Journal of Humanitarian Engineering

Volume 4, Issue 2

ISSN 2200 4904

JOURNAL OF HUMANITARIAN ENGINEERING

Journal of Humanitarian Engineering (JHE)

The Journal of Humanitarian Engineering (JHE) is an open access publication that publishes outcomes of research and field experiences at the intersection of technology and community development. The field of "humanitarian engineering" describes the application of engineering and technology for the benefit of disadvantaged communities. The field spans thematic areas from water to energy to infrastructure; and applications from disability access to poverty alleviation. The JHE aims to highlight the importance of humanitarian engineering projects and to inspire engineering solutions to solve the world's most pertinent challenges.

For more information, visit: www.ewb.org.au/journal.

PUBLISHING
Engineers Without Borders Australia

INDIGENOUS AUSTRALIAN ACKNOWLEDGEMENT

EWB respectfully acknowledges the Traditional Owners of the Country on which we work.
To learn more about our commitment to reconciliation, read EWB's Reconciliation Action Plan.

Cover photos:
Top - Collaborating on women's health projects in Malawi (photo courtesy of Taylor, et al., this issue); Middle right - Clemson engineering students with concrete masonry unit plant employees in Haiti (courtesy of Gordon, et al. this issue); Middle left - Designing solar home systems in Cambodia (courtesy of Watts, Smith and Thomson, this issue); Bottom - Solar still prototype testing in Zambia (courtesy of Maambo and Isaac, this issue)

JOURNAL OF
HUMANITARIAN
ENGINEERING

Lighting the way for a better future

Guest Editorial

In early September, my wife gave birth to a beautiful, wonderful, amazing little girl. Before, during and after the delivery, we had access to essentially the best health care. During the pregnancy, we had multiple ultrasounds and a range of blood tests to check for any health issues. During labour we had an army of well-trained midwives; an excellent obstetrician if intervention was needed; an anaesthetist; and access to all the equipment we would need if any complications arose -there were complications and intervention was needed. We then had the next five days in a maternity ward to get all the support needed for our roles as new parents. At no stage did I think anyone's life was at risk.

In many developed countries, this is the norm. Yet for billions of people around the world, access to even electricity is a struggle, let alone all the equipment that requires electricity, including basic lights and refrigeration for medicines. People are literally dying because of a lack of access to utilities, equipment and resources. This point was made very clear to me when I heard from Dr. Laura E. Stachel at the 2014 IEEE Global Humanitarian Technology Conference. In 2008, Dr. Stachel was in Northern Nigeria studying maternal mortality. What she saw was that women were dying in hospitals because there was no lighting to perform emergency C-sections, or any other operations, at night. The first proposed solution from Dr. Stachel was to help a hospital become completely solar-powered: an array of solar panels, batteries and therefore power for all the equipment they may, or may not, actually have. A long story made short is that the first idea wasn't really appropriate; and didn't take into consideration what the end-users wanted. However, using input from end-users, Dr. Stachel co-founded WE CARE Solar and started to produce the Solar Suitcase: a solar-powered medical kit, which includes lights, ultrasound systems, a solar panel and a battery pack. With over 1,500 suitcases built and deployed around the world, WE CARE Solar have efficiently and effectively help address a major problem.

To me, the story is inspirational, and more so now that I have seen my daughter born safely, despite complications. However, the story of WE CARE Solar also highlights the need for solutions to focus on human-centred design and working for and with end users to develop solutions.

The Journal of Humanitarian Engineering provides a mechanism for scientifically rigorous research to be available, not just to other researchers, but also to practitioners and community members. It helps facilitate cross-pollination of ideas, such that a solution tailored for one part of the world can be adapted and modified to another part of the world. The current issue includes papers that do just that. The design and installation of Solar Home Systems in rural Cambodia, (Watts et al. 2016) provides insight into solar home installation in rural Cambodia, but the results could be modified for anywhere else in the world, with community input. Similarly, A Sustainable Engineering Solution for Pediatric Dehydration in Low-Resource Clinical Environments (Taylor et al. 2016) provides insight into paediatric hydration in Malawi but could be just as easily applied to any other resource-constrained community in the world. This can then help education, provide technology concepts for subsequent tailoring, and enable implementation of new ideas; all in order to raise the quality of life for those most in need.

Dr. Cristian Birzer

New Dad, Board Member and Associate Editor, *Journal of Humanitarian Engineering*

Journal of Humanitarian Engineering

Volume 4, Issue 2

ISSN 2200 4904

CONTENTS

Partnership to Improve the Quality of Local Construction Materials in Haiti's Central Plateau

Aaron Gordon
Clemson University, Clemson, SC United States
asgordo@g.clemson.edu

Jeff Plumblee PhD
Clemson University, Clemson, SC United States
jplumbl@clemson.edu

Kayla Dimarco
Clemson University, Clemson, SC United States
kdimarc@g.clemson.edu

David Vaughn
Clemson University, Clemson, SC United States
dev@clemson.edu

Jennifer Ogle PhD
Clemson University, Clemson, SC United States
ogle@clemson.edu

ABSTRACT: *This paper presents a successful ongoing partnership between Clemson Engineers for Developing Countries (CEDC) and a concrete masonry unit (CMU) manufacturing plant in rural Haiti. The infrastructure destruction and resulting loss of life of the 2010 earthquake in Haiti highlighted the need for improved building materials and codes. This partnership has helped to improve the strength of CMUs in the plant, both creating a safer local built environment and expanding the economic opportunities for this plant. Using samples of aggregate and cement from the site in Haiti, students in Clemson performed experiments to optimise the CMU mix design and made other suggestions to improve efficiency and quality of their product. Consistency continues to be a challenge for the CMU plant, and this paper also describes proposed procedures to help the plant implement quality control and quality assurance plans.*

KEYWORDS: Partnership, Building Codes, Concrete Block, Construction Materials, Earthquake, Haiti

1 INTRODUCTION

Clemson Engineers for Developing Countries (CEDC) is a translational research and education program at Clemson University. By utilising a unique organisational structure that includes students in the classroom and year-round student interns in Haiti, CEDC has designed, implemented, and managed several projects throughout Haiti's rural Central Plateau. These projects have ranged from village water systems to repairing schools to constructing fish hatcheries.

Since 2012, CEDC has partnered with a concrete block plant in the Central Plateau to increase the quality of their products and the efficiency of their processes. This relationship has been mutually beneficial, as bolstering the operations of the facility not only allows CEDC projects to be built with higher quality materials, but also enables the block plant to expand their own enterprise, promoting job growth and economic development in the region. This paper describes the process by which CEDC has partnered with the block plant, the obstacles this endeavour has surmounted along the way, and the tangible results of this relationship between Clemson University and a small business in Haiti's Central Plateau.

2 PROJECT BACKGROUND

2.1 CEDC in Haiti

CEDC formed organically when a small group of undergraduate and graduate engineering students showed an interest in using their technical skills to serve in an international context. In June 2009, a group of six students travelled to the village of Cange in Haiti's Central Plateau to perform assessments and survey a site where Clemson engineers could make an impact. This information would be used to begin a design course in Fall 2009 to begin addressing Cange’s engineering issues (Plumblee 2012). The catastrophic earthquake in January 2010 greatly increased demand for aid in Cange and the Central Plateau as refugees from Port-au-Prince flocked to the area. Since May 2011, CEDC has had a near-continual student presence in Cange, with student interns providing project oversight and serving as the liaison to the community as the scope and scale of projects began to expand. These interns have been able to manage the completion of the USD $1.5 million Cange municipal water system, with support from donors, industry professionals in the United States, and local construction crews in Cange, in addition to several other projects.

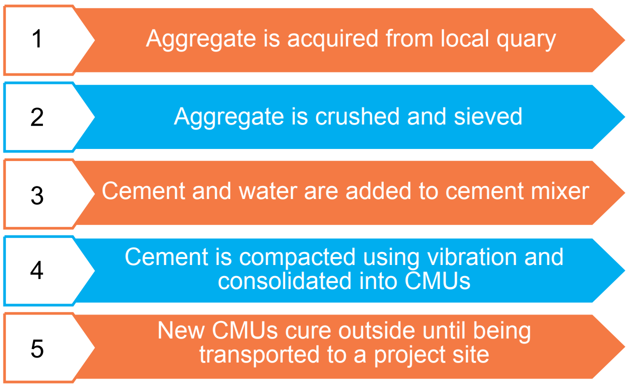
2.2 Concrete Masonry Units in Haiti

The January 2010 earthquake in Haiti was catastrophic to the people and infrastructure in Port-au-Prince. Before this event, almost 90 % of people in the capital city were living in small concrete structures made of concrete masonry units (CMUs), many of which had inadequate or no reinforcement and most of which were not held to any sort of national or international standard (Disasters Emergency Committee 2015). Building codes, such as those prescribed by the American Standards for Testing and Measurements (ASTM) in the United States or the Code National du Batiment D’Haiti (CNBH) in Haiti, are crucial to the design and construction of safe buildings and structures that can withstand loads from natural occurrences like earthquakes. It is estimated that when the 7.0 magnitude earthquake hit, nearly half a million people were killed or injured, mostly from building collapses and falling objects like CMUs (CNN Library 2015). A USGS survey of the event attributed the massive loss of human life to the “poor quality of much of the construction” and suggested that “the earthquake did not produce ground motion sufficient to severely damaged well-engineered structures” (Eberhard 2010).

A review of the 2010 earthquake damage by a team of engineers cited that shear failures in rigid and interior walls due to low-quality CMUs were responsible for a majority of structural failures (Kijewski-Correa 2012). These shear failures transferred large horizontal seismic forces to insufficiently designed or non-engineered concrete columns thereby leading to structural failure (Kijewski-Correa 2012). The exact quality of such CMUs is not known but a recent informal survey of block manufacturers around the Port-au-Prince area found that they produce CMUs at an average compressive strength of 4.45 MPa (approximately 650 psi) (Build Change 2012). For reference, the Ministère des Travaux Publics, Transports et Communication (MTPTC) guidelines in Haiti dictate that a CMU’s compressive strength should meet or exceed 15 MPa (approximately 2,175 psi) (CNBH 2013). ASTM C90-16 dictates a minimum compressive strength of 1,800 psi (12,411 kPa) or an average of 2000 psi (13,790 kPa) for three CMUs (ASTM 2016). In the wake of the devastating earthquake, many experts and critics have therefore pointed to the lack of adherence to building codes as a major reason for the catastrophic nature of the event (Lindell 2010). Unfortunately, Haiti’s strained political state makes public oversight of building codes through proper inspection and approvals extremely difficult (Kijewski-Correa 2011). Non-governmental organisations (NGOs) and federal projects could conceivablyimport building codes for externally funded projects like hospitals and schools, but smaller projects such as homes and shops would still lack these life-saving construction standards (Kijewski-Correa 2011). Consequently, it is not enough to simply provide Haitian masons, contractors, and constructors with a one-time access to superior construction methods.

Since its inception, CEDC has possessed a core principle that the organisation would only design to internationally accepted construction standards such as the International Building Code (IBC) which references the ASTM standards with regards to construction materials (International Code Council 2015). In addition, many sustainable construction practices in the developing world dictate that local materials should be used whenever possible (Pocock 2016). CEDC, in an effort to follow these practices in the developing world holds the philosophy that locally available materials and labour should be utilised with projects without compromising the safety of the structure. However, no CMU products meeting ASTM or CNBH quality requirements were available in the Central Plateau. A small CMU plant was contacted near the town of Domond along National Route 3 in the Central Plateau. This particular plant was originally established in 2011 through partnerships with the Haitian government, Partners in Health/Zanmi Lasante (a large and renowned public health NGO), and a small NGO known as 1,000 Jobs for Haiti (Farmer 2012). While this plant’s ambition was large, the actual quality of the block itself was lacking in compressive strength, durability and consistency; for instance, CMU samples that students obtained from the plant during the first visit in 2011 could be broken by students using only their bare hands or by dropping it from a mere 0.5 to 1 m (2 to 3 feet).

A team of Clemson Civil Engineering students began to establish a professional relationship with the owners of the CMU plant. The idea was that such a partnership would be mutually beneficial to both parties: CEDC would be able to use higher quality CMUs for its projects, while the CMU plant would increase their marketability and production capacity. Figure 1shows two Clemson engineering students with the block plant employees.



Top to bottom:
Figure 1. Clemson engineering students with CMU plant employees
Figure 2. The quarry where aggregate and sand are excavated
Figure 3: Process flow diagram of CMU manufacturing plant in Haiti
Figure 4: An employee sieving aggregate with a shovel

3 CONCRETE MASONRY UNIT PLANT

3.1 Plant Overview

The Domond CMU plant works on a project-by-project basis, selling various types of blocks to constructors and contractors around the Central Plateau. They have several teams of workers around their factory. One team works at a nearby quarry (see Figure 2), excavating aggregate and sand and then transporting it to their main facility.

All of the water in the plant is provided by a single hose, which is sourced from a local well. Cement is purchased from local vendors who retrieve it from the cement manufacturing facility in Port-au-Prince. Most CMUs are created for specific contracts, but the plant also creates and stores CMUs for smaller projects as well. There are approximately 20 people employed by this enterprise.

3.2 Baseline Capabilities and Operations

The following information describes the operations of the CMU plant prior to CEDC interventions and are based on the notes of the CEDC students during their first visit to Domond. Prior to the partnership with CEDC, the block plant possessed the following equipment:

- Rock crusher;
- Cement mixer;
- CMU compactor;
- Oven (to dehydrate aggregate);
- Sieve screen;
- Shipping container;
- Electronic scale; and
- Several out-of-service pieces of equipment, such as a mechanical sieve and cement mixers.

The process by which the CMU is manufactured is summarized in Figure 3. The aggregate is transported throughout the plant using wheelbarrows. Most aggregate is initially crushed using a large mechanised rock crusher. After this, an expanded metal sieve sorts the aggregate by size, which it is then stored in an outdoor, uncovered bay. If the aggregate exceeds the acceptable size, it is returned to the rock crusher to be crushed again, after which it will again be sieved. The sieving process is displayed in Figure 4.

4 RESULTS AND DISCUSSION OF CEDC PARTNERSHIP

4.1 CEDC/Block Plant Relations

During this first visit to the Domond CMU plant in 2012, CEDC students took note of the entire process summarized above and gathered several samples of coarse/fine aggregate, cement, and water to test in the Clemson Civil Engineering materials lab, while also recording the type of equipment available and the layout of the CMU manufacturing facility. During this time, the block plant had no clear mix design. The owners roughly estimated

Top to bottom:
Figure 5: Manufactured CMUs curing outside
Figure 6: A photo of CMUs prior to the partnership with CEDC
Figure 7: The mix design painted on a wall at the CMU plant

proportions of raw materials in the concrete based on visual consistency.

