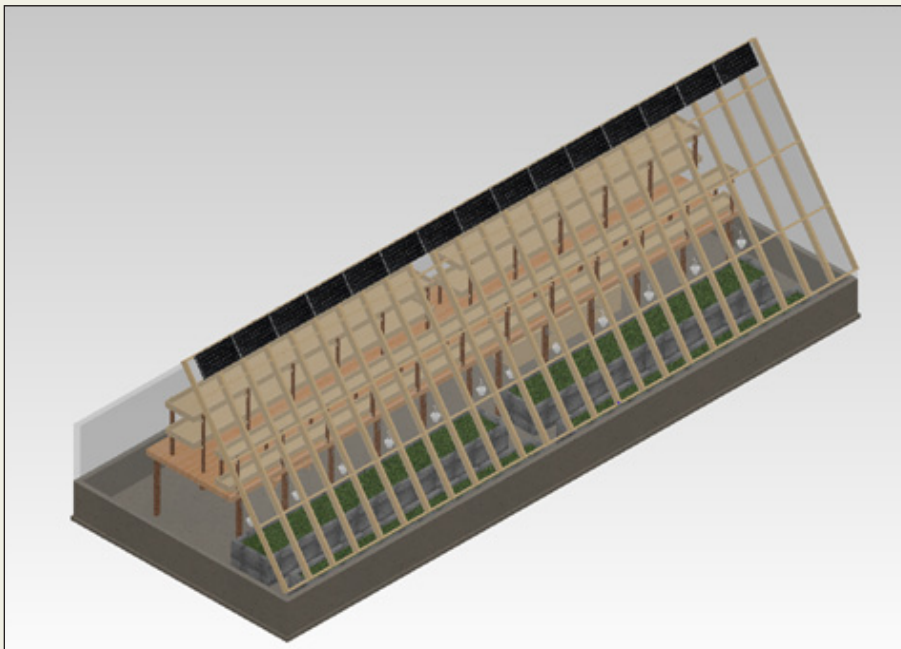


URBAN BIOSHELTERS

IN NEW ENGLAND



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Development of a Bioshelter Design Concept for use in an Urban Environment

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

This report represents the work of one or more WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review.

ABSTRACT

Urban agriculture is now seen by practitioners and planners as a means to improve food system sustainability, address food security issues in low income neighborhoods, and foster community development. We collaborated with NCAT to facilitate the growth of urban agriculture by designing a bioshelter suitable for commercial growers. Bioshelters focus on energy efficiency, renewable resources, and appropriate technologies. They balance high tech energy saving designs with passive low cost systems in order to create an indoor ecosystem rather than a typical greenhouse. This project's bioshelter was designed with the goal of four season operation in a typical New England environment.

ACKNOWLEDGEMENTS



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WPI

Thanks to our advisor Professor Robert Hersh for guiding this project effort. His ideas, support, and genuine interest helped to maintain the momentum of this project throughout the academic year. We owe thanks for his patience in reading and providing constructive criticism for the numerous drafts of this report and making this project a truly positive experience.



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EXECUTIVE SUMMARY

Cities across the US are becoming more aware of the repercussions of our industrialized food system, motivating many to promote urban agriculture in hopes of creating more sustainable, healthier communities. The growth in community supported agriculture (CSA), farmers' markets, and rooftop gardens signify an emerging alternative to our current agriculture system.¹ A vibrant urban agriculture system can provide a host of long term benefits; it can create jobs, help to sustain a local economy, provide fresh and nutritious food, promote sustainability, strengthen community development, and reduce energy consumption and pollution.

Despite its numerous advantages, urban agriculture faces many regulatory, institutional, and technical challenges.² One of the most common challenges in New England to extend urban production is the high cost of heating a greenhouse during the winter, often pushing costs of production beyond what consumers will pay. This problem can be addressed through the use of bioshelters, which can extend the growing season and reduce the cost of heating and cooling. A bioshelter is a food-producing structure that relies on energy efficiency, renewable resources, and appropriate technologies to cultivate an indoor ecosystem and is thus quite different from a typical greenhouse.

Our project sought to design a commercially successful Bioshelter that can also serve as a community amenity and education center. It was designed to operate year-long without the need for fossil fuels by relying on a combination of solar energy, compost heating and subterranean heating and cooling. We pursued a balanced approach between cost and complexity, aimed at small to mid-scale growers with limited start-up funds. We believe our concept bioshelter design could be economically feasible and appealing to urban growers as well as city neighborhoods.



Figure 1. Urban Agriculture Organization Southside Community Land Trust
Source: <http://southsidecommunitylandtrust.wordpress.com/2012/02/06/urban-agriculture-spring-kickoff/>

Emerging Interest in Urban Agriculture

Urban agriculture is gaining interest for a number of reasons. The issue of food security is a primary cause of alternate food production methods. Feeding residents with food imported to a city is challenging and inefficient. Currently food products typically travel between 1,500 and 2,500 miles from farm to plate. Fruits and vegetables can spend over a week in transit and almost 50% of these products are lost to spoilage.³ These issues drive up costs, harm the environment, and lower food quality. Instead of growing food locally with a focus on quality, it is produced elsewhere with a focus on durability.⁴

Building an urban bioshelter would provide a means of growing healthy sustainable crops for the urban community. Establishments such as GreensGrow Farm in Philadelphia PA, and Growing Power in Milwaukee WI, have developed excellent systems for urban farming with community outreach programs, mainly with the use of traditional greenhouses. In the New England region heating can amount to as much as 60% of the total operating costs of a greenhouse from October to

1 USDA. Results of DOT Survey. Accessed 4/13/2012. <http://www.ams.usda.gov/AMSV1.0/getfile?dDocName=STELPRDC5093878>

2 K. H. Brown. "Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe." *Agriculture* 27, no. October (2003).

3 Ibid.

4 Ibid.

April.⁵ Integrating bioshelters into such systems would increase their sustainability and lower their dependence on fossil fuels, but there are a number of challenges facing prospective urban bioshelter builders.

Zoning Laws

Zoning laws can limit the type of activities on a site as well as the physical size of a structure. In addition, many cities have adopted ordinances that limit land use and activities on private grounds. Although many of these ordinances are designed to protect the well-being neighbors and property they can also create many legal barriers for urban farmers. A few common city ordinances that affect urban farming are appearance standards, animal ordinances, and refuse ordinances. Many cities are working to modify these ordinances so that they are less inhibitive to urban farming.⁶

The location or size of the structure may also be limited by zoning regulations. A bioshelter type operation, classified as agriculture, may only be allowed in certain districts. Ultimately zoning laws are meant to separate different land uses and help people keep up the value of personal property and to help keep the city livable for residents and profitable for businesses. These same laws however can impede the construction of bioshelters.

Startup Costs

The initial investment required for an urban bioshelter is a common obstacle for many entrepreneurs. The many start-up costs involved include planning and design, land procurement, building materials, tools and equipment, construction, insurance, labor, packaging and marketing materials, fertilizers, along with any basic utilities. However there are many grants and incentives available for those who wish to start local food cultivation.

Bioshelter Function and Design

Perhaps the most interesting problem faced by urban bioshelter developers is the design and construction of the structure itself. Bioshelters focus on energy efficiency, renewable resources, and appropriate technologies. The largest source of heat in any energy efficient bioshelter should be from the sun, even dur-

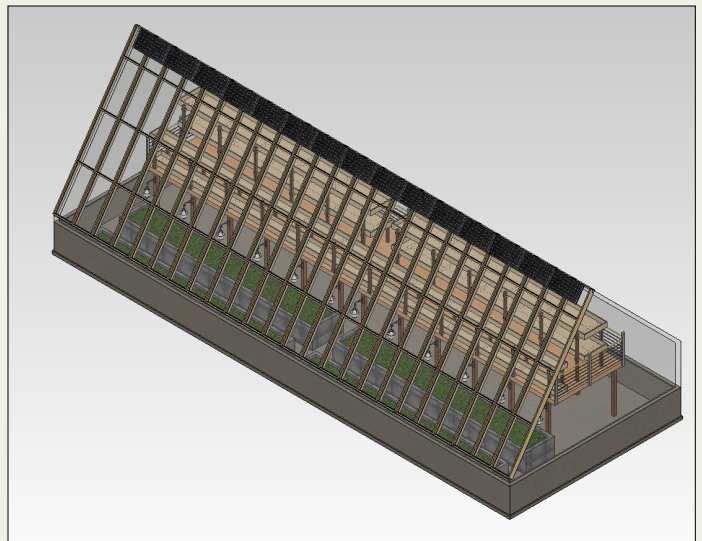


Figure 2. Artist's Rendering of WPI Bioshelter (3/4 View)

ing winter. An effective bioshelter is able to capture solar heat passively during daylight hours and store it to be released at night. To do this the structure must be well insulated while still allowing adequate light to enter. The structure must also provide adequate ventilation of more than one full air exchange per hour to maintain proper humidity and carbon dioxide levels.⁷

Findings

Construction

There are many options when choosing the size and materials for a bioshelter. The design detailed in this report has a footprint of 30' x 80' and is south facing. These parameters were determined based on the available space, latitude, and longitude of the selected location. The structure is framed in wood since it is the most economical solution and is a readily available material. The north wall is insulated, and the remaining surfaces of the structure utilize recycled e-glass. Recycled glass is an economical solution which has high insulation values, resistance to weathering, and a high light transmittance. There is a second floor within the structure which is also framed in wood. It can be easily constructed using similar guidelines to that of a raised deck. The external structure is expected to cost approximately \$24,000 for building materials.

5 James McCullagh, *The Solar Greenhouse Book*. Emmaus, PA: Rodale Press, 1978: 286.

6 M. Masson-Minock & Stockmann, D. *Creating a legal framework for urban agriculture: Lessons from Flint, Michigan*. Journal of Agriculture, Food Systems, and Community development. 2010.

7 James McCullagh, *The Solar Greenhouse Book*. Emmaus, PA: Rodale Press, 1978: 286.

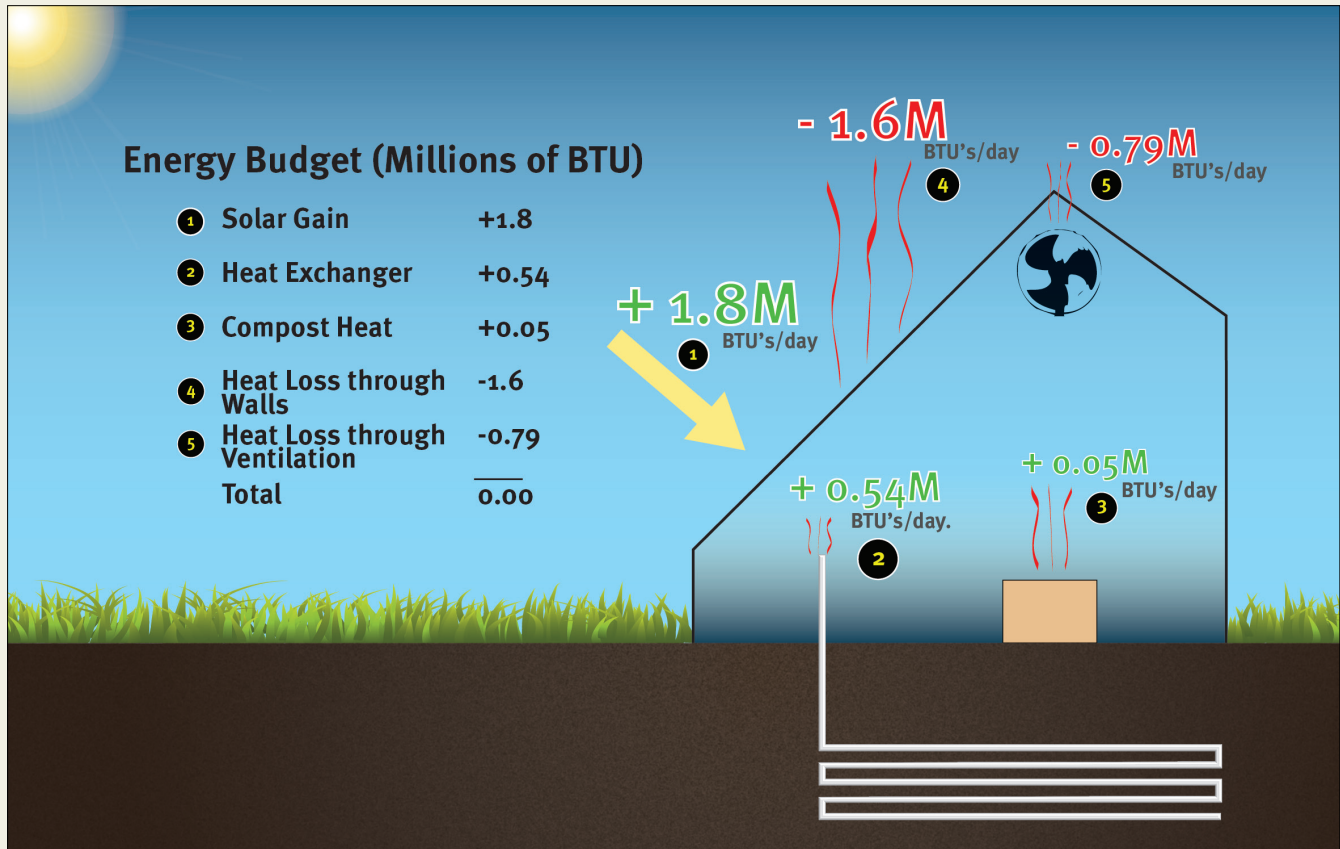


Figure 3. Energy Budget in Millions of BTU's (British Thermal Unit) for the Bioshelter in January (24°F). Demonstrated Stable Temperature of 55°F.

Heating and Energy

A component chosen for heating the structure that will utilize the power generated by the solar panels is a ground source heat pump. It was found that ground source heating is the best method of minimizing the costs of heating the structure. By installing the system of underground pipes during the laying of the foundation, the system can be easily implemented. The pump can then draw air into the bioshelter during the colder months that is much warmer than the outside air temperature. Figure 3 illustrates a hypothetical BTU budget for the bioshelter in January, the coldest month in Worcester, Massachusetts.

During winter, overcast, or rainy days, the plants may not get sufficient amounts of light. To provide supplemental lighting to the structure a combination of metal halide and energy efficient fluorescents were determined to be the most balanced solution.

The majority of the energy consumption comes from the supplementary lighting, which is why it is important to run the lights only when absolutely necessary.

Bioshelter Energy Use

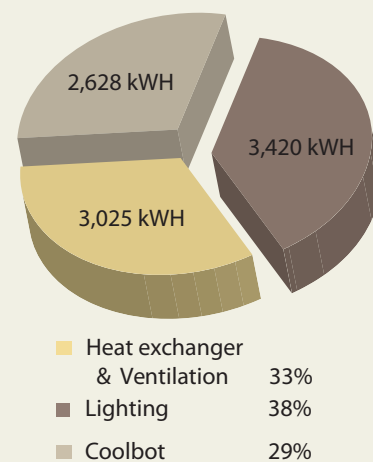


Figure 4. Bioshelter Yearly Energy Use

The coolbot (a highly efficient system for cooling a walk-in cooler) and ground source heater are both highly energy efficient systems which allows them to expend less energy yearly than the lighting. More details about the coolbot will be explained in chapter 4.5.

After researching several alternative energy op-

tions, we chose solar panels to provide energy to the structure. The panels which line the peak of the roof are used to create energy which is fed into the power grid. Power generated from the panels could also be stored in batteries for use in the bioshelter, but this option is costly and inefficient. Connecting the structure to the power grid however ensures it will never be without power. Essentially the solar panels are used to create green energy which is sold to the power company for credits. These credits are used to buy energy back from the power company through the grid. The 15 panels that line the roof of the shelter are enough to generate about 60% of the bioshelter's yearly energy needs.

Growing Space

To produce the crops in the structure, two types of growing beds are utilized. A balance of deep and internally heated concrete block beds are combined with shallow raised wooden tray beds. There will also be hanging baskets lining the support structure for the second level of shelves. They are all watered with a drip irrigation system fed by capillary action. Rich compost for the beds will be made in the structure using composting and vermiculture bins. The composting bins were determined to be an important component because they also generate heat for the structure. Additionally they provide extra income by selling high quality compost, and provide the soil necessary for replenishing the grow beds. Composting materials could be obtained for free from various community sources such as schools or restaurants. The recommended crops to be grown in the bioshelter are 80% leafy greens and 20% herbs. This permits some diversity while still allowing high levels of production and profitable margins.

Post-Harvest Needs

Once the crops are grown, they need to be harvested for shipment or sale. To carry out these tasks, carts and a service elevator are utilized. They improve the flow of the structure and allow crops to be brought to the harvest and wash station. Here the crops are washed and drip dried before packaging. They can then be stored in a cold storage area. The cold storage container is custom built with an air conditioning unit as the cooling source. This system was chosen for its economic value and efficiency. Despite the fact that it will be used continuously it will still require less electricity than either the lighting or heating. From



Figure 5. Silicon Valley Urban Farm Community
Source: <http://www.fullcirclesunnyvale.org/about-2/the-challenge/>

the storage area, the crops can be sold at an on location farmers market or shipped to other consumers.

Community Outreach

There were also many components determined to be beneficial for the community as well as the profitability and efficiency of the bioshelter. A meeting space within the structure is essential for employee satisfaction and educational tours of the structure. Compostable toilets were determined to be an environmentally friendly option of bathroom facilities. The water used for washing vegetables can be used for irrigating an outdoor area.

Chickens were determined to be an educational component of the bioshelter in addition to providing heat, eggs, and other benefits to the structure. To sell all of the goods produced in the structure including the crops and chicken eggs, an on location farm stand is the best option. It reduces the effort required to transport food, brings the community closer to where the food is produced, and also allows a hub for other farmers' markets, possibly producing extra income from seller's fees. The chickens require a coop at the edge of the bioshelter, which has a connection to the outside for the warm months.

A bioshelter could benefit the community by providing classes and workshops at the bioshelter. These classes can increase interest in local urban farming and create community awareness. It may also be possible for classes to be subsidized by local organizations such as a local regional environmental council.

AUTHORSHIP



Zach Killoy is responsible for researching and writing about ventilation, solar heat storage, insulation, and cold storage needs of a bioshelter. In addition, he researched zoning and structural code requirements that led to the final design of the bioshelter. These sections can be found in the Background and Findings chapters of this report.

Jeff Pruden was the primary author of the abstract and acknowledgements sections. In addition, he worked on numerous subsections of the report. Jeff Pruden wrote the introductory sections for the Background, Methods, and Findings chapters. In the Background chapter, Jeff Pruden also wrote “Emerging Interest in Urban Agriculture.” In the Findings chapter he contributed the sections on growing beds, hanging plants, the wash station, meeting space, and chickens. Jeff was the primary creator of the SolidWorks models of the bioshelter. He was also the primary author of the Conclusions section. Furthermore, Jeff added sections about evaluating bioshelter performance and the project sponsor to the Appendix.

Chris Thomas was the primary author on many sections in the Background, Methods, and Findings chapters. These sections included “Existing Bioshelters” in the Background chapter and “Designing a Prototype Bioshelter” in the Methods chapter. In addition, Chris wrote the sections on the layout, solar panels, ground source heat pump, energy use, drip feed irrigation system, service elevator, and costs to the Findings chapter. He was also the primary editor of the Background and Methods sections, and contributed to the Conclusions and Appendix sections.

Jeffrey Wyman conducted interviews with growers and visited sites of greenhouses and bioshelters. He contributed many sections in the Background, Methods, and Findings chapters, often served as secretary during meetings, and was the primary author of the Introduction. Jeffrey used his interest in plants to motivate his work in chapters relating to the growing schedule, plant selection and health, lighting, composting, water drainage, and revenues. He also helped determine the energy requirements of the structure, and was the primary designer of the report.

