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Article

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Balancing technical and user objectives in the redesign of a peruvian cookstove



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ABSTRACT

Over the past decade a large amount of research has been dedicated in academic literature to improving the technical capabilities of improved cookstoves; primarily the performance efficiency and reduction of emissions. Unfortunately, as published literature has highlighted, the trade-offs that result from placing such a concentrated emphasis on these technical objectives is that improved cookstoves lack the same level of usability as the traditional cookstoves. Thus, users often return to using their traditional stoves and the potential impact of the improved cookstoves is never fully realized. In order for improved cookstoves to have greater impact, there must be better balance between the two competing design objectives of technical capabilities and usability. This paper explores the challenges and benefits associated with achieving the appropriate balance, and demonstrates its application through the modification of a traditional cookstove used in the Tambogrande region of Peru. This modification includes an inexpensive set of pot skirts that integrate directly with the traditional stove. These pot skirts allow for varying sizes and number of pots, and the use of traditional fuels. Laboratory testing, using the Water Boiling Test (WBT), identified the skirts' technical improvements: 41.7% increased thermal efficiency, 32.7% decreased fuel consumption, 28.8% decreased time to boil. Field testing was performed to determine the pot skirts acceptance and compatibility with the traditional cookstoves, with over 75% of the participants recognizing some type of benefit. Although the technical improvements of these pot skirts are less than other cookstoves on the market, the higher levels of usability are likely to lead to a more positive end-user reaction, which could potentially lead to higher rates of adoption and impact. Though these results are primarily focused on the application of improved cookstoves, the need for more balance between technical and user objectives is applicable to nearly all products being designed for the developing world.

1. Introduction

Over the course of the past decade, significant effort and attention has been given to the advancement of improved biomass cookstoves for the developing world. These improvements are motivated by the fact that nearly 3 billion people worldwide still cook using open fires or biomass cookstoves, in which they burn wood, charcoal, and other solid fuels (WHO, 2014). Biomass cookstoves are a significant contributor to current global warming problems; contributing 22% of the global black carbon emissions, compared to just 7% from the burning of fossil fuels (Ramanathan and Carmichael, 2008). With nearly 3 million people dying each year due to the harmful effects of burning biomass (WHO, 2014), improved cookstove programs have primarily focused in the past on reducing indoor air pollution, greenhouse gases, and the amount of biomass fuel that is consumed. As a result of these efforts, improved cookstoves have made significant progress in achieving high levels of efficiency and high standards of cleanliness.

Despite the technical capabilities of these improved cookstoves, end users have generally adopted and used them at surprisingly low rates (Mobarak et al., 2012). Jan et al. report adoption rates of less than 20% for a random study of 100 households in rural northwest Pakistan (Jan, 2012). Pine et al. (2011) report an even smaller adoption rate of 15% for a particular cookstove project in Mexico. Other studies have found similar results for various parts of the world (Eltayebmuneer et al., 2003; Johnson and Bryden, 2013). Examples such as these demonstrate that an improved cookstove's ability to burn cleaner and more efficiently does not guarantee its adoption.

The usability of an improved cookstove is one factor that potentially influences its level of adoption. As an illustration, consider a recent cookstove study conducted as part of the Millennium Villages Project in Sub-Saharan Africa. This study included a survey that questioned users about their likelihood to purchase and use certain improved cookstoves based on factors that would contribute to its overall usability, such as fuel savings, cooking time, and average pot size. Findings indicated that

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users were more inclined to adopt an improved cookstove that was capable of cooking traditional meals using the same equipment, and with equal or greater cooking speed (Ruiz-Mercado et al., 2011). Findings such as this, in addition to other studies (Mobarak et al., 2012; Honkalaskar et al., 2013; Rosenbaum and Derby, 2013), demonstrate that improved cookstoves often have a lower level of usability compared to their traditional counterparts.

Thus we see that improved cookstoves must achieve two objectives in order for lasting impact to occur. First, they must provide technical performance improvements (i.e. decreased smoke, higher efficiency, etc). Second, they must achieve high levels of adoption, which we believe is directly tied to its level of usability. Unfortunately, these are often competing design objectives and finding the right balance between the two is difficult.

It is not uncommon for design teams to believe that in order for a product (such as a cookstove) to have meaningful impact, it must achieve the highest levels of technical performance. This notion is perhaps motivated by the assumption that end users are primarily interested in the technical performance of the product. In this article, we propose a different hypothesis: That greater impact can be achieved if improved cookstoves are primarily optimized for usability, while having at least some technical improvement over traditional stoves.

In order to assess if a usability-centered cookstove can achieve greater impact, several research questions must be explored. (1) What factors lead to desirable usability of an improved cookstove? (2) How will the technical performance of a usability-centered cookstove differ from one that is centered on technical performance? (3) How do end users initially react to such a cookstove? (4) Will there be a significant difference in long-term adoption rates?

This paper will aim to answer the first three of these research questions primarily through an experiment, in which we design and test an adaptation for a traditional Peruvian cookstove. Due to the relatively short nature of this experiment, unfortunately no conclusions will be able to be drawn about the long-term adoption rates. Potentially years of data would be needed to draw proper conclusions.

While this paper is primarily focused on the topic of improved cookstoves, it is also applicable to a more general audience. The principles introduced in this paper apply to nearly all new products that are being designed for the developing world and have intentions to provide some type of social, financial, or environmental benefit.

2. Background

2.1. Defining usability in the context of improved cookstoves

For the purposes of this paper, we refer to ISO 9241–11 for the definition of usability; *the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use* (International Organization for Standardization, 2006). The usability of an improved cookstove is more than an evaluation of whether the cookstove can perform certain functions; it is an assessment of how well the cookstove can execute cooking tasks according to the user's expectations.

