



ENGINEERING SOLUTIONS: REDUCING SMOKE INHALATION IN INDIA'S KITCHENS

LUTHERAN WORLD RELIEF (LWR) has begun partnering with universities across the United States to innovate sustainable solutions to poverty. These valuable partnerships bridge the very real-life needs of vulnerable communities in developing countries with academic research and the expertise of international development professionals.

From September 2014 to October 2015, LWR partnered with undergraduate senior engineering students from the University of Colorado – Colorado Springs (UCCS) to design improved ventilation for indoor, wood-burning stoves for communities in Bihar, one of India's poorest states. A team of UCCS engineering students involved in this project developed a smoke exhaust system for stoves that had no ventilation using locally-procured and very low-cost materials. The goal

of this project was to reduce the amount of smoke families — especially women — inhale while cooking. After the exhaust system design was vetted by engineering faculty at UCCS, two students from the team, Ryan Bell and Hannah Rather, installed it on stoves in six homes across three targeted villages in Bihar. The students instructed LWR's local partners, Professional Assistance for Development Action (PRADAN) and Action for Social Advancement (ASA), on the exhaust system's construction. These partners continue to install the exhaust system in homes by request. As of December 2015, 131 systems have been installed, and there are plans to offer the stoves in other villages.

What follows is a full report on the project, written by UCCS students, Ryan Bell and Hannah Rather.



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PROJECT SUMMARY

Smoke inhalation from poorly ventilated cooking areas is a serious problem in developing communities around the world. Many health problems, often resulting in death, are attributed to breathing in these gases. This project, which focused on the Indian state of Bihar, aimed to develop a new stove that would reroute noxious cooking smoke to the exterior of the home. The CO-Planeteers, a senior design group at the University of Colorado – Colorado Springs (UCCS) collaborated with Lutheran World Relief (LWR) and its local partners, Professional Assistance for Development Action (PRADAN) and Action for Social Advancement (ASA), to bring this project to fruition.

The project spanned 13 months from the students' project introduction to implementation. During this time, two site visits were performed by CO-Planeteers – one to understand the constraints and one to ensure proper implementation. The second visit resulted in improved ventilation systems for six stoves in three villages. The project culminated in a popular new design that people were excited to put in their homes. To date, ASA has assisted with the implementation of 65 stoves with plans to expand that total to 111. PRADAN originally planned on implementing 60 stoves. However, because the actual design cost was only one-sixth the budgeted amount, it is hoped that that number will expand as well.

This project also provided valuable proof that a successful relationship could be made between engineering senior design groups and LWR. Despite the constraints of time, money, effective cultural and social understanding, and the course load demands on students, a mutually beneficial relationship was created, and a tangible benefit offered to the communities with whom LWR works.

PARTNERSHIP

Most degrees at UCCS require a capstone project during the students' senior year. For engineers, that project typically is in the form of a two-semester class, which requires students to apply all of the knowledge they have obtained during their studies. At UCCS, the senior design director, Dr. Peter Gorder, compiles a list of companies that are interested in having students work on a company project. This could be anything from a complicated transmission redesign, a simulation of trajectory in space, vibration mitigation, or a stove for a nonprofit organization (NPO). Typically, the company or organization will pay a fee for this service as well as cover all material and operational costs. However, this fee can be waived in some instances and was waived by UCCS for the LWR project due to its nonprofit humanitarian mission.

After the projects are selected by the director, they are presented to the class by a representative of that company. After all of the presentations have been presented, students are asked to select their top five choices. The students are then placed into groups based on their selections. After the groups are formed, the students are expected to contact their sponsor company. This typically happens in October, which is two months into the project. From that point on, the students' deadlines are dictated by the company, except for the design specification, which must be presented to the senior design director at the end of the first semester in early December. The second semester is dedicated to creating and testing a functioning design. By April, students are also expected to create all deliverables for the company as well as a paper and poster for the senior design class.

Working with LWR provided a unique experience. While there is always a huge emphasis on specifications to ensure that a product meets all technical requirements, in the case of NPOs, it is much more important to meet all social, traditional and cultural needs. These additional concerns are much more difficult to quantify, and a better understanding of the end user must be obtained.

LWR excels in this area, and the structure of the organization is designed to ensure that understanding remains a focus. LWR's headquarters is in the United States; however, program management is led by a field office with national staff in-country, and that team accompanies a partner organization that implements directly with specific villages. There is an expert at every node within the organization.

An initial site visit proved invaluable for understanding the household needs in Bihar. The group was able to meet the partner organizations and get valuable feedback from them.

This trip was instrumental in developing the relationships and understanding between the four groups involved (UCCS, LWR, partner organizations and the households reached with the exhaust system).

This partnership proved very successful because each group was able to contribute toward a shared objective. UCCS was able to provide a unique selection of projects to the students, who were interested. LWR was able to address a need that was proven to be a constant problem; in every village visited, the women stressed the desire to have a more comfortable and safe cooking area. The partner organizations were able to implement a product that would help to grow the trust of the communities they serve. Each group's contributions ensured the product was acceptable, beneficial and implementable.

