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Design of Solar Ovens for Use in the Developing World

Cornell Solar Oven Team Fall 2005 - Spring 2006

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***Abstract* – The main objective of the Cornell Solar Oven Team is to help communities in the developing world design solar cookers appropriate for their specific cultural, social, economic, and environmental conditions. Food is not only a basic human need, but also a culturally important part of daily life. Thus, we seek to implement solar cookers in a way that is not only environmentally sustainable but also culturally sensitive. During the 2005-2006 school year our team's work focused on three main areas: the development and solidification of contacts with new partner organizations, parametric testing of previously constructed solar ovens, and the development of new solar oven designs. The work completed during the fall semester allowed us to produce an effective plan for the development of solar ovens. During spring of 2006, we cultivated a relationship with a new partner organization, *Grupo Fenix*, in Nicaragua. This connection facilitated the team's visit to Nicaragua, during which the team had the opportunity to experience the technical and social aspects of solar oven use in the developing world first-hand.**

Index Terms – sustainable technology, solar oven, solar cookers

INTRODUCTION

Food is a universal need, with far-reaching implications. Gathering, preparing, and consuming food is subject to many cultural considerations. In developing nations the options for cooking food can be limited. Many people rely on wood as a primary fuel, cooking on simple open fires. While wood has been a primary fuel through the ages, it is becoming more expensive, more difficult to find and environmentally costly.[1]

Gathering timber can be a grueling and time-consuming task, which is often carried out by the women and children. Due to the growing scarcity of wood fuel, people are forced to travel farther from their homes to search for it, which is often dangerous. The smoke from burning wood can damage the lungs and eyes of those in close proximity to the oven or fire, especially when cooking indoors. The Cornell Solar Oven Team seeks to address the escalating need for a new fuel source by utilizing the sun as a viable alternative to wood.

Our team seeks to develop cookers to address the needs of specific populations. In choosing and building our design prototypes, three considerations have guided our efforts. First, the materials used in the construction of the cookers should be as inexpensive as possible. Second, the cookers should be built from materials available in the local community. Third, we must take the community's needs and customs into account in the design of the cookers.

The Cornell Solar Oven Team solidified a strong working relationship with *Grupo Fenix*, an organization in Nicaragua. This partnership has allowed us to gain valuable experience and knowledge in the successful design, construction and implementation of solar cookers within a community.

This paper explicitly outlines our goals, what we have accomplished in the 2005-2006 school year, what we have learned, and what more must be done to address the important issue of making effective, community-friendly, and sustainable solar cooker technology available in developing countries, especially in Nicaragua.

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MOTIVATION AND OBJECTIVES

Our goal is to use our engineering skills to aid in the design of cookers that will be useful to people in developing countries. Our connection with *Grupo Fenix* focused our work on solar cooker use in Sabana Grande, a small rural community in northwestern Nicaragua. Massive deforestation in Nicaragua has created a substantial need for fuel sources other than wood. As a result of the efforts of *Grupo Fenix,* solar cookers are already being used in Sabana Grande. We plan to work with *Grupo Fenix* to improve their cookers and methods for using them.

Prior to the establishment of our partnership with *Grupo Fenix,* we sought to create a general plan to implement solar cookers in any community. Our plan was three-fold, managed by three sub teams:

1) The Parametric Testing Team tested simple box cookers in order to provide insight into the effects of changing different design parameters on the efficiency and performance of the cookers. This information, combined with the new design possibilities, would aid in the development of more effective solar cookers.

2) The New Designs Team focused on designing and building several different prototypes in order to provide options to prospective communities. The construction of new prototypes has allowed S'Avancer to investigate the benefits of using innovative materials and designs.

3) The Contact Research Team sought out new partner organizations and researched the cultural aspects of the communities we hoped to work with. The information they provided will allow us to spread solar cooker technology to many communities and help to integrate the cookers into their way of life. By the end of the Fall 2005 semester we had come in contact with *Grupo Fenix,* an NGO based in Nicaragua.

