Solar Water Heaters for Showers and Sinks: An EWB-USA Project

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Abstract

The University of Tulsa Engineers Without Borders USA chapter brought smiles to a small community in the Altiplano of Bolivia with their recently completed project: solar water heaters for showers and sinks. The heaters warm the spring water from a bone-chilling 37°F to more than 100°F in ambient air temperatures that do not exceed 62°F. The design and implementation were completed by a team of university freshmen and sophomores. The heaters are constructed of PVC pipe that is painted black to promote heating and to prevent degradation. The design takes advantage of the greenhouse effect using empty 2-L bottles around the pipe.

Background

Engineers Without Borders USA (EWB-USA) is an organization of more than 12,000 students, faculty, and professionals looking to make a difference in the global community through practical and sustainable engineering solutions. EWB-USA was incorporated in 2002. In their first 10 years, student chapters have been formed on more than 180 college campuses. Professional chapters bring the total to more than 250 chapters with more than 350 active projects in 45 developing countries.

The University of Tulsa's EWB-USA chapter (EWB-TU) was first introduced to the community of Cotani, Bolivia in 2009 as partners in an ecolatrine project with their local professional chapter (Oklahoma East). EWB-USA encourages chapters to form a long-term commitment to a community to assure that projects meet basic needs and are successful. As the result of meetings with community members, the EWB-TU chapter learned that they could improve the health of the community by providing warm water for hand-washing and showering. This project became the focus for the two academic years 2010-2012.

About the Community

Cotani is a small town of approximately 800 people in the Department of Cochabamba in the Altiplano of Bolivia. When EWB-USA began working in the community, all biological needs were performed outdoors and washing/bathing simply did not happen. People were exposed to the elements and sickness due to lack of sanitation was common. Eight homes now have eco-latrines due to the efforts of the Oklahoma East professional section and the University of Tulsa student chapter. The community nurse has made efforts to educate the community on the importance of washing to reduce illness. Spring water is piped to each home thanks to a community wide project by Water for People and water quality tests have demonstrated that the water is safe for drinking. However, the community still largely believes that washing brings on sickness. EWB-TU measured the water temperature to be 37^{o}F. EWB-TU members agreed that washing with such cold water was very unpleasant and it is not hard to imagine why bathing is so uncommon. Providing warm water for the community was ranked as a priority in order to make washing and bathing a more pleasant (and therefore more likely) experience. Heated water provided to sinks and showers will aid the nurse in her educational efforts and help further reduce the incidence of sicknesses such as intestine infections and parasites.

The Design

The design was based on a goal of providing a five-minute shower at a flow rate of 1.85 gallons per minute (7 L/min). The heater was designed to raise the water temperature 50°F above the inlet temperature. An alternatives analysis (see Figure 1) was used to make the primary decisions on appropriate technologies. Based on this, it was determined that the best design included both a shower and a sink with solar-heating and drainage below the ground for soil remediation of the graywater.

The size of the exchanger was selected to use materials that were readily available in Bolivia and provide the required flow capacity. Radiation calculations were used to estimate the exit temperature of the water. Calculation techniques were those typically covered in a basic heat transfer course (see for example, Chapter 8 of Holman's textbook[1]). The heat demand of the solar heater was estimated using solar constants modified for the altitude and latitude. When the prototype was built, the actual temperature rise was approximately 65°F.

One of the concerns was structural. The people of Cotani are primarily farmers, although some work in the nearby town of Colomi. The homes are made of adobe mud bricks with thatch roofs held down by large stones or corrugated ceramic or metal materials. The support beams are typically 2-3 feet apart, but may not be evenly sized. The heater was designed to distribute the weight of the water as evenly as possible for adequate support by the existing structures.

Another concern was that the systems be located appropriately for graywater runoff. EWB-USA recommended using the Summit County, CO regulations[2] for determining the location. For the soil in Cotani, it is recommended that the shower/sink be located at least 5 meters from crops and drain into a gravel bed at least 0.5 meter deep and 0.5 meter in diameter.

