Sabbatical Report

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Introduction

This document gives a brief overview of the time I spent on sabbatical during the spring semester of 2012 in the community of Sabana Grande, Northern Nicaragua. There will be a brief overview of general activities in this introduction, followed by a relatively detailed section with a description of the portable solar cooker project that was my focus and ending with some plans for future activities.

Overview of the location—Sabana Grande is a small, rural community about 30 km south of the Honduran border in the northern highlands of Nicaragua. It lies directly on the Pan-American Highway and is connected to the rest of the country by frequent bus service. Electricity is present along the “main” roads in the community (as far as 5 or 6 km from the highway), but a large percentage of households are not connected to the power grid. There is no running water (except for a few wealthier families with a private, elevated tank and electric pumps) and no septic systems or sanitary sewers—all houses have pit toilets. Nicaragua as a whole is the second poorest country in the Western Hemisphere, second only to Haiti.

Overview of the program—An organization called Grupo Fenix, affiliated with the Universidad Nacional de Ingeniería (UNI) in Managua, is working with locals on various community development efforts, focusing on solar energy and other sustainable technologies. This group also coordinates numerous volunteer groups (mostly North American college students) who spend time working on the various projects. The projects are implemented locally via a co-ops structure whose members are women from the community. Some of the projects include: solar photo-voltaic installations for families that on the power grid, solar-thermal cookers (the project area of my project), improved kitchen stoves to conserve wood and reduce respiratory problems, reforestation, biogas, composting, charcoal production, irrigation/organic gardening and natural building methods.

Other activities—In addition to the solar cooker project that will be described in detail below, I also worked on a number of small, short-term projects during my stay. In addition, my first week was a short course in solar energy that included photo-voltaic panel building/installation/debug and solar cooker build/repair as well as material on other topics such as bio-digesters, charcoal production, etc. Some of my non-project activities included repair and alignment of the tile roof on the new restaurant, re-setting of plumbing fixtures on a bio-digester toilet, structural stiffening on a building to resist the wind load of hurricanes, teaching an introduction to heat transfer to a group of non-engineering students who were studying there and working with a student-engineer group from Cornell University on their cooker designs.

This report focuses on the technical aspects of my project in Nicaragua, but the experiences there touched many areas not specifically related to engineering. Cultural, linguistic, historical and political observations were also integrated into the overall experience. For some of these observations and experiences, I maintained a blog which is still available at: http://lynn-sabbatical.blogspot.com/.

Portable Solar Cooker: Background

(Note: Most of the report that follows comes from a document prepared for Grupo Fenix as a record of the successes and failures of my project. Therefore, the level of detail is relatively high and there are several terms included that are specific to that organization, but these details can be skimmed over without losing the sense of the project and the complete report, I believe, gives a good feeling for the scope of the project.)

The portable solar cooker project began in January 2012 during the Solar Culture Course at Sabana Grande when Dr. Richard Komp presented an initial concept for a portable cooker to the course for brainstorming with some follow-up meetings as well. From there, two parallel paths were pursued: one by Dr. Komp that concentrated more on using current materials/technologies and one by me that focused more on potential material/technology improvements that might apply not only to the portable cooker, but might also find future application in existing cookers should Nicaraguan sources be found.

For some items (e.g., hook and eye latches), a successful search was done in Ocotal (nearest city) hardware stores and for some items, standard materials in current use were selected (e.g., printing laminate, hinges, screws). For other items (e.g., insulation, specialty hinges, mylar), items were ordered for deliver to the US and hand carried to Nicaragua in early March. Final assembly was completed on March 15.
Overview of Design and Construction

This section gives a general description of the design features and also describes the methods of assembly, along with photos to better illustrate certain topics.