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I.0 INTRODUCTION

People and organizations across the US are becoming more aware of the repercussions of our industrialized food system, motivating many to promote urban agriculture in hopes of creating more sustainable, healthier communities. Urban agriculture can take many forms. Over the past 5 years Community Supported Agriculture (CSA), a direct marketing mechanism for small farmers has doubled,¹ the number of farmers' markets tripled within 15 years,² and the green roof industry experienced nearly 30% growth in 2010.³ This signifies an emerging alternative to our current agriculture system.⁴

Urban agriculture is also seen as a means to help low income and minority neighborhoods create local food systems to meet their own feed needs.⁵ According to the USDA, 10% of the US population lives in "food deserts," places where low-income families have little or no access to healthy fresh foods, 82% of which are urban areas.⁶ Correspondingly, many claim a lack of access to healthy, affordable food is linked to the recent epidemic of obesity and chronic, diet-related diseases in the US.⁷ The elongated link between production and consumption (1,300 miles on average)⁸ inflicts negative environmental effects as well; our traditional industrial farming methods consume fossil fuels, water, and topsoil at unsustainable rates, contributing to pollution and environmental degradation.⁹ Additionally, vacant or unused properties are common among industrial cities and could be a resource for food production.¹⁰

A vibrant urban agriculture system provides a host of long term benefits; it can create jobs, help to sustain a local economy, provide fresh and nutritious food,



Figure 1. Time Magainze, Urban Farming.
<http://www.time.com/time/photogallery/0,29307,1825907,00.html>

promote progress and sustainability, strengthen community development, and reduce energy consumption and pollution. Growing Power, a well-known UA organization in Milwaukee, Wisconsin, has demonstrated that these benefits are possible. They use vacant or unused properties to produce food and teach the community about gardening and nutrition. Most of their production, over a hundred different varieties of plants, vegetables, and fish, goes to low-income families living close to the urban farm, employing hundreds of adults and at-risk youth from the community.¹¹

Despite its numerous benefits, urban agriculture faces many regulatory, institutional, and technical challenges.¹² Land stewardship is a common problem; without title to land or at least 5 year leases, growers may be

1 University of Kentucky. Survey of Community Supported Agriculture Produces. 2009

2 USDA. Results of DOT Survey. 2011.

3 "Green Roofs for Healthy Cities," accessed April, 19, 2012, <http://greenroofs.org>

4 USDA. Results of DOT Survey. 2011.

5 H. J. Song, et al. A Corner Store Intervention in a Low-Income Urban Community is Associated with Increased Availability and Sales of Some Healthy Foods. 2010.

6 USDA. Food Desert Locator. 2012.

7 P. Whitacre, P. Tsai, and J. Mulligan. The Public Health Effects of Food Deserts. 2009.

8 National Resources Defense Council. Health Facts: Food Miles. 2007.

9 Horrigan L, Lawrence RS, Walker P. How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture. 2002.

10 R. Schenk. A Theory of Vacant Urban Land. 1978.

11 "Growing Power Inc.," accessed April, 19, 2012, <http://growingpower.org>

12 K. H. Brown. "Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe." *Agriculture* 27, no. October (2003).

unwilling to develop inner-city plots to grow food. Zoning laws may prohibit agricultural production.¹³ Local government responsibility seems fragmented and lagging and often support for agriculture at the municipal level is difficult to secure since many see urban farming as an interim use with limited property tax revenues.¹⁴ Soil contamination is prevalent in older or industrialized cities and can be risky or expensive to remediate for growing food.¹⁵ And the high cost of heating a greenhouse in northern climates during the winter typically prevents year round production. Most of these issues go beyond the scope of this report, however, high heating costs can be addressed through the use of bioshelters, which can extend the growing season and reduce the cost of heating and cooling.

A bioshelter is a food-producing structure that relies on energy ef-

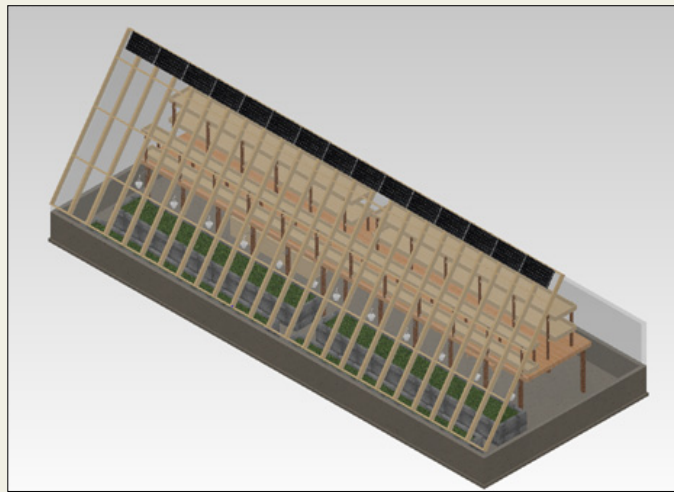


Figure 2. Artist's Rendering of the WPI Bioshelter

ficiency, renewable resources, and appropriate technologies to cultivate an indoor ecosystem rather than a typical greenhouse. Our project sought to design a commercially successful Bioshelter that could also serve as a community amenity and education center. It was designed to operate year-long without the need for fossil fuels by relying on a com-

bination of solar energy, compost heating and subterranean heating and cooling. We pursued a balanced approach between cost and complexity, aimed at small to mid-scale growers with limited start-up funds. We believe our concept bioshelter design could be economically feasible and appealing to urban growers as well as city neighborhoods.

2.0 BACKGROUND

In this chapter we provide background information on bioshelters and their potential role in urban agriculture. This chapter begins with a description of urban agriculture including what it encompasses, why it is of growing interest, and the benefits it provides to a community. We then provide an analysis of the current state of bioshelter and urban agriculture development. Next, bioshelter function and design is broken down and described in detail. Finally, we report on the

current challenges facing urban agriculture and bioshelter development. This concluded the research necessary to begin building on the work of others in bioshelter design.

2.1 Emerging Interest in Urban Agriculture

Urban agriculture can be defined in many ways. Some organizations, such as the United Nations Development Program, focus on the use of resources. This organiza-

tion defines urban agriculture as

“an industry that produces, processes and markets food and fuel, largely in response to the daily demand of consumers within a town, city, or metropolis, on land and water dispersed throughout the urban and peri-urban area, applying intensive production methods, using and reusing natural resources and urban wastes, to yield a diversity of crops and livestock.”¹⁶

Another much broader definition is provided by the Council on

13 K. H. Brown. “Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe.” *Agriculture* 27, no. October (2003).

14 Hamilton, N. *Farms, Food, and the Future: Legal Issues and Fifteen Years of the ‘New agriculture’*. 2011.

15 De Kimpe, C. R., and J. L. Morel. *Urban Soil Management: A Growing Concern*. 2000.

16 Joe Nasr, Annu Ratta, and Jac Smit. *Urban Agriculture: Food, Jobs, and Sustainable Cities*. New York: United Nations Development Programme, 1996.

Agriculture, Science, and Technology. They define urban agriculture as

“a complex system encompassing a spectrum of interests, from a traditional core of activities associated with the production, processing, marketing, distribution, and consumption, to a multiplicity of other benefits and services that are less widely acknowledged and documented. These include recreation and leisure; economic vitality and business entrepreneurship, individual and community health and well-being; landscape area beautification; and environmental restoration and remediation.”¹⁷

This definition includes more than just food production and incorporates the business aspects and effects of urban agriculture as well. For the purposes of our project, we will use a much simpler definition which has been adapted by the Community Food Security Coalition. They refer to urban agriculture as “the growing, processing, and distributing of food and other products through intensive plant cultivation and animal husbandry in and around cities.” This provides a simple and straightforward definition to contextualize our project. To further constrain our scope, intensive plant cultivation will be the focus of our research as opposed to the raising of livestock.

Urban agriculture is gaining interest for a number of reasons. The issue of food security is a primary cause of alternate food production methods. Feeding residents

with only food imported to a city is challenging and inefficient. Currently, food products typically travel between 1,500 and 2,500 miles from farm to plate.¹⁸ Fruits and vegetables can spend over a week in transit and almost 50% of these products are lost to spoilage. These issues drive up costs, harm the environment, and lower food quality. Instead of

Worcester Massachusetts, where our project is based, the authors estimate that nearly 10% of the city’s land, some 2,400 acres, is vacant. This estimate includes varying types of land such as undisturbed open space, unbuildable parcels, recently razed land, derelict property, and abandoned brownfields.²¹ Even where there is less space available

Urban Agriculture:

“an industry that produces, processes and markets food and fuel, largely in response to the daily demand of consumers within a town, city, or metropolis...”

-United Nations

growing food locally with a focus on quality, it is produced elsewhere with a focus on durability.¹⁹ In addition, food is not always evenly distributed throughout a city. A study conducted in Detroit in three low income zip codes revealed that out of all the food stores located in these regions, only 19% stocked a minimal “healthy food basket.”²⁰ In other words, less than one in five stores supplied a balance of nutritious food sufficient to fulfill the requirements of the standard food pyramid.

Also, the availability of land which is not being put to productive use provides opportunities for urban agriculture. A study conducted by Bowman and Pagano concluded that on average 15% of a city’s land is deemed vacant. In the city of

for development, there are always backyards, patios, and rooftops. All of these factors set the scene for urban agriculture as a tool to address issues surrounding food access and availability in densely populated metropolitan areas.

Different types of urban agriculture can provide a range of benefits to individual growers. At a household level, growing small produce in window boxes or small backyard gardens provides an alternative to market priced, mass produced food. This benefits impoverished areas by providing residents with the ability to grow their own healthy and culturally appropriate foods. Individuals can also collaborate with their growing efforts and form community gardens. A community

17 L. Butler and D.M. Maronek. *Urban and Agricultural Communities: Opportunities for Common Ground*. Ames Iowa: Council for Agricultural Science and Technology, 2002.

18 K. H. Brown. “Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe.” *Agriculture* 27, no. October (2003).

19 Ibid.

20 Ibid.

21 Ann Bowman and Michael Pagano. *Vacant Land in Cities: An Urban Resource*, 2000.

garden as defined by the American Community Gardening Association is simply any piece of land gardened by a group of people. These gardens provide many benefits including neighborhood beautification, increased social interaction, and a reduction in food budgets.²² On the larger scale of urban farming, urban growers can directly market his or her produce thereby increasing food availability in underserved neighborhoods as well as providing additional income.²³ Given the diversity of these methods of urban agriculture, the opportunities to increase agricultural production can be significant.

Aside from the benefits to the urban farmer, many positive externalities can be present from sustainable urban agriculture. One example is the benefit to the environment. Urban farmers often work on a limited budget which promotes energy saving techniques and reduces the use of fossil fuels.²⁴ Also, reduced food miles cuts down on fossil fuels used during transportation. This decrease in fossil fuel consumption diminishes the amount of greenhouse gases being exhausted into the atmosphere. Another benefit of urban agriculture is the prosperity it can bring to a region. It can be used to redevelop lots which otherwise may be abandoned and unsightly. In addition, larger scale entrepreneurial farms often hire workers from within the area.²⁵ This creates jobs locally,

which brings economic stability to more than just the owner of the farm. One example of this is the Greengrow Farm in Philadelphia, which is an urban farm on a formerly contaminated industrial site. They have possibilities for employment listed on their website including media relations in addition to jobs more directly related to producing food. Overall, urban agriculture can improve the quality of life for not only the farmer, but the entire community.

2.2. Existing Bioshelters

Bioshelters are indoor agricultural ecosystems that focus on efficient use of resources and space. The first bioshelters in the United States were designed and built by the New Alchemy Institute in Fal-

mouth, Massachusetts. The mission of the New Alchemists was to create “ecologically derived human support systems.”²⁶ These systems would minimize the use of fossil fuels and maximize renewable, sustainable resources. The Institute worked heavily on researching and developing greenhouse design for over two decades, from 1969 to 1991.

In 2008 a guidebook was compiled, which contained an overview of the bioshelter designs that were developed by the New Alchemist Institute over their years of operation. This Bioshelter Guidebook, written by Earle Barnhart, gives basic information, pictures, and diagrams of each of the bioshelters that were constructed by the New Alchemist Institute. One of the most well-

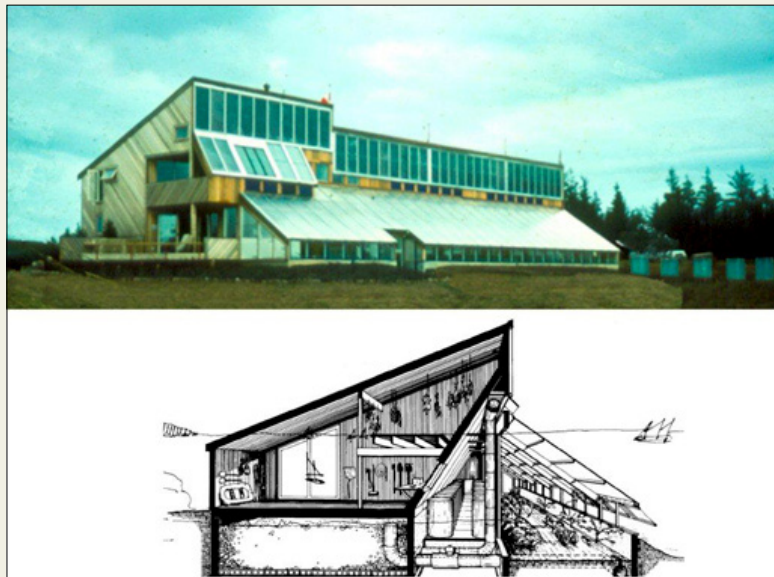


Figure 3. New Alchemy Institute Ark
http://places.designobserver.com/media/images/Braham_ArkPhoto+Section_525.jpg

22 American Community Garden Association. “What is a Community Garden?” accessed April 2, 2012, <http://www.communitygarden.org/learn/>

23 R. Nugent. “The Impact of Urban Agriculture on the Household and Local Economies.” *Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda*, DSE, Feldafing, Germany (2000).

24 K. H. Brown and A. L. Jameton. “Public Health Implications of Urban Agriculture.” *Journal of Public Health Policy* (2000): 20-39.

25 R. Nugent. “The Impact of Urban Agriculture on the Household and Local Economies.” *Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda*, DSE, Feldafing, Germany (2000).

26 Earle Barnhart. “Bioshelter Guidebook: Bioshelter Research by New Alchemy (1971-1991).”

known bioshelters that the New Alchemy Institute created is the Cape Cod Ark, which was built in 1976. There was also a sister ark built in Canada the same year. Both arks were cutting edge greenhouses at the time of their construction. The Cape Cod Ark has continued to improve over the years with new innovations in greenhouse technology.²⁷ The original Ark included nine fish ponds and a rock box thermal mass for heat storage, a rainwater collection system, permanent populations of beneficial insects to control pests, and diverse food crops that were grown year round. Since its initial construction, the structure has been updated with triple layer polycarbonate glazing, solar panels for electricity generation, and additional ventilation capabilities.²⁸

The New Alchemy Institute bioshelter design was improved in 1989 by farmer and permaculture expert, Darrell Frey, the owner and operator of the Three Sisters Farms in western Pennsylvania. The design at the Three Sister's farm incorporates many of the same features of the New Alchemy Institute, but Frey's design includes compost heating and chickens. The chickens provide heat, consume waste, and add carbon dioxide to the bioshelter environment. Plants are grown year round, and the farm continues to operate successfully today.²⁹

Frey's book, *Bioshelter Market Garden*, gives great detail about his bioshelter design and is meant to be a resource for others who intend to design bioshelters of their own; it is one of the very few pieces of documentation that currently exist to assist with the bioshelter design process. This includes the proper orientation, materials, and plants which should be selected for a design. The book is an excellent resource for many of the key components of the design, such as the structure, growing beds, and solar heat storage.³⁰ More details on the design of bioshelters will be given in a subsequent section of this chapter.

2.3 Bioshelter Function and Design

Bioshelters focus on energy efficiency, renewable resources, and appropriate technologies. They balance high tech energy saving designs with passive low cost systems in order to create an indoor ecosystem

rather than a typical greenhouse. There are many important components to consider when designing a bioshelter, including architecture, heating, insulation, ventilation, and plant health. Each of these topics will be covered in the following sections.

Architecture of Design

One important factor to take into account when designing a bioshelter is its architecture. There are many different types and shapes of bioshelters. Some large-scale bioshelters are constructed with a glazed geodesic dome. This is effective for large scale setups because the volume to surface area ratio of a dome is quite large, allowing for good solar absorption. Some small-scale bioshelters have been made by adding a second layer of glazing to an existing greenhouse and insulating the north facing wall, which can significantly increase the solar absorption capability of the structure. Perhaps the most popular and well researched bioshelter configuration is what is commonly referred to as the Brace design. This design has been researched and contributed to by many organizations including The Brace Institute and NCAT.

The design incorporates a fully glazed south-facing wall (in the northern hemisphere) and a fully insulated north-facing wall with partially glazed side walls. The shape is further defined by the region in which the bioshelter is being built. In the northern hemisphere the sun is in the southern sky most of the time, therefore the south facing wall is fully glazed to allow direct sunlight into the structure. In contrast the back northern wall is heavily insulated to trap heat and is a prime location for placing thermal masses. Ideally the south wall actually faces slightly southeast in order to optimize thermal gain.³¹ The angles of the glazed roofing are chosen based on the latitude of the bioshelter. For northern latitudes such as New England the south roof should have a 40-60° slope, and the north roof should have a steep slope as well in order to allow snow to slide off.³²

Our sponsor, NCAT, and other organizations recommend these structures based on the assumption that the greenhouse is freestanding, but the basic designs can be used for other situations as well. The north wall can

27 Earle Barnhart. "Bioshelter Guidebook: Bioshelter Research by New Alchemy (1971-1991)."

28 Ibid.

29 Darrell Frey. *Bioshelter Market Garden: A Permaculture Farm*. (Gabriola Island, BC: New Society Publishers, 2011).

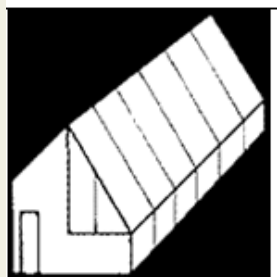
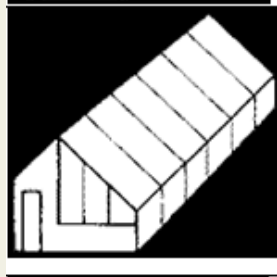
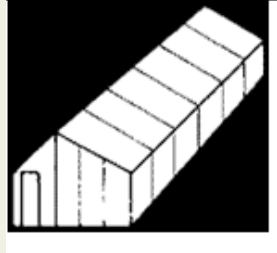
30 Ibid.

31 Joe White, "Growing in a Sunpit," *The Natural Farmer* (1991): 14.

32 Jon Sesso, Ed., *Low-Cost Passive Solar Greenhouses* (Butte, MT: NCAT, 1980), 173.

Table 1. Solar Greenhouse Shed-Type Design Examples

Freestanding shed-type solar greenhouses

	<p>For cold winters, northern latitudes, and year-round use.</p> <ul style="list-style-type: none"> • Steep north roof pitched to the highest summer sun angle. • Vertical north wall for stashing heat storage. • 40-60° Sloped south roof glazing. • Vertical kneewall is high to accommodate planting beds and snow sliding off roof.
	<p>For cold winters, middle U.S. latitudes, and year-round use.</p> <ul style="list-style-type: none"> • 45-60° North roof slope. • Vertical north wall for stacking heat storage. • 45° South roof glazing. • Vertical kneewall. • Part of end walls glazed for additional light.
	<p>For milder winters, southern U.S. latitudes, less heat storage.</p> <ul style="list-style-type: none"> • 45-70° North roof slope is steeper and north wall is shorter. • Roof can extend down to ground. • 20-40° South roof glazing. • Front kneewall as high as is needed for access to beds in front. • Most of end walls glazed for additional light.

Source: www.attra.org

be placed up against the south wall of a building in order to increase its insulation value. In this situation the north wall should be sized to be as tall as the building in question. Another option is to build the greenhouse on a south facing slope and which recedes partially into the ground. As long as the north and south walls are underground, while the roof is entirely above-ground, this design vastly increases the structure's insulation without reducing sunlight.³³ Of course one of the two side walls needs to be at least partially above ground in order to have a doorway. Table 1 comes from the NCAT website and lists the basic structure a greenhouse should have in certain regions.

Another important factor to consider when designing the basic structure of the bioshelter is the type of glazing used. Glazing is not just an insulation material, it also needs to let in the appropriate amounts of light and withstand weather conditions. In New England, glazing needs to be durable enough to not break from heavy snow or strong hail, and it needs to resist changes in size due to changing temperature. Furthermore, many glazes start to yellow over time, preventing enough light from getting through to the plants. A glazing that lasts a long time is ideal for use on a bioshelter.