With this data, Clemson students in the classroom set out to test the materials acquired in Haiti and calculate a mix design that would most effectively use the available aggregate, sand, and cement. With the support of a local cement manufacturing facility in South Carolina, Clemson students identified that a water/cement ratio of approximately 0.35 would be most appropriate (Cemex 2008). This ratio is dry enough for the factory to easily work with through the manufacturing process but has a high enough slump that the mix can still be easily vibrated into its form. The mix design was roughly converted to units of buckets and litres so that Haitian labourers could easily measure cement, sand, and water quantities with readily available five-gallon (~19 L) buckets and water bottles. This mix design was subsequently introduced to the owners of the CMU plant in March 2013 during the CEDC Spring Break trip. The block owners then painted this mix design on the side of their plant for all their labourers and workers to use as a reference, as seen in Figure 7. This mix design calls for one bag of cement, fifteen buckets of aggregate (sand and gravel), and one bucket of water for each batch of thirty-three blocks.

After the mix design was introduced and adopted, CEDC students began to address other areas of concern in the manufacturing process, such as the lack of quality assurance/quality control procedures and worker safety. Other student groups partnered with the CMU plant at this time as well in order to repair some of the derelict equipment around the facility.

4.2 Post-CEDC Intervention

In Spring 2015, after working with the Domond CMU plant for almost two years, CEDC students carried six sample CMUs from Haiti back to Clemson for official ASTM C-140 testing by Soil Consultants Incorporated (SCI), an engineering firm based out of Charleston, SC. SCI tested both gross compressive strength and net compressive strength. Gross compressive strength is the block's maximum supportable compressive load divided by the total cross-sectional area, whereas net compressive strength is the maximum supportable compressive load divided by the total cross-sectional area minus the cross-sectional area of the hollow cores in the CMU. The ASTM standard specifies minimum net area compressive strength not gross compressive strength (ASTM 2016).

The net compressive strengths of the Haitian CMUs are reported in Table 1. Two of the three samples tested for compressive strength exceeded the ASTM C90-16 standard of 1,800 psi (12,411 kPa) in a standard compression test (ASTM 2016). The average is approximately 2,200 psi (15,168 kPa) that exceeds the ASTM C90-16 standard of 2,000 psi (13,790 kPa) for an average of three CMUs and slightly above the MTPTC standard of 2,175 psi (14,996 kPa). Full test results are located in Appendix 1.

Prior to the updated mix design, the compressive strength of the CMUs was estimated at a maximum of 1,200 psi (8274 kPa), according to compressive strength measurements by the block plant owner, using a compression machine at a local trade school. Although the pre- and post-intervention blocks were tested at different facilities, the change in compressive strength is substantial. Figure 8 provides a comparison of the averages of our testing pre- and post- CEDC intervention and also shows ASTM and MTPTC standards for CMU compressive strength.

Table 1: Net compressive strengths of sample CMUs after CEDC support

Block #	Compressive Strength	
	kPa	psi
1	17,651	2,560
2	10,204	1,480
3	17,720	2,570

While this significant increase in CMU strength is an important accomplishment, the consistency of CMU strength is just as critical. One of the CMUs brought back to the lab did not meet the strength requirement due to issues with honeycombing, indicating that the problem was likely with production techniques. Figure 9 shows CMU blocks manufactured at the plant in November 2015. These CMUs exhibit far less honeycombing and other structural integrity issues than block manufactured prior to the CEDC partnership, seen in Figure 6. Honeycombing is still a problem at the facility, but this can be attributed to the fact that the workers at the plant deviate from mix design procedure at times.

4.3 Future Plans

Now that the majority of the CMUs are meeting ASTM standards, efforts must be made to ensure a more consistent output. The CEDC team and plant management concluded that the most effective way to achieve a consistently high quality product is to simplify the production process and systemise every aspect to leave little room for error. Beginning with the aggregate, a second sieve will be added to reduce fine particles and improve the aggregate grading. This addition of another sieve will allow the plant to sort the aggregate more precisely, as well as in an additional gradation. The additional aggregate size will enable the employees to create more accurate mixes that have less void space, rather than having to manually estimate aggregate sizes.

Next, the mixed concrete will be processed with the same machinery, but the mix design will be more accurately followed. Some workers of the plant do not recognise concrete production as a science or appreciate the importance of the mix design. In addition, many companies in Haiti reduce the amount of cement (the most expensive component in basic concrete) in the mix to make the concrete cheaper and easier to sell. This mix is aesthetically similar but much weaker. To complicate matters, clients of the block plant have indicated that the surface voids created by this weaker mix is actually preferable since it provides a more adhesive surface for the stucco finish common in Haiti. Therefore, CEDC students are now communicating with the owner of the block plant in order to devise strategies that can ensure adherence to the mix design while accounting for a block that provides the customer-requested surface texture. The next trip to Haiti will include a meeting with the owners to discuss how they can produce CMUs with consistently higher strength by following the advised mix design.

Finally, the curing process will be overhauled, as proper curing drastically improves the strength of concrete (Holliday 2011). The curing process is an essential part of the concrete mixing and strengthening process (Kosmatka 2016). CEDC hopes to work with the plant to bolster this step in their procedure by placing their CMUs in a shipping container for the initial week of curing. The enclosed environment will retain moisture, which the plant can use to artificially create a humid environment by placing bowls of water throughout the shipping container. While the temperature and humidity of the container will still vary, the overall conditions of the shipping container

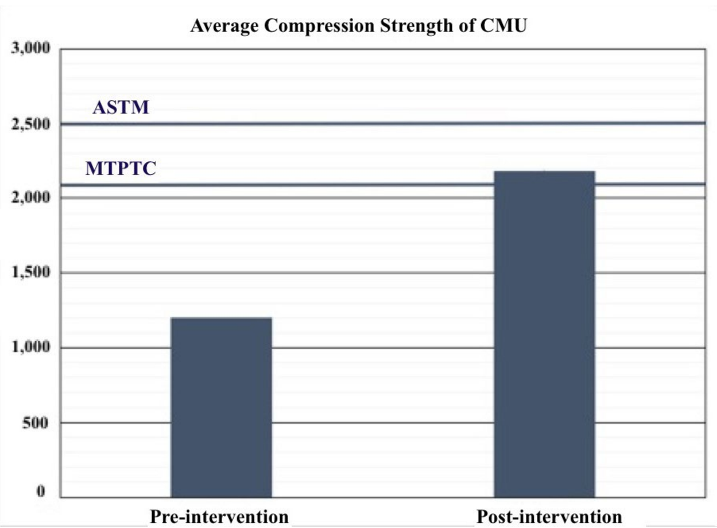


Figure 8: Average compression strength of CMU

Figure 9: A photo of CMUs currently produced by the plant

are going to be more conducive to curing than leaving the blocks outside. In addition, the higher curing temperatures in the container accelerate strength gain, expediting curing time (Kosmatka 2016). The final results should create a higher quality block with more thorough and consistent strength.

5 CONCLUSIONS AND RECOMMENDATIONS

The ramifications of such an effort highlight the impact that a student group can make on a local business, but also on the necessity for a long-term partnership. Even though the CMU consistency has yet to be established, this CMU plant is now distributing CMUs at a considerably higher quality than before partnering with CEDC. This higher quality has been noticed by local contractors and businessmen, who now purchase from the plant over other plants in the area. Since the relationship between the plant and CEDC started, the facility has greatly expanded with the addition of several pieces of equipment and trucks to transport block to various job sites.

In 2010, hundreds of thousands of people lost their lives due to structural failure of concrete buildings, in many cases stemming from poor construction materials (Marshall 2011). Now, due to collaboration of CEDC and local Haitians, buildings in the Central Plateau can be built with much stronger CMUs that are nearly to the ASTM C90 standard. These efforts can easily be replicated throughout Haiti and around the world. CMU plants litter the developing world, and in most places, their procedures can be refined to be more productive, efficient, and effective. On a broader scale, other aid groups should consider adopting more stringent standards to ensure that those in developing countries are not unnecessarily exposed to unsafe conditions.

6 REFERENCES

ASTM C90 Standard Specification for Loadbearing Concrete Masonry Units 2016, *ASTM*. ASTM International. West Conshohocken, Pennsylvania.

Build Change 2012, *Challenges and Opportunities in the Production and Purchase of Good Quality Blocks*, http://buildchange.org/tech/Challenges_Opportunities_Production_Purchase_Good_Quality_Blocks.pdf

Cemex 2008, Manufacturing Quality Concrete Products, Establishing or Upgrading a Quality Program. *Cemex USA-Technical Bulletin 8.0*

CNN Library 2015, *Haiti Earthquake Fast Facts*, viewed 9 May 2016, http://www.cnn.com/2013/12/12/world/haiti-earthquake-fast-facts/

Code National de Batiment D’Haiti (CNBH) 2013, Ministère des Travaux Publics, Transports et Communications (MTPTC), République d’Haïti.

Disasters Emergency Committee 2015, *Haiti Earthquake Facts And Figures*, viewed 9 May 2016, http://www.dec.org.uk/articles/haiti-earthquake-facts-and-figures

Eberhard, MO, Baldridge, S, Marshall, J, Mooney, W, and Rix, GJ, 2010, *The MW 7.0 Haiti earthquake of January 12, 2010; USGS/EERI Advance Reconnaissance Team report.* U.S. Geological Survey Open-File Report 2010–1048, http://pubs.usgs.gov/of/2010/1048/

Farmer, P 2012, *Haiti After the Earthquake*, New York City: Public Affairs.

Holliday, L, Ramseyer, C, Grant, FH 2011, ‘Masonry Block Construction In Haiti’, *Masonry block construction in Haiti, WIT Transactions on the Built Environment*, vol. 120.

International Code Council 2015, *International Building Code,* viewed 23 July 2016, http://codes.iccsafe.org/app/book/toc/2015/I-Codes/2015%20IBC%20HTML/index.html

Kijewski-Correa, T, Taflanidis, A, Mix, D, Kavanagh, R, 2012, ‘Empowerment Model for Sustainable Residential Reconstruction in Léogâne, Haiti, after the January 2010 Earthquake’ *Leadership Management Engineering,* vol. 12, no. 4, pp. 271-287.

Kijewski-Correa, T, and Taflanidis, A, 2012, ‘The Haitian housing dilemma: Can sustainability and hazard-resilience be achieved?’, *Bulletin Earthquake Engineering*, vol. 10, no. 3, pp. 765–771.

Kosmatka, SH, Wilson, ML, 2016, *Design and Control of Concrete Mixtures*, 16th edn, Portland Cement Association (PCA).

Lindell MK 2010, *Built-in resilience,* National Geoscience 3:739–740.

Marshall, JD, Lang, AF, Baldridge, SM, Popp, DR, 2011, ‘Recipe for Disaster: Construction Methods, Materials, and Building Performance in the January 2010 Haiti Earthquake’, *Earthquake Spectra,* vol. 27, no.1, pp. S323-S343.

Plumblee, JM, Cattano, C, Bell, L, Klotz, L 2012, ‘Fulfilling engineering program objectives through service learning campaigns in developing countries’, *Leadership and Management in Engineering*, vol. 12, no. 2, pp 46-52.

Pocock, J, Steckler, C, Hanzalova, B 2016, ‘Improving Socially Sustainable Design and Construction in Developing Countries’, *Procedia Engineering*, vol. 145, pp 288-295.

APPENDIX

Appendix 1: Full results from testing of post-intervention CMUs

SCI Construction Materials | Non Destructive | Geotechnical | Environmental

SOIL CONSULTANTS, INC.
ENGINEERS & GEOLOGISTS
Since 1951
P.O. Drawer 698 • Charleston, South Carolina 29402 • 843/723-4539 • Fax 843/723-3648

Date: August 21,2015

Client: Clemson University

Clemson,S.C.

SCI Report No: GRATIS
Date: 8/21/2015
Sampling by: CLIENT
Units Received: 8/10/2015

Unit Configuration: SINGLE END

Unit Designation/Description:
6'X8"x16" Normal Weight
CLEMSON-Haiti15-1N6SE

Summary of Test Results

	Required Values		Tested Values	
Net Area Compressive Strength	2000	psi	2203.333	psi
Gross Area Compressive Strength	N/A	psi	1413	psi
Density	>125.0	pcf	130.60	pcf
Absorption	13	pcf	10.66	pcf
Minimum Faceshell Thickness	1.25	in	1.147	in
Minimum Web Thickness	1	in	1.116	in
Equivalent Web Thickness	2.25	in	4.17	in
Equivalent Thickness	CLIENT	in	3.683	in
Max Variation from Specified Dimensions	0.125	in	0.375	in
Net Cross-Sectional Area	CLIENT	in^2	56.818	in^2
Gross Cross-Sectional Area	CLIENT	in2	87.891	in^2
Percent Solid	CLIENT	%	64.34	%
Moisture Content	CLIENT	%	11.88	%

Individual Test Results

Block ID	Average Width *(in)*	Average Height *(in)*	Average Length *(in)*	Rcv'd Weight *(lb)*	Max Load *(lb)*	Cross Sectional Area Gross *(in^2)*	Cross Sectional Area Net *(in^2)*	Compressive Strength Gross *(psi)*	Compressive Strength Net *(psi)*
Unit #1	5.625	7.25	15.625	29.414	133,500	87.891	52.249	1520	2560
Unit #2	5.625	7.25	15.625	32.765	88,000	87.891	59.544	1000	1480
Unit #3	5.625	7.25	15.625	32.231	151,000	87.891	58.662	1720	2570
Avg	**5.625**	**7.250**	**15.625**	**31.470**	**124,167**	**87.891**	**56.818**	**1413**	**2203.33**

Performance Improvement of Solar Water Stills by Using Reflectors

Humphrey Maambo
Department of Agricultural Engineering, University of Zambia, Lusaka Zambia
Staff Development Fellow
humphreymaambo@yahoo.com

Isaac Simate
Department of Agricultural Engineering, University of Zambia, Lusaka Zambia
Senior Lecturer
isaac.simate@unza.zm

ABSTRACT: *The lack of safe and clean drinking water sources is one of the problems faced in most rural communities in Zambia. Water in these communities is mostly obtained from shallow wells and rivers. However, this water might be potentially contaminated with harmful substances such as pathogenic bacteria and therefore, unsafe for drinking. Solar water distillation represents an important alternative to palliate problems of fresh water shortages. Solar water stills can be used to eliminate harmful substances from contaminated water by treating it using free solar energy before it can be consumed. Therefore, there is a need to improve solar still performance to produce a greater quantity of safe drinking water. One possible method to improve performance is through adding reflectors to solar stills. Reflectors improve performance by increasing the quantity of distillate by about 22.3 % at a water depth of 15 mm and about 2 9% at a water depth of 10 mm when compared to the distillate produced from a still without reflectors. The water produced using solar stills with reflectors was tested and adhered to World Health Organization (WHO) drinking water standards. This implies that solar distillation with reflectors could be adopted at a larger scale to produce safer drinking water at a reduced cost.*

KEYWORDS: Distillation, Pathogenic Bacteria, Reflectors, Solar Energy, Solar Still

1 INTRODUCTION

Water is the basic necessity for humans along with food and air. There is almost no water left on Earth that is safe to drink without purification. Only 1% of the Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both pathogenic bacteria and toxic chemicals (El-Sabaii, Enein and Ramadan). For this reason, purification of water supplies is extremely important.

