Mitigating Noxious Gases Produced by Traditional Cooking Methods

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An Interactive Qualifying Project submitted to Worcester Polytechnic Institute and Indian Institute of Technology - Mandi

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

by
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Report Submitted to:

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Abstract

For generations, rural village residents in Himachal Pradesh have used traditional cook stoves, or “chulhas”, which rely on firewood. Our project aimed to mitigate the gas production caused by this fuel and to alleviate the negative health effects. We designed an improved cook stove prototype with ventilation. Local women tested our prototype and provided feedback on the design, usability, and efficiency. Finally, we made a pamphlet of recommendations for the communities to mitigate the smoke and toxic gases within their homes.

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Authorship

Andrew Baker primarily contributed to the Introduction. He was a secondary author for the Literature Review, Methodology, and Recommendation sections. He participated in baseline assessment and prototype testing interviews. He filmed and created the project video. He created the roof hat prototype. He helped construct the first prototype.

Kimberly Codding primarily contributed to the Introduction, Literature Review, Methodology, and Conclusion sections. She was a secondary author for the Recommendation section. She was the primary editor for the Introduction and Methodology section, and she was the secondary editor for the Literature Review section. She formatted the Final Booklet. She created the cover page for the Final Report. She created the Construction Pamphlet. She participated in interviews for both the baseline assessment and prototype test. She was a primary builder for the test prototype and contributed to the construction of the first prototype. She helped create a cardboard model of the test prototype.

Vipul Gupta primarily conducted baseline assessment interviews and secondarily conducted prototype-testing interviews. He translated some interviews. He contributed to the building of the first prototype. He constructed the roof hat prototype. He created a cardboard model of our prototype.

Vivek Sharma primarily researched possible prototype designs. He primarily conducted interviews for both baseline assessments and prototype testing. He was a primary translator for all project work. He was the primary point person who interacted with local security guards and villagers. He was the primary contributor to the poster. He helped construct the first and test prototypes. He distributed the construction pamphlets to local villagers. He contributed to the data analysis.

Shiva Verma participated in some baseline assessment interviews. He constructed the roof hat prototype. He created a cardboard model of our prototype.

Edan Mandy Zhang primarily contributed to the Introduction, Literature Review, Results and Discussion, Recommendations, Conclusion, and Supplemental Materials sections. She was the primary editor for the Literature Review, Results and Discussion, Recommendations, and Conclusions section. She primarily edited and formatted the Final Report. She participated in interviews for both the baseline assessment and prototype testing. She was a primary builder for the test prototype and contributed to the creation of the first prototype. She was the primary data analyzer. She was a secondary contributor to the poster.

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Cooking and Heating Methods in Northern India

In much of northern India, rural populations continue to use traditional fuel sources, primarily firewood. Though residents rely on this effective and easily accessible fuel, it releases toxic gases, such as carbon monoxide, which contribute to roughly 500,000 deaths per year in India alone (Lakshmi, Virdi, Thakur, et al., 2012). Research has found that exposure to these gases is also indirectly accountable for a range of diseases such as chronic bronchitis, pneumonia, and other acute respiratory and eye infections (Sood, 2012). In these studies, women and children are identified as the most at risk due long-term exposure (Parikh, 2011). The levels of noxious gas have sparked a variety of proposed solutions including alternative power sources, stove tops, and heating methods. Despite substantial promise of the innovations, the targeted populations maintain their preference and reliance on traditional methods, thus continuing the exposure (Jeuland, Bhojvaid, Lewis, et al., 2015).

The District of Mandi, India, hosts a large number of rural villages whose residents use the traditional mud and brick cook stoves known as "chulhas" (Jeuland, Bhojvaid, Lewis, et al., 2015). Over the course of seven weeks in this region, we explored options for basic ventilation that could be an effective yet simple amendment to existing cook stoves. The goal was to manage the noxious gases produced through traditional cooking methods and to mitigate the effects on household residents. To meet this goal, we outlined the following objectives:

1. Understand the risks and limitations with current cooking and ventilation practices.
2. Design and build improved cook stove and ventilation prototypes.
3. Gather test data and feedback to develop recommendations for the communities.

These objectives established a deeper understanding of regional preferences in order to appropriately and effectively reduce noxious gases in parallel with raising awareness for safer practices in the communities.

Traditional Cooking and Ventilation Practices and their Impacts on Residential Health

Before performing our on-site fieldwork, we completed background research to identify the current methods of cooking and ventilation in the region, as well as to assess the related issues and any possible existing alternatives.

Community Resources

In order to better understand the scope of the project, it is important to recognize that stakeholders using traditional stoves are situated in small and often remote villages. While parts of the Mandi District are urban, the region has around 400 villages, sometimes consisting of just forty-three homes (see Figure 1). (Census of India, 2001).

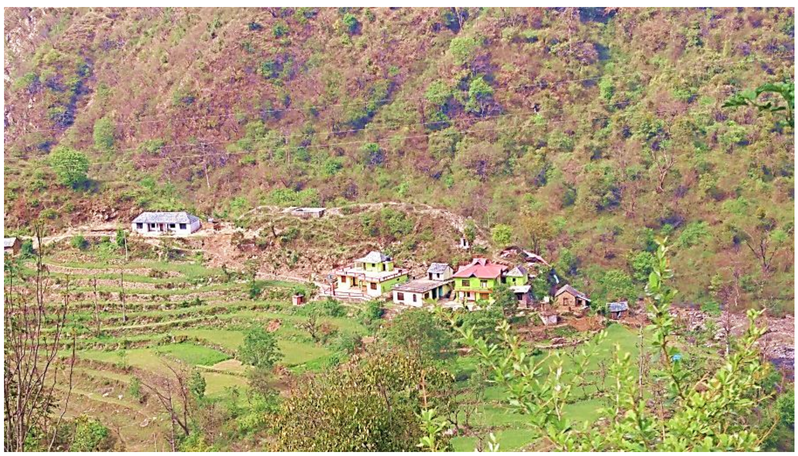

Figure 1. Village in Mandi District (Codding, 2016)

Traditional building techniques in these communities rely on locally sourced materials including wood, slate, and cement. Typical structures feature wood framing, with cement walls, a slate roof, and a cement floor. The cooking areas are sometimes detached from the home but are constructed with similar material with the exception of mud-coated walls.

