Sharing Knowledge and Building Intercultural Skills: A Solar Project Collaboration between U.S. and Ghanaian Universities

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Abstract

For ordinary people living in the villages of developing countries such as Ghana in West Africa, access to hot water supply is limited. Home-hot-water-heating systems are expensive to own and operate. Typically, in these villages, dry wood is used as a fuel and burned to heat water. This practice contributes to pollution and deforestation. In this paper, we describe a collaborative solar project funded by the United States Environmental Protection Agency that was carried out by teams of engineering students from Minnesota State University (MSU), USA and Kwame Nkrumah University of Science and Technology (KNUST), Ghana, Africa as an integral part of our design curriculum. The project focused on sharing knowledge and building intercultural skills. Each team considered numerous technical/non-technical factors associated with the project and sought feedback on their designs from their peers, faculty advisors, and practicing engineers. Communication and interpersonal skills were stressed extensively during the project. Each team gave formal and informal presentations during the period of the project. The project developed the students' ability to function on multi-cultural teams, and broadened the students' education necessary to understand the sustainability issues and the impact of engineering solutions in a global and societal context. In February 2009, two MSU students travelled to Ghana to collaborate with KNUST students to test their designs in actual Ghanaian conditions. Moreover, in April 2009, students competed in the Fifth Annual National Sustainable Design Expo, which was held on the National Mall in Washington, D.C. Through their work on the project, the students came to realize that engineering practice need not always be motivated by profit. Humanitarian factors are also very important.

Index Terms – Africa, Collaboration, Global, Solar Energy

INTRODUCTION

The purpose of the project described in this paper was to bring an affordable hot water solution to developing regions of the world, specifically, Ghana. People who live in the villages of Ghana have limited access to hot water supply. Typically, in the villages of developing countries, dry wood is burned to heat water. Not only, this practice contributes to pollution and deforestation, but the growing scarcity of fuel-wood also is another major problem facing people living in these areas. If the current trend persists, more people will be living in areas where the fuel-wood would become extremely scarce [1]. As an alternative, we had engineering students from Minnesota State University (MSU) in the United States and Kwame Nkrumah University of Science and Technology (KNUST), in Ghana, West Africa design, build, and test an inexpensive solar-hot-water system that could be made with tire inner tubes and other readily available materials. Students were to design the solar system such that it could be packaged as a kit that could easily be put together and distributed. Design specifications included having a daily hot water capacity of at least 20 U.S. gallons and temperature of 50°C. The system was to be designed for small initial cost of less than $50.00 and require no additional long-term cost to operate and maintain. They considered three collector designs, and analyzed and tested each design for performance and ease of assembly. Students also had to develop a theoretical model to predict the thermal performance of each solar collector and conduct a series of experiments to verify the models. After the most cost effective design with the best thermal performance was identified, an easy-to-assemble solar collector kit was created. This project allowed for tire inner tubes, which are still popular in developing countries, to be reused in a practical way to prevent them from finding their way to landfills. In summary, the main objectives of the project were:

- to study the feasibility of making inexpensive solar-hot-water collectors with tire inner tubes
- to explore various design options and identify at least two promising designs to pursue further
- To build these collectors and test their performance at MSU and KNUST
- To develop theoretical models that could be used to predict the thermal behavior of the collectors for other locations
- To optimize the designs to come up with a kit that could be easily assembled and distributed

The designed solar-hot-water system is mainly intended to be used to heat water for daily grooming and laundry. However, in cold African climates, if the solar collector is placed against a south facing window (or north facing in Southern Latitudes), it also could serve as a passive solar space heating system. The thermal energy stored in water during the day would transfer to the surrounding space at night by natural convection and radiation to keep a room warm. It also could be used to keep a green house – where food is grown – warm at night.

This project also promotes the use of solar energy and sustainability and provides benefit to people living in villages in the developing world. Having access to hot water for grooming and laundry will improve their quality of life. Because the proposed project makes use of solar energy (Ghana has a favorable solar climate [2]), it reduces the need to burn dry-wood to heat water, and as the result it reduces pollution and the consequent hazards to human health and the environment.