Most rural areas in Zambia face serious water supply issues that are comparable to those found in many parts of the developing world. One leading solar energy technology that can revolutionise water quality throughout the less developed world,with widespread adoption, is solar distillation. This technology not only purifies water sources, but also effectively desalinates. Purifying water through solar distillation is a simple yet effective means of providing drinking water in a reliable and cost-effective manner (Regli, Rose and Haas).

Distillation is a process of separating the component substances from a liquid mixture by selective evaporation and condensation. The process may result in essentially complete separation, or it may be a partial separation that increases the concentration of selected components of the mixture. Solar water distillation is a technology that is not only capable of removing a very wide variety of contaminants in just one step, but is simple, cost-effective, and environmentally friendly (Chargoy and Fernandez).

It is not necessary for the water to actually boil to bring about distillation. Steaming it away gently can be more effective. The process of boiling involves the breaking of bubbles which may contaminate the product water, with tiny droplets of liquid water being swept along with the vapour.

The solar distillation process is shown in Figure 1 Solar radiation passes through a glass, heats up the potentially contaminated water causing the water to vaporize. The vapour rises and condenses on the underside of the cover and runs down into distillate troughs (Tamini).

Provided the cost does not rise significantly, an efficiency increase of a few per cent is worth obtaining. Improvements in efficiency are principally sought in materials and methods of construction.

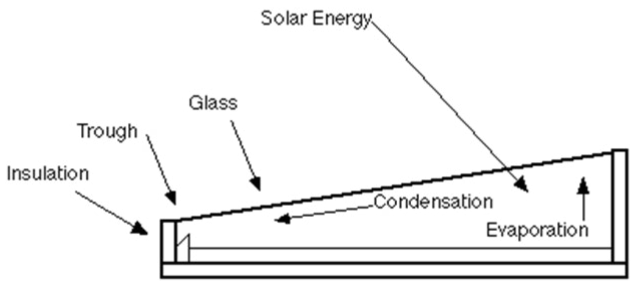


Figure 1: Solar distillation process

Solar water distillation to produce clean drinking water has been found to be only three to five times more economical than commercial water acquisition (Babalola, Boyo and Kesinro). Performance improvements of solar water distillation systems have been slow, likely because it is a low-tech solution to producing safe drinking water. One possible way of improving solar still performance is by using reflectors. Reflectors are cost-effective and improve still performance by reflecting solar radiation towards contaminated water. The quantity of distillate produced from solar water stills with and without reflectors requires investigation to determine if using reflectors is an economical solution. To carry out these investigations, a small-scale solar water still prototype was developed and tested to check whether the distilled water produced adheres to World Health Organization (WHO) drinking water standards.

2 METHODOLOGY

2.1 Product Design

To construct a solar still, materials used should have the following characteristics:

- A long life span of about 5 years under exposed conditions or is inexpensive enough to be replaced upon degradation.
- Be steady enough to resist wind damage.
- Be non-toxic and not emit vapours or instil an unpleasant taste to the water under elevated temperatures.
- Be able to resist corrosion from potentially contaminated water and distilled water.
- Be of a size and weight that can be conveniently packaged and carried by local transportation.
- Be easy to handle.

Local materials should be used whenever possible to lower initial costs and to facilitate any necessary repairs, as long as the materials are of high quality. With this in mind, one must decide whether to build an inexpensive and thus short-lived still that needs to be replaced or repaired every few years, or build something more durable and lasting with the hope that the distilled water it produces will be cheaper in the long run (Chargoy and Fernandez).

2.2 Product Improvements

To improve the performance of the solar still, the following modifications to the product design were introduced:

- Using reflectors.
- Maintaining a low but constant water volume inside the still.
- Pre-heating the potentially contaminated water before it enters the still.

2.3 Product Dimensions

The solar still design with the addition of reflectors has the following dimensions:

Base:	200 x 200 mm
Back wall height:	105 mm
Front wall height:	50 mm
Glass thickness	6 mm
Glazing angle:	15.4^{o} (55 mm rise in 200 mm)
Insulation thickness:	15 mm
Reflector angle:	60^{o} on both sides
Reflector length:	207 mm
Reflector width:	200 mm

The glazing and reflector angles are both critical for design. The glazing angle should be equal to the geographic latitude of the still's location. At this angle, the incident radiation is at right angles with the glass cover, which minimises the amount of reflected radiation.

The reflectors are fixed at a 60^{o} angle on both sides as shown in Figure 2. This angle maximises reflection of solar radiation onto the still from both reflectors at solar noon, the time when the sun is directly overhead (Nichols). Angles less than 60^{o} from the glass cover reduce the reflection effect of the reflectors towards the still. On the other hand, angles greater than 60^{o} will reduce the

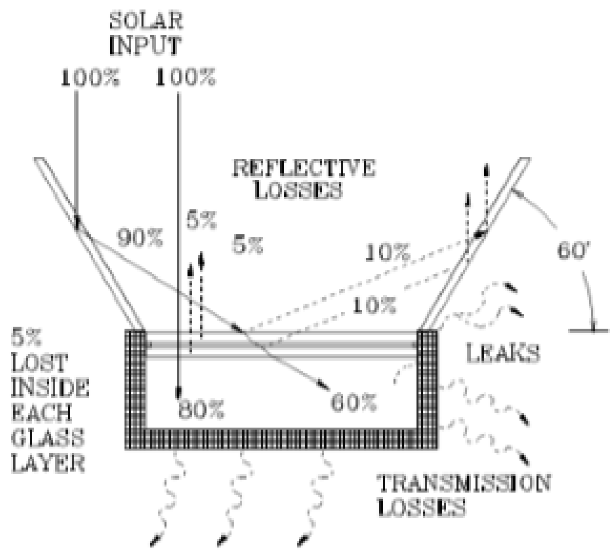


Figure 2: Solar still with reflectors

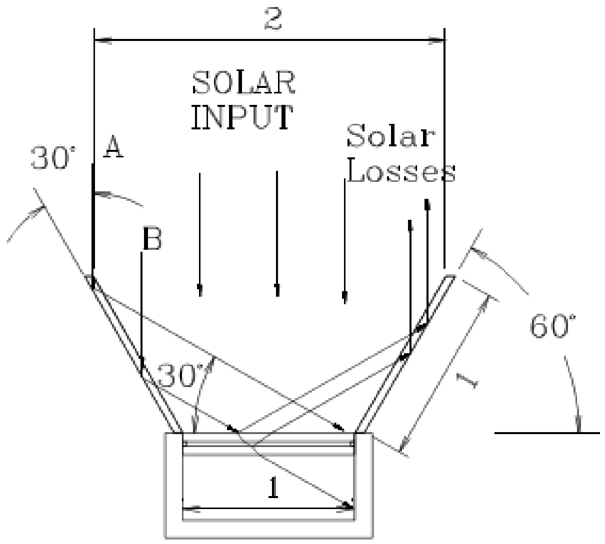


Figure 3: Optimum reflector dimensions

reflection effect at solar noon and will also increase radiation interception. Therefore, a balance is to be struck between maximising reflection of solar radiation onto the still and minimising radiation interception of the reflectors themselves.

The length of the glass is 207 mm. This is the hypotenuse distance of the top layer of the still. A reflector width of 200 mm stretching along the 60° angle was used as a width equal to the base width (200 mm in this case). This geometry means that at solar noon, all of the light reflected by the reflectors is incident upon the glass cover of the base. The optimum reflector dimensions for these still design parameters are shown in Figure 3. A longer reflector will block solar radiation reaching the still when the sun is not at its zenith, and some reflected radiation may not even fall onto the still. A shorter reflector will result in reduced reflection effect.

2.4 Approaches to Achieving Objectives

Two identical solar stills were built, one with and another without reflectors. Of the two, the one with reflectors is expected to produce more distilled water under the same conditions. Its distillate however is not expected to be of better quality.

The plan of action for this project was divided into two major parts. The first part involved theoretical investigations with analytical methods that predicted the optimum tilt angle for the glass cover and the reflectors that were used. The second part of this project involved experimental investigations with outdoor testing of the two stills. After evaluating the results, conclusions were made about the validity of the analytical findings, as verified by experimental evidence. Further conclusions were made about the optimum reflection and orientation of the proposed design.

The still basin was fabricated by a tinsmith (according to drawing specifications) using 0.2 mm galvanised iron sheets. It was insulated with 15 mm thick polystyrene that covered the basin base and all side walls. Ordinary 6 mm thick window glass was used as the glazing and tilted at an angle of 15.4° (testing location latitude) facing true north. A 12.7 mm diameter galvanised steel pipe was cut horizontally resulting in a semi-circle drainage and mounted inside both stills. This formed a collecting trough. The troughs were slanted at an angle of about 8.5° to the horizontal aiding distilled water flow by means of gravity from the condensing surface to the collecting containers.

The solar stills were placed on 25 x 25 mm welded angle iron frame supports on either side of the main supply reservoir. One reservoir was placed on a tripod angle iron stand at a height providing sufficient operating head to supply the main reservoir with water. The tank at a lower head was placed at ground level and had a flow control valve placed in it to limit the water level to a desired depth inside the stills. The angle iron frame was fabricated in such a way that it supports the two stills and the main supply reservoir. The frame on which the stills were placed was at a level equal to that being controlled in the reservoir having the flow control valve. The solar still prototype is shown in Figure 4. This 3D design was modelled in SolidWorks computer software.

The two reservoirs were left open and exposed to solar radiation to provide means of pre-heating the water before it enters the stills through the supply pipes. The supply pipes used were made of polyvinyl chloride (PVC).

Two identical solar stills were fabricated using local materials. One of them had reflectors while the other did not. The two stills each had an interior square base area of 0.04 m^2. Therefore constant water volumes of 600 mL and 400 mL could be achieved by water depths of 15 mm and 10 mm respectively. Change in depth is aided by adjusting the flow control valve; depth influenced the distillate output.

The stills were each filled with water from the same source sample as shown in Figure 5. They were subjected to the same conditions; various yields of distilled water produced from each still were measured daily on a 7-hour interval from 9:00 hours to 16:00 hours.

A data logger was used to record the radiation and ambient temperatures during the 7-hour interval with results tabulated and analysed. The logging interval for the recorded radiation and ambient temperature was one second. This means that readings were taken 25,200 (7 x 3,600) times per day implying 25,200 values for radiation and likewise, 25,200 values for ambient temperature were logged throughout the 7-hour interval. The mean was then calculated for these values resulting in ‘interval average radiation’ and ‘interval ambient temperature’ as tabulated below in Section 3.

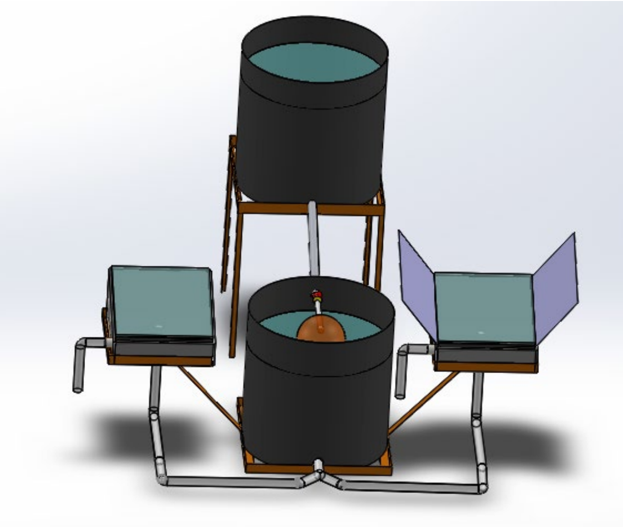


Figure 4: Solar still 3D design view

Figure 5: Solar still prototype testing

Samples of the distillate and raw water were tested for various parameters and compared to World Health Organisation (WHO) drinking water standards. The raw water was obtained from a grey water stabilisation pond called 'Goma Lakes' at the University of Zambia.

The experimental constants were as follows:

- Solar stills were positioned facing true north throughout the experiments.
- The depth of water inside the stills was maintained for the first four experiments and likewise for the last three.
- The two stills were equal in size and dimension.
- Radiation interception due to cloud cover was assumed to have an equal effect on the stills as they were in proximity to each other.
- The time interval for each experiment was maintained between 9:00 hours and 16:00 hours.

The experimental variables were as follows:

- The solar radiation intensity varied throughout the experiment intervals with peak values observed around midday.
- The ambient temperature also varied during the experiments.
- The average water feed rate from the main reservoir to each solar still varied as the distillate output was not the same.
- The experiments were carried out on different days.

3 PROJECT EVALUATIONS

The following results were obtained from the experiments conducted using solar stills with and without reflectors. Observation deductions in relation to different factors have also been presented in Table 1.

The amount of solar radiation received by the stills influenced the distillate output. The linear correlation coefficient, r, has been calculated to measure the strength and the direction of a linear relationship between interval average radiation and distillate output. The value of r is such that $-1 < r < +1$. The (+) and (–) signs are used for positive linear correlations and negative linear correlations, respectively. A positive correlation is

Table 1: Effect of still design on distillate output

Experiment no.	Distillate output		Distillate output percentage increase (%)
	Still with reflectors	Still without reflectors	
1	49.8	59.1	18.7
2	54.7	68.3	24.9
3	54.0	66.4	23.0
4	56.9	69.8	22.7
5	58.4	74.2	27.0
6	59.2	46.8	29.7
7	60.4	78.7	30.3

Table 2: Effect of solar radiation and water depth on distillate output

Experiment no.	Depth (nm)	Interval average radiation (W/m²)	Distillate output (mL)	
			Still without reflectors	Still with reflectors
1	15	622	49.8	59.1
2	15	664	54.7	68.3
3	15	626	54.0	66.4
4	15	660	56.9	69.8
5	10	564	58.4	74.2
6	10	701	59.2	76.8
7	10	700	60.4	78.7

observed for all r values obtained between experiments 1 to 4 and 5 to 7. These positive values indicate a relationship between the two variables such that as values for interval average radiation increase, values for distillate output also increase. The lowest value of r recorded was approximately 0.78.

Table 2 clearly shows that there is an incremental difference in the distillate output per day between the two different designs. Using reflectors increased the amount of distilled water produced from 19 % to 30 % that is largely due to the fact that more solar radiation was received by the still with reflectors. More radiation translates into more light to heat energy transformation and more heat energy results in increased distillate output eventually improving solar still performance. The variations in the percentageincrements were influenced by other factors (such as amount of radiation received) rather than still design factors.

