

AC 2009-306: A SOLAR-HEATED WORM COMPOST BIN

Craig Somerton, Michigan State University

Craig W. Somerton is an Associate Professor and Associate Chair of the Undergraduate Program for Mechanical Engineering at Michigan State University. He teaches in the area of thermal engineering including thermodynamics, heat transfer, and thermal design. He also teaches the capstone design course for the department. Dr. Somerton has research interests in computer design of thermal systems, transport phenomena in porous media, and application of continuous quality improvement principles to engineering education. He received his B.S. in 1976, his M.S. in 1979, and his Ph.D. in 1982, all in engineering from UCLA.

A Solar Heated Worm Compost Bin

Introduction

Landfills continue to grow in this county, with 20-25% of the trash coming from food or yard waste [1]. For several years, Woodcreek Elementary School has collected their cafeteria food waste and used a worm-based compost system to turn the food waste into fertilizer. Due to this process, there has been a significant reduction in garbage collection at the school. However, during the winter months, the worms become very inactive and composting comes to a halt. In partnership with a non-profit community agency that provides energy and environmental information and services, a mechanical engineering capstone design team has taken on the challenge of designing and implementing a heating system for the worms. In keeping with the theme of the worm composting, it was decided that this heating system must utilize renewable and sustainable energy sources. This paper will share the design process and the details of the final design implementation. The project was unique in that it involved considerable interaction among the mechanical engineering students, the staff of the non-profit community agency, and the staff and students of Woodcreek Elementary School. The paper will share the lessons learned through such interactions and will provide some guidance to engineering educators who would like to pursue projects involving a diverse set of constituents.

There are three partners in this endeavor: Woodcreek Elementary School, Urban Options, and the Department of Mechanical Engineering at Michigan State University. Woodcreek Elementary School is one of four elementary schools participating in a mid-scale vermicomposting worm bin program. Vermicomposting involves using red earthworms to consume waste and create compost [2, 3]. This process is extremely beneficial because it reduces the amount of natural waste that would otherwise be put in a landfill. Each day at lunch time, the students actively participate in emptying lunch waste into the worm bin at the school. As a magnet elementary school, the curriculum focus is math, science, and technology. Teachers consistently incorporate hands-on materials and activities to help students grasp technical concepts. The worm bin is a complementary addition and key component to the fifth grade curriculum at Woodcreek. It is used throughout the school as a valuable teaching tool.

Urban Options is a non-profit community agency that provides energy and environmental conservation information and services. The main purpose of the organization is to improve the environmental quality of urban spaces. This goal is achieved by home and yard improvement demonstrations as well as educational programs. Urban Options has been working to provide compost education to elementary school children in the Lansing School District for the past 11 years. As a result, teachers and students have participated in interactive programs concerning biology, recycling, composting and vermiculture. The most popular program, "Worms Eat Our Garbage", enables students to set up and maintain their own classroom worm bin [4].

ME 481 serves as the capstone design course in the mechanical engineering program at Michigan State University. Student teams are assigned real world projects for the semester. Most of these projects are sponsored by industry, but each semester a few are humanitarian projects that look to serve the community. The Solar Worm Bin project came about due to the publicity of one of these humanitarian projects, Solar Ovens for Tanzania. The engineering teacher at Woodcreek

read the newspaper article on the solar oven project and emailed the instructor of the ME 481 class soliciting his help on the solar worm bin project.

The coupling between a capstone design experience and K-12 outreach is not unique. Electrical engineering students at the University of Cincinnati performed their capstone project as part of the NSF STEP Fellows program [5]. At Western Michigan University, the Engineering Design Center for Service-Learning addresses equipment needs for K-12 schools with combined teams of both engineering and education students [6]. The addition of a third partner in the form of a non-profit organization does make this a unique experience.

The project was divided into two main parts: technical and educational. The technical aspect of the project includes the design, build, and implementation of a solar heating system for the worm compost bin. The educational aspect of the project involves teaching the fifth grade class on applicable engineering topics, as well as including the class at Woodcreek Elementary School in the design and build of the solar heating system.

Technical Aspects

Listed below are the technical design requirements for the solar powered worm compost bin.

- The compost bin must be heated using solar energy.
- The entire project cost must not exceed \$2100.
- The system design must be easily replicated by other schools in the future.
- The heating system must keep the compost above the freezing point.
- The heating system must be designed for an optimal temperature of approximately 70°F.
- The system should be compatible with the original compost bin.
- The entire implementation of the solar heating system must be completed by third week in November.

