Designing a Bioshelter for Worcester Schools

By

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Abstract:

Active learning can be a powerful tool for teaching all subjects. However, some elementary schools in the Worcester school district lack the resources for active learning in science. In this project we evaluate the potential use of a bioshelter (a type of greenhouse) to be used as an active learning site for two Worcester schools: Chandler Elementary Community School and Jacob Hiatt Magnet School. In order to make the bioshelter functional, we evaluate the climate and heating systems necessary to maintain a temperate interior space. Drawing on a variety of secondary sources, focus groups with educators, and interviews with owners and designers of bioshelters, we assess climate and heating systems for the bioshelter, as well as its usability as an educational resource.

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Executive Summary

I. Active learning has been underutilized in primary education even though research has shown that active learning is an effective method of teaching. In a study conducted in Indiana public schools, one group of students was given typical lectures, while another group was given a project to complete. When pre and post test scores were compared, the project group showed test score improvement when compared to the conventional lecture group (Medaris et al, 2009).

Gardens, farms, and greenhouses are often sites for active learning. These types of environments offer tangible teaching aids to teachers and allow students to directly observe and interact with the material and concepts that they have learned during class. For example, rather than simply reading about the biology of plants, students can observe a variety of plants at different growth stages and also physically examine and interact with plants. This is just one of many examples of the hands on opportunities which these sites present.

This report looks at the potential of using a bioshelter as an active learning site for two Worcester Public schools: Chandler Elementary Community School and Jacob Hiatt Magnet School. A bioshelter is similar to a greenhouse in that it uses the sun's energy to primarily maintain a temperate environment where plants can be grown. However, it is designed to use mainly passive heating and cooling techniques to maintain its interior climate while creating an indoor ecosystem that allows it to be largely self-sufficient (Frey, 2011). Additionally, a bioshelter differs from a conventional greenhouse in that it is designed to run year round without relying mainly on fossil fuels (Barnhart, 2008; Todd, 1994).

The site of the planned bioshelter is located on Jaques Avenue, adjacent to Chandler Elementary Community School, in the Piedmont neighborhood of Worcester. The sponsor of this project is Worcester Common Ground (WCG) a community development organization which works to improve neighborhoods in the Greater Piedmont Area of Worcester by providing affordable housing and facilitating community involvement. WCG has partnered with the Worcester Regional Environmental Council (REC) to create several Education and Agricultural Training (EAT) Centers in vacant lots around the neighborhoods. These are typically garden plots used for urban agriculture which are managed by community members who have a farming background or are trained in agriculture, especially refugee farmers who have settled in that area of Worcester. When WCG acquired the vacant Jaques Avenue lot, they considered using it as another EAT Center, however, they thought it would be an opportunity to do something with even broader community impact. Upon learning of bioshelter research at WPI's Center for Sustainable Food Systems, WCG decided that having a bioshelter surrounded by a community garden would have a lot of potential for improving the community by providing a gathering space and an educational resource for local schools and the community.

II. Our goal for this project was to assess the usability of a bioshelter as a learning space for local schools. In order to reach this goal, we created three objectives. Our first objective was to determine whether or not certain passive heating systems would effectively regulate the internal climate of the bioshelter. Our second objective was to understand and interpret the needs of both Chandler Elementary and Jacob Hiatt schools and the YMCA. Finally, our third objective was to determine how the bioshelter could meet the needs discovered in objective two.

Our first objective was to determine the effectiveness of two novel climate control systems, the Jean Pain Mound and the climate stabilizer. A Jean Pain Mound is a essentially a pile of dampened woodchips that is used to heat water in a coil of piping as the woodchips decompose over a period of several months. The hot water is then pumped through piping within the structure to be heated and then recirculated into the mound. A climate stabilizer, also known as a climate battery or a ground to air heat exchanger, is a series of underground ducts through which air from a small structure is cycled. As the air passes through the underground ducts, it is dehumidified and cooled by the surrounding earth. When temperatures drop at night, heat stored in the earth is transferred back into the structure. These climate control systems are well-suited for a bioshelter due to their low level of complexity and their use of renewable, abundant resources. bWe began by researching these technologies, which turned up many personal blogs written by individuals who had tried using them. We gained a basic understanding of the two systems from these sources. Moving forward, we found more substantial sources such as *The Compost-Powered Water Heater*, a book detailing the construction and approximate heat outputs (500 BTU/hour per ton of woodchips) of a Jean Pain Mound. We then built a simplified prototype mound for which we recorded internal temperature from September 2015 to January 2016. We found that at its warmest, the mound reached an internal temperature of 140 degrees

Fahrenheit. In an interview at the Radix Center, a bioshelter in Albany, NY, the owner told us about the importance of using relatively small woodchips to maintain an adequate internal temperature and sustain the composting process. Overall, the 10,000 BTU/hour produced by 40 cubic yards (20 tons) of woodchips will add a significant amount of heat to the bioshelter using a renewable resource, making it an important component in the bioshelter design.

In continuing our research for the climate stabilizer we studied the Subterranean Heating and Cooling System, a patented heat exchanger similar to a climate stabilizer. In an interview with Keith Zalzberg, a bioshelter designer, we learned some key design elements of climate stabilizers, such as depth and insulation perimeters. Upon analysis, the climate stabilizer will most likely provide a cooling and humidity reduction effect during warmers months. It is inconclusive whether or not it will provide a heating effect during the colder months, as the depth (3-4ft) the stabilizer is to be installed at is likely too shallow to have any geothermal heating effects..

Our second objective was to understand and interpret the needs of the local schools and the YMCA. To meet this objective, we held several focus groups consisting of education officials, a teacher, a principal, and a YMCA official, all from the local area. The main point taken from these meetings was that despite increasing standardized test scores in most subjects, the local schools had been relatively stagnant in the science category. This could be attributed in part to a lack of hands on learning due to the lack of a laboratory space within these schools and also the lengthy setup and takedown times for such activities. However, the relatively constant test scores in science may also be attributed to a transition new science teaching standards, which are still being developed by the state. Another concern was the need for a safe outdoor learning space due to the hazardous materials that can be found littered around the area.

Our third and final objective was to understand how the bioshelter could address the needs found in our second objective. The bioshelter would have to act as a laboratory space for elementary science classes. We conducted secondary research focused on schools with similar programs. We found several successful programs, such as the Anne T Dunphy Elementary School located in Williamsburg, Massachusetts. This school had integrated a greenhouse and garden plots into education curriculum. We also found the Life Lab organization, which focuses using gardens for educating children. Some of the Life Lab gardens made us of a garden coordinator, a person who is knowledgeable about the garden and facilitates learning. They also rely heavily on volunteers with general maintenance and education. Based on these programs we synthesized how the bioshelter could be used to help the local Worcester schools. One key takeaway was that a garden coordinator would be necessary in order to aid teachers as well as to get the most educational benefit out of the bioshelter. Another major finding was the need for prepared lesson plans. These could be prepared by the garden coordinator, while incorporating critical input from the teachers. This approach would use the expertise of the garden coordinator and would not increase the (already) heavy workload of the teachers, while also tailoring the lesson towards the teacher's class.

III. Recommendations

1. The Jean Pain Mound should be used to provide heating for the bioshelter

- We believe this should be able to provide the heating necessities of the bioshelter in all but the worst conditions of the winter. According to the data collected from our test mound, we found the highest internal temperature (140 F) was below the safe limit (150 F). With the additional heat being transferred out of the mound by water piping, it is unlikely that mound should combust during operations. The majority of the cost comes from the initial installation of the plumbing connection to the bioshelter, which includes digging trenches for the supply and return pipes, insulating the supply and return pipes, and making the pump connections. With parts and labor, it could be at least $2000. After this, the annual cost is for the woodchips and hay bales, which could be as high as $800 and $475 respectively, assuming it is bought commercially. After the winter, the mound can be dismantled and the organic material used as fertilizer and mulch. The full scope of work can be seen in Appendix A, and the temperature data can be seen in Appendix C.

2. The Climate Stabilizer should be used for humidity control for the bioshelter

- Due to the amount of biomass and the possible incorporation of aquaponics into the bioshelter, when not properly ventilated, humidity levels will rise and cause mold to grow on the wooden structure. Although there are many variables that need to be considered, when comparing the Radix Center (no stabilizer) to the Greenfield Bioshelter (has a stabilizer) we believe the climate stabilizer may have contributed to reduced humidity levels. Once the bioshelter is built, the stabilizer will become extremely difficult to add as it is located beneath the structure. The climate stabilizer would be a $4000 investment due to the bulk cost of ½ inch pea gravel. However, we believe that this upfront investment is a better alternative to the cost and inconvenience of replacing potentially molded and damaged wood in the future. It could greatly reduce the risk of mold and water damage, and extend the lifetime of the structure. For a full scope of work, see the Climate Stabilizer Guide in Appendix B for a list of materials, step by step instructions, CAD images, etc.

3. The bioshelter should have a paid designated Garden Coordinator

- This position serves multiple roles. It allows the site to be used by multiple parties, both those that have a stake in the site, such as the community, and those who don’t, such as schools and organizations from the region. It allows teachers to have assistance in coordinating lesson plans and potentially in teaching particular lessons in which the garden coordinator may have expertise. The coordinator would maintain the site and materials, as well as ensure the environment remains safe and clean. Any unseen problems can be solved quickly with a designated leadership position. The garden coordinator should be paid as compensation, as a part-time position likely only needing about 20 hours per week.

4. Teachers should be included in the design process early

- In order for the bioshelter to best integrate with the school community, members from the school should begin working together before construction begins. This will allow the schools to begin collaborating with necessary community members, and begin planning out lesson plans and allocating other resources. These teachers can help to promote and discuss the potential value of the bioshelter to parents, students, and faculty in the school and provide assistance in planning the use, and provide insight into the layout, of the site.

5. Inter-Grade Teaching should be utilized

- Older high school/college students may have the skills to teach or assist with certain lessons. These peer-learning assistants can help support teachers. This relationship is also a valuable volunteer experience for older students, and can help bridge the gap between high school/local college students and elementary aged children. Kids often get excited and pay attention more to young adults than teachers (Jyoti Datta, 2016)

6. Resources such as lesson plans should be created or made available for use by teachers

- Both educators and administration have stated to us that having lesson plans available for teachers to utilize in preparation for, during, and after the visit to the bioshelter would provide teachers with support for teaching and preparing for particular lessons. This would also allow better utilization of the bioshelter and surrounding space, especially with more specific plans produced.

7. Lesson plans for the younger students should focus on simpler activities that helps introduce them to gardening and farming

- Younger students tend to have a more difficult time staying focused than older students. For this reason, lesson plans directed towards lower grades should be more simplistic. While higher grades might delve into the inner workings of the bioshelter like modes of heat transfer, younger grades should participate in simple activities such as worm observations (Scott Kellogg, 2015). After acquiring interest, younger kids can then be challenged with tasks like worm composting and habitat control experiments (Lemon Lime Adventures, 2014).

Authorship

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Literature Review	Eric Chang, Aaron Vien, Jeremy Lane, Brendan Sullivan
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Chapter 1: Introduction

1.1: Sponsors

Worcester Common Ground (WCG) is a community development organization in Worcester, MA, working to improve the quality of life for residents in the Piedmont neighborhood of Worcester. An estimated 37.8% of residents in the neighborhood's census tract live below the poverty level, with the median family income at $22,404. This is much lower than the median for all of Worcester, at $55,894 ("Target Area," (n.d.); "Rationale," (n.d.)). WCG hopes to work together with the community to better generate community cohesion and develop better access to green spaces through an urban agricultural initiative: the development of a bioshelter on Jaques Ave.

1.2: The Bioshelter

Like a greenhouse, a bioshelter is a structure that is used to grow plant life, and is primarily heated by the sun. The primary difference is that bioshelters are intended to be as self-sufficient as possible by using an architecture that makes substantial use of passive heating and cooling techniques, and also by using living and nonliving natural resources to sustain a temperate and biologically productive indoor environment (Frey, 2011). A bioshelter is designed to operate year-round using little to no fossil fuels or petrochemicals for heating (Barnhart, 2008; Todd, 1994). It should be a closed-loop ecosystem, with emphasis on water recycling, composting waste, and natural fertilization and pest management. It is designed to retain solar energy and generate additional heat from renewable resources, like compost, while mimicking the cyclic principles of natural ecosystems to naturally manage the indoor growing environment (Frey, 2011).

Bioshelters use a combination of active and passive heating systems to regulate the indoor temperature and humidity. The minimum indoor temperature should be above freezing for optimal plant health (Frey, 2011). For the Jaques Avenue bioshelter, the target minimum temperature was chosen to be 40 degrees Fahrenheit. The target humidity will largely determine by the plants one wishes to grow, however the relative humidity should be kept below 100% in order to prevent condensation when inside air reaches the dew point temperature (“Reducing Humidity in Greenhouses”, 2003).

Although greenhouses may use some heating and ventilation systems powered by renewable energy, fossil fuels are still needed to provide sufficient heating in the winter months in colder climates, such as the New England region of the United States (Rader, 2013). It is often not economically sustainable for a community to operate a greenhouse during the winter months of cold-to-temperate climates. A solution to this problem can be found with a bioshelter design, which relies on more sustainable heating alternatives, such as composting mulch to heat water (Brown, 2014). In this report, we will discuss the use of active and passive solar, compost mounds, heat sinks via water tanks, and a climate stabilizer (also known as a climate battery). These will be examined individually and as a system in order to determine their effectiveness at maintaining temperature and humidity levels.

1.3: Education and the Community

A bioshelter possesses a number of features that make it useful as an educational resource for the community. The gardening spaces provide a multitude of opportunities for hands-on learning. Additionally, the various systems that sustain the climate and ecosystem of the bioshelter offer many learning opportunities for students, many of which also allowing for hands-on activities.

Given the state of science education in both the Worcester School District (R. Jennings, personal communication, February 24, 2016) and in the United States (Kamenetz, 2016), the bioshelter can also provide opportunities for teachers to improve on their ability to teach science, while also making it easier for them by providing a nearby prepared site for teaching science. Many resources for agricultural themed lessons exist online that follow both United States and Massachusetts education standards (“Common Core in the Garden,” 2013). These resources can be easily adapted for use in the bioshelter and the surrounding plot.

In summary, the bioshelter could make a potentially attractive educational resource for the Worcester School System and surrounding Piedmont community. In this report we will look in more depth at the uses of the bioshelter and garden-based learning as it applies to the Worcester and Piedmont communities. This will include a collection of resources that can be used by teachers to facilitate potential changes in curriculum, and short field trip-like events that could be interspersed throughout the year. There will also be a list of recommendation for courses of action to best prepare the Jaques Avenue bioshelter moving forward, and allow the best integration within the school system.

1.4: Outcomes

WCG worked with a team of IQP students from WPI from fall 2014 through the following spring of 2015. This team was tasked with creating a preliminary design of the bioshelter (Breen, Fay, Luxsuwong, & Sohn, 2015). WCG asked our team to build off their work by analyzing the climate and energy systems for the bioshelter, developing a construction guide for use by a contractor, and evaluating the bioshelter as an educational asset for the Worcester Public School system.

This led to the formation of our goal, which is “To assess and refine the climate components of the Jaques Avenue bioshelter and evaluate its usability and ability to serve as an educational center for local schools.” To meet that goal, our objectives were to: (1) Assess the climate control of the bioshelter, and determine what systems were viable; (2) Understand and interpret the needs of the local schools and the YMCA; and (3) To determine how the bioshelter could address the needs of the local schools and the YMCA.

To meet our objectives, we have created construction guides for the compost mound and climate stabilizer, a summary of the potential educational uses of the bioshelter and several resources for schools interested in using the bioshelter for hands-on learning. We will conclude with recommendations based on our findings. We expect that WCG, the local schools, and the entire Piedmont area will be able to build on and use our concrete plans to create a useful community asset to facilitate hands-on learning and reinforce science education. In the following chapters we will discuss the means to which we accomplished these objectives.

Chapter 2: Literature Review

Chandler Elementary Community School and Jacob Hiatt Magnet School lack opportunities for hands on learning in STEM fields, and in particular, science. This has had a significant impact on science literacy within these schools. While increasing standardized test scores in all other subjects, science literacy has developed at a slower pace at both Chandler and Jacob Hiatt (MCAS Annual Comparisons, 2015).

2.1: Hands-on (Experiential) Learning in Science and STEM Field

For the past 70 years, experiential or hands-on learning has been building traction within the US educational community. The use of “field” learning has been researched as far back as the 1930s. However, looking to apply credit to this work in a class setting, as well as integrating them into classroom techniques did not begin until the mid-1980s, with a push away from passive, traditional education (Lewis, 1994). At least one study has examined the knowledge and understanding that students maintain on engineering subjects when delivered via lectures or through hands-on project learning. In Indiana, they looked at teaching water quality and impact to 8th graders, and divided the grade into 2 test groups. One group was given conventional lectures, while the other group was assigned a project to construct a water purification system. The end result was a higher test improvement when compared to a baseline taken before the unit, in favor of the project group. An interesting trend they found was that students who were not native English speakers had greater gains than those who were native English speakers in the project group (Medaris et al, 2009).

