Transforming Shipping Containers into Livable Spaces: Replacing Traditional Insulation with Living Walls

Richard Ensign Mead III
May 2014

Submitted towards the fulfillment of the requirements for the Doctor of Architecture Degree.

School of Architecture
University of Hawai'i

Doctorate Project Committee
Joyce Noe, Chairperson
Andrew Kaufman
Brian Takahashi
Chad Johnston

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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawai'i at Mānoa.

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[ACKNOWLEDMENTS]

I would like to first acknowledge my committee members. Joyce Noe, Andrew Kaufman, Brian Takahashi and Chad Johnston. They sacrificed the little free time they had to work with me through this project. Their concerns, critiques and encouragement helped me get through this project and gave me the strength to persevere and be proud of what I have accomplished.

To my mother, Debbie Lebo and to my father, Richard Mead Jr. They supported me no matter what and never gave up on me. I would not be where I am today and I would not be the person I am today without the love and nourishment they have given me. My sister, Marissa Lebo and my brother, Troy Mead, were there to give me encouragement and support when I needed it most. My family means everything to me and without them; I would not have been able to get through the hardships in life without them.

To Kalina Calantoc and her family. They have been so amazing and understanding. They have given me the time, space and support that I needed in order to accomplish what needed to be done. They have given me the strength I needed to make this final push. Thank you for the love you have given my Kalina. I know this was a very difficult time. Thank you for sticking with me through it and giving me the time I needed and being patient while I ran around like a mad man trying to get everything done. Thank you for loving me and being my rock in these hard times.

The person I would like to thank the most though is Rosie MK Eckerman. I literally would not be where I am today, without her. She was there for me when I was at my lowest point. Every time I wanted to give up and be done with architecture, she would sit down with me, talk me through whatever I was feeling, and would make me realize what an idiot I was being and to get back up and finish what I was doing. She was there for me through everything. She stayed with me while I did all nighters at studio, helped me figure out why my designs were not working and what I could do to improve them. She deserves this degree way more than I do. She is one of the most loving and caring people I know. I am so very grateful to have been a part of her life and her families' lives. They are incredibly loving and generous people and I cannot put into words the love they shared with me. Rosie's grandfather, Herbert Walter Keeble, was the most incredible man I have ever had the pleasure of knowing. He once said "Whenever given the choice between do it and don't do it, always do it." These words have stuck with me throughout my life and they could not be truer. Always take chances and do not live with regrets. Thank you Rosie, for everything. Without you, I would be lost.

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[ABSTRACT]

One of the greatest issues that people are facing in Hawaiʻi today is the high cost of living and finding an affordable place to call home is becoming increasingly difficult. Hawaiʻi, unlike many places, has an environment conducive of outdoor lifestyle year round, which makes it such a desirable place to live. Because it is warm year round, homes need to be insulated properly in order to provide comfortable living conditions. By taking advantage of the unique climates here in Hawaiʻi, growing plants and vegetables on the walls of a home could replace the need for traditional insulation and replace it with a sustainable alternative.

This Doctorate Project will utilize this unique climate, exploring alternative methods of insulation by using living walls and aquaponic systems to benefit the transformation of shipping containers into livable spaces.

[INTRODUCTION]

Growing up in Hawaiʻi really opened my eyes to how isolated we are, being in the middle of the ocean. Most of the products we use in our everyday lives have to be imported from other countries, driving up the cost of goods and living because of the energy it takes to bring these products here. This also has a major effect on the building industry. Building materials have to be shipped to Hawai'i because we do not have the resources to locally produce the materials needed to build a home. The result is that homes become unaffordable for the working class and their families, and makes rent in Hawaiʻi more than double the national average[1].

[1] Hawaii 2011 Report (pp.11) http://www.hawaiibusiness.com/pdfs/2011QOL.pdf

This project explores possibilities to change the way homes are built and the materials that are used to construct these homes in order to provide a more affordable option. Shipping containers can be a possible solution to this problem. After all, everything that gets imported here arrives in shipping containers and most of those containers go back empty or lay idle in the yards. There are hundreds of thousands of shipping containers just sitting in shipping yards because there is no need for them anymore and the process to recycle the material is far more expensive than what they are worth.

According to David Cross of www.sgblocks.com, "a container has 8000 lbs of steel which takes 8000 kWh of energy to melt down and make new beams etc." To put that number in perspective, according to www.hawaiienergy.com, the average residential meter in Hawaii uses 615-kilowatt hour per month, which calculates into 7,380 kWh per year. The amount of energy to break down one shipping container requires more energy than a single home does for a whole year. Rather than melting them down, they can be used as homes. According to www.sgblocks.com, conversion of a container into an SG Block takes 1/20th the amount of energy required to reprocess a comparable weight of steel. Increasing the lifespan of a container to about 100 years, the SG Blocks system saves significant board feet of lumber and tons of new steel in addition to dramatic savings in energy expenditures, all contributing to LEED certification. Figure 0.01 shows finished converted containers.

Figure 0.01 Modified containers turned into SGBlocks.
http://www.greenhomebuilding.com/articles/containers.htm

The USA has a trade deficit of circa 50%, it imports 50% more than it exports. Therefore, some 10 thousand ISO (International Organization for Standardization) Shipping Containers are stockpiled every day in the USA because they are not used, and never will be. That represents circa 3,650,000 ISO Shipping Containers every year that will never again be used, just in the USA alone.[2]

I propose using these shipping containers as a way to provide affordable living here in Hawai'i. These containers are already structurally built to withstand harsh conditions while out at sea enduring high winds and strong surf. These containers are able to withstand a tremendous amount of force and when it comes to building a home, and this structural integrity is the most important thing. The main problem with these containers is insulating them so they can be used as a livable space. How to make these containers livable will be the focus of the research. Using projects and publications on the topic that have used shipping

[2] "HabicontecO Page Content." HabicontecO Page Content. Web. 17 Feb. 2013.

containers will provide the basic information to create an efficient and sustainable design. There are many projects that have been successful in using containers to build homes, offices, and retail shops. What will separate my design from others that have already been built is having a design that will be the most efficient in Hawai'i. There have not been many major developments that have used shipping containers here in Hawai'i and to be able to create a design that will be either carbon zero or carbon negative (meaning the home is creating more energy than what its users are using) so that these units can be off-grid as well as be a comfortable place to live in is the goal. This design using shipping containers has the potential to cut the costs of building a home, reduce the construction time, reduce the amount of energy and materials needed during the construction process and have less of an environmental impact by decreasing the carbon footprint of the home.

The purpose of this doctorate project is to research the different types of insulation that could be used to insulate a container here in Hawai'i, and use the data to confirm whether or not Living Walls would be a feasible replacement to traditional insulation. In order to transform a shipping container into a livable space it needs to be comfortable for the user. To ensure that the user is comfortable, they would have to be in an environment where it is not too hot and not too cold. The first step in making a container livable is insulating it to ensure that it does not become an oversized oven.

Small-scale experiments will be conducted using scraps of shipping containers that will be joined together to form a 3' x 3' x 3' box. There will be a total of four boxes; one being the control, meaning no insulation will be applied to the exterior. This control box will provide the data that will be used to compare how effective the insulations applied to the other three boxes. Two of the boxes will have insulation applied to them and the third will be covered with Living Walls. Data will be collected over a 16-day period. Readings will be taken using instruments that measure exterior and interior surface and air temperatures and interior relative humidity. The data will then be analyzed and recorded and from there, the results should indicate which form of insulation was most effective.

After graduation, there are hopes to build a full-scale home using shipping containers and energy efficient systems that will make a carbon zero/negative design a reality. The research conducted will focus on gathering the necessary information needed to actually build such a home. The research will focus on the shipping container itself and how it is built, insulation that can be used to minimize heat gain, building methods, site integration, energy efficient systems, both active and passive, etc.

The following content is research that has been gathered dealing with shipping containers, Living Walls, different types of insulation and case studies. This information will help with the future design of a container house and the different methods and materials that will be used.

[SHIPPING CONTAINERS]

Shipping containers have made a huge impact on the world and how countries import and export goods. These strong, steel boxes make it possible to transport anything a person needs, in a safe and secure way. They can be loaded onto ships, trains, automobiles, and even flown in by helicopter. Chances are you have seen a shipping container in your lifetime. They have been engineered to withstand the most extreme conditions while en route to their destination. Containers are weatherproof and defy hurricanes, floods and numerous other inconveniences (due to their low weight, they are also earthquake resistant), as well as being fireproof thanks to the special coating on the façade[3].

[3] Kotnik, Jure. Container Architecture. Barcelona, Spain: Links, 2008. (pp.24)

Shipping containers come in many shapes and sizes, but the most common ones found are the ISO 20' or ISO 40' containers with a width of 8 ft and a height of 8 ft 6 in. All containers share this width and height, except for some specialized containers that are made with a width of 8 ft 6 in and a height of 9 ft 6 in. The lengths also vary, ranging anywhere from 10 ft to 53 ft in length.

