Solar Electric Stove Field Research in Uganda

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Abstract

In communities all throughout Uganda, whether it be in big cities or small villages, the most common method for cooking uses a three stone open-fire stove fueled by biomass materials (most commonly wood or charcoal) [see **Figure 13]**. This form of cooking has caused a multitude of life-threatening respiratory problems for those in close proximity to the stoves on a daily basis. According to the World Health Organization "over 4 million people die prematurely from illness attributable to the household air pollution from cooking with solid fuels" and of those affected by indoor cooking pollution, women and children are impacted the most.

During a recent research trip to Uganda, four students attending California Polytechnic State University, San Luis Obispo witnessed the effect of indoor cooking pollution. Their objective for the trip was to explore the potential for solar electric cookstove implementation within Uganda. Specifically, this paper summarizes the findings from their Uganda trip including, their technical design/specifications, implementation strategy, air quality testing, cost analysis, results, and recommendations for future considerations regarding the solar electric cookstove.

Figure 1: Cal Poly students with implemented cookstove in Uganda

Technical Design / Specifications

All materials besides resistive wire for the heating element and the testing devices were purchased locally in Uganda. Prior to the trip Peter Keller of Aid Africa informed the students that all materials needed for the cookstoves could easily be purchased in the town of Gulu, Uganda, where the students would be for the majority of their stay. These materials were purchased at different stores in Gulu where price and quality varied. The prices shown in **Table 1** reflect the final price paid by the students for each item, but for future reference these prices may not reflect the average local prices.

Material	Quantity	Unit	Unit Cost	Unit Cost	Total Cost	Total Cost
-	-	-	*Shillings*	*$*	*Shillings*	*$*
9mm Rebar	24	m	1583.333333	$0.49	38000	$11.88
Rebar labor	1		2500	$0.78	2500	$0.78
Electrical Tape	1	Roll	1000	$0.31	1000	$0.31
Rice Husks	2	Bag	2000	$0.63	4000	$1.25
Switch	1	EA	10000	$3.13	10000	$3.13
1.5mm Wire	5	m	3000	$0.94	15000	$4.69
Saucepan	1	EA	7000	$2.19	7000	$2.19
Reed Mat	1	EA	2500	$0.78	2500	$0.78
Rope	1	EA	500	$0.16	500	$0.16
120W Solar Panel	1	EA	320000	$100.00	320000	$100.00
Concrete	1	kg	500	$0.16	500	$0.16
High temp wire						
Nichrome wire	10.5	in				
Total					**401000**	**$125.31**

Table 1: Cost analysis of Ugandan cookstoves

As shown in Table 1, each stove costs around $125, including the solar panel. With the solar panel costing around $100 (less than $1 per Watt), the remaining materials were only about $25. The solar panel purchased was a 120W polycrystalline panel produced by Sunshine Solar (Model AP-PM-120). The panel's technical specifications are outlined in in **Table 2**

Statistic	Quantity
P_{max}	120W
I_{mp}	6.85A
V_{mp}	17.5V
I_{sc}	7.67A

V_{oc}	22.05V

Table 2: Cost analysis of Ugandan cookstoves

These values were tested by the students using a multimeter and were deemed to be acceptably consistent. The students used these given measurements to design an optimum heating element for the cookstoves. Four separate heating elements were built, two of which were prefabricated by the other students at Cal Poly before departure. Since the prefabricated elements were designed for a 100W solar panel, their resistances were too high so more heating elements had to be built. The newer heating elements had a resistance of 2.5 Ohms. The heating elements were created by using a mold and attaching the nichrome wire in a way that would evenly distribute the heat. Once the mold and nichrome wire were in place, a mixture of one-part cement one-part sand was poured. Several geometries of the heating element and configurations of the nichrome wire were tested. The square mold with a zig-zag design was found to be the best suited for the stove since the heat was evenly distributed throughout the entire heating element. The high temperature fiberglass and copper wire attached to the heating element could withstand temperatures up to 500°C. This was a critical part of the design in order to ensure that the wire did not melt. The final mold for the heating element was created and shown in **Figure 2**. **Figure 3** shows the heating element once the cement and sand mixture has dried and hardened.