With the design problem specified, the synthesis or create stage was undertaken, which generated four design alternatives: Solar Electric, Solar Geothermal, Solar Thermal Water, and Solar Thermal Air. Each alternative is discussed below.

Solar Electric

The solar electric system consists of a photovoltaic panel, charge controller, battery, radiant floor heating pad, and a temperature control system. The photovoltaic module would be positioned on the roof of the elementary school to gain maximum exposure to the sun. The PV module converts the energy from the sun into electricity which is stored in the battery. The battery powers the electric floor heating pad, which is positioned in the bottom of the worm bin. It is anticipated that this heating will keep the compost at a temperature between 40 and 70 degrees Fahrenheit. The temperature control system would control the heating pad so that the correct temperature range would be maintained.

Design Positives

- Minimal energy losses are associated with this design due to the simplicity of the system.
- The system is very basic consisting of only four main components.

- The parts included in this design are safe for children of all ages to be around and there are no loose wires or sharp edges included in the design.

Design Negatives

- This system is five times the proposed budget.
- The extravagant costs are due to the number of photovoltaic modules required to power the floor heating pad.
- In addition to the cost of the photovoltaic modules, there is insufficient space available at the elementary school for the number of solar panels needed for this design.

Solar Geothermal

The solar geothermal design consists of a photovoltaic module, geothermal heat pump, battery, charge controller, temperature control device, and underground heat exchanger. This design uses the photovoltaic module to convert solar energy into electricity stored in a battery. The battery would supply the energy to power the geothermal heat pump. The geothermal heat pump is an electrically powered device that utilizes the natural heat storage of the earth. This pump works like any other refrigeration cycle including: an evaporator to transfer heat from the ground, a compressor to increase the pressure and temperature, a condenser to transfer the heat to the worm bin, and an expansion device to lower the pressure and temperature. This pump would transfer thermal energy from the earth through a fluid medium to the compost inside the worm bin via a piping system. The system would be maintained at the desired temperature range through a thermostat device.

Design Positives

- This design utilizes not only solar energy but geothermal energy as well. This enhances the emphasis of this project in spreading knowledge about alternative energy to the community.
- Geothermal heat pumps are very efficient with a calculated coefficient of performance between 3 and 4.

Design Negatives

- The main negative aspect of this design is the cost. The price for a geothermal heat pump was approximately \$2000, not including installation.
- Installation would increase the price drastically and would be a difficult job for team members to accomplish within the timeline for this project.
- Installation would require excavation on school grounds, which could pose a safety hazard to the school children.

Solar Thermal Water

The solar thermal water design consists of a photovoltaic module, battery, pump, and piping system. This design is relatively simple. The photovoltaic module will collect the solar energy and convert it into electricity to be stored within the battery. The battery will operate the pump device which will force water or anti-freeze through the system. As this liquid flows through the solar collector, it will increase in temperature and then transfer heat to the worm bin; keeping the

compost in the desired temperature range. As with the other designs, a thermostat device needs to be implemented to control the temperature and keep it within the desired range.

Design Positives

- The design is very simple.
- It is anticipated that this design will be relatively inexpensive.

Design Negatives

- Leakage may create overall energy losses, environmental concerns, and even safety hazards.
- This design, although simple, would be relatively difficult to manufacture.
- In order to properly design and build the piping, experts would need to be consulted.

Solar Thermal Air

The solar thermal air alternative consists of a photovoltaic module, in-line fan, and air solar collector that includes baffles. This collector device is pointed due south. It is proposed that the collector device will be positioned on the roof of the school. The photovoltaic module will convert the solar energy into electricity to power the in-line fan. This fan's movement will cause convection to occur within the enclosed baffled solar air heated collector. Air will be forced into the collector and will travel through the baffled passageway. The purpose of the baffles is to increase the amount of time the air travels through the collector. Therefore, a greater temperature increase will result. The warm air will be forced into the bin by the pipe connecting the collector to the compost bin.

Design Positives

- This system is extremely efficient.
- Due to the small amount of work required to power the fan, this system requires the smallest PV module of all the design alternatives.
- This system is inexpensive to create.
- Most of the materials can be found at a local hardware store such as: cover glass, aluminum foil, fan, plywood, foam board, insulation, and flat black paint. This enables manageable replication at other locations, which is a very important aspect of the project goal.

Design Negatives

- Although the components of this design are easily obtainable, the fabrication of the solar air collector will be time consuming.
- This design only heats the worm bin when it is exposed to sunlight. Therefore, if many cloudy days occur throughout the winter, the temperature of the worm bin will drop significantly.
- A backup system may need to be created for cloudy days.