		20 ' container		40' container		45' container	
		imperial	metric	imperial	metric	imperial	metric
exterior dimensions	length	19' 10"	6.058 m	40' 0"	12.192 m	45' 0"	13.716 m
	width	8' 0"	2.438 m	8' 0"	2.438 m	8' 0"	2.428 m
	height	8' 6"	2.591 m	8' 6"	2.591 m	9' 6"	2.896 m
interior dimensions	length	18' 10 5/16"	5.758 m	39' 5 45/64"	12.032 m	44' 4"	13.556 m
	width	7' 8 19/32"	2.352 m	7'8 19/32"	2.352 m	7' 8 19/32"	2.352 m
volume		1,169 ft^3	33.1 m^2	2,385 ft^3	67.5 m^3	3,040 ft^3	86.1 m^3
maximum gross mass		52,910 lb	24,000 kg	67,200 lb	30,480 kg	67,200 lb	30,480 kg
net load		48,060 lb	21,800 kg	58,820 lb	26,680 kg	56,620 lb	25,680 kg
area	exterior	158.972 sq ft	14.769 m^2	339.041 sq ft	31.498 m^2	359.934 sq ft	33.439 m^2
	interior	145.764 sq ft	13.542 m^2	304.607 sq ft	28.299 m^2	343.185 sq ft	31.883 m^2

Table 1.00-Dimensions of common containers. Container Architecture (pp.27)

There is a specific unit used to count the number of shipping containers. These are called TEU (Twenty-Foot Equivalent Units) and this is the unit most commonly used. FEU (Forty-Foot Equivalent Units) are sometimes used. TEU figures are calculated in terms of container length. 20ft=1.00; 24ft=1.20; 28ft=1.40; 30ft=1.50; 40ft=2.00; 43ft=2.15; 45ft=2.25; 48ft=2.40; 53ft=2.65[4]. According to the report 'Container Supply Review' by the World Shipping Council, the number of ocean shipping containers in use in the global fleet of container equipment is roughly 18.605 million units or 28.535 million TEU. It is estimated there are approximately 5.5 million 40' standards, 7 million 40' HC (High Cube-9'6" high) units and 5.5 million 20' units[5]. This was the estimate for the 2011 fiscal year. The number of containers will continue to rise throughout the years as the population grows and the demand for goods increases. According to the World Shipping

[4] World Shipping Council. "Container Supply Review." World Shipping Council-Partners in Trade. World Shipping Council, (pp.1)
[5] "FAQs." SG Blocks RSS. SG Blocks, 2013. Web. 27 Mar. 2013.

Council, it is estimated that the global fleet of containers will increase to 40,635,000 TEU by 2015.

Shipping containers have a very short life span of approximately 5 years, after which they are disposed of. They often end up sitting idle in shipping yards, but lately, shipping container architecture has gained popularity and these containers are given a new life and purpose. For more information on shipping containers and the different parts and components required to build a container, refer to Appendix A.

According to the World Shipping Council, standard containers are inexpensive ranging anywhere from $1500-$5000 depending on the condition, size, and location of the unit. The low price is not the only thing that makes it a very attractive alternative to a builder. These containers have been structurally engineered to withstand the toughest conditions and are able to handle large loads. The maximum gross mass is 67,200 lbs for a 40 ft unit and 52,910 lbs for a 20 ft unit. They are able to handle the weight of 8 fully loaded vertically stacked containers[6].

[6] Kotnik, Jure. Container Architecture. Barcelona, Spain: Links, 2008. (pp.27)


Figure 1.03 Shipping Container Yard
http://i.telegraph.co.uk/multimedia/archive/01238/ships_1238248c

These containers have already been manufactured to withstand the force of strong winds and waves while out at sea and are able to endure the daily beating it receives from poor handling. This makes it an ideal replacement to the standard wood framing structure that is most commonly used because most of the work is already done and all it needs are some cut outs for windows and doors and some reinforcing and the container can be made into a habitable space.

There are many companies here in Hawai'i that sell shipping containers, both standard and modified. Shipping container architecture has gained much popularity of the years and these companies have evolved in order to meet the demands of people wanting to use shipping containers to build a home or office. They offer services such as cutting and welding to fit windows and doors into a container and can frame, drywall, add electrical and plumbing into the interior. They are able to build most of the design at their facilities and when it comes time to deliver to the site, the bulk of the work has already been done. Just place and connect and your new home is good to go.

Some companies that offer these services are:

- Affordable Portable Housing Hawai‘i
- Container Storage Company of Hawai‘i, Ltd.
- Containers O‘ahu
- Containers Hawai‘i
- The Storage Castle

All these companies offer a variety of containers ranging from 10’ to 45’ with many modification options to fit your needs. Container Storage Company of Hawai’i, Ltd supplied the following tables that detail their modification options and their prices and the containers they supply.

CONTAINER STORAGE
COMPANY OF HAWAII, LTD.
Hawaii's Leader In Container
Sales, Service & Modifications

CONTAINER STORAGE
COMPANY OF HAWAII, LTD.

CONTAINER MODIFICATION OPTIONS PRICE LIST		
DOORS		
Roll-Up Door	6' 0" W x 6' 8" H	$875.00
Roll-Up Door	8' 0" W x 6' 8" H	$925.00
Roll-Up Door	12' 0" W x 6' 8" H	$1,300.00
Pre-Hung Door	Standard Metal Door 3' 0" W x 6' 8" H	$900.00
WINDOWS		
Window	3' W x 3' H Aluminum Sliding With Screen	$650.00
Window	4' W x 3' H Aluminum Sliding With Screen	$700.00
Window Bars	Steel Security Bars	$250.00
A/C AND VENTILATION		
Air Conditioner	11,500 BTU Installed	$1,000.00
Air Conditioner	9,500 BTU Installed	$900.00
Air Conditioner Mount	Cutout Hole And Mounting Frame Only	$300.00
Ventilator	Whirly Type Turbine Vent	$250.00
Ventilator	Side Vent 8" x 16"	$250.00
ELECTRICAL		
20' Container	2 Fluorescent Lights And 3 Outlets	$1,250.00
20' Container	As Above For Interior Walls With MC Wire	$1,500.00
40' Container	4 Fluorescent Lights And 4 Outlets	$1,750.00
40' Container	As Above For Interior Walls With MC Wire	$2,150.00
ROOFING		
20' Container	JJ Henry Protective/Reflective Roof Coating	$250.00
40' Container	JJ Henry Protective/Reflective Roof Coating	$500.00
DRYWALL		
20' Container	Drywall Interior - Framed & Insulated	$4,256.00
40' Container	Drywall Interior - Framed & Insulated	$7,616.00
PARTITIONS		
Partition	Metal Partition	$325.00
Partition	Drywall - One Side	$450.00
Partition	Drywall - Two Sides	$625.00
ACCESSORIES		
Lock Box	Steel Security Box For Cargo Doors	$150.00
Effective October 2012 - Call for quotes on other modification options		

2276 Pahounui Drive Honolulu, Hawaii 96819
Ph: (808) 841-5555 Fax: (808) 845-5552 Email: ch.thometz@hawaiiantel.net

Figure Error! No text of specified style in document.-1.04 Container Modification List
Courtesy of Chris Thometz, Container Storage Company of Hawaii, LTD.

CONTAINER STORAGE
COMPANY OF HAWAII, LTD.
HAWAII'S LEADER IN CONTAINER
SALES, SERVICE & MODIFICATIONS

CSH CONTAINER STORAGE COMPANY OF HAWAII, LTD.

CONTAINER PRICE LIST		
DRY CONTAINERS		
Used, refurbished and repainted. All units are 8' W x 8'6" H. except high cubes (9'6" H.)		
Length	Description	Price
10'	Steel with Roll-up Doors	$3,100.00
10'	Steel with Cargo Doors **	$3,100.00
10'	New Unit with 4 Corner Posts	$5,200.00
20'	Steel with Cargo Doors **	$4,000.00
20'	Cut 40' in half w/ roll up door	$3,800.00
20'	Cut 40' in half w/ cargo door	$3,800.00
20'	Steel with Cargo Doors (New)	$4,950.00
24'	Steel with Cargo Doors (Used)	$4,200.00
40'	Steel with Cargo Doors	$4,500.00
40'	Steel High Cube (9'6" H)	$4,750.00
45'	Steel High Cube with Cargo Doors	$5,000.00

** Based on Availability

We can create custom size containers. Please call for prices.
See our website at www.containerstoragehawaii.com

CONTAINER RENTAL (OAHU ONLY)		
Length	Description	Price
20'	Steel with Cargo Door	$175.00 / Month

Rental policy - One month minimum
Rental and delivery/pickup charges payable in advance.
Effective November 1, 2012

2276 Pahounui Drive Honolulu, Hawaii 96819
Ph: (808) 841-5555 Fax: (808) 845-5552 Email: ch.thometz@hawaiiantel.net

Figure 1.05 Container Price List
Courtesy of Chris Thometz, Container Storage Company of Hawaii, LTD.

The following is an estimate for a 40' Studio apartment. This is a sample of the type of services they offer.

CONTAINER STORAGE
COMPANY OF HAWAII, LTD.
HAWAII'S LEADER IN CONTAINER
SALES, SERVICE & MODIFICATIONS

May 15, 2012

Here's a representative quote showing a basic steel walled studio with a full bathroom, followed by a unit with a fully finished interior.

40' x 8' x 9 ½ ' Basic Unit:

One (1) Used, Refurbished 40' Hi Cube Steel Container 8'x9'6"x40'	$4750.00	$4750.00
Two (2) Metal Entry Doors	$875.00 each	$1750.00
Four (4) 3'x3' Aluminum Windows	$625.00 each	$2500.00
Two (2) 11500 BTU Wall Mounted Air Conditioners	$1000.00 each	$2000.00
Bathroom (Sink, Toilet, Vanity, Fan, Water Heater, Plumbed to Base)		$4250.00
Electrical & Lighting 4 Fluorescent Lights 4 Outlets		$1700.00
One (1) Interior Partition with Door		$ 950.00
Sub Total		$17900.00

40' x 8' x 9 ½ ' Deluxe Options:

Insulated Drywall Interior & Drywall Ceiling	$7616.00
Vinyl Tile or Carpet Floor	$2080.00
Additional Electric	$ 400.00
Sub Total	$10096.00

Total (Basic + Deluxe Costs)	$27996.00

While the above unit is functional, durable and portable, adding a single pitch roof and siding will greatly enhance the visual appearance and weatherproofing of the unit while reducing the maintenance needs.

Exterior Siding (T-111)	$5184.00
Single Pitch Roof	$7500.00

Site must be flat and level. Quote does not include state tax, shipping, delivery charges, permitting, design, sitework, plumbing or electrical hookup costs. Terms are 50% deposit with order, balance due on delivery. Approximately 4-6 weeks from order to delivery. If a bathroom unit is specified, the unit needs to be placed at least 18" above ground to get access underneath for plumbing hookups.

Mahalo

Chris Thometz
Sales

2276 Pahounui Drive Honolulu, Hawaii 96819
Ph: (808) 841-5555 Fax: (808) 845-5552 Email: ch.thometz@hawaiiantel.net

Figure 1.06 Container Modification List
Courtesy of Chris Thometz, Container Storage Company of Hawaii, LTD.