This is one of the reasons why hands on learning is important; it allows students who are non-native speakers, and those who are weak in language, to learn and engage in all of the material without being held up by another subject. By lowering the amount of language required for learning the material, participants can then use the material to help learn additional language, through exercises such as reports, presentations, discussions, or through some kind of activity. This can also be used to encourage more active engagement and help improve communication among classmates (Herrmann, 2014).

Experiential learning is also a great way to teach students to teach themselves and encourage self-directed learning. Additionally, by having students learn more through such methods, they will better understand what a failure really is, and that through failure you can often have an equivalent, if not better, understanding of a subject than you would from success (Teachnology Inc., 2016). Regardless of success or failure, this teaching and learning style is a great way for students to show their independence and self-guidance. Plenty of opportunities for students to learn something on their own will appear, and teaching them those techniques early, and letting them try and fail in a controlled environment, will help prevent from becoming discouraged and giving up. (Teachnology Inc., 2016) Along with this, it is important for them to be able to see how they are doing as they progress, by making self-check tools available (Cleaver, n.d.).

There are a variety of hands on learning and active learning techniques available through public updated online sources. The three primary learning types are auditory, visual, and kinesthetic (Farewell, 2012). Auditory learning is typically the traditional method used in education, involving lectures, and where directions and tasks are verbally assigned. The latter two types are more representative of the hands-on learning field, with visual learners needing to be able to see the concept that they are trying to learn, and kinesthetic learners needing an opportunity to try it out for themselves. In line with these learning styles, there are a variety of active learning techniques to help in teaching in a more active, hands-on way. At the University of Minnesota, one group organized a list of basic learning techniques that can be used for small groups. Examples of techniques that small groups could use are Reciprocal Questioning, Numbered Heads Together, and Problem-Based Learning (University of Minnesota, n.d.). In Numbered Heads Together, a small (or large) group, where one member asks the group a question, and everyone puts their heads together until everyone in the group knows the answer. Then the question asker asks a random person to answer the question, and show they know the answer.

For outdoor and garden learning, there are more specific techniques that can be used that take advantage of the specific features and capabilities of gardens and greenhouses. One of the most important techniques is keeping lessons simple and hands on. One example of this is a lesson where students could participate in “discovery teams,” observing their surroundings while recording their findings in a journal (Giroux, n.d.). It has also been suggested that discussions should be kept simple and short to keep the participants' attentions (NatureBridge, 2016). The focus on these discussions should be about concepts instead of facts. For example, you would show how a pulley works, instead of describing the place, date of discovery, and people involved. Additionally, students should be given set expectations, as this leads them to work more effectively. (Jacobs-Smith, 2016)

2.2: Using Urban Agriculture for Hands-on Learning in Primary Education

Using agriculture for educational purposes is a great opportunity for schools that lack a hands on curriculum. Research shows that the benefits of using urban agriculture for educational purposes include improved academic performance (Smith, 2005), increased interest in lessons (Roy and Packer, 2002), and improved social inclusion (Dillon et al., 2005). However, there was a lot of variability among the learning environments of field trips, after school programs, and integrated school gardens. As a result, it's difficult to perform effective case studies on them, and confirm their cause and effect claims. However, the data gathered from these studies all showed positive outcomes from integrating agriculture into student education, regardless of the style. In the following section we discuss several examples to support this reasoning.

The first study focused on a Louisiana Public Elementary Schools that visited a farm on a field trip. The field trip was not highly structured around lessons, but rather, students were allowed to observe and engage with the natural surroundings. When comparing pre and post science test scores, researchers found an overall improvement, while there was little change in scores with students who had not partaken in the program (Smith, 2005). In another study, similar to the previous, teachers noted that students were more engaged with lessons during the field trip. This interest in learning even continued after the conclusion of the visit. In addition, some students who were less social were observed participating in the lesson (Reiss, 2012).

Another case study was conducted at the Anne T. Dunphy Elementary School in Williamsburg, Massachusetts. The sample size consisted of four classrooms in the Kindergarten Initiative School, in which only half were allowed to participate in the garden program. The other half was considered to be the control group. The results suggested that the students who had taken part in the garden program had a better understanding of which foods were considered healthy and which were not. Despite this, some students still did not find healthy food appealing and had little desire for it. More importantly, most participants had memories of the farm field trips and observations they had made. From this study, 85.7% of teachers reported that they appreciated the program and would like to continue it the following year (Sands, 2012). These results indicate a stronger enthusiasm for the subject by both students and teachers.

On a larger scale, the Boston Schoolyard Initiative conducted a study on student performance after renovating two school playgrounds into school garden play areas in 2002. They investigated the 4th grade math MCAS performance of 78 schools and made a comparison of their math MCAS, as well as teacher and student attendance for the 4 years before and after 2004. According to the records, there was a 12% increase in 4th graders passing math MCAS over non-Boston Schoolyard Initiative schools. They also claimed that there was a significant increase in teacher and student attendance despite an already high attendance rate previously. An unexpected outcome was that they found that suspension rates had decreased during this time. (Lopez, 2009)

The Radix Center, a visited bioshelter within the city of Albany, New York, focused on the educational uses of their bioshelter. They determined hands-on learning to stimulate young children's learning. The Radix Center has attracted much attention from teachers, students, and educational bloggers. The Radix Center has held a variety of events, such as: the Fall Youth Employment Programs, the Radix Summer Youth Program, the Regenerative Urban Sustainability Training, and hosted local school field trips. When reviewing the Radix Center blog, there were questions sent by local teachers asking about future openings for field trips. Others commented that they wished to start their own fruit trees or herb garden similar to Radix (Kellogg, 2015).

2.3: Worcester's Plan for a Bioshelter as a Site for Active Learning

A bioshelter is a solar greenhouse that functions as a contained ecosystem (Frey, 2011). The most notable distinction from a greenhouse is that it does not rely mainly on the use oil-based fuels, but instead relies on renewable resources such as compost, or renewable energy from solar or wind. A bioshelter relies on a variety of subsystems to create a stable ecosystem inside. The structure is designed to maximize sunlight absorption and minimize heat loss. The interior climate of a bioshelter can be controlled by a variety of mechanisms. We focused our research two of these mechanisms: the Jean Pain Mound and the Climate Stabilizer, which is described in more detail in section 2.4 below.

Worcester Common Ground, a community development organization, recently came into possession of a lot at the corner Jaques Avenue and Ethan Allen Street. They planned initially to use the site for one of their EAT (Education and Agricultural Training) Center. EAT Centers are plots of land that serve as agricultural space where refugee farmers and community members can be trained in urban agriculture techniques and grow produce for personal use or to sell. While the EAT centers have been successful in allowing refugee farmers to grow their own food and also sell produce at local farmer's markets, Yvette Dyson, executive director at WCG, wanted to do a project with a larger positive impact on community development. Dyson became interested in building a bioshelter on the plot after hearing of the research on bioshelters conducted at WPI's Center for Sustainable Food Systems.

This project began in the 2014-2015 academic year with the IQP team: Designing a Bioshelter in Worcester. The team was responsible for completing many of the technical aspects of the bioshelter, including the design of the structure. Another key element was the orientation of the structure relative to the plot in order to achieve maximum solar flux, the useable solar radiation, on the bioshelter. Our team is continuing the project where our predecessors left off; by determining the viability of the climate control mechanisms and uses and benefits of the bioshelter as an education center for local schools.

2.4: Bioshelter Climate and Heating Systems

Bioshelters share many of the heating and climate management techniques used by passive solar greenhouses in that they use the principles of passive solar design to use the sun's energy to regulate their interior climate (Bellows, 2008). In particular, both are designed to absorb and retain solar energy without the use of active components. A bioshelter is still primarily heated by sunlight which passes through a glazed roof and warms the air inside. However, unlike conventional greenhouses, bioshelters are insulated everywhere except for the glazed face of the roof in order to retain as much heat as possible on cold days and at night. The glazed roof is oriented to maximize sun exposure in the winter, and consequently bioshelters in the northern hemisphere have south-facing roofs. The angle of the roof is also chosen to maximize the amount of sun exposure, while also providing partial shading during the summer (Frey, 2011).

Although solar energy provides much of the heating needs for bioshelters, an additional source of heat may be needed during the winter to sustain temperatures for plant growth (Frey, 2011). One relatively simple method of generating this heat through renewable means is a Jean Pain mound, which is a compost pile designed to heat water that can then be used for space heating. The basic idea behind this method is to use the heat generated from a pile of decomposing woodchips to heat water circulating through coils of piping within the pile, which itself is insulated with bales of hay (Brown, 2014). This idea was developed in the 1970's by Jean Pain, a French farmer and forester, as a means of providing hot water for his home, while making use of the abundant woodchips by turning them into compost for agriculture (Pellaton, 1980). Recently, the motivating factor of sustainability has brought about a resurgence of individuals who aim to investigate and make practical use of the Jean Pain mound (Brown, 2014).

During the process of composting, microorganisms break down organic matter and generate heat as they metabolize the material. In general, this process requires that the biomass be moist, porous, and open to air in order to allow microbes to aerobically digest the material and produce heat. Furthermore, it is also crucial that the biomass is not too moist, or the microbes will not have access to air. For the case of a Jean Pain mound, small diameter double-ground woodchips from hardwood trees allow for adequate aeration without the need for a powered aeration system (Brown, 2014). Also, since woodchips are primarily composed of lignin and cellulose molecules, they break down relatively slowly and thus provide a consistent heat source over a long period of time. Jean Pain himself obtained internal mound temperatures of 140 F for a maximum period of 18 months (Brown, 2014).

Before construction, a Jean Pain mound should be sized appropriately for heating needs. The amount of woodchips required can be calculated using the approximation that one ton of woodchips produces 1000 BTU per hour on average over 6 months (Gorton, 2012). To provide aeration, mounds are constructed on a foundation consisting of dry woodchips, with a diameter larger than the intended size of the compost pile. Further aeration can be added by laying a drainage pipe open to the surroundings between the hay and the pile. Polyethylene tubing is then coiled around the center and covered with a layer of woodchips soaked with water, followed by additional layers each with their own coil. Finally, rectangular bales of hay are stacked around the pile to provide insulation while allowing aeration. Hot water is then obtained by circulating water through the tubing with a pump, at a flow rate appropriate for the necessary heat transfer (Design guide, 2011).

Another component that could assist a bioshelter is the climate stabilizer. The climate stabilizer, typically referred to as a climate battery, is an underground heat exchanger that is used warm or cool air from the interior of a greenhouse or bioshelter by exchanging heat with the earth. The stabilizer consists of a simple structure of pipes or ducts running underground, with inlets and exits running up to the surface. Air is cycled through the pipes using a fan at either the exit or inlet of the pipe. The purpose of the stabilizer, as the name implies, is to add an element of stability to the internal climate of the bioshelter. It accomplishes this through two means, temperature and humidity control. When air is cycled through the stabilizer it can either be cooled or heated depending on the temperature in the bioshelter relative to the ground temperature at the depth of the stabilizer (Lambert, 1981). Climate stabilizers have also been used for their humidity control effects in bioshelters (Bershof, 2016). The theory behind the humidity control is that when humid air is cycled through the stabilizer, the moisture will condense in the pipe and drain into the ground (Zalzburg, 2016).

This concludes our literature review. In the coming chapters we will work through our process to how we came to our conclusions. We will begin with the methodology in the next chapter.

Chapter 3: Methodology

Our goal was to assess and refine the components of the bioshelter, prioritizing its usability as a way to engage the community and serve as an educational center for local schools. To meet this goal, we had developed the following objectives:

1. To assess the climate control systems of the bioshelter, and determine which are viable.
2. To understand and interpret the educational and safety requirements of the local schools and the YMCA.
3. To determine how the bioshelter could address those needs.

The following sections outline the methodological approach to our fieldwork. A careful consideration was put into research approaches and interactions with the Piedmont neighborhood.

3.1 Assessing the Climate Control Mechanics of the Bioshelter

In order to assess the climate control of the bioshelter, we investigated the feasibility of two internal components: the Jean Pain Mound and the Climate Stabilizer. To meet this objective, we engaged in both primary and secondary data collection. For primary data collection, we engaged in participant observation at the Radix Center, a bioshelter in Albany, New York that was used as an educational resource for schools and the community. There, we observed and took photos of each of the components of climate control system of the bioshelter, including fans and vents, water-based heat sinks, and a propane fueled heater, and we made notes regarding the indoor and outdoor temperatures. We also conducted semi-structured interviews with three bioshelter owners and designers to discuss the efficacy of their climate control systems, design considerations, system costs, and temperature and humidity regulation.

Additionally, we built and tested a simplified prototype of a Jean Pain Mound in order to determine its effectiveness as a heat source during the fall and winter in the local climate. This prototype differed from a fully functioning mound in that it did not contain a coil of piping to heat water, nor was it insulated with hay bales. We constructed the mound in late September using mixed woodchips from the City of Worcester. Starting from a base diameter of 8 feet, we added woodchips in layers while continuously soaking each layer with water until the mound was about 6 feet high. We measured the temperature of the interior of the mound weekly from October through February using a 20 inch Reotemp compost thermometer. Readings were taken in each cardinal direction (North, South, East, and West) at heights of 18, 36, and 54 inches in order to determine how the internal temperature changed throughout the pile and also how sun exposure affected the temperature on different sides. Monitoring the temperature allowed us to determine if the mound could keep a consistent temperature to sustain the heat-producing composting process without insulation.

For secondary data collection, we analyzed bioshelter and solar greenhouse design websites, book chapters on bioshelter climate and heating systems, reports from research centers focused on bioshelters and sustainable agriculture, case studies on greenhouse heating systems, book publications on compost heat recovery from Jean Pain mounds, and university research on Jean Pain mounds. Using this research, we created scopes of work which detail the construction and materials for the Jean Pain Mound and Climate Stabilizer designed for Jaques Avenue bioshelter. These will be discussed in detail in the results section, and the scopes of work are available in Appendix A and B.

3.2 Understanding and Interpreting the Needs of Local Schools and YMCA

In order to understand the needs of the local schools and YMCA, we conducted mainly primary research. Our primary research consisted of focus groups and semi-structured interviews with local educators and community members.

One focus group consisted of community members, including a YMCA coordinator, the WCG board president, a WCG community organizer and a WCG real estate developer, while the other consisted mainly of educators, including a teacher from Chandler Elementary School, the principal of Jacob Hiatt Magnet School, and a Worcester school district manager. The purpose of these focus groups was to receive feedback on our preliminary findings that were developed from our earlier interviews and background research. We presented our findings and background research to the first focus group, and then the following topics were discussed: space usage for education and agriculture, bioshelter management, funding, and scheduling of educational and community activities. Due to the makeup of the first focus group, the discussion was directed towards more logistics and feasibility of the bioshelter. The second group discussed the following topics: 1) challenges faced by teachers and students at Jacob Hiatt and Chandler Elementary School, 2) challenges faced by the Worcester School District, 3), the needs of particular classrooms, 4) student safety, 5) teacher confidence, 6) need for laboratory space, 7) integration into curriculum, 8) potential use by schools other than Chandler and Jacob Hiatt. The data collected in the educator group was the most critical in helping us complete our second objective.

3.3 Determining How the Bioshelter can Address the Needs of the Schools

Using the needs of the local schools that we discovered for our second objective, we sought to determine how our stakeholders and sponsor could best address these needs through the use of the bioshelter. Some potential directions of this were addressed within our discussions and interviews with our two focus groups and an interview with Josh Cohen, a teacher at the Chandler school. Interview and focus topics of discussion included: integration into the curriculum, use of interior space, potential use by more schools, safety of students, and site maintenance. We then compiled their insights, as well as additional research, and looked at how valid the solutions were when applied to both the Piedmont neighborhood and what the bioshelter could address.

For additional primary research, we interviewed Scott Kellogg from the Radix Center bioshelter. In addition to all the technical knowledge and experience he shared with us, he also shared some of his experience and knowledge using the Radix Center for educational purposes. We asked him questions regarding the age groups the Radix Center served as well as the activities that corresponded to these age groups. In addition, we asked him about the benefits of hands on learning. After asking these initial questions about the benefits for the students, the conversation shifted towards discussing the benefits for local schools.

We also conducted secondary research to understand how bioshelters can be used for educational purposes. Unfortunately, we could not find specific literature on using a bioshelter for educational purposes. Therefore, we looked for cases where gardens and greenhouses were integrated into school curriculum. We analyzed many news articles writing about experiences students had on agricultural related field trips. We examined scientific studies and searched for them using ERIC (Education Resources Information Center). We found a variety of educational programs using gardens and greenhouse, ranging from field trip visits, to fully integrated curriculums with greenhouses on the school property.