The coefficient of determination, r^2, has also been calculated. A linear association between interval average radiation and distillate output where $0 < r^2 < 1$ allows us to determine how certain one can be in making predictions from the generated model. The extent to which interval average radiation affects distillate output is shown by the values of r^2. Stronger linear relations are represented by values closer to 1 whereas weaker linear relations are represented by values closer to 0. Furthermore, values close to zero mean that the relationship between interval

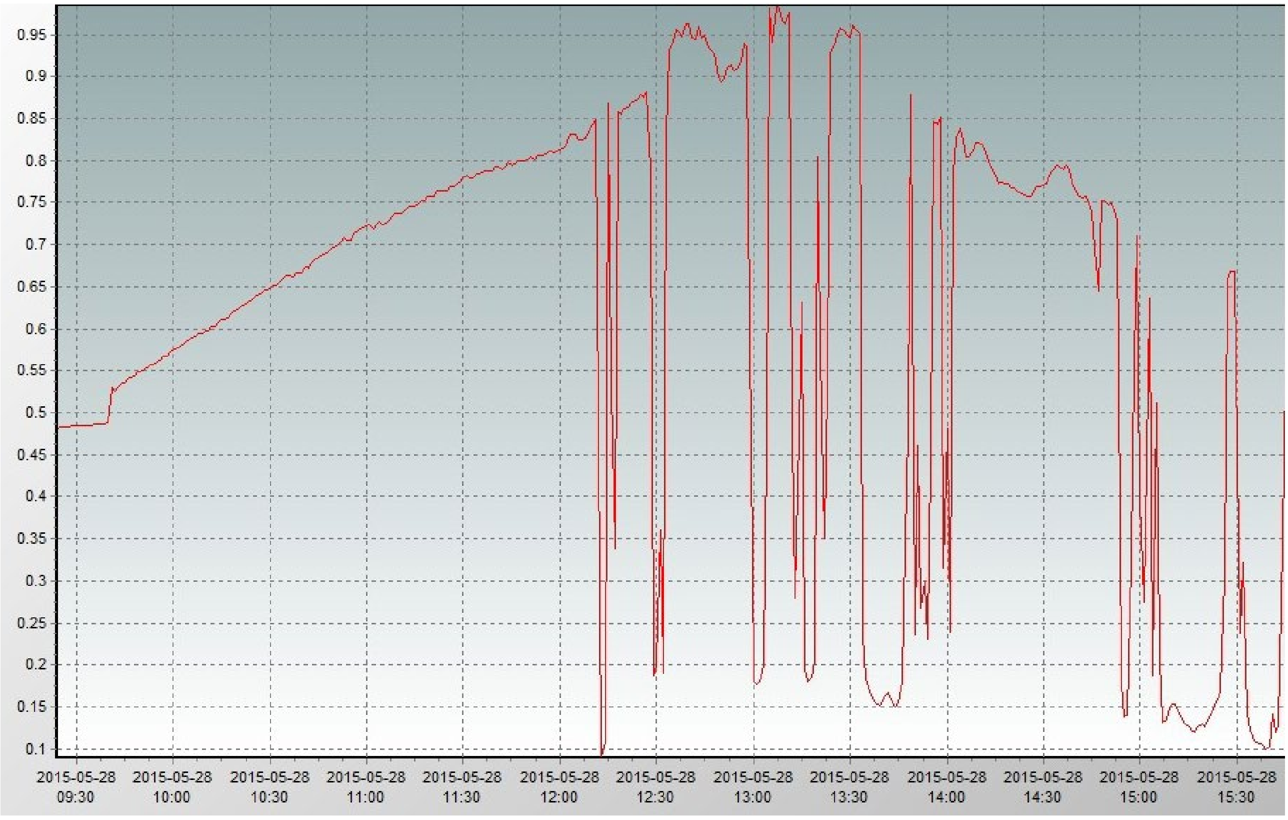


Figure 6: Radiation (kW/m²) against Time (hrs) plot for Experiment 1

Figure 7: Radiation (kW/m ²) against Time (hrs) plot for Experiment 3

average radiation and distillate output might be non-linear.

In experiments 1 to 4, r^2 is approximately 0.60 and 0.64 for the stills without reflectors and the still with reflectors respectively. Likewise in experiments 5 to 7, r^2 is approximately 0.64 and 0.82 for the stills without reflectors and the still with reflectors respectively. This means that the interval average radiation is not the only factor affecting distillate output. In experiment 3, the 626 kW/m² recorded is nearly the same as the 622 kW/m² recorded in experiment 1, but substantially higher distillate quantities are obtained from both stills.

A plot from the data obtained from the data logger reveals inconsistencies in the radiation received in Experiment 1 as shown in Figure 6 Peak radiation values of about 0.95 kW/m² were observed around 13:10 hours. Radiation interception as a result of cloud cover is also observed from about 12:15 hours to 16:00 hours, with radiation values dropping to as low as 0.1 kW/m².

A slightly uniform radiation pattern is observed during Experiment 3 as shown in Figure 7. Peak values of 0.8 kW/m² were observed around 12:00 hours. The lowest observed value was 0.25 kW/m² around 15:45 hours, about 15 minutes before the end of the experiment interval.

The inconsistency observed from the radiation pattern recorded from the data logger is a possible explanation for the disparity in distillate output between Experiments 1 and 3, despite their similarity in interval average radiation. This variation in distillate output was not expected on days where the radiation pattern is consistent and follows the same pattern throughout the day. Cloud cover reduces the interval average radiation, resulting in reduced distillate output and reflector effectiveness (percentage increase as a result of the use of the external reflectors).

Experiments 4 and 5 shown in Table 2 are at depths 15 mm and 10 mm respectively. An additional 96 W/m² of radiation was received in Experiment 4 but produces lesser

Table 3: Effect of ambient temperature on distillate output

Experiment no.	Interval average ambient temperature (°C)	Distillate output (mL)	
		Still without reflectors	Still with reflectors
1	25.2	49.8	59.1
2	28.2	54.7	68.3
3	27.7	54.0	66.4
4	29.0	56.9	69.8

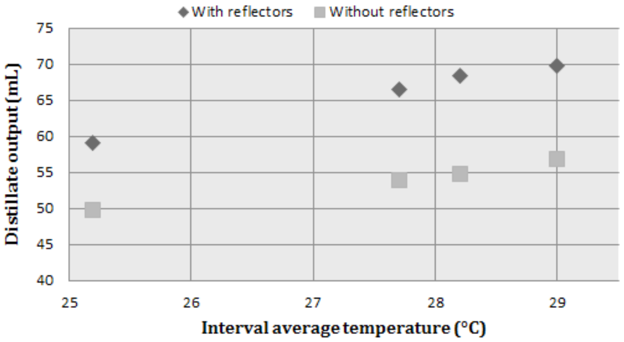


Figure 8: Distillate output as a function of interval average radiation

distillate in both still design cases than in Experiment 5. This is because water surfaces with a higher surface area per mL ratio require less intense energy to evaporate a given volume than those with relatively lower surface area per mL ratios. Therefore distillate production rates are higher from water with a volume at a depth of 10 mm as compared to that at 15 mm.

A relationship of the distillate output as a function of interval ambient temperature has been illustrated in Figure 8. Higher distillate quantities have been accompanied by higher interval ambient temperatures for each experiment in both stills (Table 3). The overall system heat losses are reduced due to the drop in temperature gradient between the still and its surroundings.

A few selected water parameters were tested at the environmental engineering laboratory at the University of Zambia and compared to World Health Organization (WHO) drinking water standards. After making the comparisons recorded in Table 4, the water produced by the still was clearly clean and safe for drinking.

Some parameters were not tested due to financial constraints but testing for hardness for example gives us an indication that other chemicals such as nitrates or sulphates are also absent. A zero count of faecal coliforms was observed from the distilled water sample. Faecal coliforms are indicator organisms for possible bacterial contamination in the water (Christian and Pipes). Positive tests for these would mean the water possibly contains pathogenic bacteria such as Escherichia coli (E. coli) making it unsafe for drinking.

It is clear that a still with reflectors will increase the amount of distillate produced from a solar still as compared to an identical still without reflectors. The increment is brought about simply by the additional light energy that the reflectors reflect towards the water to be distilled.

To justify the use of reflectors on a still to increase the distillate output, we compare the cost of making a relatively bigger solar still having no reflectors to produce the same amount of water.

Assume that a solar still without reflectors having a basin area of 1 m² can produce an average of 3 L/day (i.e. 3 L/m²/day). If the distillate quantity desired was 3.75 L/day for example, with reflectors the still will require a basin area of only 1 m². This is because reflectors may increase distillate output by about 25 %, hence, raising the distillate output from 3 L/day to 3.75 L/day. On the other hand, for a solar still without reflectors to produce 3.75 L/day, a basin area of about 1.25 m² will be required. This would result in additional costs of buying more basin material, a bigger glass cover, more tank paint, a relatively stronger basin support, more insulation material and higher fabrication labour costs. Whereas to increase the distillate output by using reflectors, only additional reflective material is required.

This additional cost incurred on stills without reflectors would be quite high when compared to costs incurred from buying additional reflector material when 7 to 10 L/day of distillate is required. The 3.75 L/day used in this scenario is simply for justification purposes.

Adding reflectors to already existing stills creates a monetary saving, as costs that may arise from

Table 4: Water quality laboratory results (sampling date: 4th June 2015; testing date: 6th June 2015)

Parameter	Raw water sample (Goma Lakes)	Still distillate water	Drinking water quality standard (WHO)
Physical			
pH (-)	7.63	7.7	6.6 to 8.5
Total dissolved solids (mg/L)	354	15.2	0 to 500
Turbidity (NTU)	14.3	0.95	< 1.5
Chemical			
Alkalinity ($CaCO_3$ mg/L)	204	7	500
Total hardness ($CaCO_3$ mg/L)	284	11	500
Microbiology			
Faecal coliforms (no. per 100 mL)	33	0	0
Total coliforms (no. per 100 mL)	129	0	0

constructing a bigger still for the purpose of increasing the distillate quantity are not incurred. The simplicity of adding reflectors also makes this improvement an attractive alternative. Other improvements mentioned earlier like maintaining a low and constant water level inside the still and preheating the potentially contaminated water may need a few adjustments to an existing still but both of them are cheaper alternatives than constructing a bigger still altogether.

4 CONCLUSIONS AND RECOMMENDATIONS

Solar water stills are innovative, effective, simple, and decentralised on-site water treatment system that provides safe drinking water in a cost-effective and reliable manner. For the purpose of this study, solar stills with and without reflectors were constructed and observed under normal environmental conditions in Lusaka, Zambia.

The addition of reflectors to the solar still improved the still’s performance, producing a higher quantity of water than the still without reflectors. The reflectors increased the quantity of distillate by about 22.3 % at a water depth of 15 mm and about 29 % at a water depth of 10 mm when compared to the distillate produced from a still without reflectors. The effect of using reflectors was greater when the water was shallower.

The total amount of distilled water produced from the stills depends on many factors, including: solar radiation, ambient temperature, water depth, and still design. In order to determine if the distillate output was influenced by modifying the design of the solar still, experiments were conducted at the same time under the same conditions using solar stills with and without reflectors. The outcome of the experiments demonstrates that improved solar still design has a positive impact on distillate quantity production.

The water produced by the solar still with reflectors was tested and the quality adhered to World Health Organization (WHO) water standards required for potable water. This implies that the distillation method could be adopted at a larger scale to produce greater quantities of clean and safe drinking water.

Based on the design, fabrication and operation of the solar water still with reflectors, the following recommendations can be made:

- Mounting an additional reflector on the back of the still further improves the amount of solar radiation received by the potentially contaminated water.
- Lower the depth of water to about 10 mm. A lower depth further reduces the amount of heat required to make the potentially contaminated water evaporate.
- Fabricating an identical solar still without providing preheating and low and constant depth improvements could help clarify the effects of the solar still design modifications.
- Selecting a better testing location for the stills, such as a vegetation-covered area which minimises or prevents dust particles settling on the glass, could also increase the efficiency. The vegetation should minimize or prevent soil erosion without intercepting incoming radiation.
- Take measurements at hourly intervals of distillate outputs from both stills and compare results.

5 REFERENCES

Babalola, TA, Boyo, AO & Kesinro, RO 2015, ‘Effect of water depth and temperature on the productivity of a double slope solar still’, *Journal of Energy and Natural Resources,* vol. 4, no. 1, pp. 1-4.

Chargoy, N & Fernandez, J 1990, ‘Multistage, indirectly heated solar still’, *Journal of Solar Energy*, vol. 44, no. 4.

Christian, RR & Pipes, WO, 1983, ‘Frequency distribution of coliforms in water distribution systems’, *Applied Environmental Microbiology,* vol. 45, pp. 603-609.

El-Sabaii, AA, Enein, SA, Ramadan, MRI. & El-Gohary, HG 2002, ‘Experimental investigation of an indirect type natural convection solar dryer’, *Energy Conversion & Management*, vol. 43.

Nichols, AC 1993,’How solar ovens work’, *The tracking solar cooker,* Tucson Arizona, http://www.solarcooking.org/plans/Cookerbo.pdf

Regli, S, Rose, JB, Haas, CN & Gerba, CP 1991, ‘Modeling the risk from Giardia and viruses in drinking water’, *Journal of American Water Works Association,* vol. 83, no. 11.

Tamini, A 1987, ‘Performance of solar still with reflectors and black dye’, *International Solar and Wind Technology,* vol. 4, pg. 443.

World Health Organization 2006, Guidelines for Drinking-Water Quality’ *First Addendum to Third Edition,* vol. 1.

The Design and Installation of Solar Home Systems in Rural Cambodia

Rebecca Watts
Engineers Without Borders, Melbourne Australia
rebecca_watts@live.com

Jeremy Smith & Andrew Thomson
Research School of Engineering,
The Australian National University, Canberra Australia

ABSTRACT: *This study contends that solar home systems (SHS) are an appropriate solution to provide affordable, reliable and clean electricity in rural Cambodia. SHS provide decentralised electricity suitable for the electricity needs of rural households and with the decreasing cost of solar energy technologies, SHS are becoming an increasingly competitive source of energy. This study details the design and installation of two SHS in a rural community in Cambodia. The SHS have replaced the use of kerosene lamps and supplemented car battery usage, which has generated a cost saving of USD$2.50-3.20 per month. The SHS have increased the hours of quality lighting making it possible for users to improve educational outcomes by studying at night and participating in private education classes as well as potentially extending their working hours that provides an opportunity to increase their income. Community involvement in the installation of SHS and participation in an education program has ensured transfer of knowledge about system operation and maintenance at a local level that has ensured economic, social and environmental were benefits. This study builds a case in support of solar energy at the household level in rural Cambodia and makes recommendations for the deployment of SHS in rural communities throughout the developing world.*

KEYWORDS: Solar energy, rural off-grid electrification, solar home systems, sustainable development

1 INTRODUCTION

Eighty per cent of the population in Cambodia lives in rural areas where access to grid electricity is as little as 18.8 % (World Bank, 2015). Due to dependence on expensive imported oil, losses in distribution and lack of high voltage transmission lines, electricity tariff in Cambodia is the highest in the Southeast Asian region (United Nations, 2007). Communities in rural areas use alternate energy sources that: are expensive, pose health risks, are potential fire hazards, and are damaging to the environment. An estimated 1.06 million rural households use kerosene lamps as their primary source of lighting and a further 1.12 million rural households (45 % of rural households) use car batteries charged at isolated battery charging stations (BCS) (International Finance Corporation [IFC], 2012).

