

Viability of Improved Chulhas in Himachal Pradesh

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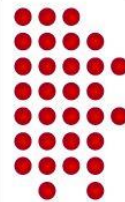
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Professors Dr. Atul Dhar, and Dr. Satvasheel Powar

Indian Institute of Technology-Mandi

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Viability of Improved Chulhas in Himachal Pradesh

An Interactive Qualifying Project
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
degree of Bachelor of Science

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Report Submitted to

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Abstract

Generations of rural village inhabitants of Himachal Pradesh, India, have used “chulhas,” a traditional cook stove. Our project investigated the viability of improved chulhas in Himachal Pradesh. We tested two prototype chulhas prior to seeking feedback from local stakeholders. Utilizing stakeholder feedback in addition to our own test results, we designed and built an improved chulha. Finally, we questioned the practicality of improved chulhas in this region based on our observations, India’s increasing LPG use and India’s infrastructure development.

Executive Summary



WPI

Viability of an Improved Chulha



Generations of rural village inhabitants of Himachal Pradesh, India, have used "chulhas," a traditional cook stove. Our project investigated the viability of improved chulhas in Himachal Pradesh. We tested two prototype chulhas ourselves prior to seeking feedback from local stakeholders. Utilizing stakeholder feedback in addition to our own test results, we designed and built an improved chulha. Finally, we questioned the practicality of improved chulhas in this region based on our observations, India's increasing LPG use and India's infrastructure development.

1. Assess the demand of an improved chulha



LPG stoves are challenging traditional chulhas



2. Identify low cost enhancements to make an improved chulha

	Prototype 1	Prototype 2
Wood (kg)	0.69	0.491
Total Time (mins)	31.06	14.85
KJ/kg	458.59	632.19

Prototype Testing

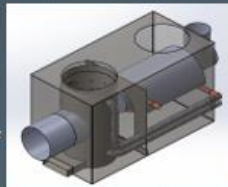
Stakeholder input influenced the design of prototype (3)



Stakeholder Testing

3. Test and implement Enhancements

- ❖ Manufacturability
- ❖ Horizontal feed pipe
- ❖ Cylindrical Burn Chamber



Prototype 3

Prototype 3 is more efficient and economically competitive

Recommendation and Outcomes

- ❖ Continue testing Prototype 3
- ❖ Make additional design modifications such as
 - Larger diameter out gas pipe
 - Additional holes in out gas pipe
 - Better seal of covers on burn chambers
- ❖ Redesign Prototype into a kit allowing for outer steel shell to be replaced with clay. This will greatly reduce cost

	Prototype 1 ❌	Prototype 2 ❌	Prototype 3 ✅
Wood (kg)	0.69	0.491	.270
Total Time (mins)	31.06	14.85	10.26
KJ/kg	458.59	632.19	1093.772

Final Thoughts

We predict LPGs will surpass chulhas in popularity as infrastructure develops.

The prototype will be a short term improvement for the region

This prototype will best suit a niche market of remote villages

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Visit our site for a more in-depth look at our project
<https://sites.google.com/site/ind17chullah/home>

Acknowledgments

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- **Mr. Stephan Marchal**, for sharing his experience and giving us insight on relevance of chulha and design requirements in Himalayan region.
- **Mr. Sham Lal**, for escorting us around his village during surveying and agreeing to test prototype 2 for a period of 4 days
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The full report and supplemental materials for this project (raw data, relevant case studies, the instruction pamphlet, and additional resources) can be found using key words from our project title at <http://www.wpi.edu/E-project-db/Eproject-search/search> and further information can be found at the IIT's ISTP page: <http://www.iitmandi.ac.in/istp/projects.html>

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Introduction

Even today, in many parts of the world, the simple act of cooking a meal poses a health risk to people as well as the environment. The World Health Organization (WHO) estimates that over four million people die prematurely from illnesses due to smoke inhalation produced by cooking fires.

In India, according to a 2004 study, most rural households burn biomass fuels for cooking. Biomass fuels, such as wood, are conventionally burned in homemade clay stoves or steel stoves, called 'chulhas' (Anuj, 2004). The combustion of these biomass fuels is often incomplete because of the inefficient design of traditional chulhas. Cooking with chulhas in the home generates pollutants that, unvented, can cause a plethora of life-threatening diseases.

Organizations and businesses have brought a range of safer and cleaner burning stoves to market. An effort has been made to sell these stoves at a range of prices to the rural Indian population. Progress in the private sector has been slow, and to date these efforts have not been successful (Bhojvaid, 2014). Recent government subsidies on liquefied petroleum gas (LPG) stoves have increased improved cook stove use throughout the country (Jain, 2016).

The district of Mandi, Himachal Pradesh, India, is made up of a primarily rural population who seem to gravitate towards traditional cooking methods using "unsafe" chulhas (Jeuland, 2015). To offset the negative effects of chulhas and increase the accessibility of improved cook stoves, the Indian government launched the social welfare program *Pradhan Mantri Ujjwala Yojana* on May 1st, 2016. The act gives government subsidies on LPG canisters and stoves to families below the poverty line. The act ultimately aims to transition at least fifty million people to cleaner and safer cooking technologies (Indian Government, 2016).

One previous Interactive Socio-Technical Practicum (ISTP) study at the Indian Institute of Technology Mandi (IIT Mandi) addressed the health effects related to chulha use. However, this study did not address the practicality of chulhas in a changing Indian society (Baker, Coddling, Gupta, Sharma, Verma, Zhang, 2016). The goal of our project is to assist in determining the viability of improved chulhas in Himachal Pradesh. We laid out three objectives that will guide us to the successful completion of our goal:

1. Assess the demand for an improved chulha
2. Identify low cost enhancements to improve a chulha
3. Test and implement chulha enhancements

Background

Before conducting fieldwork for this project, we completed background research into the current methods of cooking in Himachal Pradesh and the issues associated with them. We also investigated how the region of Himachal Pradesh is changing with respect to LPG use and infrastructure.