After this, we performed an interview to follow-up statements made during the focus groups. The follow-up interviews were again semi-structured as it was partially designed to get additional information from speakers that had seemed to be knowledgeable during the focus groups. Due to time restrictions of under 1-2 hours focus groups, we had not wanted to focus on a single person while working with the group. The people who were not present during the focus groups, but were implicated to being knowledge were looked into as well.

We recognized the valuable insight Joshua Cohen had provided during our educator focus group. We focused our questions on his previous experience running a school garden as well as using it for education. We also wanted to see how he would use the bioshelter for education. Questions regarding this included: frequency of classroom visits, student visit times, and activities on similar field trips.

3.4 Data management:

We kept our collected data on Google Drive, which is password protected. Photos taken were uploaded there and backup photos were kept in users' phones. Upon completion of our project we will protect any sensitive data and share relevant findings with our sponsor.

Chapter 4: Results

Our goal was to assess and refine the components of the bioshelter, prioritizing its usability and ability to engage the community and serve as an educational center for local schools. Our objectives were: To assess the climate control of the bioshelter, and determine what systems are viable; To understand and interpret the needs of the local schools and the YMCA; and To determine how the bioshelter could address those needs.

This chapter includes the results of our project, which are discussed in response to each of our objectives. Upon completion of our project, we have assessed and determined the viability of two components of the bioshelter, evaluated the needs of Chandler Community Elementary School, Jacob Hiatt School, and Worcester's YMCA in the context of active learning and teaching. We also identified how these needs could be met through the use of the bioshelter as a site of active learning and as a living laboratory.

4.1: Assessment of Climate Control Systems

4.1.1 Jean Pain Mound Assessment

Our prototype mound was constructed on September 27, differing from a fully functioning mound in that it did not contain a coil of piping to heat water, nor was it insulated with hay bales. It was approximately 12 feet in diameter and 6 feet high, slightly shorter than the suggested height of 8 feet due to the fact the that we did not use a support structure (such as hay bales) that would keep the side walls more vertical. We attempted to use plastic chicken wire to support the walls; however we found that it was difficult to secure to the ground and not rigid enough to keep the walls very steep. Instead, we used a wooden pallet to pack down the walls of the mound after it was constructed. We found that adding more woodchips after construction was unsuccessful in creating steeper walls, as the added woodchips would slide down the side of the mound, indicating that the walls were at their angle of repose. As seen below in Figure 1, this resulted in the finished mound having a more conical shape, as opposed to the desired cylindrical shape.

Figure 1: Completed Prototype Jean Pain Mound

Shortly after constructing the mound, we saw the temperature rapidly rise, before settling around 140 degrees Fahrenheit. We found that this temperature gradually declined over the following 4 months, before dropping rapidly to about 80 degrees Fahrenheit in late January. The outdoor temperatures in November and early December were warmer than average. In mid-February, a cold front moved through New England that brought temperatures in Worcester to below zero, with a near record low of -16 degrees Fahrenheit. During this time, we believe that mound’s microbial life started to die out as outdoor temperature began to get colder. An ideal mound would hold a relatively stable temperature and not be greatly affected by the ambient temperature. From observation of Figure 2, there is a strong correlation between the rate of temperature change of both the mound and the ambient temperature. We believe this is most likely due to the lack of insulation around the mound. It is difficult to say to what degree the insulation would help the mound maintain a high temperature relative to the outside. It is also important to note that there were no water pipes taking heat out of the mound, which would subsequently reduce the internal temperature.

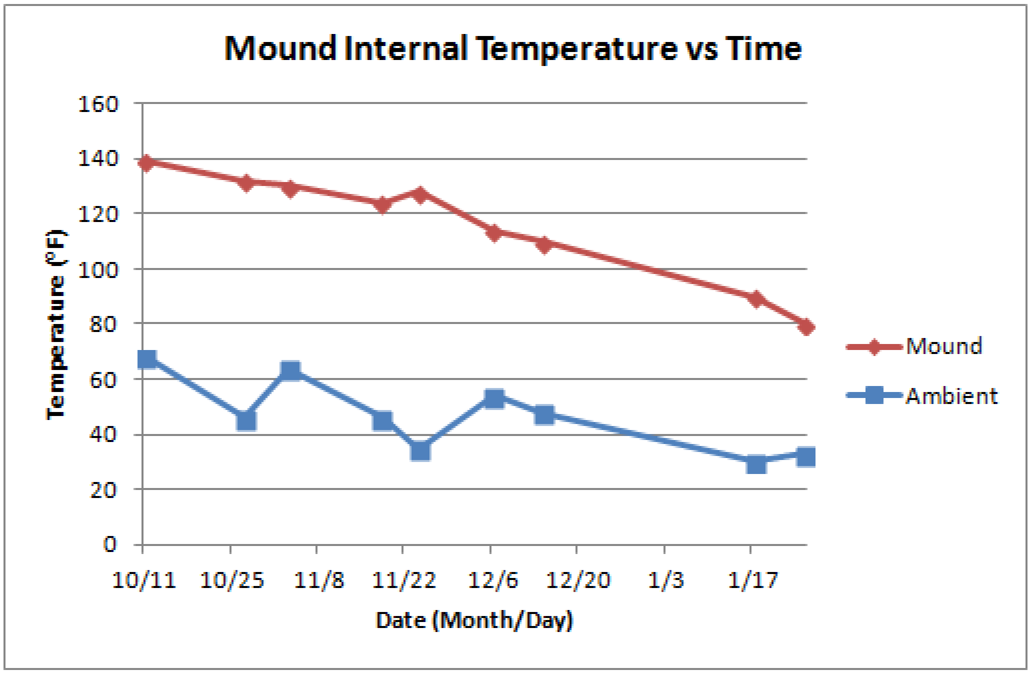

Figure 2: Mound and Ambient (Outside) Temperature Measurements from October through January

While visiting the Radix Center bioshelter, we learned that the owner tried constructing a Jean Pain Mound for winter heating a few years ago. The hot water from the mound was supplied to a coil of metal piping that was then placed in one of the aquaponics fish tanks. However, the owner found their mound froze in the middle of winter, requiring him to invest in a propane backup heater. His mound consisted of 2 inch diameter woodchips, which has significantly less surface area than smaller chips, and which he linked to the short lifespan of his mound. Kellogg noted that the mound had provided adequate heating while it was active, although it was still in the mild part of winter. Currently, The Radix Center maintains at least a 15 degree Fahrenheit temperature difference to the outside from purely solar heating. Comparatively, our test mound maintained a temperature difference of approximately 40 degrees Fahrenheit with the ambient temperature.

From our secondary sources, we found a few design parameters and heating outcomes claimed to have been tested and studied over its history. For a mound of the dimensions we propose, that is 8 feet high and a diameter of 12 feet, we can expect at least 10 000 btu’s per hour output. In order to best match this output, the mound should be formed into a proper cylinder to maximize the temperature, with a large water content, of 1 gallon per cubic foot. The wood chips should be around 1 inch in diameter; a diameter too big or small will result in the mound dropping output after a couple months.

4.1.2 Climate Stabilizer Assessment

Greenhouse type structures tend to accumulate moisture in the air due to the large quantity of plant life growing inside. Conventional techniques to reduce this humidity include opening windows and doors in warm weather, or using dehumidifiers during colder months. In our research for alternative methods of humidity control, the climate stabilizer was identified as one possible candidate.

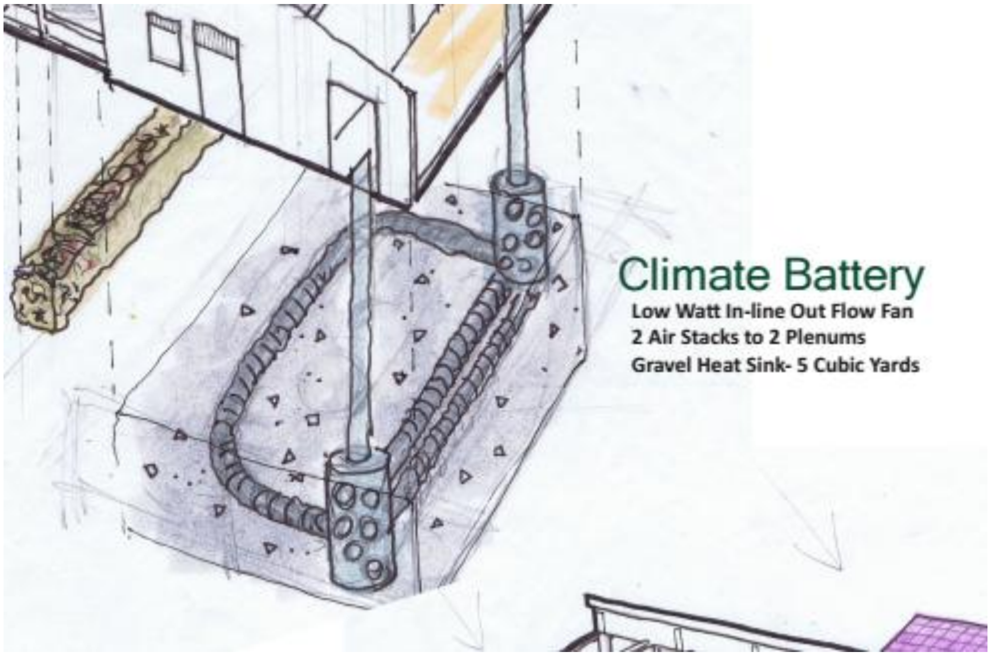

Figure 3: Greenfield Bioshelter Climate Stabilizer Design

A climate stabilizer is an underground ventilation system that can also serve as geothermal heating below certain soil depths. On our visit to the Radix Center, which did not have a climate stabilizer, we observed mold at the early stages of development inside the wooden structure. Kellogg, Radix Center’s owner, made note that this could lead to problems in the future and the rotten wood would need to be replaced. In comparison to a bioshelter in

Greenfield, which had a climate stabilizer incorporated into the design, was not experiencing problems with humidity. Observing these other two bioshelters, we saw a positive association with having a climate stabilizer and low humidity or a lack of mold. However, due to the sample size and other variables, we are not confident that the stabilizer was the sole reason for humidity control in the Greenfield bioshelter, For example, it is important to note that the Radix Center also included a larger aquaponics tank. This open volume of water could greatly increase the humidity in the air, and possibly be a contributing factor to the humidity problem in the Radix Center.

To achieve temperature stabilization, we looked at geothermal maps of New England. At 4 feet (the proposed depth of the stabilizer), the temperature is approximately 40 F in uncovered ground. This would leave little or negative temperature difference between the structure and the stabilizer, minimizing the heating effects. However there would be a significant temperature difference during the warmer months, allowing for the stabilizer to have a cooling effect. The ideal temperature for the stabilizer is 55 F (Ladek Corporation, 1984), however this temperature is reached at depth of 100 meters in New England (Southern Methodist University, 2006). This depth was unfeasible at the prohibitive excavation and labor costs.

For the design of the climate stabilizer we talked to Keith Zalzberg, the designer of the climate stabilizer designer in the Greenfield Bioshelter. Zalzberg pointed out several key design elements of the Greenfield stabilizer. The first was to aim for the entire volume of the bioshelter to cycle through the stabilizer three times a day. This would be accomplished by having a single inlet pipe which split into four to six pipes running the length of the structure, until finally reconnecting into a single outlet pipe. Other points included placing the pipes approximately three feet below ground level with a gap of four feet inside the foundation, to act as an insulation barrier.

4.2: Needs of the Local Schools and YMCA

In order to determine the educational needs of Chandler Elementary Community School, Jacob Hiatt Magnet School, and the Central Community Branch YMCA, we organized focus groups and interviews with local educators, organization members, and members of the community. Additionally, we examined school and student performance data from the Massachusetts Department of Education.

Some teachers in the Worcester public school system lack a strong background with math and, in particular, science. This can lead to some teachers feeling uncomfortable, and often unprepared, to teach science (Joshua Cohen, 2016). These feelings are not limited to Worcester, but in fact are present throughout the United States, where many teachers who teach science at the primary school level do not have a degree in any type of scientific field. This is likely due to graduating science majors being attracted to higher paying jobs in industry (Kamenetz, 2016). Such teachers prefer to have a comprehensive lesson plan while teaching science in order to guide them through the material (Robert Jennings, 2016). Additionally, elementary schools in Worcester lack science labs, which would facilitate the use of hands on learning without requiring lengthy setup time for in-class science demonstrations or activities. Since instructional time is a limited resource for teachers, some can be discouraged from doing in-class demonstrations or activities which would be more easily done in a lab environment with the appropriate resources (Joshua Cohen, 2016). The result of the lack of confidence and resources for some science teachers may be indicated by trends in standardized science test scores.

Although English Language Arts (ELA) and Mathematics MCAS scores in the Worcester public school system are steadily improving, Science and Technology/Engineering MCAS scores have remained stagnant in the past 4 years, with an average of about 30% of Grade 5 students receiving a score of what is considered proficient (Robert Jennings, 2016; MCAS Annual Comparisons, 2015). This degree of poor performance is also present at Chandler Elementary Community School, where an even smaller percentage of students achieved a proficient score, and Jacob Hiatt Magnet School, where a slightly higher percentage of students received a proficient score. Meanwhile, at Chandler the percent students scoring proficient or above nearly doubled for the Grade 5 Math MCAS and increased by 10% for the Grade 5 ELA MCAS. Proficient score distributions for the same tests at Jacob Hiatt remained relatively constant (MCAS Annual Comparisons, 2015). The lower science scores may be a result of a current transition toward STEM standards, which the MCAS does not address. This would not accurately reflect student knowledge, and could be seen as stagnated MCAS scores.

Outside of education, and moving toward safety, we found that all educators unanimously agreed that the existing fence around the bioshelter lot should be kept in place. The fence would serve as a warning sign that the area is being used and would discourage vandalism that has previously occurred at Chandler Elementary School's small learning gardens (Joshua Cohen, 2016). In addition, teachers mentioned that a fence helps set boundary limits for students and encourages them to stay in a safe area (Jyoti Datta, 2016). Educators at the local schools also pointed out that drug paraphernalia is a major problem in the area. Dangerous objects like needles are scattered over the ground, requiring teachers clean out the schoolyards and playgrounds daily. However, most students recognize these objects as hazards and know to get an adult when they notice them (Robert Jennings, 2016). A fence would also limit the accessibility of the site in off hours, which would lower the risk of such things from getting onto the site and from becoming a safety risk. This fence could be used to positively showcase local young artists as a comic strip, as well as a vertical growing space for various vegetables and flowers.

4.3: How the Bioshelter Could Address the Needs of Worcester Schools

In this section, we discuss what is needed to provide teachers with the resources to teach science through active learning at the proposed bioshelter. In order for the site to be used to its greatest potential, a coordinator is necessary (Focus Group, 2016). Garden coordinators have worked on-site with teachers twice a week to extend classroom lessons to the learning garden in CitySprouts, a program for Cambridge schools. A garden coordinator would be beneficial to the Worcester schools in several ways. They could eliminate any setup and cleanup time saving the teacher's instructional time. The garden coordinator could also reduce the need of the teacher to do their own research and lesson planning. In addition, the use of garden coordinators is one of the most effective ways to make and maintain partnerships between schools and gardens (CitySprouts, 2014). By acting as an intermediary, the garden coordinator would not only reduce the load on teachers, but also guarantee well-run educational programs.

We found an abundance of free, publicly available lesson-plans for teachers set in community gardens available on the websites of multiple learning gardens organizations (Boston Schoolyard Initiative, CitySprouts, and LifeLabs), as well as in community garden starter guides

(USDA, 2014). The lesson plans include many topics including food nutrition, water, heating, plants, energy, simple machines, language skills, culture, and mathematics (Benefits of School Gardening, 2008). These lesson plans are great baselines and building blocks to morph into a focused concept Worcester teachers could use the bioshelter to teach.

With the help of WPI librarian, Lauren Hanlan, we were directed to various lesson plan resources. One such resource is PBS LearningMedia, a website that can add additions to lesson plans, and lists both national and Massachusetts education standards on each activity. It also provides tools for creating activities for students including crossword puzzles and word searches, among others to personalize based on the classroom setting.

It is important to involve teachers with the design of the bioshelter early on. Teachers will have greater investment if they have input into the design, and as a result, the design will also be more suited to their needs. (Jyoti Datta, 2016) There are numerous articles that support this theory and the early involvement was a trait highlighted in many successful community gardens (Chung, 2005). Being involved in the design also allows teachers to incorporate the bioshelter into their lesson plans early on.

The bioshelter has the potential to help teachers who are less confident in teaching science. The bioshelter provides opportunities for hands on lesson plans. Hands on learning allows teachers to have physical aid in explaining pieces of the lesson (Freedman, 2000). Having a designated area for learning science also reduces the setup and takedown times, allowing for more dedicated lesson time (Cohen, 2016).