Prior to this project, we had done some preliminary work and studied the feasibility of a solar hot water system made with tire inner tubes. As a part of a thermal-fluid design project, engineering students at Minnesota State University had designed and tested a system that heated approximately 200 gallons of water for a farm in Minnesota (please see accompanying photo). The system was built for a cost under $100.

THE SOLAR PROJECT AS AN EDUCATIONAL TOOL

As mentioned previously, the proposed project was carried out by engineering teams from MSU and KNUST as an integral part of our design curriculum. Each team was required to consider numerous technical/non-technical factors associated with the project and to seek feedback on their preliminary designs from their peers, faculty advisors, and practicing engineers. Communication and interpersonal skills was stressed extensively during the proposed project. Each team gave formal and informal presentations during the period of the project. The project developed the students' ability to function on multi-cultural and multi-disciplinary teams, and broadened the students' education necessary to understand the sustainability issues and the impact of engineering solutions in a global and societal context. In February 2009, two students from MSU travel to Ghana and worked closely with their counterparts at KNUST to test the solar collectors under Ghanaian conditions. The MSU team also participated in the Fifth National Sustainable Design Expo, which was held on the National Mall in Washington D.C. They spent two and one-half days presenting their project to EPA judges and the public. In Summary, the project included the following major tasks:

- Define the project objectives
- Prepare a detailed schedule for project completion
- Investigate alternate concepts to achieve objectives
- Conduct engineering analyses and create engineering drawings
- Develop proof of concept model
- Test and evaluate
- Submit progress and final reports
- Present preliminary design to students, faculty, engineers, and anyone interested in the project
- Meet with faculty advisor(s) bi-weekly and document progress and activities
- Present the final project to students, faculty, engineers, and anyone interested in the project
- Prepare final report and a paper for presentation at a conference

THE PROJECT SCHEDULE

The proposed project was to be carried out during August 18, 2008 through April 14, 2009. However, the funding was delayed until mid September 2009, so students got a little late start. The introduction of team members, establishment of rules, deadlines, communication protocols, and assignment of each member's task were to take place during the first month of the project. Once the ground rules were established, design options were to be explored simultaneously by both teams. Each team was to identify two promising design concepts and share the details of their designs with the other team. Simultaneous testing of the designs was to take place at MSU and KNUST. Moreover, each team was to have remote access to the other team's experimental data to develop and verify their own theoretical models. To promote close collaboration and interaction, biweekly telephone and video conferences were to be held between the two teams. However, the communication between the teams was the most challenging part of this collaboration. We were not able to establish video conference capabilities because of narrow internet bandwidth at KNUST. Delayed e-mail responses were another obstacle that we had to overcome.

PARTERNSHIP

The faculty advisor and students from the Department of Mechanical Engineering at Minnesota State University collaborated closely with their counter parts from the Department of Mechanical Engineering at Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, West Africa. They worked together on all activities related to design and measurement of the thermal performance of the solar collectors. The proposed solar project was a continuation of a formal partnership that had recently been established between the two engineering programs and the universities. In February 2007, as a part of the collaboration, the first author, the faculty advisor for MSU team, traveled to Ghana and worked closely with faculty, students, and technicians from KNUST to restore and modify an old subsonic wind tunnel (with an 18 in. by 18 in. test section). The collaboration resulted in a functional wind tunnel that is currently being used by students [3]. To further strengthen our ties, the second author, the Head of the Mechanical Engineering Program at KNUST spent the spring and fall of 2008 at MSU campus where in addition to his teaching duties; he organized the activities for the solar project between the teams at MSU and KNUST.