PROJECT DEVELOPMENT

From the beginning of this project, it was clear that the true difficulty was in creating the design specification. The specification is a report that has a comprehensive list of each aspect of the project. This list includes the percentage of smoke removed, heat generated, size, affordability, manufacturability, adaptability, and impact to the current home. Each component must be quantified as accurately as possible by placing a target value on each area. This became challenging when specification discovery revealed unexpected concerns, such as questions about a lack of windows in homes. An incomplete understanding of the culture created gaps in the design specification.

The initial site visit provided invaluable information. For example, seeing the variability of the houses, the tools available, and the lack of money and resources available to households began to change the importance placed on each aspect of the specification. The true revelation occurred when we realized the socioeconomic situation of the communities. We discovered that only recently were households able to achieve 12 months of food security and that, traditionally, they did not have windows because their culture had the same concerns as ours — they wanted privacy and security. Even if they did want windows, expecting a solution that would provide security and privacy within their budget would be unreasonable for most families in the community. There were also many cultural revelations, especially concerning gender roles and the lingering effects of the caste system. It was encouraging to see that a few individuals and the government had tried to create a better stove. These were met with limited success. One man that tried a new stove became frustrated with it and tore it out, which highlighted the importance of a design that would work from the

beginning to reduce the feeling that they had wasted their time. It had to function well to prevent discouragement.

After returning from the site visit, the design specifications were reevaluated and it was determined that cost and manufacturability were the most important features of the new stove. The team realized that even the efficiency of smoke removal was less important than these things; however, efficiency was a close third. The new design specifications required that the stove as low cost as possible with the ability to be improved at additional cost. It was also determined that if the stove remained very close in design to the one they were used to, then it would be better received.

The final design was made completely out of mud and looked and functioned just like their familiar stove. The difference was the inclusion of a box on the back that redirected the smoke toward the outside of the house. This was a major change from the previous attempts, which had been moving toward a box-style chimney on the outside of the house. This eliminated the need for a pipe, which is expensive and very inefficient when the method of stacking roof tiles to create a make-shift pipe is used. The make-shift pipe expands and contracts the air as it travel up the pipe causing very poor airflow. Additionally, there was nothing to block the wind outside, and if the wind was blowing against the exterior wall where the smoke escapes, it would prevent smoke from flowing out. The external box chimney solved all of these problems. It was easy to create, had great smoke flow, and blocked the wind to prevent smoke from flowing back in.

The beauty of the design was its simplicity. It was able to meet all of the objectives of the design specification, including efficiency. Strict adherence to the design specifications and a more complete understanding of the socioeconomic environment helped ensure the highest likelihood for success.

This phase of the project lasted 8 months and ended in May. The deliverables had two parts, one for LWR and one for the UCCS class. The class required a presentation, poster board and paper describing the entire process in detail. The deliverable to LWR was a paper describing how the stove should be built and the intent of each component to provide a method of troubleshooting. These deliverables were delivered to LWR and all materials belong to LWR. After the presentation was given and all materials were turned over, the class portion was completed.

IMPLEMENTATION

After the class was completed, LWR began pursuing the implementation of the project. After a few months, it was made clear that the project would be implemented, and two of the original CO-Planetees team agreed to return to India to oversee the implementation. This was a quick, eight-day trip to ensure the first prototypes were built correctly. While in India, we met with partners for one day and then took three daytrips into the field.

The meeting with the partners was initially met with resistance because they seemed to want to use the money to create a more expensive stove than that of our design. We initially discussed the feasibility of the redesign, but eventually the intent of the original design was recognized and no changes were made. When the design specifications were created, the team decided that the design should be able to reach a large population because of the very low cost of construction. This requirement was at the heart of the project, and the redesign would have moved away from that by using more expensive pipe. We agreed that the original design should be built for this demonstration. But future endeavors could create a more advanced and more expensive stove option. The original design also had the benefit of being made from mud or brick, but it was decided that the demonstration pieces should be made from brick, instead of mud, to reduce the build time. Mud needed to be built in layers, requiring five or six days to dry between each layer.

The first day in the field was in a village where LWR's partner PRADAN was working. The village was selected because several residents had skills in brickmaking. We selected a house in which to install the demonstration stove. Meticulous attention to detail was taken to ensure that each portion of the stove could be replicated correctly. The first step was to dig a hole in the ground where the stove was to be installed. This hole contains the fire and anchors the stove so that a hole through the wall can be made. The hole was made in the proper place to ensure that each opening to the next feature was always higher than the inlet of the previous feature.

Next, the smoke chamber that moves the smoke from the stove to the hole in the wall was built. These components were made from unfired bricks to ensure consistent hardening throughout the stove, ensuring a longer stove life. After the smoke chamber

was built, the stove and chimney were started. Starting these features allowed the beneficiaries to visualize what the stove would look like and how it would function. They were hesitant initially, but accepted the idea after seeing the basic layout. After completing the design, the skilled brick maker commented that he could start making these stoves in addition to rice stoves — giving him one more skill and source of income.

