Fuel-Efficient Stoves: A Comparison of Berkeley-Darfur Stoves to Three-Stone Fires

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ABSTRACT

Fuel-efficient stoves have emerged as a potential technological solution to mitigate global issues of hunger, environmental and habitat depletion, and poverty. For the internally displaced persons in the Darfur region of Sudan, the act of collecting firewood is directly related to exposure to a multitude of social dangers, and as a solution, fuel-efficient stoves have been introduced in the area in an effort to alleviate these persisting issues. In this study, I analyzed the fuel efficiency of the Berkeley-Darfur Stoves (BDS) under simulated wind conditions by making a direct comparison of dry wood consumption, specific fuel consumption, and thermal efficiency of the BDS to traditional three-stone fires. These analyses were performed for both types of traditional meals from the region, *mullah* and *assida*. I discovered that the designed BDS is consistently more fuel-efficient than the three-stone fire, and this improvement in fuel efficiency significantly increases in the presence of wind. This project supports the mission of the Darfur Stoves Project, and also provides insight into future development of the cookstoves.

KEYWORDS

improved cookstoves, internally displaced persons (IDPs), fuel consumption, thermal efficiency, appropriate technology

INTRODUCTION

Five million people have been displaced by the civil war that has been ravaging western Sudan for nearly a decade. Although these internally displaced persons (IDPs) have found a relatively peaceful home within refugee camps in Darfur, they are deprived of basic resources and services and must rely on agencies and non-governmental organizations (NGOs) to provide the essentials for survival (Lari and Teff 2008). One basic resource, which has since become depleted and scarce in the areas surrounding the refugee camps, is firewood used for cooking and boiling water (Amrose 2008).

The limited vegetation has introduced numerous social concerns in the area. The refugees in the camps are forced to embark on distant journeys three days a week, 7 hours each, to collect appropriate fuelwood. Once outside the refugee camp boundaries, people relinquish their securities and are exposed to the harsh dangers of their natural surroundings, the militia, and rebel groups, leading to a staggering amount of kidnap and rape (Gadgil 2007). As a result, many IDPs have begun a trading system within the camps to purchase their firewood from other refugees. Those who choose this method spend around 250 Sudanese dinar a day on wood, which is close to a quarter of their daily living stipend. Those who cannot afford this transaction rely on trading food for firewood. Consequently, many families struggle to produce even one meal per day (Gadgil 2007). .

The dense living conditions also present an enormous environmental burden on the area. The vegetation has already been exhausted in the immediate surroundings, and the outer limits are slowly becoming more barren (Kelly 2006). This unsustainable lifestyle prevents the vegetation from naturally recovering and regenerating, and accelerates soil erosion (Robinson 2005). Not only will this greatly affect the natural ecology of the area, but it will also further exacerbate the problem of traveling far distances to collect wood. In addition, the topography and geology of the area have been dramatically altered due to changing sediments and root structures, and the available groundwater has been cut in half (Bromwich 2007). Given that the scarce fuelwood has become a valuable commodity, warring rebel groups will deliberately set fire to entire forests to prevent opposition groups from obtaining the resource (ProAct Network 2008).

The standard stoves currently utilized by the refugees in Darfur are extremely rudimentary, consisting of either a three-stone fire, or a mixture of mud, water, and animal waste

(Patrick 2007b). These stoves are inefficient and comparable to open fires, allowing much of the heat to escape and leaving a majority of the firewood wasted. Using this open-fire method, each household requires an average of two kilograms of wood to create one traditional meal (Gadgil 2007). This perpetuates the social and environmental problems by forcing families to make more frequent trips to collect firewood. Existing technologies can provide a suitable, efficient stove that would minimize the negative social and environmental effects of these current practices.