The cooker design uses a conventional, wooden frame with glued and nailed lap joints at the corners, very similar to frames currently built by the Solar Women, but with different dimensions. (Figure 1)

Two types of construction adhesive are used for the joints, one of which is available in Estelí (nearest larger city) and one came from the US. The cost of the adhesive in Estelí is about $3.60 per tube and that from the US about $2 per tube. The objective for the alternate adhesives was two-fold: first, to find something cheaper than the silicone that is currently used for some gluing/sealing functions and second, to use an adhesive that has greater gap-filling capability that the currently-used white glue. Due to construction techniques available here and the achievable tolerances of the wood after machining, gaps in joints are very common. All wood in the frame is nominally 1” x 1.25” and is the standard un-dried pine commonly available locally.

The skin, both inside and outside, is made of the aluminum printing laminate in current use (Figure 2), with the exception of the protective cap, which is made of stronger galvanized steel. The printing laminate is attached only by adhesive with no nails or screws. Construction adhesive is used on the outside and silicone on the inside, where temperatures are higher. This is accomplished by pressing parts together while the adhesive dries. (Figure 3) The galvanized cap is attached by adhesive and by screws, like the current design.
To toughen the outside skin (made of the thin, rather delicate printing laminate), rigid foam insulation (polyisocyanurate) is bonded directly to the aluminum. The insulation has a thickness of .75”, so there is nominally a .25” air gap between the reflective surface of the insulation and the printing laminate on the inside of the oven. (Figure 4) The exception to the air gap is on the oven base, where a partial sheet of .25” plywood is installed to support the weight of the pot. This plywood is bonded both to the printing laminate and to the insulation. (Figure 5) In spite of the thin (.75”) insulation, polyisocyanurate has an R-value is about 5, equivalent to about twice the thickness of fiberglass.
Both the reflector and glazing use Mylar. The reflector uses a .002” silvered Mylar that was in-stock in the Solar Center and the glazing is .005” Mylar that was ordered from the US. (Figure 6) Attachment to the frame is the same for both types. The Mylar is stretched and attached to a plywood base sheet with staples or tape, then silicone is applied to the frame, the frame is then set carefully on the Mylar and wiggled a bit to ensure good adhesion and finally weights are piled on the frame while the silicone cures. (No testing of acceptable cure time was carried out, but at least two hours was allowed.) After cure, the excess Mylar and adhesive are trimmed with a utility knife. For the reflector, only one sheet of Mylar is required, but the clear Mylar is applied to both sides of the frame for double-glazing.

![Figure 6](left) A view of the reflective Mylar being attached to the frame. The Mylar is stapled to the plywood to keep it taut. (right) A view of the Mylar reflector from the back after trimming. Press-fit braces were glued into the frame to stretch the Mylar and produce as flat a reflective surface as possible. The galvanized sheet metal cap is applied on this side.

An alternate glazing panel is also available using .08” acrylic on the outside and .18” glass on the inside. Both panes are installed in milled channels, just like the current cooker design, but the channel for the glass is made extra oversized to relieve stresses on the glass. A rubber bead is installed before sealing with silicone so the silicone will be easier to remove in case of breakage. The acrylic is simply sealed with silicone in a narrower channel since it is much more resistant to breakage.

The sides, back and door are all permanently attached to the base with hinges: standard 2” hinges for the sides and “sash hinges” for the back and door. Sash hinges are extra long on one side (asymmetric), which allows the back and door to be folded back under the base (against the exterior) in the collapsed mode. These hinges also allow the door to open without the need to elevate the oven above the surface upon which it is sitting. (Figure 7) With the 1”-thick frame, additional holes must be drilled in the sash hinges in order to have a sufficient number of screws. (Longer, strap hinges can also be used to accomplish the same thing as the sash hinges at about one-half the cost based on US prices) The sides are attached so they simply fold inward onto the oven floor. Note that the sides need to have a chamfer at the hinge locations to accommodate the hinge pins and keep the hinges flush against the sides. The reflector and window panels are also attached to each other with standard hinges along the back edge. (Figure 8)