Our trip to Nicaragua in March 2006 provided us with an opportunity to put our Fall 2005 cooker research into a real-world context. During our trip, we had the opportunity to observe a successful culturally-sensitive solar cooker project in Sabana Grande. This allowed us to learn what materials are available, thus determining which of our new oven designs from the previous semester would be feasible for use there. We were able to perform preliminary parametric tests on *Grupo Fenix*'s cookers during our one-week stay. *Grupo Fenix* and S'Avancer have formed a solid and mutually-beneficial partnership with many opportunities for future work.

PREVIOUS WORK

Considerable work had already been accomplished by the Solar Oven Team at Cornell University in past years. At the outset of the 2005-2006 school year three functioning solar cookers were already constructed – two identical box cookers and one box cooker with an angled top. A method for testing and comparing the performance of two solar cookers had been documented by the Spring 2004 team.[2] We also made use of parametric testing data on insulation and reflective material from past semesters.[3]

Efforts were undertaken to continue the cooperation that was established last year with Mohammed V University in Morocco. However, our relationships with partner organizations dissolved and we began to research new opportunities, eventually establishing our connection with *Grupo Fenix*.

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CONTACTS

The goal of the Contact Research Team during Fall 2005 was to develop and execute a plan for creating new contacts and ultimately finding partner communities. This plan was meant to be portable: applicable to any region that the team may decide to investigate in the future.

Our development plan sought to utilize previously built networks with contacts in target communities. The team used a variety of resources to research and establish relationships with new partner organizations, including domestically-based organizations such as the Peace Corps, Doctors Without Borders and the Cornell International Student and Scholars Office (ISSO).

Our relationship with *Grupo Fenix* began when Prof. Susan Kinne, Director of the Alternative Sources of Energy Project at the National Engineering University in Managua, Nicaragua, visited Cornell to give a lecture. She met with the team during her trip and we made plans for future cooperation.

PARAMETRIC TESTING OF BOX COOKERS

The Parametric Testing Team conducted tests on a variety of cooker parameters throughout the months of October and November 2005. Cookers were tested parametrically by placing them next to one other, as depicted in Figure 1. We tested the cookers under identical conditions in natural sunlight outdoors on sunny days. Several people set up thermocouples on the cookers. We ran a Visual Basic program that recorded and graphed the thermocouple temperatures every 30 seconds.

FIGURE 1. PARAMETRIC TESTING SETUP OF BOX COOKERS.

Parameters Tested

The testing focused on the effectiveness of reflective materials, the effectiveness of the number of reflector panels, and the door type in the box cookers. Table 1 shows the parameters tested along with the results. For reflectivity, the use of black vs. reflective materials for the inside cooker sidewalls and pots inside the cooker was tested. Also examined was the effect having a double-paned glass door on the top of the cooker instead of a single-paned door. To learn more about the temperature gradient inside the cookers, thermocouples were placed on the bottom, in the middle, and near the top of the cooker. A pyranometer was used for measuring incident solar radiation and unused wired thermocouples were used to find the ambient air temperature.

TABLE 1. FACTORS AND RESULTS OF PARAMETRIC TESTING.

Factors	Choice
1 Reflector Panel vs. 4 Panels	4
Single Paned Glass vs. Double Paned	Double
Metallic Pot vs. Black Pot	Black
Shiny Sides vs. Black Sides	Shiny

Without parametric changes to the cookers, we tested them side-by-side to make sure they performed the same. We used water in this control test and they performed nearly identically, as shown in Figure 2.