The usability of a cookstove is influenced by a variety of cookstove characteristics. For instance, how quickly the stove heats up and how quickly food is cooked are two items that are frequently important to end users (Rosenbaum and Derby, 2013; Bielecki and Wingenbach, 2014; Kshirsagar and Kalamkar, 2014; Ayoub and Brunet, 1996). How easily the fire can be tended, the types of fuels the stove can burn, and whether users are required to cut wood into small pieces are examples of other characteristics (Aggarwal and Chandel, 2004; Troncoso et al., 2007; Ramirez et al., 2012; Brant et al., 2013). Additionally, the usability of a cookstove is heavily impacted by how compatible the stove is with local cookware, including the size, number, and shapes of pots (Ayoub and Brunet, 1996), as well the stove's ability to cook larger meals (Rosenbaum and Derby, 2013; Michael et al., 2011). All of these

characteristics, plus others, combine to influence how users perceive the usability of a cookstove.

The usability of a particular improved cookstove is also related to how closely it mimics or exceeds the form, function, and performance of the traditional stove it is replacing (Ruiz-Mercado et al., 2011; García-Frapolli et al., 2010; Pine et al., 2011; Urmee and Gyamfi, 2014). Because users have been cooking on their traditional cookstoves for generations, and are accustomed to its nature, it becomes difficult for users to want to adapt their current cooking style to the demands of the new improved cookstove. As Honkalaskar et al. (2013) put it, "an improved cooking method that is different from existing practices has less appeal wherever the people using traditional cookstoves are bound to follow the existing practices because of economic, social and religious constraints". Thus, many improved cookstoves take a secondary role to the traditional stove in the home (Johnson, 2012), and are only employed when an extra burner is needed or when the simplicity of the meal being prepared compels its use.

2.2. Usability challenges

There are several challenges that designers face in optimizing the usability of improved cookstoves. First, there is currently no standard way to measure the usability of an improved cookstove as there is in other disciplines (Hornbæk, 2006; Bevan and Macleod, 1994; Bevan and Raistrick, 2011) – thus it is difficult to compare alternative design options. Second, the usability of an improved cookstove is dependent on who is using it and under what circumstances. Therefore, a stove that is highly usable for one user, may not be found usable for another. And third, because improved usability is often at conflict with improved efficiency and emissions, which also happens to be easily quantifiable, stakeholders tend to emphasize the importance of efficiency and emissions instead of emphasizing the importance of usability.

2.3. Benefits of a usability focused design

Despite the associated trade-offs and difficulties that result from increasing the usability of improved cookstoves, there are various potential benefits. The foremost of these benefits being the greater capacity of a highly usable, but marginally improved cookstove to reduce indoor air pollution and fuel use, in comparison to a partially usable, high performing cookstove. This is because the overall impact of improved cookstoves is dependent on high adoption and usage rates. Additionally, cookstove designs that are optimized for usability may help to reverse some of the negative perceptions customers have towards improved cookstoves due to unfavorable previous experiences. Lastly, a few studies (Besley and Case, 1993; Lee, 2005) have illustrated that users have a difficult time adopting radically different technologies. Many factors influence the rate of adoption, such as the technology's physical attributes and other economic, sociological, organizational, and psychological variables (Parente and Prescott, 1994). Thus, improved cookstoves that mimic the usability of traditional stoves, and are therefore more familiar to users, may serve as transitional devices towards cleaner forms of cooking technology.

3. Usability field experiment: Tambogrande, Peru

In order to test our hypothesis we engaged in a year-long experiment. This experiment entailed designing and testing a cooking device for residents living in rural northern Peru – specifically focusing on what effect and impact a cooking device optimized for usability would have. Though our approach is primarily experimental in nature, the methodologies used partially pull from the case study method as proposed by Yin (2014). In particular, the process of collecting and analyzing data using multiple data points and adapting the research based upon initial findings.

The Tambogrande district is a collection of small communities

located in northwestern Peru. Despite approximately 70% of the homes in this rural area having electricity (Sustainable Energy for All Americas - Peru, 2013), a significant portion of the rural population use open flame biomass cookstoves for their primary cooking duties, and only 15% of those households have a chimney (Partnerships, 2012). Over 8 million people in total in Peru are effected by high rates of household air pollution (Fitzgerald et al., 2012), with average indoor levels of PM_{2.5} being approximately 100 µg/m³ (Gonzales and Steenland, 2014). Due to the inefficient nature of these traditional cookstoves, smoke pollution and wood scarcity are concerns many residents and government leaders have.

To combat these challenges, a government initiative in 2012 distributed a two burner liquefied petroleum gas (LPG) stove and one tank of gas to each household, but these stoves go largely unused today due to the relatively high cost of LPG (Partnerships, 2012). Most residents in the rural villages continue to use their biomass cookstoves because they can operate it at little or no cost, and are accustomed to cooking in that specific manner.

During the summer of 2014, we conducted field studies in the village of Locuto and Nuevo Reque to determine the necessary design requirements for an improved cookstove. In Locuto, the research team consisted of 5 engineers (two of whom were Peruvian) and a community guide. With the help of this guide, we visited twelve homes to interview and observe how the women interacted with their cooking stoves. We also conducted six interviews with individuals employed making or selling charcoal, wood, or liquefied petroleum gas (LPG). In Nuevo Reque, 3 of those 5 engineers conducted an additional dozen interviews to collect similar information.

In response to the previous failed attempts to distribute improved cookstoves in the region, special care was given to identifying how to preserve the usability of the traditional cookstoves. Contextual information was gathered on topics ranging from local cooking practices and foods to the cost of certain commodities. The relevant results from these field studies are presented in this section.

3.1. Local cooking practices

In this portion of the article, field study results from the Tambogrande region are shared regarding the types of cookstoves used, customary foods, cooking habits, and local fuel sources.

3.1.1. Cookstoves

A variety of gas, charcoal, and wood cookstoves are all employed in this region with many residents owning and using more than one type of cookstove. The most common cookstove used, however, is the wood burning channel stove; comprising of two rows of clay bricks as illustrated in Fig. 1. The channel cookstove can be constructed at little or no cost and is very simple to operate. Most channel stoves are raised off the ground to a more comfortable height, such as on top of mud

covered tables, as shown in Fig. 1.