The alternate energy sources are more costly than grid electricity and as 90 % of the poor live in rural areas, this cost disproportionally impacts rural households. The use of kerosene lamps accounts for an average 4.9 % of total expenditure for rural households (IFC, 2012). The lamps provide low illumination, which hinders activities at night such as, cooking and studying. Furthermore, the burning of kerosene emits health-damaging pollutants and can cause structural fires to houses, severe burn injuries and the unintentional ingestion of kerosene is a risk to children (Mills, 2012). The BCS emit tons of CO2 each year, are plagued with poor conditions which pose health threats to workers and due to inadequate infrastructure allow acid to spill into the public drainage system and contaminate the groundwater and surrounding soil (Ministry of Environment, 2004). The BCS rely on expensive imported diesel thus recharging batteries accounts for an average 4.5 % of total expenditure for rural households (International Finance Corporation, 2012). To give context to this lack of affordable energy access, the average expenditure on electricity in Australia is 2 % of household income (Australian Bureau of Statistics, 2013) while the average Australian electricity usage is over 300 times higher than a rural Cambodian household (10,400 c.f. 31 kWh/capita/annum).

The Royal Government of Cambodia has made progress towards extending the electricity grid however at least 30 % of Cambodian households are not scheduled to have access to the grid until 2030 at the earliest (Ferranti et al. 2016). Due to the ease of installation and appropriateness of the technology, solar home systems (SHS) are a disruptive method of improving energy access in Cambodia. The largest injection of SHS has come from two initiatives: The Rural Electrification Fund (REF) and The Good Solar Initiative. The initiatives have installed an aggregate 20,000 SHS, with an aim to roll out a further

20,000 and 25,000 respectively by 2018 (Ferranti et al. 2016). These initiatives comprise of SHS from numerous companies that have made comparatively lower private sales.

Despite the appropriateness of the technology, care must be taken in project implementation. There are many examples of electrification aid projects that have rapid cycles of installation to failure (Quoilin & Orosz, 2013). One such project occurred in the rural Secret Beach community in south Cambodia. A solar panel and battery system was installed in the community’s local primary school in 2013 and was only operational for six months. The system was incorrectly sized and designed with no community consultation. Due to the absence of community involvement in implementation, there was a lack of local knowledge about the operation and maintenance of the system. This project implementation approach failed to create a sense of ownership and damaged the reputation of the technology. This study details a project completed by the author and a partner non-government organisation (NGO) in the Secret Beach community. The project rectifies previous failings by applying the principles of human-centred design and taking a participatory implementation approach.

2 SOLAR HOME SYSTEM BENEFITS

A community committee in Secret Beach identified electricity access as a priority to achieve economic development and increase quality of life (Saly, 2014). This study details a project that encompasses the design and installation of two SHS in the community to assess the appropriateness of SHS in achieving this vision. SHS consist of a solar panel, charge controller, battery and a load and the suitability of the technology is discussed below.

2.1 Affordable and suitable for small-scale, decentralised generation

The reduction in cost of solar panels (reaching less than USD$1.0 per Watt in 2015) (Fraunhofer, 2016) has increased the accessibility of solar energy technologies to low-income populations if accompanied by appropriate financing arrangements. Solar modules are sold according to the Watt-peak (Wp) and as the price does not scale with module size, they are appropriate for small-scale electricity generation (Advisory Group on Energy and Climate Change, 2010). SHS provide a decentralised energy supply, which is well suited to remote locations where grid extension is not economically viable like the Secret Beach community. Poor project implementation and lack of accessible financing options for households pose the most significant barriers preventing wide-scale roll out of SHS.

2.2 Reliabible and convenient

Car batteries, like those used in households in the Secret Beach community, are shallow cycle and are not designed for the current practice of overcharging and high depth of discharge. This practice reduces the lifetime of the battery that varies from eight to 24 months (Ministry of Environment, 2004),(Rijke, 2008). The SHS encompasses a deep-cycle battery that is more suitable for a high depth of discharge. The SHS also operates with a charge controller, which regulates the charging and discharging of the battery and thus increases the expected battery lifetime. As the battery is charged from the solar panel, the battery remains within the household. The time previously spent or cost incurred from transporting the battery to and from an external charging source (for example a BCS) can be spent on income creating or social activities.

2.3 Opportunity to implement clean and renewable energy technologies

The lack of existing electricity infrastructure in Cambodia presents an opportunity to leapfrog emissions intensive energy systems and satisfy growing demand through cleaner energy sources (United Nations [UN], 2010). Solar energy is a clean and renewable source and an energy system transformation to such technologies can support sustainable wealth creation while reducing the strain on resources and climate (UN, 2010).

3 SOLAR HOME SYSTEM DESIGN AND IMPLEMENTATION

The following sections detail the human-centred design of the SHS and participatory implementation approach in the community.

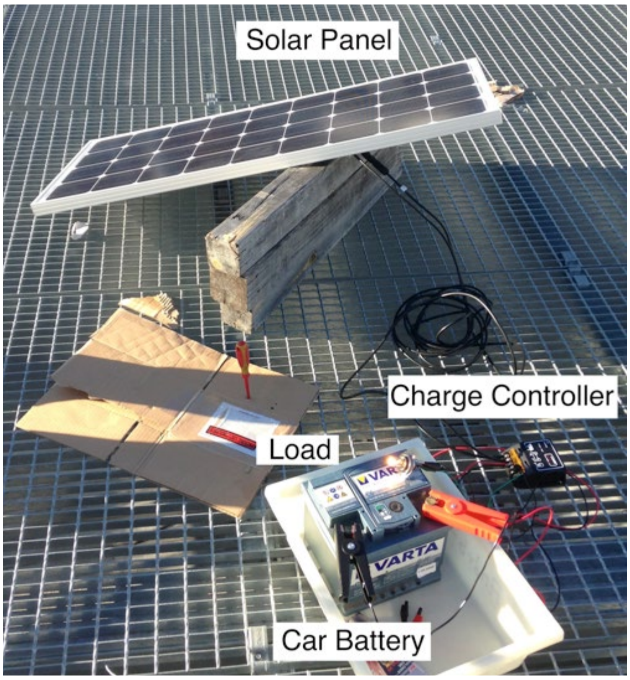
3.1 SHS design and prototype

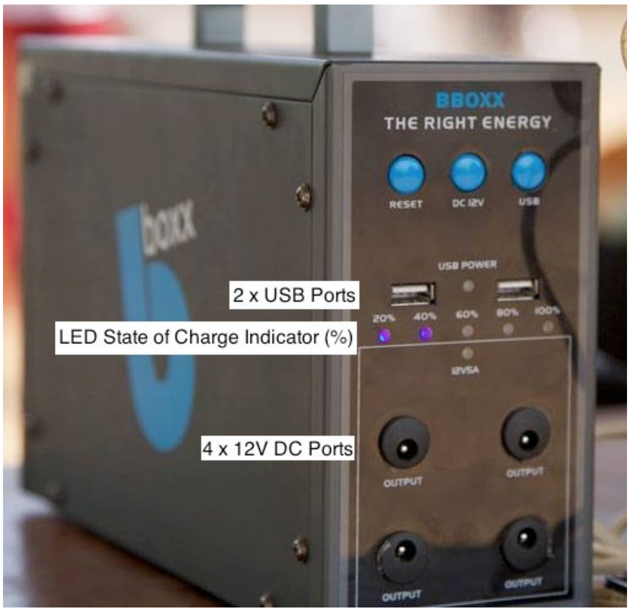
The human-centred design process starts with understanding the user (IDEO, 2015). Data about energy consumption, expenditure and the aspirations of the families in Secret Beach was gathered through a field visit by the author and community consultation (see Appendix 2). This consultation uncovered that the end-users prioritised: lights, phone charger, TV and fan and with main influencing factors being reliability and affordability. Based on this information, a SHS was designed to satisfy the user requirements and prototyped and tested, illustrated in Figure 1.

Assembling the prototype highlighted considerations for the final system configuration. Purchasing components individually allows for system customisability however requires a multistage wiring process and the system is vulnerable to tampering. Testing the system uncovered information to be communicated to the community, for example the decrease in panel output from shading and the importance of correct panel orientation.

3.1 SHS design and prototype

Based on an assessment of the usability, quality and price of the systems available in the market, the author, community and partner NGO decided the most appropriate SHS was the Bboxx BB7 (including a 15 Wp panel and 7 Amp-hour battery). The system satisfies the user





Top to bottom:
Figure 1: Photo of the model system
Figure 2: Control unit of Bboxx BB7 (Bboxx, 2015)
Figure 3: Solar energy workshop

requirements and is supplied by a suitable local supplier. The supplier provided the most comprehensive after sales support and importance was placed on this due to the lack of such support for the system installed in 2013.

Pictured in Figure 2, the Bboxx BB7 has an integrated control unit, which removes difficulties and complexities in system wiring. The infused casing reduces the chance of tampering or removal of the charge controller, which was an issue in previous SHS projects in Cambodia (Rijke, 2008). The battery (sealed lead-acid) is suitable for the generation and consumption profile of solar power and requires minimal maintenance (Power Sonic, 2009) which reduces health and safety concerns. These features address concerns identified in the prototyping stage, thus the final system design improved before reaching the end-user.

Based on community consultation, the two locations for the SHS were decided to be:

- At a household (HH1) whose family had expressed a desire to access solar energy; and
- At the local primary school (HH2) to provide electricity to teachers and students and the family who lives in the school office.

3.3 Economic viability

In 2011, 72 % of the population in Cambodia lived on less than US $3 per day (Asian Development Bank, 2014). The upfront cost of SHS like the Bboxx BB7 (RRP US $129) is unattainable for the majority of the population. Through further cost reductions in solar technologies and establishing efficient financing, SHS are becoming increasingly affordable for communities in rural areas. Appendix 1 indicates the affordability by investigating three hire-and-purchase arrangements. The arrangements are based on the model used to analyse the REF initiative (World Bank, 2012) and have similar payment periods currently offered in the SHS market.

3.4 Education and training

Education workshops (illustrated in Figure 3) were conducted with community members to raise awareness about solar energy and create user understanding about the operation and maintenance of the SHS. This education rectifies the shortcomings of the approach for the system installed in 2013. The workshops encompassed activities supported by visual tools, with material developed from research and learnings from the prototyping stage.

The activities included practical learning, for example participants practiced the operation and maintenance of the systems. Importance was placed on the communication method, as it is the process through which knowledge is shared, and determines whether learning occurs (Cummings, 2003). Through an open floor discussion, the participants shared their experiences with current energy sources and discussed the advantages of solar energy and the benefits of SHS. Development experts have identified that activities, which focus on facilitating knowledge sharing, are more likely to be successful than those focusing on transmitting Northern knowledge to South

Figure 4: Community involvement in installation

(Ellerman, Denning, & Hanna, 2001). The discussion both facilitated knowledge sharing and also indicated which information had been understood during the workshop. Thus, gaps in knowledge were explained to ensure a comprehensive understanding.

3.5 Community involvement in installation

With relevant training, community members were involved in installing the systems to develop local capacity for further SHS installation and create a sense of ownership. Community involvement also facilitated technical knowledge sharing. For example, the site for installation of the panel (Figure 4) was decided based on discussion about the importance of an unshaded location and the panel placed at the correct orientation.

4 MONITORING AND EVALUATION

As the SHS were purchased to trial the appropriateness of the technology, members of HH1 and HH2 (the users) committed to the author and partner NGO to provide feedback about user experience and system performance. The users were surveyed one, three and five months post installation to capture the initial and ongoing impact of SHS usage. There is often a lack of ongoing monitoring on similar projects. Survey results indicate the SHS have provided a reliable source of electricity and reduced usage of car batteries and kerosene lamps. The users have independently operated and maintained the systems and are able to explain to other community members how to the use systems. This information implies the workshops were successful in transferring knowledge. In addition, the workshop material was repeatedly used by community members for further training and increased the awareness of solar energy in the community.

The Most Significant Change (MSC) in behaviour is a method of participatory evaluation (Davies & Dart, 2005) that assesses the impact of technology through user stories. The MSC in behaviour for the SHS users and the associated economic, health/social and environmental benefits are described in Table 1.

5 RECOMMENDATIONS

There is significant potential for SHS to replace emissions intensive and expensive energy sources in rural households throughout Cambodia. Small-scale systems can have a significant impact on the lives of users by generating economic, social and environmental benefits as demonstrated in this study. This study provides insight into the design and implementation process of a SHS project and from this, recommendations for SHS projects in rural communities in Cambodia and other developing countries are outlined below.

5.1 Design considerations

- The SHS should be tailored to the user and the community should be involved in the decision-making throughout the project. This ensures the design is appropriate and community is empowered by the project.
- The SHS design and implementation process should be iterative, starting small scale and involve prototyping. This allows for user-feedback that ensures the design is constantly improving.

5.2 Implementation considerations

- Education should be provided to ensure systems are operated and maintained correctly. This will enable associated benefits to be generated and create user satisfaction.
- A local technician should be trained to provide local support and facilitate the expansion of SHS usage. This will assist in longevity of the SHS and create employment opportunities.

5.2 Project considerations

- A suitable user pays arrangement (see Section 3.3 and Appendix 2) should be established to provide access for low-income households and assist in the financial sustainability of the project.
- The project should leverage on existing strengths in the community, for example engaging organised groups and leaders within the community.
- Effective monitoring and evaluation tools should be established to capture user feedback and influence each iteration of the project. This ensures the project design implementation approach is constantly improving.

6 CONCLUSION

The project presented in this paper demonstrates the economic, social and environmental benefits SHS can generate for rural households in Cambodia. By taking a human-centred design approach, the project designed SHS that were suitable for users. Involving the community in project implementation built capacity and ensured technical knowledge was embedded locally. Successful monitoring and evaluation tools captured feedback from the users ,which validated that SHS can replace emission intensive and expensive energy sources. By providing

Table 1: MSC in behaviour for the SHS users and the associated economic, health/social and environmental benefits

MSC1: Members in HH1 have reduced the frequency of recharging their car battery and now charge mobile phones in their home rather than at a neighbour's home.	
Indicator	**Benefit**
Economic	Cost saving ($3.20 per month) due to reduced frequency of battery recharging. Increased productivity as the time previously spent taking the battery and phone to charge at external sources can be spent on income creating activities.
Health/social	Reduction in exposure to toxic gases and toxic effects of lead absorption from the battery.
Environmental	Reduction in emissions from BCS due to reduced frequency of battery recharging.

MSC2: Members in HH1 have run private education classes at night due to the increased hours of quality lighting.	
Indicator	**Benefit**
Economic	Extended working hours and potential to increase income.
Health/social	Increased education opportunities for children in the community.

MSC3: The teachers have charged their mobile phones at the school (HH2) rather than at their respective houses or at a café.	
Indicator	**Benefit**
Economic	Cost saving from previous charging source (either from café purchases or reduced frequency of battery recharging). Increased productivity due to increased connectivity from higher access to mobile phones.
Health/social	Increased awareness of solar energy as students and teachers at the school are exposed to the SHS. The ability to charge phone at the school has incentivised teachers to attend classes, which has in turn increased education for students. Increased access to information due to increased access to mobile phones.
Environmental	Reduction in emissions from BCS due to reduced frequency of battery recharging (as car batteries were used to charge mobile phones).