These structures, however, present certain limitations. There is no central heat in traditional Himachali buildings, and conventional electric appliances are rare. According to the Indian National Census of 2011, 58% of households in the state of Himachal Pradesh rely on firewood as fuel for heating and cooking (The Registrar General & Census Commissioner, 2011). Most households gather wood on a daily basis to fuel their chulhas (NIC Himachal Pradesh, 2015). However, as noted in numerous studies, "cooking with solid fuels (biomass such as wood, crop resides, dung, charcoal, and coal) over open fires or in simple stoves exposes household members to daily pollutant concentrations that lie between those of second-hand smoke and active smoking" (Pope et al. 2009, 2011; Smith and Peel 2010). The open stove surface does not include a chimney and kitchen windows are often placed too far away from the cooking area to act as natural ventilators.

Health Risks and Guidelines

In this scenario where ventilation is lacking, the largest and most directly affected household members are women, as they are the ones most exposed to the noxious gases and smoke produced through traditional cooking practices. Across India, 34,000 women die annually from chronic obstructive pulmonary disease (COPD) as a result of long-term exposure to solid biomass fuel gases within their homes (Balakrishnan, Ramaswamy, Sambadam, et al, 2011). These gases contaminate the home and cause adverse health effects when released into a confined area with poor ventilation. Common conditions range from acute respiratory infections to eye infections to chronic health issues, such as cataracts, cardiovascular disease, chronic lung disease, pneumonia, tuberculosis, and problems with pregnancy (Epstein, Bates, Arora, et al, 2013; Parikh, 2011).

The science behind these practices is well known. Any combustion reaction fueled by solid biomass fuels has the potential to release harmful chemicals or particles into the air. The primary noxious gases caused by biomass fuels are carbon monoxide and dioxide, nitrogen oxide, sulfur dioxide, and hydrocarbons (Lakshmi, Virdi, Thakur, et al, 2012). While carbon monoxide can be directly measured as a gas, the fine particles simultaneously produced by combustion are measured as levels of "particle pollution", or PM. Specifically, inhalable particulate matter caused by fires are classified as $PM_{2.5}$, meaning they are 2.5 micrometers or less in diameter. Theses are the ones that contribute to respiratory problems and other hazardous health issues (see Figure 2) (EPA, 2015).

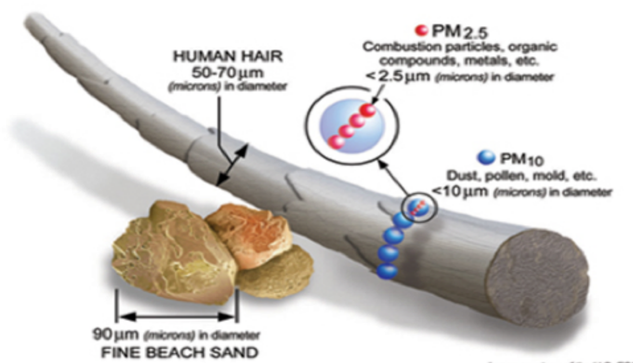

Figure 2: $PM_{2.5}$: Hazardous particle pollution (EPA, 2015)

The United States Occupational Safety and Health Administration (OSHA), the United States Environmental Protection Agency (EPA), and the World Health Organization (WHO) have set standards for the most prominent particles and noxious gases produced through the combustion of solid biomass fuels, but they assume an eight-hour workday. In the typical poorly ventilated kitchen environment found within many village homes, these gases accumulate, exposing the residents for a majority of their time in the day. The policy guidelines fail to account for the inconsistency within a residential setting, including differing levels of gas production throughout the day, temperature, house settings, and the number of people exposed at one time. Various researchers have tried to establish a new set of international guidelines that take into account the difference in gas exposure levels in residential settings compared to strictly industrial settings (Clark, 2013; Jetter, 2012). However, the fact remains that the levels of noxious gases produced in the homes are dangerously high, with a large number of lasting adverse health effects.

Proposed Alternatives: Successes & Failures

In early 2015, in rural western Indian villages, alternative cook stoves (ACS) specifically designed with the aim to reduce noxious gas emissions were tested in homes and compared to the emissions from a tested traditional clay stove. The household air pollution (HAP) levels of each were monitored and compared to each other as well as to the WHO standards. The tested ACSs showed a reduction in noxious gas levels, but the traditional cook stoves produced an average $PM_{2.5}$ measurement roughly 36-fold higher than the WHO health recommendation of 25 ug/m^3 (Muralidharan, Sussan, Limaye, et al, 2015). The importance of this case study is twofold. First, the elevated levels of air pollution reinforce the need for improvement of current cooking and heating methods. Second, it conveys the need for a better standard of residential exposure levels. In the case of proposing alternative cooking and heating methods or ventilation system solutions, a baseline measurement of CO and/or $PM_{2.5}$ is essential. The significance of the value is not in its precision compared to the world standards, but in its use as a comparison when determining the success of an improvement method.