A design decision matrix approach was then employed to identify the best design. The solar thermal air collector design was identified as the best design alternative for the solar heated worm compost bin. This design was determined to be the best after evaluating the design matrix and weighing the pros and cons of each alternative. The solar air collector design had the highest

score in the design decision matrix. This design scored best on important criteria such as cost, operating cost, energy consumption, delivery date, weight, size, and quantity in comparison to the other alternatives. Although the design scored well in the function/performance category, it did not exceed the other designs' scores. Ultimately the size, cost, delivery date, simplicity, and quantity were the main considerations that lead to this design decision.

The preferred design will include additional insulation, both in the worm bin and on the collector device. It has been estimated that no more than 4 watts will be needed to power the fan motor. On average, Michigan receives three hours of sunlight per day in the winter. Therefore the fan must run for an approximately three hours a day in the winter. The fan should not run during periods of zero sunlight because this will bring cool air into the system resulting in a decreased bin temperature. In order to solve this problem, the photovoltaic panel will be sized to supply enough electrical energy to run the fans on a day with enough solar radiation to heat the worm bin.

Calculations were performed to size the solar collector and the photovoltaic module, the angle of tilt, and the heating load of the worm bin. The following values were obtained:

Solar Collector Area: 8 m^2

Photovoltaic Area: 0.5 m^2

Tilt Angle: 60.2°

Worm Bin Heating Load: $2400 \text{ W}\cdot\text{hr}$

The student team then bought materials and built and installed the system. The final system is shown in Figure 1.



Figure 1. Final Solar Heating System

Because of time constraints and the magnitude of the build component of the project, testing was very limited and the photovoltaic powering of the air fans was inoperable. Fortunately, a graduate student with an interest in the energy and environment completed these aspects through a three credit independent study course.

The basic diagram for a photovoltaic (PV) system setup is depicted in Figure 2. The PV system is composed of a PV panel, a solar controller, a battery source, and an electric load. The PV

panel generates power from the sun and directly charges a battery. A solar controller regulates the PV panel. Once enough power is generated the controller directs the power to charge the battery, which in turn operates the inline fans. For this application, the fans are required to operate during daylight which is the same time as the battery is charging. A timer was installed between the solar controller and the fans to regulate when the fans will operate.