3.1.2. Customary food and cookware

Rice and potatoes serve as the main food staples along with supplements of corn, fish, and other meats. These items are primarily combined into soups and cooked with aluminum pots ranging in diameter from 20 to 28 cm. Users cook with anywhere from one to three pots simultaneously and occasionally fry fish in small skillets. In addition, a significant amount of fuel is consumed in the preparation of tea, coffee, and chicha morada (sweetened corn based drink). It is also common in the region to prepare a large batch of chicha de jora (corn beer) once a week. Due to the large pots used (upward to 50 cm in diameter) and the long cooking times (7 h), a second open fire is typically built outdoors for this task.

3.1.3. Cooking habits

Most cooking is performed indoors with many of the households having two separate buildings; one for living and one for cooking. Lunch is the primary meal of the day and typically requires 30 min to start the fire and build a bed of coals, and then another one to two hours to cook the meal. Breakfast and dinner are typically smaller meals and may consist of reheated food or other simple dishes.

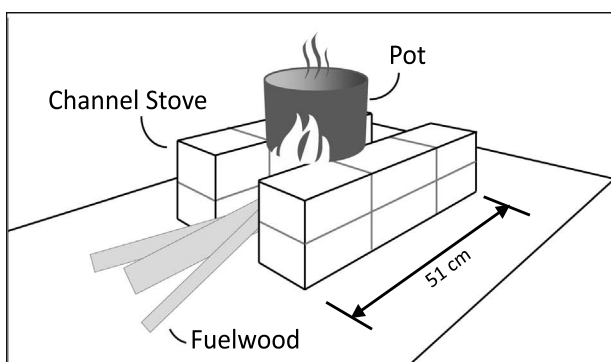
3.1.4. Fuel sources

Fuels are both purchased and collected for free in this region. A tank of LPG costs approximately 35 Peruvian Nuevo Soles (~11 USD). A 25 kg bag of charcoal costs approximately 30 Peruvian Nuevo Soles (PEN), or residents can purchase smaller quantities of charcoal for roughly 1 PEN. Wood fuel can also be purchased, costing about 1 PEN for three “sticks”. However it takes about four sticks to cook a large meal, so most people prefer to collect their own fuel at no cost.

Biomass fuels are gathered from the surrounding regions in the form of sticks and branches. Residents are concerned about the increasing difficulty associated with collecting free fuel and government leaders are worried about any associated negative environmental impacts. The sticks and branches collected range in diameter from 1.5 to 10 cm and up to one meter in length. Residents typically do not cut their fuel into small pieces before stoking fires. Dried leaves, scrap plastic, and paper are all used for kindling.

3.2. Customer requirements for an improved cookstove

The data from the field studies allowed us to categorize the customer requirements into two categories; the characteristics of the channel stove that the residents find highly desirable and are essential to preserve, and additional cookstove characteristics they aspire to obtain.



(a)



(b)

Fig. 1. Schematic (a) and photo (b) of a traditional channel stove in Tambogrande, Peru.

3.2.1. Channel stove features to preserve

The following cookstove characteristics are currently embodied in the traditional channel stove and should remain as requirements for any new or modified improved cookstove:

- *Pot flexibility*- The improved cookstove retains the capability to cook with one, two, or three pots at a time. In addition, it accommodates pots ranging in diameter from 20 to 28 cm.
- *Easily tended*- The improved cookstove is easy to load with fuel and maneuver the hot coals; similar to the case with the channel stove.
- *Fuel flexibility*- The improved cookstove preserves the ability to burn the same variety of fuels as the channel stove, primarily long tree branches ranging from 1.5 to 10 cm in diameter.
- *Low cost*- Because the channel stove can be constructed at little cost (the price of approximately 12 bricks), residents will have a difficult time paying large sums of money for expensive alternatives, thus the target cost should be less than 10 PEN. In addition, any modifications must retain the ability to burn fuel from free sources.

3.2.2. Additional customer requirements

Despite the considerable usability of the channel stove, residents identified several items that they did not enjoy about their current cooking situation. The top three additional characteristics to include with any improved cookstove design or modification would be as follows:

- *Decrease the cooking time*- Residents desire an improved stove that cooks more quickly than their current channel stove. Currently, it takes approximately 30 min to heat up the channel stove and an additional one to two hours to cook the remainder of the meal. The desire for quicker cooking time is one of the few reasons why residents occasionally cook with a gas stove.
- *Decrease the amount of fuel*- Since free fuel wood is becoming more scarce, and some residents have already begun paying for fuel wood, residents desire a stove that uses less wood. It is estimated that a reduction of at least 15–20% will be needed in order for users to perceive this benefit.
- *Reduce the amount of smoke*- Residents frequently commented on the discomfort that comes from indoor air pollution, as well as being impacted by the smoke from other households in the neighborhood.

3.3. Improved design

Once the appropriate customer requirements were identified (as listed in the previous section), numerous design concepts were developed to satisfy those requirements. Because the primary design objective was to design a cookstove that would be well received, and not just achieve the highest levels of technical performance, a wide variety of concepts were considered. Ultimately, the design team determined that the greatest number of customer requirements were satisfied when design concepts deviated the least from the form and function of the channel stove. Instead of designing an entirely new cookstove that would be foreign to the residents, the aim became to modify the Peruvian channel stove by incorporating a mechanism that would improve the stove's efficiency without compromising the usability of its traditional design. The final design converged upon was a set of inexpensive, adaptable pot skirts that rest on top of the channel stove and partially encircle the cooking pot (see [Figs. 2 and 3](#)).