In 2012, Gunther Bensch and Jorg Peters presented a case study in which they recorded the overall response to the introduction of an improved cook stove (ICS) in a controlled trial in Senegal, Africa. When observing the impact of the implemented ICS, the authors examined the popularity of various types of cooking methods with both the experimental "treatment" group and the control group (see Table 1).

Table 1: Usage Percentage of Various Cooking Methods (Bensch & Peters, 2012)

	ICS Owners (Treatment)	ICS Non-owners (Control)
3 stones or Os	18.6 %	70.8 %
Traditional wood stove	7.1 %	23.6 %
ICS	70.9 %	-
LPG stove	3.4 %	5.6 %

Unlike other ICSs, Bensch and Peters' ICS continued to use traditional biomass fuel, but it was much more efficient in its fuel consumption. By continuing the use of traditional fuel, Bensch and Peters were able to extend the technology to a much wider base of recipients. In addition, the ICS consumed less biomass per meal cooked, and thus resulted in shorter meal preparation times. Bensch and Peters' ICS acted more as a "bridging technology", rather than a complete shift in the current culturally accepted cooking methods (Bensch &

Peters, 2012). This approach can be paralleled to the villages in Himachal Pradesh, India, where this “bridging technology” may be more widely accepted.

Meanwhile, a recent case study in Kwale, Kenya focused on the effectiveness of different ventilation strategies on the reduction of biomass-related particle exposure in homes. Through some adjustments to a real-life kitchen replica, four scenarios were tested. The results presented that the use of any ventilation type decreased the concentration levels within the kitchens, with the chimney being most effective. The absence of a ventilation system did not show signs of lowered concentration levels. The study indicated that simple ventilation systems, especially chimneys, were an effective method in mitigating the gas level exposure in indoor areas.

Although a myriad of case studies have been done to improve traditional cooking methods, many models have only proposed modern alternatives like liquid petroleum gas (LPG) stoves, solar cookers, rocket stoves, and so forth. While these are suitable devices, they have not been widely adopted. Some villages even have LPG stoves, but nevertheless rely primarily on their traditional stove for cooking purposes. In sum, our review of literature revealed some positive case study recommendations, as well as several modern cooking advancements that have failed to take hold. With these precedents, our team worked to find a balance between current cooking practices and advanced cooking technology.

Methodology: Fieldwork and Prototype Development

The goal of our project was to manage the noxious gases produced through traditional cooking methods. Figure 3, below, summarizes our objectives.

1 Understanding Current Practices

- Conduct baseline assessments to understand the risks and limitations of current cooking and ventilation practices.

2 Prototype Design and Creation

- Design and build improved cook stove and ventilation prototypes.

3 Feedback Analysis and Recommendation Development

- Gather prototype test data and feedback to develop recommendations for the communities.

Figure 3: Objectives for fieldwork and prototype development

3.1: Understand the risks and limitations with current cooking and ventilation practices

Our team identified participants from surrounding communities that were willing to partner with us so that we may understand local cooking and heating practices. We conducted a baseline assessment of the village communities through interviews with these participants by Hindi-speaking teammates. Responses were translated into English immediately following the interview. Additional documentation included photographing and filming the kitchen setup for the physical spaces and equipment used for cooking and heating. In addition, we made qualitative observations of the kitchen, which included noting if there was evidence of a smoke smell and blackened walls.

3.2: Design and build improved cook stove and ventilation prototypes

We designed a cook stove using traditional materials that included a simple ventilation system. We constructed an initial prototype inside an enclosed simulated kitchen structure on campus. Local materials were used to build the chulha in the traditional manner, and it included chopped pine needles, bricks, soil, fresh cow dung, iron rods, and metal sheets. We learned the proper mixture of these materials as well as how to use it most effectively in building by a campus worker familiar with the art of building traditional stoves. As per convention, the chulha included three holes for cooking pots and an open area in the front for feeding firewood and cooking chapatis. We added a vent to our prototype that was not be found in a common traditional cook stove for the purpose of connecting a pipe to act as a ventilation system. This first prototype required several days for drying. Meanwhile, we created a second, smaller-scale prototype with a slightly varied and improved design. While still made out of traditional conventional materials, this prototype added several innovations in order to further mitigate the smoke production and increase stove efficiency: a brick baseplate, an enclosed box shape, one side intake vent pipe for airflow, and one chimney pipe to channel smoke out of the house.

3.3: Gather test data and feedback to develop recommendations for the communities

After testing our improved campus prototype for its ability to hold a fire and boil water in a wok, we invited several primary household cookers to use our prototype. We asked them in semi-structured interviews to communicate feedback regarding its usability and efficiency. The field test generated results on both the functionality of the designed prototype and participant interest in using a non-traditional method. Empirical data included factors such as firewood efficiency, smoke containment, construction costs, and design limitations. User feedback was essential for determining perception of quality and usability. These criteria were used to refine the design and build recommendations for our stakeholder partners. The advantages, materials, visual construction instructions, and maintenance of the improved cook stove with ventilation were included in a final recommendation pamphlet. It was printed in both Hindi and English.

Results and Discussion

The results of our baseline assessment interviews and fieldwork confirmed our suspicions about traditional practices as they may promote undue exposure to noxious gases. The data are presented here by objective.

Objective 1: Understand the risks and limitations with current cooking and ventilation practices.

We visited six villages and engaged with a total of twenty-seven households. In these interviews, we found that 98% of households had either women or children cooking, and 2% of households had men cooking.