The drug paraphernalia is a major problem in the area, and as previously discussed, teachers must clean out the playground daily, and the students know to get an adult when they needles. Therefore, the area and community garden around the bioshelter should be clear of drugs, alcohol, urination, and defecation (Totem Town Community Gardeners, 2007). In order to minimize safety hazards a physical barrier (like the existing fence) should be made so that children do not enter alone in the community garden.

Chapter 5: Recommendations

1. The Jean Pain Mound should be used to provide heating for the bioshelter.

- We believe this should be able to provide the heating necessities of the bioshelter in all but the worst conditions of the winter. According to the data collected from our test mound, we found the highest internal temperature (140 F) was below the safe limit (150 F). With the additional heat being transferred out of the mound by water piping, it is unlikely that mound should combust during operations. The majority of the cost comes from the initial installation of the plumbing connection to the bioshelter, which includes digging trenches for the supply and return pipes, insulating the supply and return pipes, and making the pump connections. With parts and labor, it could be at least $2000. After this, the annual cost is for the woodchips and hay bales, which could be as high as $800 and $475 respectively, assuming it is bought commercially. After the winter, the mound can be dismantled and the organic material used as fertilizer and mulch. The full scope of work can be seen in Appendix A, and the temperature data can be seen in Appendix C.

2. The Climate Stabilizer should be used for humidity control for the bioshelter

- Due to the amount of biomass and the possible incorporation of aquaponics into the bioshelter, when not properly ventilated, humidity levels will rise and cause mold to grow on the wooden structure. Although there are many variable to determine, the case of Radix Center and Greenfield Bioshelter comparison suggested the climate stabilizer reduced humidity levels. Once the bioshelter is built, the stabilizer will become extremely difficult to add as it should be located beneath the structure. The climate stabilizer would be a potential $4000 investment due to the bulk cost of ½ inch pea gravel. However, we believe that this upfront investment is a better alternative to the cost and inconvenience of replacing potentially molded and damaged wood in the future. It could greatly reduce the risk of mold and water damage, and extend the lifetime of the structure. For a full scope of work, see the Climate Stabilizer Guide in Appendix B for a list of materials, step by step instructions, CAD images, etc.

3. The bioshelter should have a paid designated Garden Coordinator

- This position serves multiple roles. It allows the site to be used by multiple parties, both those that have a stake in the site, such as the community, and those who don't, such as schools and organizations from the region. It allows teachers to have assistance in coordinating lesson plans and potentially in teaching particular lessons in which the garden coordinator may have expertise. The coordinator would maintain the site and materials, as well as ensure the environment remains safe and clean. Any unseen problems can be solved quickly with a designated leadership position. The garden coordinator should be paid as compensation, as a part-time position likely only needing about 20 hours per week.

4. Teachers should be included in the design process early

- In order for the Bioshelter to best integrate with the school community, members from the school should begin working together before construction begins. This will allow the schools to begin working with necessary community members, and begin planning out lesson plans and allocating other resources. These teachers can help to promote and explain the value of the bioshelter to parents, students, and faculty in the school and provide assistance in planning the use, as well as insight into the layout, of the site.

5. Inter-Grade Teaching should be utilized

- Older high school/college students may have the skills to teach or assist with certain lessons. These peer learning assistants can help support teachers. This relationship is also valuable volunteer experience for older students, and can help bridge the gap between high school/local college students and elementary aged children. Kids often get excited and pay attention more to young adults than teachers (Jyoti Datta, 2016)

6. Resources such as lesson plans should be created or made available for use by teachers
    - Both educators and administration have stated to us that having lesson plans available for teachers to utilize in preparation for, during, and after the visit to the bioshelter would provide teachers with support for teaching and preparing for particular lessons. This would also allow better utilization of the bioshelter and surrounding space, especially with more specific plans produced.
7. Lesson plans for the younger students should focus on simpler activities that introduce them to gardening and farming
    - Younger students tend to have a more difficult time staying focused than older students. For this reason, lesson plans directed towards lower grades should be more simplistic. While higher grades might delve into the inner workings of the bioshelter like types of heat transfer, younger grades should participate in simple activities such as planting, observing worms and insects, and feeling and tasting plants (Scott Kellogg, 2015; Josh Cohen, 2016). After acquiring interest, younger kids can then be challenged with tasks like worm composting and habitat control experiments (Lemon Lime Adventures, 2014).

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Appendices

Appendix A: Jean Pain Mound Guide

Jean Pain Mound Scope of Work

The Jean Pain Mound is a compost pile designed to heat water to 110°F-130°F for a radiant floor heating in the bioshelter. It is often referred to as a Pain Mound or even just a compost mound. The compost is primarily made up of hardwood woodchips, with no more than 10% being manure and food, in order to keep a neutral smell near homes, as well as using about a gallon of water per cubic foot.[1] By controlling the size and ratio of the wood chips and shaving, you can control the max heat and how long the heat can be sustained.

Smaller woodchips and a higher percentage of sawdust result in a higher heat output, but as the ratio increases the system will compost too quickly and be useless within a couple months.[3] This also will increase the risk of combustion, particularly if the compost is not thoroughly soaked with water. Too many large particles will result in a low temperature being sustained over a long period of time. Given our climate, this temperature would be too low to sustain the composting, and it would freeze.

Along with this, the amount of water you use is very important in sustaining the composting process necessary for the mound to heat the bioshelter. Too little water results in the compost drying out inside, and the composting will slow down substantially, enough for the system to freeze in winter.[2] We could not find anything that would inhibit the system from being completely soaked in water, as any excess would drain out as the composting process began. However, as water isn't free within the city, we feel that maintaining a good monitor on rate usage over the volume is necessary, while taking time to ensure the center is especially soaked.

The use of compost mound within the New England climate is quite well documented.[1] However, it hasn't been used as a heating component in a bioshelter nor greenhouse in a significant documentation, and as a result the actual ability of the system to heat the bioshelter could be brought into question.

From our research, we found that a Jean Pain mound consisting of 40 cubic yards of compost feedstock can sustain a heat output of about 10 000 btu/hr[1] for a period of about 6 months. As a result we believe that the mound, coupled with the passive heat absorbers in the form of water tanks, should be able to maintain temperatures well above freezing in all but the most extreme conditions.

In order for the compost to be of use after the mound has been used for one heating season, we suggest the mound be constructed in two locations, which will alternate each year. As a result, two piping trenches will need to be laid, with water tank hookups that can be switched inside, or with valves that can open and close the supply and return lines for both trenches.

Citations:

[1] Brown, G. (2014). The compost-powered water heater: How to heat your water, greenhouse, or building with only compost. Woodstock, Vermont: Countryman Press.

[2] Our data from the test mound

[3] Kellogg, S (2015, Nov 14) Personal Interview.

Gorton, S. (2012). Compost power! | cornell small farms program. Retrieved from http://smallfarms.cornell.edu/2012/10/01/compost-power/

Design guide. (2011). Retrieved from http://www.compostpower.org/node/24

Whitney, D. (2014). Slade hall compost heat: Final report. Westford, Vermont: ecoSolutions LLC.

Jean Pain Mound Construction Guide

Below is a guide for the construction of a Jean Pain Mound, with a list of materials that should be bought.

Materials:

- Compost material feedstock (40 cubic yards):
    - At least 70 % Double-ground (stringy) woodchips
        - Smaller than 1 inch diameter
            - Not too small or the effects are similar to sawdust
        - Avoid woodchips and sawdust from rot-resistant trees (hemlock, cedar, Douglas fir, black locust, etc.)
        - Woodchips should result in a 130-140 °F mound for about 6 months, assuming a ¾ to 1 inch diameter woodchip consistency.
        - Using 100% Woodchips is feasible if the woodchips are the ideal size and stringy, however, additional materials that might otherwise be wasted can be used to enhance the performance of the mound (see below)
    - If using any of the options below to create a blended feedstock, all material must be thoroughly mixed before used for constructed the mound
    - Up to 30% Sawdust (optional)
        - Sawdust helps to increase the maximum temperature of the mound, but too much of it can shorten the time that the mound produces heat, and it might not last the entire winter.
    - Up to 10% Manure (optional)
        - Manure helps the compost weather cold temperatures better, but too much can cause odors and may be a nuance for residents.

- Haybales (~95) (14 x 18 x 40 in)
    - 13 for each of the 7 layers
- 4 inch Corrugated Drainage Pipe (100 feet)
- 1/8th HP Pump (Taco Brand); additional pump needed to radiant floor heating system in bioshelter
- 1 inch diameter 100 psi Polyethylene (PEX) Tubing (3 x 300 foot coils)

- 1 inch diameter PEX Couplings (2)
- 1 inch diameter PEX elbow
- Fill/bleed valve
- Foam pipe insulation (2 x 15 foot sections - depends on length of trench)
- 4 inch diameter PVC Conduit (2 x 15 foot sections - depends on length of trench)
- Temperatures sensors (at least 2)
- Flow rate sensor
- Cinderblocks or similar weights
- Water (at least 1000 Gallons for soaking feedstock)

Preparation:

- Placement for mound
    - Closer to building is better
        - If on south building face, avoid obstructing sky
- Construct pipe trench coming from bioshelter to within 8 feet of mound center
    - Drill hole (at least 2 inch diameter) in foundation for pipes to enter
    - Insulate each end of PEX piping (supply/return) for length of trench
    - Lay piping only along trench length, as well as monitoring wires
    - Place 10 foot pole at center of mound
        - have cold water supply affixed near bottom of pole
        - have hot water return affixed near top of pole
- Set up pump mount and water tank connection in bioshelter
    - Connect cold-water supply piping to tap near bottom of water tank
    - Insert fill/bleed valve into hot-water return pipe
    - Connect hot-water return piping to top of tank
        - connects to pump outflow
            - connect piping from trench to pump inflow

Construction:

1. Mark 12 foot diameter around pole
    a. Keep piping at least 4 feet from edge
    b. Lay out one layer of hay bales along perimeter

2. Lay out the aeration tube, spiralling out from the center (Figure 1)
        i. Have the last few feet come out from haybales (Figure 2)
3. Mark the first 20 feet of the PEX tubing
    a. Connect this end to the cold water supply line
4. Add 20 inches of compost feedstock (Figure 3)
    a. Add a layer of hay bales as you near clearing it
5. Lay the first layer of PEX tubing (Figure 4)
    a. Start 1 foot from outer edge of feedstock (11 foot diameter)
    b. Spiral the tubing inwards
        i. Keep the tubing 6 inches apart
    c. Stop when the tubing reaches a 20 inch diameter circle
6. Add 10 inches of feedstock (Figure 5)
    a. Add hay bale layers as needed, to avoid spilling over
    b. Pack outer edge of feedstock as you go up
7. Repeat 6 times Steps 5 and 6 (total of 7 layers)
    a. On the 7th layer, connect end of piping to hot water supply line
    b. Place piping down with the last layer, being careful to avoid kinking it
        i. be sure to detach it from pole
    c. Then continue with step 6, adding the 10 inch feedstock the final time (Figure 10)
8. Add about 12 inches of feedstock to last layer (total of about 24 inches)
    a. Place wet, loose hay over top layer (Figure 11)

Deconstruction:

1. Close cold water supply and pump water pipe empty
    a. Shut off pump
2. Remove Hay bales
3. Uncover top layer of mound and disconnect it from the hot water supply
    a. Begin removing piping and coil it as you remove it
    b. Begin removing it down to the base, moving compost as needed
        i. Avoid yanking out the end piping where it becomes marked
4. Carefully remove the bottom layer,
    a. Be sure to avoid the aeration tubes and tubing from the trench
5. Store everything not needed

Figures and Model

Below is a series of images created in Sketchup to visualize each step. We did not model the installation of the piping trench.

Figure 1: Aeration tubing (black) is laid in concentric circles around the center stake

Figure 2: First two layers of hay bales placed around 12 foot diameter base, with aeration tubing extending through insulation