Chulha - The Traditional Stove



Figure 2. Basic Chulha (Wordpress.com)

In Himachal Pradesh, the traditional stove used for cooking is called the *chulha*. Chulhas are typically placed on the floor inside the home. Some, but not all, households have a separate room for cooking. The most basic form of the chulha is a bowl with a u-shaped slot. Chulhas are commonly constructed from a mixture of clay and cow dung. An example of a traditional chulha can be seen in Figure 1. Note that there is no ventilation of the smoke produced from burning biomass fuels within the homes. The main fuels used in chulhas are wood and cow dung, both considered biomass fuels. Biomass fuel types produce a wide range of pollutants when burnt that can affect everyone inside the home, whether they are the ones cooking or not (UNDP, 1997). A more advanced chulha design can be seen in Figure 2. It is a hollow block with several openings allowing for multiple cooking surfaces. This design also includes an oven. Some more advanced chulhas include chimneys to help ventilate smoke out of the home. Neither traditional design is effective or efficient. The basic chulha's main flaw is its open fire cooking, requiring large amounts of wood to maintain cooking temperature. The more advanced chulha addresses this flaw, but has limited airflow. Chulhas have now been surpassed in design by other types of stoves that use cleaner burning fuel sources and are far more efficient.

In Himachal Pradesh, the traditional stove used for cooking is called the *chulha*. Chulhas are typically placed on the floor inside the home. Some, but not all, households have a separate room for cooking. The most basic form of the chulha is a bowl with a u-shaped slot. Chulhas are commonly constructed from a mixture of clay and cow dung. An example of a traditional chulha can be seen in Figure 1. Note that there is no ventilation of the smoke produced from burning biomass fuels within the homes. The main fuels used in chulhas are wood and cow dung, both considered biomass fuels. Biomass fuel types produce a wide range of pollutants when burnt that can affect everyone inside the home, whether they are the ones cooking or not (UNDP, 1997). A more advanced chulha design can be seen in Figure 2. It is a hollow block with several openings allowing for



Figure 1. Advanced chulha with chimney (chulha.org)

LPG Stoves – Increasing in Popularity

In Himachal Pradesh, LPG stoves have become the desired improved cook stove to use alongside traditional chulhas. In our visit to Bagi Village, where no families currently had access to LPG stoves, some families said they would prefer to use an LPG stove. It shows that the families knew about LPG stoves, but they simply did not have the means to acquire one. The PMUY social welfare act subsidizes LPG canisters for Indian households at an affordable rate. The goal of this act is to increase access to LPG cooking for households below the poverty line (BPL) (PTI, 2016).

In March of 2015, Prime Minister Shri Narendra started a campaign called “#giveitup” to persuade those who could pay market price for LPG canisters to give up their government

subsidies (Indian Government, 2015). With the upper and middle classes giving up their government subsidies, more and more money was freed up in the national budget for the less fortunate (PTI, 2016). Government subsidies will help BPL households transition from their use of chulhas and biomass fuels to LPG stoves for cooking.

The PMUY act caters directly to BPL families and set requirements to ensure subsidies are exclusive to BPL families. There are three main requirements to the act (BankBazaar, 2016):

1. One subsidy would be provided per household.
2. A female, over the age of 18 from the house must register in her name for the subsidy.
3. The household must be registered as a BPL household with the respective state government.

The PMUY act will be effective from 2016 to 2019 and is projected to influence over 5 million households (Jain, 2016). However, even with the current act and those that have come before it already in place, LPG stoves have not completely phased out chulhas.

A 2015 study has found that the rural population of Himachal Pradesh follows a system called 'stove stacking' (Wang, 2015). The basis of this system is the continued use of traditional biomass burning chulhas, alongside the use of the new improved cook stoves. While conducting surveys, we found that 63% indeed follow this practice of owning both an LPG and a chulha, a much greater percentage than we anticipated.

There are several different theories as to why LPG stoves have not completely superseded chulhas as the primary stove used by the rural population of Himachal Pradesh. One theory is that the rural population does not know the environmental and health effects of burning biomass fuels. The population assumes that renewably harvested biomass fuels do not harm their surrounding environment. According to a study at the beginning of the century, they believe carbon released through the burning of biomass fuels is entirely recycled through photosynthesis (Smith, 2000). Additional theories take into account economic, geographic, and social factors that prevent LPG stoves from entirely replacing the chulha.

Even with government subsidies, LPG prices can be still be too high for BPL families. According to a recent survey, 95% of BPL households without LPG connections cite their inability to pay as the main reason for not using an LPG stove (Jain, 2016). Most households survive on a subsistence level. The yearly income per household for the Himachal Pradesh region is about 1000 USD (India Census, 2015).

Another reason why LPG's have not completely replaced chulhas has to do with the geography of Himachal Pradesh. Traveling in Himachal Pradesh can be time consuming due to the mountainous terrain. Furthermore, during monsoon season, many roads become dangerous to the point that driving is not feasible. Delivering LPG canisters to remote villages is always difficult and occasionally impossible (Jain, 2016). Availability and access can make the preference for chulhas over LPGs for a rural household easy.

Social factors also play into why the region has not converted to LPG stoves exclusively. Lack of awareness about the PMUY act is negatively impacting the conversions in the most rural areas of the region. About 40% of households in the rural regions of the country that do not have LPG stoves entirely lack the information about the act and its

benefits, or lack the information pertaining ways of obtaining a subsidized LPG connection (Jain, 2016).

Finally, LPG stoves can also fail to meet households' culinary preferences, which are tied to the use of traditional chulhas. The chulha is valued for its perception that food cooked on the chulha has superior taste, an opinion strongly held especially by elders (Wang, Y., 2015). This social factor can possibly explain why some households in Himachal Pradesh still retain a chulha even though they also own an LPG stove.

Health Risks Associated with Burning Biomass Fuels

India's indoor air pollution is an environmental problem and a major health problem. In developing countries, biomass fuels burned in stoves within households create dangerous pollutants (Arora, 2014). Nearly 50% of the world's population and 75% of Indian households burn biomass fuels - primarily wood and cow dung (Prasad, 2012). The noxious gases produced from burning biomass fuels in high volumes is a primary contributor to indoor air pollution. The noxious gases also contribute to greenhouse gas emissions in northern India.

Biomass fuels are inefficient, meaning they must be burned in large quantities to maintain a cooking fire. The efficiency of biomass fuels when burnt in traditional chulhas is typically as low as 10-15% (Perez-Padilla, 2010). In other words, this means that up to 90% of the energy produced by burning biomass fuels is not used for cooking.