The students built a small solar heater in Tulsa to evaluate their design and built a prototype in Cotani in the summer of 2011. At this point, the team discovered another important design challenge: pressure. The village is built on the side of a mountain in the Altiplano of Bolivia. The water system is spring-fed from the top of the mountains. It is piped to one of three collection tanks before being piped to homes further down the mountainside. The hydrostatic pressure at the lowest elevation homes can exceed 195 psia. In the United States, it is recommended that home water pressure be between 40 and 80 psia. PVC pipes are adequate for normal household pressure, but fittings may burst at these extreme pressures. Several methods of dealing with the excessive pressure were considered, but it was determined that the most reliable solution was to install pressure reducing valves in line before the heater. These added approximately $30 to the unit cost, but also prevented other over-pressure problems that residents reported with their existing water system.

Consideration / Option	Health/Safety	Cleanliness	Cost	Operating Cost	Maintenance	Social Stature	Acceptance by Community	Materials Available	Limits on Flow	Weather Conditions	Attract Bugs?	Attractive Nuisance	Easy to Teach to Build	Grade
Shower only	+	+	0	0	-	+	0	0	0	0	0	0	0	2
Sink only	+	+	0	0	-	+	-	+	0	0	0	0	0	2
Combo	++	+	-	0	-	++	0	0	0	0	0	0	0	3
Nothing	--	-	+	0	0	--	+	+	0	+	0	0	0	-1
Solar	+	+	0	+	0	0	+	+	-	-	0	0	0	3
Electric at shower head	-	+	0	-	-	0	0	+	+	0	0	-	0	-1
Electric at tank	+	+	-	-	-	+	0	+	0	+	0	0	-	1
Gas heat	-	+	--	-	--	+	0	-	0	+	0	0	--	-6
No heat	-	0	+	+	+	-	-	0	+	-	0	0	0	0
Drain to dirt	0	+	+	+	+	-	+	+	+	-	0	0	0	5
Drain to collector	0	+	-	+	0	0	+	+	0	0	-	0	0	2
Walls - no drain	-	-	-	+	0	-	-	+	-	-	-	0	0	-6
Reclaim water	+	+	---	---	---	++	0	0	-	-	0	0	--	-9

Recommendation: Shower/Sink Combo with solar heat that either drains to the dirt (if area is available for safe placement) or has a drain to a collector tank that is open to the atmosphere with lots of surface area for quick evaporation which will minimize bugs

Figure 1: Alternative Analysis

The heat exchanger at the heart of the design uses black 2" PVC pipe with recycled 2-liter plastic bottles. The heater uses no electricity and tests have confirmed that it heats water rapidly. It is designed to hold enough water for a 5 minutes shower at a flow rate of 7 liters per minute. The hot water from the heat exchanger is piped to a shower head (surrounded by a shower stall for privacy), a sink faucet (emptying into a porcelain basin), and a bucket-filler (a valve used to fill large containers for cooking or cleaning). Each unit costs approximately $280. A diagram, a list of parts, and installation instructions are included in the Appendix.

Student Preparation

TU students participated in several activities after the design work described above to prepare for the implementation of this project: writing EWB-USA reports, constructing a practice system, and developing educational materials.

EWB-USA requires a pre-implementation report, which describes the community, its needs, the design, the expected impacts on the community, and assessment plan to evaluate the design. A detailed health and safety plan is required. After these two reports were submitted, the students prepared and gave a 15-minute web presentation to a technical advisory committee of professional engineers from four engineering disciplines. They asked for clarifications of a few aspects of the report and required revisions before approving the team for travel.

The chapter built a practice shower at a local scouting facility. This made sure that all of the travel team had the basic experiences of cutting and gluing PVC pipe and constructing the bottle greenhouses. It also gave the entire chapter experience in visiting a site to take measurements, adapting a design to fit the circumstances, and troubleshooting problems as they developed.