These modifications are reasonably priced and if you have experience in the field of construction, you can simply have the container modified and do the work yourself. Some people buy a standard container and do all the work themselves. By doing this you can save money on the cost of labor and take pride in something you built yourself. The finish on the exterior of these containers usually depends on the user who is occupying it. It can be left alone with the corrugation exposed as a design aesthetic or cover it up with something that is more traditional such as wood or drywall. Another way of covering up the façade of the container is by using Living walls. The following chapter will explore Living Walls, what they are, their components, how they work, case studies, and applications.

[LIVING WALLS]

Living walls are a relatively new term that has become very popular in the built environment. Although the concept of a living wall has been around for a long time, the technology is still in its early stages and implementation into the building industry has just started to expand. There are many different types of living wall systems, each one having a unique mounting system and way of integrating the plants onto a buildings façade. Some living walls have little or no maintenance required and can be left alone if desired. There are also many benefits to having living walls compared to traditional ones that will later be discussed.

There are many challenges when it comes to living walls. Usually plants are found growing on horizontal surfaces and not on vertical ones. Plant leaves and stems grow towards the light and so any attempt to grow them vertically is liable to result in distorted growth, or the physical collapse of the stem; such a planting can soon develop an unattractive gappy appearance[7]. There needs to be careful planning when it comes to the selection of plant types used in a living wall to ensure that it will thrive in the environment it is put in. Some extremely varied and visually attractive plant communities can be found growing on cliffs where there is a sufficiently constant supply of nutrient-laden water flowing over and down the rock surface. Often the plant communities are highly distinctive, frequently offering refugia for locally rare or highly specialized species. In the temperate zone, some of the best known are the 'costal bluff' communities of cliff and canyon walls in the Cascade Range in northwest North America[8] (Figure 2.01).

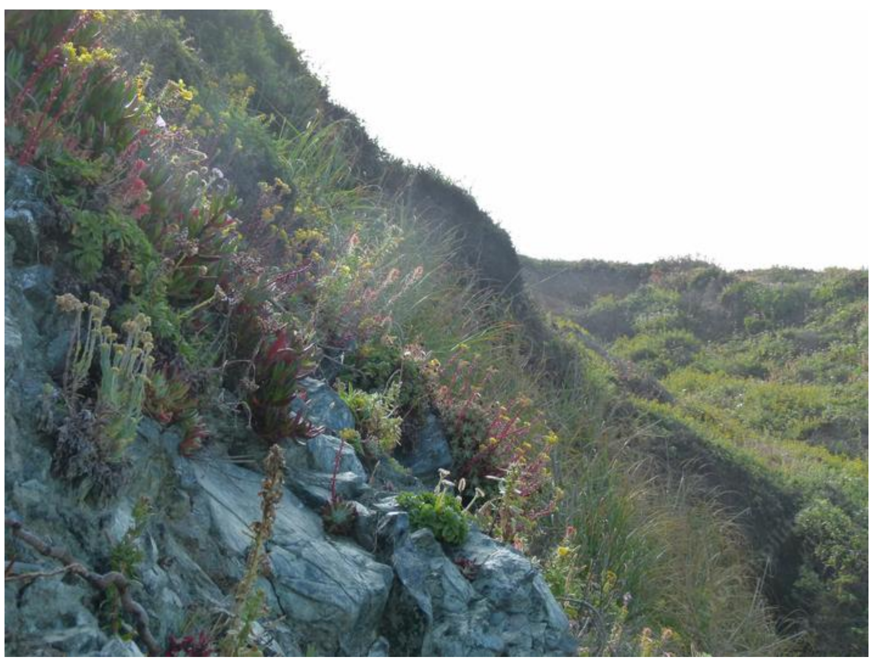


Figure 2.01 Plant community on coastal cliff
http//www.laspilitas.com/images/grid24_18/11417/images/rocks/serpentine-coastal

[7] Dunnett, Nigel, and Noël Kingsbury. Planting Green Roofs and Living Walls. Portland, Or.: Timber, 2008. (pp. 241)

[8] Dunnett, Nigel, and Noël Kingsbury. Planting Green Roofs and Living Walls. Portland, Or.: Timber, 2008. (pp. 241)

Plant selection is not the only component needed in a successful living wall. The technology it uses plays a very important role as well. Growing plants vertically demands:

- a growing medium, preferably inert and non-biodegradable (to minimize the need for replacement);
- a means of delivering water/nutrients in solution;
- a way of holding the growing medium and plants in position[9].

There are many companies that provide many different types of living wall systems, each having their own unique mounting system, water/nutrient delivery system, growing medium, etc. Choosing a system that is right for the project can be a difficult task, making sure the right plants and systems are used to provide the most efficient and comfortable environment must be taken into account to ensure that the living wall is successful. A failed living wall is a nightmare, as shown in Figure 2.02. Not only does it look bad but also it will start to attract unwanted pests and allergens and will have a negative impact on the building and its users. The whole system will need to be replaced causing the user to lose money and have to pay for another system.

[9] Dunnett, Nigel, and Noël Kingsbury. Planting Green Roofs and Living Walls. Portland, Or.: Timber, 2008. (pp. 241)

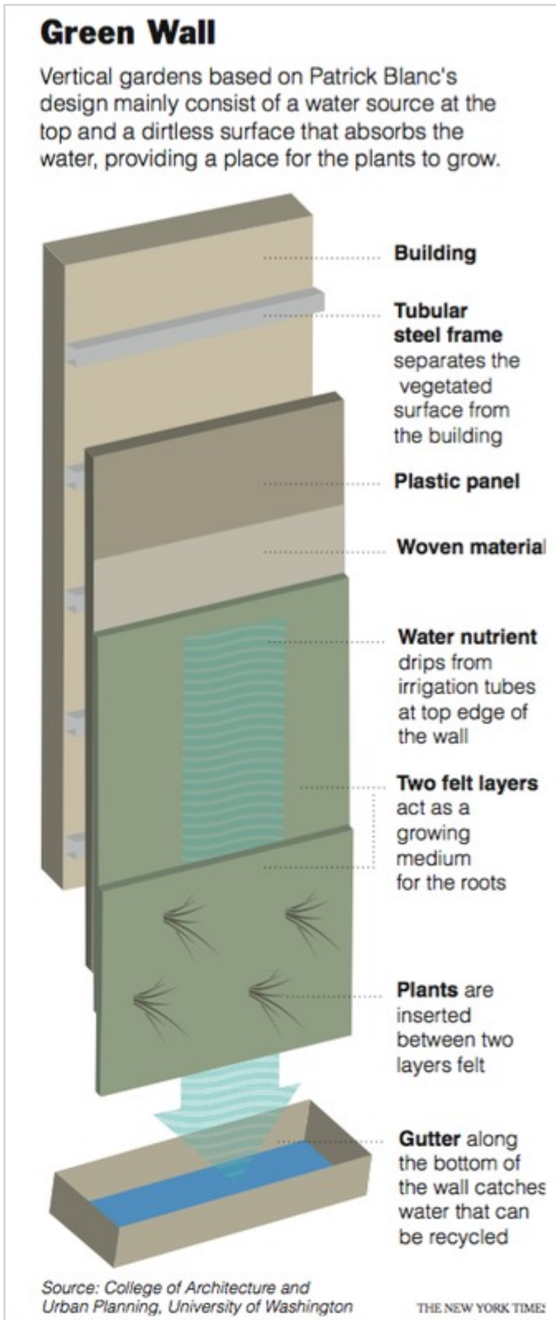
Figure 2.02 Failed Living Wall
http://www.jetsongreen.com/images/old/6a00d8341c67ce53ef0120a5ac0b66970c-800wi.jpg

The basics of a Living Wall system consist of the following:
The building or wall itself, some type of tubular steel framing system, a plastic panel, a woven material, a water and nutrient delivery system, a growing medium for the plants, the plants themselves and a catchment system for the excess water that can be recycled and used again. Figure 2.03 illustrates a basic Living Wall system.

The great thing about Living Walls is that they can be installed on the interior or exterior of a space, but there are factors that need to be considered when installing these systems.

• Vertical gardens are heavy, and not every wall is strong enough to support one. Check with a carpenter or your landlord to make sure the designated wall can handle the load.

• When selecting a spot for your living wall, make sure the area gets plenty of light. The best light is natural, but you will also need to install artificial lighting.



• Custom installations like the ones Patrick Blanc builds require a frame that can be attached to the wall, a waterproof barrier to protect the wall, a surface material like felt or cork to hold the plants in place and an irrigation system with PVC or polyethylene tubing and a submersible pump (the kind found in aquarium shops).

• Ready-made vertical garden kits have small containers angled to hold dirt and can be watered manually. After you plant your cuttings in the dirt, you'll need to let them grow horizontally for several months so they develop strong roots. Once the roots have taken hold, you can attach the kit to the wall.

• Each wall has different requirements, depending on its light and plants (talk to a local nursery or green-roof specialist about the best plants for your wall), but many people water their vertical gardens three times a day for 8 to 10 minutes. You will need to add fertilizer to the water to make sure the plants get necessary nutrients[10].