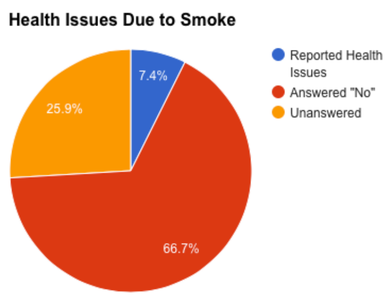

Figure 4. Responses from question asking about health issues due to smoke

Figure 4 indicates the majority of respondents answered "no" when asked to report if there were any health issues that they believe were a direct result of long-term smoke exposure. However, 22% of respondents that stated "no" to this question went on to describe health issues they are experiencing in a question asking about issues they are having with their current cooking practice. In an effort to better understand these health reported issues, we began focusing on the cooking methods directly.

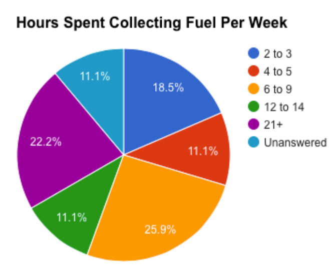

Figure 5. Reported hours spent gathering firewood per week

When cooking, the most common fuel used is wood with all households using it as their primary fuel source due to its accessibility. The upkeep of the wood stock within the homes was reported to be a prominent use of their time (see Figure 5). The reason for this wide range of data was not explained. Due to the amount of time these households spend collecting firewood, village residents have expressed interest in a chulha that burns wood more efficiently. Currently, meals are taking long periods of time to prepare due to the inefficiency of the stove (see Figure 6). Along with the long hours spent cooking, women are being potentially exposed to these noxious gases for additional hours as they are boiling water, heating their homes, and maintaining their cooking area. Most of their additional hours spent in the kitchen are dedicated to maintenance as the excessive smoke production causes blackening to the cooking area and utensils (see Figure 7).

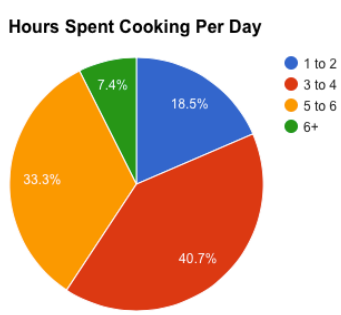

Figure 6. Total time spent cooking per day

Beyond the actual use of the current stove, we assessed the awareness within the communities of the need for an ICS or ventilation system. Twenty-six homes presented criticisms of their current methods. Many residents noted that the production of smoke was at an elevated level and some stated that their use of current traditional methods was causing health problems. Yet, the majority of the homes surveyed were unaware of proper ventilation techniques. These homes were using only small windows, which were blocked by various items and located far from their stoves, open doors for airflow, or simply tiny cracks in their roof as their main form of ventilation. However unaware of methods to alleviate the issue, all homes conveyed what improvements they wanted made to their current cooking method, which included a chulha that would produce less smoke while cooking and consume less wood.

Figure 7. Blackened cooking area and utensils in Runjha Village (Sharma, 2016)

Objective 2: Design and build improved cook stove and ventilation prototypes.

Our team formulated our chulha design by adapting it to be more efficient based on heat transfer theory. The first prototype had three cooking chambers, one central elbow pipe, and an open front for firewood (see Figure 8). It was built over the course of seven hours, including the collection of materials. This prototype was created in a simulated room with no proper windows and one door. The second prototype had one cooking chamber, one pipe situated in the top back corner and another on the side of the stove, and one closeable open front for firewood. It also took about seven hours to build, and around three hours were spent collecting materials. This second prototype was constructed in a shed with a metal-ridged roof.

Figure 8. Initial prototype (Baker, 2016)

Our second prototype included several modifications from the traditional cook stove and a few imperative adjustments from the first prototype. The traditional stovetop has an open area for firewood as well as an open stovetop. There is no pipe or chimney, thus the smoke disperses everywhere and is not channeled in a certain direction. Modifications from the traditional cook stove include a box-shaped cook stove, two pipes (top and side), a baseplate, a closed stovetop, and a closeable front opening. The few adjustments made from the first prototype are the addition of a second pipe and the placement of the top pipe (see Figure 9).

Figure 9. Comparison of traditional stove in Nehri Village to second prototype. Arrows note the changes made, which include a box-shaped stove, a closeable front opening, a top and side pipe, a closed stovetop, and a baseplate. (Zhang, 2016)

Objective 3: Gather test data and feedback to develop recommendations for the communities.

During the first prototype testing, thin steel sheets covered two of the three chambers, and one chamber was covered with a small pot filled with water. Fire initially came out of the elbow pipe, but after a few minutes, smoke began flowing out instead. The water in the pot took about ten minutes to boil.

The second prototype was tested twice with a wok filled with water. The lip of the cooking chamber immediately blackened once smoke started producing. Smoke traveled out of the top back pipe as well as the front opening. No smoke travelled out of the side pipe. The side pipe stayed at normal temperature. Once the fire had gone out, smoke dissipated out of all open areas. During the second round of testing, our team blocked airflow to the side pipe. When the side pipe was covered, we observed that more smoke came out of the front opening than when it was left open (see Figure 10). We tested closing all openings except for the top back pipe when the fire had gone out. As a result, we observed thick smoke quickly escaping from the top pipe (see Figure 11).