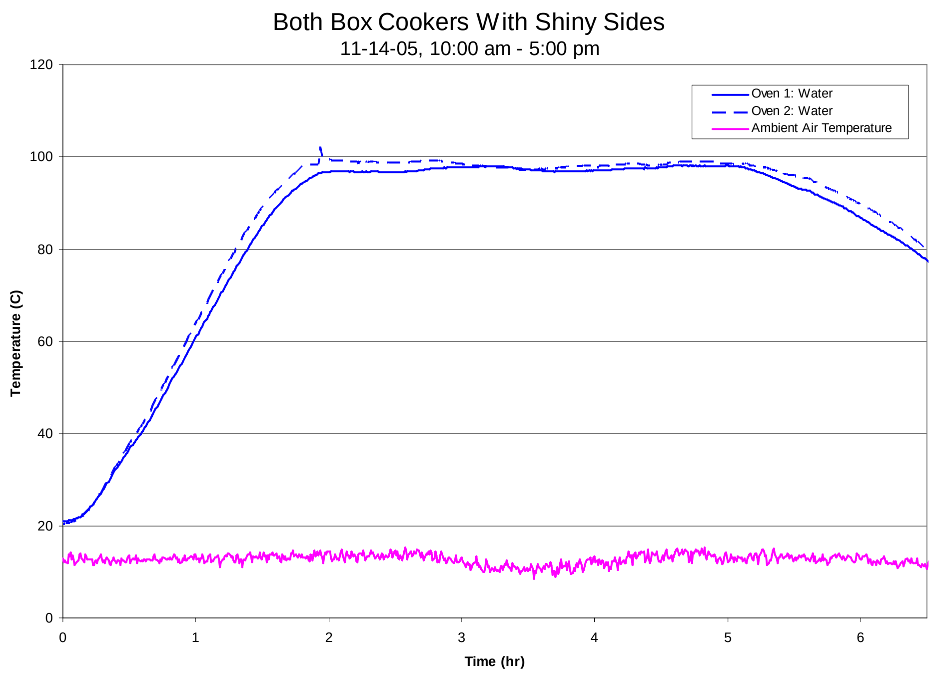

FIGURE 2. CONTROL TEST.

Test Results

Temperature Distribution

While we measured the temperature distribution within the cooker several times, our results were somewhat inconclusive. More tests are needed in this area. It is an important area of exploration since it would be advantageous to put the food at the hottest region of the cooker.

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Glass Type

We found that the double-paned glass door produced significantly greater cooker temperatures than the single-paned door. On average, the cooker with double-paned glass was 7°C warmer. At the top, near the glass, the temperature difference was 13°C, as shown in Figure 3. This performance difference was because the air space between the panes made the double-paned door a better insulator.