One final dimension to consider is the height of the roof. Due to

the steep slopes of the two sides of the roof there will be a large quantity of open space near the peak. If this space is left empty then it only serves as extra area that needs to be heated in the greenhouse. In order to compensate for this and use space effectively, plants can be grown vertically, which increases the overall square footage of the growing space.

Heating

Heating and heat storage are particularly important for bioshelters in regions such as the northeastern U.S. There are several ways to effectively trap and store heat within a greenhouse or bioshelter. The largest source of heat in any energy efficient greenhouse or bioshelter should be from the sun. An effective bioshelter is able to capture solar heat passively during daylight hours and store it to be released at night. Different construction methods such as using stone, earthen, or concrete knee walls and floors can significantly add to the amount of heat storage.

compost piles can provide a large amount of heat

Another effective and inexpensive method of heat storage is to use drums of water within the structure for use as a thermal mass. The drums will capture heat during the day and release it as the temperature lowers. This method can be combined with solar thermal collectors placed outside the structure to further increase the amount of heat that is absorbed.

An alternative heating method utilizes the heat exhausted from com-

³³ James C. McCullagh, Ed., *The Solar Greenhouse Book* (Emmaus, PA: Rodale Press, 1978), 133.

post within the structure. Compost releases heat from the breakdown of organic material by microorganisms.

Compost piles can provide a large amount of heat, and the compost can later be used in the planting beds of the greenhouse. Animals may also be kept within the greenhouse for the heat they release through metabolic action. Domesticated chickens are best suited for this. Chickens are also beneficial because they eat several common garden pests.

Insulation

Insulation is very important to consider when building a bioshelter. It is one of the items that separate a bioshelter from a traditional greenhouse. Effective insulation methods are needed to trap heat within the bioshelter while still allowing adequate light to enter. All forms of bioshelter insulation methods will lower the amount of light that can pass through the structure to a degree, so a proper balance between insulation and light transmission is crucial.

Most greenhouses have glazing with an insulation value of about R-1.25 to R-2.5, whereas the recommended value for insulation to be used in the walls of a house in the northeastern United States is R-25. The R-value or insulation value is a measure of how much resistance a material has to heat flow, the higher the R-value, the more resistance a material has.³⁴ The type of glazing used will have a large impact

on the insulating properties of a bioshelter. There are many material properties to consider including light transmittance, durability, insulation value and cost when choosing glazing. Of the popular glazing materials, polycarbonates are the most expensive, followed by acrylics, glass and fiberglass.³⁵ All of these materials have similar light transmission and insulation values, but polycarbonates and fiberglass are the most durable and are also quite resistant to weathering.³⁶

Multilayered glazing is a popular option to increase insulation. Glazing materials such as glass acrylic and polycarbonate are available in multilayered sheets or panels. This can more than double the R values of the material.³⁷ Dual layered fiberglass panels are not readily available. In addition to using multilayered glazing, a dual glazing system can be used to further increase the insulating properties of the structure. Dual glazing refers to a design that has inner and outer glazing panels with a layer of insulating air in between them. It is important to understand that multilayered and dual glazing will have a large effect on light transmission, and the amount of multi-layering that is possible is limited in this respect.

Even with these methods implemented the bioshelter may not be well enough insulated for use in colder climates. Insulated walls similar to those on a house could be incorporated into the structure to fur-

ther increase efficiency. These walls can have insulation values ranging from R-19 to R -30, but they allow no light to pass through them. Bioshelters have been built with insulated walls on as many as three sides, while still allowing adequate light to enter. The south facing side of a bioshelter should always be designed to let in as much light as possible, whereas the north facing side, which receives the least amount of light in northern climates, would be the first wall to consider insulating.³⁸

Another more traditional method of greenhouse insulation and energy conservation would be to build a subterranean bioshelter. Even in cold climates the temperature below ground stays relatively constant throughout the year, this will be able to help keep the bioshelter at a more constant temperature as well. Insulating panels could also be installed underground around the structure to further enhance the energy efficiency. However being built partially underground, a lesser degree of light will be able to enter the structure through its walls.³⁹

Ventilation

Proper ventilation is a very important design parameter that is often overlooked in the conceptual design of a bioshelter. Ventilation is needed to assist in regulating humidity and CO₂ levels and to detour pests and prevent the growth of fungi or bacteria. Without adequate ventilation crops will exhibit vari-

34 James C. McCullagh, Ed., *The Solar Greenhouse Book* (Emmaus, PA: Rodale Press, 1978), 45.

35 "Greenhouse Gardener's Companion," accessed April 1, 2012, <http://www.greenhousegarden.com/author.htm>

36 Ibid.

37 Ibid.

38 Darrel Frey, *Bioshelter Market Garden: A Permaculture Farm* (Gabriola Island, BC: New Society Publishers, 2011).

39 Ibid.

ous growing problems.⁴⁰ It can be challenging to provide adequate ventilation and efficient heating at the same time. The various methods of greenhouse ventilation can be broken up into two types; forced convection and natural convection.

Forced convection ventilation involves the use of a fan for air exchange. The benefits to using forced convection are that the level of ventilations can be controlled very easily and the incoming air can be conditioned to the proper temperature before entering the growing environment. To do this cold forced air from outside can be set up to go through a heat exchanger using compost or latent heat as the heat source. Natural convection may also be used for air exchange by using vents or roll up walls to allow for passive airflow. Un-

fortunately the amount of ventilation is difficult to regulate this way and the incoming air cannot be warmed prior to entering the growing area.

Plant Health

The economic success of a bioshelter is not possible without excellent growing conditions. Plant health will involve regulating temperature, humidity, proper light levels and duration of exposure, fertilization and fresh air exchange. These conditions can also change depending on the stage of the plant's life cycle (seedlings typically require higher temperatures to develop more quickly, budding and flowering stages may require different amounts of light and light temperature, as well as different nutrients).

Plant stress can ultimately ruin

an entire harvest if left unchecked. Common stress occurs mainly to factors such as sudden changes (or extremes) of temperature, humidity, over or under watering, deficiencies or excesses of nutrients, extremes of sun exposure, soil PH or salinity.⁴³

In addition, plants are also susceptible to biotic factors (insects, fungi, bacteria, and nematodes), phenological stages (budding, flowering, fruiting and ripening) and crop management techniques (handling and transplanting, pruning, pesticides).

The techniques used to reduce plant stress in a bioshelter include environmental management strategies, biodiversity of plants, beneficial insects and fungi, and appropriate supervision and adaptation to changes in the environment.

2.4 Challenges Facing Urban Agriculture and Bioshelter Development

The stages of planning, construction and operation of an urban agriculture site include a number of challenges: land use planning, start-up costs, seasonal limits, access to markets and the support of the local community.

Land Tenure

Land tenure is a common barrier to obtaining a space for growing. Most growers agree to short term (less than 5 years) leases if they cannot purchase the land (either due to lack of initial funds or to unwilling owners) and subsequently risk their investment if the owner chooses not to renew the lease.⁴¹

Other options exist that may help

alleviate this problem, such as land trusts which secure land for urban agriculture,⁴² or rooftop properties (many so-called "green roofs" exist today, but may not take advantage of crop production) since there is no competition for the space. Abandoned industrial lots would offer plenty of space for growing, however they are often contaminated with lead or other xenobiotic (human-made) pollutants, and often require an expensive bioremediation process.

Zoning Laws

Zoning laws can limit the type of activities on a site as well as the physical size of a structure. In addition, many cities have adopted

ordinances that limit land use and activities on private grounds. Although many of these ordinances are designed to protect the well-being neighbors and property they can also create many legal barriers for urban farmers. A few common city ordinances that affect urban farming are appearance standards, air pollution standards, animal ordinances, and refuse ordinances. A table highlighting the legal barriers for urban farming in Flint, Michigan has been included as an example of common ordinances that affect urban farming.

Many cities, including Flint Michigan are working to modify these ordinances so that they are more applicable to urban farming.

40 James C. McCullagh, Ed., *The Solar Greenhouse Book* (Emmaus, PA: Rodale Press, 1978), 250.

41 R David Rhodes and Anna Nadolska-Orczyk. "Plant Stress Physiology." In *ELS* (John Wiley & Sons, Ltd, 2001).

42 K. H. Brown. "Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe." *Agriculture* 27, no. October (2003).

43 Ibid.

Table 2. Challenges Facing Urban Agriculture.

Ordinance	Challenge to Urban Agriculture
Zoning Ordinance Definitions	What types of agricultural uses are allowed is unclear since no definitions dealing with agriculture are provided.
Zoning Ordinance Appearance Standards	While the regulation is currently used in historic areas, it could be used to prevent the building of a hoop house or greenhouse in an established neighborhood.
Zoning Ordinance Site Plan Review	Any structure, defined by the zoning ordinance as any structure anchored to the ground, must go through site plan review by the planning commission with the exception of fewer than three single-family dwellings.
Zoning Ordinance Use Districts	"[C]ustomary agricultural uses including noncommercial nurseries and greenhouses, but expressly excluding the keeping of farm animals" are listed as principal permitted uses in A-1, A-2, B, B-1, C-1, C-2 and D-1 zones (if the D-1 property abuts a residential zone). No agricultural uses are currently allowed within the commercial and industrial districts of the city. The sale and processing of food within the city is restricted exclusively to these districts, however.
Zoning Ordinance Off-street parking & loading	The parking and loading requirements do not have specific requirements for agricultural uses.
Air Pollution Ordinance	Section 4-13 bars open burning of refuse. Gardening or farm sites are sometimes best cleared by a controlled burn rather than the use of chemicals.
Animals and Fowl Ordinance	The ordinance restricts all meat and egg production to the mainstream industrial food chain, allowing animals to be kept only at slaughterhouses. It does not allow for poultry or domestic fowl on residentially zoned lots.
Business and Occupations General Ordinance	This ordinance has a number of restrictions on who may sell food and how food is sold.
Fences Ordinance	The regulations for fence placement and materials in the residential zoning districts, where agricultural uses are allowed, are difficult to understand and may not be appropriate for gardeners.
Nuisance Ordinance	Some provisions of this ordinance could be used to limit composting, an essential activity in organic gardening.
Parks Ordinance	This ordinance places restrictions on gardening in the city's parks. It bans picking or breaking flowers and plants, and the removal of turf.
Refuse, Garbage and Weeds Ordinance	This ordinance does not specify what department would be responsible for refuse collection at an urban agricultural enterprise of any size and does not specify the type of trash receptacle required.

Source: Masson-Minock, M., & Stockmann, D. (2010, Fall).

One particular example in the city of Worcester is the push to amend the local animals and fowl ordinance. The current Worcester ordinance does not allow animals to be raised in the city, but advocates petitioned to amend the ordinance to allow chickens to be kept on private property. On June 14th, 2011 the issue was brought before city council.⁴⁴

Some concerns were voiced about

the implementation for allowing chickens to be raised in the city, but the motion was not without supporters. Children holding signs with the message of "Give Peeps a Chance" were present, along with the District 4 City Councilor Barbara Haller and Mayor Joe O'Brien who filed the order. The new ordinance does not include the butchering of chickens, so the main focus

is on producing eggs.⁴⁵ If the new ordinance were passed, chickens could become an important part of a Worcester bioshelter design, however as of today they are not allowed.

The location or size of the structure may also be limited by law. In the city of Worcester, a bioshelter type operation, classified as agriculture, would only be allowed in certain districts.⁴⁶

⁴⁴ Noah Bombard. Chicken proposal gets mixed reception at city council. (June 14, 2011).

⁴⁵ Ibid.

⁴⁶ City of Worcester. "Ordinances & Regulations." Accessed September 25, 2011, <http://www.worcesterma.gov/city-clerk/ordinances-regulations>.

There are several districts in Worcester that allow agriculture, horticulture, viticulture, or flora culture on parcels of less than five acres. These districts with a zoning map can be found in Appendix A. Ultimately zoning laws are meant to separate different land uses and help people keep up the value of personal property and to help keep the city livable for residents and profitable for businesses. These same laws however can impede the construction of bioshelters.

Startup Costs

The initial investment required for urban agriculture is a common obstacle for many entrepreneurs. The many start-up costs involved include planning and design, land procurement (sale or lease), building materials, tools and equipment, construction, insurance, labor, packaging and marketing materials, fertilizers, along with any basic utilities (water, gas, electricity).

However there are grants and incentives for those who wish to start local food cultivation, such as the "Know Your Farmer, Know Your Food" initiative administered by the USDA's National Institute of Food and Agriculture who recently announced \$5 Million in grants.⁴⁷ Other grants (community development, "seed" grants, among others) and tax breaks are available, along with additional incentives for non-profit organizations.⁴⁸



Figure 4. "Growing Power," a Popular Story in Urban Agriculture
Source: http://www.goodlifer.com/wp-content/uploads/2011/07/GL_LEX55_GOOD-FOOD.jpg

47 USDA. 2010. "USDA Awards More Than \$5 Million in Grants to Support Local Foods Initiatives."
Accessed September 25, 2011, www.nifa.usda.gov/newsroom/news/2009news/11181_cfp.html

48 K. H. Brown. "Urban Agriculture and Community Food Security in the United States: Farming from the City Center to the Urban Fringe." *Agriculture* 27, no. October (2003).

Growing Season Limitations

The winter season in northern climates is a tremendous barrier to urban agriculture, as it is not economically feasible to heat a greenhouse to maintain growing conditions, or the crops do not acquire enough sunlight for proper growth. In order to be competitive, most farmers aim to sell their crops at a minimum of \$2.00 per square foot per harvest. The cost of heating in the winter amounts to 70-80% of typical greenhouse energy consumption and can cost the grower \$3-5 per square foot per harvest. In this situation, it is difficult to offer competitive prices. Season extension techniques exist but are not common and do not allow year-round production of crops. Common methods include the use of hoop houses (plastic roof covering flexible tubing), cold frames and high tunnels (similar variations of a hoop house) and the utilization of compost as a heat source. Bioshelters typically design their structure based around this problem by incorporat-

ing passive solar energy systems with a thermal mass.

Community Support

Possibly the most influential factor towards urban bioshelter development include support from the community to aid in policymaking, fundraising, building and operating. Local governments and officials normally consider UA a low priority and tend to favor other forms of land development. Support from the community can help change policies to support an infrastructure for urban food and recognize it as an industry.

Beneficial changes to policies would include: more encouragement from government, banks, and private businesses to offer start-up funds or incentives to UA farmers as well as opportunities for land tenure, educating the public on the importance of agriculture in health and nutrition, and promoting the use of vacant lots for food production.⁴⁹ A list of grants and incentives that have already been implemented is available in Appendix F.

3.0 METHODS

This project intends to expand the opportunities for urban agriculture by providing a design and supporting information to build and operate a bioshelter. Our bioshelter design demonstrates how an urban farmer can extend the growing season, expand production, increase yields, and increase availability of healthy food in low income neighborhoods. To ground our work, we chose an actual site for our bioshelter in Worcester with the help of a local organization that works on urban agriculture, the Regional Environmental Council (REC). The following is a list of objectives to help realize the main goal of this project.

- **Document existing bioshelters** and assess their strengths and weaknesses relative to grower satisfaction, energy efficiency, performance, costs, and other important criteria.
- **Research existing energy saving practices** and technologies in the greenhouse industry and identify important lessons and models for new bioshelter construction and greenhouse retrofitting.
- **Design a prototype bioshelter** in collaboration with key stakeholders for use in urban agriculture.
- **Create a distribution channel** for urban farmers to access information and designs for bioshelters.

This chapter describes the techniques and methodologies used to complete the objectives listed above, which in turn achieved the main goals of this project.

3.1 Documenting Existing Bioshelters

As bioshelters are a fairly new concept in modern day farming, there is relatively little in the academic literature about their performance. The team visited sites of bioshelters, greenhouses, and farms in order to gain first-hand information. Places visited included The New Alchemy Institute's Ark, The WPI greenhouse, the greenhouse at UMass Boston, and the REC's YouthGrow Farm. The information obtained during these visits supplemented the information obtained through researching online and through books, and allowed for a greater understanding of what components should be present in our bioshelter.

49 L. J. A. Mougeot. "CFP Report 31-Urban Agriculture: Definition, Presence, Potential and Risks, Main Policy Challenges." 1999.

3.2 Research Alternative Energy Practices and Appropriate Technologies

In order to be cost-effective, a bioshelter must maintain high energy efficiency and reuse or conserve as much energy as possible. We examined new technologies and alternative energy practices. Many greenhouses in the New England area only operate three out of the four seasons due to high costs associated with winter heating. Extending the growing season requires high energy efficiency, and in most cases, alternative energy strategies and techniques to recover lost energy. Our team examined the benefits of using passive solar energy to heat a thermal mass, but we also investigated the possibility of subterranean heating, solar panels, and wind energy. Unlike searching for bioshelter information, alternative growing methods and energy efficient technologies are readily available online in academic journals and science compendiums. Additionally, NCAT makes available an abundance of information related to renewable/efficient energy, including farm energy audits, usefulness and costs, and renewable energy guides for anaerobic digesters and other biomass options, along with wind, solar, and hydro power publications.

3.3 Design a Bioshelter Prototype

The bioshelter design must address the needs of the urban farmer (types of crops, construction and operating costs, location, access to utilities, etc.) and restrictions of the location (e.g. zoning regulations, contaminated soil) while making the best use of resources available (access to water, electricity, sunlight etc.). These factors influence the overall sustainability and cost-efficiency of the shelter. In order to complete this objective it was necessary to gather information on bioshelter and greenhouse design, and sustainable energy practices. The location of the site of the project was chosen with the help of the REC staff in the fall of 2011. This site was the Youth-Grow Farm in Worcester, MA. (This location is identified in Appendix A)

We performed a visual inspection of the site in order to determine the resources and restrictions associated with the site. Water access was limited, requiring new connections to the city water main. Electricity would also require completely new connections to the grid. The soil in areas that were not being used for farming was contaminated with lead. However, sunlight exposure was excellent, with no buildings or trees blocking the sun from the site. This information was taken into account when designing our bioshelter.

The actual designing of the bioshelter was an iterative process. The group utilized their research

to propose components necessary to the bioshelter. Then each component was researched in more depth, and exact parameters were specified for our bioshelter. These were presented to our sponsor Andy Pressman for review, and components were added, removed, or modified based on his feedback.

After the bioshelter was designed a detailed list of components was created based on the design elements. This includes a cost analysis of the bioshelter for an estimate of the expense of the design. This allows potential builders to decide against certain individual components on a basis of cost. Finally expected revenues generated from the crops of the bioshelter are included with the design. This shows how long it might take to pay off the initial cost of the bioshelter as well as display the viability of having a profitable urban bioshelter.

3.4 Distributing Information to the Community

Through our project web site, we will provide information about the design, construction, and use of bioshelters to as many communities and farmers as possible in the New England area and beyond. We created a website using Google sites. The site provides links to the REC and NCAT websites, allowing those browsing the site to find further information either about farming, or the Worcester Community.

4.0 FINDINGS

This chapter contains our findings. It begins with information on zoning laws, building codes, and permit requirements to make a bioshelter venture possible. Next, we consider the construction process along with the general layout of the structure's key components. We then examine heating and energy considerations, agricultural production, crop harvest and storage, and community outreach. Each of these sections details individual components of the bioshelter including the selection process and function. Lastly, the economics of the bioshelter are discussed with estimates of costs and revenues.

In order to develop our findings, several assumptions were made. The first assumption was regarding the size and location of the available space. In regards to these parameters, the YouthGrow farm in Worcester, Massachusetts was used as a guideline. The overall size of their lot was decidedly large enough to hold a structure approximately 80 feet long. Using this dimension, the footprint of 30' x 80' was derived for a practical bioshelter. The bioshelter detailed in this report was also specifically designed for the latitude and longitude of Worcester, Massachusetts. Parameters such as light angles and climate were assumed to match typical conditions at the chosen location.

Other assumptions were made to focus the scope of the project in terms of function. A bioshelter can be designed as a commercial enterprise or as a demonstration bioshelter

for community benefit and education. The bioshelter detailed in this project was designed with a focus on commercial production and profitability, but community aspects were built in as well. Another goal of this project was to reduce the level of inputs such as electricity, water, and natural gas, propane, or oil for heating. This minimizes costs and results in more long term sustainable solutions. To keep this goal central to the design, it was assumed that little to no fossil fuels were available to heat the bioshelter. This was especially challenging, particularly in dealing with the project's final assumption of year round operation. Overall, these assumptions helped us to define the scope of the project and key parameters for the bioshelter.