Figure 10. Smoke leaving from front opening during testing; side pipe covered (Zhang, 2016)

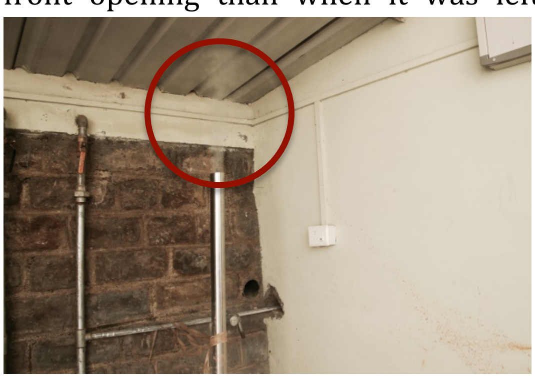

Figure 11. Smoke escaping from top back pipe during testing (Zhang, 2016)

Following our initial testing, we worked with a total of eight local village women who tested our prototype and provided observational feedback. Their initial thoughts were concentrated on their excitement of the traditional construction method. They felt the heat efficiency of our prototype was better than their traditional stove, as additional firewood was not needed. They commented on all the new structural changes as being added benefits for them. While there were many new aspects these women liked, they were critical of the aesthetics of the stove with emphasis on the front opening needing to be wider.

Figure 12. Smoke leaving top pipe (Zhang, 2016)

With less wood being consumed and smoke being directed up (see Figure 12), they expressed their preference to use our stove over their current cook stove. In particular, they stated that the pipes were the key modification they wanted. Less smoke would create less blackening of the walls. Final remarks included advice on traditional construction.

Along with qualitative feedback, we recorded gas level readings for our prototype and compared them against readings taken in a village home located in Nehri Village (see Table 2).

Table 2. Comparative Gas Level Readings

Carbon Monoxide (ppm)	Traditional Stove		ICS Prototype		
	Top of Stove	Front of Stove	Top of Stove	Front of Stove	Pipe
Start of Fire	122	144	83	76	51
During Cooking	100	104	51	44	>1000
End of Fire	452	116	38	74	>1000
Control Air	58		47		

Gas level readings taken in Nehri were difficult as smoke quickly scattered as soon as it was produced. Women are exposed to a constant average of 173 ppm for the duration of cooking as well as the clean up process when using a traditional stove. However, when testing, they were exposed to an average of 61 ppm during the two processes. Little to no smoke was channeled out of the side pipe and front opening during cooking (see Figure 13). The readings taken from the above back

Figure 13. Stove during cooking (Zhang, 2016)

pipe are not a factor in this average comparison, as the smoke would travel directly out of the house through the roof.

Discussion

The data raised interesting points about the path forward, as well as some questions about appropriate technological design and engineering. Indian village women in the Himachal Pradesh region are reluctant to change their traditional cooking and heating practices. Regardless of all the new modern advancements being introduced, these women have still stuck with their traditional methods for decades. It begs the question, why would another new ICS design motivate them to switch out their traditional stove?

It was important to begin our project by understanding our stakeholders' perspective on traditional methods. From our findings, we see two key topics emerge that village women are passionate about and will, thus, determine the feasibility of our design being adopted within their homes: (1) fuel source and (2) stove construction. Wood is their primary source of fuel as it is easily accessible and available to them at no cost. Any other type of fuel is expensive and would require travelling long distances to obtain. Furthermore, traditional stove construction is a sacred practice that these women have stuck to for generations and have expressed their unwillingness to give up. To be compatible with their expectations, we created an ICS design that would continue those two practices. We simultaneously made several structural changes to increase efficiency and reduce smoke production during cooking. Change is incremental, and so it is important to recognize the hesitancy these women have when new ICS designs are proposed. Our team has found an appreciation for the availability and use of local materials as well as staying cost sensitive. While the stove is a new design, it is still identifiable as a "chulha". Based on our testing feedback, the women enjoyed the continual use of traditional mud and dung and only had criticisms with small cosmetic aspects.

Although traditional practices can continue being respected in a new ICS design, the most important question must be answered to completely determine the success of our ICS being implemented: what incentive do these women have to adopt our ICS? This project was grounded on the notion that a redesigned cook stove is necessary for women's health. While the science in the literature review supports this, our stakeholders have not identified it as a critical issue. Our findings around reported health effects were underreported and vague. Specifically, there was a low percentage of households that expressed having health issues related to long-term exposure. However, in another question focused on problems with their current cooking practice, many of the responses indicated their top issue was health-related. Based on this, we believe we may have either encountered an issue with the language barrier or our participants did not recognize certain symptoms as actual health issues. Our team has only collected self-reported medical data, and thus, answers to this question may not be accurate. These results raise the question of whether or not an improved health benefit can be seen as an incentive to them. However, it appears from the lack of reaction to prompts about health that this is not a good enough reason to change their current cooking method.

Moving forward to find a key incentive, we compared toxic gas level readings between the traditional stove and our ICS. The results show a significant change with about a 50%

difference from the traditional stove readings. Though the gas level exposure has decreased substantially, this data has no bearing on local adoption. We predict this kind of awareness will develop more gradually over time as interestingly enough, we interviewed a doctor during our baseline assessment who expressed concerns about the harmful health effects associated with long-term smoke exposure. He built a rudimentary chimney to try to alleviate this issue, and some of these chimneys have been implemented in homes around the area.

Although his word-of-mouth approach to spread awareness about the harmful effects is commendable, it may take years for these women to actually value this information. For now, the two incentives that seem to resonate with the women are better fuel efficiency and a lesser amount of smoke produced during cooking. Women were persistent with their request for a cook stove that could burn less firewood and produce less smoke. The results from our ICS show the potential to meet these two attributes.

