AC 2008-176: STUDENT IMPLEMENTATION OF A UNIQUE GREENHOUSE HEATING PROJECT

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Student Implementation of a Unique Greenhouse Heating Project

Abstract

For the past two years, successive Western Kentucky University (WKU) Mechanical Engineering undergraduate student teams have designed, installed and tested the performance of a bio-generated heat collection and distribution system to heat a prototype greenhouse for the WKU Agriculture Department.

WKU Agriculture Department takes leaves collected by the city of Bowling Green to process and sell the resulting compost. Compost temperatures of 150 ºF are reached in the center of the pile and by capturing this heat it may be possible to operate a greenhouse during winter months. The goal of the project is to demonstrate the feasibility of an agricultural heating system that could be used in various climates throughout the United States.

The 2006 – 07 student team designed and began the installation of a water piping system to capture and deliver energy to a root-zone heating system in a 30' x 60' greenhouse installed on the Agriculture Department campus farm. The 2007 – 08 team is verifying the analytical and computational techniques used in the initial design and conducting experiments to determine the actual performance of the system. Through construction of the system, the students have experienced team work to manage the project with external customers and contractors, while maintaining a schedule and budget. Through the testing of the final system the team is developing and implementing the validation of the system.

This paper details the design and ongoing installation of the heat collection system, including sizing calculations, experimental verification, and system construction. Energy storage and the greenhouse root-zone heating design will also be covered. Finally, the assessment of the teams' performance and lessons learned on the project will be discussed.

Project Motivation and Scope

The Western Kentucky University (WKU) Department of Agriculture receives the municipal leaf collection from the city of Bowling Green. The leaves are ground before delivery, composted and sold to the community. During the composting process, the piles of leaves become quite warm, with measured temperatures in the center of the piles of over 150 ºF. In 2006, the Agriculture Department partnered with the Mechanical Engineering program to investigate the feasibility of capturing the heat generated from the composting process to heat a greenhouse at the Agriculture facilities during winter months. The primary hindrance to using a greenhouse year-round in moderate climates such as Kentucky is that heating costs are too great to economically justify winter operation. Having a greenhouse available throughout the academic year would provide a significant benefit to the Agriculture Department, but a means of heating that was less expensive than conventional heating was desired. The Agriculture Department hopes to increase revenue to the school by using a non-conventional source of heat to lengthen the growing season, and also to provide a model for local farmers to replicate this heating system.

In 2006 – 2007 a team of four ME seniors began the project investigation and accomplished design, selection and acquisition of major project components during their year-long capstone design course sequence. The team performed preliminary tests to determine leaf pile temperatures and the duration of heating that would be expected. Concurrently, the team gathered historical temperature data for the region and physical property data on the greenhouse. With this information, the amount of energy needed was determined. The initial concept of heating the entire greenhouse airspace proved costly and unnecessary, and a revised system is being implemented to heat plant roots in the greenhouse through plant bed tables.

A two-person 2007 – 2008 senior project team is currently implementing the heat collection design, and is also completing the design of the heat release system into the greenhouse plant beds and the overall system control. A representation of the overall concept is shown in Figure 1. In brief, energy from the leaf piles will be collected using water circulated through cross-linked polyethylene (PEX) tubing embedded in a concrete pad under the leaves. The pad facilitates handling of the composting leaves (supply, turning and removal) by existing WKU equipment without damaging the water tubing. The heated water is pumped into the greenhouse to warm the plants using a similar network of PEX tubing embedded within sand in plant bed tables. The plants will sit on top of the sand. A submerged tank has also been included to increase the system's capability to maintain required temperatures on the coldest nights. The system will circulate water from the storage tank to a main pump, through the compost pad, into the greenhouse and finally back to the storage reservoir buried beside the greenhouse.

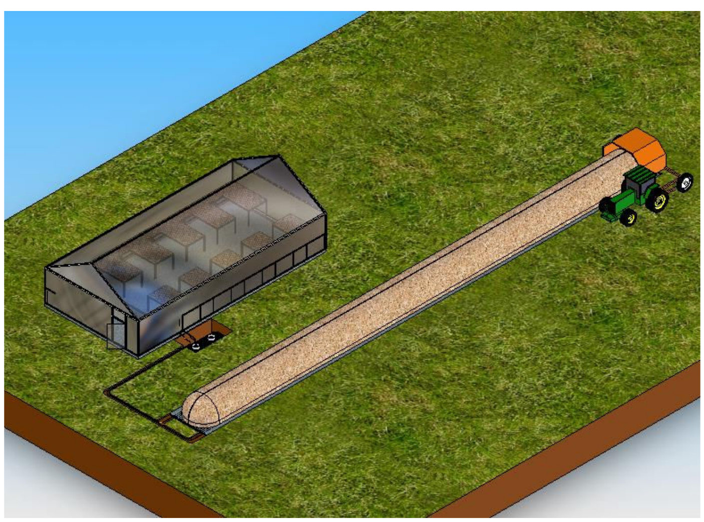

Figure 1: Overall Heating System

The ultimate project goal is to construct a working prototype of a bio-generated greenhouse heating system that will allow verification of the design assumptions made by the student teams, as well as empirical validation of the heat available from the leaves collected by WKU Agriculture. WKU Agriculture will also benefit with the year-round availability of a greenhouse. The WKU greenhouse will be made functional throughout the winter months using energy from the bio-generated heat, and supplemental heat if required. With information gathered from the prototype it will be possible to more accurately evaluate the economic viability. WKU ME seniors who have worked on this project have gained a valuable practical project experience, requiring their demonstration of technical competence and the use of design skills to solve a challenging problem.