Women and children are at the greatest risk for health complications, as they are tasked with cooking in the home. There are many diseases and health effects caused by exposure to pollutants produced by traditional chulha use. Health effects include: chronic obstructive pulmonary disease (COPD), lung cancer, tuberculosis, acute lower respiratory infection, and asthma (Perez-Padilla, 2010, and Forum of International Respiratory Societies Report, 2016). Acute lower respiratory infections and asthma are the two main health complications seen in children. Unborn children in women exposed to pollutants can also develop health issues (Perez-Padilla, 2010). COPD and lung cancer can be diagnosed in individuals as early as 30 years of age. COPD is a major contributor to premature deaths due to smoke inhalation from burned biomass fuels. Lung cancer is primarily found in those who smoke tobacco products and cook with biomass fuels (Perez-Padilla, 2010).

Difficulties in Supplying LPG's to Rural Villages

LPG stove users in the region of Himachal Pradesh rely on the availability of LPG canisters. Availability is determined largely by the quality of roads that connect users and suppliers. We believe India's infrastructure, at least in Himachal Pradesh, will continue to develop, which will open the door for those who want to make the switch from chulha to LPG.

In the past five years, hundreds of millions of dollars have been spent for the improvement of Himachal Pradesh roads. Improvements include the paving and widening of existing roads and the construction of new roads. The state government in Himachal Pradesh proposed 188 road projects to receive funding under the *Pradhan Mantri Gramin Sadak Yojana* (PMGSY) act in December of 2015 (Bhandari, 2015).

The PMGSY act is under the authority of the Ministry of Rural Development and aims to provide roads to villages (Government of India, 2004). It was broken down into 4 stages to provide roads to villages, shown below:

1. with a population of 1000 persons and above by 2003
2. with a population of 500 persons and above by 2007
3. in hill states, tribal and desert areas with a population of 500 persons and above by 2003
4. in hill states, tribal and desert areas with a population of 250 persons and above by 2007

PMGSY is still currently being completed, and its progress can be monitored on *omms.nic.in*. To date, 12,200 kilometers of roads have been built in Himachal Pradesh as a result of PMGSY act (Indian Government, 2017).

In May of 2016, approval was obtained for 17 new national highways in Himachal Pradesh (Press Trust of India, 2016). These 17 national highways will undergo much needed improvements to improve their quality. At the conclusion of the project, the highways will meet the country's national highway standards.

India's infrastructure is improving, but there is no clear timeline as to when projects like those described above will be completed. However, it is almost certain there will be similar projects in the future. These projects will greatly improve LPG access to the villages of Himachal Pradesh. With increased access to LPG canisters, life in the region will continue to evolve. As more improvements to infrastructure are completed, the once rural region of Himachal Pradesh may become more modernized.

Methodology

The goal of our project was to assist in determining the viability of improved chulhas in Himachal Pradesh. We laid out three objectives that guided us to the successful completion of our mission:

Objectives

1. Assess the demand of an improved chulha

2. Identify low cost enhancements to improve a chulha

3. Test and implement chulha enhancements

Assessing the Demand of an Improved Chulha

To assess the demand for an improved chulha our team, with the help of our teaching assistant Vipul Sharma, identified eight villages to survey. These surveys allowed us to identify what type of stove individuals were using to cook with, if the government's subsidies were benefitting the area, and the price that individuals interested in the prototype would be willing to pay for it. Each interview was conducted in Hindi. Our IIT teammates would translate the responses to our survey questions as the interview was conducted. As we moved from village to village our team made quantitative and qualitative observations of the location and condition of household. These observations included distance from a main road/India highway, stacks of firewood, new house constructions, LPG canisters, and visual signs of smoke. Appendix A contains all questions asked during initial surveys.

Identifying Low Cost Enhancements to Improve a Chulha

IIT students and faculty advisors had built a prototype chulha prior to our arrival. The prototype was made out of steel and was based on a design by Mr. Stephan Marchal, that had already been put into practice in a village outside Kullu. For the purpose of this paper, Stephan Marchal's prototype is referred to as #1, the IIT Mandi prototype is #2, and our group's prototype is #3. Prototype 3 was designed with the intention of further improving the original design. The re-design was based on the feedback received from stakeholder testing and was guided by two primary goals: lowering the price to build the prototype and increasing its manufacturability.

Our group conducted baseline tests of the two existing prototypes to identify strengths and weakness in each design. The data from the testing was compared to determine the more suitable prototype for stakeholder testing and for further improvement. Prototype 2 was determined to be more efficient and was chosen to be used for stakeholder testing. Three tests were performed on the primary burn chamber in each chulha. This consisted of timing how long it took for one liter of water boil over the burn chamber. Before each test, each stove was brought to cooking temperature. This was determined when the syphons were visually directing smoke up the chimneys. Each test would begin when the smoke exiting the chimney became clear and almost invisible, indicating a good burn. The

total time and total weight (in grams) of wood require to complete each test was recorded. At our altitude, which is about 3,500 feet above sea level, we estimated that water boils at ninety-six degrees Celsius. Data was recorded in a notebook. To ensure accuracy between tests, each stove was tested once per day to allow each stove to cool down completely after each test. Data was transferred at the conclusion of the testing day into an Excel spreadsheet. The estimated energy output was calculated in this spreadsheet using the recorded data and the specific heat of water.

Stakeholder testing was conducted with local construction workers and with local villagers who use chulhas on a daily basis. Each stakeholder household was given prototype 2 for a minimum of 24 hours. Stakeholders were interviewed after the completion of their testing to find out how user-friendly the design was, what benefits and liabilities stakeholders associated with the prototype, and what they would like modified. Our comprehensive interview guide can be found in Appendix B.

Testing and Implementing Chulha Enhancements

While testing was being conducted in stakeholders' homes, our team began building prototype 3. Baseline testing allowed us to determine the better of the two existing prototypes. We had planned to allow stakeholders to test both prototypes, but because of the significant difference in how much wood was burnt and how long each took to get to temperature, we decided only to use prototype 2 for stakeholder tests. The first draft of the design focused on manufacturability of the prototype. Improving manufacturability helped us reduce the cost of prototype 3. The final design also factored in stakeholder feedback of prototype 2.

