oven heat up without someone watching it. Therefore, running through an entire experiment will take significantly longer than originally expected. We did, however, succeed in developing and constructing a new experiment to help analyze the insulation degradation problem that we have successfully tested. Since this research will continue next semester, we can be confident that the experimental unit will help to provide insightful information in the future. Although our objectives changed throughout the semester, we have stilled succeeded in creating a complete product and fulfilling this goal.

Since alternate energy sources have a big future in engineering, I set a goal for myself to become knowledgeable in the area of solar energy. Before each subteam began their own project, we worked together to research articles that explain the concepts of heat transfer through a solar oven. Although we may not have directly used this information, we all felt it was important to understand all aspects of the solar oven. This allowed me to understand useful principles of how solar energy could be utilized.

Professionally, I set a goal to work on becoming accustomed to a group environment. Many jobs, especially in engineering, involve working with a group of people from diverse professional backgrounds. Although we chose to break up into small subteams, we still worked to maintain communication as a group. When we had to compile large reports and presentations, so we also had to become accustomed to passing on some work to others and making sure everyone is contributing equally.

References

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3. “Spherical Aberration.” <http://www.tutornext.com/magnification-terms-u-v-f/16049>.

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Appendix

Appendix A – Past Concentrated Cookers

Figure 1: Shallow Modular 3D Parabolic Reflector

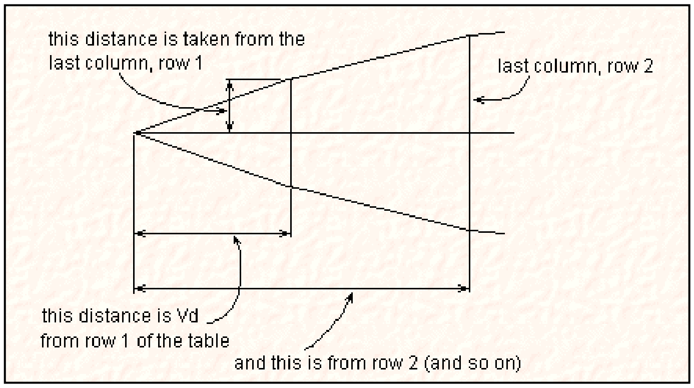
Figure 2: Large 2D Parabolic Reflector

Appendix B – Paraboloid Construction

Table 1: Coordinates for Partition Construction in Paraboloid

row number	***x***	***y***	***y1***	***z***	***Vd***	***from centre***
1	0	0.00	0.26	5.11	5.11	1.01
2	5	0.26	1.04	5.16	10.27	2.03
3	10	1.04	2.34	5.26	15.53	3.04
4	15	2.34	4.16	5.42	20.94	4.06
5	20	4.16	6.50	5.61	26.56	5.07
6	26	6.50	9.36	5.85	32.40	6.09
7	31	9.36	12.74	6.12	38.52	7.10
8	36	12.74	16.65	6.42	44.94	8.12
9	41	16.65	21.07	6.75	51.69	9.13
10	46	21.07	26.01	7.10	58.80	10.14
11	51	26.01				
x increment	5.1					
f (focal length)	25					
sections	16					

Figure 1: Sample Construction of One Partition (Given above Data Points)



Appendix C – The Compound Parabola

Figure 1: Diagram of Compound Parabolic Cooker Surface