Fuel-efficient stoves, measured by the percentage of heat energy used to heat food or water, have already been researched, designed, and distributed in numerous countries (Jahangiri 2008). However, none have been successful in Darfur. The national parks in the Democratic Republic of Congo have sold efficient stoves to save the mountain gorillas' habitat (Wildlife Direct 2009), and Honduras has implemented a similar project in order to reduce air pollution and particulates (Ashden Awards 2005). In addition, field studies and testing have shown that the Tara Stove, which is a metal stove originally designed for India, required 50% less fuelwood than the three-stone fires (Academy for Educational Development 2008). All three programs have found tremendous success and have collectively brought thousands of appropriate stoves to communities. The reduced use of fuelwood has already improved the quality of life for families, who save money and time, and have a heightened sense of security (Patrick 2007a). However, these stoves were designed to accommodate different regions, with different conditions, resources, and practices. When analyzed in the Darfur region, the Tara stove was found to tip easily while stirring the *assida* or *mullah*, two traditional regional dishes created using large wooden sticks (Gadgil 2007). The Tara stoves also could not withstand the windy conditions, and its fuel efficiency decreased dramatically (Amrose 2008).

In 2005, Berkeley students, scientists, and engineers began work on the Darfur Stoves Project (DSP), which aims to create a fuel-efficient stove while prioritizing the needs of the refugees and catering to the unique characteristics of the Darfur region. Through field observations, the new designed cookstove was found to save 56% fuelwood when used with wind and 40% fuelwood when used without wind when compared to the Tara stove (Amrose 2008). While the project is considered to be successful in reducing the amount of required fuelwood, design of the Berkeley-Darfur Stove (BDS) has evolved continually with feedback from the community. The latest prototype provides practical stability fixtures and insulation to reduce outside surface temperature while maintaining both the appropriate inside temperature for cooking and low-cost production to keep the stove affordable for the refugees.

The next step in the project is determining the best subsequent model to manufacture and distribute. The new insulated stove must be tested to ensure similar levels of fuel efficiency as the uninsulated prototype, and both prototypes of the BDS should be directly compared with the traditional three-stone fires. Previous reports only indirectly compared these two through the Tara Stoves data, but this project ultimately seeks to provide a more definite comparison. I expect that both prototypes of the BDS will be significantly more fuel efficient than the three-stone fire. In addition, since wind has been reported to greatly affect the performance of the stoves, I will perform analysis on the stoves both with and without wind. I predict that the presence of wind will reduce the heat capture and fuel efficiency of both the designed stove and the three-stone fire. By comparing the fuel consumption of the three-stone fire and the BDS design, we can more precisely model and gain insight into the effects of the fuel efficient stoves on the lives of the Darfur refugees.

METHODS

Study system

The Darfur Stoves Project is an ongoing initiative of the Environmental Energy Technologies Division of the Lawrence Berkeley National Laboratory. All testing was performed at the Lawrence Berkeley National Laboratory at the University of California, Berkeley, with wind tests performed outside and non-wind tests performed under the hood.

Methods and objectives

There are four categories of tests: designed BDS with and without wind, and three-stone fires with and without wind. The two prototypes of designed BDS follow the exact same protocol, and the three-stone fire has a few adjustments. As this is a comparative test of all categories, there is no control group. Regardless of the type of test, there are a few universal concepts that apply to the testing process.

The protocol aims to replicate the actual cooking practices of the IDPs as closely as possible. The chosen amounts, timing, and setup have been carefully picked to reflect project reports from workers in the field. The type of wood used in these tests is comprised of mixed softwood, which is derived from conifers. Though this is not an exact match of the various species found in the Darfur area, it does accurately reflect the range of fuelwood used in the area, most of which are pines, firs, cypresses, and other similar bushes. As the IDPs try to utilize any wood they can find, our selection of wood is representative of potential wood species.

To simulate common cooking practices in the Darfur region, each test has two phases: a water boiling test (*assida*), and a controlled cooking test of an onion and oil mixture (*mullah*). The order in which these tests are performed does not matter since they are performed in two separate pots and do not affect one another.