Our overall field test results were overwhelming positive. All of the women who tested our prototype shared their enthusiasm to use our ICS and even voiced they would be willing to pay for this ICS to be implemented in their homes. They were extremely impressed with our design as it was able to incorporate a solution to their two top issues while still maintaining traditional function and form.

Project Outcomes

Prototype Recommendations

Due to time restraints, we recommend testing our prototype in a village home for a period of several weeks. This will provide a proof of concept prototype that will gauge if it can be adopted over time. The prototype would need to be built to exact local specifications with a chimney fitted to the roof.

Other recommendations include adding an eighth-portion of cement to the cow dung and dirt mixture to prevent cracks from forming during the drying period. Cement will also reduce the maintenance frequency as it will not crack or degrade as quickly as the dirt and cow dung mixture will. Furthermore, we recommend adding a damper to the side pipe to more easily open and close the side pipe when needed. The side pipe must remain horizontal without a bend or an "L" shape in order to properly function as a chimney damper. A bend would distract the pulling of air in and thus damage the back pipe's performance.

Figure 14: Chimney "cap" (Codding, 2016)

When constructing the chimney, we recommend using a flat metal sheet as the means of attachment to the roof. In the case of the typical household slate roofing, one slate would be replaced with this metal sheet. To secure the pipe, a hole should be cut in the sheet that is to the exact dimensions of the pipe. It is important to run the pipe through the hole and weld it in place so that it fits tightly in the metal sheet. Drill holes through the pipe above the metal sheet to allow for smoke to escape and cover the top of the pipe by welding an additional piece of metal sheet to it and adding a metal "cap" (see Figure 14). This top cover prevents rain from entering the chimney and protects the stove from weather. The pipe should be installed in an area that is away from flammable items as the chimney becomes extremely hot during cooking.

When cooking, our team suggests opening the side pipe to promote airflow in and thus reduce the amount of smoke leaving from the front opening. After cooking, we recommend closing the front opening with a mud-coated thin steel sheet and covering the side pipe. By doing this, the smoke will be directed up through the top pipe and out of the house.

Our design calls for yearly maintenance in order to prevent potential house fires. The chimney pipe should be removed from both the side and back top once a year. It is recommended that both pipes be properly swept out with a steel brush to clear out any built-up soot. After, the pipes can be put back into the stove structure and mud can be reapplied.

Construction Pamphlet

In order for future residents of the Mandi region to be able to build their own cook stove with the design of our ICS prototype, we have created an instructional pamphlet. This pamphlet contains a list of the necessary materials, step-by-step instructions with ample visual aids, maintenance information, and a gas exposure health fact. The pamphlet, which can be found in Supplementary Materials, was written in both Hindi and English.

Conclusion

Ultimately, while our findings and recommendations appear to take a step back from newly proposed cook stove innovations, we learned that modern stove advancements will not be adopted without incremental steps that can bridge the two extremes. Thus, our team stressed the importance of continuing traditional construction methods and fuel use for our ICS design. Incorporating these two key aspects was significant for the gradual progression of improving traditional cooking practices. These themes were the primary passions of the village residents, as found by our initial interviews, and they remained as two of the most praised aspects of our ICS prototype during stakeholder testing. While the goals of this ICS is to reduce smoke production and increase heat efficiency for the immediate benefits of less maintenance, fuel, and cook times, these are the perfect ways to decrease exposure to the produced toxic gases, and therefore improve overall health of the exposed families in the Himachal Pradesh region.

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Supplemental Materials

A. Literature Review

Stakeholders

Additional stakeholders involved in this project included several subcategories within the residents of the Mandi District. Particularly, several staff members of IIT-Mandi campus as they were the initial point of contact between our team and the surrounding village communities. Another critical group is the faculty of the IIT-Mandi Mechanical Engineering Department. They helped supply materials for our technical solution.

Supplemental Case Studies

A case study performed on a population in Ahmedabad, India tested for risk factors associated with perinatal mortality. The study took data from participants that experienced stillbirths, early neonatal deaths, and a number of controls. The data collected for early neonatal deaths only represent the mortality rate of deaths that ensued within the first few days of life. Interviews targeted maternal socio-demographic characteristics, use of health care during pregnancy, maternal behaviors, and reproductive history. In addition to conducting interviews, hospital records were also collected for type of delivery, intra-partum complications, medical conditions upon time of admission into hospital, and infantile conditions. The perinatal mortality rate was 79 deaths for every 1000 births. Results showed that maternal age ranging from 30-34, prior infant death, prolonged labor, and exposure to cooking smoke often led to increased risk for stillbirth. The study concluded that the exposure to biomass fuel smoke causes an increase in the level of carboxyhemoglobin in the blood of the mothers, which can have adverse effects on the fetus (Mavalankar, Trivedi, & Gray, 1991). The increased risk of stillbirths has been linked to biomass smoke for years, yet it continues to be an issue as traditional cooking and heating methods are still in use.

A recent study from 2005, conducted on the Nepal-India border, studied indoor cooking smoke exposure and the risk of acquiring cataracts. It observed women aged 35 to 75 years of age with confirmed diagnosis of cataracts, and used control patients, who were matched for age and were at the same hospital. The study considered previous research on the development of cataracts, specifically investigation on age-related cataracts cataract risk factors and the connection between biomass fuel use and blindness based on data provided by the Indian National Family Health Survey (Mohan, Sperduto, Angra, et al, 1989; Zodpey and Ughade, 1998; INFHS, 1992-1993). The study further examined the association of indoor smoke exposure and the formation of cataracts through interviews that obtained data on urban or rural residence, cooking stove and fuel use, house and kitchen type, ventilation, socioeconomic variables, and other factors. The results of this case study confirms past research findings that exposure to indoor smoke produced from solid fuel cooking use does increase the risk of developing cataracts (Pokhrel, Smith, Khalakdina, et al, 2005).