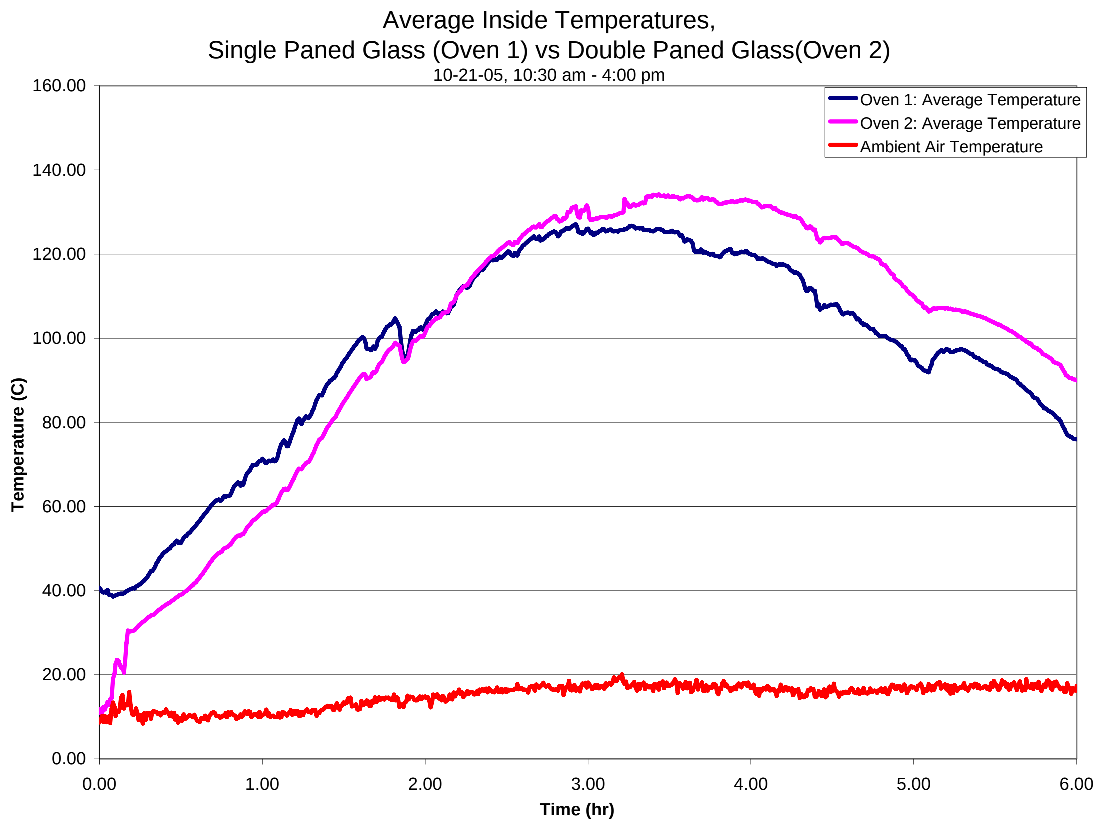

FIGURE 3. PARAMETRIC TEST OF GLASS TYPE.

Pot Type

The use of black cooking pots produced higher temperatures than unfinished aluminum cooking pots. Using a black pot resulted in a 10°C higher temperature inside the pot and 13°C warmer on the surface of the pot.

Sidewall Reflectivity

The cooker with shiny interior sidewalls heated water considerably faster than the cooker with black interior sidewalls. While both pots of water in our test reached the boiling point, the box cooker with shiny sidewalls was able to accomplish this approximately 40 minutes faster, as shown below in Figure 4.

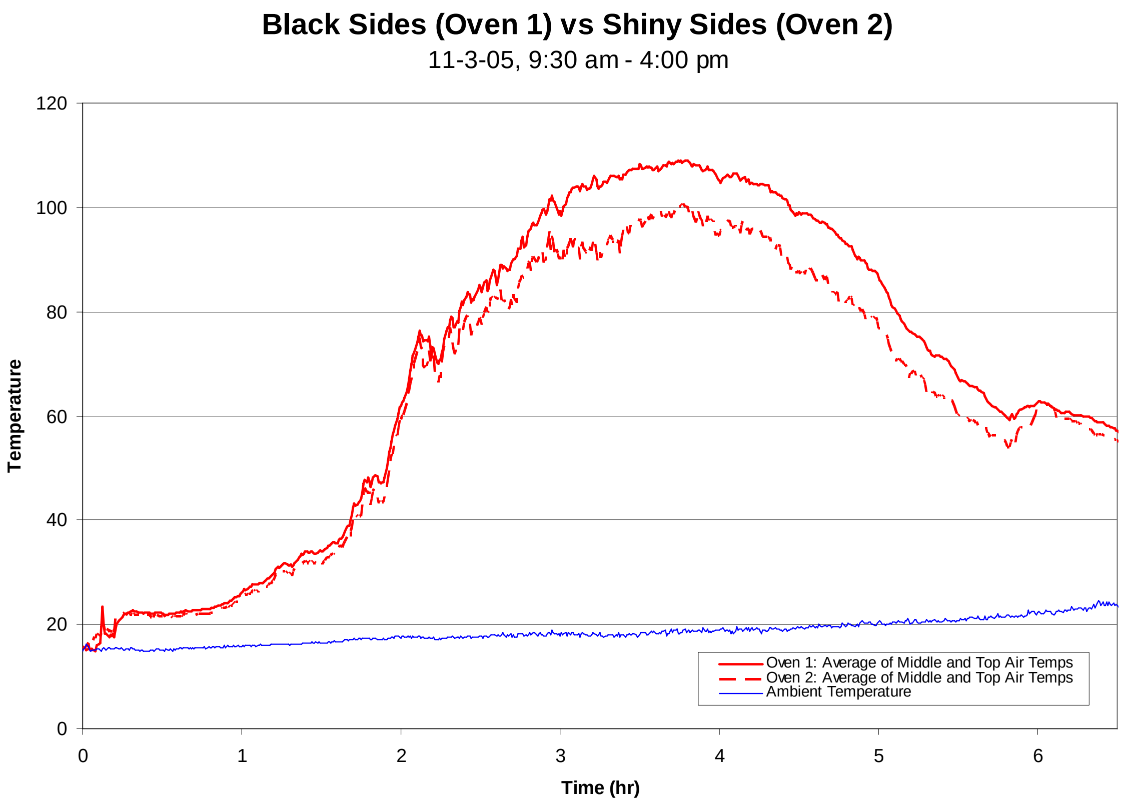

FIGURE 4. PARAMETRIC TEST OF SIDEWALL REFLECTIVITY.