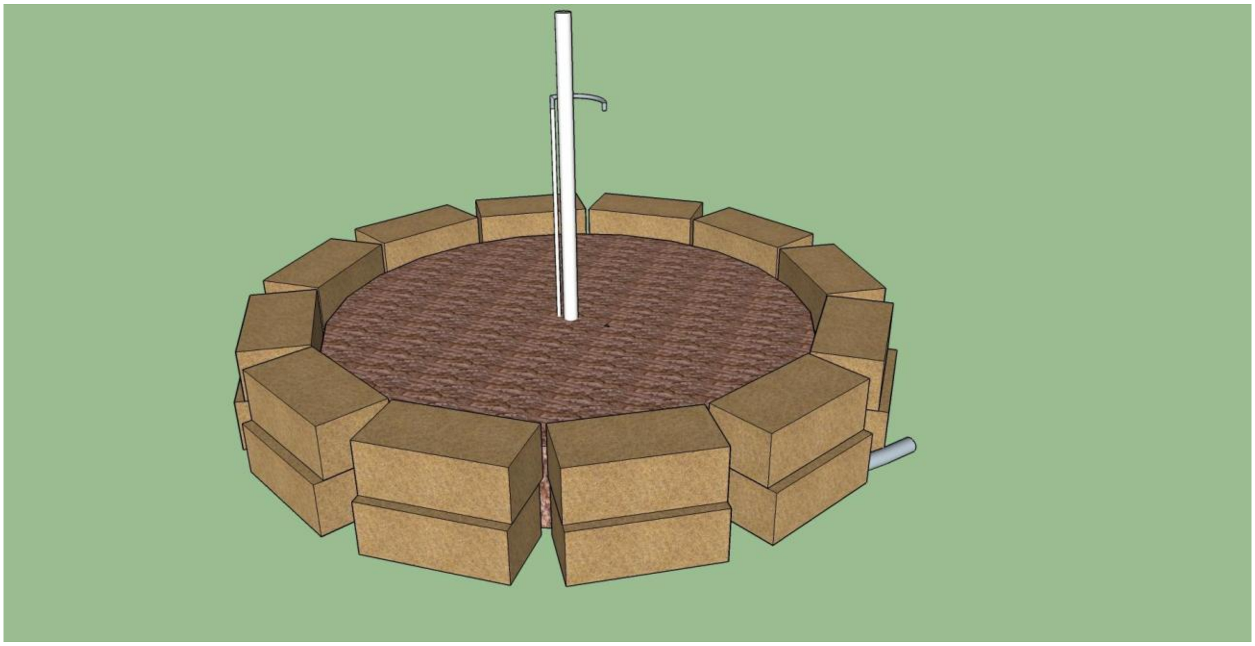

Figure 3: First layer of compost feedstock added

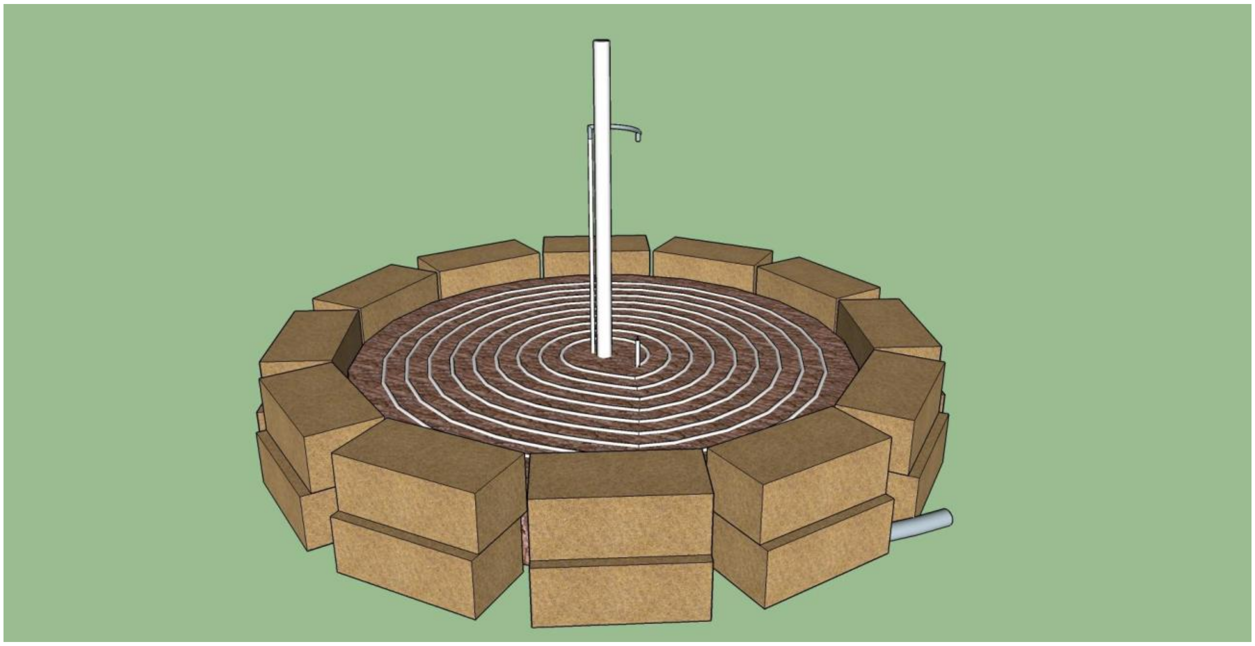

Figure 4: First coil of PEX tubing on first layer of compost feedstock

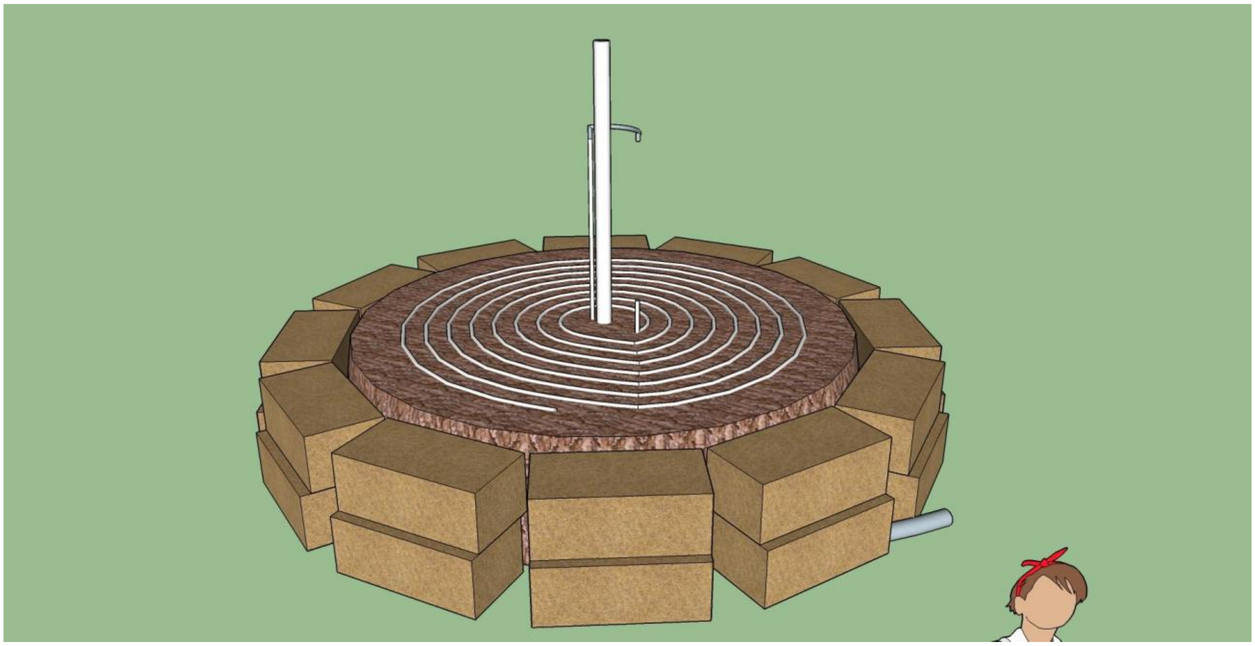

Figure 5: Second coil of PEX tubing on second layer of compost feedstock

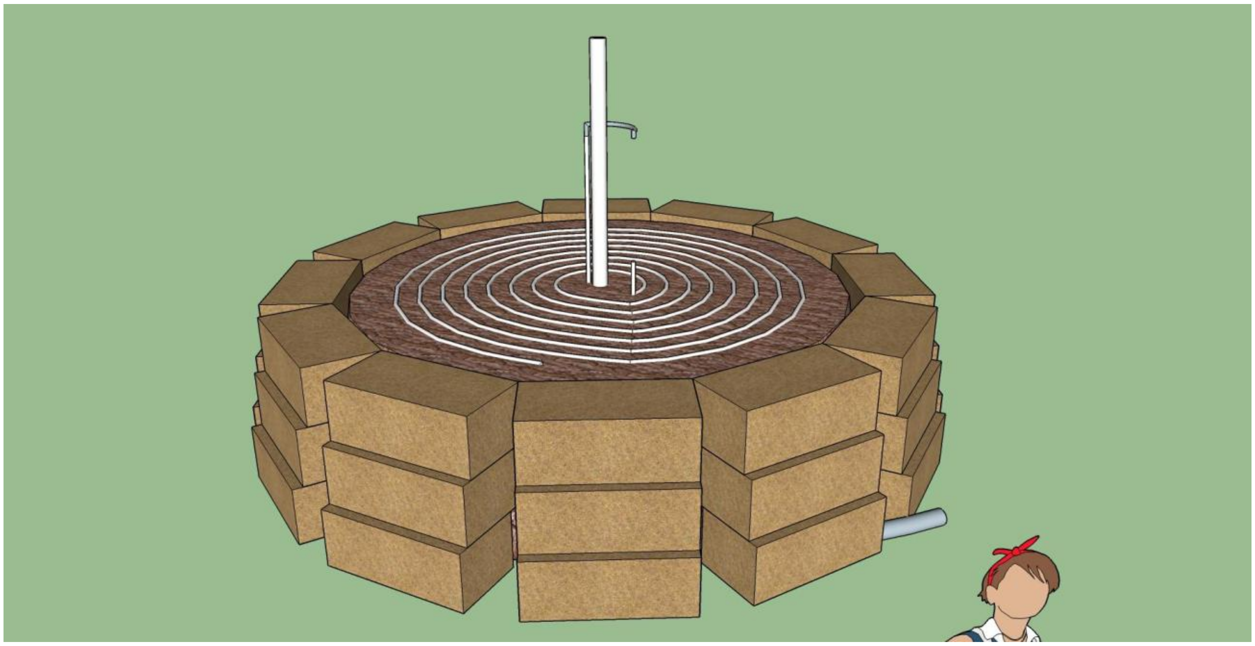

Figure 6: Third coil of PEX tubing on third layer of compost feedstock, with additional ring of hay bales added

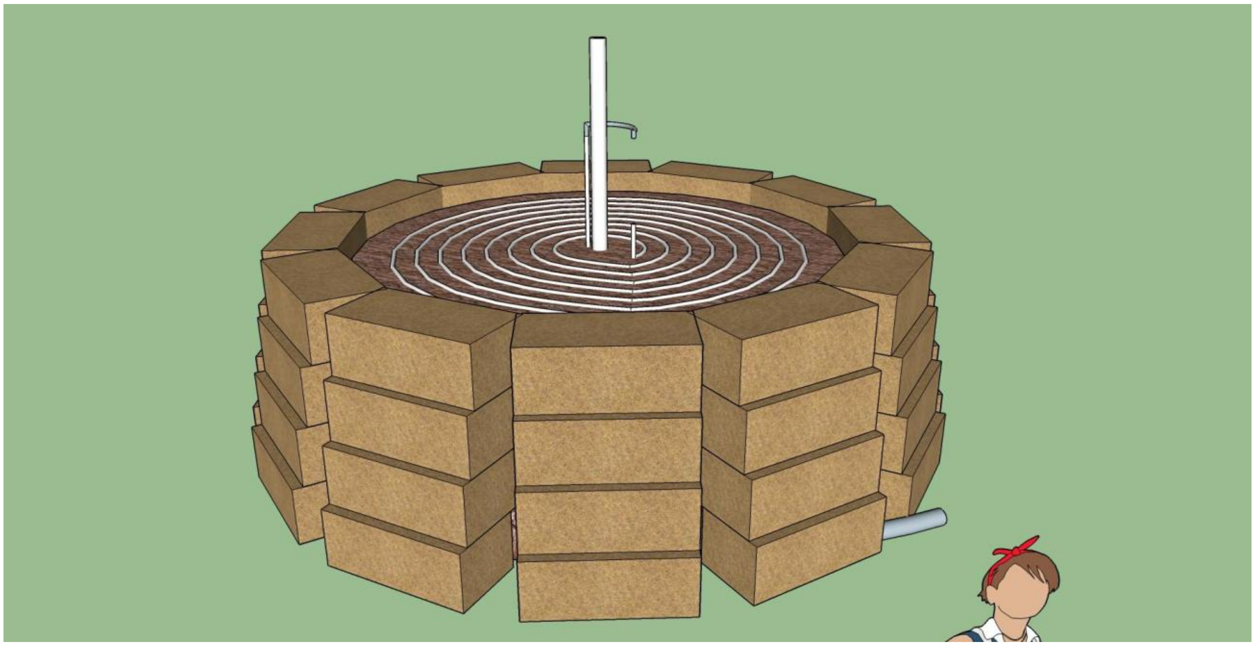

Figure 7: Fourth coil of PEX tubing on fourth layer of compost feedstock, with additional ring of hay bales added

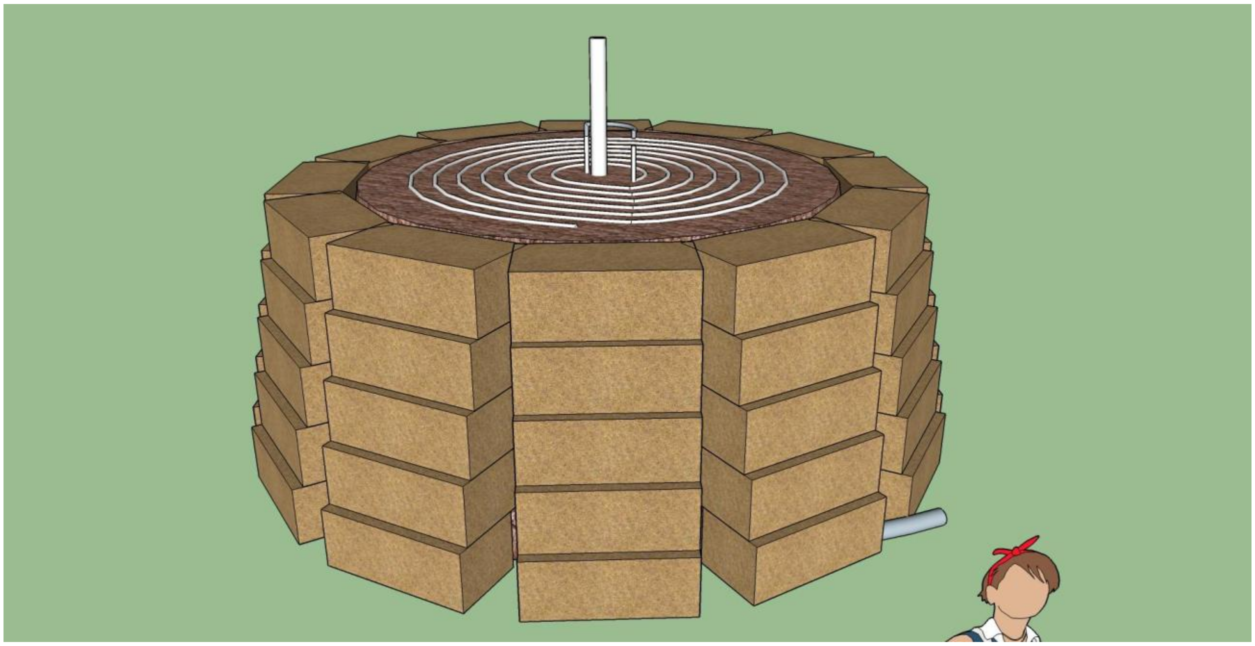

Figure 8: Fifth coil of PEX tubing on fifth layer of compost feedstock, with additional ring of hay bales added

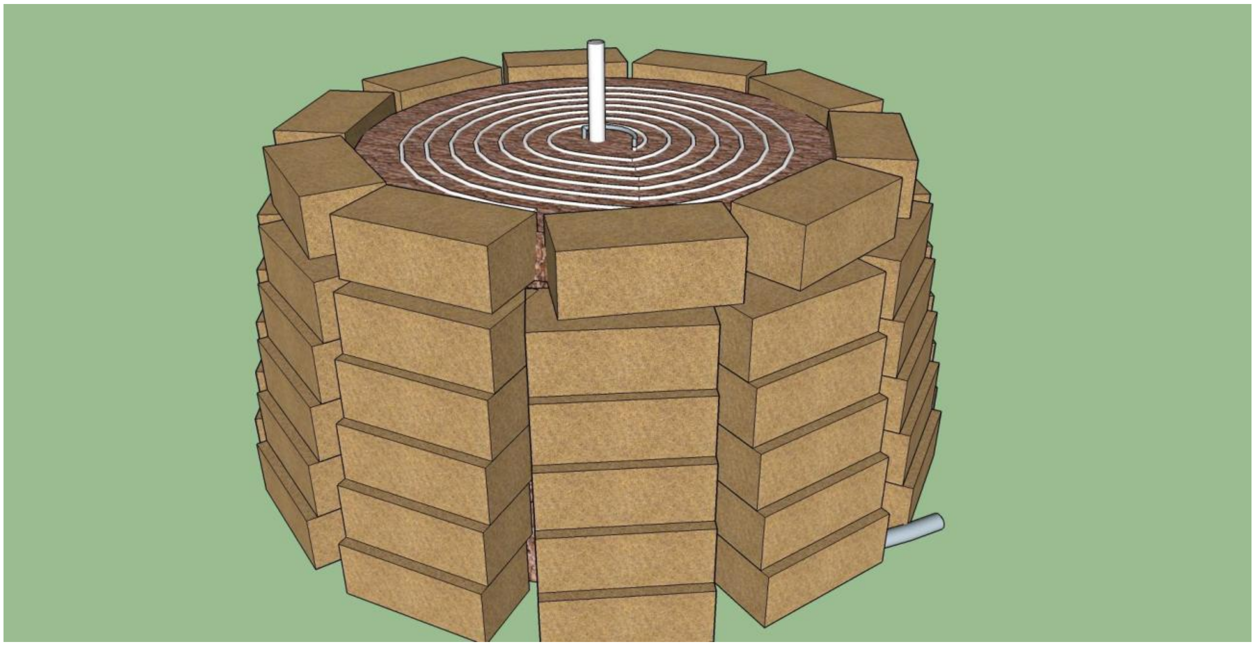

Figure 9: Sixth coil of PEX tubing on sixth layer of compost feedstock, with additional ring of hay bales added

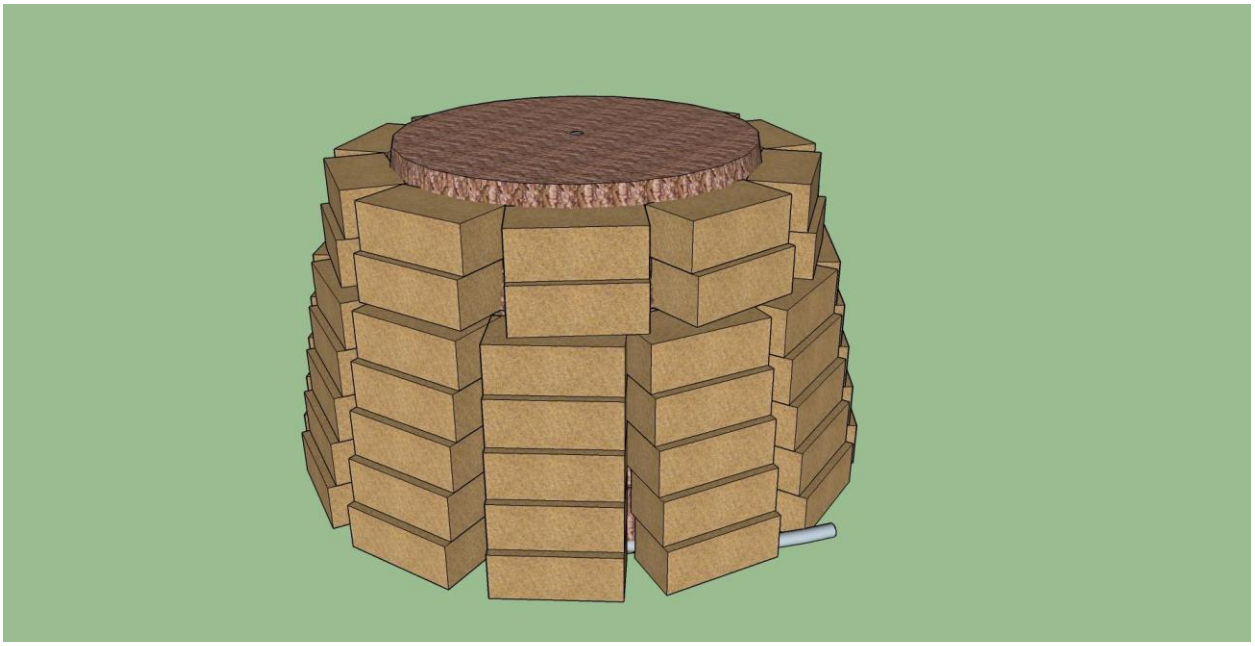

Figure 10: Final (seventh) layer of compost feedstock covering seventh coil, with additional ring of hay bales added