This paper will detail the two teams' design and ongoing installation of the heat collection system, including sizing calculations, experimental verification, and system construction. Energy storage, supplemental heating and the greenhouse root-zone heating design will also be covered. Finally, the assessment of the team's performance and lessons learned on the project will be discussed.

Heating Requirements and Collection

The heating needs of the greenhouse dictate the size of the heat collection system – the dimensions of the compost pad for heat collection and the size of the storage reservoir to extend the transient capabilities of the system. Greenhouse heat losses by convection and radiation to the outside air depend on a combination of outdoor temperatures and wind speed. Local historical temperature data was gathered over a period of several decades. Figure 2 shows the average and maximum daily high/low temperatures. Average and record low temperatures from November to March guided the sizing of the heating system. The design condition selected for the initial system was a 10 ºF outside temperature, which is experienced only a few nights per year. An energy storage tank has also been designed into the system for thermal mass so that the system will provide sufficient heat for all but a few record cold nights, when supplemental heating (see Auxiliary Heat and System Controls section) will be provided.

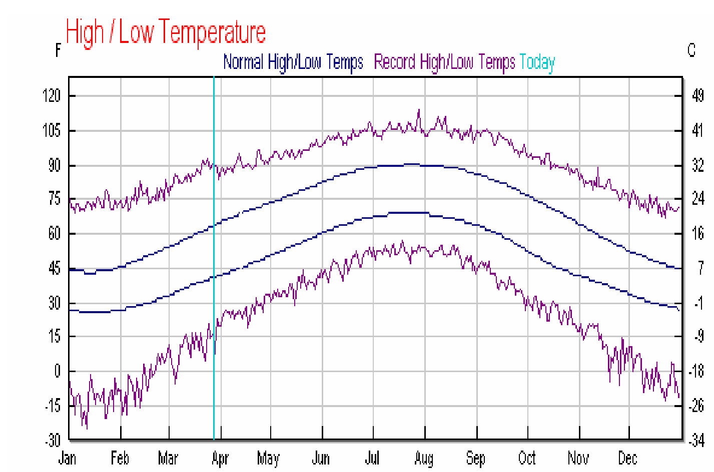

Figure 2: Average Temperatures in Bowling Green, KY

Discussions with the WKU Agriculture faculty led to the selection of a 55 ºF minimum inside temperature for the greenhouse for the intended plants. The greenhouse manufacturer (Winandy Greenhouse Company, Richmond IN) provided an overall heat transfer coefficient of U = 1 BTU/(hr*ft^2* ºF) for the greenhouse WKU owns. The overall heat transfer coefficient includes convection and radiation effects. The initial determination of the heat required is then calculated from the heat loss equation:

$$Heat_{req} = U \cdot A_s \cdot \Delta T \qquad \text{Eqn. 1}$$

Using the area, A_s, of the total exterior surface of the 30' by 60' greenhouse, and a temperature difference of ΔT = 45 ºF between the minimum 55 ºF internal greenhouse and 10 ºF exterior temperatures, it would be necessary to provide 154,000 BTU/hr during worst case conditions. Capturing sufficient energy from the composting leaf pile to heat the entire greenhouse proved challenging, so an alternative approach was considered (see Energy Distribution section).

Making valid design decisions on the heat input from the leaf decomposition was one of the more challenging issues faced by the 2006 – 2007 team. The WKU Agriculture Department has an abundant supply of composting leaf energy for the project from the city of Bowling Green. Therefore the design would not be limited by energy availability. However, sizing an efficient system requires some knowledge of the energy density that could be extracted from the leaves. Heat generation from the breakdown of hydrocarbon chemical bonds during composting of biomass has been used in a variety of applications, including floor heating and the heating of fluids for agricultural uses. Heat collection systems have been proposed using a variety of composting materials, often blowing air through the compost to capture the heat[1]. Interest in capturing energy from composting is growing with the increasing levels of concern about greenhouse gas emissions, as well as rising fuel costs[2]. Prior greenhouse heating project studies where the compost was placed inside the greenhouse were also investigated[3].

The team needed some knowledge of the leaf pile temperature distribution, duration of composting process, and thermal properties of the pile to make system design decisions. Research data exists regarding thermal conductivity of leaf compost[4], the range of pile temperatures possible with the variation of nitrogen content of the compost material[5,6,7], and factors that affect the duration of the composting process[8,9]. However, there is considerable variability with all of these parameters. The design strategy to accommodate this uncertainty has been to use appropriate analysis techniques to assess the energy generation aspects of the heat transfer process, but to assume upon validation of the prototype design that operating conditions can be modified, including altering compost content, to create necessary thermal conditions.