Prototype 3 was built in the machine shop located on the IIT Kamand campus. Overall construction took about twenty-one hours for a single person. Materials used to build the prototype were sourced from the machine shop or obtained in Mandi Town. Final estimates of the cost to build the prototype were made on the basis of building a single product.

When we finished constructing prototype 3, we tested the chulha in the same manner as the previous two prototypes.

Results and Discussion

Some of our results from surveying and fieldwork didn't yield what we expected. In fact, what we found from completing field work the first few weeks surprised us. We found that most of the local population uses both chulhas and LPG stoves, contrary to what most previous studies suggested. LPG stoves are used as the primary method for cooking, while chulhas are used seasonally – primarily in the winter when chulhas are needed for heating the home.

Objective 1: Assessing the Demand for Improved Chulhas

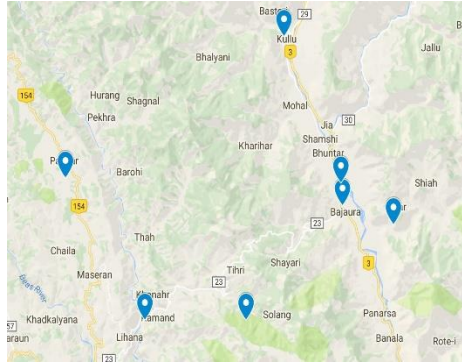


Figure 3. Map of Survey Locations (Google Maps). 2017.

We engaged with stakeholders from forty-three households in eight different villages. The map to the left (Figure 3) shows seven of the eight village locations. In response to a question asking if they use a chulha or LPG stove for cooking, we found that only 2% of households use solely LPG for cooking, whereas 35% of stakeholders use only chulhas. 63% of stakeholders surveyed use both a chulha and LPG stove for cooking (see Figure 4). Therefore, 98% of the households we engaged with use a chulha for some kind of cooking. We then became curious as to why families would use both a chulha and an LPG stove. Most families responded by stating the chulha is only used for boiling water used to make tea or

preparing small snacks. In these households with both chulhas and LPGs, chulhas are used as a backup, especially when a household needs something to cook on while they wait for their next LPG cylinder to be delivered. Furthermore, these households increase the number of hours spent cooking per day on the chulha in the winter, since it is cheaper to heat their home by burning free firewood.

Additionally, we asked all households that use LPGs to share with us how many LPG cylinders they purchase each year. Our results indicated that every household purchases subsidized cylinders. Of the twenty-six homes using LPG stoves, the average number of cylinders consumed per year was six. One household informed us they use twenty-four LPG cylinders per year, which we confirmed later in the interview. This household represented the 2%

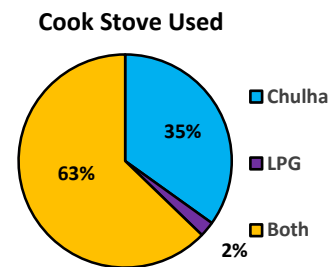


Figure 4. Reported cook stove used in homes

Interest in Prototype Chulha

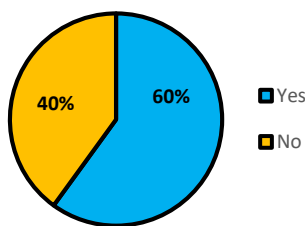


Figure 5. Reported interest in improved prototype chulha

household represented the 2% of those interviewed who use only LPG stoves. Additionally, we asked families whether or not they would be interested in an improved prototype chulha. We did **not** inform them of the current manufacturing cost of the chulha, which is about INR 3,000. This was done to determine their overall interest in the concept, but also to establish an unbiased price range stakeholders would be willing to pay for the improved chulha. Figure 5 represents the interest of households in an

improved chulha. 60% were immediately interested and 40% were not interested. While we were satisfied the majority of those interviewed were interested in potentially owning an improved chulha, we had believed that far more than 60% would be interested. It is important to note that more families who were initially hesitant could become interested if allowed to test a working prototype. We asked families who replied they were not interested if they could provide us with a reason why so we could address their concerns and make our prototype suitable for everyone. Some families cited low income as the main reason they were not interested. Others claimed they were more comfortable cooking on the traditional clay-made chulhas they were accustomed to.

We asked families who replied that they were interested if they could give us a price range that seemed reasonable to them. We found a general range of about INR 1000-2000 to be the most acceptable. Some asked for a cheap model to be available in the range of INR 1,000 or below. Figure 6 (below) shows the preferred price of an improved prototype chulha among stakeholders. The current manufacturing cost of IIT's prototype is INR 3000, which was well out of the range stated by most stakeholders. If the manufacturing cost alone is well above what consumers want to pay, the product will most likely not be commercially successful nor helpful to consumers.