Figure 2.03 Living Wall Basics
http://graphics8.nytimes.com/images/2010/05/05/garden/05green_popup/05green_popup-articlenline.jpg

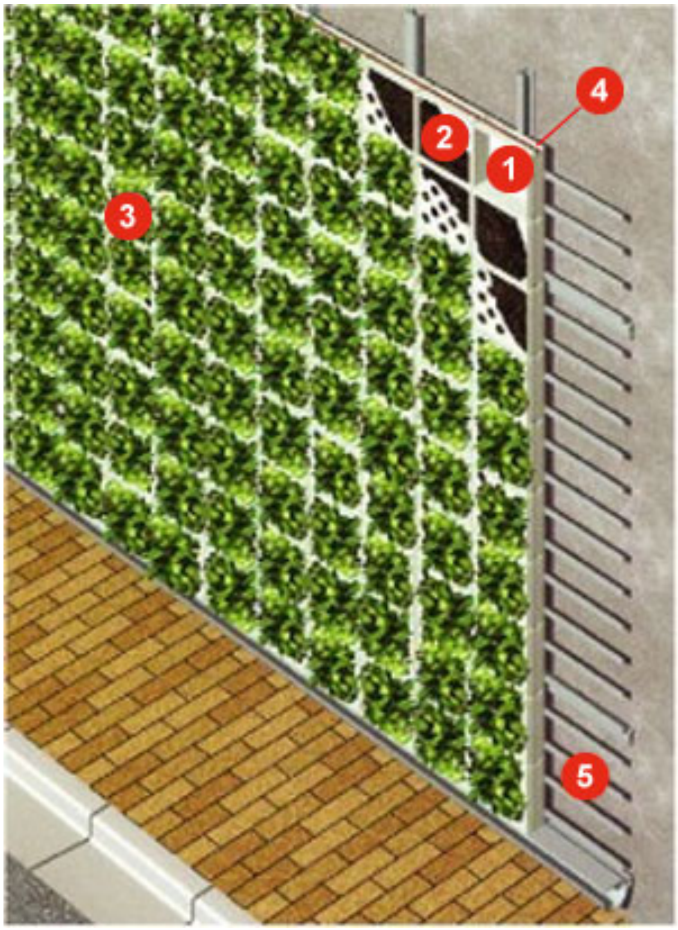
ɛf=garden

These are some of the factors one has to consider when installing a Living Wall system in order to ensure that it will be successful. Each living wall company will offer either cellular or monolithic systems or both. Each system has its own advantages and disadvantages depending on the site location and size of project. The cellular systems are modular with a tray like design. The tray sizes vary, but typically they come in 1'x2' and 2'x3' sizes. The advantage of having this tray system is that you can control what type of plants you grow and where they are placed. If some plants aren't growing well, they can be pulled out and placed in another area that will offer better growing conditions. The placement of the plants can also be arranged to create an aesthetically pleasing design or a company's logo. Figure 2.04 shows a green wall done by Gsky Plants Systems, INC. for a shopping mall located in Palm Beach County. This 840 square foot project was designed with 11 different plant types and were grown offsite before installation.

Figure 2.04 Green Wall tray system design
http://gsky.com/palm-beach-daily-news/

Gsky has done many green wall projects around the world, both interior and exterior. They offer a tray system approach and have three different types of systems. GSky Pro Wall System is the most sustainable, comprehensive and widely used system in the industry. The flexible, modular system can be installed on virtually any outdoor surface in any hot or cold climate, and is designed to resist heavy winds, wind drive rain and earthquakes[11].

[11] http://gsky.com/green-walls/pro/



1 Panels: patent-pending 1 square foot stainless steel panels can be customized to fit any design or wall type.

2 Non-Soil Structural Growth Medium: patent-pending growth material is non-eroding to ensure plant longevity, and much lower maintenance than loose soil systems.

3 Plants: grown into the panels for several months before shipped to the site so that they will not blow away under strong winds or shake out of the panels under seismic activity.

4 Remote Irrigation/Fertilization System: computerized vertical drip irrigation system with temperature and moisture sensors that allow for 24/7 remote monitoring- high efficiency since water is used only when needed.

5 Stainless Steel Frame Wall Mounting System: can be mounted on concrete, wood frame, steel beam, and more, and allows panel removal for inspection as needed[12].

The following are detailed drawings of the Pro Wall system and its components.

---

[12] http://gsky.com/green-walls/pro/

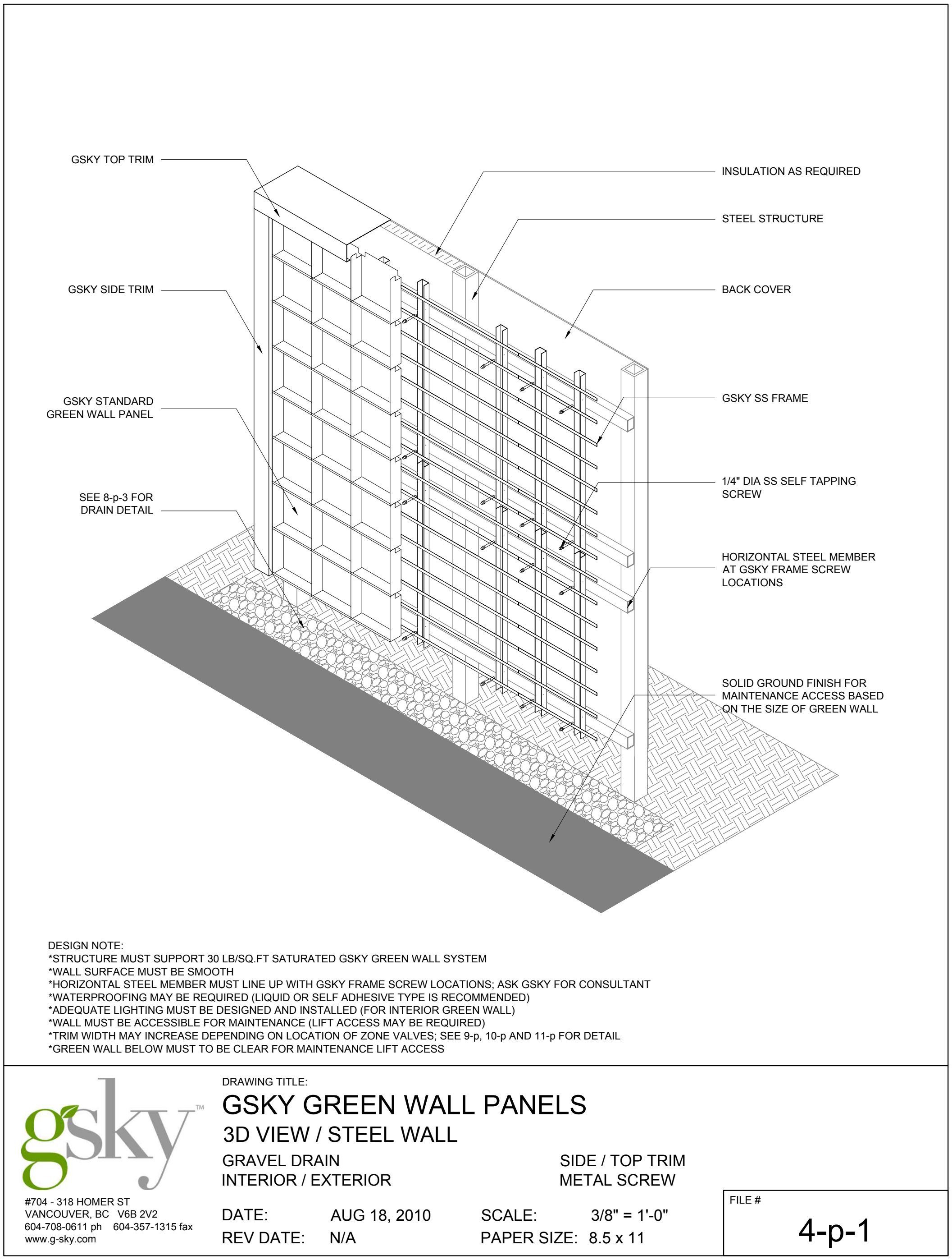
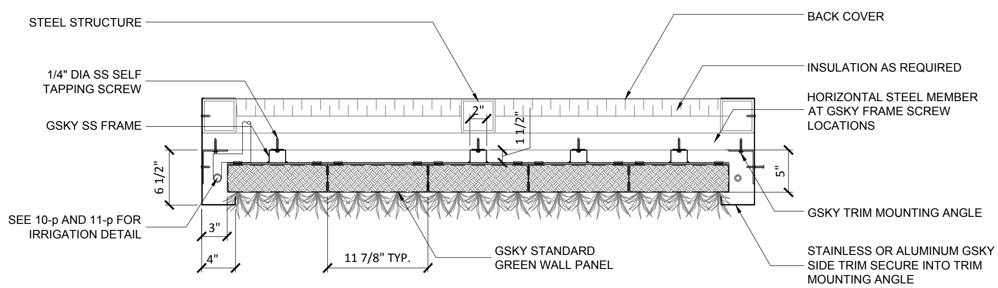


Figure 2.05 3D VIEW/STEEL WALL
http://gsky.com/green-walls/pro/cad-spec/



DESIGN NOTE:
*STRUCTURE MUST SUPPORT 30 LB/SQ.FT SATURATED GSKY GREEN WALL SYSTEM
*WALL SURFACE MUST BE SMOOTH
*HORIZONTAL STEEL MEMBER MUST LINE UP WITH GSKY FRAME SCREW LOCATIONS; ASK GSKY FOR CONSULTANT
*WATERPROOFING MAY BE REQUIRED (LIQUID OR SELF ADHESIVE TYPE IS RECOMMENDED)
*ADEQUATE LIGHTING MUST BE DESIGNED AND INSTALLED (FOR INTERIOR GREEN WALL)
*WALL MUST BE ACCESSIBLE FOR MAINTENANCE (LIFT ACCESS MAY BE REQUIRED)
*TRIM WIDTH MAY INCREASE DEPENDING ON LOCATION OF ZONE VALVES; SEE 9-p, 10-p AND 11-p FOR DETAIL
*GREEN WALL BELOW MUST TO BE CLEAR FOR MAINTENANCE LIFT ACCESS

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DRAWING TITLE:

GSKY GREEN WALL PANELS

PLAN DETAIL / STEEL WALL

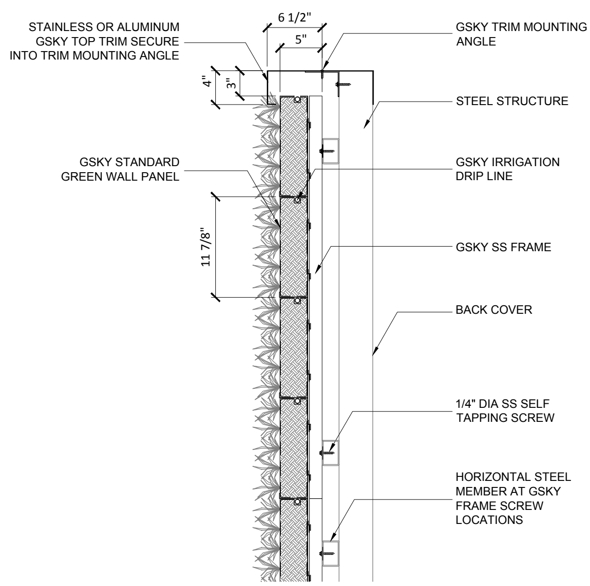
SIDE TRIM
INTERIOR / EXTERIOR

IRRIGATION STUB-OUT / HEADER
METAL SCREW

DATE: AUG 18, 2010
REV DATE: N/A
SCALE: 3/4" = 1'-0"
PAPER SIZE: 8.5 x 11

FILE #
4-p-2

Figure 2.06 PLAN DETAIL/STEEL WALL
http://gsky.com/green-walls/pro/cad-spec/



DESIGN NOTE:
*STRUCTURE MUST SUPPORT 30 LB/SQ.FT SATURATED GSKY GREEN WALL SYSTEM
*WALL SURFACE MUST BE SMOOTH
*HORIZONTAL STEEL MEMBER MUST LINE UP WITH GSKY FRAME SCREW LOCATIONS; ASK GSKY FOR CONSULTANT
*WATERPROOFING MAY BE REQUIRED (LIQUID OR SELF ADHESIVE TYPE IS RECOMMENDED)
*ADEQUATE LIGHTING MUST BE DESIGNED AND INSTALLED (FOR INTERIOR GREEN WALL)
*WALL MUST BE ACCESSIBLE FOR MAINTENANCE (LIFT ACCESS MAY BE REQUIRED)
*TRIM WIDTH MAY INCREASE DEPENDING ON LOCATION OF ZONE VALVES; SEE 9-p, 10-p AND 11-p FOR DETAIL
*GREEN WALL BELOW MUST TO BE CLEAR FOR MAINTENANCE LIFT ACCESS

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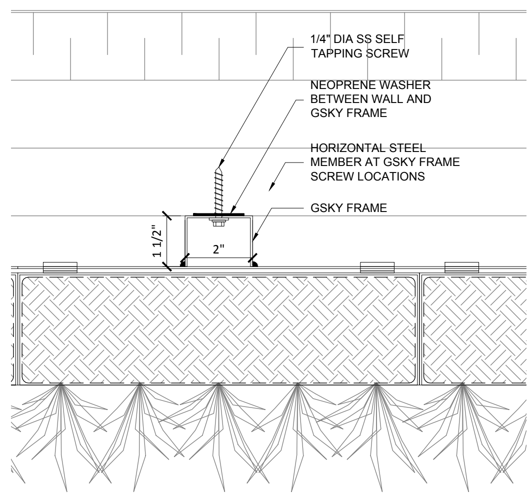
DRAWING TITLE:
GSKY GREEN WALL PANELS
SECTION DETAIL / STEEL WALL
TOP TRIM
INTERIOR / EXTERIOR
IRRIGATION DRIP LINE
METAL SCREW

DATE: AUG 18, 2010
REV DATE: N/A
SCALE: 3/4" = 1'-0"
PAPER SIZE: 8.5 x 11
FILE # 4-p-3

Figure 2.07 SECTION DETAIL/STEEL WALL
http://gsky.com/green-walls/pro/cad-spec/



DESIGN NOTE:
*STRUCTURE MUST SUPPORT 30 LB/SQ.FT SATURATED GSKY GREEN WALL SYSTEM
*WALL SURFACE MUST BE SMOOTH
*HORIZONTAL STEEL MEMBER MUST LINE UP WITH GSKY FRAME SCREW LOCATIONS; ASK GSKY FOR CONSULTANT
*WATERPROOFING MAY BE REQUIRED (LIQUID OR SELF ADHESIVE TYPE IS RECOMMENDED)
*ADEQUATE LIGHTING MUST BE DESIGNED AND INSTALLED (FOR INTERIOR GREEN WALL)
*WALL MUST BE ACCESSIBLE FOR MAINTENANCE (LIFT ACCESS MAY BE REQUIRED)
*TRIM WIDTH MAY INCREASE DEPENDING ON LOCATION OF ZONE VALVES; SEE 9-p, 10-p AND 11-p FOR DETAIL
*GREEN WALL BELOW MUST TO BE CLEAR FOR MAINTENANCE LIFT ACCESS

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604-708-0611 ph 604-357-1315 fax
www.g-sky.com

DRAWING TITLE:

GSKY GREEN WALL PANELS

FASTENER DETAIL / STEEL WALL

INTERIOR / EXTERIOR -
METAL SCREW -

DATE: AUG 18, 2010 SCALE: 3" = 1'-0"
REV DATE: N/A PAPER SIZE: 8.5 x 11

FILE #
4-p-4

Figure 2.08 FASTENER DETAIL/STEEL WALL
http://gsky.com/green-walls/pro/cad-spec/

There are many benefits that come with using green walls in a design, but there are also some drawbacks to it as well. The following is a list of pros and cons according to http://easyverticalgardening.com/types-of-vertical-gardens/pros-and-cons-of-vertical-gardens.

Pros

- Reduces temperature fluctuations on the exterior surfaces and, therefore, inside the building and insulates the building envelope year round.
- Protects the facade from the elements (which means less maintenance on the building) and can be designed to provide privacy.
- Lowers energy consumption (a living wall can reduce electricity usage by up to 20%).
- Improves aesthetics (which is good for marketing the building to tenants and customers – not to mention the fact that it also serves as a graffiti deterrent!).
- Improves air quality and health.
- Cleans interior air space by removing VOCs and other harmful toxins like benzene and formaldehyde and cleans outside air of pollutants and offsets carbon footprint.
- Ongoing scientific research indicates that plants have unique healing qualities and that integrating plants into our work and living environments provides health benefits.
- Soil and plants are a natural filter that can clean the water that flows through the wall.
- Increase space efficiency.
- Improves acoustics (mostly by absorbing sound and decreasing noise level within and around the building).
- Increases property value (studies have shown increased property values of up to 20%).
- Contributes to sustainability.
- Can provide new habitats by attracting beneficial insects.

- Gives the building credits toward LEED certification (for environmentally-responsible/green buildings).

Cons

- Maintenance and care of plants depending on systems used.
- Added weight to structure approximately 20-45 lbs. per sf.
- Cost.
- Insects.
- Bacteria, molds, allergies.

There will always be advantages and disadvantages when it comes to architecture and the different systems, materials and methods that we use. The pros clearly outweigh the cons when it comes to Living Walls. If done right, insects, bacteria, molds and allergies can be avoided. The main factor is the cost, which ranges from $90-$150/square foot depending on which system is chosen, but the savings and benefits will be paying for itself in the long run.


Figure 2.09 LiveWall Tray System. Photo: Richard E Mead III

Using this information, Living Walls will be integrated into the container design. The insulation properties will be a key factor in using Living Walls, as it will provide the necessary protection to provide a comfortable space for its occupants. Living walls can also provide the users the opportunity to have a vertical garden. They can grow herbs and spices as well as vegetables. They can have a self-sustaining garden that provides them with food if done properly. One company that deals with green roofs and living walls is called Hawaiian Sunshine Nursery located in Waimanalo. They grow many different types of plants at their location, some which can only be found here in Hawaiʻi. In recent years, they have become licensed growers of green roofs and walls. They use a cellular tray system from a company called LiveRoof and LiveWall. While touring the facilities, the LiveRoof and LiveWall systems are found around the site, displaying what the nursery can do with them and the benefits of one.

Figure 2.10 LiveWall applied to 20' container. Photo: Richard E. Mead III

A LiveWall system was installed on the side of a 20' shipping container. This system was a spice garden and had various plants that are used in everyday cooking such as basil, parsley, lavender, etc. David Fell, the director of the nursery, explained the advantages of these systems and how easy they are to install and maintain. These examples clearly demonstrate the possibility of using Living Walls in the project and show promising results. As seen in Figure 2.10, the plants provide enough coverage to cover the exterior wall, which would then reduce heat gain to the interior.

LiveWall uses soil and drip irrigation to deliver water and nutrients to the plants. What if that system could be replaced with aquaponics? Having a soil-less system that did not require fertilizer would cut down not only on costs, but the need for unwanted chemicals in the plants. In the following chapter, Aquaponics will be explored as a possible replacement to traditionally grown plants that use soil. What aquaponics are, the different types of systems and how they can be integrated into living walls will be explored as well.

[AQUAPONICS]

Aquaponics is actually a combination of aquaculture and hydroponics. Hydroponics is the production of plants in a soilless medium whereby all of the nutrients supplied to the crop are dissolved in water. Liquid hydroponic systems employ the nutrient film technique (NFT), floating rafts, and noncirculating water culture. Aggregate hydroponic systems employ inert, organic, and mixed media contained in bag, trough, trench, pipe, or bench setups. Aggregate media used in these systems include perlite, vermiculite, gravel, sand, expanded clay, peat, and sawdust. Normally, hydroponic plants are fertigated (soluble fertilizers injected into irrigation water) on a periodical cycle to maintain moist roots and provide a constant supply of nutrients. These hydroponic nutrients are usually derived from synthetic commercial fertilizers, such as calcium nitrate, that are highly soluble in water[13]. Aquaculture is a method of farming fish and other aquatic organisms. When you put these two together, they create the ultimate symbiotic mutualistic relationship. It can be a very sustainable and efficient system when done properly.