Figure 2: Nichrome wire configuration of the heating element. Future designs will not hold the wires in place with a conductor that will allow the current to short. Instead, use something like string, that will just vaporize or at least won't conduct.

Figure 3: Finished heating element

Once the heating elements were tested, the students built two separate prototypes in their office in Gulu for testing prior to implementation. The first prototype consisted of two separate burlap sacks containing rice hulls, one for the base of the stove the other for the top. As pictured in **Figure 4**, a circular hole with a diameter slightly larger than the diameter of the pot being used was cut in the base. Mesh wire was laid and mudded in so that the rice hulls would not fall out of the base. Small wooden supports were placed at the bottom of this to hold the heating element flush against the pot. Once the pot was placed on the heating element, the other burlap sack would be placed on top of the pot to cover the pot and base of the stove to retain heat.

Figure 4: Burlap Sack Prototype

This prototype was tested twice. The first test was not recorded due to insufficient sunlight. Test #2 was completed on July 26th, 2016. One and a half cups of local peas were boiled in two and a half cups of water starting at noon. The test lasted around five hours; its high cook time was attributable to inconsistent sunlight and rain. The temperature inside the pot was recorded every thirty minutes using a thermocouple while power measurements were taken every thirty seconds using an Arduino data logger. **Figure 5** shows the temperature of the food graphed over the power output of the solar panel throughout the test. The gap in the temperature data was during a rainstorm where the panel and logger had to be brought inside. As you can see from the figure, the hottest the stove got up to was around 144 degrees °F. The slope of the temperature data was calculated during these two periods of more consistent sunlight in order to compare the rate of temperature change of this prototype to the other.

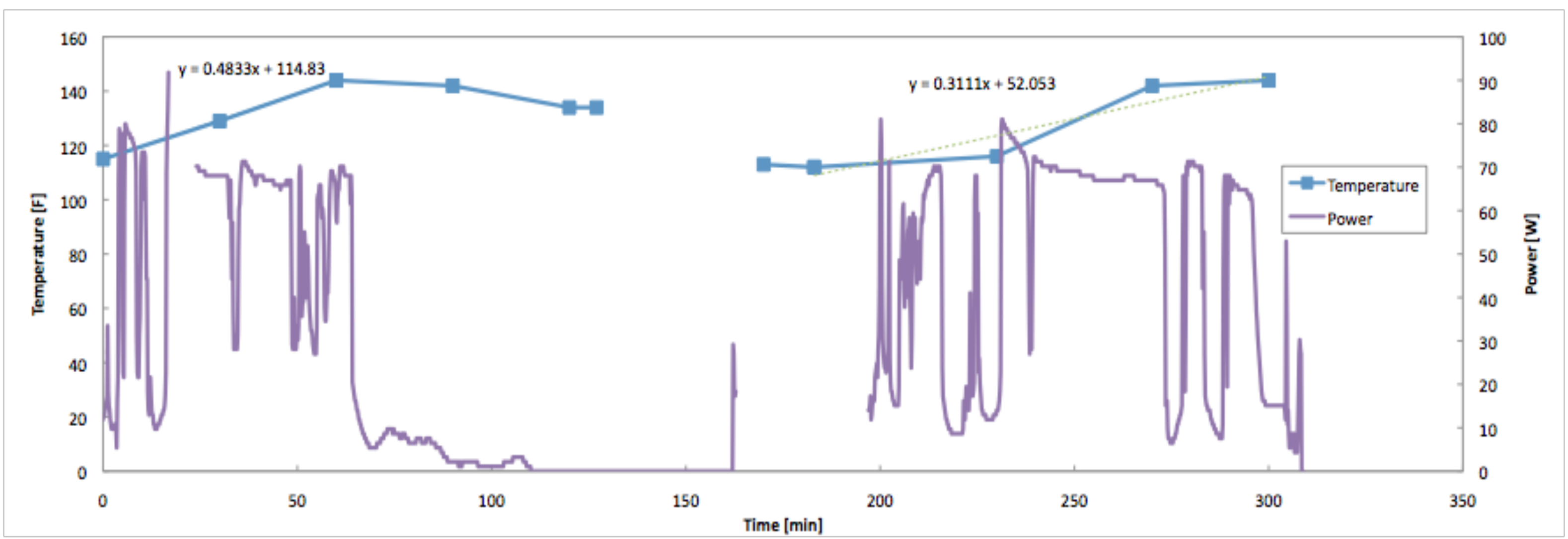

Figure 5: Burlap Sack Prototype Test #2

This design was not implemented within any villages due to its low durability. The students thought that if the stove needed to last around 10 weeks with several uses a day then this design would not be feasible.