Stove set-up

Three-Stone Fire. The stones are placed in a circular pattern on a tray at an appropriate distance so ensure that both size pots are able to be balanced between the three stones. For each pot, the distance from the bottom of the pot to the ground is recorded to maintain consistency, and varies between 10-13 cm. The fire is lit in the center of all three stones, directly on the tray.

Berkeley-Darfur Stove. There are minimal preparations for the Berkeley-Darfur Stove. The grate opening needs to be clear of any residue char or ash. The fire is lit in the grate, directly below the pot.

a.  b. 

Figure 1. a. The Berkeley-Darfur Stove with a small Tungutungus pot. Both the insulated and uninsulated prototypes share the same outer appearance. **b. Three-stone fire with large Tungutungus pot.**

During a wind test for either type of stove, ambient wind speed must be <1 m/s to ensure minimal external effects on the data. If this condition is met, then the fan system can be set up so that the wind speed between the fan and the stove varies between 2-3 m/s. Although the fan should maintain an average distance of 0.5m away from the edge of the stove, the actual distance and power can be adjusted accordingly as long as the window of 2-3 m/s is maintained. All wind speeds are measured using a standard anemometer. The fan will stay stationary during the entire test, aimed either directly at one of the rocks of the three-stone fire, or perpendicular to the grate opening of the designed stove. This is the only difference in protocol between the wind and non-wind tests.

Testing Implementation

The wood was cut into reasonable and usable sizes, around 2in. x 2in. x 7in each. About 2kg of pre-cut firewood was weighed, with the exact initial weight of wood recorded to determine the amount used throughout the experiment. Before each test, the moisture content of the wood was assessed by using a digital moisture meter on randomly selected pieces of split wood to determine an average value. The fire was lit using newspaper as the starting material, and mainly the smaller slivers of wood and twigs. Once the wood actually catches fire and is lit, the pot can be placed on the stove and the experiment time officially begins.

Mullah. A mixture of 3.5 cups of finely diced onion and 400 mL corn oil was used. The onions were diced to 1 cm^2, as this is reflective of the cooking practices of the refugees in the area. Once the fire was lit, the pot is placed directly above the fire, and the mixture is constantly stirred at about one revolution per second until the onion and oil mixture reaches 120°C. At this time, this phase of the test is officially over.

Assida. The *assida* test was performed with 2500 mL of water in a large Tungutungus pot. The goal of this test was to heat the water to 100°C, and then keep it simmering for 15 minutes. During these 15 minutes, the water was stirred with a wooden spoon attached to a temperature probe. Once 15 minutes have passed, this phase was officially over. To maintain testing consistency, the temperature must remain above 94°C throughout the 15 minutes simmering. If the temperature dropped below this threshold, the experiment was considered to be “failed” and must be restarted.

During either test, a tester must tend to the fire at all times. Pieces of wood are added individually at a minimal rate that prevents overstuffing, as the refugees are frugal with this valuable resource. This will result in a minimal amount of char.

After each phase of the test was completed, the fire was extinguished using minimal drops of water. The collection of ashes and char was placed on the metal tray to dry, and then subsequently weighed. The weight of the remaining unused firewood is also recorded.

Data Analysis

With the collected data, we can effectively assess the hypotheses of relative fuel efficiency. In addition to evaluating pure mass consumption of the fuelwood, three other metrics were calculated to account for potential variability in testing protocol. These parameters were equivalent dry wood consumed for both *assida* and *mullah*, thermal efficiency for *assida,* and specific fuel consumption for *mullah*.

Equivalent Dry Wood Consumed (F_d). This parameter is measured in grams and adjusts the mass of wood consumed to account for the amount of wood that must be burned in order to vaporize moisture in the wood as well as the amount of char remaining unburned after the cooking task is complete.

$$[F_d = W_w * (1 - (1.12 * m) - 1.5 * c)] \quad Eq. 1$$

W_w = the weight of wood consumed
m = average moisture content of wood
c is the weight of the remaining char.