Confidence is warranted in the proposed energy collection from decomposing leaves because the final 145 feet by 12 feet concrete pad design (discussed later in this section) will hold approximately 40 tons of compost. Using average compost property values[6,10], the energy rate required by the greenhouse will require only 5 – 10% of the energy generated by 40 tons of compost, reducing concerns that heat extraction would lower the compost pile temperature and affect the composting process.

To quantify necessary design parameters with greater uncertainties, the 2006 – 2007 team performed tests on sample leaf piles to determine that the system would be able to extract sufficient heat from the compost pile. A 20' x 5' test pad using 1"inch PVC pipe spaced 6" apart was covered with a typical leaf compost pile that was approximately 8' across and 6' high at the center (Figure 3).

Figure 3: November 2006 Testing of Compost Heat

Water was circulated at a flow rate of 1 gallon/minute through a 50' long piping network and returned to an insulated reservoir. The following average temperatures were measured:

- Inlet Water 58.6 ºF
- Exit Water 64.2 ºF
- Mid Pile (Hottest Region of Pile) 146.9 ºF
- Pile at Pipe Surface 104.6 ºF
- Ambient Air 55.0 ºF

The test leaf pile was considerably smaller than the final design pile will be, however its 6' peak height was comparable to the final pile. The test involved circulating water at the 1 gpm flowrate and measuring the temperature rise as well as the compost temperatures throughout the pile. The maximum pile temperature was measured to be just less than 150 ºF, and did not change whether water was circulating or not. The temperature of the compost on the outside of the piping was just less than 105 ºF when water was circulating, and several degrees warmer when there was no circulation. The temperature rise measured for 1 gpm represents 2800 BTU/hr extracted from the pile. The final compost pile dimensions are scaled up to provide sufficient heat transfer to the water in the prototype system.

The testing also provided a sense of the spatial temperatures across the pile. Only the outer two pipes which were 6" from the edge of the compost pile had surface temperatures appreciably below the 105 ºF average of pipe surface temperature. The final pad design will be two feet wider than the piping to allow for sufficient compost pile covering on the outer runs of piping. Over the course of testing, the ambient air temperature changed from 45 to 65 ºF, which had only a minimal effect on the mid pile temperatures or the heat transfer to the water. If the prototype system heat collection proves inadequate, the option does exist to cover the pile, enhancing composting temperatures[11]. This decision would be made when final system testing takes place.

The tests helped select two major design parameters: anticipated outlet water temperature, and expected temperature at the concrete/compost pile interface. Based on the test water temperature increase for a small section of piping, the final design will heat the water to an exit of 85 ºF. The test setup placed the water pipes at the bottom of the compost pile for ease of testing and the compost temperatures at the base were 105 ºF. The final system will have pipes buried in a pad below the compost, and will be extracting more heat with a greater water flowrate. Therefore, sizing of the concrete pad has been based on a lower 100 ºF temperature at the top of the pad.

Similar waste heat capturing projects have been attempted or suggested in the past; however practical issues ultimately hindered these projects. The selected design buries heat collection piping within a concrete pad, and places the compost pile on the pad. While it would be thermally advantageous to place heat capture piping directly into the composted material, the piping would interfere with aerating the leaf pile, which must be done by turning several times. The selected design balances heat transfer from the pile with practical requirements of composting in a farm environment. The concrete pad had a suitable thickness to support common farm equipment, but also includes insulating material below to maximize heat transfer to the water, and minimize heat lost to the ground.

A concrete slab has been installed to collect the heat generated and transfer it to water running through embedded pipes and to provide a convenient means for processing the composting leaves (Figures 4 and 5).

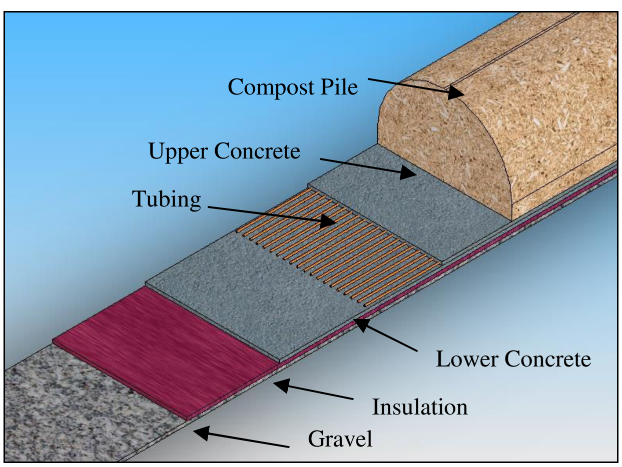

Figure 4: Concrete Pad Concept

Figure 5: (a) Pad Base Gravel/Insulation/Lower Concrete Layer; (b) Initial Piping Installation on Concrete; (c) Final Upper Concrete Layer.

A gravel base supports the pad, followed by two-inch insulation boards to reduce heat loss to the ground (Figure 5a). A one-dimensional, finite difference numerical heat transfer analysis of a 6" layer of concrete was performed to determine the benefit of insulating concrete with a top temperature of 100 ºF and a lower ground temperature of 50 ºF. Insulation produces a 10 ºF higher temperature at the 2" depth where the water piping will be located compared to an un-insulated design; this was the reason for the use of insulation.