The EWB-TU chapter had great plans for preparing and familiarizing themselves with Spanish educational materials, but did not follow through very well. The plans included creating an illustrated instruction guide for building the solar heater in Spanish, a Spanish activity booklet for the school children, and Spanish scripts for educational activities with both the adults and children of the community. In addition to simply preparing the scripts, the team planned to take these educational activities to local bilingual classrooms to practice in Spanish. In reality, the team managed to have written instructions in Spanish without illustrations. Most of the homeowners are illiterate and only speak the native language (Quechuan) well. These instructions were essentially useless. A Spanish activity book was created and scripts for the educational activities created. Only one bilingual classroom session which involved only one travel team member was scheduled. Completing all of the materials and practicing the activities in Spanish would have made implementation of the project easier.

Implementation

Nine representatives of EWB-TU traveled to Cotani, Bolivia in May 2012 to deliver this project to the community members. The primary purpose of the trip was to teach the community members how to build their own solar water heaters and to teach the schoolchildren the importance of washing. EWB-TU provided materials for 15 homeowners to construct a heater with sink and shower and held lessons in the schoolyard. With the team’s guidance, the men pitched in to build all 15 heaters during these lessons. Since water pressures in the village are measured to be as high as 180 psig, pressure-reducing valves were provided and proper installation taught. The TU team also emphasized the importance of proper drainage. At the conclusion of these lessons, each homeowner carried their heater and supplies to their homes to complete installation. The EWB-TU team visited each home to approve the installation site. Members verified that the structures were sound for supporting the heaters and that the selected drainage sites would not harm crops or animals. During these rounds, TU team members noticed that empty 2-L bottles were becoming valued commodities and not filling roadside ditches as seen on previous visits.

Figure 2: TU students work with community members to construct solar heaters for their homes.

One afternoon, the team made a presentation to the school and provided an activity book about germs, the importance of handwashing and the effectiveness of solar heating. Lessons included a demonstration of the thermal effect of the sun on water in a white container, a black container, and a black container under a cut-away 2-L bottle. Another lesson used glitter to demonstrate the spread of germs from one person to another. After a lesson on proper hand-washing technique, the older students were invited to use the working system at the teachers' courtyard. The students initially refused to wash their hands because they normally find it unpleasant. With some convincing, one young man was finally willing to go first. With great hesitation, the boy turned on the water, grabbed the soap and put his hands under the running water. His face broke into a huge grin when he felt the warm water. After his enthusiastic recommendation, the remaining students were excited (even pushing and shoving) to get their turn at the sink.

Conclusion

This project was well-received by the residents of Cotani and promises to positively impact the health of the community. A few weeks after the team returned to the U.S. another colleague had an opportunity to visit the village. She reported that people in town were still excited about the warm water. No system was fully operational yet, but most homeowners were in the process of making adobe bricks or building shower houses so that they can complete the project. One resident thought that he would have his operating in a day or two. The team will return to Cotani in a few months to be sure that the systems have been properly installed and are working as designed. A visit to the health clinic will also provide an opportunity to see if there are improvements to overall health in the community as a result of this project.

Due to the large community support and excitement, the EWB-TU team anticipates seeing replicas or variations on this design elsewhere in the community. It is hoped that the community members will take the technology and knowledge that was given to them and apply it to other facets of their lives. In follow up trips, the team hopes to introduce other simple, yet effective, uses of solar energy such as solar ovens for cooking, black rooftops for better heating, and solar bottle lights to save on electricity during the day.

Bibliography

1. Holman, Jack P., *Heat Transfer 10th Edition*, Published by McGraw-Hill Higher Education, 2010.
2. Summit County Public Health Department Environmental Health, "Onsite Wastewater System Regulations," Summit County, CO, 2010.