Since the traditional channel cookstove has a very low heat transfer efficiency, pot skirts were found to be one of the most effective ways to improve this deficit, compared to other options considered. Pot skirts, in general, function by directing the hot gases released during combustion to pass directly along the sides of the pot, which results in higher flow temperatures and higher heat transfer efficiencies ([Zube, 2010](#)). An increase in heat transfer efficiency is ideal for users since it leads to decreased cooking time and smoke reduction. The pot skirts

also absorb some of the convective heat released by the gases and re-radiates it back to the combustion zone to promote more efficient combustion ([Wohlgemuth et al., 2009](#)). In the study by [Wohlgemuth et al. \(2009\)](#), it was demonstrated that maximum skirt benefit is achieved with the addition of an insulating layer. However, in order to minimize cost and maintain affordability, no insulation was included in the design.

Each pot skirt used in this study is constructed from 24 gauge thickness sheet metal but other thicknesses may also be acceptable. It can be cut or stamped out of a single piece of metal, thus decreasing manufacturing costs. The two trapezoidal side panels are bent to lay against the sides of the cooking pot and force the hot air to circulate around the pot on all sides. The skirt also includes a wood covered handle which allows for easier placement and adjustment. The expected cost to manufacture one set of pot skirts is 3.78 PEN.

Although pot skirts have been incorporated with previous improved cookstoves, they have often been problematic from a usability perspective. They are commonly restrictive in only allowing one size of pot, or are cumbersome for users to work with. This is driven by the need to achieve maximum technical performance. The pot skirts designed in this study attempt to overcome these drawbacks by allowing users to use any size of pot ranging from 20 to 32 cm, and allow for easy adjustment or temporary removal of the skirts. An additional difference compared to other pot skirts is that these pot skirts have been designed to be integrated directly with a channel stove and allow users to retain the ability to cook in their customary fashion. These features were all strategically chosen to increase usability, even at the cost of some technical performance.

4. Usability field experiment: stove testing and evaluation

The pot skirts were subjected to a formalized testing process, involving both field tests with end users and controlled laboratory tests. The purpose of these tests were to determine (1) if the end users found the pot skirts to be highly usable, and (2) if the pot skirts make a difference in the technical performance of the stove (i.e. efficiency, fuel reduction, etc). Collectively, the answers to these two questions play a significant role in predicting the skirt's overall impact.

4.1. Laboratory testing of the channel cookstove and pot skirts

To determine what degree the pot skirts increase the technical performance of the channel stove, a replicate channel stove was created at the biomass burn facility at Brigham Young University. The channel stove's efficiency, fuel consumption rate, and time to boil were measured under two scenarios: with and without the pot skirts. The results were then compared to determine statistical significance.

4.1.1. Laboratory testing procedure

The test procedure that was followed was according to the Water Boiling Test protocol (WBT) ([The Water Boiling Test 4.2.3, 2014](#)). This test is a lab based test and provides for repeatable and low cost testing of biomass cookstoves. Because of its repeatable nature, it is an excellent test to determine the effect of certain design changes throughout the development process.

There are a variety of variations and options of the WBT that exist in academic literature. Therefore, we chose the variations that were most representative of the daily cooking conditions in Peru. The amount of water boiled during each test was 2.5 l, compared to the more common 5 l. A lid was placed on the pot throughout the duration of the tests as recommended by [Sutar et al. \(2015\)](#), [Guidelines for Testing Charcoal Stoves with WBT 4.2.2 \(2013\)](#), [Compiled Comments for WBT Version 4.1.2 \(2009\)](#). And since the presence of a lid significantly affects the analysis of the simmering phase, as highlighted by [Raman et al. \(2014\)](#), the simmering phase of the WBT was omitted. The amount of water boiled during each test was 2.5 l, using 25.5 cm

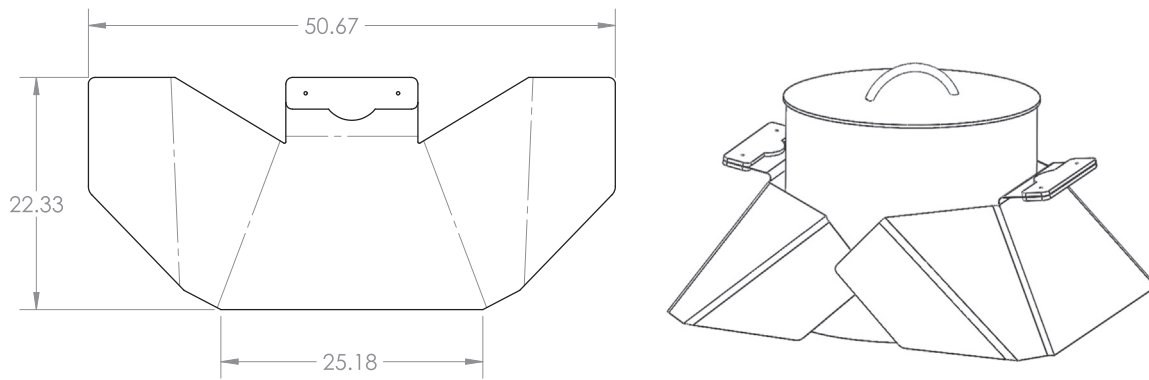


Fig. 2. Schematic of the pot skirts, shown in their flattened and assembled forms. All dimensions in cm.



Fig. 3. A picture showing the final prototype.

diameter pots.

Effort was taken to replicate the channel stove as accurately as possible. Clay bricks were used instead of cement bricks, and the height, width, and depth of the replica stove were set to match the common dimensions measured during the 2014 field study and as set forth in Table 1.

It should be noted that WBT results presented here do not necessarily represent the channel stove's actual performance in the field, but are only accurate for comparing alternative designs tested in this particular lab setting. This disparity between WBT results and field use has been clearly documented by several previous authors (Roden et al., 2009; Raman et al., 2014; Johnson et al., 2008). Despite the limitations of the WBT in predicting actual performance, it is useful in “selecting the most promising products for field trials”, and thus we have employed it in this study (The Water Boiling Test 4.2.3, 2014).

4.1.2. Water boiling test results

The results from conducting the WBT on the traditional channel cookstove, without modifications, can be found in Table 2. Results for both cold start and hot start portions of the test are presented. The WBT was then conducted again on the channel stove, but this time with the presence of the pot skirts. The results from these lab tests are presented in Table 3.