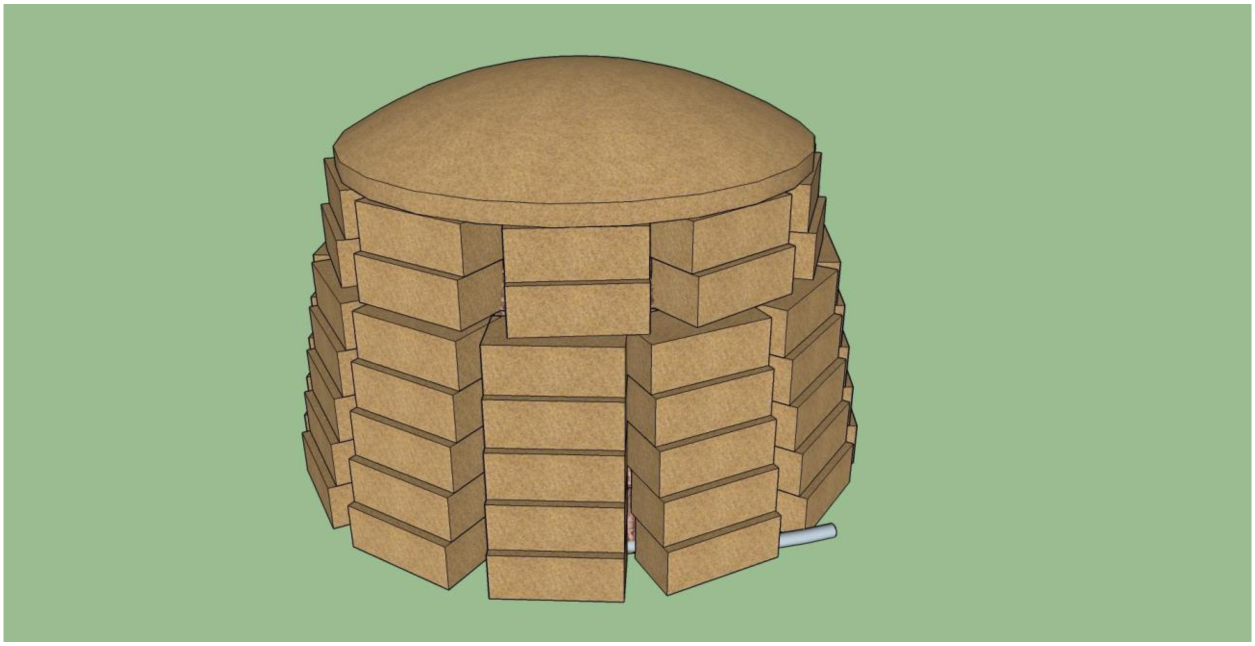

Figure 11: Cap of mound consisting of dry woodchips and loose hay

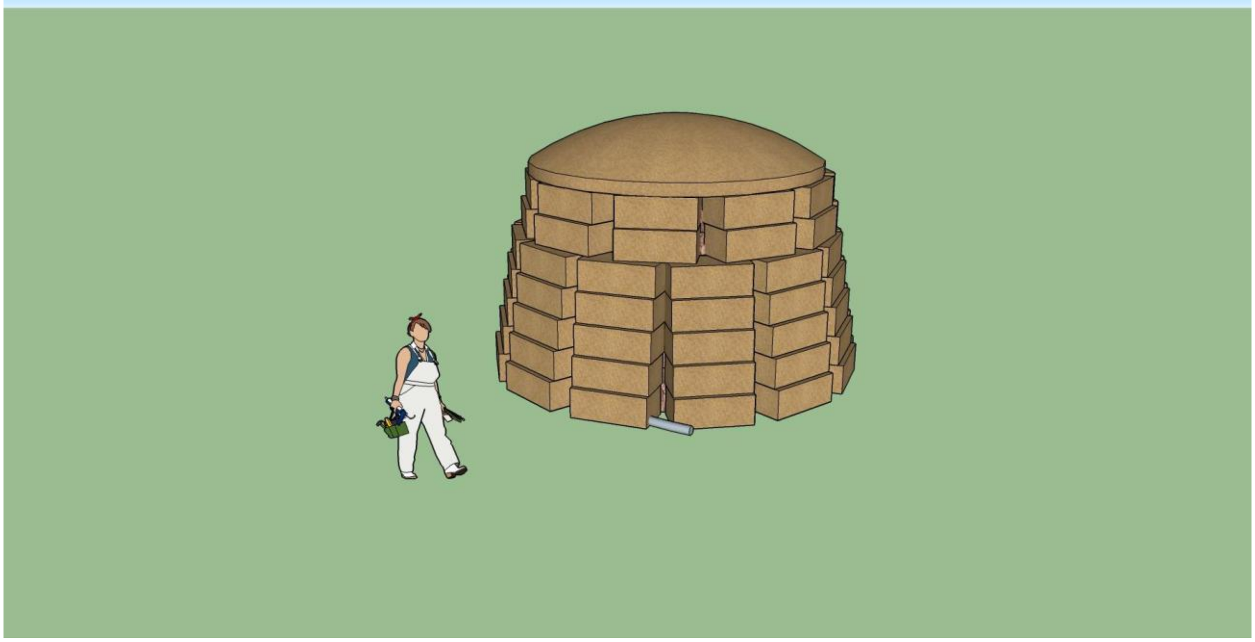

Figure 12: Completed Jean Pain mound

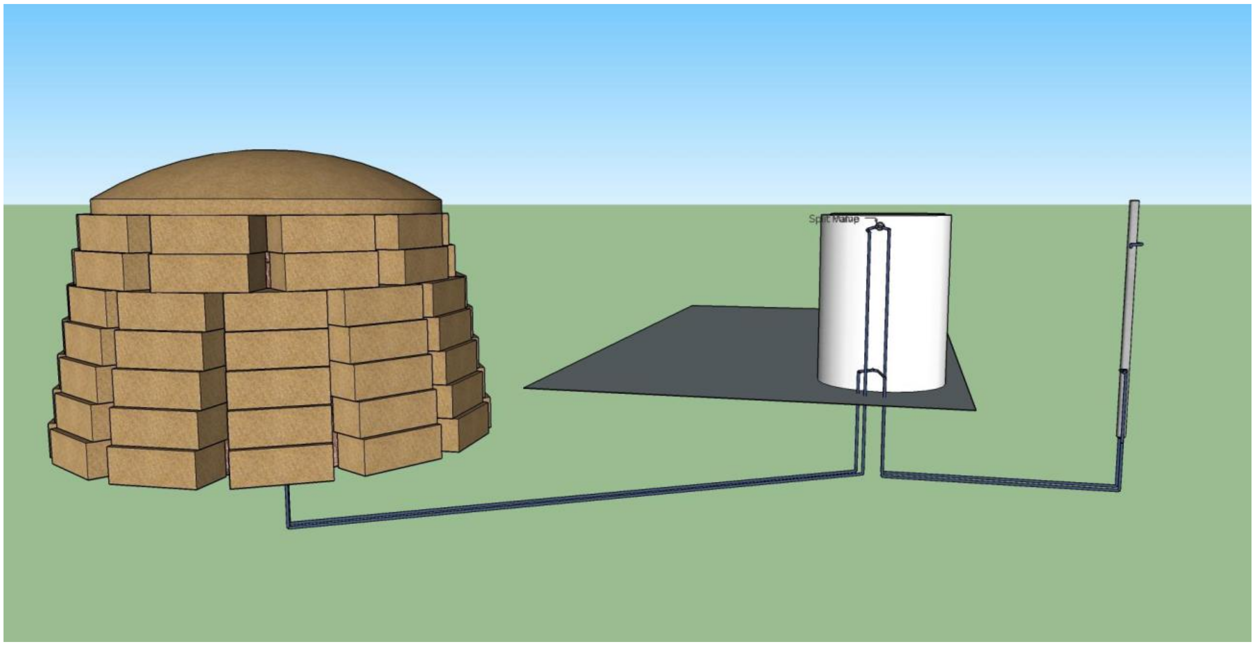

Figure 13: Jean Pain mound with Second hookup, and tank

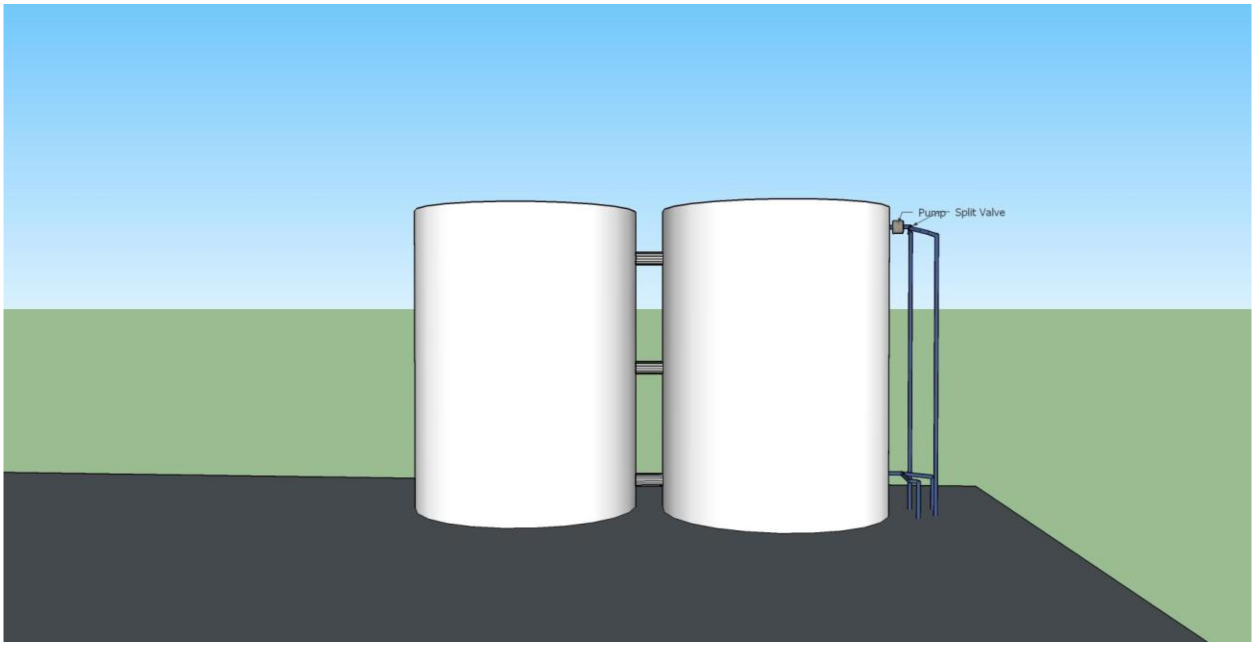

Figure 14: Water tanks with pipe connections

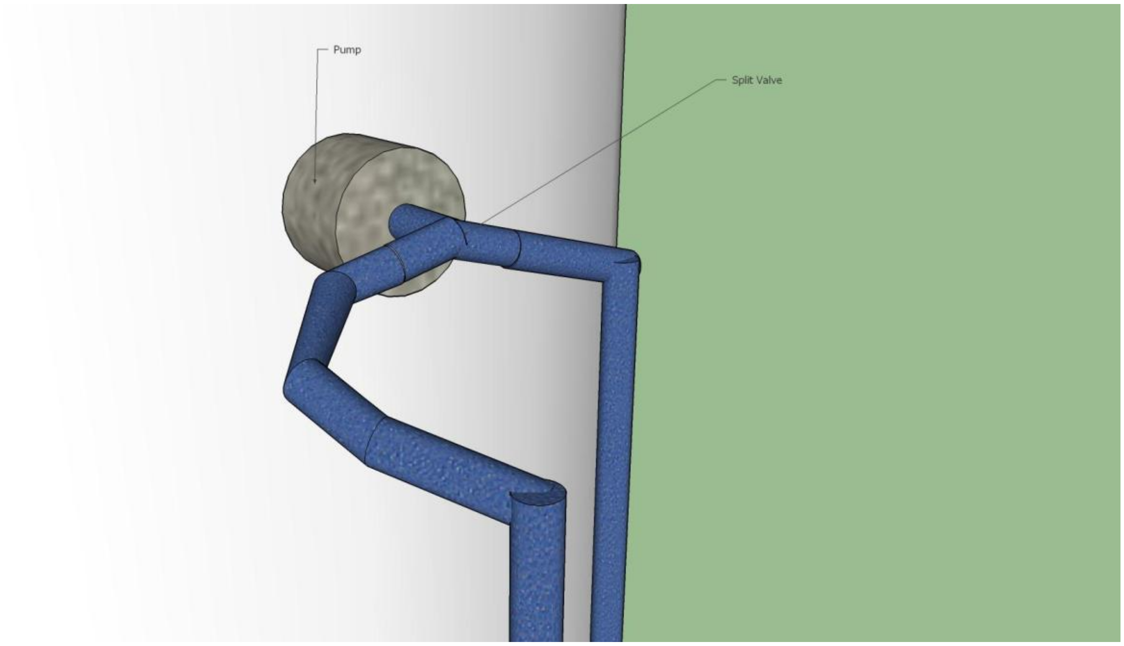

Figure 15: Upper connection, showing pump and split valve. Alternatively you could disconnect the pipe and switch them out.

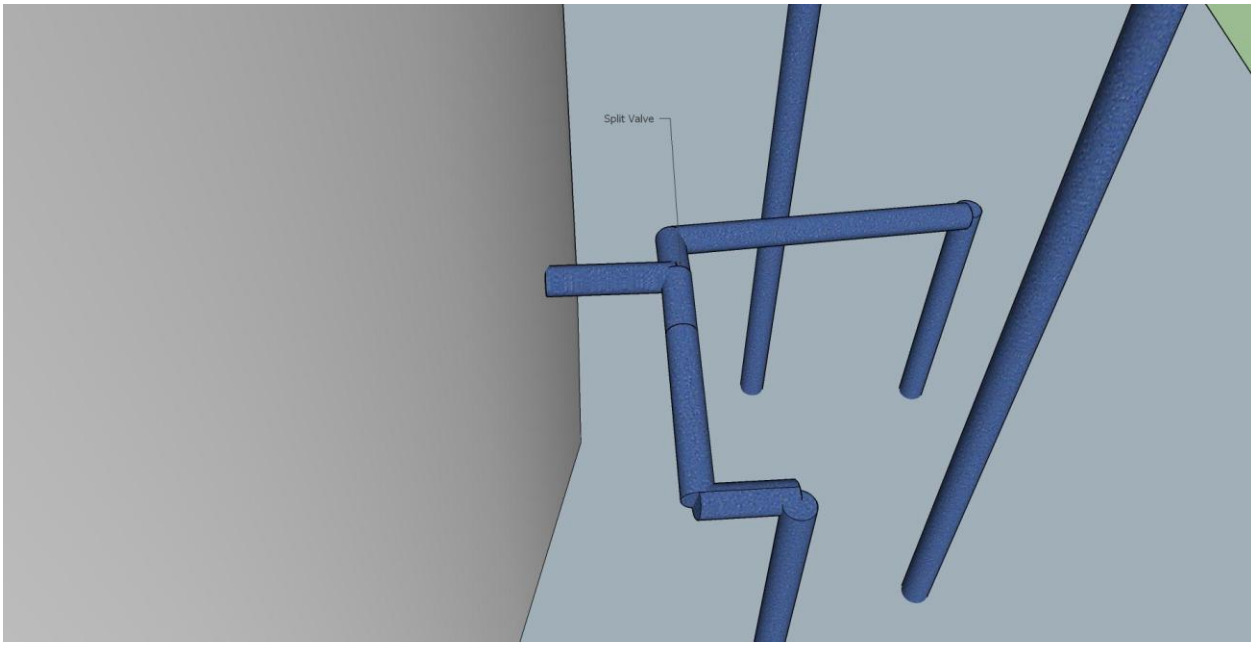

Figure 16: Lower connection, also a split tube. This could also be a standard valve and you switch the piping out.

Appendix B: Climate Stabilizer Guide

Climate Stabilizer Findings

Typically referred to as a climate battery in literature, we have chosen to refer to the device as a climate stabilizer for clarity sake. Any place where either term is used, they can be taken to be synonymous to each other. In reviewing scholarly work and several non-scholarly collections of work, we have found that the climate stabilizer has typically been used as a geothermal heating source throughout hot, dry topographies.

The climate stabilizer is a series of ducts that are 2-4 ft below ground surrounded by a high heat capacity material and is thermostatically controlled to absorb the ambient air when it is hot and release the stored heat when it is cold.[1] The typical materials are polyvinyl-chloride piping and gravel for the heat sink. This design incorporates a heat pump in the patent, but we have not included it in our design[2]. The stored air is able to maintain a temperature of ~40F at 3 ft below ground and soil temperature at 50 F in the popular places of use. These places includes India, China, and California as case studies have been documented of the 3-4°C increase and decrease of temperature in summer and winter respectively. These studies have shown more than 60% humidity levels dropping. In general there is better cooling effect when the ambient air is hotter than ground temperature[3].