Although the stove seemed to be a success and other individuals were asking when one could be made in their house, there was an issue that should have been identified in the design specifications. The chimney only goes partially up the exterior wall and, as a result, soot from the fire would



Figure 1: Initial vent design



Figure 2: Improved vent design



Figure 3: Single stove in use

blacken the wall. This was not identified as a potential problem until this trip. Despite the stove being built out of mostly brick, it still needed time to dry, so we were not able to watch it function. Despite these two setbacks, the project seemed to be well received and was a general success. The stove took 50 bricks (although a brick-less version could be made) and would cost between 400 and 550 rupees (\$6-\$9) depending on the bricks and labor required.

The second day took us to a village with ASA. This day proceeded much like the previous day, except two stoves were to be built and a brick expert was not used. Just as before, there was hesitation towards the new design. However, as the first stove began to take shape, more people wanted to make this type of stove in their homes. With ASA, there did not seem to be as much attention to detail, and some of the engineering principles were ignored. Thankfully, the design is robust and will be effective even without precise implementation. These two stoves were single burner, and the one PRADAN built was a double. The ASA stoves used fired bricks, which will work, but might not last quite as long as the unfired in areas exposed to high heat.

On the third day, the team split up so that one member went with ASA and the other with PRADAN. During this visit, the team checked on the stove that was made three days earlier. After that, the group sat down with the brick expert that had built the stove and discussed the design. The engineering behind each feature was explained, and he asked some excellent “what if” questions. PRADAN wanted to wait and make sure that the stove functioned to the level expected before rushing to build more, so they insisted that the other community members wait before building more despite the many inquiries. In ASA’s selected village, three stoves were built using the same, less precise construction style. The stoves were built with differing amounts of bricks. It was pointed out that the external chimney would not last long when constructed of mud so households were advised to use brick for that section.

It was very interesting to see the two styles of implementation — one precise and thorough and the other quick and less precise, yet still effective. The fact that ASA has since built 65 stoves and intends to build 66 more is proof of the stove’s robust design. However, it will be interesting to see how much more efficient the PRADAN built stoves are and how much longer they last. Despite the differences in construction and after their initial hesitation, the communities were very excited by the new stove and many seemed anxious to build one in their homes.

LESSONS LEARNED

Throughout the entire process, many lessons were learned that could benefit future UCCS student groups and LWR’s plans for future engagement with engineering teams. The following are observations and opinions made through each step of the process.

Firstly, during the initial selection phase, Dr. Gorder expressed some observations concerning students’ selections of NPOs. He observed that students will typically either have NPOs at the top of their list of preferred organizations they wish to work with or not at all. I believe that this is because of two things. First, if the students are simply not interested in humanitarian projects, they would not select them. However, I also believe that NPO projects often seem less technical, and the students want to have a project that shows their technical abilities. Senior design projects often lead to job offers because of either the success of their work or because of the relationship formed between the students and the company. I believe that a clear explanation of the added difficulty of the design specification for NPO projects should be given to assure students of their unique complexities. Also, with some NPO projects, it may be possible to tackle multiple projects in the time provided by the class. There is a balance to this, and care should be taken to select projects that could be understood, designed and implemented in a reasonable time frame.

The next observation was that our initial attitude was flawed and needed to be corrected before we could effectively understand the problem. Going to India for the design specification was probably the most important step toward overcoming that gap in understanding. Most Americans, especially young students, have not had the opportunity to travel to other countries and help in underdeveloped regions of the world. As a result, bridging this gap in understanding might be difficult. This might be even more difficult for a group of engineers that tend to want to build the biggest and greatest, and we often have trouble dealing with the monetary restrictions within the U.S. It is easy to find examples of engineering projects that are incredibly efficient and meet all the technical requirements perfectly but cannot be implemented because they are not easily replicated or are prohibitively expensive. Developing an understanding of the cultural and socioeconomic environment by seeing the daily struggles of the community changed our preconceptions and encouraged a design that was more sympathetic to their needs.



Another observation is that the NPO's partner organizations should be brought in early to consult on the project design. The misconceptions about the intent of the implementation and wanting to redesign at the last minute is a clear example of why their early buy-in is so crucial. The partners also have valuable insight into what concerns might arise out of a particular design.

There are many limitations to partnering with a senior design group that bear mentioning. The time constraint to a university course is huge. This project lasted 13 months from initiation to implementation. However, there would never be a guarantee that students would be available to assist with the implementation because most graduated students will have moved on to jobs. The best way to address this would be to have the students go on a site visit as early as possible, so that the design phase could start sooner.

It is clear that the design specification is the most critical component of the entire process. It defines how well the project will meet the technical need as well as ensuring that the socioeconomic constraints are considered. Without well-defined specifications, the likelihood of a sustainable and well-received project decreases drastically. With our project, this realization occurred during our first trip to India, and that trip was the most important step toward designing the stove.

As a final thought, this project has been one of the most rewarding experiences our lives, and we appreciate the opportunity to participate. Seeing the challenges of other communities and taking action to help has, in turn, helped us to grow. It is encouraging to see the relationships that LWR, ASA and PRADAN have developed within the communities, which have enabled them to empower so many people, and to see that these actions are having lasting effects. We are incredibly impressed by their work, and as a result of this experience, we will always seek out opportunities to participate in these noble endeavors.