The second prototype built and tested had a much different design. It consisted of two separate parts: the outer cylinder and the inner cook chamber. To form the outer cylinder a locally-sourced reed mat was used in order to keep the rice hulls contained. The mat was held up by pieces of 9mm rebar hammered upright into the ground in a circular formation. Once the reed mat was placed upright and woven through these rebar uprights, the mat was tied together end to end and an additional two support ropes were tied around the entire cylinder to keep it from bulging under the weight of the rice hulls.

The inner cooking cylinder was built out of an aluminum cooking pot with a hole cut in it for the wiring of the heating element. This inner chamber was dimensioned so that the cooking pot being used had a slightly smaller diameter allowing it to fit snuggly into the cooking chamber. This decreases the chance of free convection within the cooking chamber. The cooking chamber was also shorter than the cook pot so that after the food is cooked it can easily be removed from the cook chamber. Once assembled, the inner cooking chamber was placed directly in the middle of the outer cylinder, as seen in **Figure 6**.

The inner cook chamber's diameter allows 8 inches of room for insulation between it and the outer reed mat cylinder. To elevate the cooking chamber and allow room for insulation under the cook chamber, three rebar supports were tied onto the outer part of the chamber. These rebar supports were dimensioned to allow 8 inches of insulation directly under it.

Figure 6: Top view of reed mat design

This prototype was tested five times but only the two initial tests were recorded. Both have temperature data but only the first has power data, which is limited within this test. These two tests can be seen in **Figure 7** and **Figure 8**.