In northern India, a case study led by Jeuland analyzed the specific attributes of an ICS that generated positive feedback. The data suggests that traditional cooking methods are preferred over alternative option. When asked to explain why, respondents indicated that the top reasons for using the traditional methods were that the cost of the traditional stove was less and that the traditional stove could cook all types of food. Conversely, the respondents also indicated that their top complaints were the amount of smoke produced, the heat given off, and the cleaning and fuel requirements. The parallels between the desired aspects of an ICS in this case study and the attributes of the successful Senegal ICS implementation offer insights into implementing an ICS in Himachal Pradesh.

B. Methodology

Interview Guide 1: Baseline Assessment Interview Questions

1. How many people live in your home?
2. Who normally does the cooking
3. What fuel source do you use to cook and heat your home with?
4. How many times do you cook per day? How long do you cook for (hours)?
5. Are the stoves being used for anything other than cooking food?
6. What type of cooking and heating practices do you use for the different seasons?
7. How much time do you spend gathering fuel?
8. How accessible is the fuel (location/cost)?
9. How much wood do you use per meal?
10. Do you find any issues with your current method of cooking and heating?
11. Are there any specific maintenance required to keep the stove functioning properly?
12. Has there been any alternative solution that has been proposed to you?
13. Why do you continue to use the traditional methods opposed to alternatives?
14. Have people used anything to get rid of the smoke or lessen it (i.e. ventilation system)?
15. If an alternative solution that would relieve some of these issues was presented, would you use it?
16. What would you want to see in an alternative solution? What is an important aspect to the alternative solution?
17. Would you be willing to pay for an alternative cooking solution? If so, how much?
18. Have you experienced any health issues, which you believe have been caused by cooking smoke? If so, what are your symptoms and how frequent are they?

Interview Guide 2: Prototype Testing Interview Questions

1. What are your initial thoughts/reactions to the prototype?
2. What did you like about the cook stove?
3. What did you not like about the cook stove?
4. How is the smoke production?
5. How is the amount of wood compared to your cook stove at home?

6. What is structurally different about our stove? Is there any differences in the structure you would change?
7. Would you use this stove over your stove at home?
8. How much would you pay for this stove?
9. Any other feedback?

Participant codes were given to each village household surveyed based on letter, indicated which village, and number, indicating which household number.

C. Results

Based on the data collected during our baseline assessment interviews, 19% of residents reported using alternative biomass fuels as a secondary fuel source. This included cow dung, leaves, and paper. Furthermore, 63% of households cooked two meals a day. While all households are at risk for being potentially exposed to these harmful gases, the remaining 37% are at a higher risk as they spend more time in their kitchen cooking three meals a day. The can be exposed for up to nine hours a day.

These households were not aware or informed of any alternative cooking solutions aside from LPG stoves, which they noted were too expensive to use for daily cooking needs. However, residents were interested in new cooking approaches as all but one home said they would be willing to test an ICS in their home. Additionally, they indicated they would be willing to pay for an ICS as long as they could test it out first. The results after our field test indicated households would be willing to pay between five hundred and one thousand rupees for our ICS prototype.

Table 3. Supplemental Results Collected from Baseline Assessment Interviews

<table>
<tr><th rowspan="5">Total</th><th rowspan="4">No. of Villages Assessed</th><th rowspan="4">No. Village Homes Assessed</th><th colspan="3">Kitchen Room Separate and Attached to House</th><th colspan="4">Kitchen Room Detached from House</th></tr>
<tr><td colspan="3">11</td><td colspan="4">16</td></tr>
<tr><th colspan="7">Frequency of Stove Maintenance</th></tr>
<tr><th>Every day</th><th>Every few days</th><th>Every week</th><th>Every month</th><th>Every few of month</th><th>Every year</th><th>No Maintenance Required</th></tr>
<tr><td>6</td><td>27</td><td>1</td><td>4</td><td>11</td><td>8</td><td>1</td><td>1</td><td>2</td></tr>
</table>

D. Construction Pamphlet

English version:

Hindi version:

E. Photos and Film

Figure 15. Collecting dirt for prototype (Baker, 2016)

Figure 16. Learning from village expert (Baker, 2016)


Figure 17. Cow dung, dirt, pine needles, and water mixture (Baker, 2016)


Figure 18. Creating the first prototype (Baker, 2016)