4.1 Permitting/Zoning

The steps for zoning and structural approval can be somewhat difficult, and can vary significantly from place to place. Typically, the first step in building a permanent structure is to receive zoning board approval. This is usually handled through the local zoning board. To receive approval for a large scale agricultural building such as a bioshelter, the area of interest would likely have to be zoned for agriculture, however, in some cases a variance can be passed by the board that allows for a structure to be built outside of its proper zone.⁵⁰

Pending approval by the zoning board, the structural design of the building will have to be

reviewed and passed by the local building inspector. Building inspectors typically require complete blueprints to be submitted for approval of new construction.⁵¹

A building permit is usually issued after approval of the building plans, which means that construction can begin. During construction there are typically three building inspections that must take place before occupancy of the building is allowed. The first is an inspection of the foundation, which happens before the structural work begins. The second inspection occurs after the structure has been built, plumbed and wired. This is when the inspection of plumbing and electrical components takes place. The final inspection occurs after the building has been fully constructed. An occupancy permit is usually issued shortly after passing the final inspection.⁵²

It is important to note that there are many cases in which a building permit is not needed. If the bioshelter has a piling or structural post foundation, as opposed to one made with poured concrete or blocks, then it is not considered a permanent structure and may not require a building permit, if being built on private land. However, any new wiring or plumbing may still require an inspection.⁵³ It is important to contact the local zoning board and building inspector before building any structure to make sure that all of the legal regulations have been met.

⁵⁰ Massachusetts Trial court Law Libraries. Accessed march 18, 2012, <http://www.lawlib.state.ma.us/subject/about/zoning.html>

⁵¹ New Complete do-it-Yourself Manual. 10th ed. United States: Reader's Digest, 1991, 28.

⁵² Ibid.

⁵³ Ibid.

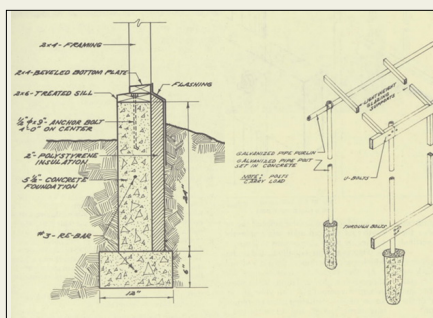


Figure 5. Poured concrete foundation and wall (left) and post foundation (right)

Source: Jon Sesso, Ed., *Low-Cost Passive Solar Greenhouses* (Butte, MT: NCAT, 1980), 52.

4.2 Construction

Structure

When considering how to build a bioshelter or solar greenhouse there are many options. There are numerous different types of greenhouses available and their design often reflects how they are used.

Although many greenhouses do not have structural foundations, a bioshelter is typically a more expensive permanent form of greenhouse and will usually need a solid foundation. The grade of any plot of land changes over time due to various factors including freezing and thawing, and erosion due to wind and rain. A foundation provides a stable, level footing that, unlike the ground, will remain relatively stable over time. Typical foundations for permanent bioshelters use structural posts, concrete blocks, or poured concrete. Structural posts are a less expensive option but are more than adequate for single story structures.⁵⁴

As with the foundation there are many different methods and different materials that can be used to

build the greenhouse structure. The three most common materials used in building the frame of a greenhouse are structural steel, aluminum and wood. Aluminum is likely the most popular material for commercial greenhouse framing because it is inexpensive, lightweight, and strong.

Unfortunately, building a custom structure with aluminum framing can drive up costs significantly. The same can be said for steel framing. A prospective bioshelter builder would likely have to hire an outside company to have the structural members designed and built, because most general contractors do not have the capacity or qualifications for structural welding and framing of aluminum or steel.⁵⁵

Conversely the bioshelter frame could be built using wood. The majority of small-scale custom-built greenhouses use a wood frame. This is because a custom wood frame can be built relatively easily compared to an aluminum or steel frame. Most wood-framed greenhouses use a combination of “post and beam” and “platform” framing techniques that are similar to what is seen in a house.⁵⁶ This can be handled by the average contractor or by a landowner with building experience. The use of a wood frame also allows for the option of using salvaged building materials which can greatly reduce the overall cost of the structure. Also, since wood is a much better insulator than aluminum or steel, less heat will escape through glazed walls; this is an important element for an energy efficient design.

Wood will deteriorate in moist environments so it is necessary to treat and protect any exposed wood in the structure. Also, since wood is not as strong as aluminum or steel, the structural members used will be larger in size compared to the latter, so the structure will appear less open, and slightly less light will be able to enter.⁵⁷ These negatives, however, are likely outweighed by the relative low cost, customizability, and insulator properties of a wood frame.

Insulation

Insulation is the main distinguishing factor between a bioshelter and a traditional greenhouse. Bioshelters typically have a fully insulated north facing wall. East and west side walls are often partially insulated as well. The perimeter of a bioshelter is also insulated beneath the ground because a large amount of heat loss can occur through the earth.⁵⁸ Adding insulation to these areas will increase the heat trapping abilities of the structure significantly while still allowing adequate light to enter the bioshelter through the glazed front wall.

The insulation techniques for a wood frame bioshelter are comparable to those in a house with conventional wood framing. The most common type of insulation for the structure is fiberglass batting. Fiberglass insulation designed for use in walls made with 2 x 4 studs is typically R-15 or R-20. Using 2 x 6 stud walls allows for thicker insulation, which can have an insulation value of R-25 or R-30.⁵⁹ This is an important design consideration for any bioshel-

54 James C. McCullagh, Ed., *The Solar Greenhouse Book* (Emmaus, PA: Rodale Press, 1978), 129.

55 *New Complete do-it-Yourself Manual*. 10th ed. United States: Reader's Digest, 1991, 74.

56 James C. McCullagh, Ed., *The Solar Greenhouse Book* (Emmaus, PA: Rodale Press, 1978), 129.

57 *Ibid.*

58 Jon Sesso, Ed., *Low-Cost Passive Solar Greenhouses* (Butte, MT: NCAT, 1980), 49.

59 “Lowe's Website” accessed January 12, 2012, <http://www.lowes.com>

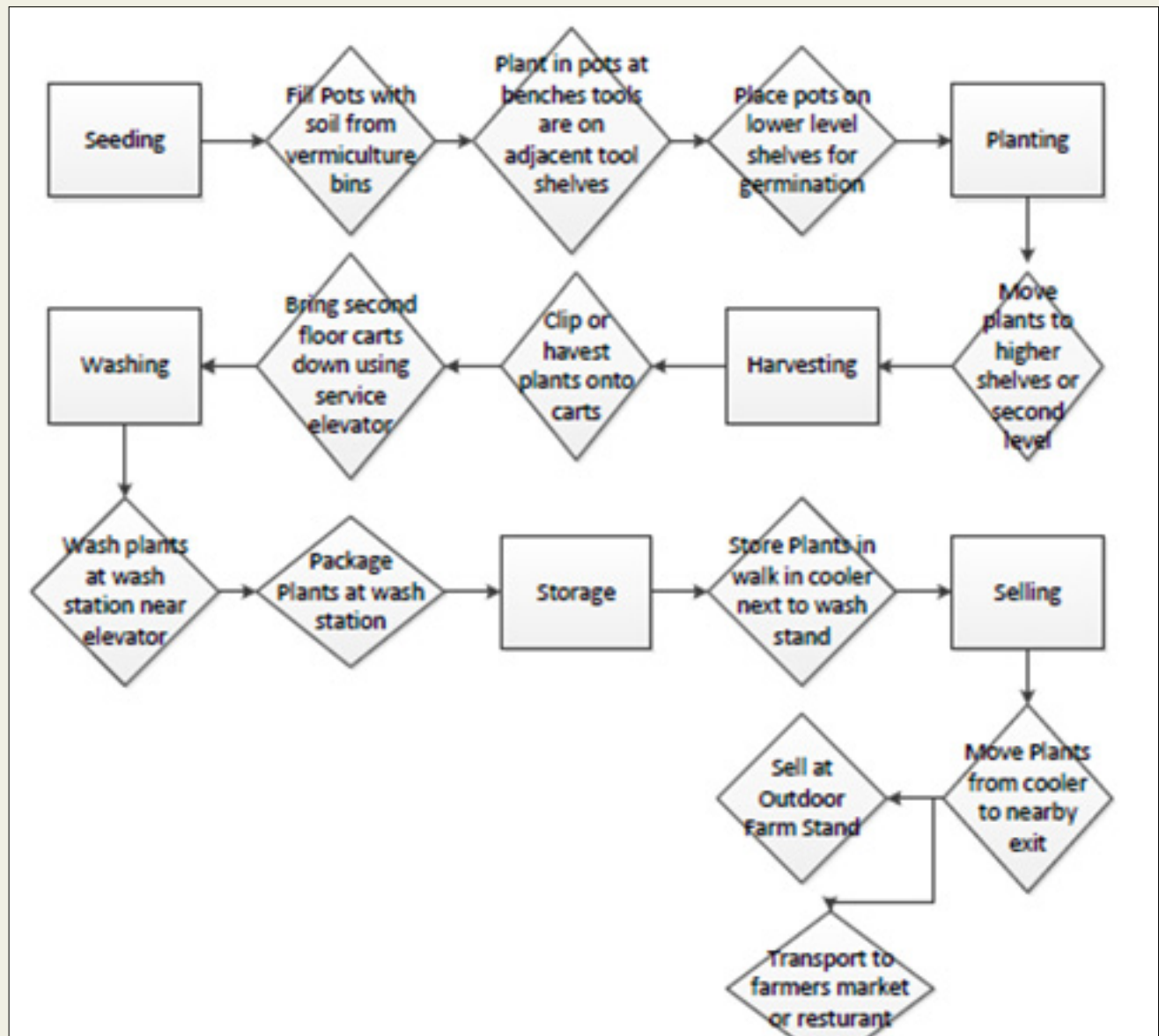


Figure 6. Layout Workflow.

ter built in an area with seasonal cold climates. Note that it is important to use the correct size batting for the stud walls; forcing too much insulation into the walls will actually lower the insulating ability of the material. For ground insulation, foam insulating panels can be used. The best panels for ground insulation are those designed to insulate house foundations. These are readily available at most contractor supply stores. Calculations for heat loss and insulation requirements for a bioshelter can be found Appendix B.

Layout

The layout of the bioshelter was optimized to take advantage of the entire space, while still being practical and providing a logical workflow. The largest component is the grow shelves. There are two rows of shelves on the ground floor, located at the southern side of the bioshelter, where there is less ceiling clearance. The rest of the shelves are located on a second floor in order to maximize growing space and sunlight exposure without sacrificing floor space. A staircase towards the middle of

the northern part of the bioshelter is used to access this upper floor. Carts are used to transport harvested plants from the top floor, and are transported to the bottom floor with a service elevator located at the back of the staircase. Underneath the staircase is the liquid to air heat pump, tucked out of the way. Finally hanging baskets are also accessible from the top floor, which grow some year round plants and flowers.

The ground floor of the bioshelter contains all of the remaining bioshelter components. A door is located

near the middle of both end walls for accessing the bioshelter. Along the east wall of the shelter there is a chicken coop and a bathroom containing a composting toilet and a sink. Both of these components extend to stick out of the wall and thus need to be at the edge of the bioshelter. Underneath the eastern portion of the second story shelving are the composting bins. The vermicomposting is located across from the regular composting. This location keeps all of the components that could have unpleasant odors on the same half of the bioshelter. The bathroom is located near the entry on that side for ease of access. Underneath the western portion of the second floor shelves is a small meeting area with picnic tables for employees and guests. This area is open to the entire for ease of access and so that it can be used as an area to explain about the shelter to community members. Between the composting area and the rest area there is a set of shelves to store the various tools needed in the bioshelter.

In the northwest corner there is a cold storage area. This is placed in a corner so that it can take advantage of the insulation of the bioshelter walls, and thus only two additional insulated walls need to be built. Next to the cooler along the north wall is the wash stand. This is located between the service elevator and cooler so that plants are brought from the second floor, washed, and stored in a logical fashion. Plants from the first floor have to travel a greater distance, but there is ample walkway space to bring them through. The remaining areas of the north wall, as well as above the wash stand, are filled

with water jugs for thermal storage. The above flow chart shows the order in which tasks are carried out for a single harvest. Obviously multiple different plants are being planted and harvested on different schedules, but this chart gives a basic idea of the way work is carried out. Note that related tasks are done at locations that are near each other. This is because the layout was created with convenience and ease of use in mind.

4.3 Heating and Energy Considerations

Solar heat storage

Heat storage methods are necessary to moderate temperatures within the bioshelter. Without proper heat storage, temperatures within the bioshelter would be far too high during daylight and far too cold during winter nights. Popular heat storage materials for bioshelters include rock, sand, and water, although water holds about 5 times more heat than sand or rock. A concrete or stone foundation will also add significantly to the heat storage capacity of a greenhouse, especially if the foundation perimeter

has been insulated. Phase change materials, which utilize the absorption and release of energy during melting and solidifying, are somewhat better than water at maintaining temperatures but are much more costly.⁶⁰

Cost and efficiency considered, water is probably the best heat storage medium for use within a bioshelter. Solar greenhouse expert Dave McKinnon recommends using at least 4 gallons of water per square foot of growing space for heat storage.⁶¹

Ideally the heat storage should be located against the back insulated wall of the bioshelter where they will be exposed to direct light without encroaching on growing space.

The type of storage container being used is also important. Containers should ideally be small to maximize surface area and square to maximize space efficiency and conduction between the containers. Containers should also be dark and non-reflective to absorb solar energy. Alternatively translucent containers may be used with the water inside dyed black. Dave McKinnon affirms that large containers such as 55 gallon drums are inefficient for

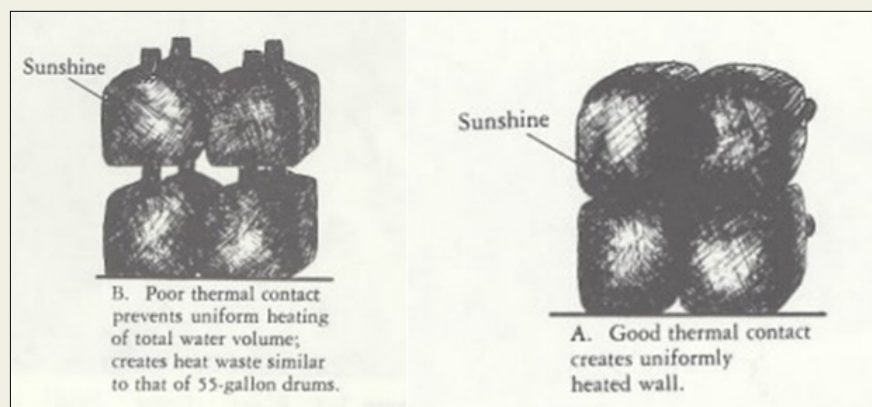


Figure 7. Examples of Good and Bad Stacking for Thermal Masses (Water Jugs)
Source: James C. McCullagh, Ed., *The Solar Greenhouse Book* (Emmaus, PA: Rodale Press, 1978), 82.

⁶⁰ Jack Ruttle. "The Solar Greenhouse Project." (Solaripedia 2012): April 4, 2012.

⁶¹ Ibid.

heat storage for several reasons.

Drums leave empty about a third of the space they occupy, because they are big and round. They also permit warmed water to gather into a few large areas, which causes both greater heat losses and poorer collection in those areas. Smaller containers keep the energy more evenly distributed.⁶²

Ground Source Heat Pump

Bioshelters need to maintain proper levels of humidity for healthy plant growth. During the warm months this can be achieved with natural ventilation to bring in fresh air. However during the winter, air needs to be preheated before entering the bioshelter in order to maintain heat for the plants. In order to achieve this heating a ground source heat pump will be installed in the bioshelter.

A ground source heat pump is a system that utilizes the year-round warm temperatures underground as a heating source. Water is pumped through piping underground at a depth of eight feet. At this depth the temperature stays at approximately 50°F year round. The water passes through a liquid to air heat exchanger in the heat pump which transfers the heat to incoming air.⁶³ The air is heated to 50°F in the heat exchanger and then is routed through the plant beds. The air runs through corrugated pipes in the drainage layer of the grow beds in order to heat the plants from below.⁶⁴ The remaining air is then pumped out of the bioshelter now that it has absorbed

some of the humidity. An additional option is to run the pipes through the composting bins in order to raise the temperature further before sending the air to the grow beds. Because the air coming from the heat pump is always 50°F, the heat pump can be used for cooling in the summer, if absolutely necessary.

One of the greatest advantages in the ground source heat pump is that it changes the temperature to 50°F using the same amount of energy, no matter what the starting temperature was. This effectively means that the heat pump has a variable BTU output for the same energy input. The minimum operating temperature of the bioshelter is 55°F, so additional energy is needed. The bioshelter loses 1.6 MBTU per day through the walls of the structure, but gains 1.8 MBTU per day from sunlight. Thus, to raise the temperature by 5°F, an additional 1.5 MBTU are needed each month. This amount can easily be gained through compost heating. To see the calculations for these numbers, look in appendix B.

It is necessary to perform a site evaluation before installation to ensure that there are no obstructions to the piping prior to digging.⁶⁴ The two main setup types are horizontal loop and vertical loop. Horizontal loops have piping snaking back and forth closely packed at about eight feet below the ground. This type requires 1,500 square feet of surface area per ton air to be cooled.⁶⁵ This design is cheaper, but if not enough space is available, a vertical loop can be used. Vertical loops stretch from

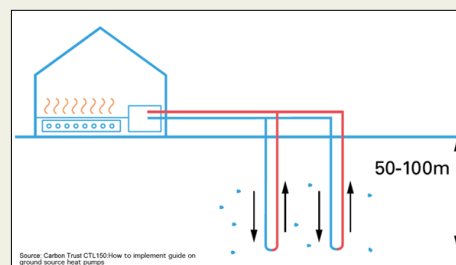


Figure 9. Vertical Closed Loop Ground Source Heat Exchanger System. Source: http://www.b-es.org/files/6213/2544/2908/Closed_loop_vertical_schematic.gif

eight feet underground to anywhere from 150 to 400 feet deep. This large bore depth makes them more expensive, and some urban areas may have obstructions further below. However, only 250 square feet of surface area is needed per ton of cooling.⁶⁶ For this bioshelter design it is assumed that space is available for the horizontal loop system.