![Figure 7](left) Standard hinges for the sides are shown on top and the door is already attached with sash hinges and folded under the base. (right) The sides are now attached and can fold inward. The door is in the open (but not folded) position.
After assembly with the hinges, there are two separate assemblies: 1) the base with attached sides, door and back and 2) the window-reflector assembly (plus the black absorber plate, which must be a separate part). These two assemblies are connected with dowel pins for positioning and hooks-eyes for securing. All of these are positioned on edges of the panels to allow everything to fold flat in the collapsed position. There are two dowels in the back of the sides that insert into matching holes in the back. This positions the sides properly in the rear. In addition, there are four dowels in the top edges that are inserted into matching holes in the glazing frame, one each on the sides near the door and two on the back near the corners. These hold the back and the front half of the sides in their proper positions.
To properly align the dowels with their respective holes in the mating parts, the hole into which the dowel is to be glued is drilled first. Then, before gluing in the dowel, dowel center transfer plugs are inserted into the holes and the abutting piece is positioned carefully then marked (by pushing or lightly hammering) with an indentation for the other hole. Before gluing, each dowel was put into a drill and the end tapered using a file. This allows easier alignment during the assembly process. The dowel pins only serve for alignment; the hooks and eyes are needed to securely hold the cooker together.

Before the hooks are attached, the gasket material is applied¹. Like the dowels and hooks/eyes, the gasket material is always applied to an edge rather than a face so the cooker will fold as flat as possible. For testing

¹ The description above is for the methods used for the preparation of the prototype design, which used commercial gasket materials. If the method of fabricating gaskets out of silicone with non-sticking plastic is used, the hooks and eyes should be attached BEFORE the gaskets are formed.
purposes, there were three different gasket materials tried: 1) a 3/16” silicone sponge rubber that was attached with silicone, 2) a tubular, flexible, silicone gasket that was attached with silicone and 3) a plastic V-strip gasket that was attached with both silicone an staples. The gasket material is applied to all four edges of the sides, to the top edge of the back, to the front and back edges of the base and to the front edge of the window frame. All three initially seemed satisfactory for sealing purposes, but durability is already observed to be a problem with the V-strip and the others also need to be evaluated.

![Figure 12](image1.png)

**Figure 12** The three types of gaskets tried: plastic V-strip on the left, silicone tube in the center and 3/16 high-termperature silicone foam on the right.

![Figure 13](image2.png)

**Figure 13** Front view of cooker with the door gasket shown. All gaskets are located on an edge and the ones seen here are high temperature silicone foam.

With the gaskets applied, one end of the hook/eye is attached to the window frame and the other end to the edges of the back panel or the door. The hooks at the back only hold the window/reflectors assembly down (the dowel pins already prevent the back from opening). On the door, however, the hooks both hold the top parts down and hold the door closed. So to open the door, the front hooks must be unfastened.
Finally, the reflector support/adjustment rod is sized and fabricated. It is made so the angle of the reflector relative to the glass (i.e., clear Mylar) can be varied from about 50° to 120° and additionally, in the closed position, it does not protrude beyond the frame when the cooker is collapsed.

As another experiment to try other technologies, a black Teflon sheet designed to line the bottom of ovens was purchased. While expensive, it is lightweight, very compact and will not break. More comparative testing with a traditional placa negra is needed to determine the effectiveness of the Teflon and whether or not an air space is needed to separate the Teflon from the aluminum cooker floor.
This completes the description of all the components of the oven and it can be assembled or folded into the transport position. It takes less than one minute to either assemble or disassemble the cooker. The final statistics for the cooker are:

a) Interior size: 43 cm x 43 cm x 18 cm (17” x 17” x 7”)
b) Weight: 6.8 kg (15 lb)
c) Collapsed envelope: 53 cm x 53 cm x 14 cm (21” x 21” x 5.5”)

Figure 16 Photo of the finished cooker assembled and in the open position.
Feedback on the Design and Areas for Improvement

While the design went together reasonably well, there were a number of things that came up during construction or during testing that might be improved upon. Additionally, there are a number of items that have both positive and negative aspects whose impact should be evaluated before finalizing the design.