Appendix

Table 1. Parts List

Description	Quantity
½" PVC: 6 m lengths	4
2" PVC: 6 m lengths	4
PVC glue	1
PVC primer	1
Teflon tape roll	1
½" metal threaded ball valves	3
2" elbows (slip fit)	17
½" elbows (slip fit)	16
½" x 2" reducing coupling (slip fit)	2
½" tee (slip fit)	4
½" male adapters slip fit to threaded	8
Output 45 psia pressure reducing valve	1
Sink kit	1
Shower kit	1
Cement mix (sack)	1
Drain kit	1
Empty 2-L bottles	90
Clear packaging tape rolls	4
Black matte spray paint cans	5
Wire (meters)	2
Rubber hose (meters)	1
Plastic anchor sets for ½" PVC	6

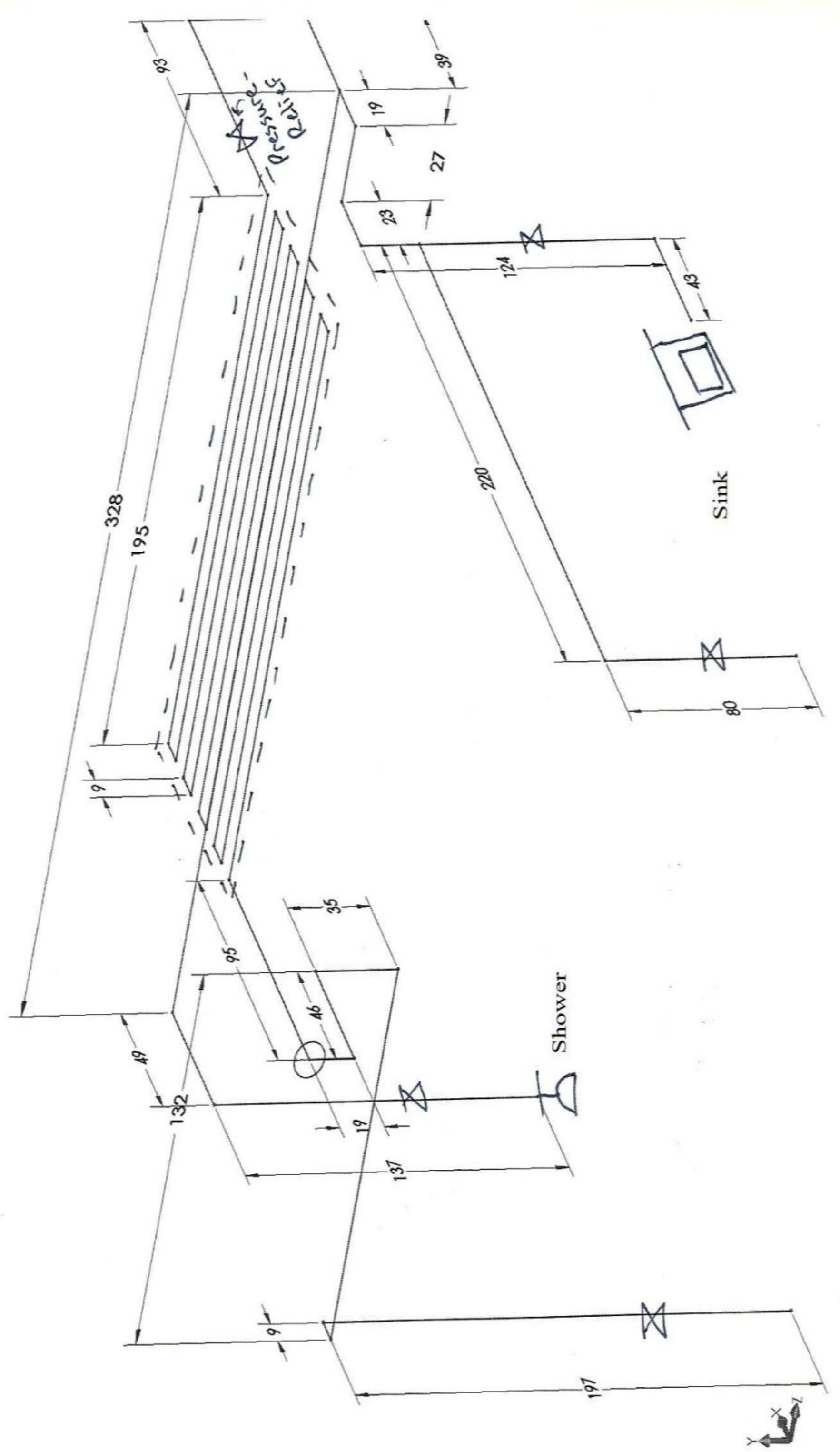

Figure 3. Piping diagram for shower/sink and heater. All pipes are ½" PVC except for the heat exchanger (enclosed in dashed lines) which are 2" PVC. All measurements are in cm.