Number of Reflectors

The peak air temperature of the cooker with four reflectors was approximately 20°C higher than the oven with only one reflector, as shown in Figure 5 below. While more reflector panels achieved a higher temperature, this test was conducted in Ithaca, where the sun was lower in the sky than it would be in Nicaragua. More testing is required to determine if the increase in temperature is worth the loss in ease of use because of the bulkiness of the four reflector panels.

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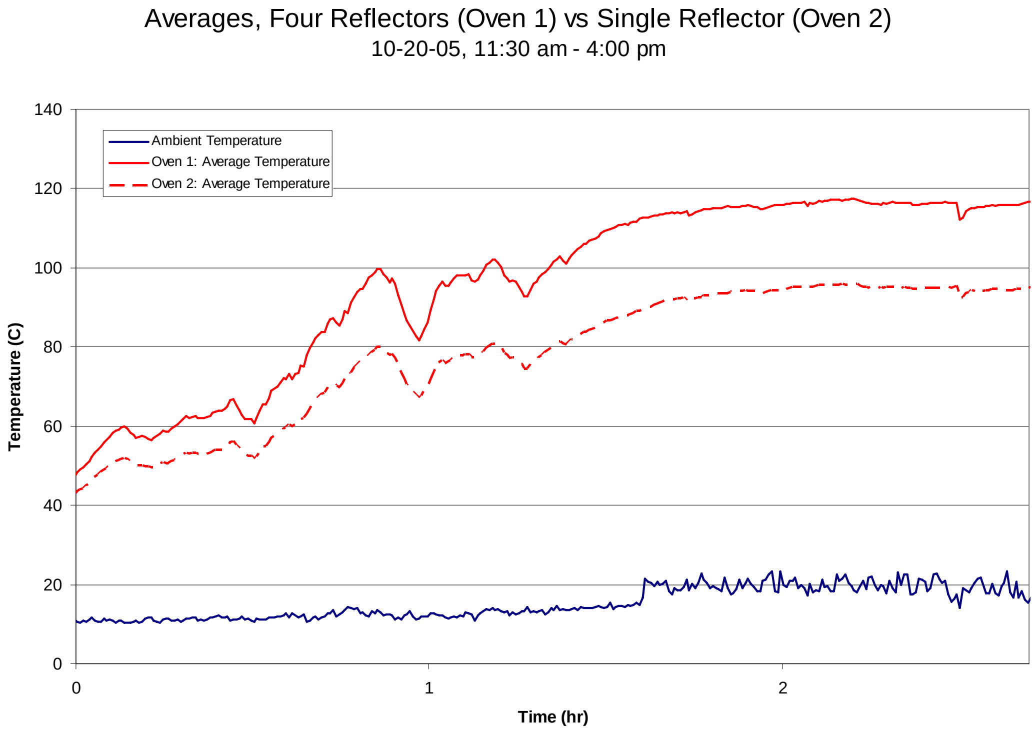

FIGURE 5. PARAMETRIC TEST OF REFLECTOR NUMBER.

While a universally perfect solar cooker cannot be created, recommendations can be provided for specific components of the box cooker. The recommendations from parametric testing are summarized in Table 1.

Weather conditions in Ithaca, NY (central NY, 42.47° N, 76.5° W) posed significant problems. Testing was often problematic as Ithaca tended to be completely overcast or rainy for most days in October and November. Additionally, some days it could be quite cold and windy. However, as a result of their insulation, the box cookers did quite well. Emphasis was placed on sealing the cookers more effectively in order to trap as much heat as possible. The temperatures in which the cookers were tested were still a cause for concern because these cookers are supposed to be used in the tropics. It is assumed that with a higher ambient temperature, insulation would be less important.

Testing indoors under artificial lighting would solve weather-related problems. Many more tests could be conducted with more consistent results. We plan to design a lighting system to use as a replacement radiation source. The testing lights will need to approximate the UV, infrared and visible light that reaches the earth's surface. We are unlikely to obtain true sunlight conditions from a single light, but hope to approximate it with a multiple-bulb lighting system.