1) Tolerances on wood parts—
Because a collapsible cooker generally requires a better fit than a standard cooker so that swinging or sliding components will reliably function, the tolerances on parts is more important. The wood generally available, however, is ripped rather than surface planed, to thickness is not controlled very well. Additionally, the wood received is often green (not dried) and tends to warp after machining. With current technologies available in Sabana Grande, there is really no solution for this problem, but some strategies to mitigate difficulties are:
   a. Let the wood dry for several days or weeks prior to building cookers then hand-select pieces for straightness and consistency
   b. Use jigs/stop blocks when cutting pieces to ensure consistency
   c. Make frames slightly oversized with the intent of planning each side to a straight, square condition. This requires a plane in good condition, some level of skill in using a plane and a good woodworking vice (the vice on the Solar Center’s porch is a metal-working vice). Alternatively, plane each piece flat before assembly. A relatively cheap tool that could achieve some of these results is a hand belt sander with coarse (60-80 grit) sandpaper. Again, this requires some practice to successful use.
   d. Maintain an awareness of the importance of consistent, accurate parts during the fabrication process.

2) Moisture in the wood and windows--
When first placed in the sun, moisture immediately started to condense on the upper (cooler) pane of Mylar. As mentioned above, the wood is green and therefore naturally contains moisture that will be trapped once the Mylar is sealed to the frame. The liquid drops may have a negative impact on the cooker’s performance. A vent hole might alleviate the condensation problem by letting moisture escape more easily, but would also be subject to moisture entering during the rainy season and insects/dirt entering at any time. For the initial tests, I detached the top Mylar sheet at one corner to let moisture escape. Experimentation here might determine if the frame can be initially dried with a vent hole then permanently sealed with silicone. There may also be materials that would block liquids, dirt and insects, but allow vapor to escape.
Finally, some of the other cookers/dryers might be used to dry the wood for the glazing before making the window.

![Figure 18](image)

**Figure 18** View of the moisture between the glazing when cooker was first placed in the sun.

3) **Limited adjustment positions with rod due to short length**--
   This is a tradeoff issue because the goal to keep the reflector support short enough to be within the envelope of the folded oven means that the increments of angle adjustment are not very fine. One strategy to increase the adjustment resolution would be to add one or two additional screws at slightly different positions along the edges of the glazing panel. Experience will show if finer adjustment is necessary.

4) **Corner sealing**--
   Corners where strips of gasket material meet tend to have holes, meaning that the oven is not completely sealed. Care and precision of making parts can help this and perhaps one could wrap the gasket material around the corners. The danger here is that the material at the corner becomes so compressed by the bend that it still fails to seal. With square corners, this is often an issue.

5) **Durability of gaskets**--
   Another sealing issue is the durability of the various gasket materials. This will have to be determined by use and experience, but it is already observed that the V-strip material does not spring back well, so the seal is compromised—this material is not recommended for further models. Durability also depends on how often the oven is assembled and collapsed. If the goal is to have the small size for delivery ease and the cooker easy to assemble, but it will generally stay assembled for extended periods of time, then durability will not be as great an issue. However, if the goal is a nomadic cooker that may be collapsed on a daily/weekly basis, then the concern becomes greater. If more durability is needed, the currently-used method of molding silicone to the gap might be the best option, however, it will be challenging to get all the seals made simultaneously because there are so many (12 different surfaces need a gasket with the current design). They should all be done simultaneously because the gap at every location is a function of how all the cooker parts are positioned. Another consideration with silicone is that it doesn’t have as much compliance (“squishyness”) as some of the other materials. If the wood should warp after manufacture, the silicone will stop sealing whereas a more compliant material may still be able to maintain a seal.

6) **Installation of the gasket material**--
   When using silicone to glue the gaskets to the cooker, it is important to make sure the sealing surface stays clean so that it doesn’t bond permanently to the opposing surface. We only want the gasket fixed
to one surface and free to separate from the other one. Also, spacing of the parts before applying the gaskets is important and something that does not have to be controlled so tightly with the custom, silicone gaskets currently used.