13 http://www.backyardaquaponics.com/Travis/aquaponic.pdf (pp.2)

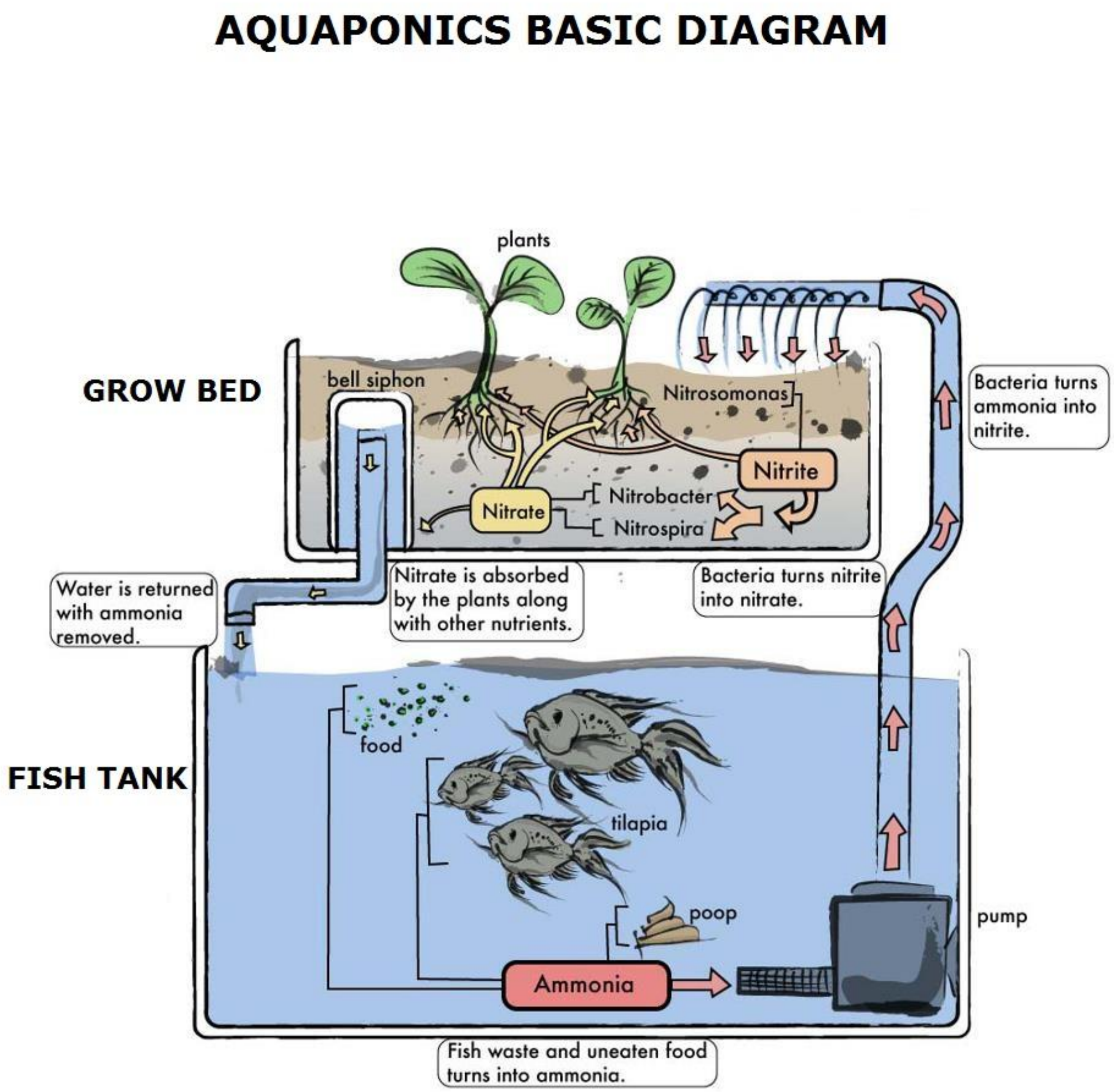

Figure Error! No text of specified style in document.Error! No text of specified style in document.-3.00- Aquaponics Basic Diagram. How the system works and the process of recycling water. http://myaquaponic.files.wordpress.com/2012/05/aquaponics2.jpg

In aquaponics, nutrient-rich effluent from fish tanks is used to fertigate hydroponic production beds. This is good for the fish because plant roots and rhizobacteria remove nutrients from the water. These nutrients—generated from fish manure, algae, and decomposing fish feed—are contaminants that would otherwise build up to toxic levels in the fish tanks, but instead serve as liquid fertilizer to hydroponically grown plants. In turn, the hydroponic beds function as a biofilter— stripping off ammonia, nitrates, nitrites, and phosphorus—so the freshly cleansed water can then be re-circulated back into the fish tanks. The nitrifying bacteria living in the gravel and in association with the plant roots play a critical role in nutrient cycling; without these microorganisms the whole system would stop functioning[14].

Figure 3.01-The different Aquaponic systems used. http://pacificaqua.org/wp-content/uploads/2011/11/Aquaponics-Systems.jpg

The whole idea of using aquaponics in this project is really exciting and the idea of having aquaponics integrated into the living walls of the container design would be a really innovative and sustainable aspect that could really make the design standout from the rest. Especially here in Hawai‘i where space is limited and often times people don’t have the space to grow their own food. By going

[14] http://www.backyardaquaponics.com/Travis/aquaponic.pdf (pp.1)
14

vertical and growing your foods along the side of your house, there are more opportunities to live a better and more sustainable life. Another advantage when growing on the side of your house is that it provides insulation. The plants need sunlight to live and grow and by orienting the living walls to be on the sides of the house where there is most sunlight are beneficial for everyone. This causes a decrease in heat gain resulting in less electricity that would have to be used for fans, A/C, or other cooling devices. And the plants continue to grow and produce food for the user resulting in less money spent on groceries and less energy used to go and buy produce that has to be imported here from elsewhere. By keeping it local, you improve the quality of life for not only you, but for everyone on the island by using less energy.

The issue is figuring out a way to integrate aquaponics into a living wall system. There are some things that need to be considered if this is going to be a successful system. The weight of the plants and water will have to be calculated and measured to see if the container will be able to structurally hold it. The container should not have any problems holding this system as they were built to withstand the weight of eight shipping containers stacked vertically on top of it. Another thing is how to get the right amount of water to all the plants and how to get it back into the fish tank. There are many other things that will have to be considered when it comes time to design a system that will function.

There are many different ways you can construct an aquaponics system, and there are a variety of systems to use. Each is unique in its own way, but they all perform in the same manner. Some stack the plants above the fish tank and other systems have a side-by-side or staggered design.

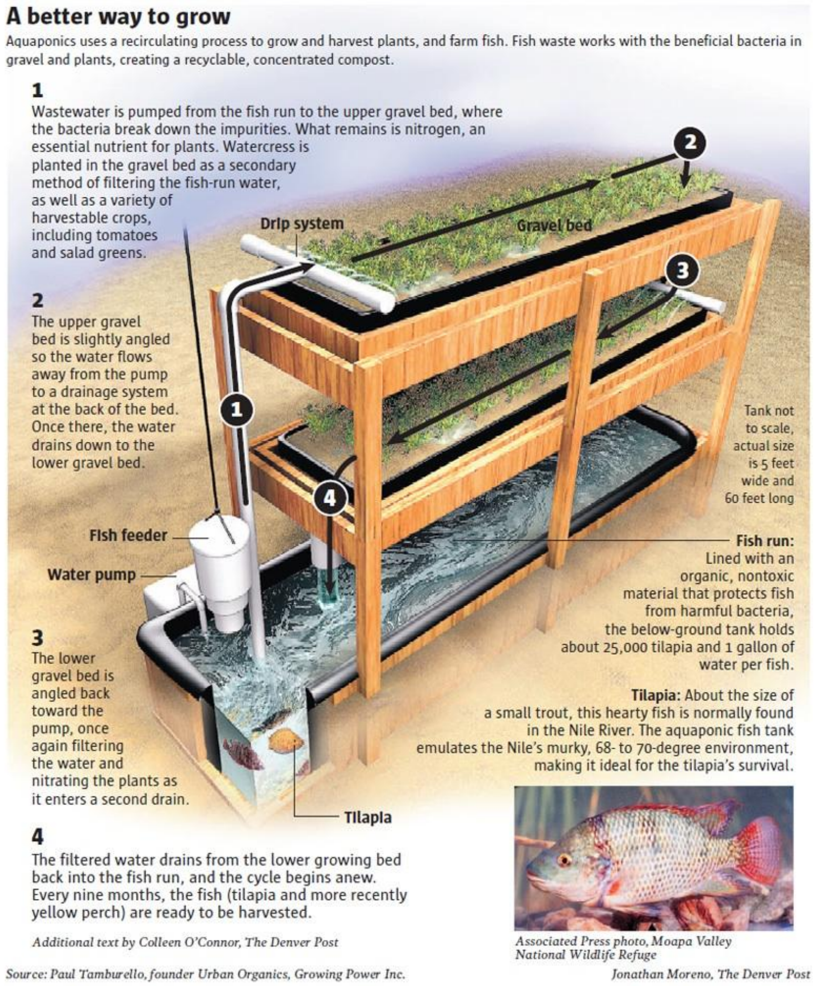

Figure 3.02- Aquaponic Design http://aquaponicsplan.com/wp-content/uploads/2013/05/aquaponic-farm-18.jpg

Regardless of what system will be used, each one will grow plants and fish. Some may do better than others. There are many factors to think about when choosing a system so that it will have the greatest yield. The climate, location, species of fish and plants that will be grown, what the fish will be fed, what kind of growing medium will be used for the plants are a few, keeping in mind that all of these factors need to be compatible with each other to ensure a successful system. The beauty of aquaponics is that it can be applied to any location, as long as there is a source of water to start up the system, and to top it off every once in a while. Even arid environments can sustain an aquaponics system and provide fresh fruit, vegetables and fish. Here in Hawai'i, aquaponics does very well. We have such a rich and lush environment. The windward side of O'ahu is very lush because of the ample amounts of rainfall it receives, and by harvesting the rainwater a self-sufficient system can be maintained without having to rely on water from the ground. Windward Community College has a great system set-up near the hospital where the patients can help care for the plants and fish and in turn grow produce for themselves and others. It is also a therapeutic activity that gets them outside in the fresh air and makes them happy when they see that the work they have done has grown fruits and vegetables they can eat. Aquaponics can be very time consuming at first, but once the system is established and the right bacteria and enzymes are grown, it is very rewarding.