Specific fuel consumption (SC). This is the principal indicator of stove performance for any controlled cooking test and expresses the quantity of fuel required to cook a given amount of food. This ratio is measured in g/kg.

$$\left[SC = \frac{F_d}{W_f} * 1000\right] \quad Eq. 2$$

F_d = equivalent dry wood consumed
W_f = weight of total food in grams.

Thermal Efficiency (H_c). This metric looks at the ratio of work done by heating and evaporating water to the energy consumed by burning wood and produces a percentage.

$$\left[Hc = \frac{4.186 * (W_{init\_water}) * \Delta T + 2260 * W_{cv}}{F_d * LHV}\right] \quad Eq. 3$$

W_{init_water} = weight of water before heating
ΔT = difference between final and initial temperatures
W_{cv} = weight of vaporized water at the end of the test
F_d = equivalent dry wood consumed
LHV = net calorific value of dry wood

The calculated values of these above metrics can be compared to each other to determine relative fuel efficiency between the different stove types. The results from the *assida* and the *mullah* tests are independent of each other and can be analyzed separately.

RESULTS

Stove fuel efficiency comparison

A qualitative statistical analysis on the three parameters shows differences in stove fuel efficiency performance as well as the effects of wind on fuel consumption.

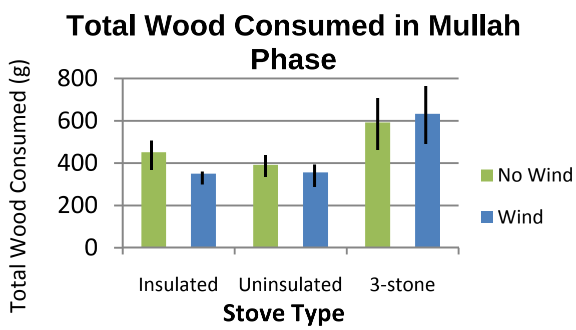
Mullah

The average values obtained from this phase of tests are represented in table 1. For the *mullah* cooking test, the three parameters that were evaluated were total wood consumed, equivalent dry wood consumed, and specific fuel consumption.

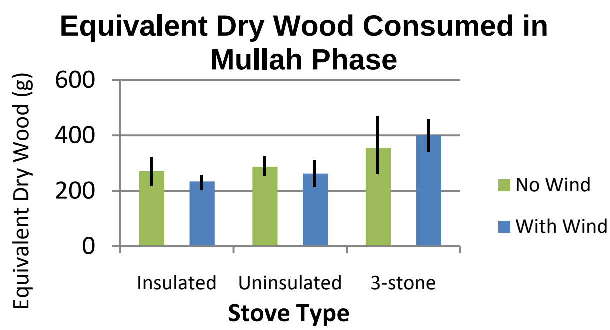
Table 1. Averages and standard deviations for *mullah* parameters for all three stoves under wind and no wind conditions. Bold values represent averages and italicized values represent standard deviation.

MULLAH	Insulated BDS		Uninsulated BDS		3Stone	
	no wind	*wind*	*no wind*	*wind*	*no wind*	*wind*
Total Wood Consumed (g)	**451.74**	**349.77**	**391.37**	**356.37**	**592.34**	**633.03**
	53.81	*13.58*	*41.19*	*43.89*	*126.96*	*119.49*
Equivalent Dry Wood (g)	**271.05**	**233.64**	**287.13**	**262.36**	**355.15**	**401.02**
	43.66	*13.35*	*26.06*	*40.7*	*117.01*	*48.55*
Specific Fuel Consumption (g/kg)	**650.81**	**538.1**	**698.21**	**592.5**	**846.71**	**939.45**
	83.05	*27.4*	*71.63*	*82.6*	*263.41*	*32.45*