The most important factor in choosing ground source heating as the method for heating the air intake is energy efficiency. According to re-

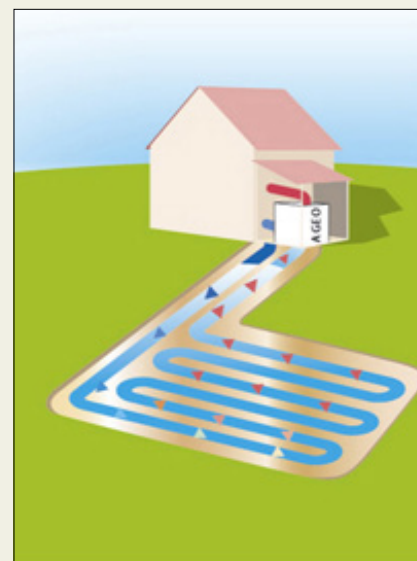


Figure 8. Horizontal Closed Loop
Source: <http://greenew4u.com/images/horizontal-loop.jpg>

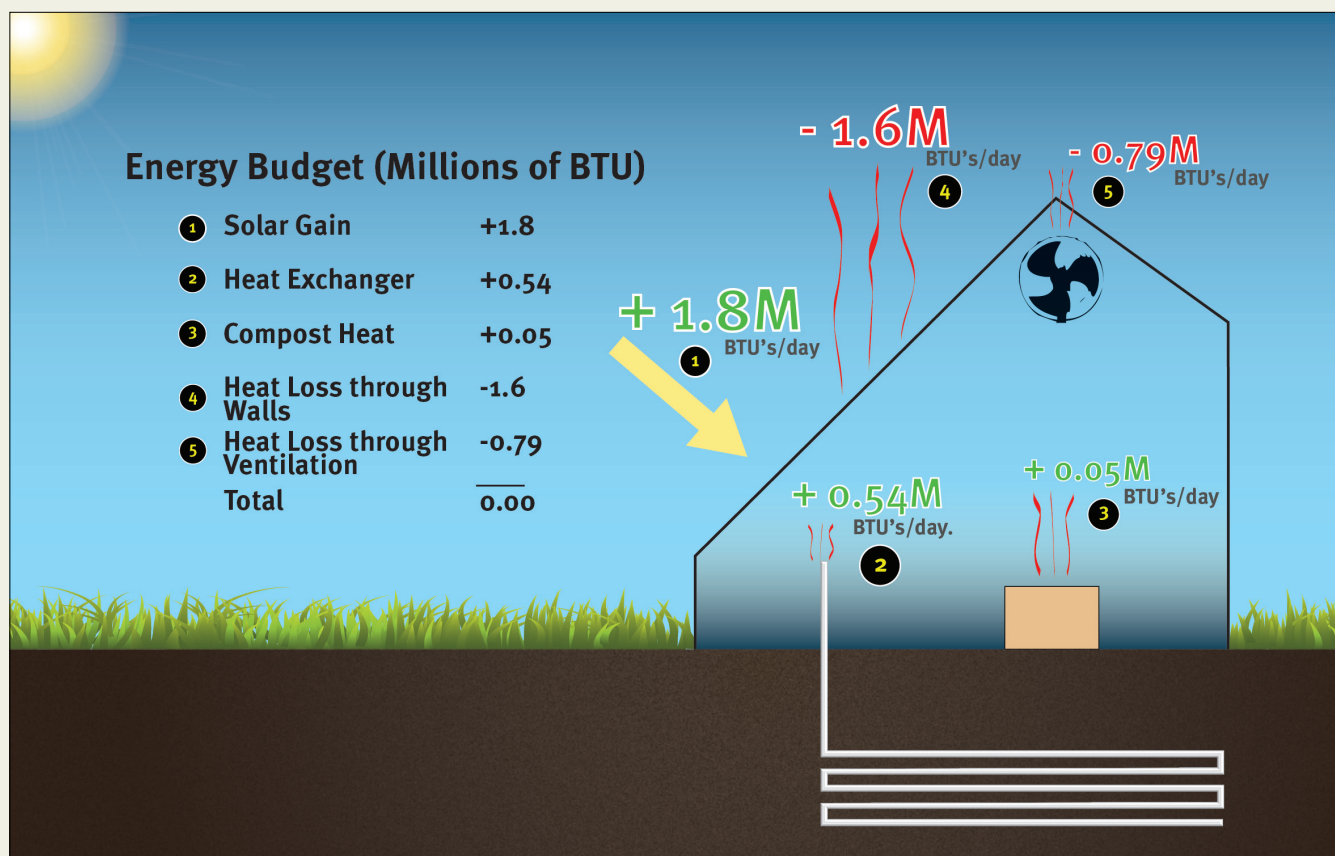
62 Jack Ruttle. "The Solar Greenhouse Project." (Solaripedia 2012): April 4, 2012.

63 Andrew Collins and Carl Orio. Geothermal Heat Pump Manual. 2002.

64 Ibid.

65 McQuay International. Geothermal System Types. 2012.

66 Ibid.



searchers at the University of Florida, winter ventilation in a greenhouse should have a minimum of two air exchanges per hour in order to maintain healthy plant growth.⁶⁷ This means that the entire volume of air in the bioshelter must be exchanged twice each hour. According to the McQuay International website, a



Figure 10. Mcquay heat pumps of various sizes http://www.mcquay.com/McQuay/ProductInformation/WSHP/images/WSHP_vertical_Collage.jpg

McQuay vertical floor mounted 096 heat pump can circulate air at a rate of 3,600 cubic feet per minute at 3.49kW.⁶⁸ Since our bioshelter has a volume of approximately 39,000 cubic feet, the pump can complete one air exchange in just under eleven minutes. This means it needs to run about one third of every hour to complete the two exchanges. Due to this massive amount of heating that needs to take place, the efficiency of the system is essential to keeping energy costs down. Ground source heating does not generate any heat itself, but rather utilizes the natural heat of the earth. For this reason it has an advantage over electric and gas heating, in that the only ex-

pense is to run the pumps for the air and water. For this reason, ground source heating is a highly efficient and effective heating method.⁶⁹

Supplemental Lighting

Supplementary lighting is necessary for winter greenhouse production in order to increase low levels of natural light. The appropriate amount varies with crop selection (light-hungry plants or shade dwellers), the technology used (high power or high efficiency), and the cost of installation, maintenance, and energy or “price per square foot,” which is simply the total cost per square foot for one growing season. A large installation of high power

67 D. E. Buffington, R. A. Bucklin, R. W. Henley, and D. B. McConnell. "Greenhouse Ventilation." (Publication no.AE-10.Department of Agricultural Engineering, University of Florida, Gainesville, FL)
 68 McQuay International. (2010). Enfinity™ large vertical water source heat pumps with R-410A refrigerant. Catalog 1109-1 (4/10)
 69 P. S. Doherty, S. Al-Huthaili, S. B. Riffat, and N. Abodahab. "Ground Source Heat pump—description and Preliminary Results of the Eco House System." Applied Thermal Engineering 24, no. 17-18 (12, 2004)

eco-induction lamps can shorten crop time and increase profit, but installation costs and the price per square foot are high and the return on investment could take years even with an expert grower. A smaller installation is inexpensive, yet the crop time will be longer with less light, decreasing efficiency.

In our design to reduce upfront costs as well as operating costs, we opted to use traditional greenhouse lighting technologies. Our combination of more traditional MH (metal halide, high output) lights with energy efficient fluorescent lights allows us to achieve an acceptable balance between cost and crop security.

This strategy uses a “diversified portfolio” of MH lights on larger areas (high cost per square foot, but can greatly increase yields) and fluorescent lights on smaller areas (lower layers). Growing Power uses a similar strategy; using fluorescent lighting to grow a second layer of leafy-greens (fluorescents’ high efficiency allows sustainable production with lower profit-margin crops).

Energy Consumption

The bioshelter has three main sources of energy consumption. These are the supplementary lighting for winter growing, the heating and ventilation system, and the coolbot freezer for storing harvested plants. The coolbot will be discussed in more detail in a later section. Rough estimates for yearly energy consumption were made for these systems. These estimates use the current average wattage for each of the chosen appliances, and a near worst case estimate of the amount of time they will

Bioshelter Energy Use

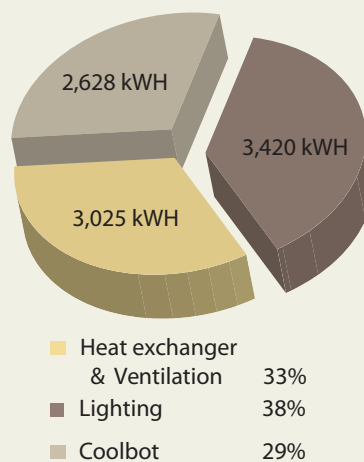


Figure 11. Bioshelter Yearly Energy Use

each be running throughout the year.

The majority of the energy consumption comes from the supplementary lighting, which is why it is important to run the lights only when absolutely necessary. The coolbot and ground source heater are both highly energy efficient systems which allows them to expend less energy yearly than the lighting. This is the energy required by the bioshelter for its operation, without taking into account any energy that can be generated by the bioshelter using alternative energy practices.

Solar Panels

This bioshelter is a large structure and thus has significant energy needs. Reducing energy consumption was a critical part of the design process, but not all could be eliminated. The ground source heating system, lights, and coolbot require energy, as shown by the usage chart above. For this purpose a 30kW solar panel system has been included in the bioshelter design. This will significantly reduce the long term costs of running the bioshelter in exchange

for a higher initial investment.

This solar system consists of 15 solar panels running horizontally along the top of the south facing roof. The reason for this location is that the south facing side receives more sunlight in the northern hemisphere, especially during the winter months and at higher latitudes.⁷⁰ The solar panels are high enough that they do not obstruct sunlight from the plants in the bioshelter to any significant degree. The efficiency of the solar panel was prioritized over initial cost in order to improve the long term payoff. The Sanyo HIT Power 215N Solar Panel was used as the basis for our solar panel system due to its high efficiency. These panels are 31.4” x 62.2” and generate 15.85 watts per square foot.⁷¹ A solar panel system calculator associated with the provider estimated that this system would provide 59% of the energy needed and reduce the energy bill by 61%.⁷² This calculation assumes worst case scenario energy consumption, so the system could obtain even greater results.



Figure 12. Solar panels
Source: <http://www.msbs.net/Portals/0/images/MonocrystallineSolarPanel.jpg>

70 Barbara Bellows. “Solar Greenhouses.” NCAT, accessed February 15, 2012, <https://attra.ncat.org/attra-pub/viewhtml.php?id=59>.

71 Sanyo Energy Corp. (2009). HIT power 215N photovoltaic module

72 Sunwize Technologies Inc. “The Sunwize Solar Calculator.” Sunwize Technologies Inc., 2012.

Solar energy was chosen as the primary energy source because it is free and renewable once the panels are installed. The solar system utilizes “net metering,” which is when excess generated energy is sent to the energy grid and turns the meter back. The national grid will give energy credits to take energy later, so long as the total amount does not exceed 1% of the power plant’s maximum historical output.⁷³ Thus the system utilizes the energy grid rather than a battery pack for energy storage.

Wind turbines were considered as an alternative to solar energy for powering the bioshelter. Wind turbines are not efficient enough to be used in urban areas where wind conditions are not consistent, and require extensive and expensive on site analysis to properly utilize.⁷⁴ Many sites would be unsuited for wind turbines, and

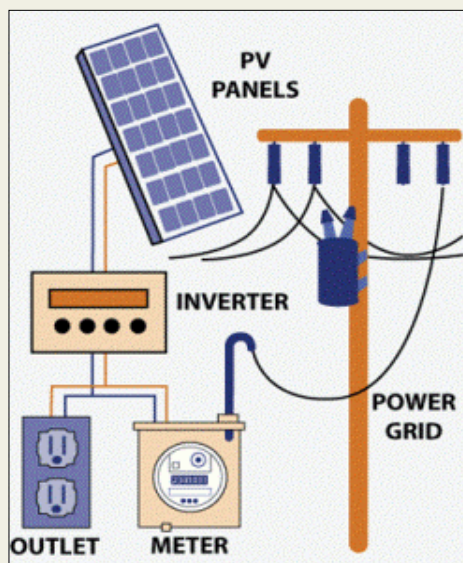


Figure 13. The basics of net metering. Source: <http://www.greencollareconomy.com/images/GreenCollarImages/BlogImages/net-metering.gif>

thus solar panels were chosen instead because solar access is already an essential factor when selecting a site.

4.4 Agricultural Production

Growing Beds

The most central component of the bioshelter is the growing beds. All of the beds are permanent structures and are arranged on two levels. The overall layout of the beds and their structure can be seen in Figure 15 above. On the ground level, there are four deep concrete beds. All four beds are 40 inches high, and are constructed from 16” x 8” x 6” cinderblocks. This is a standard building material for raised beds. The blocks are relatively cheap, easy to use, and low maintenance.

To create the beds, the blocks are stacked with the edge of one block ending at the center of the blocks above and below it. This alternating pattern gives the bed greater strength. It is also recommended to further reinforce the beds with concrete mix and rebar. At each corner of the beds, four foot long by half inch diameter rebar is driven through the holes in the blocks and into the ground.⁷⁵ The corners are then filled with concrete mix as seen in Figure 16. To add additional strength, every other cavity in the block wall can be filled with concrete as well.⁷⁶

By following these methods, both sizes of concrete beds can easily con-



Figure 14. Reinforcing the Cinderblocks with Concrete Mix. Source: <http://wildgingerfarm.com/ConcreteBlockRaisedBed.htm>

structed. All of the concrete beds are about 34’ long, but they have different widths. The two beds towards the front of the structure are only two feet wide, and the other two beds are four feet wide. The second row of growing beds is wider than the first because they can be accessed by walkways on either side. The front bed can only be accessed on one side, therefore is smaller so that the plants can still be easily reached.

An additional feature of the concrete beds is a forced air heating system. Perforated pipes allow heat to be distributed directly into each

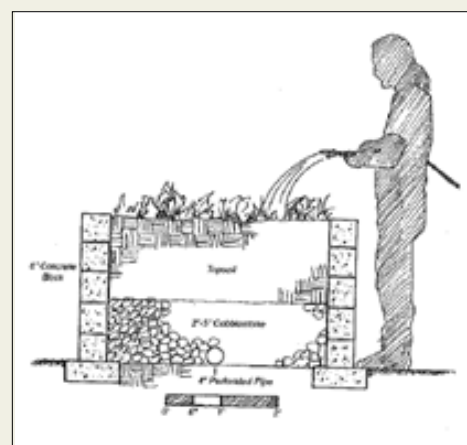


Figure 15. Three Sisters Farm Growing Bed with Layered Sections. Source: <http://www.bioshelters.com>

73 National Grid. (2012). Net metering. Accessed April 12, 2012,

http://www.nationalgridus.com/masselectric/home/energyeff/4_net-mtr.asp

74 Barbara Bellows. “Solar Greenhouses.” NCAT, accessed February 15, 2012, <https://attra.ncat.org/attra-pub/viewhtml.php?id=59>.

75 Wild Ginger Farm. “Build a Concrete Block Raised Bed.” Accessed March 15, 2012,

<http://www.wildgingerfarm.com/ConcreteBlockRaisedBed.htm>.

76 Jennifer Stimpson. “How to Build a Picnic Table.” Accessed March 3, 2012,

<http://www.thisoldhouse.com/toh/how-to/intro/0,,20291200,00.html>.

of the raised beds from beneath the soil. This type of system is already used at the Three Sisters Farm, and a schematic is provided in Figure 17. The extra depth of these beds as well as the internal heating system makes them ideal for deeper rooting crops as well as anything that requires slightly higher temperatures. These first floor beds provide slightly less than 400 square feet of growing space.

On the second level, there are two rows of raised wooden beds. The wooden construction is lighter than the concrete beds on the ground level, but is still a durable solution. The beds are arranged at several heights in order to maximize sunlight exposure. They are supported by 4' x 4' lumber legs spaced six feet on center. The bottoms of the beds are half inch thick sheets of plywood, and the sides are made from 2' x 8' lumber. The sides are fastened to the plywood using standard deck screws. To maximize the lifetime of the wooden beds, they may be lined with plastic sheeting and drainage holes may be added to the bottoms of the trays. This type of bed is currently used at Growing Power. Even if these precautions are not enough to eliminate all maintenance on the bed structure, the modular design and common building materials make repairs simple and inexpensive.

In order to support these eight inch deep trays, 2' x 4' cross braces are fastened to the 4' x 4' legs using lag screws. For the front row of beds, the cross braces are sufficient to stiffen the beds. For the second row of beds which are four feet wide instead of two, additional support is required. In order to provide this support and stiffen the beds, a two by four is mounted using joist hangers between each set of cross braces. This bracing can be seen in Figure 18.

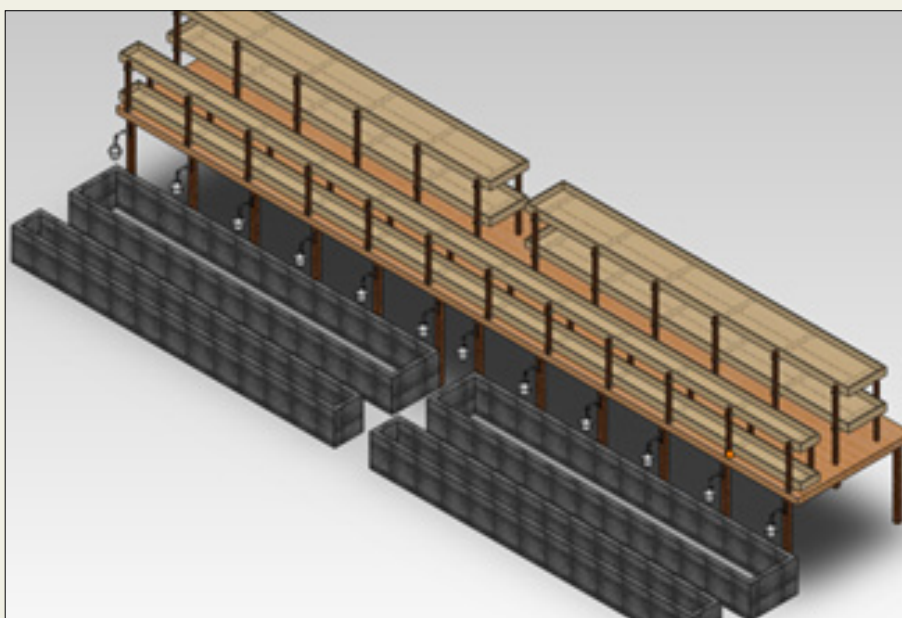


Figure 16. Growing Bed Layout Modeled in Solidworks.

These beds are not as deep as the concrete beds on the ground level, but they are sufficient for most greens and herbs which will be grown in the bioshelter since these plants have shallow roots. These upper beds provide slightly more than 750 square feet of growing space.

Overall, the beds provide approximately 1,150 in total square feet of growing space. This value excludes hanging planters which are placed on the supports of the second floor. Also, the beds are designed

with manufacturability in mind. Standard materials can be used to create the beds on both floors.

All of the materials and tools needed to build the bed structure can be purchased at a typical hardware store such as Lowes or Home Depot. This is important not only to keep initial costs down, but also to ensure ease of maintenance. More details on the costs of building this growing bed setup are found in a subsequent section of this report.

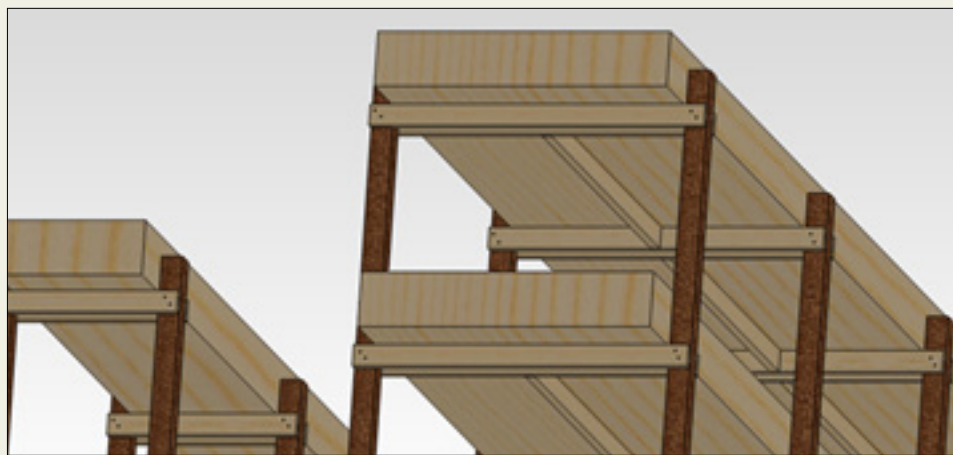


Figure 17. Upper Growing Beds With a Closer Look At the Support Structure.

Hanging Plants

An additional way to provide growing space is through hanging baskets. These baskets are mounted above the plant beds on the first floor. A model of a typical hanging basket and a simple bracket can be seen in Figure 19. These baskets are a good solution to expand growing space because they block much less sunlight than a second level of shelving. Also, the hanging baskets can be used for flowering herbs such as rosemary which attracts useful insects.⁷⁷ Overall, adding baskets is a cheap and easy way to expand growing space and add to the aesthetics of the structure.



Figure 20. Hanging Basket

Drip Feed Irrigation System

An essential component for any greenhouse or bioshelter is a method for watering plants. It would be inef-

ficient for a building as large as this bioshelter to utilize hand watering techniques to tend to the plants. Instead an automated system to water them either by timer or by opening a valve is the ideal solution. In order to reduce the energy consumption of the building a drip feed system was chosen over a sprinkler system.

Drip irrigation utilizes passive water movement in small tubes to water plants. This is achieved through capillary action, the same method plants use to move water up the stems.⁷⁸ The system is composed of a 1/2" tubing mainline from the water hookup, 1/4" branch tubing from the mainline to the plants, 1/4" barbed couplers to attach the branch tubing, 1 gallon per hour drippers, and 6" stakes to support the drippers.⁷⁹ This system is inexpensive and can easily be customized for any growing layout by increasing or decreasing the amount of branch tubing. Water will not flow vertically in the mainline, so only branches will go upward to the second level. The exact

amount of time for each watering session is determined by the rate of the drippers (1 gallon per hour) and the specific needs of the plants.