A three-inch concrete layer was poured on the insulation to provide a level surface to secure the water pipes (Figure 5b). Cross-linked polyethylene (PEX) tubing was selected for ease of installation and its ability to withstand the expected 30 psi circulation pressure. A second three-inch pour covers the tubing to a depth of two inches (Figure 5c).

The orientation, diameter and length of the PEX tubing required was determined using a Conduction Shape Factor, S, for rows of equally spaced parallel, isothermal cylinders buried in a semi-infinite medium[12]. The distance from the top surface of the pad to the piping is 2", the distance from the piping to the insulation below is 3". The use of a semi-infinite shape factor, when the geometry is clearly not semi-infinite is supported by the addition of insulation. The shape factor models the heat transfer between the piping and the upper surface of the concrete. With the insulation on the bottom of the concrete there will be little heat transfer out to the ground. Edge effects also weaken the semi-infinite assumption. Because the perimeter area of the pad is only 10% of the top surface, the shape factor approach was deemed acceptable. The heat transfer between the compost and the piping is calculated using:

$$Heat_{req} = S \cdot k \cdot (T_1 - T_2) \qquad \text{Eqn. 2}$$

where k is the concrete thermal conductivity, T_1 is the 100 °F temperature at the top of the concrete and T_2 is the 80 °F average water temperature (water enters at 75 °F and exits at 85 °F). The details of the pad dimensions and piping configuration are all contained within the shape factor S, which is a function of pipe spacing, lengths, and diameter.

The original design maintaining the entire greenhouse airspace at 55 ºF when the exterior temperature is 10 ºF, required 154,000 BTU/hr (Eqn. 1). Providing this rate of energy made the size of the compost pad and the water circulation requirements less practical. The revised heat requirement will be described in the next section (Energy Distribution), however the calculated heat required will only be 77,000 BTU/hr. The shape factor, S, achieving the required heat collection uses 3000' of 1-1/2" PEX tubing spaced 6" apart – this is ten 300' PEX coils looped from one end of a 145' long by 12' wide concrete pad and back.

Recognizing the uncertainty in the heat input from the compost, as well as the simplification of the shape factor approach to calculating the piping configuration in the pad, the proposed design dimensions has been selected to provide 125% of the 77,000 BTU/hr required to account for calculation simplifications used in the design process.

Some effort was made to optimize the pad dimensions and piping layout. It is theoretically possible to maximize heat transfer for any of the shape factor variables, however dimensions are more constrained by practical issues, such as accommodating the dimensions of the existing tractor and compost tumbler equipment used to process the compost and available PEX sizes.

With the required energy determined, the water flowrate necessary to create desired temperatures is found using the energy balance equation:

$$Heat_{req} = m_{dot} \cdot c_p \cdot (\Delta T) \qquad \text{Eqn. 3}$$

where m_{dot} is required flowrate, c_p is the water specific heat, and ΔT is the desired 75 to 85 °F temperature rise. To transfer 77,000 BTU/hr, 15 gallons per minute of circulation yield a 10 °F temperature change. Piping loss calculations for 15 gpm flowing through 3000' of tubing yields a 25 psi pressure drop and requires 0.4 pump horsepower when 1-1/2" diameter PEX tubing is used. This is atypical sized PEX, however reducing the tubing size to 1" diameter significantly increases the required pressure and pump horsepower. A ½-horsepower centrifugal pump has been purchased and will be located inside the greenhouse; a throttling valve will control the flow.

Energy Distribution

The initial design approach was to heat the entire greenhouse (Eqn. 1). Instead it is possible to properly protect the plants by conduction heating the roots though sand below the plants, rather than convection heat through the air. The plant bed design will route PEX tubing with heated water through the plant beds, maintaining sand at 75 ºF. Figure 6 provides a top view of two of the eleven connected plant beds (each 6' x 8') that will contain the heated sand.

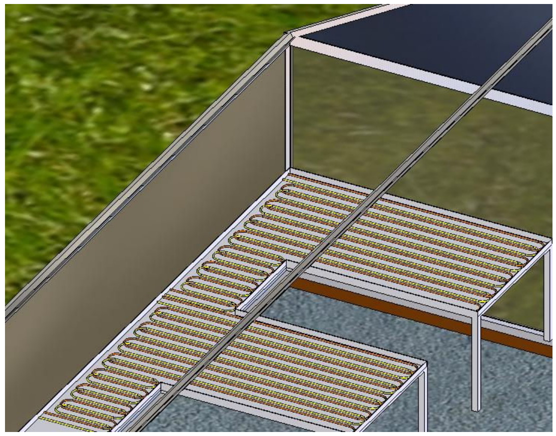

Figure 6: View of greenhouse plant beds

Natural convection heat transfer coefficients were determined for the top and bottom surfaces of heated horizontal surfaces (h_{top} and h_{lower}) [13], and then the total heat for the revised system is calculated with the equation:

$$Heat_{req} = \left(h_{top} + h_{lower}\right) \cdot A_s \cdot \Delta T \qquad \text{Eqn. 4}$$

where A_s is the top surface area of all of the plant beds in the greenhouse and ΔT of 35 ºF is used to maintain a sand surface temperature of 75 ºF when the interior air temperature is 40 ºF. The heat now required is 77,000 BTU/hr, which was used to size the concrete compost pad. With the addition of 77,000 BTU/hr into the greenhouse, the average air temperature in the greenhouse will begin to drop below 40 ºF when the external temperature drops below 15 ºF (Eqn. 1). This again is expected to occur only several nights per year, and with the heated sand in close proximity to the plants, the air around the plants is not expected to cool below 40 ºF.