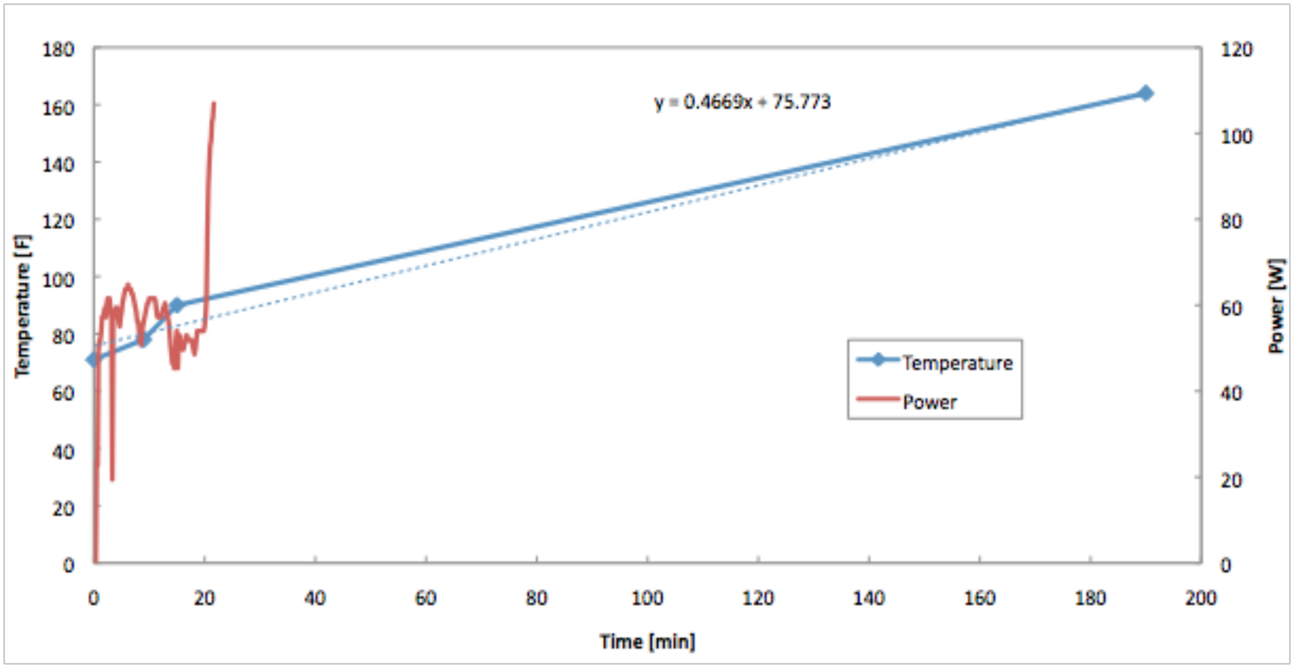

Figure 7: Reed Mat Prototype Test #1

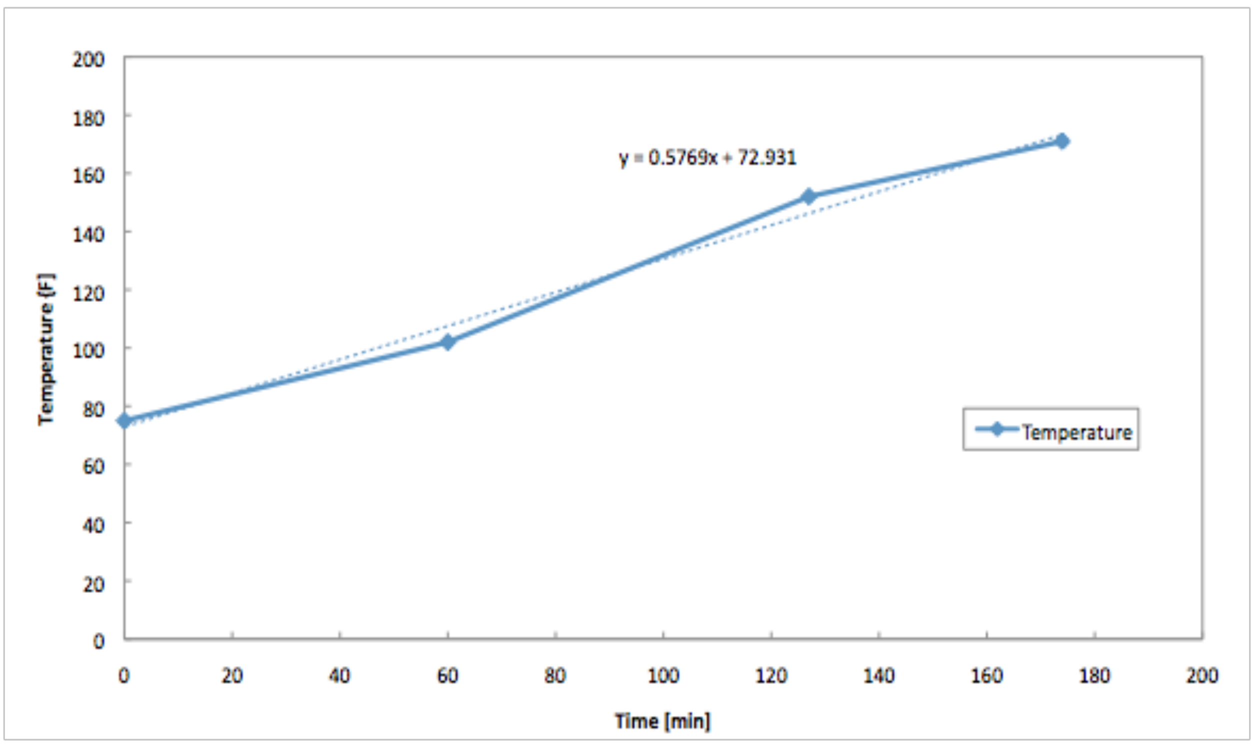

Figure 8: Reed Mat Prototype Test #2

Although it is a very environmentally affected variable, the average rise in temperature over time was taken from all of the prototype tests and tabulated in **Table 3** to compare these two prototypes.

Test # -	**Burlap Sack Design** *[°F/min]*	**Reed Mat Design** *[°F/min]*
1	0.4833	0.4669
2	0.3111	0.5769
Average	**0.3972**	**0.5219**

Table 3: Prototype test coefficients

As you can see from the table the second prototype had a higher rate of change in heat, making it a more efficient oven. Also due to its durability and more aesthetically pleasing design, this prototype was chosen to be implemented into the village huts.