Table 1. Dimensions of the replica channel stove used during WBT tests.

Parameter	Dimension (cm)
Cookstove length	51
Cookstove height	13
Channel width	13
Overall stove width	33

Table 2. Water Boiling Test results from testing the traditional channel stove.

	Cold Start			Hot Start		
	Value	Number of samples	Standard deviation	Value	Number of samples	Standard deviation
Thermal Efficiency	9.19%	8	1.20	9.38%	12	1.78
Time to boil (min)	20.20	8	3.16	19.96	12	5.35
Temp corrected specific fuel consumption (g/l)	191.5	8	27.23	165.5	12	51.01

4.2. Discussion and analysis of WBT results

To determine if there exists a significant difference in performance between the two test groups (the channel stove with and without pot skirts), a *t*-test comparison was performed. The results are presented in Table 4. Since the *t*-calculated values exceed the *t*-critical values (at a 95% level), we conclude that the pot skirts make a significant improvement for both hot and cold starts. Meaning, the pot skirts statistically improve the channel stove's thermal efficiency, reduce the amount of fuel required, and decrease the time required to boil water.

4.3. Field testing setup

During the summer of 2015, we traveled to the small community of Locuto, located in the Tambogrande district of Peru, to conduct field experiments (see Fig. 4). Fifty-four households, in different parts of the community, accepted the invitation to participate in the study. Participants were given one set of pot skirts, along with a brief tutorial of how to use the skirts. After using the pot skirts for at least a week in duration, the researchers returned and interviewed them. In total 42 households were interviewed.

During the follow up interviews, the researchers asked a series of predetermined questions, as well as observed the actual use of the pot skirts inside the kitchens. Pot skirts that received heavy use showed significant amounts of heat discoloration and noticeable soot accumulation on the inside surface. These visual signs were used to check for efficacy and accuracy in the respondent's answers. Answers to the following questions were collected:

1. How well did the pot skirts interface with the traditional channel cookstove and pots?
2. What challenges or difficulties did the users experience?

Table 3.
Water Boiling Test results for the channel stove with pot skirts.

	Cold Start			Hot Start		
	Value	Number of samples	Standard deviation	Value	Number of samples	Standard deviation
Thermal efficiency	13.01%	8	1.51	12.91%	13	0.95
Time to boil	13.60 (min)	8	1.86	14.23 (min)	13	1.89
Temp corrected specific fuel consumption	136.38 (g/l)	8	17.53	117.54 (g/l)	13	19.44

Table 4.
Comparing the impact of pot skirts on the channel stove with *t*-test comparison testing at a 95% confidence interval.

	Cold Start			Hot Start		
	<i>t</i> -calc	<i>t</i> -critical (95%)	Percent change	<i>t</i> -calc	<i>t</i> -critical (95%)	Percent change
Thermal efficiency	4.20	1.76	41.7%	6.26	1.71	37.6%
Time to boil	4.51	1.76	-32.7%	2.15	1.71	-28.7%
Temp corrected specific fuel consumption	1.91	1.76	-28.8%	2.13	1.71	-29.0%



Fig. 4. One of 54 households participating in the field study.

3. How often were the pot skirts used?
4. Did the users perceive any benefits or disadvantages from using the skirts?
5. Were the users willing to purchase the pot skirts and at what price?

The answers to these five questions are presented in the following section:

4.3.1. Field testing results

Q1-Interfacing with traditional stove. Field studies revealed that the pot skirts were compatible with nearly all the channel stoves they were tested on. Meaning, the shape and size of the pot skirts fit as expected on the top surface of the channel stove, despite there being some variance in the size of each channel cookstove. In a few cases, the channel stoves were not long enough to accommodate more than two pots and the skirts, thus users would have to extend their stoves by simply adding additional bricks.

There were some minor difficulties with the differing pot sizes. The pot skirts were originally designed to work with pots ranging from 20 to 28 cm in diameter. Field studies confirmed that nearly every household had a pot this size and the pot skirts interfaced well with these sizes. However, nearly every household also had at least one pot smaller than 15 cm in diameter. Although the participants still noticed many perceived benefits, it was apparent to the researchers that the pot skirts' height made it cumbersome to work with the shorter, smaller pots.

Table 5.
The amount of usage the pot skirts received over the course of one week (*n*=42). Heavy use is defined as at least once a day. Moderate use is defined as 2–6 times per week.

	Number of participants	Percentage
Heavy use	15	35.7%
Moderate use	16	38.1%
No or little use	11	26.2%

Q2-User difficulties. In response to the question of “Did you experience any difficulties?”, five of the 42 participants reported the handles being too hot. Three of the households reported difficulty in using small pots. One additional participant each found the skirts to be cumbersome to use, dislike for the rusting of the steel, or the skirts seemed to get more ash in their food. Lastly, it was observed that of the 42 households, six of them attempted to use the pot skirts in the wrong configuration; placing the skirts vertically on one edge and leaning it against the pot.

Q3-Usage amount. The amount the pot skirts were used over the course of the week is best described by the distribution outlined in Table 5. As seen, over 73% of the participants used the pot skirts regularly. There was however 26.2% of the participants that did not use the pot skirts. This is due to a variety of reasons. Four of the households were under the opinion that if they used it, they would be required to pay. Thus they did not use it. Two households did not use it because they cooked all of their meals that week with a gas stove. The remaining 5 households chose not to use it for unreported reasons.

Q4-Perceived benefits. As part of the interviewing process, each participant was asked the open ended questions of “How did it go?” and, “Did you notice any difference?” Out of the 31 participants who had used the skirts at least once, 24 of them (77.4%) mentioned some type of perceived benefit. Some of them noticing several benefits. Their responses are summarized in Table 6. As shown in the table, slightly over half of the participants who used the skirts noticed that the pot skirts cooked faster, while one-third also noticed a decrease in the amount of smoke. The category of “fire control” refers to participants' observations that the skirts kept the fire together and prevented it from spreading out towards the end of the stove.