When assessing the use in New England climates, 2-4 feet below ground average temperature is roughly 40 F. From analysis of a geothermal map of the United States it would take a depth of 100 meters to reach 55 F. Therefore, we do not believe the climate stabilizer will have significant geothermal heating effects. The humidity control, on the other hand, is still

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[1] Choudhury, T. (2014, October). Minimizing changing climate impact on buildings using easily and econo.

[2] Roland, L. (1984, May 22). Subterranean heating and cooling system.

[3] Zhang, Y., Li, Z., Yu, Z., Guo, L., Jin, X., & Xu, T. (2015, February 1). Evaluation of developing an enhanced geothermal heating system in northeast China: Field hydraulic stimulation and heat production forecast

applicable as there are many organisms in the bioshelter that transpire and evaporate water to increase the humidity. The exact effectiveness of the climate stabilizer for controlling humidity and temperature is unknown, as this is a relatively new and niche category of science, and there is not much recorded data.

In support of the humidity control effects, we have a comparison of two bioshelters; one that uses a climate stabilizer and one that does not. To start, we visited the Radix Center, which operates without a climate stabilizer. We observed mold growing and the owner mentioned the need to replace the rotting wood within the next few years. We then contacted the Nancee Bershof, the owner and operator of the Greenfield Bioshelter. The Greenfield bioshelter was built with a climate stabilizer incorporated in the design. Nancee told us that humidity had not been an issue for her (Bershof, 2016). It is difficult to infer whether or not the climate stabilizer was the main factor why Greenfield Bioshelter did not have humidity trouble like the Radix Center. An ideal case study would be of a single bioshelter, with and without a bioshelter.

Nancee gave additional contacts for Keith Zalzberg, who helped design the Greenfield Bioshelter. We contacted Keith and discussed the mechanisms, layout of the design, and the materials used. He suggested we cycle the air three times the volume of the bioshelter, running between 4 and 6 pipes underground and a minimum of 4 feet from the foundation as insulation[4]. The climate stabilizer lasts as long as the material used to make the pipes as that is what is mostly consisting of[5]. The guide below was made with the information gathered from our research and interviews.

While going through the materials cost, a large portion was the ½ inch gravel to fill the trench. The method we based our calculations off of called for the entire 12ft * 32 ft * 3 ft

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[4] Greenfield Bioshelter Design [Telephone interview]. (2016, February 29).

[5] Barakat, S., Ramzy, A., Hamed, A., & El Emam, S. (2016, March 1). Enhancement of gas turbine power output using earth to air heat exchanger (EAHE) cooling system.

volume to be filled with gravel. We estimated that the cost of gravel to fill this would be about $3800.

Citations

Barakat, S., Ramzy, A., Hamed, A., & El Emam, S. (2016, March 1). Enhancement of gas turbine power output using earth to air heat exchanger (EAHE) cooling system. Retrieved April 05, 2016, from http://www.sciencedirect.com/science/article/pii/S0196890415011693

Choudhury, T. (2014, October). Minimizing changing climate impact on buildings using easily and econo. Retrieved March 02, 2016, from http://link.springer.com/article/10.1007/s11027-013-9453-3

Greenfield Bioshelter Design [Telephone interview]. (2016, February 29).

Roland, L. (1984, May 22). Subterranean heating and cooling system. Retrieved April 5, 2016, from http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=0&ND=3&adjacent=true&FT=D&date=19840522&CC=US&NR=4449572A&KC=A http://www.sciencedirect.com/science/article/pii/S0196890415011693

Zhang, Y., Li, Z., Yu, Z., Guo, L., Jin, X., & Xu, T. (2015, February 1). Evaluation of developing an enhanced geothermal heating system in northeast China: Field hydraulic stimulation and heat production forecast. Retrieved April 05, 2016, from http://www.sciencedirect.com/science/article/pii/S0378778814010433

Climate Stabilizer Guide

Supplies:

- VenTech VT DF-4 DF4 Duct Fan, 100 CFM (ft^/min), 4"
  - Cost ~$30
  - Conditions met: suitable in humid conditions
- **~155 feet of perforated corrugated 4” diameter polyethylene drainage pipe**
  - Cost ~$1/foot
- **~20 feet of corrugated 4” diameter polyethylene drainage pipe**
  - Cost ~$1/foot
- **4-4 in. Polyethylene Snap Tee**
  - Cost ~$10/per part
- (3.5ft*12ft*32ft) **1350 cubic feet of half-inch washed gravel**

Half-inch washed gravel

(~upper estimate)

Method 1: 1350 ft^3 * 150lb/ft^3 * 1ton/2000 lb = 101.25 ton*$50/ton = $5100

Method 2: 960 ft^3 * 150lb/ft^3 * 1ton/2000 lb = 72 ton*$50/ton = $3750

(calculations based off of pea (⅜”) gravel,)

Construction: (the ground level is considered to be z = 0)

1. Mark out perimeter for trench inside the foundation (for this design, rectangular).
   - Leave a minimum of 4 feet between pipe layout and inner foundation.
   - For 20ft.*40ft. foundation this would be approximately 12ft.* 32 ft. perimeter inside.

2. Remove soil in this 12ft * 32ft area, to a depth 3ft below surface (Bottom of foundation). (**Fig. 1A, 2A**)

3. Layer a depth of .5ft of gravel by 12ft * 32ft evenly over the bottom of the trench. (**Fig. 1B, 2B**)

4. Now at z = -2.5 ft, lay the drainage pipe on top of gravel base. In the design shown here, the pipes are laid out in a rectangular pattern of 12ft*32ft, with 2 addition 32ft

lengths running through the rectangle, and the outlet and inlet pipes at opposite corners. (**Fig. 1C, 2C**)

- Use pipe fittings to connect piping.
- The inlet and outlet should be located at opposite corners using junction pipes.
  - the outlet should be on the 4‘ knee wall and should protrude above floor to keep debris from getting into the pipes.
  - the inlet should be on the 17’ back wall.

5. At z = -2.5 ft, the perimeter pipes should connect to the inlet and outlet via a junction, where they are turned from horizontal to vertical.

- The exit should extend above the floor of the structure, to keep debris from falling into the pipes.
- The inlet should be near the peak of the roof, approximately 17 ft high.

6. Install the ventilation fan to the outlet of the pipes (**Fig. 1E, 2E**)

- Orient the fan so airflow is directed out of the pipes.
- Set humidity sensor to desired control humidity.

7. Layer additional 2-2.5 ft of the gravel around and above the pipes. (**Fig. 1D, 2D**)

Note:

It is important to note that the climate stabilizer is not an isolated system. There are also other features planned for the bioshelter which could cause space conflicts. One of these are the underground compost bins. As this was written, it is the writer’s understanding that these will protrude from the foundation, three feet inward. If this is true, then there would still be a one foot gap between the bins and the stabilizer. Another consideration is that there will structural beams running into the ground. If there is a conflict, the stabilizer pipes can simply be moved to accommodate the structure.

Calculations:

The target ventilation for these calculations is based off having the entire volume (V) of air inside the bioshelter be circulated through the climate stabilizer three times per day. Knowing the both the target flow rate (Q) and the cross-sectional area of the pipe (Ac) we calculated the necessary velocity (v) of the fan. From this we found an example of a fan that could fulfill this requirement.

- $Q = 3V/1$ day
    - $V = (20ft*40ft*4ft) + (20ft*40ft*.5*13ft) = 8400\ ft^3$
    - $Q = 3*8400ft^3/day = 1050ft^3/hr = 0.292ft^3/s$

$A = (½*4/12)^2*3.14 = .0873\ ft^2$

$v = Q/A = 3.34ft/s = 2.28mph$

Diagrams:

The following diagrams display cross sectional views of the climate stabilizer. The diagrams are organized such that: gray for foundation, black for gravel, white for piping, red dots for pipe junctions, green displays ground level (0 feet). The gray box atop the shorter vertical piping stands for the fan which powers the stabilizer. All units are in inches.