MSC4: The family that resides at HH2 have replaced kerosene lamp usage with high quality light-emitting diodes (LEDs). This has increased the hours of lighting and the quality of lighting, which has enabled the teacher (father of the family) to write his lesson plan and allowed the children read at night.	
Indicator	**Benefit**
Economic	Extended working hours and cost saving of US$2.50 per month due to the elimination of kerosene use.
Health/social	Increased education for the children. The extended work hours for the father has increased recreational activities and time spent with children during the day.
Environmental	Reduction in indoor pollution and reduced risk of burns and indoor fires caused by the kerosene lamp.

affordable, reliable and clean electricity SHS are thus an appropriate energy solution for rural households.

Given the lack of existing electricity infrastructure, the high and volatile price of electricity and remoteness of rural communities, SHS have huge potential in transforming energy usage in rural households. Rural communities comprise almost 80 % of the population in Cambodia and with the limited successful market penetration; there is a significant market for SHS. Increasing access will translate the benefits demonstrated in the project into widespread economic growth, poverty reduction and environmental sustainability. The author encourages prospective entrepreneurs, NGOs and the public and private sector to consider the recommendations made in this paper and increase the deployment of SHS.

7 REFERENCES

Advisory Group on Energy and Climate Change, 2010, *Energy for a Sustainable Future: Report and Recommendations*. United Nations, New York.

Asian Development Bank, 2014, *Cambodia: Country Poverty Analysis 2014,* Phillipines: Asian Development Bank.

Australian Bureau of Statistics 2013, 4671.0 - *Household Energy Consumption Survey,* http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/4671.0~2012~Main%20Features~Data%20availability~28

Bboxx 2015, *Solar Calculator,* viewed September 8 2015, http://www.bboxx.co.uk/solar-calculator/

Cummings, J 2003, Knowledge Sharing: *A Review of the Literature*, The World Bank Operations Evaluation Department, Washington DC: The World Bank.

Davies, R & Dart, J 2005, *The 'Most Significant Change' (MSC) Technique*, RJ Davies and J Dart, http://www.mande.co.uk/docs/MSCGuide.pdf

Ellerman, D, Denning, S, & Hanna, N 2001, 'Active Learning and Development Assistance', *Journal of Knowledge Management*, vol. 5, no. 2, pp. 171-179.

Ferranti, R, Fullbrook, D, McGinley, J, & Higgins, S 2016, *Switching on: Cambodia's Path to Sustainable Energy Sector,* Phnom Penh: Mekong Strategic Partners.

Fraunhofer Institute for Solary Energy Systems, *2016 Photovoltaics Report,* updated 11 March 2016. Fraunhofer ISE.

IDEO. 2015, *The Field Guide Human-Centered Design*, Canada: IDEO.org.

International Finance Corporation 2012, 'Lighting Asia: Solar Off-Grid Lighting' International Finance Corporation, World Bank Group.

Mills, E 2012, *The Lumina Project: Technical Report #10,* Lawrence Berkeley National Laboratory, University of California.

Ministry of Environment 2004, *Technical Report: Status of Used Lead Acid Battery Management in Kingdom of Cambodia,* Department of Environmental Pollution Control. Phnom Penh: Royal Government of Cambodia, Phnom Penh.

Ministry of Industry, Mines and Energy 2013, *National Policy, Strategy and Action Plan on Energy Efficiency in Cambodia,* Phnom Penh: Royal Government of Cambodia, Phnom Penh.

Power Sonic 2009, *'Sealed Lead-Acid Batteries: Technical Manual',* Power-Sonic Corporation.

Quoilin, S, & Orosz, M 2013, 'Rural Electrification through Decentralised Concentrating Solar Power: Technological and Socio-Economic Aspects', *Journal of Sustainable Development of Energy, Water and Environment Systems,* vol. 1, no. 3, pp. 199-212.

Rijke, K 2008, Strategy and Design of a Solar Shop in Rural Cambodia, masters thesis, Industrial Design Engineering, Delft University of Technology, http://www.kcstrategicdesign.com/kamworks_files/StrategyDesignSolarShopWEB.pdf

Saly, K 2014, *BeeKeeper Solar Research,* Unpublished.

United Nations 2007, *DRAFT: Cambodia Energy Sector Strategy* Agenda 21.

United Nations Secretary-General's Advisory Group on Energy and Climate Change 2010, *Energy for a Sustainable Future,* New York.

World Bank 2015, *Access to electricity, rural (% of rural population),* online database, World Bank, Sustainable Energy for all (SE4ALL) database from World Bank, Global Electrification database, viewed 26 March 2015, http://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=KH

World Bank 2012, *Implementation Completion Results Report: to The Kingdom of Cambodia for a Rural Electrification and Transmission Project,* Sustainable Development Department, Southeast Asia Country Management Unit, East Asia and Pacific Region.

APPENDICES

Appendix 1: Community survey

The partner NGO provided a survey of 19 households in Secret Beach on energy usage and sources of energy (Saly, 2014). The households were a sample selected as a representation of the entire community. Consistent with the research presented in Section 1, the households use a variety of energy sources. For lighting, the households use a combination of lights powered from disposable batteries (700 riel USD $0.175 per set), kerosene lamps (USD $0.875 per litre) and/or car batteries. The usage and expenditure on kerosene was not captured in the survey and will not be included in calculations. Car batteries were the predominant source of energy for the households and will be included in the economic analysis.

As a representation of the survey, Table 1 details the expenditure on recharging a battery and appliances used by three households. Based on the data the assumed usage in Watt-hours (W?hrs/day) and associated levelised cost of electricity (LCOE) were calculated.

Appendix 2: Economic analysis

As there were only two systems installed, one being at the school (a public place and with public usage), it was not viable to establish a user-pays financing arrangement. To provide insight into affordability and potential financing arrangements, the following section investigates scenarios for the repayment of the Bboxx BB7 (USD $129). To cater to the different financial capacity of rural households, three scenarios were investigated and described in Table 2. Scenario 1 is for the total cost to be paid upfront, whereas scenario 2 and 3 hire-and-purchase arrangements. This model is based on the model used to analyse the SHS initiative under the REF initiative (World Bank, 2012).

Key considerations to incentivise households:

- Repayments are interest free as the cost of financing is borne by the provider.
- A subsidy provided under scenario 3.
- The households are no worse off in any year as the repayment amount is equal to or less than the recharge and replacement savings, with the O&M cost deducted.
- Assumptions: The Bboxx BB7 is used in conjunction with the car battery; it therefore reduces the reliance on the battery. This in turn reduces the recharging and replacing frequency, with a cost saving of USD $19.50* and USD $8.33* respectively.
- The Bboxx BB7 battery would be replaced every 10 years. The long lifetime is due to the high quality battery and support services provided by the supplier.

Table 1: Household (HH) energy usage and expenditure in the Secret Beach community (Saly, 2014)

HH	Cost per charge (USD $)	Frequency of charging	Cost per day (USD $)	Capability	Approximate usage (W-hrs/day)	LCOE (US$/kWh)
1	0.75	Every week	0.11	TV, phone, lights	84	2.25
2	2 batteries, 0.50 each	Every week	0.14	Lights, 3 phones	42	3.62
3	0.8	Every four days	0.20	TV, Video player, lights, 2 phones	118	2.49

Table 2: Costing of SHS repayments for various scenarios

		Scenario 1	Scenario 2	Scenario 3
Initial Capital	Initial capital cost required by provider	USD $129	USD $129	USD $129
	Subsidy	USD $0	USD $0	USD $32.25
	Cost owing at year 0 for household	USD $0	USD $129	USD $96.75
Benefit for household	Avoided costs (from battery recharging)	USD $19.50 per year	USD $19.50 per year	USD $19.50 per year
	Avoided costs (from battery replacement)	USD $8.33 per year	USD $8.33 per year	USD $8.33 per year
Costs for household	Periodic installments	N/A	Year 1 - 4: USD $25.33 Year 5: USD $25.67	Year 1 - 3: USD $25.33 Year 4: USD $19.25
	O&M cost	USD $2 per year	USD $2 per year	USD $2 per year

- The O&M cost is USD $2 per year (includes $1 for a cloth and $1 for 2 litres of water).
- The increased productivity due to longer working hours and the reduction in time involved with transporting the battery and/or phones to external sources to be charged has not been included as a benefit.
- Evaluation Period is 10 years.
- Subsidy was one quarter as this was the subsidy proportion provided to households in the World Bank SHS initiative (World Bank, 2012).
- Discount rate is 12 % as this was the rate used in the World Bank SHS initiative (World Bank, 2012).
- According to the datasheet, the Bboxx BB7 provides up to 60 W-h/day. This is over half current of current electricity consumption from households (ranging 48 W-hrs/day-118 W?hrs/day). Therefore, it was estimated the batteries are charged half as often, saving half the recharge cost which equates to USD $19.50 per year. Furthermore, the reduced usage of the batteries means the batteries are to be replaced less frequently, it is estimated as every 2 years rather than every 3, saving one third of the replacement cost which equates to USD $8.33 per year. These figures are used to calculate the net benefits in Figure 5.

Figure 5 graphs the present value of the accumulated benefits under the various scenarios. In scenarios 2 and 3 the systems are paid off within five and four years respectively, after which the systems generate economic benefits and essentially "free" electricity (not including replacement costs). For scenario 1, the household would be worse off until year seven and only then reap benefits, illustrated by a negative present value of accumulated benefit in Figure 5. As no interest rate is charged, the NPV is higher under scenario 2 and 3 than under scenario 1.

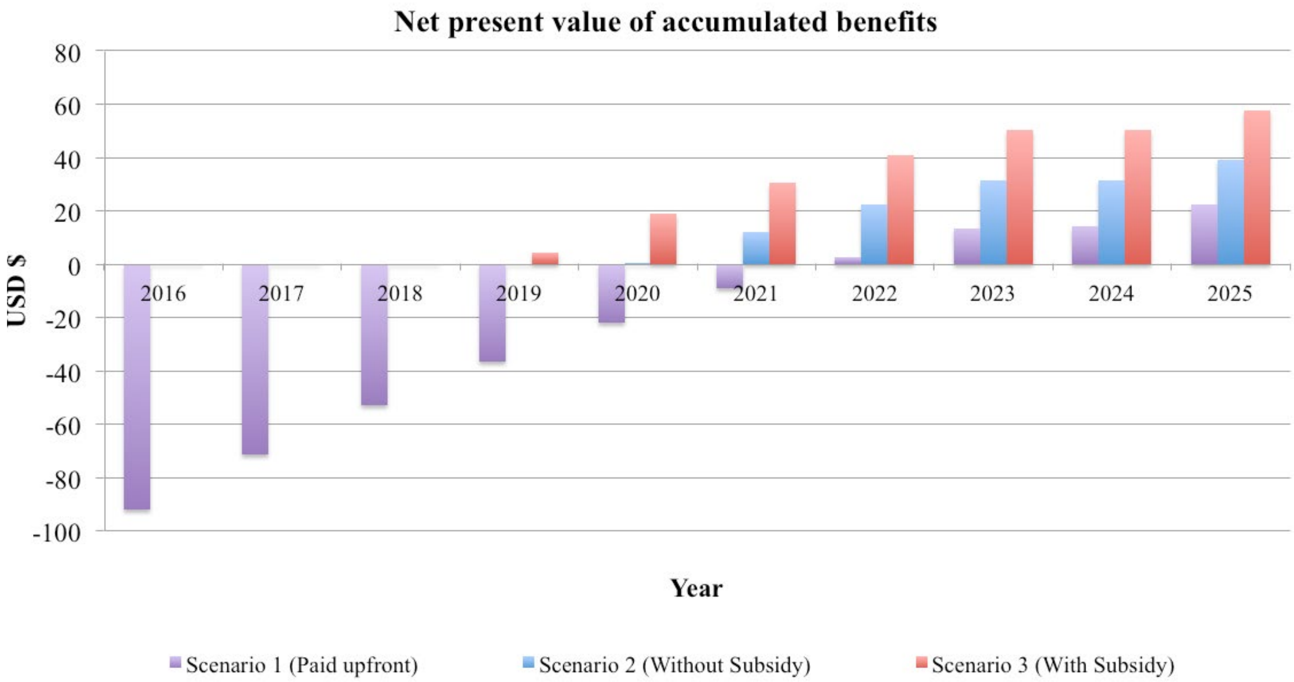


Figure 5: Net present value of accumulated benefits

A Sustainable Engineering Solution for Paediatric Dehydration in Low- Resource Clinical Environments

Ashley R. Taylor
Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg Virginia
ashleyt1@vt.edu

Jeffrey Turovskiy
Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg Virginia
jefft@vt.edu

Benjamin Drew
Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg Virginia
Ben.Drew@trane.com

Dr. Andre Muelenaer
Section of Paediatric Pulmonology/Allergy, Virginia Tech Carilion School of Medicine, Roanoke Virginia
aamuelenaer@carilionclinic.org

Dr. Kerry Redican
Department of Population Health Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
kredican@vt.edu

Dr. Kevin Kochersberger
Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg,Virginia
kbk@vt.edu

Dr. Lissett Bickford
Department of Biomedical Engineering and Mechanics, Virginia Polytechnic Institute and State University, Blacksburg Virginia
bickford@vt.edu

ABSTRACT: *Engineering efforts in low resource environments pose a unique set of challenges, requiring an in-depth understanding of local needs, comprehensive mapping of community resources, and extensive collaboration with local expertise. The importance of these principles is demonstrated in this paper by detailing the novel design and field demonstration of an affordable, locally manufactured intravenous fluid regulation device. Collaboration with clinical personnel in Uganda and Malawi guided device design. In-country physicians emphasised the need to regulate volume of intravenous (IV) fluid delivered to a paediatric patient without use of electricity. The proposed device regulates IV fluid delivery within ±20 mL of total prescribed dosage, providing a method of reducing fatalities caused by over-hydration in low resource environments; the feasibility of building the device from local resources was demonstrated by a field research team in Malawi. The device was successfully constructed entirely from local resources for a total cost of $46.21 (USD). Additionally, the device was demonstrated in rural clinics where 89 % of surveyed clinical staff reported that they would use the device to regulate IV fluid delivery. This paper emphasises the importance of collaborating with communities for community-based engineering solutions. Mapping community assets and collaborating with local expertise are crucial to success of engineering efforts. Long-term, community-based efforts are likely to sustainably improve health outcomes and strengthen economies of communities worldwide.*

KEYWORDS: Engineering for low resource environments, global health, paediatric dehydration, intravenous fluid volume regulation, community-based solutions

1 INTRODUCTION

As the second leading cause of death in children under five years old, diarrhoea-induced dehydration kills approximately 760,000 children annually (World Health Organisation, 2013). Dehydration related deaths pose the greatest burden in areas where access to water and sanitation resources may be limited. Dehydration is a treatable condition with appropriate medical care, with a recommended treatment of oral rehydration (Rouhani et al, 2011; World Health Organisation, 2013). However, this treatment has several critical limitations; oral rehydration may be too slow to provide adequate hydration for a patient and is not viable when the patient is vomiting. In such instances, intravenous (IV) fluid delivery becomes necessary (Reid and Bonadio, 1996).