The water will exit the compost pad and flow to the greenhouse root-zone heating system. Eleven plant beds will be built and installed in the WKU greenhouse. A common 2” PVC hot water inlet manifold will connect all of the beds, with ½” PEX tubing running from the header through each bed at 2” spacing. The PEX tubing will be buried 1” in a 4” deep sand bed. The tubing will return to a 2” PVC cold manifold, where the water will be circulated to the underground storage tank outside the greenhouse. The ½” PEX will be routed from the manifolds using multiple passes – not a single entrance and exit location – to generate an average sand temperature of 75 ºF from circulated water that enters at 85 ºF and exits at 75 ºF.

The ½” PEX configuration has been designed using the same calculations as the compost pad (Eqn. 2). The design dissipates 77,000 BTU/hr to the greenhouse when supplied with 85 ºF water and greenhouse air is 40 ºF. The heat maintains the plant bed sand at 75 ºF and also heats the air in the vicinity of the plants. Based on the magnitudes of the two convection heat transfer coefficients (h_{top} and h_{lower} in equation 4), 1/3 of the heat will be convected through the bottom of the tables. This energy still heats the greenhouse, however if final testing indicates that losses through the bottom are excessive, it will be possible to insulate the bottom of the plant beds and increase the heat available to the top surface of the beds.

One final comment on the root zone heating is that the relatively poor quality of heat is an advantage with the plant heating. Root zone heating works well with water systems between 90 and 110 ºF [14]. Based on preliminary testing, it is expected that water entering the greenhouse won't exceed 95 ºF even during moderate daytime conditions, making it impossible to overheat plant roots and simplifying system controls.

Auxiliary Heat and System Controls

Energy from the composting process will be generated continually, while the heat will only be needed during most winter nights and some cold days. A submerged water reservoir has been incorporated into the system to store energy when not needed, extending the system capabilities to maintain temperatures during the coldest weather. A 1250-gallon septic tank (Figure 7) was purchased as a cost effective means of insulating the water in the ground for heat retention.

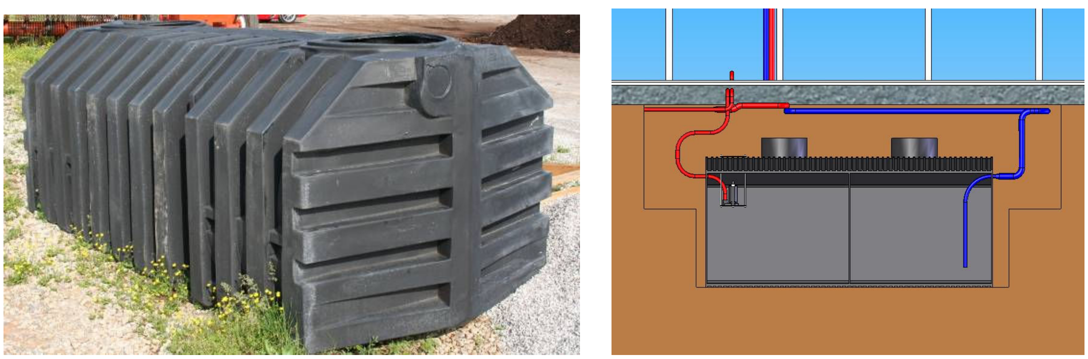

Figure 7: Storage Reservoir Prior to Burying and Reservoir Piping

In addition to 1000 gallons of water held in the septic tank, there will be 1200 gallons of water filling all of the piping (compost pad, greenhouse beds and interconnecting) throughout the system. The storage tank roughly doubles the system water volume. A transient analysis of the behavior of the system was performed to estimate how quickly the water would cool when colder outside conditions exist. In the event of a 5 ºF night temperature, the heat required exceeds the anticipated heat collection by 31,000 BTU/hr. The 2200 gallons of water in the system will cool by just less than 2 ºF per hour during these conditions. The added submerged storage tank capacity extends by two to three hours the time to lower the water temperature by 10 ºF. This would allow the system to protect the plants for all but historically cold nights in the region, and even on cold nights will work for the majority of the time. When water reaches an unacceptably cold temperature a supplemental heating system is being considered as a final backup.

The storage tank also provides a moderating benefit during the daytime operation when the system is operating, but the heat is not required. An advantage of this relatively low temperature heating system is the absence of concern for excessively heating the water – maximum water temperatures in the mid 90 ºF range are expected during warm winter days. The retention time of one hour that the water spends in the storage tank that is buried in 55 ºF soil will slightly lower the average temperature during this period of operation. This will permit the continuous operation of the system during the winter months, without the danger of any damage to the plants on the greenhouse beds.

For coldest conditions, an additional heat source may prove necessary to supply extra energy to keep up with greenhouse losses. Supplemental heating could be added to the water leaving the compost heating pad, just prior to entering the greenhouse plant beds. Readily available tankless water heaters (either electric or gas) can provide the additional energy to raise the water temperature by 5 to 10 ºF on the coldest nights. It is expected that this type of supplemental heater will be controlled via thermostat once water reaches a sufficiently low temperature.