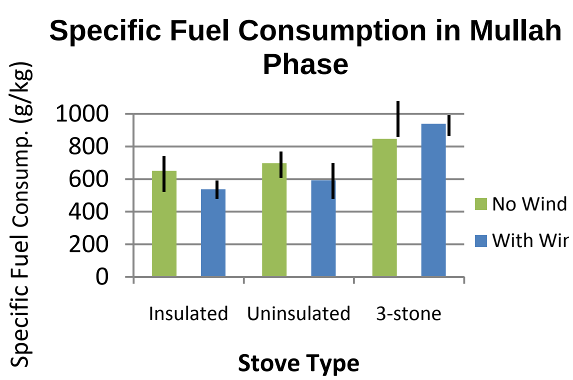
The following graphs (fig. 2) depict the comparison of the three parameters in all six categories of the mullah tests.



a.



b.



c.

Figure 2. a. Total wood consumed, **b.** Equivalent dry wood consumed, and **c.** Specific fuel consumption in the *mullah* phase for all three stoves under wind and non-wind conditions.

Stove differences. There were little to no differences between the fuel efficiency values of the two different BDS prototypes. Under wind conditions, the insulated stove required 1.85% fewer grams of wood, while equivalent dry wood consumed and specific fuel consumption differed by 10.95% and 9.9%, respectively. Without wind, the differences in the three parameters were 13.35%, 5.6%, and 6.79%, though the insulted BDS did not consistently outperform the uninsulated prototype, which consumed less total wood. With large standard deviations in the data, these differences do not suggest a strong performance difference between the insulated and uninsulated stoves.

However, when compared to the 3-stone fire, both stoves consumed considerably fewer amounts of wood. Under non-wind conditions, the insulated and uninsulated stoves required 23.8% and 33.93% less wood than the three-stone fires, respectively, and the specific fuel consumption was 23.14% and 17.54% lower for the insulated and uninsulated stoves, respectively. With the addition of wind, these differences increased to 44.75% for total wood consumed and 42.72% for specific fuel consumption.

Wind effects. The addition of wind to the stove testing increased the amount of wood required by the three-stone fire while decreasing the amount of wood required by the Berkeley-Darfur Stoves. The 3-stone fire saw an increase of 9.88% in specific fuel consumption under wind conditions compared to non-wind conditions. Conversely, both the insulated and uninsulated BDS prototypes experienced a decrease in required fuelwood under wind conditions. The insulated BDS reduced its specific fuel consumption by 17.32% with the presence of wind, and the uninsulated prototype reduced its specific fuel consumption by 15.14%

Assida

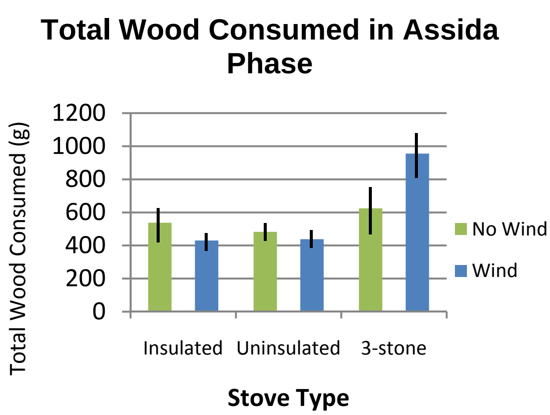
The average values obtained from this phase of tests are represented below in table 2. For the *assida* water boiling test, the three parameters that were evaluated were total wood consumed, equivalent dry wood consumed, and thermal efficiency.

Table 2. Averages and standard deviations for *assida* parameters for all three stoves under wind and no wind conditions. Bold values represent averages and italicized values represent standard deviation..