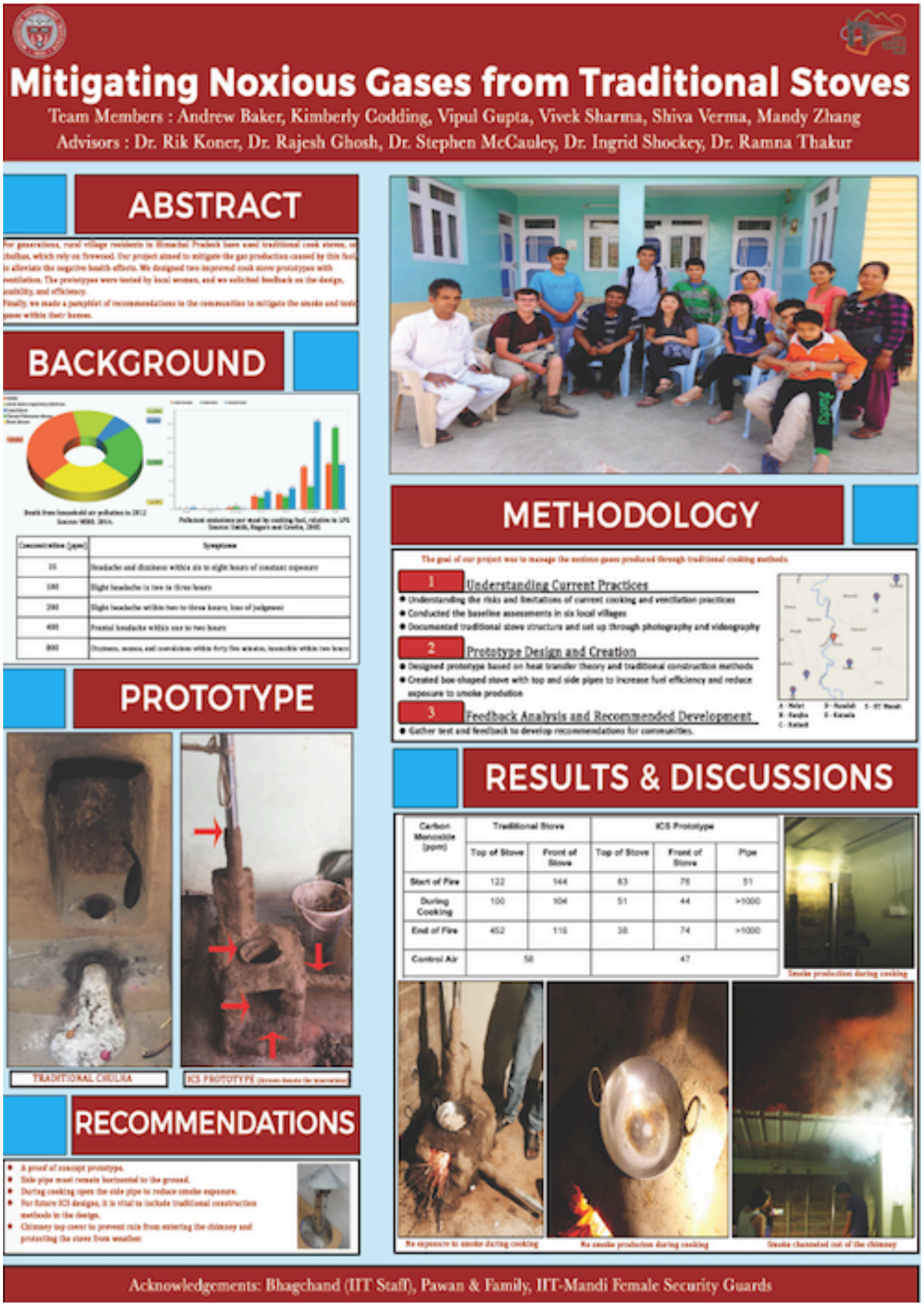
Figure 19. Local village woman testing our prototype (Zhang, 2016)

Figure 20. Conducting a prototype testing interview (Zhang, 2016)

Figure 21. Our prototype after testing (Zhang, 2016)

Our project film can be viewed here: https://youtu.be/pHSo-BRslkU

F. Poster


Mitigating Noxious Gases from Traditional Stoves
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Advisors : Dr. Rik Koner, Dr. Rajesh Ghosh, Dr. Stephen McCauley, Dr. Ingrid Shockey, Dr. Ramna Thakur
ABSTRACT
For generations, rural village residents in Himachal Pradesh have used traditional cook stoves, or chulhas, which rely on firewood. Our project aimed to mitigate the gas production caused by this fuel to alleviate the negative health effects. We designed two improved cook stove prototypes with ventilation. The prototypes were tested by local women, and we solicited feedback on the design, usability, and efficiency.
Finally, we made a pamphlet of recommendations to the communities to mitigate the smoke and toxic gases within their homes.
BACKGROUND
PROTOTYPE
TRADITIONAL CHULHA
ICS PROTOTYPE
RECOMMENDATIONS
• A proof of concept prototype.
• Side pipe must remain horizontal to the ground.
• During cooking open the side pipe to reduce smoke exposure.
• For future ICS designs, it is vital to include traditional construction methods in the design.
• Chimney top cover to prevent rain from entering the chimney and protecting the stove from weather.
METHODOLOGY
The goal of our project was to manage the noxious gases produced through traditional cooking methods.
1 Understanding Current Practices
• Understanding the risks and limitations of current cooking and ventilation practices
• Conducted the baseline assessments in six local villages
• Documented traditional stove structure and set up through photography and videography
2 Prototype Design and Creation
• Designed prototype based on heat transfer theory and traditional construction methods
• Created box-shaped stove with top and side pipes to increase fuel efficiency and reduce exposure to smoke prodution
3 Feedback Analysis and Recommended Development
• Gather test and feedback to develop recommendations for communities.
RESULTS & DISCUSSIONS
Carbon Monoxide (ppm)	Traditional Stove		ICS Prototype		
	Top of Stove	Front of Stove	Top of Stove	Front of Stove	Pipe
Start of Fire	122	144	83	78	51
During Cooking	100	104	51	44	>1000
End of Fire	452	116	38	74	>1000
Control Air	58		47		
Smoke production during cooking
No exposure to smoke during cooking
No smoke production during cooking
Smoke channeled out of the chimney
Acknowledgements: Bhagchand (IIT Staff), Pawan & Family, IIT-Mandi Female Security Guards