Administering IV fluids to paediatric patients remains a challenge in low resource clinical settings. Physicians in resource-limited settings face many challenges, including an unstable electric grid, inadequate equipment, and very high patient-to-staff ratios (Lehmann et al, 2008; Marchal and Kegels, 2003; Vujicic et al., 2004; World Health Organisation and The World Bank, 2015). A recent study found that 82,949 physicians in sub-Saharan Africa are responsible for providing care to 660 million people, resulting in a ratio of 13 physicians per 100,000 people (Hagopian et al, 2004). In 2014, the World Health Organisation estimated that the physician-to-patient ratio in Malawi is approximately 2:100,000, and the nursing ratio is approximately 29:100,000 (World Health Organisation, 2014). In contrast, the United Kingdom and United States have 164 and 279 physicians per 100,000 people, respectively (Hagopian et al, 2004). Intravenous fluid delivery for paediatric patients requires careful monitoring, and in clinical settings that are understaffed, this may not be feasible. Without adequate monitoring by clinical staff, the World Health Organisation does not recommend IV therapy due to the risk of paediatric patients becoming fatally overhydrated (Shah et al, 2015; World Health Organisation, 2005).

Though robust IV delivery systems, such as electronic infusion pumps and burettes, have been designed for clinical settings in developed nations, appropriate and affordable solutions for resource-limited environments remain sparse (Oden et al, 2010; Shah et al, 2015). One successful design was presented in 2015 by Rice University's Beyond Traditional Borders program; the proposed device was designed for use in low-resource settings and is able to function without access to the electric grid or consumables (Shah et al, 2015). The development of this device was a leap in technology innovation for the developing world; however, the cost ($80 for the proposed device) may be improved by designing technology that does not use steel or aluminum, which may be prohibitively expensive (Shah et al, 2015).

Designing for low resource settings poses a set of diverse challenges for engineers and requires an extensive understanding of the collaborating community, locally available resources, and cultural values (Black, 1999; Malkin, 2007; Mohan, 2014). For sustainable medical solutions, device designs should utilise local materials to enable local maintenance and repair (Malkin, 2007; Schumacher, 1973). Additionally, locally-manufactured devices may promote empowerment and independence of communities instead of dependence on medical device donations. Designing for low resource settings must also consider local constraints, such as an unstable electric grid. Mapping community assets is also critical for designing in resource-limited clinical settings; maintenance personnel and local masons are invaluable resources in the design process and may provide essential knowledge on availability of local materials and manufacturing processes (Black, 1999; Mohan, 2014).

2 PRELIMINARY DESIGN OF IV REGULATION SYSTEM

The following section outlines the design process for the IV fluid regulation device.

2.1 Identification of Clinical Need and Design Requirements

In order to design a robust IV fluid regulation system for low resource clinical settings, it was first necessary to seek a comprehensive understanding of system requirements. Clinicians in rural Uganda expressed the original need, and clinicians in rural Malawi expressed similar needs. Clinics in Malawi and Uganda exhibit many differences, including varying patient-to-staff ratios, healthcare system structures, and availability of resources, such as pharmaceuticals and medical equipment. However in both locations, clinicians

Table 1: Intravenous fluid regulation system design requirements

Functionality of Device	Performance of Device	Construction of Device
Device can be operated mechanically	Device dispenses volumes of fluids within 10 % of total fluid volume to be delivered to the patient	Device is built from locally available materials and tools
Device stops fluid flow independently of clinician intervention	Device dispenses accurate fluid volume ranges between 0 to1000 mL	
Device alerts caregiver of completion of fluid delivery		

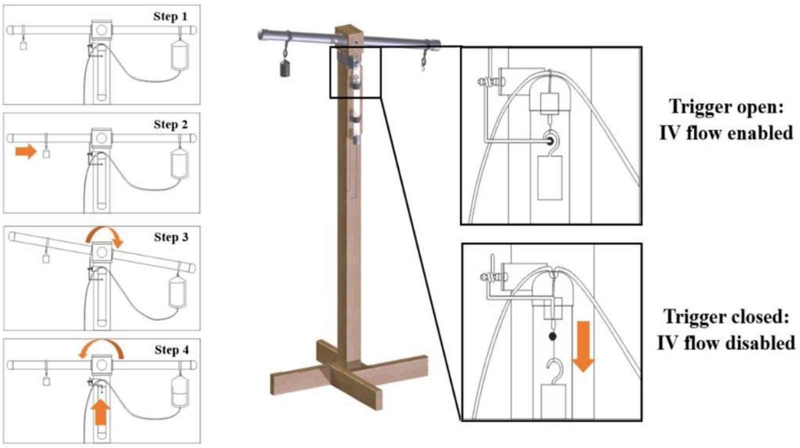


Figure 1: Diagram of system design. Starting at equilibrium (Step 1), the counterweight is adjusted towards the centre (Step 2) and the system shifts out of equilibrium (Step 3). As fluid empties from the bag, the system returns to equilibrium (Step 4), which activates the cut-off. Inside the cut off is a small mass suspended by the wire trigger and tied on a string to a hook. When the cut-off is activated, the wire trigger releases the mass, and the resulting downward force pulls on the hook, creating a kink in the tubing. This kink in the tubing restricts fluid flow.

expressed similar key challenges associated with working in low resource environments; these shared challenges in Uganda and Malawi formed the design requirements for the IV fluid regulation system. Among the challenges identified were an unstable electric grid, shortage of staff, and lack of spare or replacement parts to repair equipment. Table 1 shows design requirements developed in response to insight from clinicians in low resource settings. One of the most critical design requirements was for the device to be manufactured entirely from local resources to enable local maintenance and repair.

2.2 Consideration of Community Assets and Local Resources

To achieve a design that is sustainable in low-resource areas, engineers must consider available local resources for their designs. By using only local parts, engineered products can be manufactured and maintained efficiently. Designs should also consider the manufacturing capabilities of the area. Precision machining and injection molding are rarely available and usually are prohibitively expensive. Thus, designs that are limited to locally available materials and manufacturing create a sustainable product that can succeed in low resource environments. To meet these criteria, the proposed device was originally designed using only materials found in local North American hardware stores, which are comparable to materials available in hardware markets in Malawi and Uganda. Additionally, the device was constructed by hand exclusively using simple hand tools. Building and construction materials are abundant in many low resource areas; markets are often filled with items ranging from PVC and metal hardware to rope and wire. Hand tools are also in abundance in areas that do not have consistent access to an electric grid.

2.3 Proposed Device for IV Fluid Volume Regulation

The IV fluid volume regulation device is shown in Figure 1. The device utilises a simple lever-based counter-balance methodology to dispense a defined amount of IV fluid to a patient. The user adjusts the position of a fixed-mass counterweight to set the desired volume. The IV bag will be suspended at a fixed distance from the lever pivot. As fluid is drained from the IV bag, the lever arm rotates in the counterclockwise direction.

The counterweight distance (d) for a given mass of fluid can be determined from the following (Equation 1):

$$d_{cw} = \frac{\left(m_{IV} - \rho V_{dosage} + m_{offset}\right) * d_{IV}}{m_{cw}} \qquad (1)$$

where:

m_{IV} is the initial mass of the IV bag;

ρ is the IV fluid density;

V_{dosage} is the target volume of fluid to be dispensed;

d_{IV} is the distance between the IV bag and the lever pivot (centre of device);

m_{cw} is the mass of the counterweight; and

m_{offset} is a linear offset term accounting for the friction in the pivot bearing and the force required to trigger the fluid cut off mechanism.

Equation 1 was used in the design of the IV fluid regulation system and is provided above as a starting point for calibration of the device in the field. As explained in section 2.3.2, the device can be calibrated without precise measurements of the mass of the IV bag and the linear offset term. Estimates for the counterweight position at each dosage increment can be made based on Equation 1, visually represented by Figure 2. Adjustments must be made accordingly to the counterweight position of each device during calibration to account for the varying offset in the system.

2.3.1 System Cut-off

The mechanism for stopping the fluid flow is enclosed inside a vertical polyvinyl chloride (PVC) pipe mounted onto the system support (Figure 1). Inside the pipe is a hook created from looping wire through a dowel rod, which is tied with a string to a small mass. The mass is an eyebolt holding up a stack of washers. The hook is pulled through a hole in the centre of a PVC end cap, and the IV tubing rests under the hook. The mass is suspended by a thick wire that

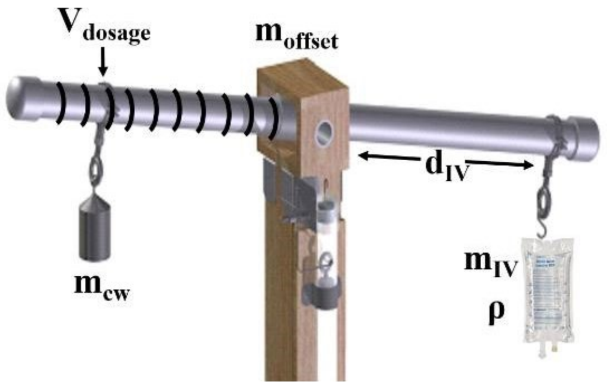


Figure 2: The device utilises a simple lever-based counter-balance methodology to dispense a defined amount of fluid to the patient

acts as the trigger for system cut-off. This wire is looped around a bolt on the side of the system support and bent up to rest under the equilibrium position of the counterweight side of the lever arm. When the system approaches equilibrium, the lever arm rotates until it comes into contact with the trigger wire, applying enough pressure to rotate it out of position. When it rotates, it releases the mass inside the PVC pipe. The mass falls and applies a downward force to the hook, which gets pulled through the hole in the PVC end cap, pulling the IV tubing with it. The downward motion of the hook creates a kink in the tubing, which stops the flow of fluid. The system cutoff is shown in Figure 1. The cut-off mechanism meets the design criteria in Table 1 that states "device alerts caregiver of completion of fluid delivery". The alert accomplished by the cut-off mechanism is two-fold; first, an audible alert is given when the counterweight falls, and second, a visual alarm is accomplished when the cutoff mechanism is open upon completion of IV fluid dosage delivery.

2.3.2 Construction and Calibration

The original prototype of the system was built exclusively using materials sourced from domestic (North American) hardware stores. This allowed the design to focus on simple yet robust methods for the system to accomplish necessary functions. The main body of the device was originally assembled from timber. PVC pipes and fittings allowed for smooth rotational motion and sturdy connections. Nuts, bolts, washers, and wire were used for smaller components. A simple construction allowed for easy repair or replacement if components were to break.

Once a new system is built, the following process can be used to calibrate it for use. The calibration equation (Equation 1) will calculate the relative distances from the counterweight to the centre of rotation that bring the system to equilibrium at various delivered dosages. For example, if 100 mL dosages are desired, the distances corresponding to 100 to 1000 mL should be calculated at 100 mL increments. It is important to note that the counterweight adjustment (shown by adjacent lines in Figure 2) is the same length for each increment of 100 mL dosage; however, this length may differ from device to device depending on the materials used in its construction.

To calibrate a new device, several test trials should be performed. The distances calculated from Equation 1 are to be measured and marked on the lever arm (Figure 3a). Three initial trials are to be performed at 100, 200, and 300 mL, respectively. After each trial, the amount of fluid drained from the IV should be measured, and the system should be set up again to continue draining into the same container. Then, the actual delivered dosages may be compared to the intended dosages. If too much fluid is being dispensed, the markings should be adjusted away from the centre of rotation (Figure 3b); if too little fluid is being dispensed, the markings should be adjusted towards the centre (Figure 3c). This process can be repeated for dosages of 400, 500, and 600 mL. If finer adjustment is required, repeat the process again for dosages of 700, 800 and 900 mL. With this process, only one bag must be utilised in order to accurately calibrate the system.

2.4 IV Fluid Dosage Testing

To ensure safety, the device was pilot tested for accuracy and reliability to demonstrate the proof of concept of the system and obtain pertinent standard deviations as a baseline. Full 1000 mL IV bags were drained by increments of 100 mL for a total of ten target volumes (100 mL, 200 mL, 300 mL, etc.); subsequently, the volumes of fluid dispensed at each increment were recorded. This procedure was repeated five times to provide five data points at each target fluid volume. Testing was conducted at the highest possible flow rate, with the standard IV bag roller clamp fully open. Additional testing was conducted at a slower flow rate (50 mL/hr) to ensure device functionality across a range of flow rates. It is important to note that flow rate is controlled independently of the IV fluid regulation device using a standard roller clamp; the device only regulates the volume of IV fluid to be delivered. The height of the device can be adjusted to meet the needs of individual hospitals. If the height of the device is adjusted, the calibration procedure (section 2.3.2) should be repeated.

Comparing experimental volume delivery results to the projected volume delivery results found during calibration, the uncertainty associated with each target volume, as well as uncertainty in the overall system, was determined. Statistical methods (standard error and student's t-distribution) were used to quantify uncertainties and develop appropriate confidence intervals. Based on discussions with clinicians, the device must regulate fluid deliver within 10 % of total fluid volume to be delivered to the patient.

A 99 % confidence interval and standard error were formed for each target volume. It is important to note that the total error at each interval is a combination of the total system error, most specifically in the cut-off mechanism, and any error that arises due to the placement of the counterweight. The overall system standard error was ±20 mL at a 99 % confidence interval, falling within the acceptable range

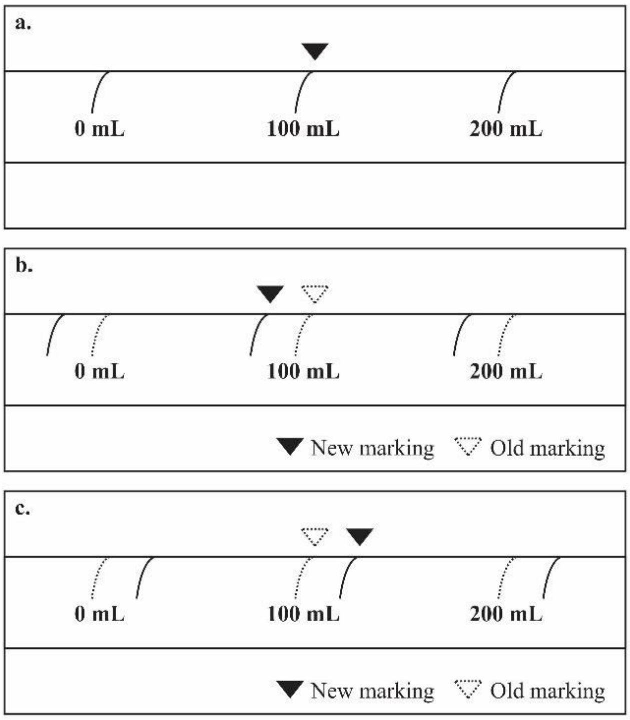


Figure 3: The calibration process for a newly built system

of ±30 mL. As shown in Figure 4, a linear relationship was found between the volume of fluid dispensed and the distance of the counterweight from the zero position. Figure 4 also reflects the consistency of fluid volume delivered at each counterweight position.