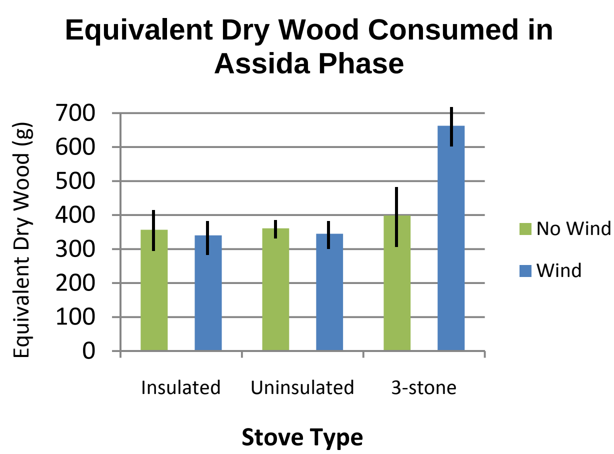
ASSIDA

	Insulated BDS		Uninsulated BDS		3Stone	
	no wind	*wind*	*no wind*	*wind*	*no wind*	*wind*
Total Wood Consumed (g)	**537.53**	**430.5**	**482.15**	**438.47**	**624.3**	**955.03**
	93.57	*47.15*	*55.83*	*50.05*	*146.82*	*114.8*
Equivalent Dry Wood (g)	**356.64**	**340.27**	**360.92**	**344.88**	**398.57**	**663.04**
	51.19	*45.49*	*38.8*	*43.36*	*91.5*	*49.19*
Thermal Efficiency (%)	**31.59**	**26.71**	**31.8**	**26.82**	**25.81**	**15.17**
	5.14	*1.00*	*3.02*	*3.22*	*6.10*	*0.54*

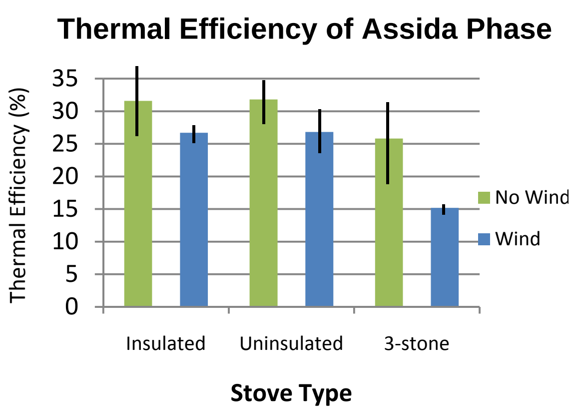
The following graphs (fig. 3) depicts the mass of fuelwood consumed in all six categories of the *assida* tests.



a.



b.



c.

Figure 3. a. Total wood consumed, **b.** Equivalent dry wood consumed, and **c.** Thermal efficiency in the *assida* phase for all three stoves under wind and non-wind conditions.

Stove differences. As with the *mullah* phase of the test, there were little to no differences between the fuel efficiency values of the two different BDS prototypes. Without wind, the uninsulated BDS required 10.3% less total wood, but consumed 1.80% more equivalent dry wood. With wind, the differences in wood consumed and equivalent dry wood consumed were 1.82% and 1.34% respectively, Thermal efficiency, which is the most common indicator of a water boiling test, was extremely close between the two stoves; without wind, there was a difference of 0.67% and with the addition of wind, the difference was 0.42%.

There is a substantial difference when comparing the two BDS prototypes to the three-stone fire. Both stoves consumed considerably fewer amounts of wood and had higher thermal efficiency values. Under non-wind conditions, the insulated and uninsulated stoves required 13.9% and 22.77% less wood than the three-stone fires, respectively, and the thermal efficiency was around 18.5% higher for both BDS prototypes. With the addition of wind, these differences increased to 54.46% for total wood consumed and 43.29% for thermal efficiency.