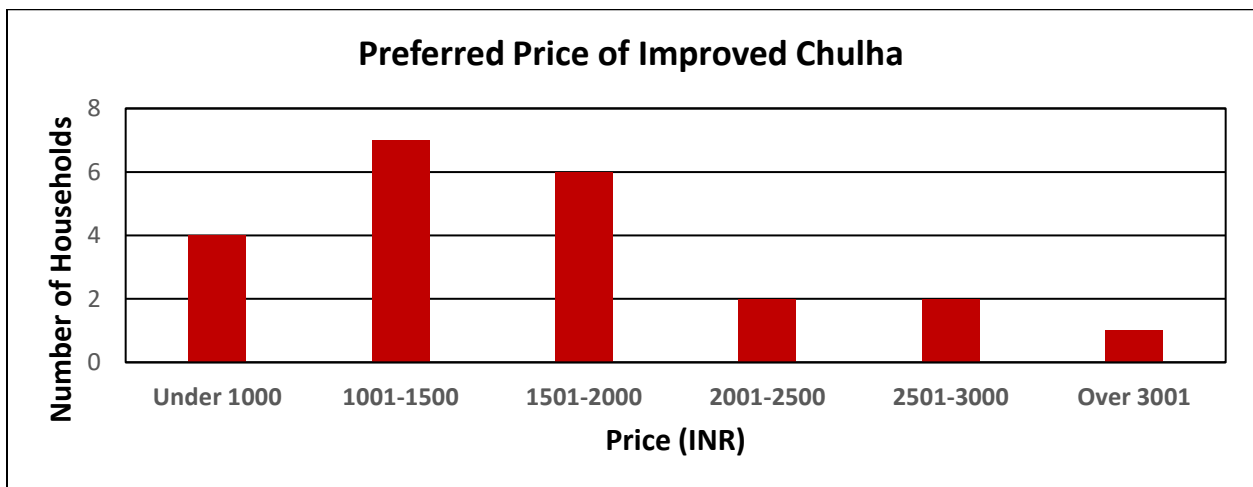


Figure 6. Preferred Price of Improved Chulha

Objective 2: Identifying Low-Cost Enhancements to Improve a Chulha



Figure 7. Prototype 1

To identify enhancements for prototype 3, we first performed baseline tests of prototypes 1 and 2 to give us an idea of how well each chulha performed. Figure 7 shows a picture of prototype 1, designed by Stephan Marchal, a resident of a village near Kullu. In a conversation with Mr. Marchal, he informed us that he worked on the prototype solely to help the women who cook in his village. Total design and fabrication of Stephan's final chulha spanned 2 years. By comparison, our surveys, the testing of prototypes 1 and 2, and the construction of prototype 3 all occurred within five weeks. Prototype 2, which can be viewed in Figure 8, was designed

by a graduate student and professors at IIT Mandi. Prototype 2 is based on the design of prototype 1.

Both prototypes work in the same fashion to provide hot water and less smoke in the home. A copper coil resides in the second chamber behind the primary burn chamber. Heat is transferred from the outgassing smoke to the copper coil through convection. Water flows through the copper coil and is heated through conduction. This harnesses energy that would otherwise be lost in the outgassing smoke.



Figure 8. Prototype 2

Producing less smoke is achieved through two design aspects, a syphon and increased air flow to the burn chamber.

Prior to igniting wood in the primary burn chamber, newspaper is placed in the flue, located under the chimney. After lighting the newspaper, the burn chamber is ignited. This process causes smoke created in the burn chamber to flow through the chulha to the chimney and out of the home. The outgassing smoke is syphoned up and out of the home through the chimney due to the design of the prototypes. Increased air flow is the second aspect that reduces smoke within the home. Air pipes provide air to flow through the entirety of the burn chamber. The air is directed through pipes running through the secondary chamber. This action heats the air being provide to the burn chamber through convection from the outgassing smoke that is flowing through the secondary burn chamber. This warm air flow in the burn chamber at all levels achieves a more complete burn, which produces less smoke. These design aspects are how these prototypes provide heated water and less smoke in the home for users.

Two notable attributes of prototype 2 are that it is wider and much heavier than prototype 1. Internal differences from prototype 1 to prototype 2 include large air flow pipes, the removal of a funneled ash collection, and a larger burn chamber.

The average test results to boil one liter of water using prototypes 1 and 2 are compared below in Table 1.

Table 1. Average Results Comparison of Prototype 1 to Prototype 2

	Wood (g)	Total Time (mins)	KJ/sec	KJ/kg
Prototype 1	690	31.1	0.19	458.6
Prototype 2	491	14.9	0.35	632.2

Compared to prototype 2, prototype 1 used about 200 grams more wood and took about twice as long to boil a liter of water. After determining how many kilojoules (kJ) were produced by each stove during testing, the kJ produced per second and kJ produced per kilogram of wood for each prototype could be calculated. Looking at kilojoules produced per second for both stoves, prototype 2 yielded almost double that of prototype 1. In terms of

energy output vs weight of wood, prototype 2 again bested prototype 1, with an average of 632 kJ/kg.

Based on our baseline test results, we decided to only test prototype 2 with stakeholders. Our initial stakeholder assessments took place on IIT's campus, where we were fortunate to enlist three households to test prototype 2 and provide us feedback, which was used in the later design stages of prototype 3.

Stakeholder testing was completed on the campus of IIT and in Bari Village. Three households located on IIT's campus tested and provided feedback about prototype 2. Additionally, one household in Bari tested the prototype, with friends they invited to test it with them. Although we were satisfied prototype 2 used less wood and allow for faster cooking, there are still many improvements that could be made.

Many suggestions by stakeholders were taken into consideration when we began construction of prototype 3. One recommendation we included in our design is making the wood inlet horizontal. This will allow users to insert larger sticks into the chulha. Some other recommendations included: a net to be placed in the chimney to catch newspaper when lighting the flue, a chulha made of a less conductive material that would not give off heat in the summer time while cooking, and a container located inside the chulha that could store water and dispense it when cooking.

Objective 3: Implementation and Testing Results

To implement the enhancements identified with our tests and surveys, we built a third prototype chulha. A 3D computer model of prototype 3 was designed in SolidWorks. Over the course of our study, the design of prototype 3 was altered almost daily. Prototype 3 is based on the design of Prototype 2, with some modifications. Our group kept the idea of a syphon and increased air flow to the burn chamber. One person (with moderate assistance) was able to construct prototype 3 in about twenty-one hours of work. We believe this time can be reduced, especially by someone who has had practice building prototype 3 with proper instructions.

Perhaps our most significant "enhancement" in the design of prototype 3 is the cost. Prototype 2 costs about 3000 INR to manufacture, which is higher than the preferred amount for 83% of the households surveyed. If people can't afford the chulha, it doesn't matter how well it works or what additional features it has. Our initial surveys helped us identify a reasonable price stakeholders would be willing to pay for an improved metal chulha. The cost of materials for prototype 3 was estimated to be 2500 INR. This results from smaller dimensions and improved manufacturability of the main differing components of prototype 3.

Figure 9 shows our final design for prototype 3. Some notable modifications from prototype 2 are a cylindrical inlet for biomass fuels and the cylindrical burn chamber. These two features are emphasized by the blue and red arrows. An influencing factor for making both of these parts cylindrical is for better manufacturability. Instead of having to bend and weld materials into a square prism shape, it is quicker and cheaper to use prefabricated cylindrical pipe.