Since this system does not utilize a pump it is energy free and thus cheaper than a standard sprinkler system. The flexible tubing can easily be affixed to the support structure of the shelving unit in order to reach the second level. The system obtains water from the same hookup as the wash station and thus does not need any additional pumping. This water of course comes from either



Figure 19. Gallon per hour dripper
<http://bit.ly/I2gXmL>



Figure 18. A field set up for drip irrigation.

Source: <http://acarainstitute.files.wordpress.com/2010/06/drip-irrigation-system.jpg>

77 Steve Masley. "Beneficial Garden Insects, the Second Line of Defense Against Garden Pests." Accessed March 19, 2012, <http://www.grow-it-organically.com/beneficial-garden-insects.html#predators>.

78 The Urban Farm Store. 2001. Introduction to drip irrigation. Accessed February 10, 2012, <http://www.urbanfarmerstore.com/drip/drip.html>

79 "Drip Irrigation." 2004. Drip irrigation for the greenhouse. Accessed February 10, 2012, http://www.dripirrigation.ca/HowTo_GrnHouse.asp

a city hookup or an on-site well, depending on what is available.

Compost and Vermiculture

Our initial goal aimed to accommodate a “future without oil,” utilizing alternative heat production methods, but also included creating our own quality compost. To accomplish this we recommend one area designated for vermicompost production, and the other for “standard” compost production. Vermicompost techniques, which rely on the chemical and biological interactions of earthworms, mesophilic bacteria, and fungi, generate far more nutritive soil compared to conventional methods characterized by thermophilic bacteria.⁸⁰ The vermicompost bins serve as the main supply of soil production for the bioshelter, an area to which Darrel Frey contributes his key to success.⁸¹

With the support of highly insulated walls and glazing, the heat generated by thermophilic bacteria, in combination with a ground-source heat pump, allows the bioshelter to remain independent of gas, oil, or electric heat (electricity via solar panels is used to run the pump). The “conventional” compost bins function as a heat-generation platform in colder months, in addition to producing composted soil which can be

used in secondary areas (outside orchard or gardens) or sold to the local community. By using our own compost, above ground, we avoid the risk of soil contamination commonly found in urban environments.⁸²

According to figures provided by Darrel Frey,⁸³ along with calculations used for a ground-source heat-pump, the minimum amount of compost needed to maintain 55°F in January (with an average temperature of 24°F, typically the coldest month in New England⁸⁴) is approximately 90 cubic ft. We recommend a slightly larger footprint to account for any imperfections, to which organic matter can be added as needed to increase temperature. The space required to supplement soil consumption from crop growth is much less (20 cubic ft.), however the excess soil can be marketed to the public as “bioshelter quality compost.” We also recommend converting the traditional compost bins to vermicompost during warmer months to avoid excess heat in the bioshelter.

Optimum Plant Selection

With the right information it is possible to grow crops which meet specific demands in the area, as some small plot intensive (SPIN) farmers⁸⁵ recommend, in order to maximize earnings. However, sales to high-end

restaurants remain a stable and lucrative choice, especially as more locations are “skirting the increase in fuel and commodities prices by buying locally grown food.”⁸⁶ Leafy greens and herbs are among the highest profit margins in this market, but crops that are in demand can yield higher margins. We suggest growing a mixture of 80% leafy greens (salad greens, arugula, spinach, kale, chard, mache, Asian greens), and 20% herbs (cilantro, fennel, rosemary, dill, parsley, thyme), with an exception to some vegetables that may be in demand (tomatoes, radish, beets, scallions, carrots). This allows room for large scale production of greens while maintaining some diversity with high-margin herbs.

A varied selection of plants (we recommend three different crops for each growing season) supports biodiversity within the bioshelter, decreasing susceptibility to diseases and pests.⁸⁷ Plants can be germinated in a warm, dark area such as a short, light-proof container above the compost bins (heat from thermophilic bacteria in compost will help speed germination). Some greens may be clipped periodically and sold in “salad mix” like containers instead of directly harvesting the whole plant, a method many growers

80 Rajiv Sinha. “The Wonders of Earthworms & its Vermicompost in Farm Production.” *Agricultural Sciences* 1, no. 2 (-08-31, 2010): 76.

81 Darrell Frey. *Bioshelter Market Garden: A Permaculture Farm*. Gabriola Island, BC: New Society Publishers, 2011.

82 R. M. Atiyeh. “Effects of Vermicomposts and Composts on Plant Growth in Horticultural Container Media and Soil.” *Pedobiologia* 44, no. 5 (2000): 579-590.

83 “One cubic yard of compost generates an average of 1 Million BTU’s per month.” Darrel Frey. *Bioshelter Market Garden*. 2011.

84 NOAA. “Daily Temperature and Precipitation Records at Worcester, MA,” accessed March 19, 2012, <http://www.erh.noaa.gov/box/climate/orhrecords.html>.

85 SPIN Farming LLC. “SPIN Farming,” accessed March 22, 2012, <http://www.spinfarming.com/>

86 Kristen Morales. “Restaurants Look to Combat Higher Food Prices by Buying Local.” *Athens-Herald*, accessed March 28, 2012, http://onlineathens.com/stories/032711/bus_805979179.shtml.

87 Daniel Hillel and Cynthia Rosenzweig. “The Role of Biodiversity in Agronomy.” In *Advances in Agronomy*. Vol. Volume 88, 1-34: Academic Press. doi:10.1016/S0065-2113(05)88001-0.

Table 4. Crop Selection

Month	80% Leafy Greens	20% Herbs
January	Spinach, Arugula	Parsley
February	Spinach, Arugula	Fennel, Rosemary
March	Spinach, Kale	Parsley
April	Spinach, Arugula	Thyme, Dill
May	Spinach, Arugula	Fennel, Parsley
June	Tomatoes	Dill
July	Tomatoes	Parsley
August	Tomatoes	Fennel, Dill
September	Spinach, Kale	Parsley
October	Spinach	Dill
November	Spinach	Parsley
December	Spinach	Parsley

Table 3. Planting and Harvesting Schedule

Plant Name	Seed or Transplant	Harvest	Special Notes
Spinach	Every week	After 21-40 days	N/A in Jun., Jul., Aug.
Arugula	Every two weeks	After 28 days	Minimal spacing between plants
Kale	Early Spring & Fall	Every 28 days	Keeps growing after harvest
Dill	Every 50 days	Every 40-50 days	Can be harvested several times
Fennel	Every 80 days	After 80 days	N/A in Feb., Mar., Apr.
Parsley	Twice a year	After 75 days	Can be harvested several times
Rosemary	Once	After re-growth	Perennial, planted once
Thyme	Once	After 90-95 days	Perennial, planted once
Tomatoes	Once	After 60-80 days	Good alternative in the Summer

(including Growing Power) adapt to increase efficiency and revenue. This is more efficient because it takes much longer for a plant to grow from seed than to grow after being clipped. Finding local prices of vegetables and herbs will aid in choosing the most profitable crops; an example crop schedule is shown in Table 4. This table

shows which vegetables and herbs are in production for each month.

Each plant has a different seed, transplant, and harvest schedule. This information can be found in the Table 4, although it is left to the discretion of the grower. Most plants will be germinated in a separate area and then transplanted to the growing platform. When

the plant has reached optimum size, it may be clipped and sold as “baby greens” or in a salad mix, or nurtured until a total harvest.

This table is based upon information provided by Andy Pressman, an experienced grower in New England, who uses similar planting regimens based on weather and time of year.

4.5 Harvest and Storage of Crops

Carts

Push carts can be used to transport materials within the bioshelter. They should be narrow enough to fit through the lanes in between growing beds. They should also be able to be lifted to the second level using a service elevator. Heavy duty carts similar to those used at home improvement stores would be ideal for this because they can handle heavy loads.

Service Elevator

In order to most effectively get harvested crops from the second floor to the first, a service elevator is used. The elevator will be capable of carrying a fully loaded cart full of either tools or harvested crops. The elevator allows for the carts to be directly brought to the first floor instead of having to unload them and carry crops down the stairs. It is more space efficient than a ramp, can be manual, rather than electric in order to save energy.

Harvesting and Wash Station

Another component that is essential for operation of the bioshelter is a vegetable wash station and harvesting area to prepare products for sale. This step in the production process includes harvesting, washing, drying, and packing. The chosen setup for these tasks is a design developed by the Leopold Center for Sustainable Agriculture. This organization has developed a vegetable wash station and has provided detailed drawings of their design online. It has been built and tested, and therefore is a proven design. An image of this design can be seen in Figure 22. This design contains one hand wash sink, which is important to avoid contaminating the crops. It also contains one shallow vegetable wash sink, one wide tub sink made from a 55-gallon food-grade plastic drum, one deep vegetable wash sink, and two racks for drip drying the vegetables.

This design was chosen for several reasons. It is an existing working design, and while it is possible to develop a new design, it is best to include something that has already been tested in the field. This design was also chosen due to its ease of construction. De-

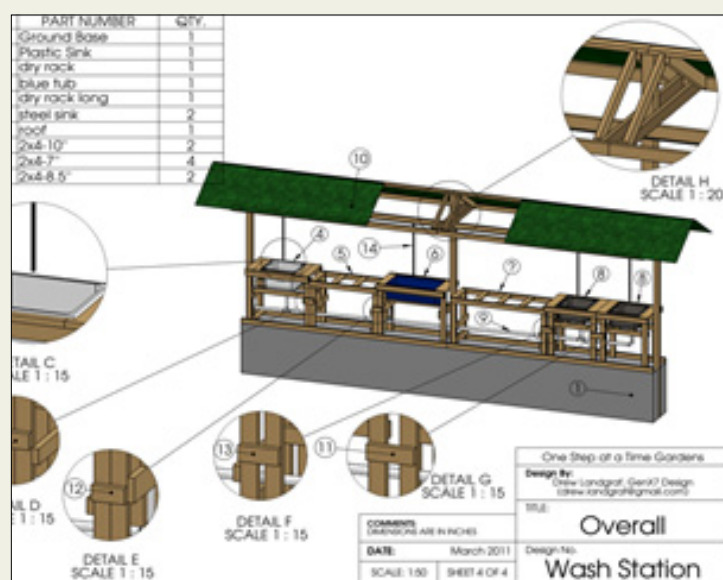


Figure 21. Vegetable wash station

Source: http://www.leopold.iastate.edu/cool_tools/wash_stations1

tailed plans are available online to anyone who wishes to use them. The materials for the build are reasonably priced, and can be purchased from typical hardware stores.⁸⁸ The only modification which is required for this design to be used in the bioshelter is the removal of the roof. Since the wash station will be located inside the bioshelter, there is no need to purchase the extra sheeting for a protective roof. Only a small overhead structure will be needed to hang the wash hoses from above. The water will be provided through the city for various reasons discussed in a subsequent section. Once used, the water will either be recycled to irrigate land outside the structure as described later, or be fed back into the city sewer. Overall, this design is a simple yet efficient method to prepare vegetables for shipping.

Cold Storage

Cold storage is often a necessity for small-scale farmers who need to preserve their harvests up until market day. There are several options for cold storage available to the small scale farmer, including prefabricated refrigeration units and custom built units. Prefabricated units are often less expensive than having a custom refrigeration system installed, but recently a product has become available that eliminates the need for custom-built refrigeration systems for small cold storage rooms.⁸⁹

The Cool Bot™ is a product that was first released in

88 Leopold Center for Sustainable Agriculture. "Two Vegetable Wash Station Designs." Accessed March 1, 2012, http://www.leopold.iastate.edu/cool_tools/wash_stations1.

89 Store It Cold LLC. "CoolBot." accessed March 11, 2012, <http://storeitcold.com/>



Figure 22. CoolBot Unit
Source: "Store it Cold with CoolBot," <http://storeitcold.com/index.php>

2006 that connects to a standard air conditioner so that it can be used as a refrigeration unit. It works like an electric thermostat that tricks an AC unit into cooling below 65°F with a small heating element that attaches to the original thermostat on the air conditioner. A second sensor monitors the ac unit to make sure it doesn't get too cold and ice up. When this point is reached, the air conditioning unit is allowed to idle.⁹⁰

The cost of the Cool Bot is \$300 and the company claims that is about 30% more efficient than the typical custom refrigeration unit. The total cost of building a cold storage room with the Cool Bot is less than one third the cost of a prefabricated unit by any estimate, which makes this the lowest cost and most efficient option by far.⁹¹

4.6 Community Outreach

Meeting Space

A meeting area is another vital component for a fully integrated bioshelter design. A space set aside for social interaction provides several benefits. One benefit is to increase worker satisfaction. The bioshelter is likely to employ or serve several people simultaneously. These workers need a space to take breaks and eat lunch whether they are volunteers or on a pay roll. Providing a comfortable space within the work environment for these activities is important. There have been many studies on the effects of employee satisfaction. One such study concluded that employees with high levels of psychological well-being and job satisfaction perform better and are less likely to leave their job.⁹² Overall, a comfortable space open to the rest of the structure will be a welcome addition for employees. In turn, it is also beneficial to the business.

Another benefit of a meeting



Figure 23. Picnic Tables for Use in Bioshelter

space is for educational purposes. This bioshelter is not only a commercial enterprise, but it is also for spreading knowledge of urban agriculture. It can educate the community about growing techniques and the benefits of producing local and nutritious food. Records can be maintained in this area to help run the bioshelter. There will be seating for approximately 15 people which will allow small groups to observe the operations of the bioshelter. Scheduled tours can be offered, and the area can be used for information sessions on urban agriculture.

To best provide these benefits, a few simple components are brought together to create the space. The primary components are picnic tables. This type of seating is ideal for such a meeting space because it is cheap, easy to build, easy to maintain, and space efficient. A simple design is provided from This Old House's website.⁹³ The design was created in SolidWorks, shown in Figure 25. Another component that is included in the meeting space is a chalkboard. A chalkboard mounted on a movable stand like that in Figure 24 can be used for educational purposes, or to keep track of ongoing business in the bioshelter. Since it is on wheels, it can be easily moved out of the way if necessary.

These components will be arranged in an open space in the bioshelter. The meeting area will not be closed off like a conference room, but placed in the middle of the structure open on all sides. This

90 Store It Cold LLC. "CoolBot." accessed March 11, 2012, <http://storeitcold.com/>

91 Ibid.

92 Kansas State University. "Happy Employees are Critical for an Organization's Success, Study shows." accessed March 18, 2012, <http://www.sciencedaily.com/releases/2009/02/090203142512.htm>.

93 Jennifer Stimpson. "How to Build a Picnic Table." accessed March 3, 2012, <http://www.thisoldhouse.com/toh/how-to/intro/0,,20291200,00.html>.



Figure 24. A Moveable Chalkboard
Source: http://ep.yimg.com/ca/I/yhst-35500505434080_2112_67660424

not only increases the educational value of the space since the full operation will be visible from the seating, but it will also decrease the required square footage. It is recommended to have 450 square feet of space for 14 people in conference rooms, but this number can be reduced since there will not be walls to constrict the space.⁹⁴ Overall, the meeting space is a multipurpose area integrated with the rest of the bioshelter layout.

Chickens

Chickens are an important component that sets a bioshelter apart from more typical greenhouse designs. Chickens are useful because they generate additional heat for the winter months, generate additional CO₂ for the plants, eat garden and greenhouse wastes, produce manure for composting, and produce eggs for human consumption.⁹⁵

Chickens also add an educational component to the bioshelter. For the bioshelter, there will only be space for about eight birds. With this low number, the eggs will not provide a major revenue boost, nor will the



Figure 25. Nest Boxes for the Hens
Source: <http://www.backyardchickens.com/a/pictures-of-chicken-nesting-boxes-how-to-build-a-nest-box>

chickens provide significant heat or CO₂. Despite this, the chickens are still valuable to demonstrate the concept of a closed loop system. The manure needs to be composted since it is very high in nitrogen. There is very little waste by introducing chickens to the system.

*chickens can
provide heat, CO₂,
manure, and eggs*

In order to provide living space for chickens there are a few requirements. Indoors, chickens need about 4 square feet of space per bird. This is in addition to about eight square feet of space per bird of outside run space.⁹⁶ Chickens also need a structure to contain them inside the bioshelter. This can be a simply constructed chicken coop with nest boxes. An example of simple nest boxes within a coop can be seen in Figure 26. They also need feeding stations, water stations, and bedding. Pine shavings are a

common solution for the bedding. The feeding and watering stations are commercially available from a number of stores including Sears.

Overall, chickens were chosen for their educational value as well as the resources they provide. They require little space inside the structure and will be located near a wall so they have access to the outdoors. A small insulated hatch can be added so minimize heat loss in the winter. The only other consideration when it comes to chickens is the legal restrictions. Currently they are not allowed in Worcester, but there is a movement to change this law.

Composting Toilets

Composting toilets provide a number of benefits such as a steep reduction in water use (typically 20-50%),⁹⁷ lower maintenance costs (absent sewer rates, cheap and simple to fix), a usable end product (fertile compost, probably more suited for non-edible plants), and no effect on city sewers or marine pollution. This addition resonates with the overall theme of the bioshelter, which is based on re-using and recycling energy.

We chose to implement a toilet system which recedes slightly underground, where a south-facing window helps retain solar warmth to avoid freezing. This unit will attach to the side of the bioshelter to allow for easy maintenance and separation from work areas. An optional small exhaust fan helps with aeration and the removal of odors.

94 Guidance Corporate Realty Advisors. "Calculate Your Office Square Footage Requirements." accessed March 17, 2012, http://www.guidancebrokers.com/Tool1/office_space_square_footage_calculator.php.

95 Jeff Johnston. "The Multi-Function Chicken." Natural Life Magazine no. may/June (1998).

96 Terry Golson. "Chicken Keeping." accessed March 17, 2012, <http://www.chickenkeeping.com/>

97 "Composting Toilet World." Accessed January 26, 2011, <http://compostingtoilet.org/>

Although it is possible to safely compost human excreta for use with edible plants,⁹⁸ some studies show evidence of possible risk,⁹⁹ therefore from a safety and marketing perspective, it may be favorable to only use compost from toilets on non-edible plants (flowers, shrubs, etc.).

Water Drainage

Runoff from rain and snow can be collected in rain barrels and recycled for use in agriculture, however some studies show risk from contamination by chemicals, bacteria, viruses, and/or pathogens.¹⁰⁰ Thus, a run-off water recycling system would require sanitization and purification, and would introduce unnecessary risks to consumers.

We recommend one of two simpler, inexpensive methods; convey outside water runoff, as well as excess water used indoors for production and cleaning or washing, to an outdoor constructed wetland, rain garden or orchard. This is a common method used in permaculture design, where a constructed “wetland” area collects greywater (waste water) and naturally purifies the water (assuming no toxins are introduced). The amount of runoff with an 80’ x 30’ footprint in Massachusetts is approximately 70,000 gallons per year.¹⁰¹ To give some perspective, a foot-deep wetland of the same footprint holds around 18,000 gallons of water,¹⁰² although in the winter its capac-

ity to retain runoff is reduced.

It may be counter-productive to irrigate an orchard and a wetland at the same time, as wetlands generally transpire large amounts of water.¹⁰³ Both choices require some outdoor land but are suitable methods to recycle excess water; an orchard would bring in revenue from selling non-edible, outdoor plants, trees, and shrubs, whereas a wetland is not typically profitable, but works better as a natural purifier and would support a diverse habitat of wildlife. Wetlands are used as a common lesson in environmental biology and ecology, thus it could also serve as an educational component of the bioshelter

On-location Farm Stand

A farm stand on site at the bioshelter offers the chance to sell produce or other plants directly to the consumer, and allows customers a year-round location (most markets are only open during the summer) to develop social connections and support community engagement. Size permitting, the bioshelter could host a farmers’ market, acting as a hub and strengthening the social fabric of the community, while also generating some profit from seller fees. The Massachusetts Federation of Farmers Markets, or similar state organizations elsewhere, can help determine if the location has the customer base necessary to survive, and to make sure thriving,

existing markets are not too close as to reduce each other’s revenue. In one instance, sales at one market dropped by 30% from another opening less than two miles away.¹⁰⁴

4.7 Economics

Costs

The following table lists the estimated costs of the major components of the bioshelter. These estimates were made using the current prices of materials found locally to Worcester. In the case of the solar panels and ground source heat pump the prices were rough quotes from local installation companies and include the cost of the entire system and installation based solely on the size of the system being installed. Aside from these two components, labor costs have been not been included. The reason for this is that labor prices vary greatly by region and company, so they are difficult to estimate. Additionally, some or all of the costs could be mitigated using volunteer labor. Some of the components have more detailed cost breakdowns in the appendix.