Wind effects. The addition of wind to the stove testing increased the amount of wood required by the three-stone fire while decreasing the amount of wood required by the Berkeley-Darfur Stoves. For the 3-stone fire, the presence of wind increased the average fuelwood consumed by 330.73g for this phase of testing, which was an increase of 34.64%. While the three-stone fire saw negative effects of wind, the BDS prototypes required a decrease in wood consumption with the addition of wind. The amount of wood required by the insulated stove decreased by 19.01%, and the amount of wood required by the uninsulated stove decreased by 9.06%. However, while the mass of wood consumed was reduced, the thermal efficiency of the BDS did not increase in the presence of wind. Instead, both prototypes saw a decrease in thermal efficiency of around 15.7%.

DISCUSSION

This study aimed to provide a direct comparison of fuel efficiency between the designed Berkeley-Darfur Stove and the traditional three-stone fires of the Darfur refugees. By incorporating the additional wind aspect, the study also sought to provide a more realistic model of the conditions under which these stoves are used. In our analysis, we found a considerable reduction of fuelwood required for both the BDS prototypes when compared to the three-stone fires. Under both the wind and non-wind conditions, the three-stone fire required more fuelwood to perform the same tasks. However, there was no strong distinction between the two BDS prototypes despite the added insulation to one of the models. We also found that the presence of wind served to further polarize the results, as the fuel efficiency of the three-stone fires was negatively affected, and the two BDS prototypes were found to require less fuelwood. Therefore, the results of this study strongly support the mission of the Darfur Stoves Project and also provide areas to explore and assist in the successful implementation of these stoves.

Stove Comparison

Both designed models of the Berkeley-Darfur Stove produced comparable results. There was no distinguishable difference in fuel efficiency, and wind had no consistent effect on either stove. For both the *assida* and *mullah* phases, the two designed BDS prototypes alternated in outperforming the other in the different metrics and categories. For example, the uninsulated stove outperformed the insulated stove in the *assida* tests without wind, but the opposite held true for the *mullah* phase without wind. Since all three parameters factor into the comprehensive assessment of fuel efficiency, no conclusive differences were observed and the added insulation can be assumed to have no negative impact on the fuel efficiency of the stoves.

The designed Berkeley-Darfur Stoves greatly outperformed the three-stone fires. Under wind conditions, the designed stove was up to an average of 54% more fuel efficient than the three-stone fires. Overall, the study hypothesis was confirmed in that the two prototypes of the BDS were significantly more fuel efficient than the three-stone fire.

Effects of Wind

The addition of wind did not have a universal effect on all of the stoves as we had expected. The wind levels reduced the fuel efficiency of the three-stone fires and increased wood consumption. However, the wind was actually beneficial to the two BDS prototypes, and reduced the fuelwood consumption for both the insulated and uninsulated stoves by an average of 15%. The wind provided a constant stream of oxygen to be utilized by the fire, and while the metal stoves were able to capitalize on this extra oxygen due to its contained metal grate design, the wind was a hindrance for the three-stone fire and provided an obstacle (Beer). The metal grate in the BDS elevates the wood and allows for the oxygen to better circulate within the fire and provides a greater temperature differential to drive a convection current into the stove (Taylor). In addition, while the wood in the three-stone fire consistently toppled over, the inner metal lining provided support against this collapse. The wind aspect only serves to deepen the difference between the performance of the three-stone fires compared to the Berkeley-Darfur Stoves, but provides a more realistic simulation of the conditions in Darfur.

Variability in Fuel Consumption

During our experimentation, we witnessed an extreme amount of variability in the success of the tests. In our protocol, there were conditions under which the test failed, and the three-stone fires had considerably more failed tests or tests that never reached the target temperatures than the BDS models. Though this isn't specifically reflected in the data, as they are considered to be failed tests, this was also an important evaluation tool for the project. The three-stone stove fire was much harder to maintain, as seen by the standard deviations of around 120 grams of wood for both the wind and non-wind tests. This variability was significantly less for the BDS prototypes, which had standard deviations consistently around 50 grams. This variability is extremely important to consider, as the consistency of the BDS performance is another benefit over the unpredictable three-stone fire.