Figure 3.03- Aquaponic facility located at Windward Community College on O'ahu
http://sbccaquaponicsproject.edublogs.org/files/2012/11/DSC_0040-pzhrvc.jpg

Many different Living wall systems were investigated as possible systems to use in the prototype design. Some aspects will work, but no system as a whole will be able to work. Unless it is heavily modified, a hybrid of a couple of different systems will have to be created. Each system follows the same basic design. A structural framing system attaches to the wall and a hard surface such as PVC sheeting or gypsum board is layered on. A water proofing membrane is applied, then the growing medium and then the plants. A water catchment system is also installed. Each green wall follows a design such as this, but each one has some modifications and extras designed into it to make it unique.

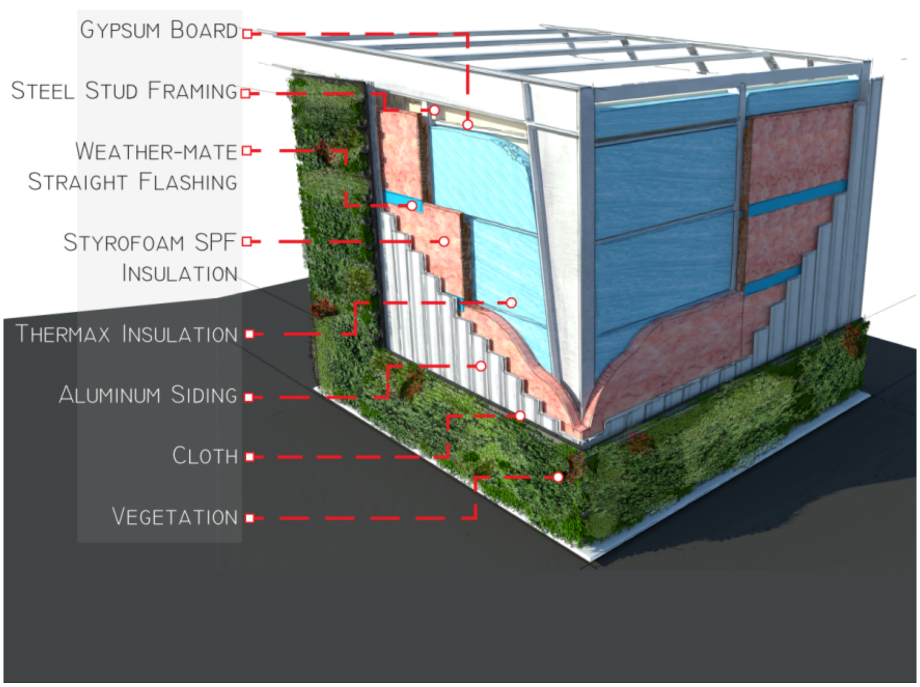

Figure 3.04- Components of a Living Wall. http://1.bp.blogspot.com/ScaledforPORTFOLIO.png

Figure 3.05- Living Wall applied to exterior of storefront.
http://www.greenroofs.com/projects/grand_rapids_downtown_market_living_wall

A company called LiveWall produces a tray like system that would be the most successful to use in the design. The trays can easily be removed or added onto for maintenance. The trough like design has the most potential to be integrated with aquaponics. A delivery system would have to be figured out that would work with the aquaponic system.

Figure 3.06- LiveWall system. http://ww1.prweb.com/prfiles/2012/06/07/9823601/LiveWall_3b.jpg

The following are examples of a LiveWall system that were installed on the exterior of a market and results can be seen in Figure 3.07.

Figure 3.07- LiveWall just after two weeks. https://62a4ce0f8d-custmedia.vresp.com/Downtown_Market_LiveWall_5.24.2013.jpg

Figure 3.08-Another type of Living wall System.
http://gbssmag.com/wp-content/uploads/2012/08/LiveWall_MAIN_PIC.jpg

Other systems researched were grid-like designs that were not as easily removable as the LiveWall was. These would be much harder to combine with an aquaponics system. It was still interesting looking at how they are designed and how they work. The following are some examples of the grid/tray system.

Figure 3.09- Gsky Green Wall http://www.resourcedir.com/insight/natural-living-wall-gardens-from-cnforefront.html

Figure 3.10- Gsky system applied to storefront. http://www.hydroscapesolutions.com/wp-content/uploads/2013/11/CIMG0086.jpg

Another system that was investigated used vertical growing designs. This design has the potential to be successful when paired with an aquaponics system, but they lack the coverage needed to properly insulate a container.

Figure 3.11- Vertical design. http://blog-imgs-60-origin.fc2.com/c/r/i/criuse603/Aquaponic-System-Sump-Tank-5.jpg

After researching the many different living wall and aquaponic systems, research was done to see if any systems exist that had integrated these two together. There were a couple of different designs that were found that were very interesting and promising. One design actually uses a shipping container. They are called "Urban Farming Units" and are successfully producing vegetables and fish. They took the idea of a greenhouse and placed it on top of a shipping container. The aquaponic system is housed in the interior of the container, which includes the pumps, electrical equipment, fish tank, and other supplies. There are stairs leading up to the growing area where they have a tray like system set up just like LiveWall did. It's more of a continuous trough and this system has the most potential to be applied to the design. It is very efficient and is able to grow enough food for ten people. It's great because these units can be added to one another and modified to fit the users' needs.

Figure 3.12- Urban Farming Unit. http://sustainablediary.blogspot.com/2013/02/ufu-urban-farming-unit-by-damien.html

Figure 3.13- Actual Urban Farming Unit. http://sustainablediary.blogspot.com/2013/02/ufu-urban-farming-unit-by-damien.html

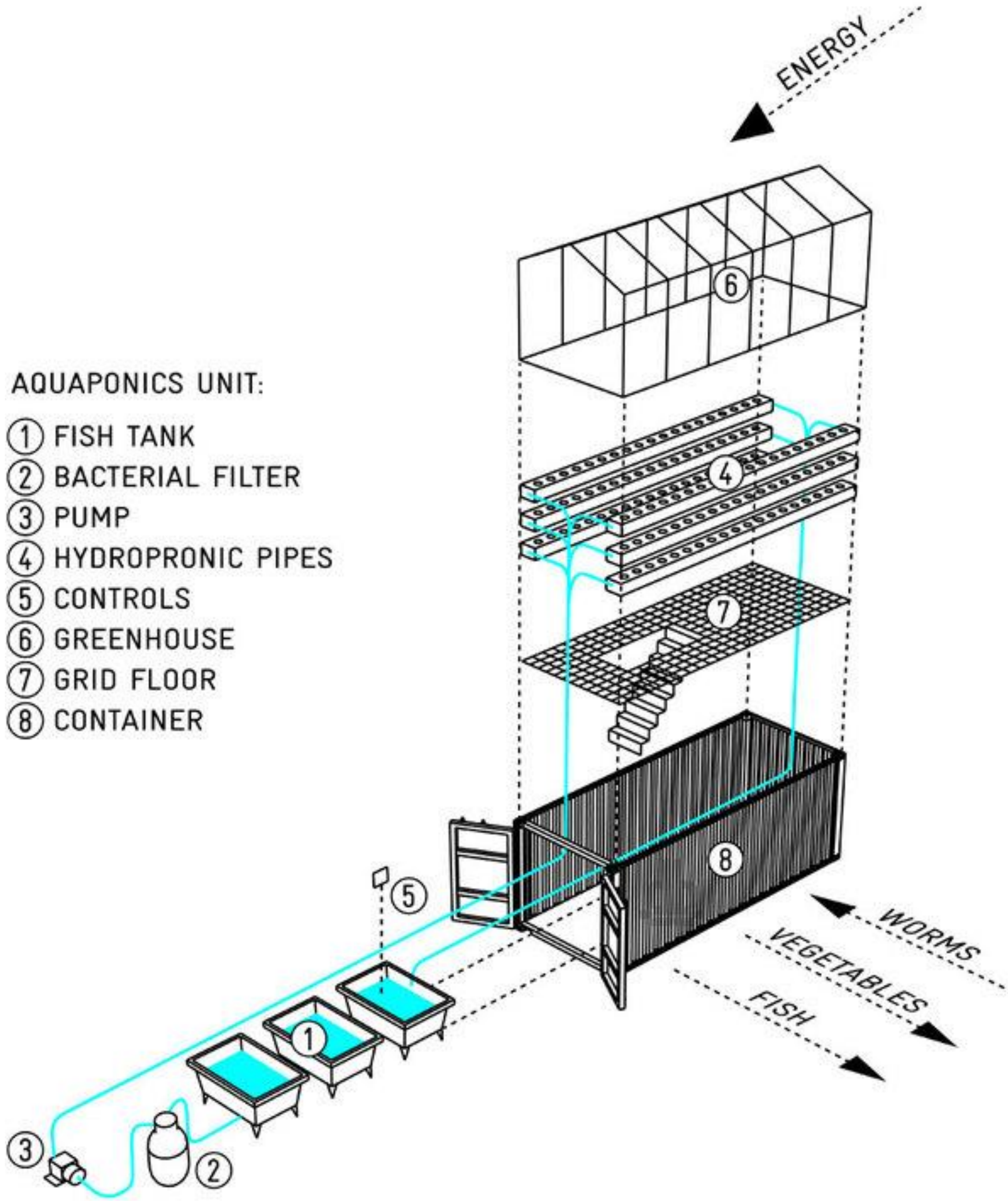

Figure 3.14- Axonometric drawing of UBU. http://sustainablediary.blogspot.com/2013/02/ufu-urban-farming-unit-by-damien.html