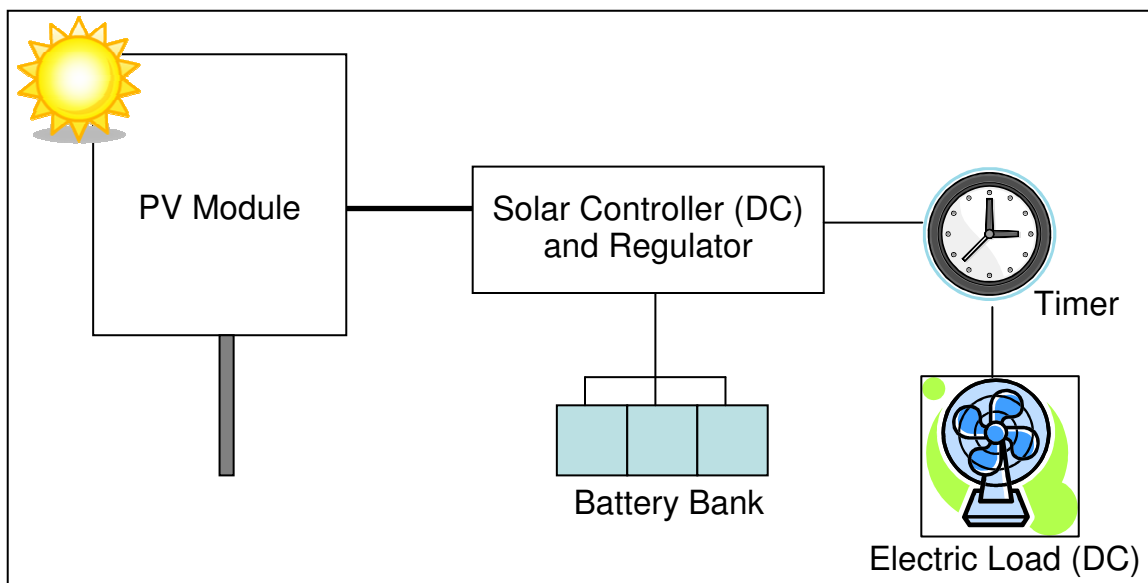


Figure 2. Basic Diagram for PV system and load set-up

At Woodcreek Elementary, the PV panel generates approximately 24V and is designed to power 2 inline fans. Each fan operates at 12VDC, 0.3amps, and 3.6 W. The electric load dictates the battery selection. This system needs 30.5 amp-hours per week, so a 32 amp-hour battery was purchased. The solar controller selection was based on the PV panel voltage output and the electric load amperage requirements. In this design, the PV panel's output is approximately 24V and the fans will use 0.6 amps. The selected controller characteristics are 15 amps, 24V. In addition, the controller features a battery monitor and a low-voltage disconnect which prevents the fans from operating when battery is nearly drained. A programmable timer was set to operate the fans on a daily basis from 11:00 am until 4:00pm.

The compost bin was instrumented with thermistors to track the temperatures and to evaluate the system's heating capabilities. It is important to note heat was also generated from the earthworms, and contained by their biomass. The thermistors were placed in five different locations as noted in Figure 3. One thermistor tracked the incoming air temperature, another outgoing air temperature, two thermistors tracked compost temperature and the fifth tracked ambient temperature. The thermistors within the compost were placed centrally in the compost pile and were distributed along the mid-plane.

A data logger was programmed to record temperatures on an hourly basis. Figure 4 illustrates hourly temperature fluctuations from the incoming and exiting airflows. Incoming airflow temperature is significantly higher than exiting airflow temperature. Both incoming and exiting temperatures are higher than ambient temperatures when the fans are operating. The two areas where there are no temperature spikes correspond to days in which the fans were not operating.

The hourly temperatures were averaged per day, displayed in Figure 5. Ambient temperatures are the lowest when compared to the inflow and outflow air temperatures.