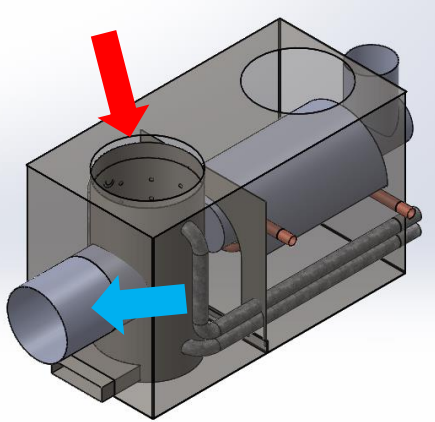


Figure 9. Final design of Prototype 3 – blue arrow indicates wood inlet and red arrow points to burn chamber

We modified the fuel inlet to be horizontal because of stakeholder feedback, which neither of the previous two chulhas adopted. This feature was implemented based off of feedback from the four households that tested prototype 2. Eliminating the angled wood inlet will allow users to slide larger pieces of wood into the burn chamber.

The burn chamber consists of two concentric cylinders. This ensures there is constant air flow throughout the chamber. The inner cylinder contains the burn chamber while the outer cylinder directs air into the burn chamber. Air flows from the outer to inner cylinder through holes drilled at varying heights in the inner cylinder. These small holes allow air to flow into the burn chamber and fuel the fire.

Prototype 3 also differs from the initial two prototypes by running the air pipes along the sides of the interior. This configuration, combined with our concentric cylinder chamber design, frees up space in the burn chamber. The air pipes provide air to all levels of the burn chamber similar to prototypes 1 and 2 (see Figure 10). Prototypes 1 and 2 ran the air pipes through the center of the burn chamber at varying levels, which resulted in a cluttered burn chamber and made adding biomass fuels difficult for stakeholders. We have included a representation of the air flow within prototype 3 that can be located in Appendix D.

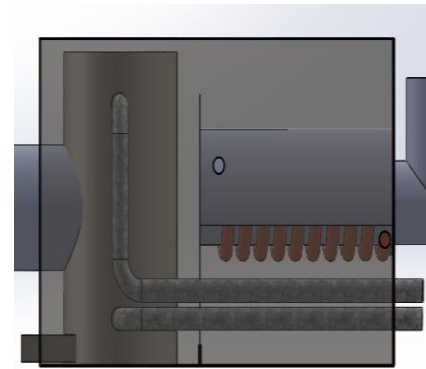


Figure 10. Side view of prototype 3 showing air flow pipes

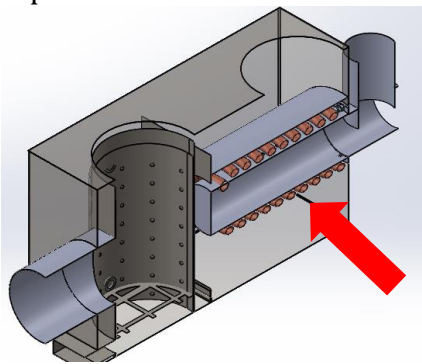


Figure 11. Copper coil to heat water while cooking

Figure 11 is a different view of our SolidWorks design for prototype 3. The figure splits prototype 3 in half, so although it is not visible, the coil wraps around the entire pipe. The coil was integrated in prototypes 1 and 2 but in a vertical orientation. We placed the coil horizontally to investigate whether or not it would work better than the vertical alignment in earlier prototypes. The copper coil allows stakeholders to heat water using heat transferred from smoke produced from the main burn chamber while they cook. Prototype 3 retained the copper coil since the ability to heat water while cooking is an added incentive for the purchase of the prototype. Figure 12 shows a picture of

the completed prototype 3 that can be seen below alongside the previous images of prototypes 1 and 2. Table 2, below Figure 12, shows the test average results for prototype 3.



Figure 12. From left to right: prototype 1, prototype 2, and prototype 3

Table 2. Average Test Results for Prototype 3

	Wood (g)	Total Time (mins)	kJ/s	kJ/kg
Prototype 3	270	10.3	0.53	1,229.9

As can be seen in Table 2, prototype 3 used an average of 270 grams of wood, which is less than prototype 2. On average, prototype 3 was able to boil one liter of water in just over 10 minutes. Prototype 3 produced 0.53 kJ of energy for cooking per second and almost 1,230 kJ per kg of wood. Table 3 shows the comparison of all 3 prototypes. (The complete results of all tests for each prototype can be found in Appendix C.

Table 3. Average Test Results Comparison of All 3 Prototypes

	Wood (g)	Total Time (mins)	kJ/s	kJ/kg
Prototype 1	690	31.1	0.19	458.6
Prototype 2	491	14.9	0.35	632.2
Prototype 3	270	10.3	0.53	1,229.9

Discussion

When our group arrived at the IIT Mandi campus it was apparent that the background research our group had completed in the United States was no longer up-to-date.

Through our research, we identified two factors that had made our background information less relevant, the first being that the Indian government had subsidized LPG stoves for BPL families. This gave many households in the region access to improved cook stoves. The second factor was the road network improvements being carried out in Himachal Pradesh. Understanding these two factors impacted how we conducted our fieldwork and how we would analyze the data we collected.

The data collected from our surveying showed that chulhas are still in use in almost every household in the area. In these households, chulhas had become seasonal cook stoves, reserved for cooking traditional meals or just for hot water heating. It became apparent that a prototype chulha that could heat water and cook more efficiently was best suited for those households that used chulhas exclusively. Though households who used both LPG stoves and chulha did express an interest in an improved chulha, we do not believe an improved prototype would have a substantial benefit for these households due to their limited use of chulhas.

For the success of our prototype we needed to offer incentives for the stakeholders to buy the prototype. Our prototype was designed to be economically competitive, provide the ability to heat water while cooking, and provide a smokeless environment for the user. To understand our design decisions, it is important to understand the basis on which our prototype chulha has been built. The faculty of IIT Mandi had previously designed an improved chulha based off a prototype chulha that had been introduced into a community outside Kullu by Stephan Marchal. Stephan's and IIT's design both included the ability of chulhas to provide hot water and a smoke free environment. Our prototype was created in an attempt to improve upon IIT's design. Prototype 3 is smaller and easier to manufacture on a larger scale. The ease of manufacturing our chulha was the main focal point in our design. Improving manufacturability results in a lower cost per unit, making the prototype economically competitive. The final design was also influenced by feedback from stakeholder testing of prototype 2.