THE COLLECTOR DESIGNS

Three collectors were designed and tested for thermal performance and ease of assembly. From the data collected, then the most effective design was identified and made into an easy-to-assemble kit. To measure the thermal performance, each collector was instrumented with an array of T-type thermocouple wires that were connected to National Instruments data acquisition system. A modular weather station recorded the test area's ambient temperature, the incident solar radiation, barometric pressure, relative humidity, and precipitation levels. The collected data was managed by LabView software and was used to develop theoretical models and determine the thermal performance of each collector [4-10]. The theoretical models were used to predict the thermal behavior of the collectors at other locations.

Design I – The Inner Tube – Inner tubes, which are commonly found in developing countries, are made from black vulcanized rubber and are made to hold pressurized air. This fact, together with their mechanical and radiation absorption properties, makes them ideal as a solar collector. Since tire inner tubes are completely sealed – except for the air valve – a means for filling and draining the inner tubes with water had to be developed. The solution that students developed consists of manufacturing a simple bulkhead fitting. The fitting is bolted in place and allows for a threaded pipe fitting to be connected to the inner tube. The bulkhead fitting keeps the inner tube completely sealed and leak free. To test the thermal performance, a series of tests were conducted at MSU and KNUST. A data acquisition system recorded the temperature of water for consecutive days. The collector was tested in multiple configurations including: 1) directly on the ground without any insulating material placed between the collector and the ground, and without a plastic cover, 2) configuration 1 with a plastic cover to reduce the heat loss to the surrounding air, 3) configuration 1 with insulating material, and 4) configuration 3 with a plastic cover to reduce the heat loss to the surrounding air. These different configurations are shown in Figure 1. The collector was tested only in configuration 4 in Minnesota.

From the experience gained in Ghana, it was decided that utilizing a large reservoir connected to the tube with a hose was the best approach for filling the collector with water. The water would then slowly drain from the reservoir and fill the tube, allowing any trapped air to escape. A single person could easily accomplish this task. When the desired water temperature has been reached, the water is then removed by disconnecting the hose from the reservoir and applying pressure to the tube either by slightly lifting it up or pushing down on the tube.

The solar kit contains an inner tube, two bulkhead fittings with hardware, two pipe fittings, a length of hose, a quick-disconnect coupler, an inexpensive stick-on thermometer, and a bucket to be used as a reservoir. All of these items are packaged within the bucket allowing for a minimal amount of packaging waste. The cost of the complete kit is under $50. For maintenance purposes, if future damage occurs to the collector due to mishandling, the inner tube can be repaired using inexpensive tube patches.

Figure 1. Design – I – Different test configurations. (a) directly on the ground without a cover, (b) insulated from the ground without a cover, (c) insulated from the ground with a cover, and the final design.

Design II – The Bladder Box – The second solar collector design was made with ethylene propylene diene M-class (EPDM) rubber, a material typically used in roofing applications. This material was formed into a bladder and acted similar to the tire inner tube, however, because of its flat geometry, it offered a better thermal performance. This design also was tested in Ghana, in all four configurations that were previously discussed. Design II was tested in Mankato only in configuration 4. It was eventually determined that this design was better suited for space heating in cold climates, whereby the solar collector would be placed against a south facing window (or north facing windows in south latitudes). This design costs slightly more than Design I and requires extra materials and assembly of parts. It is projected that the EPDM bladder could be manufactured inexpensively and with expansion restraint seams. The kit would then include a manufactured EPDM bladder and the necessary bulkhead fittings needed for filling and draining water, and detailed assembly instructions.

Design III - Drain Tile Collector – As an alternative to the rubber collectors, students also made a collector from corrugated polyethylene tube, commonly used as drain tile in agricultural applications for controlling moisture in soil. Like the rubber used in Design I and II, the drain tile is black, making it a good absorber of incident solar radiation. The tube that was made into a solar collector had a 4-inch diameter, which corresponds to a 0.65 gallons per-linear-foot water capacity. Seventy feet of the tube was oriented in a serpentine arrangement inside a box-frame for a total water capacity of approximately 45 U.S. gallons. A PVC reducer and bushing was used in each end of the tube to seal the water in, and to provide for a connection to a hose for filling and draining. The major performance and usability advantage to the drain tile collector was its rigidity. Because the tube holds its shape, the water was heated more uniformly resulting in a constant water temperature along the tube. However, the rigidity of the tube also is a disadvantage when trying to supply a compact easy to assemble kit. Unlike the bladder or tire inner tube the drain tile tube cannot be folded or compressed for packaging or shipping. This design would be more suitable for space heating in a greenhouse.