NEW OVEN DESIGNS

The objective of one subgroup was to design a variety of cookers, each having different advantages. The diversity of the cookers would give the community where they would be used a choice, hopefully increasing the chance of long-term acceptance. Since the project partner organization changed during the course of the project, the exact location/climate in which the

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cookers would be used was unknown and therefore a variation in designs would allow a mixing and matching of components, creating a cooker best suited for the environment. After conducting much research on current solar cooker designs, a brainstorming session was conducted in which five final designs were chosen. They were then built and tested. As with the box cookers, thermocouples were used to monitor the temperature increase inside the new ovens. Some cookers were tested with a pot of water, for thermal mass, and some without.

Tire Cooker

The first cooker was based on a design by Solar Cookers International.[4] It was appealing due to its simplicity. It is made from a car tire, a piece of glass and a reflective surface, as shown in Figure 6. A team member with solar cooker fabrication experience in Senegal remarked that, in Senegal, there were old tires everywhere. The availability of materials for this cooker is probably its best feature. Unfortunately, the tire cooker did not test well and the maximum temperature reached was 58°C. Due to the low solar altitude during testing, the wall of the tire cast a shadow on the pot inside. However, we have not given up on the tire cooker; a different location might make this cooker more effective and if not, perhaps the tire will serve as an insulator in another design.

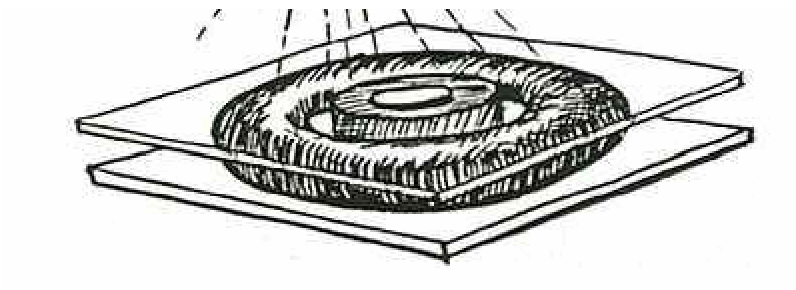

FIGURE 6. TIRE COOKER.

Bowl Cooker

The bowl cooker is made out of a wooden bowl lined with aluminum foil, a piece of glass on top, and then a reflector on top of the glass. The reflector is shaped like a cone with most of its tip cut off. The assembly of the bowl cooker takes about one hour, and most of this time is spent on the reflector construction. The bowl cooker works best with food in a black pot. Although not tested, food could potentially be cooked directly in the bowl. Set-up of the bowl cooker requires food to be placed in the bowl, then the glass to be placed on the bowl, and next the reflectors. Finally, the bowl needs to be propped using rocks to face the sun.

One weakness of the current bowl cooker design is that the reflectors did not resist wind well. Also, they sometimes blocked the sun instead of increasing the amount of sun allowed into the cooker. One of the main strengths of the design is that the reflectors and glass could be placed on any pot or cooking vessel to cook. The glass and reflector pair also costs less than five dollars. A blanket can act as the insulation of the cooking vessel.

Cone Cooker

The cone cooker as seen in Figure 7 is made out of one foam car window reflector and two staples. It takes only about two minutes to fold the reflector into a cone and staple it near the top and bottom. This design requires a black pot to cook in. The basic design produced two cone

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cookers, with different methods of insulating the cooking area. In one design a piece of glass is placed over the opening of the cone once the pot is inside. In the second, the entire cone is sealed in a plastic bag once the pot is inside. The clear plastic bag is an easier design to set-up and has performed better in testing than the glass set-up.

This design has many strengths. The first strength is its simplicity. This was by far the simplest design to construct. Second, the cost of the basic design is $6, although glass could add some cost. Therefore, this option is much more economical than the box cookers. Third is its performance during testing. With ambient temperatures of about 10°C, the air inside the black pots of the cone cookers typically reached temperatures of over 60°C. However, this cooker has very little insulation, so in a hotter climate with more sun, this design could reach much higher temperatures.

FIGURE 7. CONE COOKERS.