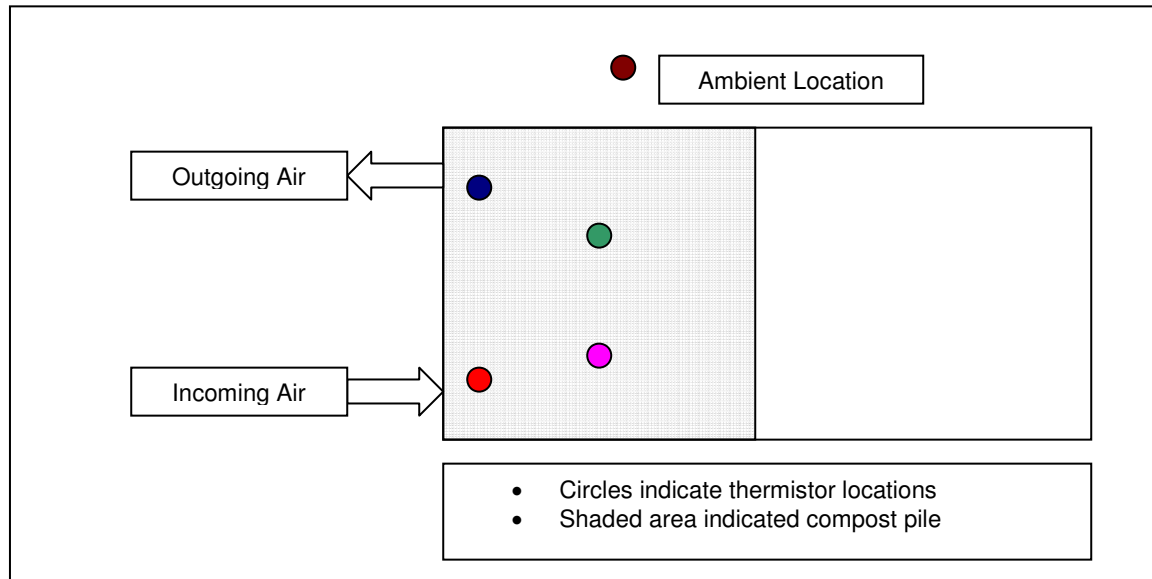


Figure 3. Thermistor Distribution

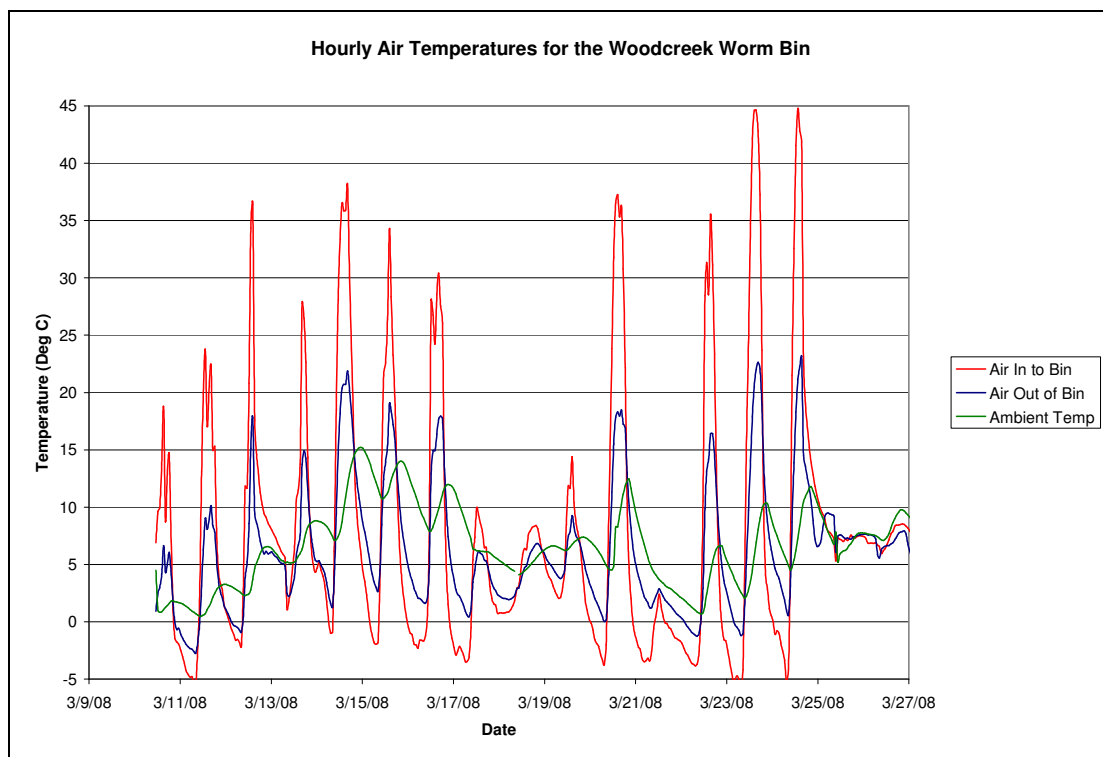


Figure 4. Incoming and Exiting Airflow temperature vs. Ambient Temperature

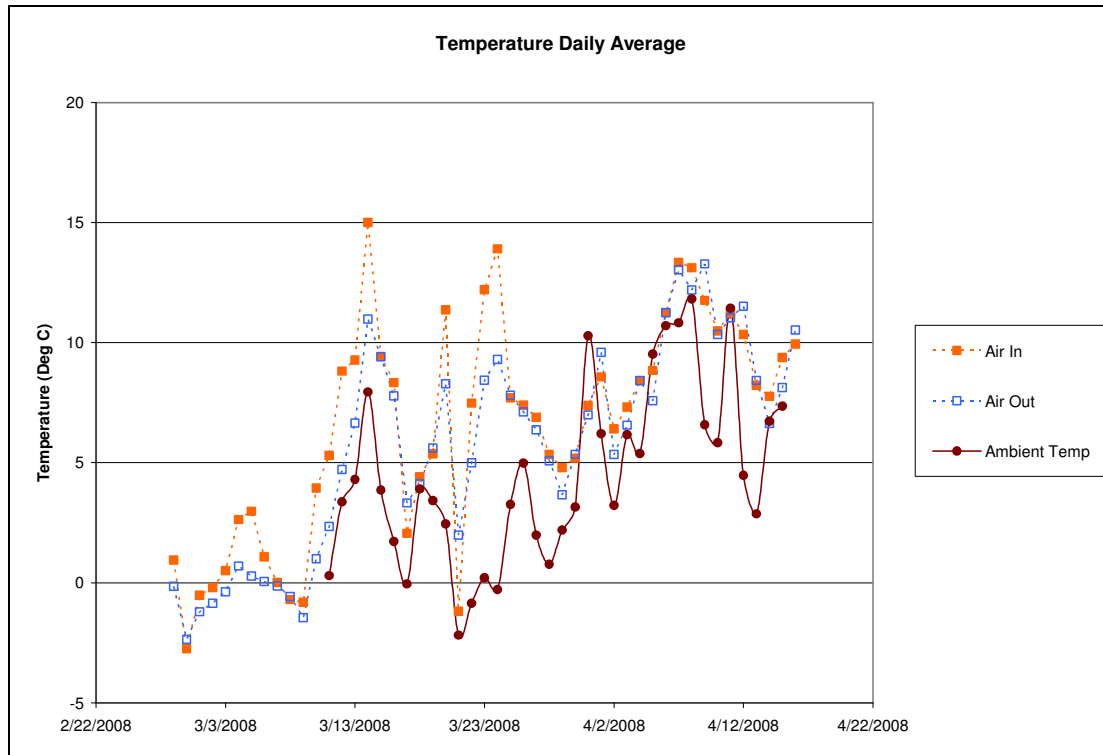


Figure 5. Incoming and Exiting Airflow Daily Averages

The daily average temperatures inside the worm bin and ambient temperatures are displayed in Figure 6. The temperatures inside the worm bin were consistently higher than ambient temperatures. There is a temperature gradient within the worm bin, since not all temperature points are equal. It is not possible to quantify how much heat was provided from the thermal collector versus earthworm biomass; however, the combination of both heat generators was conducive to continue composting throughout the winter.

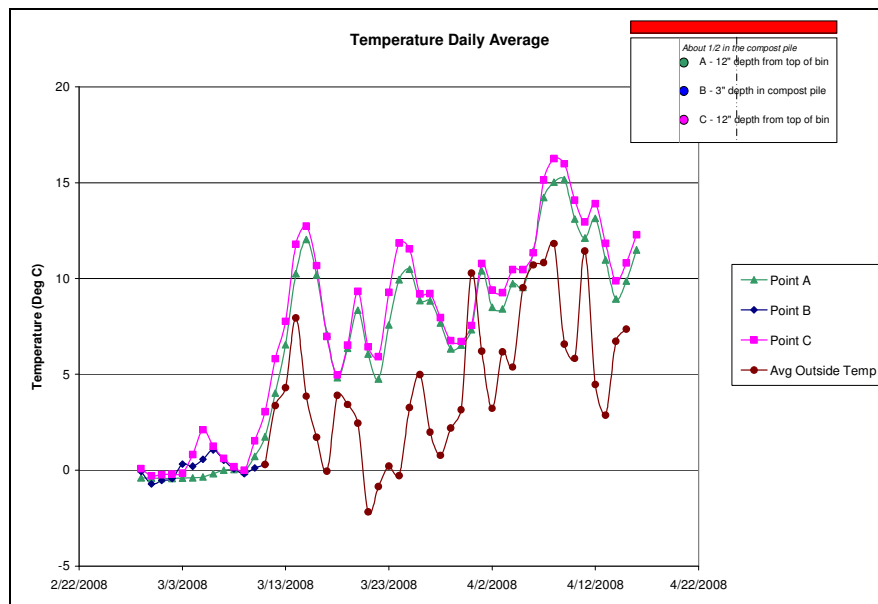


Figure 6. Compost Temperature vs. Ambient Temperature

Educational Aspects

Listed below are the Woodcreek Elementary School and Urban Options requirements for the educational aspects of the project.

- The team must present four lessons to the class that complement the fifth grade curriculum.
- Woodcreek students should be engaged in the development, design, and construction of the warming system.
- A website will be created to serve as a communication tool among MSU, Woodcreek, and Urban Options.
- The website should be updated on a bi-weekly basis.

Prior to presenting lessons to the class, the team met with teachers from Woodcreek Elementary School to become aware of the students' current level of understanding of engineering, energy, and sustainable systems. The team consulted with professors and other educators on relevant topics and leveraged applicable presentations.

In-class Lessons

The design team taught five different lessons to the fifth grade class. In order to keep continuity throughout the semester, the lessons followed a similar format. Each lesson encompassed a theme question and focused on a particular engineering topic. The theme question was created on the basis that "no question is a bad question." Slide titles were typically questions and at the end of each lesson the students were encouraged to ask the design team questions pertaining to engineering topic discussed. Pictures, videos, and bold colors were incorporated into each presentation in order to captivate the students' attention throughout the 30-minute lessons.

The theme of the first lesson was titled *Engineering Basics*. This lesson started with the basic definitions of engineering and mechanical engineering. Dialogue then moved to different types of engineering. For example, PowerPoint slides with pictures of automobiles, planes, buildings, and medical equipment shown and discussed in detail. Good and bad engineering designs were then explained with the aid of two short video clips: the engine combustion cycle and the Tacoma Narrows Bridge Disaster. The bridge disaster led to discussion as to why engineers are important. This presentation ended with a slide about how to become an engineer: an interest in math and science, hard work, and motivation.