Implications

Overall, this study provides valuable data in the evaluation of the Darfur Stoves Project. The results have shown that both prototypes save a considerable amount of wood required for a traditional meal, and the difference in savings is increased with the presence of wind. This data strongly supports the Darfur Stoves Project as it provides a closer model for the realistic use of these stoves as well as a foundation for potential future development focusing on wind design aspects. In addition, the close fuel efficiency results obtained from the two BDS prototypes suggests that the added insulation within the inner grate of the stove does not have a negative effect on the fuel consumption, and can maintain the same standards of firewood savings while significantly reducing surface temperature (Xiong et al. 2005). By distributing an insulated stove with controlled surface temperature, the stove is much safer for the women and children who work closely with them.

This project has vast economic and environmental implications for the refugees in Darfur. The average Darfuri family utilizes 1.8 tons of firewood each year for cooking (El-Farouk), and this strain on the environment has intensified the crisis in the region (Baldauf). However, by reducing the necessary amount of firewood by almost half, this project has major positive effects on the daily lives of the refugee families as well as the overall environmental condition and deforestation issue persisting in the area. In addition, existing fuel-efficient stoves in other developing countries in other parts of Africa, as well as parts of Latin America, have shown increased indoor air quality (Pennise) and a reduction in respiratory health problems due to the reduced amount of wood being burned indoors (Bruce).

Methodological Concerns

Through the course of our experimentation, we noticed many ambiguities in our methods and worked to mitigate these effects. User variability issues involving feed rate definitely affected test length and ultimate wood consumption to complete each task. As each tester progressed in their personal training, the tests became more efficient. This suggests that there is a learning curve to tending a fire. In our attempt to avoid these factors, we allowed for 10 practice burns before collecting actual data, and limited the fire tenders to control variability.

However, our experiments were performed under controlled lab settings and do not replicate the exact practices of the Darfur refugees. While we attempted to replicate the cooking practices as closely as possible, there is definitely room for variability. In addition to the discrepancies in practices, the conditions also vary. This project attempted to mitigate these confounding effects by selecting similar wood and incorporating wind speeds observed in the Darfur area, but there still exist numerous other factors that influence the efficacy of the BDS. These lab tests should be performed in conjunction with field observations in order to obtain the most comprehensive evaluation of the cookstoves (Roden).

Future Research

The field of fuel efficient cookstoves has the potential for much more exploration and research. This study aimed to look at the project from an environmental and social standpoint by looking at the amount of wood the refugees were directly saving. However, there are many other factors that affect the daily lifestyles of the refugees other than direct biomass consumption. For example, the effects of these stoves on greenhouse gas emissions would be an integral aspect of the environmental burden alleviation for these stoves (Bhattacharya and Salam 2001). The emitted CO and CO2 levels can be analyzed to determine carbon savings, which can ultimately be transformed into policy applications towards carbon credits (Jindal).

In addition, the environmental health aspects have been a topic of great interest in the field. Women and children spend hours a day working in extremely close proximity with these stoves, and to accurately assess the impact of these stoves on their lives, their health should be considered in terms of particulate matter and smoke exhaust and hydrocarbon emissions (Zhang).

To assess the scope and reach of the project, research regarding the amount of actual implementation of the stoves has already been initiated. An array of stove-use monitors can be applied towards this project such as thermoregulated devices attached to each stove to determine actual use in the field (Ruiz-Mercado et al. 2008). This, coupled with the derived models of fuel efficiency, can provide a more comprehensive depiction of the effects of this project.

The Darfur Stoves Project has already brought improved cookstoves to the lives of thousands of families living in the Darfur region of Sudan as a solution to a myriad of social, environmental, and economic issues in the area. This experiment served to further support the objectives of the project by providing concrete evidence of the fuel efficiency improvements of the designed Berkeley-Darfur Stove as well as potential areas of future research. The success of the Darfur Stoves Project is an example of the potential scope of appropriate technologies and opens the door for many similar initiatives.

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