Implementation Strategy

The group of research students worked closely with a non-profit organization, Aid Africa. Aid Africa is located in Gulu, a city in Northern Uganda and their primary projects focus on tree distribution, clean-water wells, and improved cookstove distribution. The students were put into contact with the president of the organization, Peter Keller, who gave them all the necessary resources and information they needed for the trip.

Once in Uganda, the students first visited the villages to see what the current cooking situation is like. Once they got an understanding for the logistical cooking constraints that are common within the Ugandan villages, they began reiterating their solar electric cookstove design to fit the witnessed needs of the village women. As previously mentioned, the students purchased all the necessary materials for the solar stove in Gulu. This is an important point which supports the long term sustainability of their stove given that the necessary materials are readily and inexpensively available within this specific region.

Once the group had chosen the reed mat design that they felt would fit the needs of the end users in the villages, they were ready to install the solar electric stoves. The implementation of the solar cookstoves involved all four students as well as a translator. The students made sure to explain the basic principle of the solar electric cookstove, the potential uses for the stove, and the proper maintenance/upkeep for the stove. One key emphasis made was that the solar electric stove could be used to completely cook a raw meal or, if time or weather was an issue, it could be used as an insulated cooker that does not require energy from the solar panel. This would mean the women could briefly heat up food with their traditional cookstove and then transfer it to the insulated cook chamber of the solar electric stove for it to continue cooking without the use of additional fuel or energy. Furthermore, the students asked that the women help them in building the stove: hammering the rebar supports into the ground, building the outer cylinder, laying the rice hulls, cleaning the solar panel. The students thought the women may have more pride and understanding for something that they also put work into building. Lastly, the students emphasized that those who used the implemented solar electric stove could adapt the design to fit their needs as they saw fit. The students only hoped that the villagers would share with them their thoughts regarding the stove's design, both positive and negative, as well as any adaptations that they made to the stove for enhanced usability or efficiency.

Air Quality Improvement

The solar electric stove provides an emission-free way to cook, eliminating any irritants and carcinogens from the air. On their research trip, the students wanted to record their progress, so they brought an array of air-quality monitors. The data that they collected from the air quality monitors would serve as a great baseline for understanding how much particulate-matter exposure could be prevented with the solar electric stoves. The students implemented the air

quality monitors within the same two homes where the solar electric cookstoves were installed. They collected air quality data from before and after the solar electric stove installation. The data they collected implied that the families cooked with traditional stoves about 75% less than they did prior to the solar electric stove being installed.