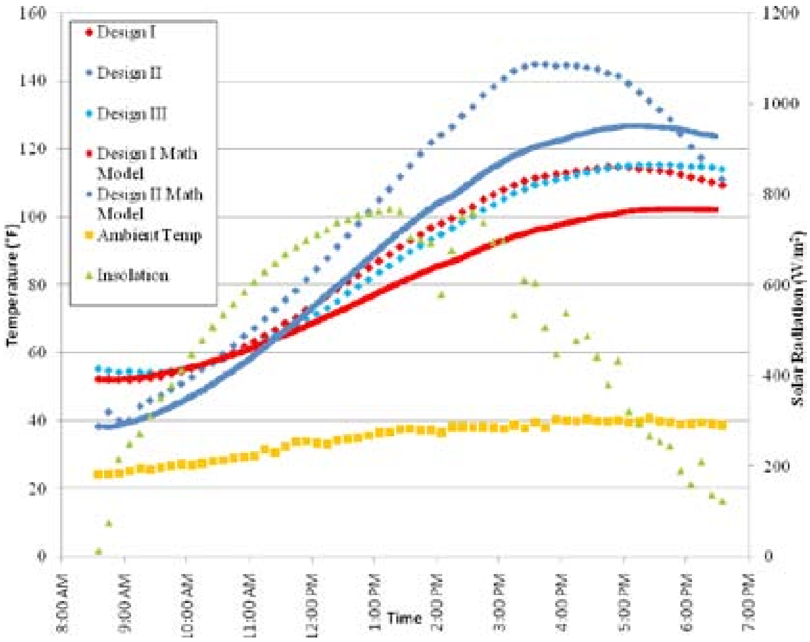
The drain tile collector, because of its size, was not tested in Ghana. It only was tested in Minnesota. When filled with 45 gallons of water, it reached a temperature of 47 °C in approximately 9 hours, with the average ambient air temperature1.3 °C and an average solar irradiance of 533 W/m2. Photos of Design – II and III are shown in Figure 2.

Figure 2. Photos of Design II and III.

THE MATHEMATICAL MODEL

Students also developed a mathematical model to predict the thermal performance of the solar hot water collectors. The model was developed by applying energy balances to various components and surfaces of the collector. This resulted in series of equations that had to be solved simultaneously. Inputs to the model included ambient temperature, incident solar radiation, wind speed and initial water temperature. Various parameters also were included in the model, including water capacity, critical dimensions and material properties. The output of the model is the temporal variation of water temperature and other surface temperatures such as collector surface, and cover plate. The comparison between experimental and mathematical model is shown in Figure 3.

Figure 3. The results of tests conducted in Minnesota in March 2009.