To simplify system control, the water will flow uninterrupted throughout the greenhouse and reservoir during the winter months. When the greenhouse does not need additional heat, the water will still circulate throughout the greenhouse beds and the heat will be stored in the reservoir. At system start-up, the operator will activate power to the system by holding a momentary-on switch located on the control panel inside the greenhouse. This will energize the sump pump, which supplies water to the main circulation pump. When a pressure switch located between the two pumps senses sufficient inlet pressure the main pump will be energized. Water will be pumped through the compost heat collection pad, through the greenhouse heating to a throttling valve controlling overall system flow at the exit of the greenhouse. When sufficient pressure exists at the throttling valve it will no longer be required to manually hold the momentary-on switch.

During operation, the two pumps will be protected by the two pressure switches located upstream of the main pump and upstream of the system throttling valve. This simple control system ensures that a loss in pressure from a leak in the system will not damage either pump. The pressure switches used for this control system will be in watertight switch boxes. Watertight conduit will also provide power safely to the system components and control panel.

System Installation, Validation and Alternative Uses

Final greenhouse and heating system installation has been delayed from the spring 2007 semester to a current schedule for the spring 2008. Delays in purchase approval and greenhouse installation, and unexpected delays in acquiring some of the heating system components slowed progress. Heating system components have been received, concrete pad installation for the compost heating (including embedded thermocouples for testing) and greenhouse foundation took place in fall/winter 2007, and plant bed construction was completed in winter/spring 2008. The greenhouse and storage tank were installed in the winter/spring 2008, and setup and initial prototype testing is currently ongoing.

The goal of the testing is to validate the design decisions made with the prototype by verifying the actual heat collected from the compost and delivered to the greenhouse beds under a variety of environmental conditions. This will be done by testing different water temperature changes and flow rates throughout the system. The flow rate of water will be measured using an in-line flow meter, temperature measurements will be taken with thermocouples placed in direct contact with the water. Pressure measurements will be made at various points throughout to verify the system pressure requirements and pump performance. These pressure measurements will allow the setting of control pressure switches that will protect the pumps in the event of a leak.

It will also be important to characterize the thermal behavior of the compost under varying water flows, and to quantify the heat loss within the concrete. This will be done by measuring temperatures within the compost piles and inside the concrete pad to improve the understanding of the composting process and determine if any improvements are possible. Thermocouple arrays were embedded in the concrete pad during construction for this test, and a frame to place thermocouples within the compost pile has been designed. Temperature vs. flow results will guide the final judgment on both system modifications as well as the feasibility of the system.

A variety of benefits are expected from the successful completion of this project, but the primary objective remains to create a viable prototype system permitting the WKU Agriculture Department to operate a greenhouse in the winter. The larger goal of creating an economically viable means of capturing biogenerated waste heat and using it in an agricultural setting.

The economic viability of this project can be partially assessed by comparing the system cost to traditional heating methods. If a comparable greenhouse in our region were heated by propane heat to the desired 55 ºF interior temperature at all times, nighttime heat would be required in Kentucky from late October through early April. Using the average low temperatures shown in figure 2 during the winter months and assuming that this heating will occur only during the night time, the energy demands and propane consumption were determined. Using current pricing of propane, the annual heating fuel cost would be approximately $2000.

To date the estimated cost of the heating system is provided in Table 1. The greenhouse is not a part of the cost shown, and labor is also not included. The current prototype costs are clearly not viable; however pending validation testing and possible improvements, it appears that a biogenerated heating system cost on the order of $6000 could be economically justified.

Description	Price
Main Components	
Plumbers' Choice Type 304 Stainless and Noryl Sump Pump	$150
Gorman-Rupp Series 2700 Pump with 1/2hp motor	$550
1-1/2" X 3000' Coil Aquapex Tube	$5,500
1/2" X 1000' Aquapex Tube	$1,000
PEX fittings	$250
1250 Gallon Reservoir	$1,150
2" PVC piping and fittings	$250
Controls	$350
Installation	
2" Styrofoam Insulation Boards	$1,400
Bulldozer for Excavation	$700
4000 psi Concrete with Fibers	$1,400
4000 psi Concrete	$1,300
Gravel for the Trench	$1,500
TOTAL	**$15,500**

Table 1. Preliminary Project Cost

Finally, there is a possibility that alternative uses can be applied to a comparable system to capture waste heat from bio-generated processes. The US Department of Agriculture is interested in this system's potential use for chicken farmers, who could use chicken waste heat generated to partially heat the beds where chicks are raised. Another potential is for this system to be simplified and to replace a greenhouse with removable covers for the protection of plants on cold nights, reducing the potential for frost damage. The ability to quantify the performance of this type of system will be important in the evaluation of this system to solve the intended design problem, heating a greenhouse in the winter in Kentucky, as well as the other potential uses for this system.