Of course, our prototype is far from perfect and still needs to be tested. Mr. Marchal spent over two years perfecting his design of prototype 1, while we created prototype 3 in about five weeks. Mr. Marchal informed us that he expects his chulhas typically only last about three years, an issue that could prove to be major for impoverished households. Traditional, homemade chulhas can last longer than a decade, although maintenance needs to be performed up to three times a week, according to locals. Because of the time constraint in our study, we unfortunately cannot accurately provide any kind of estimate about the durability or expected lifetime of our prototype.

While our prototype can be a competitive and beneficial product to the state of Himachal Pradesh, the future for the chulha use is unclear. While completing surveys and traveling throughout the region our group observed the improving infrastructure, which completely changed our outlook. With improving infrastructure our group feels that LPG use will only increase as access to LPG's and the knowledge of government subsidies increases. This effectually addresses two of the key factors highlighted in our background research for why households did not obtain LPG stoves.

We do not believe, however, that chulhas will be done away with completely. In the single homes and villages that are very remote we believe traditional chulhas will continue to be used almost exclusively. This market of chulha users will eventually become a very niche market and our prototype would have the biggest impact in such niche markets only. In urban rural areas, we believe people will continue to stove stack. Using chulhas for simple tasks such as hot water heating and small space heating in the winters is an intelligent way to use traditional technology.

We do not see this prototype becoming a need for the population of Himachal Pradesh. Overall, we believe this prototype and its future iterations will be a band-aid for a significant percentage of those who don't yet have LPG stoves due to low income or lack of accessibility.

Conclusion and Recommendations

Although chulhas have long been a part of the culture in rural Himachal Pradesh, the region's ever changing infrastructure as well as the recent government subsidies on LPG canisters have jeopardized chulha popularity in the region. LPG use is growing, and for those who are able to afford the cost of subsidized cylinders, the decision to switch is easy. Our surveys indicated that (contrary to popular belief) most households in the region own both an LPG stove and a chulha. Because of this, we believe as infrastructure continues to develop and more households become aware of the government subsidies, stove stacking will continue to increase.

Despite our prototype not working as well as the previous two improved prototypes, we do not consider our design a failure. We set out to determine if improved chulhas were a practical necessity for residents of Himachal Pradesh, and we believe improved chulhas will be practical for a small percentage of the population, at least for some time. Keeping in mind our limited time, reducing the cost and making an easier-to-manufacture prototype were our main focuses in designing prototype 3, and we successfully accomplished both of those goals. Increasing efficiency significantly could take years of testing and slight modifications. All in all, we believe improved chulhas are a "band-aid" fix that will prove useful, but only to a very niche market of households who will struggle to obtain access to LPG stoves.

Recommendations

Because of time restraints, we recommend testing the prototypes 2 and 3 in the homes of stakeholders for several weeks. These tests can be used to produce additional prototypes that can better meet the specifications of users. Additional modifications should be made as the team sees necessary. Performing tests in the homes of villages will help expose prototype to the population of northern India.

The following recommendation comes directly from feedback we received during stakeholder testing. A household recommended making a smaller prototype, about half the size of all three existing models. The ideal prototype should be light, easy to move, contain one burn chamber, and cost between 1000 and 2000 INR. It would be best suited for workers who need to travel often. We would like to recommend further investigation about the feasibility of this idea.

A major recommendation we would like to discuss is to make the body of the prototype out of traditional materials such as clay and cow dung. This topic was discussed in one of our meetings with Dr. Atul and Dr. Satvasheel of IIT Mandi. A large part of the cost comes from the steel body of prototype 3. The internal design of prototype 3 allows for adaptation of the body walls to be replaced with clay. By replacing the steel body traditional materials overall cost of prototype 3 is drastically reduced. Some stakeholders also recommended a body not made out of metal because of how hot it gets during the summer. The chulha would heat the room even more because of the metal body. It must be noted that ability to move the chulha is greatly reduced when the body is made out of traditional materials. A prototype made of traditional materials would need to be tested as well prior to stakeholder testing. While we do not believe the traditional design of chulhas has much of an impact on the younger generation, this more traditional design of an improved cook stove

may be more popular among the elderly, as we found the elders tend to prefer traditional methods of cooking in our surveys.

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Appendices

Appendix A: Sample Survey Questions

Questions	Answers Translated from Hindi
1. Do you currently use a chulha, LPG, or both for cooking?	
2. How many canisters do you purchase a year?	
3. How much did the LPG canister cost you?	
4. Is the canister subsidized?	
5. How are you acquiring the canisters? (Are they delivered to home or must you pick them up?)	
6. Did you buy or build your chulha?	
7. How much did the chulha cost to build (or buy)?	
8. Do you only use your chulha for cooking or for heating as well?	

9. How many hours do you spend cooking on your chulha?	
10. What do you do to heat your home in the winter?	
11. What fuel are you burning in your chulha? Wood? Leaves? Trash? Cow Dung?	
12. Would you be interested in a chulha that could produce hot water while you cooked?	
13. How much would you be willing to spend on a new chulha?	
14. If you could make monthly payments on a new chulha would you be interested in buying?	
15. Would you be interested in testing a new chulha, free of charge, provided by IIT Mandi?	
16. How far away from the nearest town are you?	
17. May we enter your home and look at your chulha?	
18. Do you think you will be using chulhas 5-10 years from now?	

Appendix B: Questions for Feedback Interviews

Questions	Answers Translated from Hindi
1. How many times did you cook on the chulha?	
2. For how long did you use the chulha per use?	
3. Did you cook a meal on it?	
4. How long did it take for you to cook a meal?	
5. Did you use more or less wood to cook the meal?	
6. What did you like about the prototype chulha?	
7. What did you dislike about the prototype chulha?	
8. What modifications would you make to the prototype chulha?	
9. What did you have difficulties with while using the chulha?	
10. Do you have any questions about how the chulha works?	
11. Would you buy this prototype chulha, for how much?	
12. Would you prefer if the chulha was made out of clay or steel?	