In order to pay for this expensive structure, loans and grants can be utilized. The Massachusetts department of agriculture offers up to \$30,000 in grant money for renewable energy and energy efficient projects.¹⁰⁵ The state also has a program that matches up to \$10,000 of startup costs for new commercial farming

98 Caroline Schonning and Thor Stenstrom. “Guidelines for Safe use of Urine and Feces in Ecological Sanitation Systems,” 2004.

99 Thomas Redlinger, Jay Graham, Veronica Corella-Barud, and Raquel Avitia. “Survival of Fecal Coliforms in Dry-Composting Toilets.” *Applied and Environmental Microbiology* 67, September, 2001.

100 S. Struck. “Rainwater Harvesting for Non-Potable use and Evidence of Risk Posed to Human Health.”

101 E. S. Rubin and C. I. Davidson. *Introduction to Engineering and the Environment* McGraw-Hill Boston, MA, 2001.

102 B. Miller. *Wetlands and Water Quality*. Purdue University: Department of Forestry and Natural Resources, 1990.

103 “Wetland Information.” accessed January 23, 2012, <http://greywateraction.org/content/wetland-information>.

104 Katie Zezima. “As Farmer’s Markets Go Mainstream, some Fear a Glut.” *The New York Times*, 2011.

105 Commonwealth of Massachusetts. 2012. Massachusetts agricultural energy grant program (ag-energy).

Accessed January 28, 2012. <http://www.mass.gov/agr/programs/aegp/index.htm>

businesses.¹⁰⁶ There are many other programs and grants available as well, both on the state and federal level, as well as from private organizations. A short list of URLs for sites with information about such loans can be found in appendix F.

Revenue

Predicting revenue for a bioshelter is difficult without information on likely prices in surrounding markets. To provide an estimate for our sample crop schedule in table (table number), we evaluated commodity prices in Boston, Massachusetts, provided by the USDA.¹⁰⁷ The USDA Fruit & Vegetable report offers evidence of current or past prices according to commodity and region. We expect sales during the first year to range from \$37,500 to \$57,000. This is based on 1,100 square feet of growing space, average retail prices from the USDA report, and target crop yields from NCAT. According to our sponsor, most farmers aim to produce at least \$2.00 per square foot, each harvest. This number usually accounts for all operating costs, and to accommodate our high installation and operating costs, our design and sample crop schedule will target \$2 to \$6 per square foot. This higher target is achievable by focusing on in-demand crops and high value greens/herbs, such as in the next table, in addition to the ¼ season (winter) of added harvest. The USDA does not offer prices on Thyme or Fennel, so an average of other herbs was used.

As we stated earlier, marketing towards high-end restaurants is a

Table 5. Cost of Components

Component	Estimated Cost	Notes
External Structure	\$24,000	See table in Appendix C
Solar Panels	\$11,400	Includes Installation and Rebates
Solar Heat Storage	\$0	Recycled Containers and Rocks
Ground Source Heat Pump	\$15,000	Includes Installation and Rebates
Supplemental Lighting	\$3,500	
Growing Beds	\$4,000	See table in Appendix C
Drip Feed Irrigation	\$100	
Compost/Vermiculture	\$400	
Carts	\$250	
Service Elevator	\$500	
Harvesting and Wash Station	\$1,000	
Cold Storage	\$1,200	See table in Appendix C
Meeting Space	\$2,000	
Chicken Coop	\$500	
Composting Toilet	\$300	
Farm Stand	\$250	
Total	\$64,400	

Table 6. Estimated Yearly Revenue by Crop

Plant Category	Plant Name	Targeted Yearly Revenue*
Greens	Spinach	\$21,000 – \$30,000
	Arugula	\$3,500 – \$7,000
	Kale	\$2,000 – \$3,500
Herbs	Parsley	\$5,000 – \$7,000
	Rosemary	\$1,000 – \$2,000
	Dill	\$2,000 – \$4,000
Other	Tomatoes	\$3,000 – \$3,500
Total		\$37,500 – \$57,000

*Estimate based on USDA retail prices and information provided by ATTRA

106 Commonwealth of Massachusetts. 2012. Matching enterprise grants for agriculture program. Accessed January 28, 2012. <http://www.mass.gov/agr/programs/mega/index.htm>

107 USDA. "Agricultural Marketing Service. Accessed April 25, 2012. <http://www.marketnews.usda.gov/portal/fv>

lucrative alternative to retail or terminal marketing. Mainstream restaurants are willing to pay more for fresh, high quality greens and herbs; growers can expect an increase of at least 10% over wholesale prices,¹⁰⁸ which would put our estimate at \$41,000 – \$62,000 per year.

5.0 CONCLUSIONS

City officials, public health advocates, community groups, urban farmers and other interested in local, healthy, nutritious foods are increasingly looking for new methods of integrating food production into the fabric of city life. As urban agriculture expands, innovations such as bioshelters can create more opportunities for year round local production and urban development. A well planned and organized system that integrates technology, efficient planning, and social policy changes will allow urban agriculture to grow and flourish. With the increase in farmers markets, and interest in local foods and reducing the carbon footprint of agriculture, the time is ripe for bioshelters. Bioshelters are not just a pure commercial enterprise, but can enrich the community as a whole, and serve to move urban agriculture forward into a new era.

The Regulatory Environment

The first step to pursue a bioshelter is to ensure it is legal to build the structure at the chosen location. We have found that there are certain legal barriers which must be overcome depending on the zoning laws for

Return on Investment

An essential piece of information to know when making any sizable purchase is the return on investment. There are many incentives, rebates, credits, or grants, in addition to a wide range of installation, operating,

the chosen site. To receive approval for a large scale agricultural building such as a bioshelter, the area of interest would likely have to be zoned for agriculture. In some cases however, a variance can be passed by the board that allows for a structure to be built outside of its proper zone. Aside from the zoning regulations, the structural design of the building must be reviewed and passed by the local building inspector. A building permit is usually issued after approval of the building plans, which allows construction to begin. During construction there are typically three building inspections that must take place before occupancy of the building is allowed.

To better serve potential urban farmers, cities should make these rules and regulations clear and succinct. More agricultural zones would benefit the spread of urban agriculture as well as a simplified permit system. In addition, urban planners can facilitate urban agriculture and bioshelter development by pushing for a grower friendly community. This entails creating an urban network to provide incentives to growers to make urban agriculture easier and more profitable. One way is for growers and

and maintenance costs, which is unfortunately beyond the scope of this project. However, future research in the financial opportunities and limitations of an urban bioshelter would be universally beneficial.

city officials to work together to organize drop off and pick up routes for compost. Also, providing water access and waste removal to small farming productions could mitigate startup and operating costs of urban agriculture. The final step would be to provide markets for growers to sell their goods to the community.

Construction

There are many options when choosing the size and materials for a bioshelter. The design detailed in this report has a footprint of 30 feet by 80 feet and is south facing. These parameters were determined based on the available space, latitude, and longitude of the selected location. The structure is framed in wood since it is the most economical solution and is a readily available material. The north wall is insulated, and the remaining surfaces of the structure utilize recycled e-glass. Recycled glass is an economical solution which has high insulation values, resistance to weathering, and a high light transmittance. There is a second floor within the structure which is also framed in wood. It can be easily constructed using similar guidelines to that of a raised deck.

¹⁰⁸ “Sustainable Agriculture Research and Education Program,” accessed April 20, 2012. <http://www.sare.org/publications/marketing/market07.htm>

Heating and Energy

A component chosen for heating the structure is a ground source heat pump. It was found that ground source heating is the best method of minimizing the costs of heating the structure. By installing the system of underground pipes during the laying of the foundation, the system can be easily implemented. The pump can then draw air into the bioshelter during the colder months that is at a constant 50°F regardless of the outside air temperature. This means it always takes the pump the same amount of energy to raise the air temperature to 50°F, regardless of the starting temperature. This is essentially a variable BTU heater. The bioshelter needs a minimum of 55°F, so an additional 1.5 MBTU are needed per month. This additional heat is provided by the composting bins. To provide supplemental lighting to the structure a combination of metal halide and energy efficient fluorescents were determined to be the most balanced solution.

The majority of the energy consumption comes from the supplementary lighting, which is why it is important to run the lights only when absolutely necessary. The coolbot (a system for cooling a walk-in cooler) and ground source heater are both highly energy efficient systems which allows them to expend less energy yearly than the lighting. More details about the coolbot will be explained later.

After researching several alternative energy options, we chose solar panels to provide energy to the structure. The panels which line the peak of the roof are used to create energy which is fed into the power

grid. Power generated from the panels could also be stored in batteries for use in the bioshelter, but this option is costly and inefficient. Connecting the structure to the power grid however ensures it will never be without power. Essentially the solar panels are used to create green energy which is sold to the power company for credits. These credits are used to buy energy back from the power company through the grid. The 15 panels that line the roof of the shelter are enough to generate about 60% of the bioshelter's yearly energy needs.

Growing Space

To produce the crops in the structure, two types of growing beds are utilized. A balance of deep and internally heated concrete block beds are combined with shallow raised wooden tray beds. They are all watered with a drip irrigation system fed by capillary action. Rich compost for the beds will be made in the structure using composting and vermiculture bins. The composting bins were determined to be an important component because they also generate heat for the structure. The recommended crops to be grown in the bioshelter are 80% leafy greens and 20% herbs. This permits some diversity while still allowing high levels of production and profitable margins.

Post-Harvest Needs

Once the crops are grown, they need to be harvested for shipment or sale. To carry out these tasks, carts and a service elevator are utilized. They improve the flow of the structure and allow crops to be brought to the harvest and wash station. Here the crops are washed and drip dried before packaging. They can then be stored in a cold storage

area. The cold storage container is custom built with an air conditioning unit as the cooling source. This system was chosen for its economic value and efficiency. From the storage area, the crops can be sold at an on location farmers market or shipped to other consumers.

Community Outreach

There were also many components determined to be beneficial for the community as well as the profitability and efficiency of the bioshelter. A meeting space within the structure was concluded to be essential for employee satisfaction and for educational tours of the structure. Compostable toilets were determined to be an environmentally friendly option of bathroom facilities. The water used for washing the vegetables can be used for irrigating an outdoor area.

Chickens were determined to be an educational component of the bioshelter in addition to providing heat, eggs, and other benefits to the structure. To sell all of the goods produced in the structure including the crops and chicken eggs, an on location farm stand is the best option. It reduces the effort required to transport the food, brings the community closer to where the food is produced, and also allows a hub for other farmers' markets, possibly producing extra income from seller's fees.

A bioshelter could benefit the community by providing classes and workshops on the grounds of the bioshelter. These classes can increase interest in local urban farming and create community awareness. It may also be possible for classes to be subsidized by local organizations such as a local regional environmental council. Establishments such as

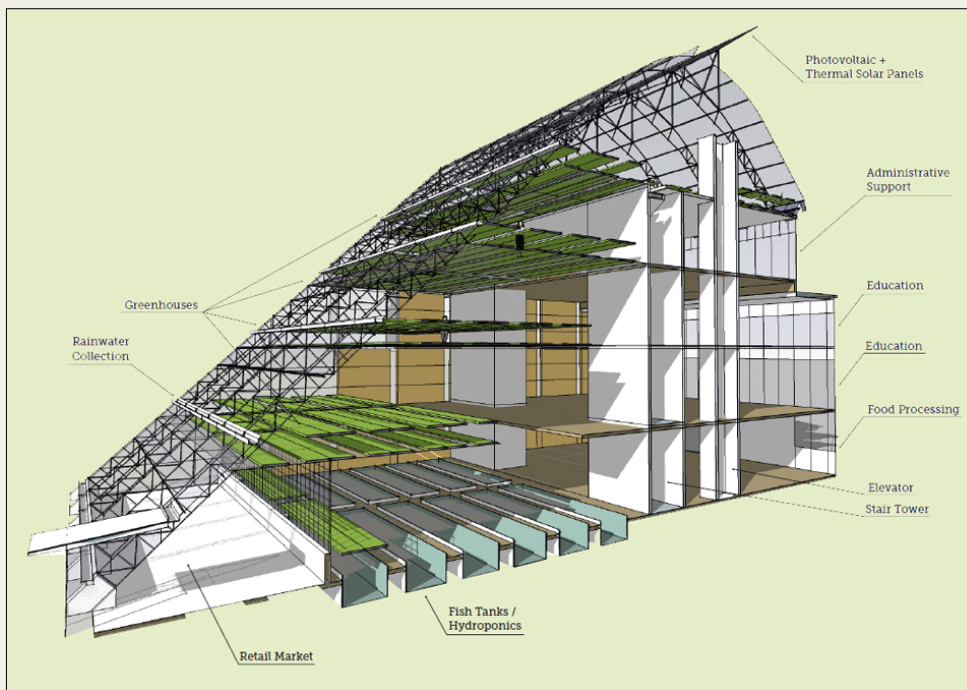


Figure 26. Growing Power Vertical Farm Design
 Source: <http://www.growingpower.org/verticalfarm.html>

GreensGrow Farm in Philadelphia PA, and Growing Power in Milwaukee WI, are excellent examples of successful urban farms with community outreach programs.

Areas for Future Research

Knowing that urban agriculture is often limited to industrial areas due to zoning regulations, it may be beneficial to consider opportunities in integrating urban farming with unused factory buildings and warehouses. Rooftop gardening on flat-roofed factory buildings and warehouses could provide acres of seasonal urban farming with very little modification to the structure; with a rooftop bioshelter the season could be extended year-round. A more involved approach to urban farming in the factory setting would be to modify warehouses and

factories for vertical farming. The result would be similar to a multi-level bioshelter, with a glazed sloped south facing wall and a largely unmodified insulated north facing wall. Retrofitting a building for urban farming would require much less overhead costs and permitting when compared to construction from the ground up. Many organizations, including Growing Power, have already begun to investigate these opportunities.¹⁰⁹

In addition, there is a possibility for future research on evaluating bioshelter performance. As growers or investors create new and innovative designs, the structures can be analyzed by numerous criteria. This information can be used to improve both existing and future designs. Information on evaluating a bioshelter can be found in Appendix D.

¹⁰⁹ “Growing Power Vertical Farm,” accessed on April 1, 2012. <http://www.growingpower.org/verticalfarm.html>

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APPENDICES

Appendix A: Zoning Districts

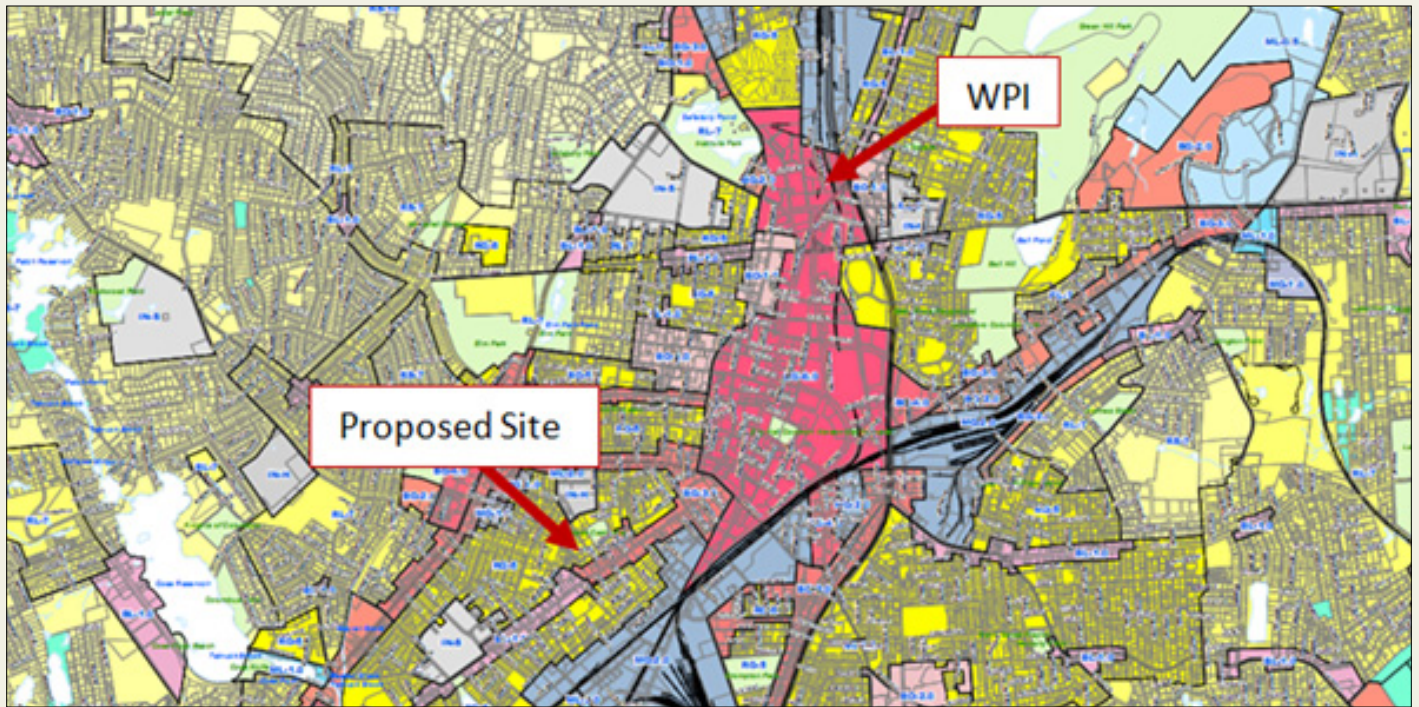


Figure 27. Zoning Map for Worcester, Massachusetts, Location of Proposed Bioshelter Site
 Source: <http://www.worcesterma.gov/uploads/5a/75/5a7513418812edd5f0b5e5cd09bd6474/zoning-map-2607.pdf>

District Legend	
Business	<ul style="list-style-type: none"> A-1 Airport District BG-2.0 General, 2 to 1 FAR BG-3.0 General, 3 to 1 FAR BG-4.0 General, 4 to 1 FAR BG-6.0 General, 6 to 1 FAR BL-1.0 Limited, 1 to 1 FAR BO-1.0 Office, 1 to 1 FAR BO-2.0 Office 2 to 1 FAR
Institutional	<ul style="list-style-type: none"> IN-H Medical IN-S Educational
Manufacturing	<ul style="list-style-type: none"> MG-0.5 General, 0.5 to 1 FAR MG-1.0 General, 1 to 1 FAR MG-2.0 General, 2 to 1 FAR ML-0.5 Limited, 0.5 to 1 FAR ML-1.0 Limited, 1 to 1 FAR ML-2.0 Limited, 2 to 1 FAR
Open Space	<ul style="list-style-type: none"> OS - C Conservation OS - P Parks
Residential	<ul style="list-style-type: none"> RG-5 General, 5000 SF. Min. Lot Size RL-7 Limited, 7000 SF. Min. Lot Size RS-7 Single Family, 7000 SF. Min Lot Size RS-10 Single Family, 10000 SF. Min. Lot Size

Figure 28. Zoning District Legend for Worcester, Massachusetts

PERMITTED USES BY ZONING DISTRICTS – Table 4.1																					
GENERAL USE																					
	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
1. Agriculture, horticulture, viticulture, flora culture on parcels less than five (5) acres	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Figure 29. Permitted Zoning Districts for Worcester, Massachusetts

Appendix B: Heat Gain/Loss Calculations

The amount of heat lost per day (in Millions of BTUs) is used to calculate the heat needed to sustain 55°F in the bioshelter in the coldest months of the year. Some equations are derived from The Bioshelter Market Garden book.¹¹⁵

Average High/Low in Worcester, MA over past 100 years (in January): 31°/16°F

(24°F Average [¹¹⁶])

Daily Solar Gain:

Sq. ft. of glazing = 2,000 ft²

Daily BTU gain per ft² in January = 1,000 [¹¹⁷]

Light transmission = 0.9 (based on transmissivity of glass panels) (1 = invisible)

$$2,000 * 1,000 * 0.9 = \mathbf{1.8 \text{ MBTU/day}}$$

Average Daily Heat Loss (in January):