Student, Project and Program Assessment

The ME program at WKU was initiated in 2000 as a baccalaureate degree, project-based learning environment. Since its inception, the ME faculty at WKU have developed and implemented a professional experience sequence that is consistent with overall mission of the engineering department (the complete Department of Engineering mission statement is found at http://www.wku.edu/engineering/depmiss.php):

> *…to produce, as its graduates, competent engineering practitioners…(who have) a foundation of basic science, mathematics, and engineering knowledge, combined with practical knowledge and experience in applying existing technology to contemporary problems. … Program curricula will be project-based. Students will have sufficient opportunity to engage in project activities to support development of a clear understanding of engineering practice…*

A Professional Component Plan has been created for defining, teaching, assessing and improving students' competencies as they implement mathematics, basic science and engineering science in professional experiences. A guide for the WKU ME Professional Component Plan has been the Engineering Accreditation Criteria of ABET's Criterion 4 : "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints". [16]

To accomplish the production of "competent engineering practitioners" upon graduation, the ME Program Professional Component Plan has evolved (and been disseminated to the engineering education community) in the following areas:

- Engineering Design[16,17,18,19]
- Professional Communications
- Professional Tools
- Engineering Ethics[20]

Engineering Design Plan integrates design-and-build experiences with a structured approach to problem solving across all four years of the curriculum, culminating in a year long senior project. Professional Communications and Tools are concurrently introduced in the design courses throughout the four-year sequence to support the execution of design projects. The Engineering Ethics component provides students with a framework for understanding and accommodating professional expectations.

The interdisciplinary greenhouse heating project with the WKU Agriculture Department provided an excellent vehicle for this integration and major design experience to occur. The six students on the two project teams demonstrated technical competency in heat transfer, fluid mechanics, numerical analysis and system controls to successfully design, build and perform preliminary testing on the project. They were forced to educate themselves in areas of biological decomposition processes and concrete pad design. They implemented a preliminary testing procedure to make initial design decisions, and have incorporated a more complete testing setup for prototype validation that is now ongoing. Their implemented design has certainly been subject to realistic timing, budget and scheduling constraints, and to a lesser degree has followed existing engineering standards (concrete pad design requirements, for example).

Concurrently with their project they performed a variety of professional communication tasks including project scope proposals and final project documentation; they made initial scope presentations and project update presentations to faculty and classmates, and project overview presentations to industrial contacts, external WKU faculty and students, and engineers from regional companies. Teams have conducted a minimum of three graded design reviews with faculty and project contact personnel. The teams used professional tools such as SolidWorks, Microsoft Project and AFT Fathom (pipe flow software). Team members were given opportunities each semester to perform peer assessments of each other and to assess themselves in terms of their effectiveness on the design team.

The project has been executed in a two-course capstone engineering design sequence. The final product of the fall semester course, ME400, is a detailed design proposal. The project is then to be executed in the spring ME412. The grading in both courses is 2/3 team based and 1/3 individual contribution. Teams have performed well over the five years that the capstone sequence has been offered – 79 students have completed or are currently working on 23 projects.

The student performance in each class is assessed via scores on intermediate activities related to their final projects (design reviews, presentations) and the final results of their projects (reports, presentations, demonstration). These assignments have been matched with the following course outcomes:

1. Students will be able to use structured problem solving techniques, appraise the needs of clients, produce product/project definition documents, and propose appropriate engineering solutions.
2. Students will be able to execute a design from inception through completion, and convey/document solutions in a wide variety of formats – including effective oral business presentations, and clear, concise project documentation that flows from general to specific.
3. Students will be able to successfully manage projects using management tools such as timelines, responsibility charts, etc.
4. Students will be able to participate effectively in multi-disciplinary teams, demonstrating that they are effective team members and evaluating the performance of team members.

Students self assess their achievement of the course outcomes, with a 0 indicating no mastery and 10 very proficient. The results of the student self assessment and instructor grade based assessment of the course outcomes are shown in Figure 8 for the spring 2007 capstone class. A target score of 8.0 for each outcome reflects student demonstration of competence in these professional components. Students' self-evaluation was consistently comparable (slightly higher or lower) to faculty evaluation, and met the target score. In the past, deficiency areas have resulted in modifications to the capstone sequence content, or modifications to the coverage in the sophomore or junior design courses.

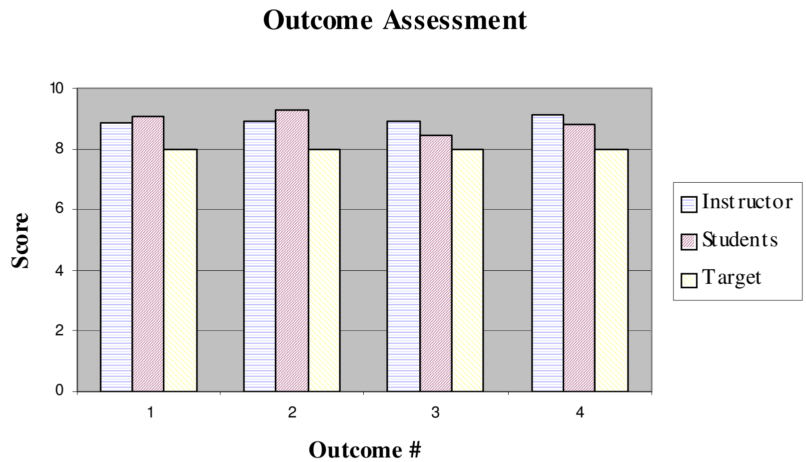

Figure 8: ME412 Course Assessment Results for Spring 2007

For the greenhouse heating project and all projects in general, students are proving themselves to be effective engineering practitioners. The current level of student performance, scope and challenge of senior projects, and faculty member involvement will be maintained; lessons from the past years allow the senior capstone experience to be effectively managed. The program Professional Plan is in place and appears to be working to evaluate activities and make decisions regarding these courses to properly address the Professional Component of the program.