Appendix C: Complete Test Results for Prototypes 1-3

Table 4. Complete Prototype 1 Results

Test	Start	End	Wood (g)	Time (s)	kJ/s	kJ	L of Water	Specific Heat of Water	kJ/kg
1	20	95.2	758	1840	0.171	314.8	1	4.186	415.3
3	22.1	95.9	588	1800	0.172	308.9	1	4.186	525.4
3	18.5	93.7	724	1951	0.161	314.8	1	4.186	434.8
AVG	20.2	94.93	690	1863.6	0.168	312.8	1	4.186	458.5

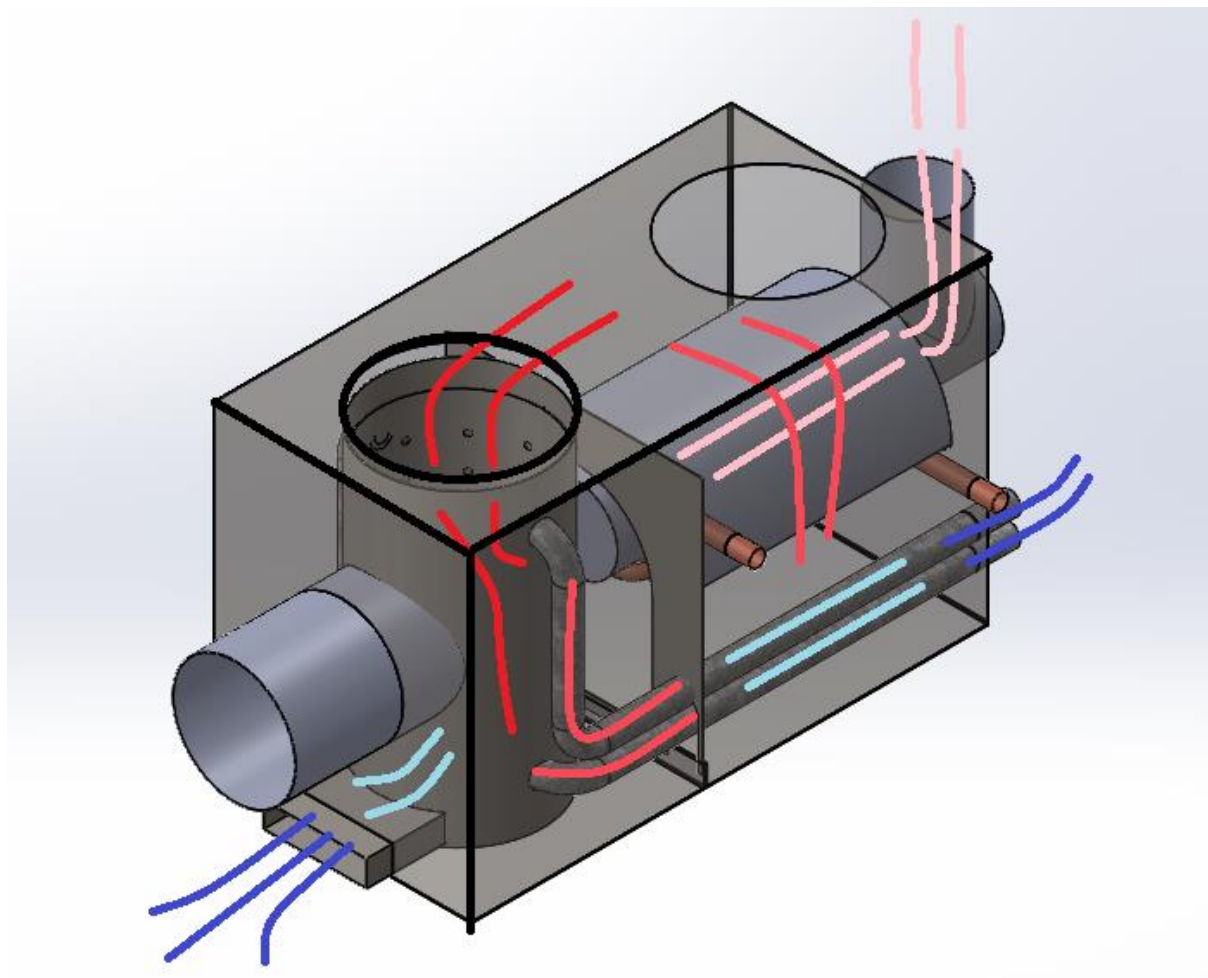
Table 5. Complete Prototype 2 Results

Test	Temp Start (°C)	Temp End (°C)	Wood (g)	Time (s)	kJ/s	kJ	L of Water	Specific Heat of Water	kJ/kg
1	25.6	96	442	908	0.324	294.7	1	4.186	666.7
2	21.1	95.8	536	881	0.355	312.7	1	4.186	583.4
3	19.4	96	496	884	0.363	320.6	1	4.186	646.5
AVG	22.03	96.93	491.3	891	0.347	309.3	1	4.186	632.2

Table 6. Complete Prototype 3 Results

Test	Temp Start (°C)	Temp End (°C)	Wood (g)	Time (s)	kJ/s	kJ	L of Water	Specific Heat of Water	kJ/kg
1	17.8	96	324	646	0.508	327.3	1	4.186	1010
2	18.1	96	258	600	0.543	326.1	1	4.186	1264
3	18.9	96	228	602	0.536	322.7	1	4.186	1416
AVG	18.3	96	270	616	0.529	325.4	1	4.186	1230

Appendix D: Visual Representation of Syphon in Prototype 3



Appendix D is included to visually portray the air flow and syphon within the design of the chulha. Air flows from the dark inlets from underneath the burn chamber and through the four air pipes located at the rear of the chulha into the main burn chamber. Air that flows from the rear is heated as it flows towards the burn chamber through convection from the hot exhaust smoke that is flowing through the secondary chamber and out the chimney. As combustion occurs within the chamber hot exhaust smoke flows up and out of the burn chamber. It flows over the barrier wall and around the shroud in the secondary burn chamber. As the exhaust air moves through the burn chamber, heat from the exhaust smoke is transferred to the copper coil located under the shroud and the air pipes supplying air to the burn chamber. The smoke flows into the chimney pipe and then up the chimney until it exits the home.

Appendix E: Additional Photos



Figure 13. Chulha inside a home



Figure 14. Demonstration of how to ignite prototype 2 to Household 1



Figure 15. Demonstration of how to ignite prototype 2 to Household 2



Figure 16. Demonstration of how to ignite prototype 2 to Household 3



Figure 17. Prototype 3 during the build stage

*Additional information can be found on our website at
<https://sites.google.com/site/ind17chullah/>*