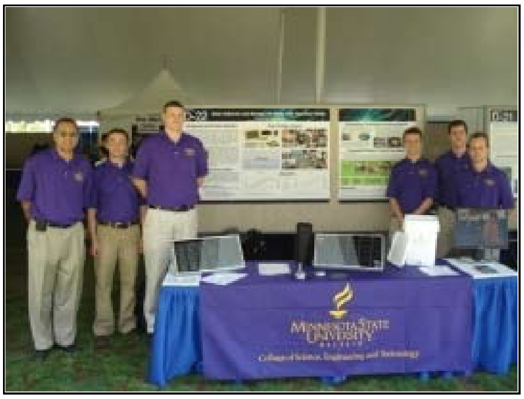
CONCLUDING REMARKS

The ability to collaborate with students thousands of miles away was a challenge for both Ghanaian and our students. Originally, the proposed communication path, video conferencing on Skype, required a fast, reliable internet connection, which was not available on the KNUST campus. Even e-mail communication was very difficult, because image sizes overloaded the internet resources available at KNUST. During the visit to KNUST, it was found that Facebook, a social networking site, was a better means of communication. Even with the successes achieved during this project, one change would be recommended. The American students' visit to the KNUST campus in Ghana should have taken place much sooner in the project. A number of design changes resulted from the visit. Many assumptions or ideas about the end user's habits, needs, and resources were incomplete, but this was not evident until the visit to Ghana in mid February. Before the visit to Ghana, communication between MSU students and KNUST students was very slow. After the visit, the communication became much better for two reasons: the identification of a convenient communication gateway and a stronger sense of connection between the two groups of students.

Collaborative efforts between students from MSU and KNUST also allowed students from each university to develop a more accurate view of each other's unfamiliar culture. The supplies for the proposed kit could all be purchased from Ghanaian suppliers. If the kits can gain popularity both within Ghana and other neighboring countries, the project could prove to be very prosperous for the Ghanaian local economy. The solar-hot-water system is a start to meeting the needs of the current population without taking resources from future generations. It utilizes an inexhaustible energy resource (solar energy), reducing pollution and reducing solid waste.

The MSU's team participated in the Fifth National Sustainable Design Expo, which was held on the National Mall in Washington D.C. The participation allowed students to spend two and one-half days presenting their project to EPA judges and the public. An experience that could not be matched in a classroom setting. Moreover, through their work on the project the students came to realize that engineering practice need not always be motivated by profit. Humanitarian factors are also very important.

In the near future, for the follow-up project, we are planning to fabricate and distribute 300 inexpensive solar collectors (solar kits) made with tire inner tubes (with protective linings against Butyl rubber (isobutene-isoprene copolymer) that is commonly found in inner tubes) to people living in the villages of Ghana, West Africa. After the units are distributed, their effectiveness and user-friendliness will be monitored closely. During the first round of the study, 200 collectors will be distributed and their use will be surveyed. The results of surveys and frequent on-site inspections would then lead to additional modification that may be necessary. Those modifications will then be made and 100 new collectors will be fabricated and distributed. Additional surveys will also be conducted for potential improvements. The main objectives for the follow-up study are:



- To study the effectiveness and user-friendliness of the solar kits and make modification if necessary.
- To study how these inexpensive environmentally friendly hot-water systems could be promoted
- To promote cultural exchange and understanding of sustainable global issues.

The introduction of new team members, establishment of rules, deadlines, communication protocols, and assignment of each member's task will take place during the first month of the follow-up project. Once the ground rules are established, we will review the design of solar collectors based on input provided by the judges at National Sustainable Design Expo and implement any necessary changes. Simultaneously, the MSU team will travel to Ghana to identify people in the villages who will participate in the study. Based on the initial information gathered from Ghana, we will create a plan for fabrication, distribution and survey data collections. Survey questions will be developed simultaneously. During the first year, two hundred collectors will be fabricated and distributed. From initial survey results modification may be made and additional one hundred collectors will be fabricated and distributed during the second year. The effectiveness and user-friendliness of the second generation of the collectors will be evaluated further and modifications made. During the second year of the proposed study, to assist with design and fabrication of second generation of collectors, two KNUST students will spend the academic year at MSU. This arrangement also will allow students to interact with the MSU community and to share their culture with the University at large. A faculty advisor from KNUST also will visit to observe the progress of KNUST students and interact with our students and faculty.

Warning: It is important to note that *Butyl rubber (isobutene-isoprene copolymer)* is typically used in the manufacture of inner tubes and could cause cancer. The solar collectors described in this paper are never meant for a potable water system because of the levels of toxins in inner tubes and in general the implications of recycling materials. A lining to protect *against isobutene-isoprene copolymer* must be used in these types of collectors.

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