Cardboard Box Cooker

The cardboard cooker is a box cooker made out of cardboard with four-sided trapezoidal reflectors (also made out of cardboard), as shown in Figure 8. Assembly of the box cooker involves a lot of cardboard cutting and takes an estimated time of 6-10 hours (depending on the final size of the cooker). Like the wood box cookers, the cardboard cooker can cook food in any color pot as well as in jars and other baking cookware. The set-up is similar to the set-up of a box cooker. First, the pot should be placed in the cooker, then the glass is placed over the box and the reflectors are put on top. The only difference in set-up between the cardboard and wooden cookers is that the cardboard cooker needs to be propped at an angle with rocks and bricks every time it is used since it has no built-in supports to hold it at an angle.

One of the cardboard cooker's main strengths is that it is constructed with materials that are mostly free and reused. All of the cardboard was retrieved from a cardboard dumpster near where the testing and construction of our cookers took place. The only purchased materials were aluminum foil, thread, and the glass, which means that this cooker costs less than $5. Although we have not tested this cooker, its designer reported that the cooker reached temperatures as high as or higher than our current box cooker design.[5]

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FIGURE 8. CARDBOARD COOKER.

Parabolic Trough Cooker

One of the drawbacks of the box cookers is that they can only bake or boil food. In many developing countries, it is customary to fry food. In Senegal for instance, fried fish and rice is the typical meal. Using only box cookers in this setting would mean changing their traditional cooking techniques, which makes solar cooking much less appealing. The parabolic trough design, shown partially completed in Figure 9, focuses all incoming solar rays on a black collector plate, in an attempt to reach frying temperatures near 175° C. The collector plate could then be used as a griddle for frying. Unfortunately, we ran out of sunny days and time to test the trough design so are unsure of its performance.

FIGURE 9. PARTIALLY COMPLETED PARABOLIC TROUGH COOKER.

TRAVEL TO SABANA GRANDE

In March 2006, five team members traveled to Nicaragua to meet with Grupo Fenix and learn about current solar cooker use in Sabana Grande. We worked for six days with several residents

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of Sabana Grande to build two box cookers using the current design promulgated by Grupo Fenix, which is shown in Figure 10. We also conducted preliminary tests on these and other cookers. Through this process, we were able to learn of some problems that the community members face in using this design and were also able to identify some aspects of the design that, if changed, could yield higher temperatures.

FIGURE 10. GRUPO FENIX BOX COOKER.

Sabana Grande is a dispersed community of about 200 families located in the municipality of Totogalpa, Madriz, in the northwestern region of Nicaragua. Most families there cook entirely on wood stoves made of bricks and adobe, contributing to the growing problem of deforestation. Also, smoke inhalation during cooking and the necessity for community members, usually children, to search for and cut wood in the mountains present significant health risks. Luckily, due to the intense sunlight at 13° N latitude, Nicaragua in general is an ideal location for solar cooking. In addition, skies are typically clear for most of the year and, during the rainy season (May-November), sun is still available for part of the day. Therefore Grupo Fenix has been working with *Las Mujeres Solares de Totogalpa* (The Solar Women of Totogalpa) since 1999 making and distributing solar cookers. There are currently about 20 solar cookers in use in Sabana Grande and the number of community members adopting renewable solar technology is increasing.

The current solar cooker design is a shallow square box (30” x 30” x 10” deep), with a double-glazed top and a single aluminum-foil reflector. This reflector can additionally serve as a sturdy lid when the cooker is not in use. The contents of the cooker are accessed through a hinged door on one side of the cooker. One minor complaint that the women mentioned was the lack of durability of the hinges on the doors, which would often fall off after a few years. One possible solution to this problem is placing the hinges in such a way that they wrap around the bottom of the cooker. This approach will decrease the amount of torque on the door since the hinge placement in the previous design creates a significant amount of torque when the door is opened. There were no complaints about the level of heating the cookers were able to produce. However, it did appear that the cookers could be used for heat-intensive tasks more often, such

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as cooking beans and rice, if the cookers could more quickly reach higher temperatures. For this enhancement, we are looking to improve the insulation of the cooker. As we built the cookers, we noticed that the insulation (wood shavings and sawdust) was haphazardly placed into the space between the outside box and the inside box. We also are not sure if using all sawdust insulation would be more effective. Therefore, during the next school year we are going to conduct tests to determine how the insulation (or process of packing the insulation) can be changed in order to increase the cooker temperature. We also noticed that it was necessary to rotate the large and heavy box cookers every 2-3 hours. This job can be exhausting for older women and perhaps a swivel design would make more sense.