Q5-Willingness to pay. Although the participants were allowed to keep the pot skirts free of charge as compensation for their participation, data on their willingness to purchase was collected as part of the interviews. The results are displayed in Table 7. Though efforts were taken to try and minimize the effect, it is likely that some of the participants heard they would be receiving the pot skirts for free prior to their interview, thus potentially influencing their responses.

Table 6.
The perceived benefits from those who used the pot skirts at least once (*n*=31).

	Number of participants	Percentage
Faster cooking	16	51.6%
Decreased smoke	10	32.3%
Fire control	7	22.6%
Decreased soot	1	3.2%
Better taste	1	3.2%

Table 7.
The willingness of all the participants to purchase the pot skirts ($n=42$) and at what price.

	Number of participants	Percentage
Greater than 7 PEN	7	16.7%
Between 5 & 7 PEN	7	16.7%
Less than 5 PEN	2	4.8%
Not willing to purchase	23	54.8%
Unknown	3	7.1%

4.3.2. Field experiment conclusions

The results from the 2015 field study allow us to draw conclusions regarding whether the end-users found the pot skirts to be highly usable and their initial acceptance of the product. To draw conclusions about the pot skirts' usability, we reference the fact that only 10 of the households reported some type of difficulty with the pot skirts' fit, form, or function with the traditional channel stove.

We also reference the fact that the pot skirts satisfy six of the seven customer requirements outlined in Section 3.2. The exceptions to this include that many of the customers did not indicate a willingness to pay for the pot skirts and that the pot skirts do not work well with small, short pots, even though the initial customer requirement did not call for this. With all these things considered, we conclude the pot skirts were found to be highly usable.

5. Usability field experiment: discussion

Based upon the results presented, for both field and laboratory testing, we conclude that the pot skirts are positioned to make an impact in the Locuto community: meaning they have the capability to reduce indoor smoke pollution and decrease cooking time when compared to traditional methods, and achieve a higher rate of use and adoption compared to other cookstoves previously introduced in this community. The pot skirts minimally disrupt the customary way of cooking, and significantly improve the technical performance of the stove. We recognize though that the pot skirts are not flawless. Areas of future work include altering the design to work better with smaller pots, especially those that are short in height. In addition, the usability of the pot skirts could further be enhanced by modifying the handles such that they are not as hot during operation.

We acknowledge that these pot skirts combined with the channel stove do not achieve the same levels of efficiency or cleanliness obtained by other advanced improved cookstoves on the market (Foundation et al., 2012; MacCarty et al., 2010). However, by preserving the usability of the traditional channel cookstove, higher adoption rates are likely to occur; a tradeoff that we believe is more important than achieving the highest technical performance. As an example, consider the following scenario.

In the Locuto community, our estimates predict approximately 75% of the residents burn biomass in their channel cookstoves daily. With approximately 300 households, and each household consuming about 16 kg of fuel each week, this totals approximately 4800 kg of wood burned weekly in the community.

If a new top-of-the-line improved cookstove, that reduced wood consumption by 60% were introduced, it would be capable of decreasing fuel use by 2880 kg per week if users exclusively cooked all their meals with the new stove. But, as with other advanced biomass cookstoves, adoption rates may be as little as 15% of the households, or only 15% of the meals cooked. That results in a fuel reduction of only 432 kg of wood per week. In comparison, consider the proposed pots skirts presented in this article, that potentially reduce fuel consumption up to 28.8% (using the rough assumption that field performance is similar to the WBT laboratory test results). In order to achieve the same amount of overall fuel savings as compared to the top-of-the-line model, only 31.3% of the community would need to adopt the pot

skirts—a number potentially attainable based upon the results of this study.

We realize that such an illustration makes some simplifying assumptions, but the principle is clear; if only a few people adopt an improved cookstove, it is very difficult to make an impact, regardless of how efficient or clean the cookstove is. Therefore, our emphasis has been to design a cookstove that is easily adoptable. We did this by creating a product that can integrate directly with the traditional cookstove already in use, and allow it to use the same types and sizes of fuel, as well as the same sizes and number of pots.

We do not view these pot skirts as the ultimate solution to the regional problems these people face due to biomass cooking. The ideal situation is for the residents to move up the so called energy ladder and start cooking with cleaner fuels and technologies. But, as it has been documented in other sources, people do not make this transition in just one step (Barnes et al., 1994). They employ a variety of transitional technologies first, such as improved biomass cookstoves. Thus, the pot skirts presented in this article provide one of those transitional steps to help users recognize the benefits that come from cooking with cleaner, and more efficient methods.

This experimental study has primarily been focused on the design of improved cookstoves and how a usability focused design has the potential to achieve higher adoption rates compared to a technologically focused design. However, a cookstoves design is not the only variable that determines whether it will be adopted or not. Other authors have hypothesized a wide variety of social, environmental, and economic factors that also go into influencing adoption rates. Such factors include education levels (Jan, 2012), occupation (Troncoso et al., 2007), household income (Pine et al., 2011), household decision making processes (Eltayebmuneer et al., 2003), and many others. Thus we cannot definitively predict what the long term adoption rates of these pot skirts would be without years of actual data.

6. Conclusions

In this article, the need for a more balanced approach to improved cookstove design was presented. This balanced approach emphasizes the importance of providing high levels of usability, in addition to providing technical performance improvements. Unfortunately, these two objectives typically compete against one another and it is common for usability to be seen as a second priority.

The primary hypothesis posed at the beginning of this paper is that greater adoption, and therefore greater impact, can be achieved if more priority is given to the usability of an improved cookstove during design. While this paper does not test long-term adoption rates, this paper does provide evidence of why including usability into the design process is important.