7) Location of dowels--
   For the prototype, the dowels were placed at approximately the center point of the edges. However, when gasket materials were applied, they sometimes had to be trimmed, so it would be better to place the dowels closer to the outside surface of the cooker to give as much room as possible on the edge for the gasket.

8) Gap control--
   It is desired to maintain enough gap between mating parts such that there is room for the gasket material to compress. If the surfaces are touching before the gasket is applied, the hinged part may not be able to reach its desired “closed” position. When hinges are fitted to the various parts, it may be advisable to use a fixed spacer to maintain the desired compression on the gasket. (This also relates to the issues of tolerance, squareness, etc., in item 1 above.)

9) Spacing of Mylar glazing and protection of the lower Mylar sheet when collapsed--
   Because this design the same size of wood for all the frame pieces, including the glazing, the spacing of the two sheets of Mylar is 1 inch. From a heat transfer perspective, this is probably a bit too wide as free convection currents may be present in the space, reducing its effectiveness as an insulating layer. Additionally, the Mylar flush with the frame is more susceptible to damage from hitting other parts. A possible solution here is to make the window frame to an optimum thickness for spacing the two sheets of glazing, then add a thin strip on the bottom surface so the bottom Mylar sheet is recessed slightly into the frame for a bit more protection.

10) Mylar gluing--
    For the current cooker, the Mylar was on a surface and the frame placed on top of it followed by weights. With this method, one cannot actually see how well the silicone has sealed and filled the gaps. An alternate that may be worth trying is to put the frame on the ground (or table) with the silicone adhesive up. Then the Mylar is laid on the frame and stretched until taut. A finger or small stick can be rubbed on the bonded surface and the silicone guided so it makes a 100% bond between the Mylar and the frame.

    The long-term durability of the silicone-Mylar bond needs to be researched more as it appears to be a relatively weak bond between Mylar and silicone, especially at higher temperatures (i.e., it can easily be separated with relatively gentle pulling). This does not appear to be a major problem in a controlled, laboratory setting, but in the real world might prove otherwise. A frame or edging (e.g., wood or aluminum angle) to physically hold down the outside edge might be necessary to improve durability.

11) Assembly with adhesive only--
    The method of attaching the printing lamina and Mylar without fasteners appears to be satisfactory. It has the advantage of fewer penetrations through the protective skin, so the wood should be protected better. On the other hand, it is important to ensure that corners are well sealed and durability testing should be done to determine if the life of the adhesive is sufficient. An additional negative is that the construction takes longer since one must wait for adhesive to cure instead of using nails or screws to hold pieces together while the curing takes place.
Conclusion

The project was successful in building a demonstration model of a collapsible solar cooker that was small, lightweight and easily assembled/disassembled. A number of items were identified as areas for improvement or for additional testing and comparison testing against other cookers under the same conditions has not been extensively carried out. The problem of moisture between the panes of Mylar has not been totally resolved at this point but opening a corner has removed most all of the condensation without apparent degradation to the thermal performance. On the other hand, some features, such as the folding scheme and the use of positioning dowels, seem to be quite successful and are features that can perhaps be included in future design refinements. The total material cost as built is about $67 and with local material substitutions would be about $53.

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Future plans

I have made one presentation on the trip to the residents and Park Place Assisted Living and will be available for similar presentations to other groups both inside and outside the university. Either this fall or next spring, I plan to present to colleagues and students on campus.
Last May, I attended a UWP workshop on the planning of short-term study abroad courses and my longer-term goal is to develop such a course and return to Nicaragua with a group of UWP students for 10 days or so. The target date for this course would be January or spring of 2014 and it is hoped that it can be integrated in some way with the sustainable energy major/minor at UWP. I have already outlined a tentative syllabus for the course and this fall, I will discuss options with the sustainable energy steering committee. I believe the success of such a course depends on its counting toward some major or minor requirement and sustainable energy seems like the best fit. This would also allow the course to be designed for non-engineering majors at UWP.