Front Cross Sectional Diagram

Figure 1A

Figure 1B

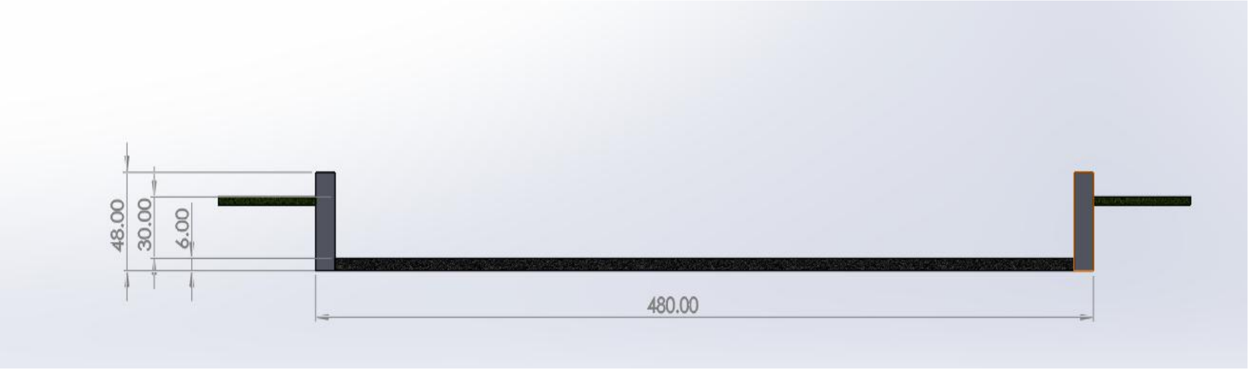


Figure 1C

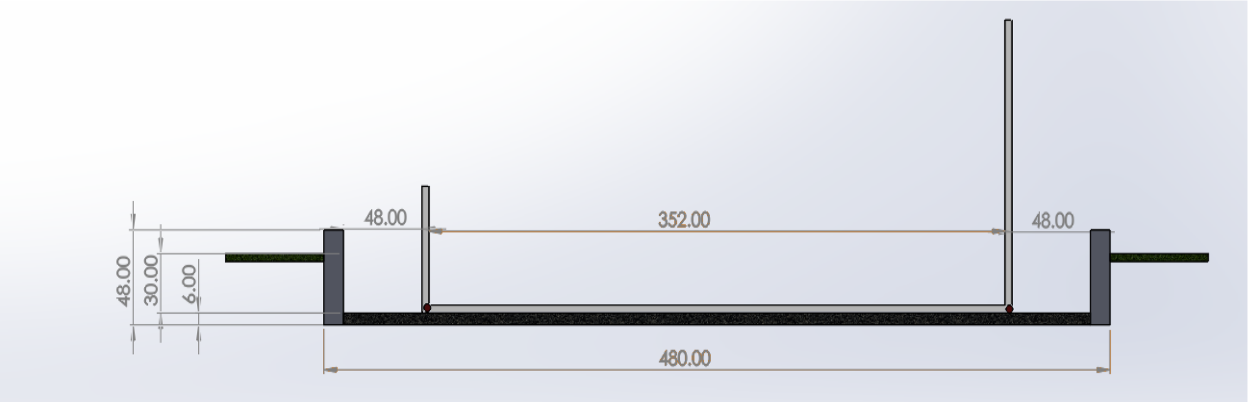


Figure 1D

Figure 1E

Right Side Cross Sectional View

Figure 2A

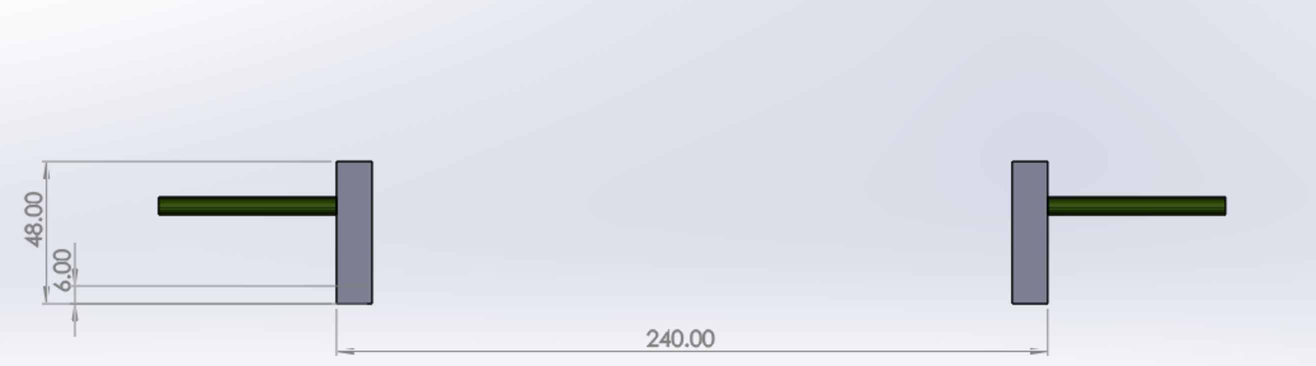


Figure 2B

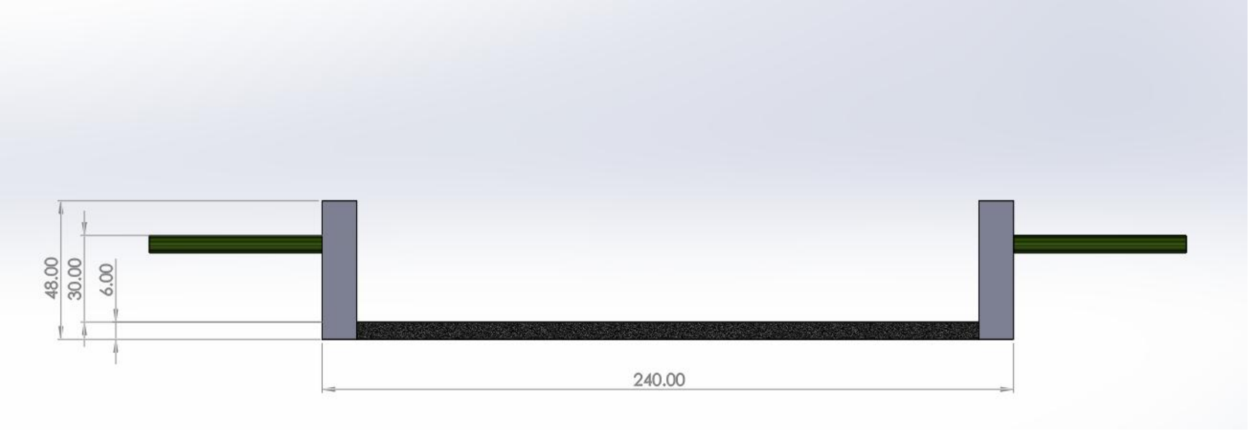


Figure 2C

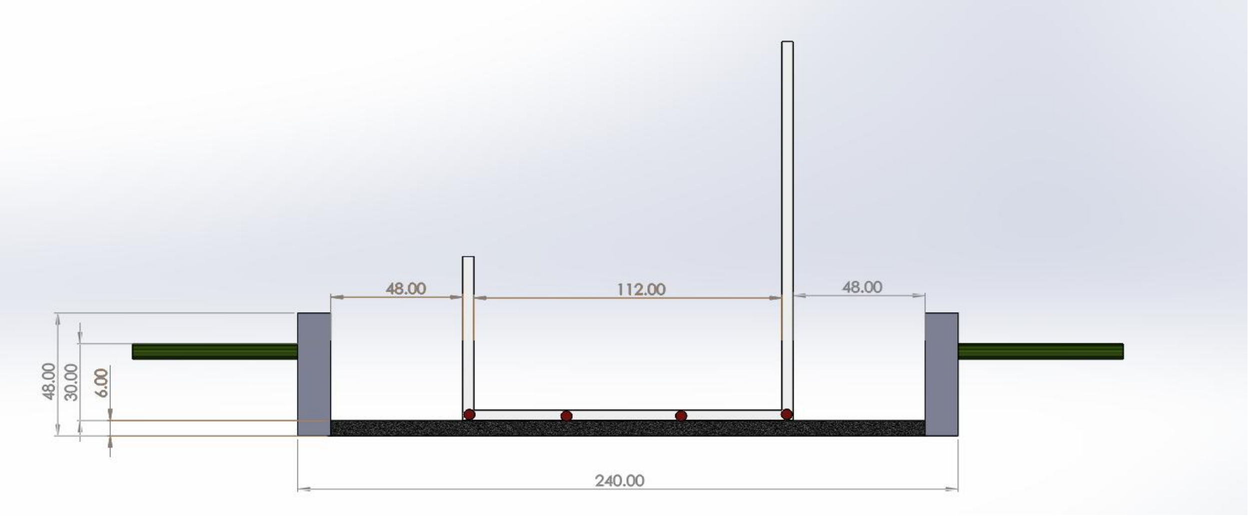


Figure 2D

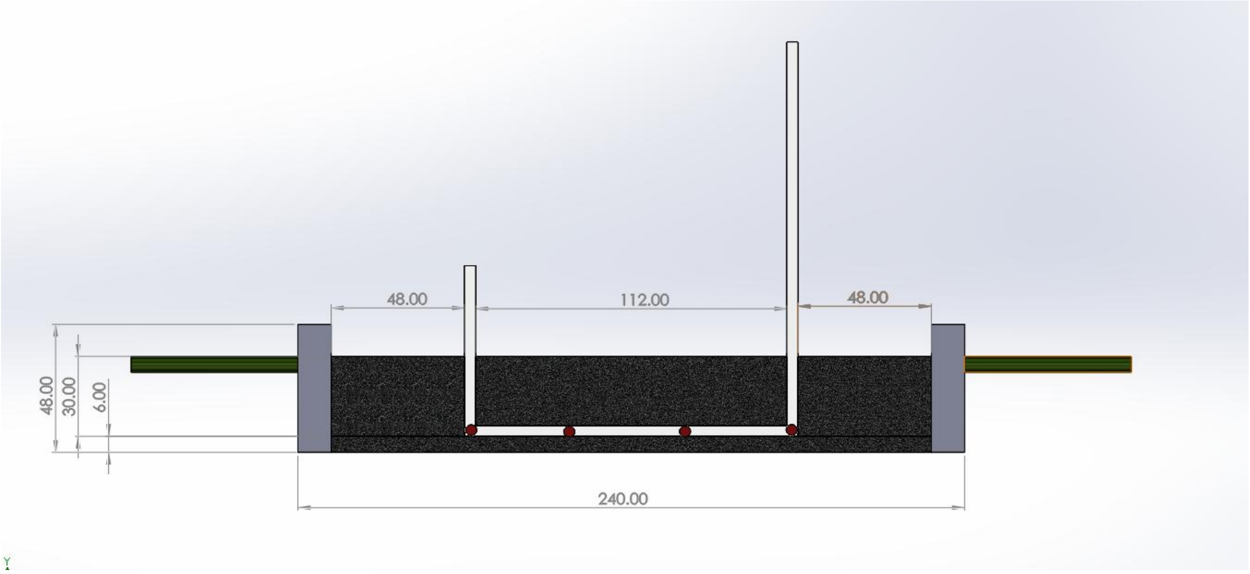
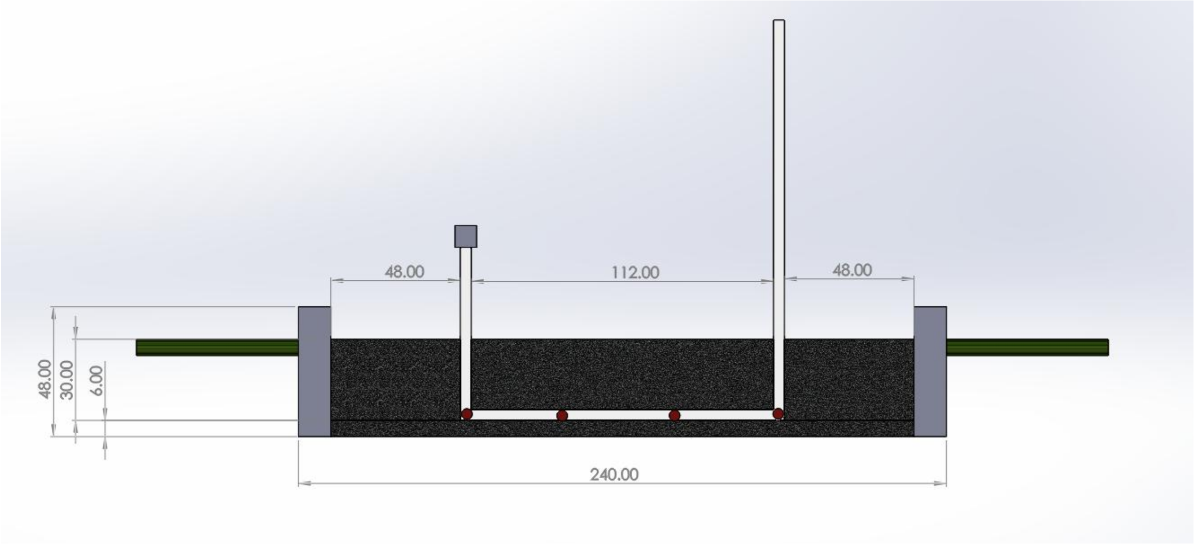


Figure 2E



Isometric Views

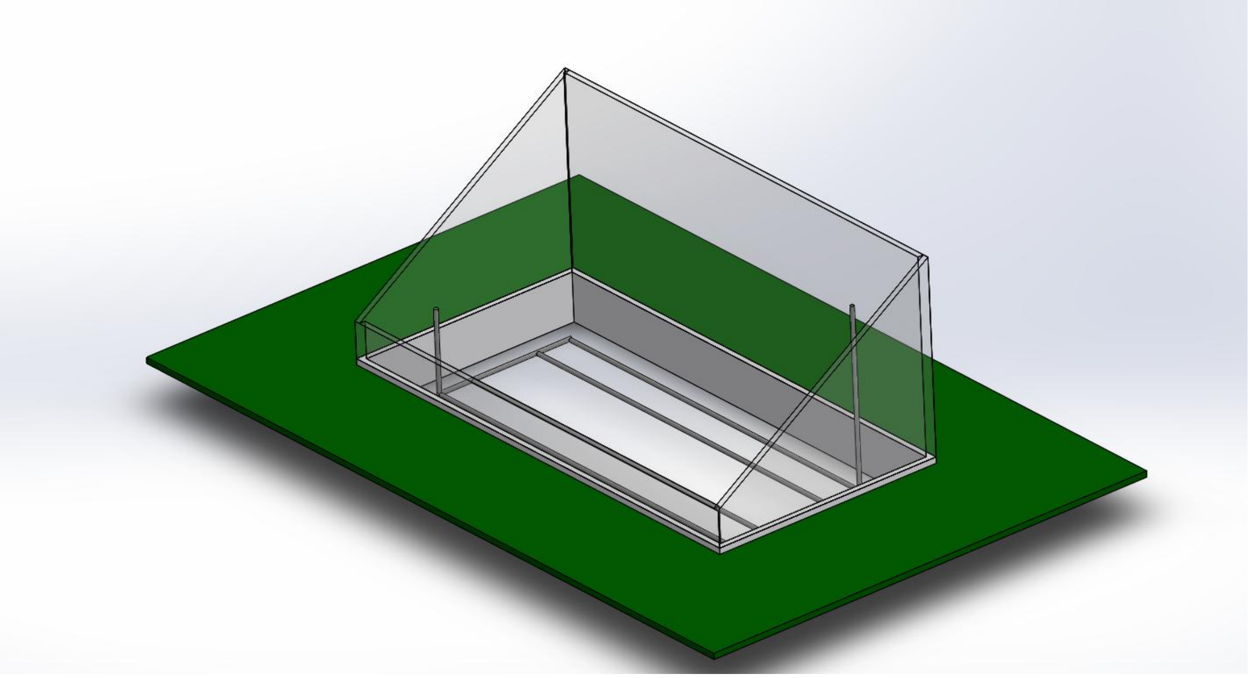


Figure 3A

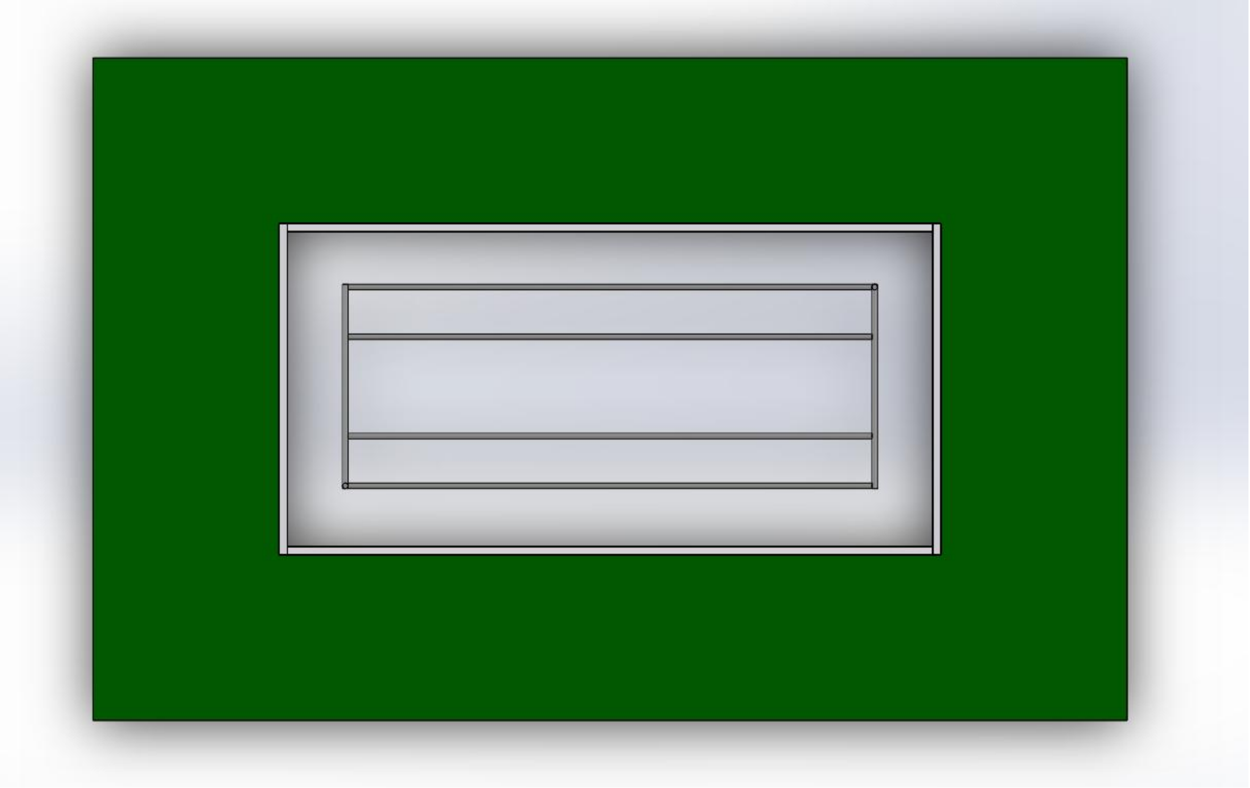


Figure 3B

Figure 1 is an isometric view (upper picture) and Figure 2 is a top-down view (lower picture) of climate stabilizer relative to bioshelter foundation and structure. The stabilizer is shown in grey, while the foundation is white. The green plane indicates ground level.

Appendix C: Test Mound Temperature Data

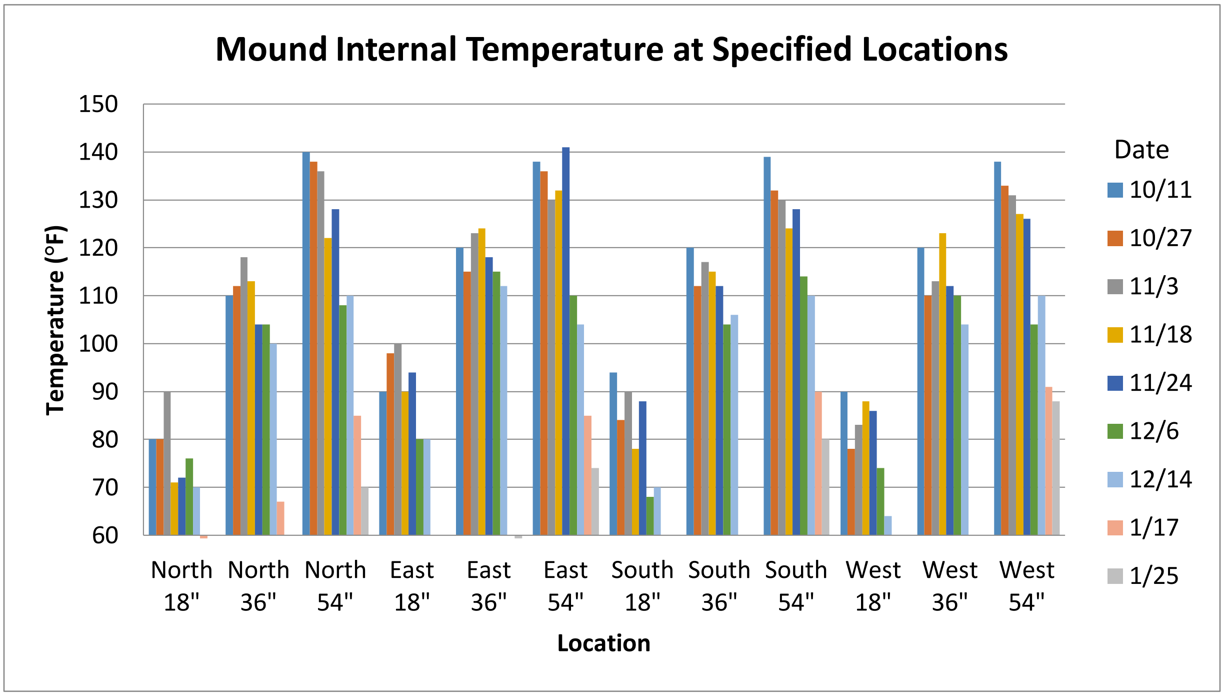


Figure C-1: All mound temperature measurements for each location and date

Table C-1: Temperature measurements for North and East face

Date	Ambient	North 18"	North 36"	North 54"	East 18"	East 36"	East 54"
10/11	68	80	110	140	90	120	138
10/27	46	80	112	138	98	115	136
11/3	64	90	118	136	100	123	130
11/18	46	71	113	122	90	124	132
11/24	35	72	104	128	94	118	141
12/6	54	76	104	108	80	115	110
12/14	48	70	100	110	80	112	104
1/17	30	42	67	85	N/A	N/A	85
1/25	33	N/A	N/A	70	N/A	54	74

Table C-2: Temperature measurements for South and West face

Date	Ambient	South 18"	South 36"	South 54"	West 18"	West 36"	West 54"
10/11	68	94	120	139	90	120	138
10/27	46	84	112	132	78	110	133
11/3	64	90	117	130	83	113	131
11/18	46	78	115	124	88	123	127
11/24	35	88	112	128	86	112	126
12/6	54	68	104	114	74	110	104
12/14	48	70	106	110	64	104	110
1/17	30	N/A	N/A	90	N/A	N/A	91
1/25	33	N/A	N/A	80	N/A	N/A	88

Appendix D: Interview Questions

Focus Group Questions

Principal:

- What the kids could get out of it?
- Is this a safe place for kids to be?
- What the transportation system?
- What would/could they be doing?

Teachers:

- How do the teachers interact with it?
- How will this help me teach?
- How will this encourage kids to learn?
- What kind of preparation (on the teacher's part) would this require?

YMCA:

- What kind of summer activities could be held there?
- What could be done in small groups?
- Will this be useful for them after they leave?
- Can they learn about nutritional guides?

General:

- Would the kids be under supervision while exploring the environment?
- What is the main educational curriculum would you be trying to teach?
- How long would the kids be staying? How long would each activity would you estimate to last?
- Would there be a sort of assessment that would be done afterwards?
- Are there any unsafe places that should be sectioned off?
- Could we see an example of what the students would be doing?
- Are there sitting spaces available?
- Who pays for stuff/what?
- Who is liable? Is there insurance?

- In case of a conflict, where would the student go?
- Who will be running it?
- What features of the bioshelter would be engaging to kids?
- What age range would this be appropriate for?

Questions for Josh Cohen

1. How often would you take your students to the bioshelter, if you could and feasibly, and what would you expect them to get out of it?
2. What specific considerations are important for 2nd graders (ex: attention span, reading mastery)?
3. What are some challenges to incorporating the bioshelter into the elementary school curriculum that you can picture? Both in general and at specifically at Chandler? What challenges did you experience with your school garden?
4. How do you think your colleagues, particularly those who aren't confident teaching science, would respond to using the bioshelter as a tool for teaching science?
5. Is there a higher priority on the inside space or the outside space? Which space seems the most useful to you? How would you use both spaces?
6. Does Chandler have an existing relationship with high school students or other schools (like WPI).
7. Is there anything that worries you about potentially using the site for K-6 teaching? Anything that gets you excited?

Questions for Keith Zalzberg

1. What general materials did you use for the climate battery and how much did it all cost?
2. How deep do you typically bury the pipes?
3. Are there any other viable ways to handle what the climate battery is designed to do?
4. Do you have a method or is there a science behind the sizing of the climate battery compared to the bioshelter?