One important outcome of this study is that a usability-focused approach encourages design teams to examine a broader set of design solutions than would normally be considered. This was illustrated in the experiment presented, in which the solution was a set of inexpensive pot skirts instead of a modern improved cookstove. A second outcome of this study is that the usability a new cooking device for the Tambogrande region is closely related to how it mimics or exceeds the form, function, and performance of the traditional stove it is replacing. However, further study is needed to determine if this same outcome holds true for other regions outside of Tambogrande, though we believe it will.

Lastly, conclusions can be drawn that although the pot skirts were deliberately designed in this paper to not achieve the same levels of technical performance as other advanced cookstoves on the market, they are still capable of achieving an equal, and possibly higher level of overall impact. This is because a cookstove that is highly usable but less technologically advanced may be more likely to be used on a regular basis than a highly advanced cookstove. This same principle is also true for other products outside of improved cookstoves, as any product

intended for the developing world could potentially achieve higher impact with a usability focused approach.

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References

- Aggarwal, R.K., Chandel, S.S., 2004. Review of improved cookstoves programme in Western Himalayan State of India. *Biomass- Bioenergy* 27 (2), 131–144. <http://dx.doi.org/10.1016/j.biombio.2004.01.001>.
- Ayoub, J., Brunet, E., 1996. Performance of large portable metal woodstoves for community kitchens. *Renew. Energy* 7 (1), 71–80. [http://dx.doi.org/10.1016/0960-1481\(95\)00107-7](http://dx.doi.org/10.1016/0960-1481(95)00107-7).
- Barnes, D.F., Openshaw, K., Smith, K.R., van der Plas, R., 1994. What Makes People Cook with Improved Biomass Stoves, Tech. Rep. 242, World Bank. URL (http://ehs.sph.berkeley.edu/krsmith/publications/94_barnes_1.pdf).
- Besley, T., Case, A., 1993. Modeling technology adoption in developing countries. *Am. Econ. Rev.* 83 (May), 396–402.
- Bevan, N., Macleod, M., 1994. Usability measurement in context. *Behav. Inf. Technol.* 13, 132–145. URL (<http://www.usabilitynet.org/papers/music94.pdf>).
- Bevan, N., Raistrick, S., 2011. ISO 20282: Is a practical standard for the usability of consumer products possible?. In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) Lecture Notes in Computer Science*, vol. 6769, (PART 1), pp. 119–127. http://dx.doi.org/10.1007/978-3-642-21675-6_14.
- Bielecki, C., Wingenbach, G., 2014. Rethinking improved cookstove diffusion programs: a case study of social perceptions and cooking choices in rural Guatemala. *Energy Policy* 66, 350–358.
- Brant, S., Pennise, D., Charron, D., Milner, E., Kithinji, J., 2013. Monitoring and Evaluation of the Jiko Poa Cookstove in Kenya.
- Compiled Comments for WBT Version 4.1.2, 2009. [http://dx.doi.org/10.1016/S0022-3913\(12\)00047-9](http://dx.doi.org/10.1016/S0022-3913(12)00047-9). URL (<http://cleancookstoves.org/technology-and-fuels/testing/protocols.html>).
- Eltayebmuneer, S., Mukhtarmohamed, E., Muneer, S.E.T., Mohamed, E.W.M., Eltayebmuneer, S., Mukhtarmohamed, E., 2003. Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. *Sci. Total Environ.* 307 (1–3), 259–266. [http://dx.doi.org/10.1016/S0048-9697\(02](http://dx.doi.org/10.1016/S0048-9697(02)
- Fitzgerald, C., Aguilar-Villalobos, M., Eppler, A.R., Dörner, S.C., Rathbun, S.L., Naehar, L.P., 2012. Testing the effectiveness of two improved cookstove interventions in the Santiago de Chucos Province of Peru. *Sci. Total Environ.* 420, 54–64. <http://dx.doi.org/10.1016/j.scitotenv.2011.10.059>, URL (<http://www.sciencedirect.com/science/article/pii/S0048969711012538>).
- Foundation, U.N., Air, B., Group, M., 2012. Stove Performance Inventory Report Prepared for the Global Alliance for Clean Cookstoves United Nations Foundation Berkeley Air Monitoring Group (October).
- García-Frapolli, E., Schilman, A., Berrueta, V.M., Riojas-Rodríguez, H., Edwards, R.D., Johnson, M., Guevara-Sanginés, A., Armendariz, C., Masera, O., 2010. Beyond fuelwood savings valuing the economic benefits of introducing improved biomass cookstoves in the Purépecha region of Mexico. *Ecol. Econ.* 69 (12), 2598–2605. <http://dx.doi.org/10.1016/j.ecolecon.2010.08.004>.
- Gonzales, G.F., Steenland, K., 2014. Environmental health in Peru outdoor and indoor air contamination. *Rev. Panam. De. Salud Publica* 36, 141, (http://www.scielosp.org/scielo.php?script=sci_arttext&pid=S1020-49892014000700010&nrm=iso).
- Guidelines for Testing Charcoal Stoves with WBT 4.2.2, 2013. URL (<http://cleancookstoves.org/technology-and-fuels/testing/protocols.html>).
- Honkalaskar, V.H., Bhandarkar, U.V., Sohoni, M., 2013. Development of a fuel efficient cookstove through a participatory bottom-up approach. *Energy, Sustain. Soc.* 3 (1), 16. <http://dx.doi.org/10.1186/2192-0567-3-16>.
- Hornbæk, K., 2006. Current practice in measuring usability challenges to usability studies and research. *Int. J. Human-Comput. Stud.* 64 (2), 79–102. <http://dx.doi.org/10.1016/j.ijhcs.2005.06.002>, URL (<http://www.sciencedirect.com/science/article/pii/S1071581905001138>).