Assembly Instructions:

1. Cut 2” PVC pipe into 9 sections of length 2 m. (It is more important that the pieces be the same length than that they be exactly 2m.)
2. Cut 2” PVC pipe into 8 sections of length 1 ft.
3. Cover 2” at both ends of each the long pieces with tape. Spray paint the pipe with matte black paint and let dry.
4. While drying, cut the top and bottom off 2-L plastic bottles. (You need enough to encase the PVC pipe. Depending upon exactly how you cut the pipes it will vary. Plan on 9-10 per pipe.)
5. Once the paint has dried, remove the packaging tape from the PVC pipe and slip the plastic bottles over the pipe.
6. Use clear packaging tape to form a sealing greenhouse of the 2L bottles.
7. Apply PVC primer (if available) and glue to the end of one pipe and the inside of one ell. Push the ell onto the pipe securely.
8. Connect a short piece to the ell using the same method then an ell to the short piece so that it will form a U-shape. Attach another long piece to this ell. Continue steps 7 and 8 until all of the cut pieces of 2” PVC have been used. (See diagram.)
9. Attach 2” x ½” reducers to each end of the exchanger using the same technique.
10. Attach a ½” tee before the inlet reducer.
11. Take a 4-inch length of ½” pipe and thread one end using PVC threader. Attach pop-off valve to threaded end and glue other end to one branch of the tee installed in step 10.
12. Close the valve at the water supply and make a cut on the house side of the valve. Allow the remaining water in the line to bleed out. Glue a ½” tee to this line, a short piece of ½” pipe, and a valve. Use ½” PVC piping to run from the valve to the location where the heat exchanger will be placed.
13. Allow all glued connections to dry for 8 hours or longer.
14. In the meantime, find anchor points on the roof where the heat exchanger will be placed. It is best to orient the exchanger so that the long pipes of the exchanger are positioned in line with the corrugation of the roof. If anchor points are not well-situated for this purpose, you may need to add a wooden anchor at the top and/or bottom. This can be done by locating two anchor points and attaching a length of wood between them.
15. Place the heat exchanger on the roof and anchor it. This may be done by attaching wire inside of tubing (such as a 8” length of rubber hose) to the anchor points. The rubber hose will surround the pipe and prevent the wire from cutting through the pipe over time.
16. Use additional ½” PVC pipe to complete the connection of one end of the heat exchanger to the water line from step 10.
17. The exit end of the heat exchanger now needs to be connected to the shower and sink. Add a tee. One end will provide flow to the sink and one to the shower. Add a cut-off valve at each end of the tee.

18. Run ½” pipe to the sink and to the shower.
19. Assemble sink and shower heads according to the instructions that come with them. Make final connection to ½” pipe.
20. Allow glued connections to dry for 8 hours.
21. Anchor all piping that runs along buildings. Bury piping that runs along the ground.
22. Once dry, open the valves and conduct leak tests. Re-glue any pieces that are not water-tight.
23. Note on construction of drains: It is recommended that you dig a hole to a depth of 2 ft or more and fill it with gravel. (If this is being installed on land with a significant slope, you will need to dig deeper depending upon the grade.) The drainage pipe should end in this gravel. The top of this gravel may be covered in dirt or concrete, but it is important that loose gravel be used below the drain pipe to prevent clogging and to allow dirty water to disperse adequately. Soapy water in the small quantities of a shower will not poison the surrounding ground if the drain is installed properly.

Biographical Information

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WESTON KIGHTLINGER is a Junior studying Chemical Engineering/Pre-Med at The University of Tulsa. As the project lead, Weston managed this project through the design and implementation. Weston has received many honors in his academic career including being awarded a CH2M Hill Engineers Without Borders-USA Scholarship for 2012.