3 EVALUATION IN LOW-RESOURCE CLINICAL SETTINGS

After the device was constructed and calibrated, field-testing and demonstration was conducted in the southern region of Malawi, located in sub-Saharan Africa. In preparation for travel, it was necessary to modify the design slightly upon realisation that wood materials for the base of the device were not readily available. Instead, the team constructed the base from PVC pipes, which also improved sterility of the device since PVC can be easily cleaned with a sterilising solution.

3.1 Building the Device from Local Resources

Working with the in-country PVC manufacturer and distributor, the field research team constructed a device entirely from local resources, shown in Figure 5. The mass of the constructed device was approximately 9 kilograms. The base shown in Figure 5 is approximately 0.8 metres wide with a depth of 0.45 metres. The total height of the constructed device was approximately 1.8 metres, and the length of the lever arm was approximately 1.1 metres.

It was necessary to modify the design of the cut-off mechanism in the device. The original bent wire trigger was replaced with a pin inserted through the vertical piece of PVC to suspend the small dropping mass. This pin was tied by a string to the rotating arm near the stationary IV bag. The length of the string is determined so that the pin is pulled out of place just as the system reaches the equilibrium position.

Table 2 provides an itemised list of local resources used for in-country design as well as an image of the final device. The total cost of building a single IV regulation device in southern Malawi amounted to $46.21 (USD). It is important to note that the cost of building a single device is significantly greater than the unit cost of building many devices, since the cost of PVC components decreases as the purchase quantity increases. Additionally, there may be some variability in pricing of the device due to the inconsistent pricing of parts in local hardware markets. Future work will include fabrication of multiple devices in-country, enabling the determination of

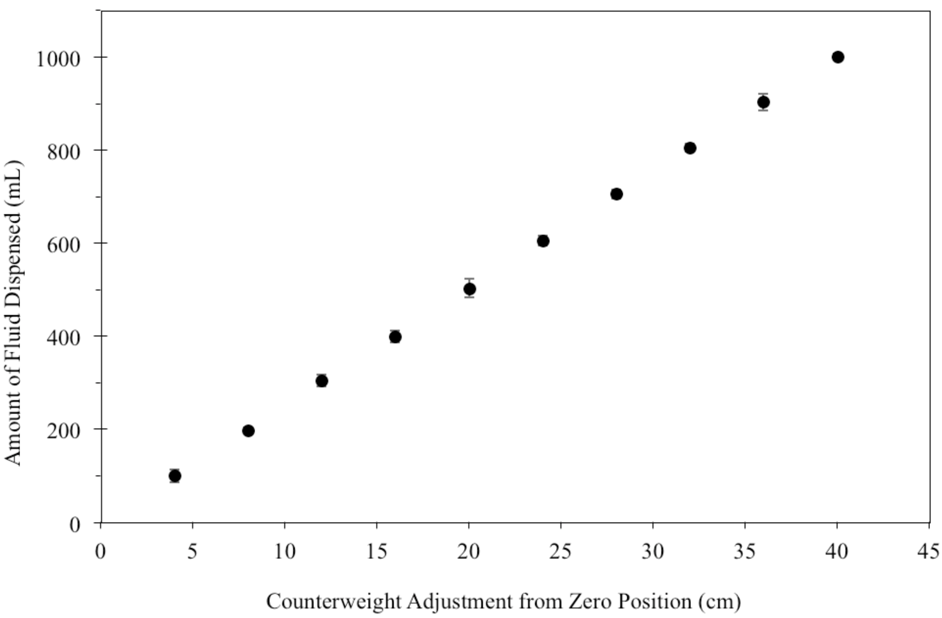


Figure 4: Average dispensed volumes in millilitres (mL) plotted against counterweight adjustment in centimetres (cm) with error at 99 % confidence level.

Table 2: Cost of manufacturing single device in southern Malawi

Material Type	**Quantity**	**Total cost of materials ($USD)[1]**
PVC T-Joint	10	$14.78
90° PVC Elbow	2	$2.19
PVC Unions (Double Sockets)	4	$1.15
3 metre length of 40 mm PVC pipe	2	$10.39
6 metre length of 32 mm PVC pipe	1	$6.58
1 metre length wire	1	$2.22
Washers	30	$6.67
Dowel	1	$1.11
2 metre length string	1	$1.11
Total cost of device in southern Malawi		**$46.21**

Notes:
1. Prices from PVC distributor and manufacturer in Blantyre, Malawi. Materials purchased in Malawian Kwacha (MKW). Conversions to USD based on conversion rate 1 USD = 450 MKW.

a median price of the device and reducing uncertainty on price variability.

Several challenges arose when fabricating the device from local resources. First, design modifications were necessary as a result of availability of local materials and tools. An unstable electric grid made using power tools for fabrication infeasible; instead, hand-powered tools were necessary to build the device. Lastly, inconsistent availability of parts in local hardware markets created challenges for fabrication; this was mitigated, largely, by collaborating with in-country PVC distributors.

Figure 5: IV fluid regulation device constructed in southern Malawi. Photo taken in Mulanje, Malawi

3.2 Evaluation of Clinical Feasibility and Local Acceptance

The field research team also evaluated the clinical feasibility and local acceptance of the device. The Virgina Tech research team conducted demonstrations of the device three clinical settings in southern Malawi. Clinical staff provided feedback on the device demonstration through a qualitative survey. In an effort to elicit transparent feedback and respect cultural differences in comfort with direct speech, clinical staff provided anonymous feedback through the aforementioned survey. The survey was approved by the Virginia Tech Institutional Review Board as well as by the hospital administrators of collaborating institutions in-country. Nurses and maintenance personnel piloted the survey with help from a public health colleague in Malawi.

Twenty-nine clinical staff provided feedback on device usability in low-resource clinical settings. All respondents (100 %) reported that the device was "easy to use", and most respondents (93 %) reported that the device was "easy to clean". When asked about feasibility of the building the device locally, 57 % of respondents reported that the device could be easily "manufactured using local resources". Of surveyed clinical staff, 89 % reported that they would use the device to regulate IV fluid delivery for paediatric patients. However, none of the respondents (0 %) reported that the device was "easy to move around as needed". The general consensus was that the size of the device needed to be reduced. Several clinical staff also commented that the device should be more portable to allow for easy transition from one bedside to another.

4 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

In conclusion, the proposed IV regulation system offers a feasible solution for safely treating paediatric dehydration in low-resource clinical settings. Through collaboration with in-country clinical personnel, a thorough understanding of needs was developed to guide device design. The proposed device regulates IV fluid delivery within ±20 mL, providing a safe and reliable method of preventing fatalities caused by over-hydration.

Field testing and demonstration in Malawi confirmed the feasibility of building the device locally. The field research team successfully constructed the device entirely from local resources. Cost of building the device in-country was $46.21 USD. Additionally, 89 % of surveyed clinical staff reported that they would use the device to regulate IV fluid delivery. Clinical staff recommended that the size of the device be reduced and the portability of the device be improved.

This work has several limitations. First, life-cycle testing to determine durability and reliability of the device was not fully completed before demonstration in Malawi. The original prototype device was tested for 7 months prior to demonstration in Malawi, and the device constructed in Malawi was demonstrated for 2 weeks. During demonstrations, fatigue effects on device performance were not apparent. However, further testing on multiple devices should be conducted to quantitatively determine device durability and reliability over a longer period of time (including consecutive days, weeks, and months) to fully examine the long-term accuracy and reliability of the system. This long-term testing must be done at the work site with equipment developed using local resources, such that meaningful data can be obtained and a possible preventative maintenance schedule developed. Additionally, this study did not include a training program for clinical staff on device use or device fabrication. Future work will include a formal training program and an evaluation for training on utilisation of device and fabrication of device. Long-term, this work aims to enable local masons to fabricate the devices independent of research team.

Field testing of the device in-country emphasised the importance of collaborating with communities for community-based engineering solutions. Constructing the device in country was successful, thanks to the insight and expertise of local hardware store owners. The importance of mapping community assets should not be underestimated for humanitarian engineering efforts. Designs that incorporate or exclusively use local resources are likely to promote empowerment of communities and decrease community dependence on medical device donations. Long-term, community-based solutions that incorporate local resources are likely to improve health outcomes and strengthen economies of communities worldwide.

5 ACKNOWLEDGEMENTS

Malawian public health specialist and nurse midwife Mr. Keith Lipato was crucial to the success of this project by providing invaluable expertise during both the design process and field implementation. Clinical staff at Domasi Rural Hospital, Zomba Central Hospital, and Mulanje Mission Hospital provided critical feedback that will guide future efforts. Design team members Dylan Hesse, John Kutz, and Brian Magley are acknowledged for their tireless contributions to the project. The Virginia Tech Student Engineers' Council, the Virginia Tech Mechanical Engineering Department, and the Virginia Tech College of Engineering International Programs are gratefully acknowledged for their generous contributions to these global health efforts.

6 REFERENCES

Black, JK 1999, *Development in theory and practice: paradigms and paradoxes*, 2nd edn, Westview Press, Boulder, Colorado.

Hagopian, A, Thompson, MJ, Fordyce, M, Johnson, KE & Hart, LG 2004, 'The migration of physicians from sub-Saharan Africa to the United States of America: measures of the African brain drain', *Human Resources for Health*, vol. 2 no. 1, doi: 10.1186/1478-4491-2-17

Lehmann, U, Dieleman, M & Martineau, T 2008, 'Staffing remote rural areas in middle- and low-income countries: A literature review of attraction and retention', *BMC Health Services Research*, vol. 8 no. 1, doi: 10.1186/1472-6963-8-19.

Malkin, R 2007, 'Barriers for medical devices for the developing world', *Expert Review of Medical Devices,* vol. 4, no. 6, pp. 759-763, doi: 10.1586/17434440.4.6.759

Marchal, B & Kegels, G 2003, 'Health workforce imbalances in times of globalization: brain drain or professional mobility?', *International Journal of Health Planning and Management*, vol. 18, no. S1, pp. S89-101, doi: 10.1002/hpm.720

Mohan, G 2014, 'Participatory Development' in Desai, Vandana, Potter & Robert (eds.), *The Companion to Development Studies,* 3rd edn, Routledge, London, pp. 131–136.

Oden, ZM, Mirabal, Y, Epstein, M & Richards-Kortem, R 2010, 'Engaging undergraduates to solve global health challenges: A new approach based on bioengineering design', *Annals of Biomedical Engineering*, vol. 38, no. 9, pp. 3031–3041, doi: 10.1007/s10439-010-0036-0

Reid, SR & Bonadio, WA 1996, 'Outpatient rapid intravenous rehydration to correct dehydration and resolve vomiting in children with acute gastroenteritis', Annals of Emergency Medicine, vol. 28, no. 3, pp. 318-323, doi: 10.1016/S0196-0644(96)70032-X

Rouhani, S, Meloney, L, Ahn, R, Nelson, BD & Burke, TF 2011, 'Alternative rehydration methods: A systematic review and lessons for resource-limited care', P*ediatrics* vol. 127 no. 3, pp. e748–e757, doi:10.1542/peds.2010-0952

Schumacher, EF 1973, Small is beautiful; economics as if people mattered, Harper & Row, New York.

Shah, K, Skerrett, E, Nojoomi, M, Walker, T, Maynard, K, Pan, M, Flynn, B, Yuan, M, Horton, P, Vaughn, T, Miros, R, Molyneux, E, Saterbak, A, Oden, ZM & Richards-Kortem, R 2015, 'A new tool to prevent overhydration of children receiving intravenous fluid therapy in low-resource settings', *The American Journal of Tropical Medicine and Hygiene*, vol. 92, no. 5, pp. 92, 1053– 1058, doi: 10.4269/ajtmh.14-0495

Vujicic, M, Zurn, P, Diallo, K, Adams, O & Dal Poz, MR 2004, 'The role of wages in the migration of health care professionals from developing countries' *Human Resources for Health,* vol. 3, no. 3, doi:10.1186/1478-4491-2-3

World Health Organisation 2014, Country Cooperation Strategy at a glance – Malawi, fact sheet, viewed 11 March 2016, http://www.who.int/countryfocus/cooperation_strategy/ccsbrief_mwi_en.pdf

World Health Organisation 2013, *Guideline - Updates on the management of severe acute malnutrition in infants and children,* Geneva, viewed 11 March 2016, http://apps.who.int/iris/bitstream/10665/95584/1/9789241506328_eng.pdf

World Health Organisation 2005, *Department of Child and Adolescent Health and Development - The treatment of diarrhoea: a manual for physicians and other senior health workers (WHO/FCH/CAH/05.1),* Geneva.

World Health Organisation, The World Bank 2015, *Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings: A Review of Status, Significance, Challenges and Measurements,* World Health Organisation, Switzerland, viewed 11 March 2016, http://apps.who.int/iris/bitstream/10665/156847/1/9789241507646_eng.pdf

JOURNAL OF
HUMANITARIAN
ENGINEERING

SUBMISSION GUIDELINES

All paper submissions for the *Journal of Humanitarian Engineering* are to be submitted electronically via the JHE website: http://www.ewb.org.au/jhe/. Authors are required to register and submit their paper by following the 'Register' link on the home page. All submission enquiries can be directed to the Editorial Team: journal@ewb.org.au

Submission style and templates: Please download the paper template which can be found in the 'Author Guidelines' heading in the 'About' section on the JHE website: http://www.ewb.org.au/jhe/. The template consists of the full formatting instructions required for submission. For ease of editing it is requested that the paper be submitted as a Microsoft Office Word text document (or equivalent with .doc or .docx extension) and that the length of the submission does not exceed 8 pages.

More information is available on the JHE website: http://www.ewb.org.au/jhe/

JOURNAL OF
HUMANITARIAN
ENGINEERING

ABOUT JOURNAL OF HUMANITARIAN ENGINEERING

Humanitarian engineering is about applying and developing technology – not to meet a market or financial opportunity – but to address a real human need. It is about serving a disadvantaged community or group, often overlooked by traditional engineering and technology projects. From poverty alleviation to disability access, humanitarian engineering highlights a new approach to developing and implementing technologies. The JHE was established in 2012 to provide a forum for such research to be published. The JHE is published by the Education and Research arm of Engineers Without Borders (EWB) Australia.

Research that collects dust on shelves or is stored away in the depths of an electronic archive is research that fails to make an impact. Dissemination is key, and this is why the JHE is free to submit to and free to access. This is made possible by a hard-working team of volunteers and generous support from EWB Australia's partners.

We love to receive contributions from all occupations within the sector; practitioners, policy-makers, academics, students and communities themselves. We encourage submissions which focus on the application of engineering and technology for the benefit of disadvantaged communities; topics include, but are not limited to:

- Water, sanitation and hygiene
- Waste treatment
- Appropriate technologies
- Renewable energy
- Disability access
- Affordable housing and construction
- Information and communication technologies
- Humanitarian engineering education / service learning
- Applications of humanitarian engineering in policy and practice

Please note that "humanitarian engineering" is often known by a plethora of other names, some of which include "development engineering", "global engineering", "technologies for development" and "appropriate technologies". We are very happy to receive submissions from all of these fields.

If you are interested in submitting an article but may require some assistance in preparing a submission in English, please contact us (journal@ewb.org.au) as we may be able to support you with authorship mentoring.

And don't forget to follow us on Twitter: @Journal_Hum_Eng