- International Organization for Standardization, ISO 9241–11 Ergonomics of Human System Interaction, 2006.
- Jan, I., 2012. What makes people adopt improved cookstoves? Empirical evidence from rural northwest Pakistan. *Renew. Sustain. Energy Rev.* 16 (5), 3200–3205.
- Johnson, N., Bryden, K., 2013. Establishing Consumer Need and Preference for Design of Village Cooking Stoves, IDETC/CIE 2013, pp. 1–9. <http://dx.doi.org/10.1115/DETC2013-13629>. URL (<http://ebooks.asmedigitalcollection.asme.org/pdfAccess.ashx?url=/data/Conferences/ASMEP/77575/V03AT03A042-DETC2013-13629.pdf>).
- Johnson, M., Edwards, R., Alatorre Frenk, C., Masera, O., 2008. In-field greenhouse gas emissions from cookstoves in rural Mexican households. *Atmos. Environ.* 42 (6), 1206–1222. <http://dx.doi.org/10.1016/j.atmosenv.2007.10.034>.
- Johnson, N.G., 2012. Village Energy System Dynamics of an Isolated Rural West African Village (Ph.D. thesis). Iowa State University, Ames, Iowa.
- Kshirsagar, M.P., Kalamkar, V.R., 2014. A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design. *Renew. Sustain. Energy Rev.* 30 (0), 580–603. <http://dx.doi.org/10.1016/j.rser.2013.10.039>.
- Lee, D.R., 2005. Agricultural sustainability and technology adoption issues and policies for developing countries. *Am. J. Agric. Econ.* 87 (5), 1325–1334.
- MacCarty, N., Still, D., Ogle, D., 2010. Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy Sustain. Dev.* 14 (3), 161–171. <http://dx.doi.org/10.1016/j.esd.2010.06.002>.
- Johnson, Michael, Pennise, N.L., David, Charron, Dana, 2011. In-Home Emissions of Greenhouse Pollutants from Rocket and Traditional Biomass Cooking Stoves in Uganda, Tech. Rep.
- Mobarak, A.M., Dwivedi, P., Bailis, R., Hildemann, L., Miller, G., 2012. Low demand for nontraditional cookstove technologies. *Proc. Natl. Acad. Sci. USA* 109 (27), 10815–10820, URL (<http://www.pnas.org/content/109/27/10815.full>), <GotoISI > : //000306641100027 (<http://www.pnas.org/content/109/27/10815.full.pdf>).
- Parente, S.L., Prescott, E.C., 1994. Barriers to technology adoption and development. *J. Polit. Econ.* 102 (2), 298. <http://dx.doi.org/10.1086/261933>.
- Partnerships, A.D., 2012. Global Alliance for Clean Cookstoves Peru Market Assessment Sector Mapping. Tech. rep., Accenture Development Partnerships.
- Pine, K., Edwards, R., Masera, O., Schilman, A., Marrón-Mares, A., Riojas-Rodríguez, H., 2011. Adoption and use of improved biomass stoves in Rural Mexico. *Energy Sustain. Dev.* 15 (2), 176–183. <http://dx.doi.org/10.1016/j.esd.2011.04.001>.
- Raman, P., Ram, N., Murali, J., 2014. Improved test method for evaluation of bio-mass cook-stoves. *Energy* 71, 479–495. <http://dx.doi.org/10.1016/j.energy.2014.04.101>.
- Ramanathan, V., Carmichael, G., 2008. Global and regional climate changes due to black carbon. *Nat. Geosci.* 1 (4), 221–227.
- Ramirez, S., Dwivedi, P., Bailis, R., Ghilardi, A., 2012. Perceptions of stakeholders about nontraditional cookstoves in Honduras. *Environ. Res. Lett.* 7 (4), 44036.
- Roden, C.A., Bond, T.C., Conway, S., Osorto Pinel, A.B., MacCarty, N., Still, D., 2009. Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves. *Atmos. Environ.* 43 (6), 1170–1181. <http://dx.doi.org/10.1016/j.atmosenv.2008.05.041>.
- Rosenbaum, E.D.K., Derby, J., Understanding Consumer Preference and Willingness to Pay for Improved Cookstoves in Bangladesh, Tech. Rep., 2013.
- Ruiz-Mercado, I., Masera, O., Zamora, H., Smith, K.R., 2011. Adoption and sustained use of improved cookstoves. *Energy Policy* 39 (12), 7557–7566. <http://dx.doi.org/10.1016/j.enpol.2011.03.028>.
- Sustainable Energy for All Americas - Peru: Rapid Assessment and Gap Analysis, 2013. Tech. rep., Inter-American Development Banks.
- Sutar, K.B., Kohli, S., Ravi, M., Ray, A., 2015. Biomass cookstoves: a review of technical aspects. *Renew. Sustain. Energy Rev.* 41, 1128–1166. <http://dx.doi.org/10.1016/j.rser.2014.09.003>, URL (<http://linkinghub.elsevier.com/retrieve/pii/S136403211400776X>).
- The Water Boiling Test 4.2.3, 2014. Tech. rep., Global Alliance for Clean Cookstoves. URL (<http://cleancookstoves.org/technology-and-fuels/testing/protocols.html>).
- Troncoso, K., Castillo, A., Masera, O., Merino, L., 2007. Social perceptions about a technological innovation for fuelwood cooking: case study in rural Mexico. *Energy Policy* 35 (5), 2799–2810. <http://dx.doi.org/10.1016/j.enpol.2006.12.011>.
- Urmee, T., Gyamfi, S., 2014. A review of improved Cookstove technologies and programs. *Renew. Sustain. Energy Rev.* 33, 625–635. <http://dx.doi.org/10.1016/j.rser.2014.02.019>.
- WHO, 2014. Household air pollution and health. URL (<http://www.who.int/mediacentre/factsheets/fs292/en/>).
- Wohlgenuth, A., Mazumder, S., Andreatta, D., 2009. Computational heat transfer analysis of the effect of skirts on the performance of third-world cookstoves. *J. Therm. Sci. Eng. Appl.* 1 (4), 41001. <http://dx.doi.org/10.1115/1.4001483>.
- Yin, R.K., 2014. *Case Study Research 5th edition.* Sage Publications.
- Zube, D.J., 2010. Heat Transfer Efficiency of Biomass Cookstoves (Ph.D. thesis). Colorado State University, Fort Collins, Colorado.