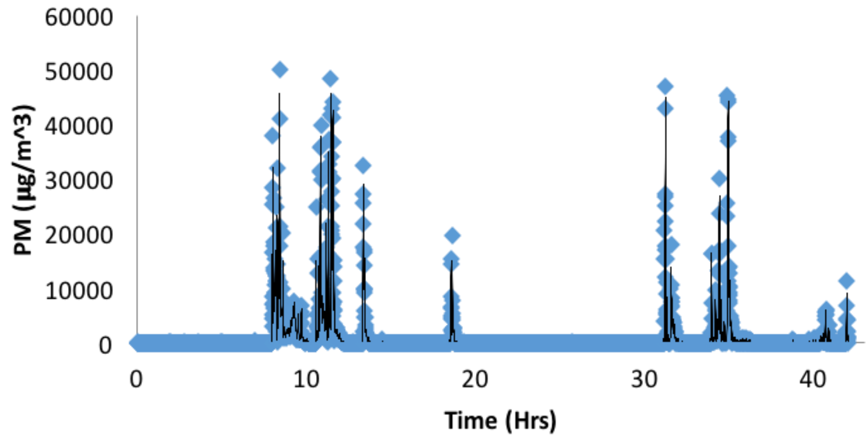

Figure 9: Pre-stove particulate matter

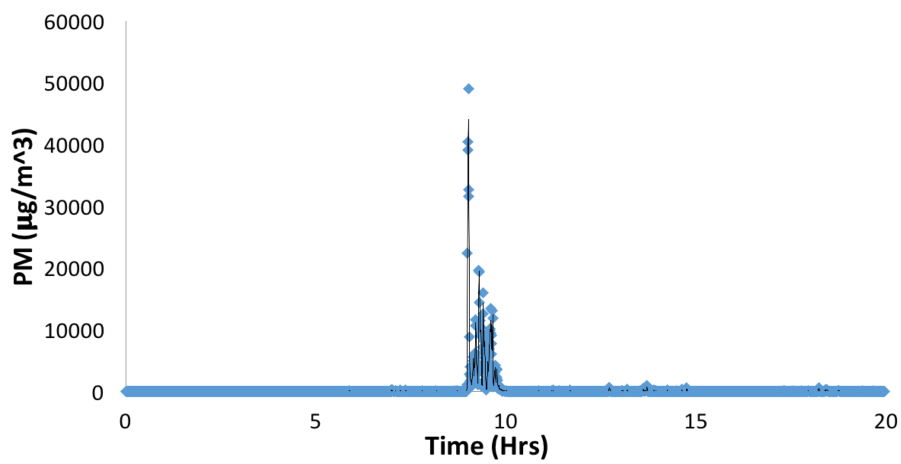

Figure 10: Post-stove particulate matter

Though the data is promising, the students could only record about 80 total hours of data and there are external variables that could affect the data. Placing air monitors and solar panels in a house prompted the families to lock their doors and keep them closed more often to decrease the chance of theft. This in turn meant that there was less fresh air circulating through the house.

Another concern is that the families will decrease their use of the solar stoves as time progresses and they become less curious about the technology. To get truly relevant data it would be ideal to have a monitor on site for at least a month, not four days.

Results

The villages that the students implemented the solar electric cookstoves in were located in very remote parts of Uganda where phone and other telecommunications are rare. This highlights another salient reason for the students' partnership with the local Ugandan non-profit, Aid Africa. The students were able to keep track of the progress and adoption of their solar electric cookstoves by having the Aid Africa team make periodic check-ins to the villages. On the most recent field check-in, the Aid Africa staff gave the following report following their direct field visit:

> "Hi all, Here's your subject with your cooker. We visited her yesterday and she tells us they've used the cooker every day. They cooked beef in about 3.5 hours and they've cooked rice, okra and eggplant. Then, there's was enough daytime left to heat water for bathing. Don't underestimate the significance of that. They would never waste precious firewood on an extravagance like bathing water. We all like our hot baths; they do, too. One note: the water was too hot and they had to dilute it. You've made a significant improvement in their lives. Staff will return periodically to check on the cookers. No one was at the other homestead but the father came by to unlock the hut and tell us that whenever they are home, they use the cooker. We saw that the panel was there and was kept clean. I asked them to think about how the cooker could be made better and this family had a ready answer. They want a battery system to charge cell phones and to use a light. Again, on behalf of these families whose lives you have impacted, thank you!"

Figure 11: Recipient of first solar cookstove

The students, whom have since returned to the United States, plan to keep in close contact with the Aid Africa staff and look forward to more updates about the use of their solar electric stoves as well possible design modifications that could be used to enhance its utility in this type of rural setting.

Recommendations/ Future considerations

The Cal Poly students who travelled to Uganda have had an incredibly educational and enlightening experience on their research trip to test the solar electric stove in Uganda, one of its potential end markets. After witnessing the living and cooking conditions of those living within rural and urban setting in Uganda, the students envision a large need and potential fit for the solar electric cook stove. Especially after receiving a positive review from the villagers using the cookstoves, the students are hopeful that this technology could be spread to other parts of the world and adapted to help combat similar issues of indoor cooking pollution and environmental degradation.

The students understand that implementation of the solar electric stove in different regions around the world will necessitate alternative designs which are made from different available materials and with varying cultural parameters. However, the product design modifications are expected to vary on region and should not increase the price or change the utility of the solar electric stove drastically.

For the reasons outlined in this paper including the possible socioeconomic, health and global environmental improvements that could be made with the solar electric cookstove, the students are very interested in continuing their research and work with the design. Their future considerations and points of interest regarding the development of the solar electric cook stove include increased thermal efficiency, built-in electric plug-ins, ease of use, and developing relations within other potential markets around the world.

Appendix

Figure 12: Unassembled reed mat design

Figure 13: Traditional three stone fire

Works Cited

Household air pollution and health. (2016, February). Retrieved September 16, 2016, from http://www.who.int/mediacentre/factsheets/fs292/en/