We also conducted some rudimentary tests on the new and existing cookers using simple cooker thermometers and digital multi-meters equipped with thermocouples to monitor cooker temperature. We taught several women how to use the multimeters and donated them to Sabana Grande to be used for future testing. We also taught the woman why we conduct tests and what the results mean. This was accomplished through the conduction of one parametric test that compared the use of a black base vs. a shiny base, as well as through calibrating the two cookers we built. We found that the new cookers performed very similarly to each other and that the black metal trays used as pans in the bottom of the cookers appear to improve their performance. However, due to lack of testing devices and cookers in the Sabana Grande workshop, the black base vs. shiny base test had to be performed on two different days, and, although the temperatures of the two days were similar, the test still should not be considered conclusive.

Most importantly, perhaps, the trip helped our team learn about the process of actually cooking with the cookers. Most of the women we spoke with in Sabana Grande avidly praised their solar cookers, and we were eager to understand the many tasks they use them for. These tasks included cooking beans, rice, eggs, and chicken, baking cakes, and roasting coffee beans. Rumalda Lopez, one of the Sabana Grande women, gave very helpful demonstrations on how to make a soy dish similar to couscous and a banana cake. In addition, we found that using the cookers to roast coffee beans seemed particularly promising, since solar-roasted coffee beans could be a marketable product for the women. Overall, they said anything that doesn't require the intense heat of fire could be cooked in the solar cooker. The solar cookers will never replace the fires for cooking tortillas, a staple of the Nicaraguan diet, but with all their capabilities, the solar cooker will certainly reduce the amount of time women spend over the open fires as well as the demand for firewood.

One team member will return to Sabana Grande for two months this summer to continue research and cooperation with the community there, passing along any design improvements the team accomplishes, and possibly investigating the process of solar coffee roasting.

LOOKING FORWARD: TRANSITION PLAN

Now that we have a better understanding of Sabana Grande's current cooker design, we plan to help them improve that design to increase the cooker's cooking power. For some meals, such as beans and rice, higher cooker temperatures and faster cooking times would make the cookers more usable. Possible design modifications could include different insulation techniques, different material for the cooker's outer shell or the addition of more reflector panels. Next semester, with new students joining the team, we will build two cookers in Ithaca using the *Grupo Fenix* design. These cookers can be used for parametric testing of possible design changes here in Ithaca, hopefully with the help of a new indoor light system. The data from our testing in Nicaragua will be used to calibrate indoor test conditions to those found in Nicaragua.

Another long-term goal is to model the heat transfer into, out of, and within the cooker using computer modeling software such as ANSYS or Fluent. Ideally, the model will incorporate heat transfer due to conduction, convection and radiation. We have already explored modeling possibilities and are convinced that a usable model is attainable. The model will help us see which design factors are the most important in increasing cooking power and will hopefully provide a way around the guess-and-check methods of parametric testing we are currently using.

In addition to further cooker testing in Ithaca, we will continue to be in close contact with *Grupo Fenix*. We hope to travel to Sabana Grande next year to help them implement some of our design changes.

CONCLUSION

Our approach to solar cooker design is a combination of laboratory testing and research done in the field where the cookers are being used. Successful implementation of solar cookers requires adequate background knowledge of the cookers, but also willingness to adapt the cooker design to those who will be using it. For the implementation of solar cookers to be sustainable, the users must be closely involved in the design, construction, and testing processes. Current cooking practices must also factor into to cooker design.

Working with Grupo Fenix and the residents of Sabana Grande gave our team the opportunity to observe solar cookers in action. We hope to use our knowledge and experience from laboratory testing to help them improve their cooker design, with the goal of reducing the use of woody fuel in the community. The process used in our work with Grupo Fenix can be modified and built upon for use with other communities in the developing world.

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