Conclusions

The greenhouse bio-generated heating project is providing the experiences necessary to achieve the desired outcomes of the WKU ME Program Professional Component Plan. The execution of the project has experienced delays, however the current team of seniors is completing the installation and beginning the validation of the prototype design. WKU Agriculture will have a greenhouse that can be used in the winter 2008, and pending the completion of prototype testing, a viable non-traditional heating design will be made available to regional farmers. The students on the two senior project teams effectively demonstrated engineering design principles in the compost pad design, the greenhouse bed design, the selection of appropriate pumps and controls, and the management of the project. The design and selection of these project components were constrained by both financial and organizational issues typical of realistic engineering projects. The project was managed a faculty advisor and industrial contact, further giving the students a meaningful experience in a dynamic environment with multiple managers.

The final design consists of concrete pad heat collection system underneath compost, a root-zone greenhouse heating system, a submerged water reservoir system, and two pumps to circulate water at a sufficient rate. In addition to these components, a controls system has been designed to monitor the pressure at key locations to protect the system.

The system has been constructed to allow normal processing of the compost materials. The operation of the system will be simple and require minimal operator actions. The intended final product is not only a system that works for WKU Agriculture, but also the plans that can be provided for farmers in our region, and other users of energy to heat agricultural-based processes.

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Bibliography

1. Editor, BioCycle, September 1999 page 12-13.
2. Brown and Subler, BioCycle, March 2007 page 37-41.
3. Fulford, "The Composting Greenhouse at New Alchemy Institute: a Report on Two Years of Operation and Monitoring," New Alchemy Institute Research Report #3, November 1986.
4. Chandrakanthi, Mehrotra and Hettiaratchi, "Thermal conductivity of leaf compost used in biofilters: An experimental and theoretical investigation," Environmental Pollution, 2005 July, v. 136, no. 1, p. 167-174.
5. Churchill, Horwath, Elliott and Blisland, "Low-input, on-farm composting of high C:N ratio residues," American Journal of Alternative Agriculture, 1996. v. 11 (1), p. 7-9.
6. Alkoaik and Ghaly, "Determination of Heat Generated by Metabolic Activities during Composting of Greenhouse Tomato Plant Residues," Journal of Environmental Engineering Science, 2006. v. 5, p. 137-150.
7. Curtis, Kleiner, Claasen and Dahlgren, "Differences in a Composted Animal Waste and Straw Mixture as a Function of Three Compost Methods," Compost Science and Utilization, 2005. v. 13 (2), p. 98-107.
8. Hartz and Giannini, "Duration of composting of yard wastes affects both physical and chemical characteristics of compost and plant growth," HortScience, Dec 1998. v. 33 (7), p. 1192-1196.
9. Outamane, Provenzano, Hafidi and Senesi, "Compost Maturity Assessment using Calorimetry, Spectroscopy and Chemical Analysis," Compost Science and Utilization, 2000, v. 8 (2), p. 124-134.
10. Keener, Ekinici and Michel, "Composting Process Optimization – Using On/Off Controls," Compost Science and Utilization, 2005, v. 13 (4), p. 288-299.
11. http://www.cvcompost.com/covers.htm
12. Sunderland and Johnson, "Shape factors for Heat Conduction through Bodies with Isothermal or Convective Boundary Conditions," Trans. ASME 10, 1964, pp. 2317-41.
13. Elsherbiney, Raithby and Hollands, "Heat Transfer by Natural Convection Across Vertical and Inclined Air Layers," Journal of Heat Transfer 104, 1982, pp. 96-102.
14. Diver, "Compost Heated Greenhouses," Appropriate Technology Transfer for Rural Areas, January 2001, www.attra.org.
15. Accreditation Board for Engineering and Technology, Baltimore. (http://www.abet.org/index.shtml)
16. Byrne, Choate, Lenoir and Schmaltz, "Integrated Professional Component Plan from Freshmen Experience to Senior Project," 2004 ASEE Annual Conference Proceedings, Salt Lake City, UT

17. Choate and Schmaltz, “Industry-Based Design Projects in the Junior Year: Making the Transition to Senior Projects,” 2006 ASEE Annual Conference Proceedings, Chicago, IL.
18. Choate and Schmaltz, “Improving Student Design Skills Through Successive Design And Build Projects” 2006 ASME International Mechanical Engineering Conference Proceedings, Chicago, IL.
19. Choate and Schmaltz, “Air Flow Test Bench: A Senior Capstone Project,” 2007 ASEE Annual Conference Proceedings, Honolulu, HI
20. Schmaltz, “Engineering Ethics Instruction as an Integrated Professional Component,” 2006 ASEE Annual Conference Proceedings, Chicago, IL