Glazed wall = 2,000 ft² R-value = 1

Back & Side Walls = 1,500 ft² R-value = 20

Back Roof = 2,200 ft² R-value = 40

Floor = 2,400 ft² R-value = 40

Desired Temperature in Bioshelter 55° F

Average Temperature in January 24° F

Temperature difference 31° F

$Q = U * A * \Delta T = \text{Heat (BTU)} = \text{inverse in R-value} * \text{area} * \text{change in temperature}$

$$Q = 2,000 * 1/1 * 31 + 1500 * 1/20 * 31 + 2200 * 1/40 * 31 + 2400 * 1/40 * (20) [^{118}]$$

$$= 67,000 \text{ BTU/hr}$$

$$67,000 \text{ BTU/hr} * 24 \text{ hours/day} = 1.6 * 10^6 \text{ BTU/day} = \mathbf{1.6 \text{ MBTU/day}}$$

Heat Loss through Ventilation:

Volume of bioshelter = 30 * 80 * 25 * 0.5 = 30,000 ft³

Total Volume Air exchanges per hour = 2

$Q = V * APH * 0.018 * \Delta T = \text{Volume} * \text{Air Exchange per Hour} * \text{Specific Heat of Air} * \text{Difference in Temperature}$

$$Q = 30,000 * 2 * 0.018 * 10 = 33,000 \text{ BTU/hr}$$

(Assuming air from ground source heat pump = 45°F)¹¹⁹

$$* 24 \text{ hours} = \mathbf{0.79 \text{ MBTU/day}}$$

110 Darrell Frey. Bioshelter Market Garden: A Permaculture Farm. (Gabriola Island, BC: New Society Publishers, 2011).

111 <http://www.erh.noaa.gov/box/climate/orhrecords.html>

112 <http://www.susdesign.com/windowheatgain/index.php>

113 Assuming ground temperature is slightly warmer (3-4 feet below surface)

114 "Earth Temperature and Site Geology," Virginia Tech. Accessed on April 4, 2012. <http://www.geo4va.vt.edu/A1/A1.htm>

Heat Gain through Subterranean Heating:

$$\text{Volume of bioshelter} = 30 * 80 * .7925 * 0.5 = 30,000 \text{ ft}^3$$

$$\text{Total Volume Air exchanges per hour} = 2$$

$$Q = V * APH * 0.018 * \Delta T = \text{Volume} * \text{Air Exchange per Hour} * \text{Specific Heat of Air} * \text{Difference in Temperature}$$

$$Q = 30,000 * 2 * 0.018 * 21 = 22,680 \text{ BTU/hr}$$

(Assuming air from outside = 24°F)

$$* 24 \text{ hours} = \mathbf{0.54 \text{ MBTU/day}}$$

Average Daily Heat Gain/Loss in January:

$$\text{Solar Gain} + \text{Sub-Heat Gain} - \text{Heat Loss} - \text{Ventilation Heat Loss} =$$

$$1.8 \text{ MBTU} + 0.54 \text{ MBTU} - 1.6 \text{ MBTU} - 0.79 \text{ MBTU} = \mathbf{-0.05 \text{ MBTU/day}}$$

$$* 30 \text{ days/month} = 1.5 \text{ MBTU/month needed to sustain } 55^\circ\text{F}$$

$$\text{Average heat gain from cubic yard of compost} = 1 \text{ MBTU/month}$$

$$1 \text{ cubic yards} = \mathbf{27 \text{ ft}^3 \text{ of compost needed to sustain } 55^\circ\text{F}}$$

It is recommended to increase this space (we use 90 ft³) to allow for imperfections in insulation, variation in ground temperature, or other forms of energy loss.

Appendix C: Cost Breakdowns

Material	Quantity	Price Per Unit	Total Cost	Purpose	Source
Concrete Block 16"x8"x6"	1150	\$1.27	\$1,460.50	Concrete Beds	Home Depot
Rebar 1/2"x4'	16	\$2.98	\$47.68	Concrete Bed Corner Support	Home Depot
Quikrete 80lb Concrete Mix	100	\$3.55	\$355.00	Concrete Bed Support	Home Depot
Lumber 4"x4"x6'	24	\$5.97	\$143.28	Front Upper Beds Legs	Lowe's
Lumber 4"x4"x8'	24	\$7.27	\$174.48	Rear Upper Beds Legs	Lowe's
Lumber 2"x4"x8'	16	\$3.27	\$52.32	Front Upper Beds Cross Supports	Lowe's
Lumber 2"x4"x10'	24	\$4.27	\$102.48	Rear Upper Beds Cross Supports	Lowe's
Lumber 2"x4"x8'	20	\$3.27	\$65.40	Rear Upper Bed Middle Supports	Lowe's
Joist Hangers	40	\$0.73	\$29.20	Rear Upper Bed Middle Support	Lowe's
Joist Hanger Nails Tub	1	\$14.28	\$14.28	Rear Upper Bed Middle Support	Lowe's
Lumber 1/2"x4'x8'	9	\$27.97	\$251.73	Front Upper Bed Bottoms	Lowe's
Lumber 1/2"x4'x8'	18	\$27.97	\$503.46	Rear Upper Bed Bottoms	Lowe's
Lumber 2"x10"x8'	38	\$8.97	\$340.86	Front Upper Bed Sides	Lowe's
Lumber 2"x10"x8'	38	\$8.97	\$340.86	Rear Upper Bed Sides	Lowe's
3/8"x3" Lag Screw (100ct)	4	\$11.24	\$44.96	Bed Support Fasteners	Home Depot
Deck Screws (700ct)	1	\$49.98	\$49.98	Fasteners	Lowe's
		TOTAL	\$3,976.47		

Figure 30. Growing Beds Cost Breakdown

Material	Cost
Framing Materials	\$100
Insulated Door	\$115
Paneling/Plywood	\$75
Foam Insulation	\$200
Cool Bot	\$300
LG 10,000 BTW AC Unit	\$399
Total	\$1,189

Figure 31. Walk-in Cooler Cost Breakdown

Structure Cost Analysis

Prices used from LOWE's for Worcester area

1. Foundation
 - a. Volume
 - i. $8\text{in} \times 36\text{in} \times 2640\text{in} + 24\text{in} \times 12 \times 2640\text{in} = 1520640 \text{ cu in} = 32.8\text{cu yd} + 1.25 \text{ yd for column footings} = 34.05\text{yd}$
 - b. Forms $3\text{ft}(60+160) = 660 \text{ sq ft}$
 - c. Cost analysis
 - i. Excavation estimated $4\text{hr} \times \$100/\text{hr} = \400
 - ii. Concrete estimated $\$150/\text{cu yd delivered} (\$150 \times 34.05\text{yd}) = \$5,540$
 - iii. Forms $\$1.50 \times 660 \text{ sq ft} = \990
 - iv. Total foundation cost = $\$6930$
2. Dimensional Lumber
 - a. Back wall
 - i. Sills $80\text{ft} \times 3$ using $2\text{X}6\text{X}16 (\$13.12 \times 5) = \65.60 leftover: none
 - ii. Studs using $2\text{X}6\text{X}10, 16 \text{ in o.c.} (\$6.32 \times 60 \text{ studs}) = \379.2 leftover: 60 $2\text{X}6\text{X}3$
 - b. Back Roof
 - i. 60 rafters. Rafters length $22\text{ft} +$
 - ii. Using $2\text{X}6\text{X}12 (\$7.59 \times 120 \text{ pieces}) = \910.80 leftover: none
 - c. Side walls
 - i. Sills $60\text{ft} \times 3$ using $2\text{X}6\text{X}10 (\$6.32 \times 18 \text{ pieces}) = \113.76 leftover: none
 - ii. Studs using $2\text{X}6\text{X}10, 16\text{in o.c.} (\$6.32 \times 45 \text{ studs}) = \284.4 leftover: 45 $2\text{X}6\text{X}3$
 - iii. Roof studs for side walls using $2\text{X}6\text{X}10$
 - a. $(\$6.32 \times 35 \text{ studs}) = \221.20 leftover: various
 - d. Front and side kneewalls
 - i. Sills $80\text{ft} + 44\text{ft} = 124\text{ft}$ $124 \times 3 = 372\text{ft}$ needed
 1. Using $2\text{X}6\text{X}16 (\$10.12 \times 23 \text{ pieces}) = \232.76 leftover: none
 - ii. Studs := use extra $2\text{X}6\text{X}3$
 - e. Front Glazed wall
 - i. $(80\text{ft} \times 12\text{in}) / 40\text{in on center} = 24 \text{ supports needed}$
 1. Supports := double $2\text{x}12\text{X}25\text{ft} +$
 - a. Using $2(2\text{X}12\text{x}12) + 2(2\text{x}12\text{x}16)$ per support
 - b. Cost per support $(\$21.44 \times 2 + 16.10 \times 2) = \75.08
 - c. $(\$75.08 \times 24 \text{ supports}) = \1801.92 leftover: insignificant
 - f. Collar Beams
 - i. $(80\text{ft} \times 12\text{in}) / 40\text{in on center} = 24 \text{ beams } 12\text{ft each}$
 - ii. Using double $2\text{X}12\text{X}12 (\$16.10 \times 2 \times 24 \text{ beams}) = \772.80 leftover: insignificant
 - g. Collar Studs
 - i. $24\text{count} \times 6\text{ft}$ using $2\text{X}12\text{X}12 (\$16.10 \times 24) = \386.40 leftover = none
 - h. Ridge Beam
 - i. Using double $2\text{X}12\text{X}16$ $80\text{ft span} = \$214.40$ leftover: none
 - i. Total cost = 5383.24
3. Other materials
 - a. Engineered lower beam $80\text{ft span} \quad \$428.80$
 - b. R-30 insulation $11\text{pack } 48\text{in} \times 16\text{in} \times 10.25\text{in} = 8448\text{sq in}$
 - i. Wall Area
 1. Back $7\text{ft} \times 80\text{ft}$
 2. Sides approx. $16\text{ft} \times 18\text{ft}$
 3. Back roof approx. $21 \times 80\text{ft}$

- 4. Total 2608 sq ft= 375,552 sqin
 - a. $375552/8448\text{sqin} = 45 = 45 \times 44.97 = 2023.65$
 - c. OSB 7/16in 1200 sq ft with 4X8ft panels \$325.66
 - d. High moisture basement dry-wall 4X8ft panels 1200sqft \$418.00
 - e. 20ft steel support column 6 needed (6columns*\$125)= \$750
 - f. 25 year roofing \$29/sqft
 - i. Roof area $22 \times 80\text{ft} = 1760\text{sqft}$
 - ii. $(18\text{count} \times \$29) = \522
 - g. Wall vapor barrier 1000sqft = \$120
 - h. Roof underlay = \$100
 - i. Foundation insulation
 - i. Sq ft = 1320, $(\$17.79 \times 42\text{count}) = \747.18
 - j. Siding 1200sqft $(\$4.25 \times 1200) = \$5,100$
 - k. Aluminum flashing= \$100
 - l. Steel insulated doors $(2 \times 116) = \$232$
 - m. Fasteners = \$200
 - n. Total= \$11067.29
 - o. Glazing
 - i. 75 3ftx7ft low-e double pane argon windows $\$250 \times 75 = \$18,750$
 - ii. 25 3ftx3ft low-e double pane argon windows $\$125 \times 25 = \$3,125$
 - iii. 10 3ft*3ft low-e venting double pane argon windows $\$175 \times 10 = \1750
 - iv. Glazing total: 23,625
 - 4. Total Estimated cost of materials = \$46,858.69
 - 5. Estimated Building costs
 - a. Contractors often estimate labor costs at \$100 per square foot for a wood framed structure
 - b. $2400\text{sqft} \times \$100 = \240000
 - 6. Total estimated cost = \$47005.50
 - 7. Using recycled materials
 - a. Recycled building materials can typically cost 0-50% of the cost of new materials depending on how they are sourced
 - b. Recycled window glazing can often cost as little as 10% of the cost of new windows
 - c. Some materials such as foundation insulation etc. cannot be recycled
 - d. In this situation all dimensional lumber, glazing, doors and structural columns have the potential to be recycled
- New materials (cannot be recycled)
- Foundation \$6930
 - Engineered lower beam 80ft span \$428.80
 - R-30 insulation 2023.65
 - OSB \$325.66
 - High moisture basement drywall \$418.00
 - 25 year roofing \$522
 - Wall vapor barrier \$120

- Roof underlay \$100
- Foundation insulation \$747.18
- Siding \$5,100
- Aluminum flashing \$100
- Fasteners \$200
- Total \$17765.29

Highest materials cost (assuming all new materials)

Material cost= \$47005.53

Lowest possible materials cost (assuming free glazing, doors, structural columns, and dimensional lumber)

Material cost= \$17765.29

A reasonable estimate for cost of materials
(Assume glazing at 10% cost, dimensional lumber at 50% cost, doors and columns at 25% cost)

Material cost= $\$17765.29 + (23,625 \times .10) + (5383.24 \times .50) + .25 \times (\$750 + \$232)$
Material cost= \$23064.62

Appendix D: Evaluating Bioshelter Performance

In order to improve on the bioshelter designs, growers and researchers should conduct a variety of experiments on plant growth, energy efficiency, post-harvest efficiencies, and community acceptance. There are several factors that have been deemed important for greenhouse and bioshelter performance. The first group includes parameters associated with the condition of the air. Temperature, relative humidity, and CO₂ concentration all affect plant growth. Also, even distribution of air in the structure is essential. Ideally all of the plants will be exposed to equal and controlled conditions.

The performance of the ventilation system plays a key role for this distribution. The bioshelter can be analyzed on a much broader scale by monitoring the costs of consumables. The ultimate measure of performance for the bioshelter will be the crop yield. The table below provides a template to perform a bioshelter evaluation.

Table 7. A Sample Template for Experimentally Analyzing a Bioshelter

Bioshelter Performance Evaluation		
General Information	Design Name	
	Design Type	
	Location	
	Size (Square Footage)	
Growing Environment Conditions	Temperature (°F)	
	Relative Humidity (%)	
	CO ₂ Concentration (ppm)	
	Light Level (lux)	
Ventilation Performance	Static pressure difference (in. H ₂ O)	
	Air exchange capacity (cfm)	
	Air distribution	
Design Consumables and Costs	Energy consumption (dollars)	
	Water consumption (dollars)	
	Other consumables (dollars)	
	Total monthly maintenance costs (dollars)	
Crop Yield	Type of crops grown	
	Crop yield (lb/ft ²)	
	Total value of crops produced (dollars)	

This table is vital for optimizing the bioshelter design and determining its performance. The first section is general information needed to identify the bioshelter being analyzed. The next section of growing environment conditions includes the temperature, relative humidity, CO₂ concentration, and light levels. The ventilation performance section includes parameters which correlate to air movement in the bioshelter. The static pressure difference is an important parameter to note. Usually measured in inches of water, the difference in pressures from outside the structure to inside the structure correlates to how air is drawn into the bioshelter. The air exchange capacities of fans included in the structure also contribute to the airflow. The air distribution in the bioshelter should also be analyzed. Although there isn't a way to quantitatively describe the distribution, qualitative methods can be used. The distribution can be determined using visualization methods such as smoke. This allows the analyst to see where air is escaping and entering the bioshelter. The last two sections of the table describe the some of the end results of the bioshelter. The cost of consumables and crop yield will ultimately reveal the success or failure of the design.

Table 8. Some Example Values for the Parameters that Require Analysis

Bioshelter Performance Evaluation		
General Information	Design Name	N/A
	Design Type	N/A
	Location	N/A
	Size (Square Footage)	Depends on available space
Growing Environment Conditions	Temperature (°F)	50 - 85
	Relative Humidity (%)	45 - 60
	CO2 Concentration (ppm)	1,000 (enriched environment)
	Light Level (lux)	Maximize, although dependent on types of crops
Ventilation Performance	Static pressure difference (in. H2O)	0.05 with an acceptable range of 0.03 - 0.13
	Air exchange capacity (cfm)	8 - 10 cfm per square foot of floor area
	Air distribution	Even distribution, minimal leakage
Design Consumables and Costs	Energy consumption (dollars)	Depends on size
	Water consumption (dollars)	Depends on size
	Other consumables (dollars)	Depends on size
	Total monthly maintenance costs (dollars)	Depends on size
Crop Yield	Type of crops grown	N/A
	Crop yield (lb/ft ²)	Depends on type of crops grown
	Total value of crops produced (dollars)	Depends on crop yield

Source: Badgery-Parker, Both, Martell

Once the results are recorded, they can be compared to conditions found to be ideal for a particular crop. Some typical values are included in the table below, although the types of crops and size of the structure can influence these values.

Overall, experimental analysis can lead to optimized performance. It can also lead to better bioshelter designs in the future. These experimental methods should be employed for every bioshelter design.

Appendix E: Sponsor Information

The sponsor for our Interactive Qualifying Project is Andy Pressman, an agricultural specialist who works for the National Center for Appropriate Technology (NCAT). To be more specific, Pressman works for a subsidiary of NCAT called the Sustainable Agriculture Project. Until recently, this project was known as the Appropriate Technology Transfer to Rural Areas (ATTRA). NCAT is public non-profit organization concerned with sustainable energy and agriculture challenges. It is run primarily by a board of directors and a chairman. NCAT currently has 81 staff members listed in its staff directory and has six regional offices including the main headquarters located in Butte Montana.

Andy Pressman is associated with the Northeast regional office in Shavertown Pennsylvania. The other offices are located in Des Moines Iowa, Davis California, Fayetteville Arkansas, and San Antonio Texas.

The organization receives approximately four to five million dollars in funding each year, primarily from federal grants provided by various departments of government.¹¹⁵ Major funders and partners include the U.S. Department of Agriculture, the Natural Resources Conservation Service, and the United States Department of Health and Human Services. Other sponsors include the U.S. Department of Agriculture Risk Management Agency, the New England Small Farm Institute, Piedmont Biofuels, the Center for Environmental Farming Systems, and the Northeast Organic Farming Association.¹¹⁶ In addition to these specific organizations, many local and statewide programs and companies located in the West and North West United States make contributions. The total amounts that NCAT has received each year since 2004 can be found in Table 1 below.

Andy Pressman works primarily within the Sustainable Agriculture Project and specializes in organic crop production, season extension, local foods, and urban agriculture. Their mission is to educate students by providing them with internships across the country, and by providing their teachers with pertinent information. The organization also provides local farmers and ranchers with information about urban farming. This includes creating sustainable local food sources through urban agriculture, community gardens, and farmer's markets. They create connections between local farmers and the community by using these markets as well as education. A goal of the Sustainable Agriculture Project is to inform the community on the health benefits of eating locally grown organic food. Additionally they provide information to any farmers or community members with questions. Their website contains a large database of articles on agriculture for those who seek guidance.

The Sustainable Agriculture Project is mostly an informational group and thus its resources are mostly centered on educational and technical assistance. The project has a large number of specialists who have a great deal of farming experience in addition to technical knowledge. Many hold advanced degrees in the field, as well as numerous article publications. These publications are one of the main resources that the organization provides, although due to recent budget cuts it is now necessary to pay for access to the articles. The articles cover the latest in agricultural technologies as well as information and techniques for people both new to the agricultural business and agricultural veterans who are looking for new ways to improve their career. In addition to providing publications and technical documents, the Sustainable Agriculture Project also has a free newsletter which provides handy tips and some of the latest news. Project members are available to answer direct questions from members of the agricultural community. The Sustainable Agriculture Project is a valuable resource for local ranchers, farmers, teachers, and other organizations that work with agriculture in any way.

Table 9. NCAT Funding

Year	Grants	Total support
2004	\$5,311,308	\$5,320,036
2005	\$4,570,714	\$4,588,127
2006	\$4,252,427	\$4,292,344
2007	\$3,807,003	\$3,863,265
2008	\$3,796,597	\$3,892,651
2009	\$5,280,102	\$5,295,954
2010	\$5,875,181	\$5,933,453

Source: <http://www.ncat.org>

¹¹⁵ National Center for Appropriate Technologies. "Who we are: National Sustainable Agriculture Project." accessed 8/29, 2011, <https://attra.ncat.org/who.html>.

¹¹⁶ Ibid

Appendix F: Websites for Financial Assistance

<http://www.sare.org/Grants/Grants-Information>

<http://www.stateagfinance.org/types.html>

<http://www.nal.usda.gov/afsic/pubs/funding.shtml>

http://www.nal.usda.gov/ric/ricpubs/small_farm_funding.htm#FPA

<http://www.rurdev.usda.gov/Energy.html>

<http://sustainableagriculture.net/publications/grassrootsguide/farm-bill-programs-and-grants/>