The second lesson focused on the design process and how it applies to the problem at Woodcreek: how to keep the worm bin at a warm temperature so that composting continues throughout the winter. The lesson began with background on the problem; which included explanations of composting, vermicomposting, and the worm bin at Woodcreek. The design process was then presented as an ongoing procedure including:

1. Problem recognition
2. Imagination
3. Plan and Analyze
4. Optimization
5. Implementation

It was explained that the design process can be applied to all engineering problems; specifically the solar heated worm bin project. To illustrate the imagination phase, the team facilitated a class brainstorming activity. The fifth grade students generated a poster of design ideas for the solar heating system. The second lesson concluded with design process reminders. It was restated that the design process is ongoing, and that team work and careful planning are key components of a quality design.

The title of the third lesson was *An Introduction to Energy*. This lesson included information about energy, types of energy, energy transportation, and work. Thermodynamic laws were discussed at an elementary level, explaining that energy cannot be created or destroyed; it can only be transformed from one form into another. Types of energy and ways to transport energy were then explained. In order to more clearly illustrate these difficult topics, a ball dropping activity and a candle powered turbine demonstration were incorporated into the third lesson. The ball dropping activity was used to show the transformation of potential energy into kinetic energy. The candle powered turbine was made from a pie pan, play-dough, a pencil, and a birthday candles. The pie pan turbine's spinning movement was powered by the energy from the candle's heat, which demonstrated thermal energy transformation to kinetic energy to the students.

The fourth lesson was a presentation of design alternatives. This presentation incorporated schematics and explanations of each of the four designs, positives and negatives of each design, and the team's final design recommendation. The design process was revisited at the end of this presentation to show that the team had moved onto the next phase, optimization. The team further explained that complicated calculations and research were required in order to optimize the solar collector system.

The fifth and final lesson covered solar energy. This lesson began with the simple question, "What is Solar Energy?" This question was answered by several students: solar energy is heat and light that comes from the sun. Common examples of solar energy and the different forms of solar energy were then discussed with the class. The reason behind the optimal tilt angle of the solar collector was explained to the students with the help of a basketball. The basketball was used to show that the Earth is on a tilt and rotates around the sun. Likewise, the optimal tilt angle of the solar collector was found based on the seasons and Lansing's location on the planet.

Student Feedback

A final visit to the fifth grade was used to test the students' level of understanding. In order to increase interaction between the students and the design team, the students were split into four different groups; one group for each member of the design team. In the different groups, the students were asked questions related to the five lessons. Table 1 shows the results for each question as well as the class average for each question.

Table 1. Semester Wrap Up Results

Semester Wrap Up Results						
5: Exceptional Reponse 3: Good Response 1: No Comprehension						
Question		Class Average	Group 1	Group 2	Group 3	Group 4
Lesson 1						
1	What is Engineering?	4.5	5	4	5	4
2	What is Mechanical Engineering?	3.5	3	4	3	4
3	What do engineers do?	4.25	3	4	5	5
4	Why are engineers important?	4	3	3	5	5
5	How can you become a Mechanical Engineer?	4.5	4	5	5	4
6	Why do you want to become a Mechanical Engineer?	4.25	5	4	3	5
Lesson 2						
7	What is vermicomposting?	3.75	3	4	3	5
8	What are the benefits of the worm bin?	4.25	3	4	5	5
9	Discuss the Design Process	4	5	4	4	3
Lesson 3						
10	What is energy?	4.5	5	5	4	4
11	Name different types of energy	4.75	4	5	5	5
12	How is energy transported?	3.25	4	3	3	3
13	Discuss the ball dropping & turbine activities	3.25	3	5	2	3
Lesson 4						
14	What were the design alternatives?	3.5	4	3	4	3
15	Why did we choose the solar collector system?	4	5	3	5	3
16	How do you conserve energy?	4	5	3	4	4
Lesson 5						
17	What is solar energy?	4	5	5	3	3
18	Name some examples of solar energy	4.25	5	4	4	4
19	What are two forms of solar energy?	3.5	3	4	4	3
20	What is a solar panel?	4.5	5	5	4	4
21	Why do we have seasons?	4.5	5	5	4	4
22	How did we decide the angle of the solar collector?	3.25	4	3	3	3

It is apparent from Table 1 that the students' knowledge of the engineering topics discussed in the lessons has increased significantly since the beginning of the school year. The class averages for each question were all above 3, meaning that the majority of the class answered the wrap up questions well and confirmed understanding of the discussed topics. The class demonstrated the highest level of understanding in lesson 3 when the students were asked to name different types of energy. Table 2 below displays the class results based on each lesson. The students have the highest level of understanding of Lesson 1, which discussed basic engineering themes.

Table 2. Semester Wrap Up: Lesson Comprehension

Semester Wrap Up		
Lesson Comprehension		
5: Exceptional Reponse 3: Good Response		
Lesson		Class Average
1	Engineering Basics	4.17
2	Design Process & Worm Bin Basics	4.00
3	Energy	3.94
4	Presentation of Design Alternatives	3.83
5	Solar Energy	4.00

Project Website

The website created by the team that includes all of the teaching materials can be found at

www.egr.msu.edu/classes/me481/course/SolarWorms/

This site was used by the students throughout the semester and documents all of the lessons discussed above. This website was used for communication among all parties involved with this project as well as for online class activities.

Throughout the past 4 months, the fifth grade students have participated in interactive online activities in order to expand their engineering knowledge. “Roofus’ Solar and Efficient Home” is apart of the Energy Efficiency and Renewable Energy website maintained by the U.S. Department of Energy [7]. On this website, students were able to click on different aspects of an energy efficient home. The site also included activities such as making a pizza box solar oven, sundial, completing a word game, and a coloring page. “The Adventures of Vermi the Worm” is an online activity that furthered students’ vermicomposting knowledge [8]. This activity resulted from research completed on the California Integrated Waste Management website. The students also watched an online video titled, “You’ve Got the Power” which includes information on how power is created, different types of power, and how to conserve power throughout everyday life. This online video is apart of Energy Quest, which is maintained by the California Government website for children [9].

Journal entries, or letters to the class, are also posted on the website as a way for the design team to keep the class updated on the project. One entry includes pictures and brief descriptions of how the team constructed the solar thermal system. Video clips of past design projects are also included on the website in order to expose the class to other engineering design examples.

Lessons Learned

For those engineering educators who may wish to pursue a similar endeavor the following issues should be considered.

- A student design team can become very anxious about having multiple clients for a project. The faculty advisor needs to calm these anxieties and, at time, run interference for the team.
- Many K-12 programs are excited about partnering with an undergraduate engineering program, but it requires the effort of a faculty member to make and maintain the connection.
- The design project itself was quite challenging, especially since a final product was required. It is suggested that a contingency plan be developed for tying up loose ends. If the ends are really loose, perhaps a second team could be assigned the project the following semester. In the case of this project, a student is tying up the loose ends as a independent study the following semester.

Conclusions

A design project was undertaken that involved a partnership among a mechanical engineering capstone course, an elementary school, and an environmental non-profit organization. The project included both a technical component, building a solar energy heating system for a worm-

based compost system, and an educational component, interacting with a fifth grade class on the engineering design method and the fundamentals of energy. An operational solar heating system was design and built that provide a strong technical educational experience for the mechanical engineering students. The educational component proved successful by instilling in the fifth grade class an understanding of the engineering design method and the importance of energy in our society.

References

1. Mid Atlantic Solid Waste Consultants, "Larimer County Two-Season Waste Composition Study", <http://larimer.org/solidwaste/Publications/WasteSort.pdf>, visited 3/6/2009.
2. Cochran, Soni, "Vermicomposting: Composting with Worms", <http://lancaster.unl.edu/pest/resources/vermicompost107.shtml>, visited 3/6/2009.
3. Datar, M.T., Rao, M.N., and Reddy, S., "Vermicomposting - A Technological Option for Solid Waste Management", **Journal of Solid Waste Technology and Management**, v 24, n 2, May, 1997, p 89-93.
4. <http://www.urbanoptions.org/school.php>, visited 3/6/2009.
5. Davis, Karen C., Perkey, Megan L., Harth, Nicholas B., and Dees, Nathan, "STEPing into the Classroom: An Alternative Capstone Experience", **Proceedings of the 2005 ASEE Annual Conference and Exposition**, Portland , June 2005.
6. Kline, Andrew, Tsang, Edmund, and Aller, Betsy M., "Service-learning Engineering Design Activities at Western Michigan University to Support K-12 STEM Education", **Proceedings of the 2005 ASEE Annual Conference and Exposition**, Portland , June 2005.
7. Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Roofus' Solar and Effiecient Home", <http://www1.eere.energy.gov/kids/roofus/>, visited 3/6/2009.
8. <http://www.ciwmb.ca.gov/vermi/game/introduction.html>, visited 3/6/2009.
9. <http://www.energyquest.ca.gov/movieroom/index.html>, visited 3/6/2009.