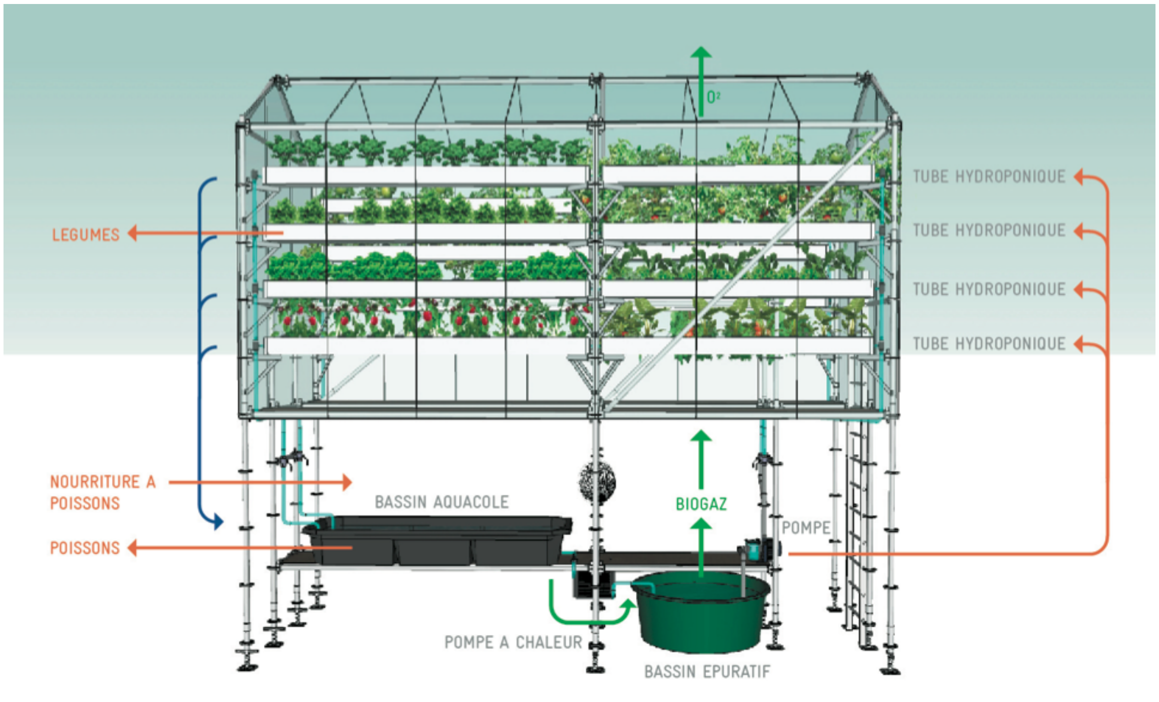

Figure 3.15- Components of a UBU. http://sustainablediary.blogspot.com/2013/02/ufu-urban-farming-unit-by-damien.html

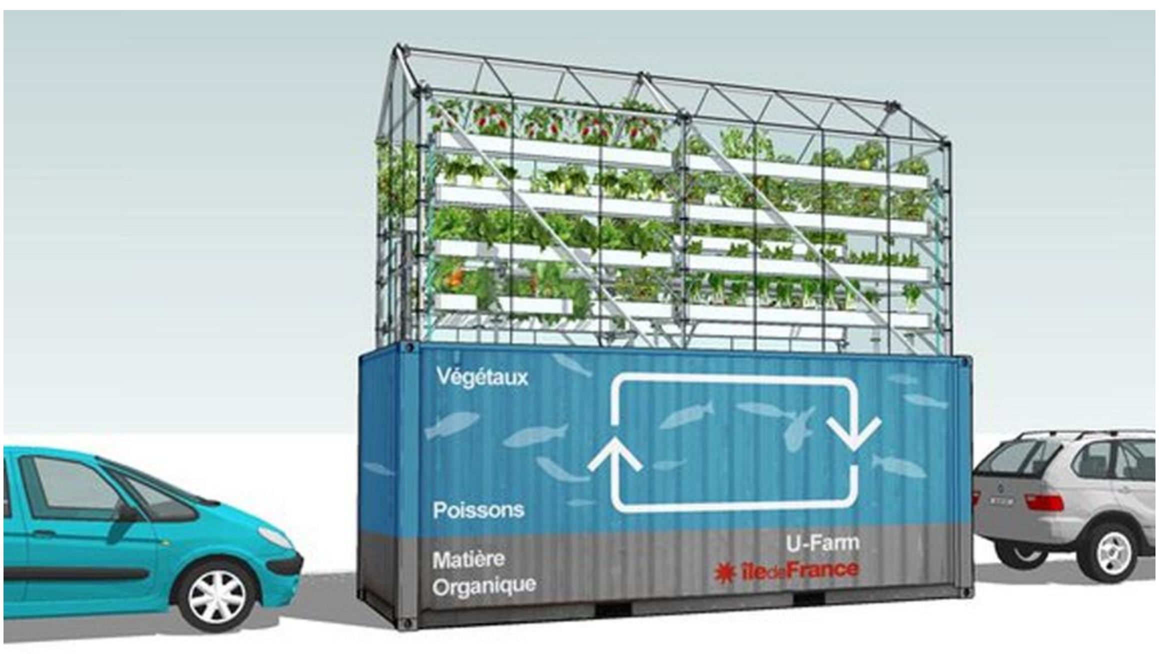

Figure 3.16- http://sustainablediary.blogspot.com/2013/02/ufu-urban-farming-unit-by-damien.html

One other system that was found had all the components that were being researched, integrated into one design. It was a self-sufficient system that used solar as the energy source for the aquaponic system, allowing it to be off grid. It was named the "Inka Sun Curve". The design is very appealing and if it could somehow be applied to a shipping container, it has the potential to be successful. It is quite large, but it could be scaled down in order to fit on the side of a container and is aesthetically pleasing as well as functional.

Figure 3.17- Inka Sun Curve. http://webecoist.momtastic.com/wp-content/uploads/2009/12/inka-sun-curve-2.jpg

Figure 3.18- http://www.inkabio.com/images/home_agricultural.png

There are many different types of aquaponic systems out there, each having a unique variation to it. After researching these systems, a better understanding of how aquaponics work was gained and gave inspiration to the Living Wall system that would be part of the experiment.

The following chapter will explore the proper way to insulate a container and will also look at what types of insulations would be best applied to the exterior of a container. The different types of insulations that were researched can be found in Appendix B.

[INSULATION]

Insulation is a very important factor here in Hawaiʻi. Due to our mild tropical climate, temperatures are relatively warm year around. Hawaiʻi is the nation's largest per capita consumer of electricity. Air condition is the most substantial component found on the average electricity bill. On Oahu alone, 20% is used for the sole purpose of cooling commercial buildings year-round[15]. In residential buildings, typical utility bills are $90 per month. The cost jumps up to more than $200 per month for air-conditioned homes[16]. Choosing the right insulation is one of the most important decisions to make when designing a building. There are many different types of insulation out there, each having their own advantages and disadvantages and some that work best in certain conditions and environments.

[15] http://honoluluswac.com/_assets/_pdfs/HSWAC-BrochureNew.pdf
[16] http://energy.hawaii.gov/wp-content/uploads/2011/09/HI-Home-Owners-Guide.pdf

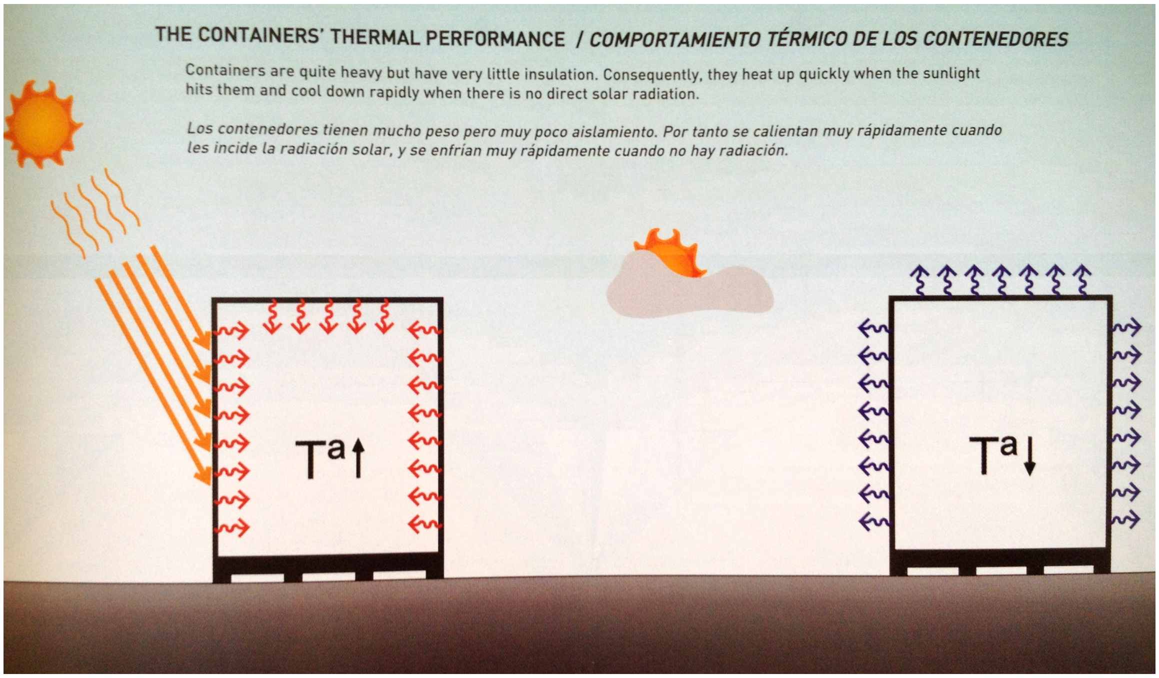

Figure 6.00- The Containers' Thermal Performance. Sustainable Architecture Containers (pp.17)

The Containers' Thermal Performance

Containers are quite heavy and they come with very little insulation. Consequently, they heat up quickly when the sunlight hits them and cool down rapidly when there is no direct solar radiation[17]. Since containers weigh quite a lot, they will have a high thermal inertia. According to the Merriam-Webster Dictionary, thermal inertia is defined as: the degree of slowness with which the temperature of a body approaches that of its surroundings and which is dependent upon its absorptivity, its specific heat, its thermal conductivity, its dimensions, and other factors. This means that containers are able to absorb and lose heat very quickly, turning the interior into a very uncomfortable place. Therefore insulation must always be installed on the exterior.

[17] Sustainable Architecture Containers. (pp.17)

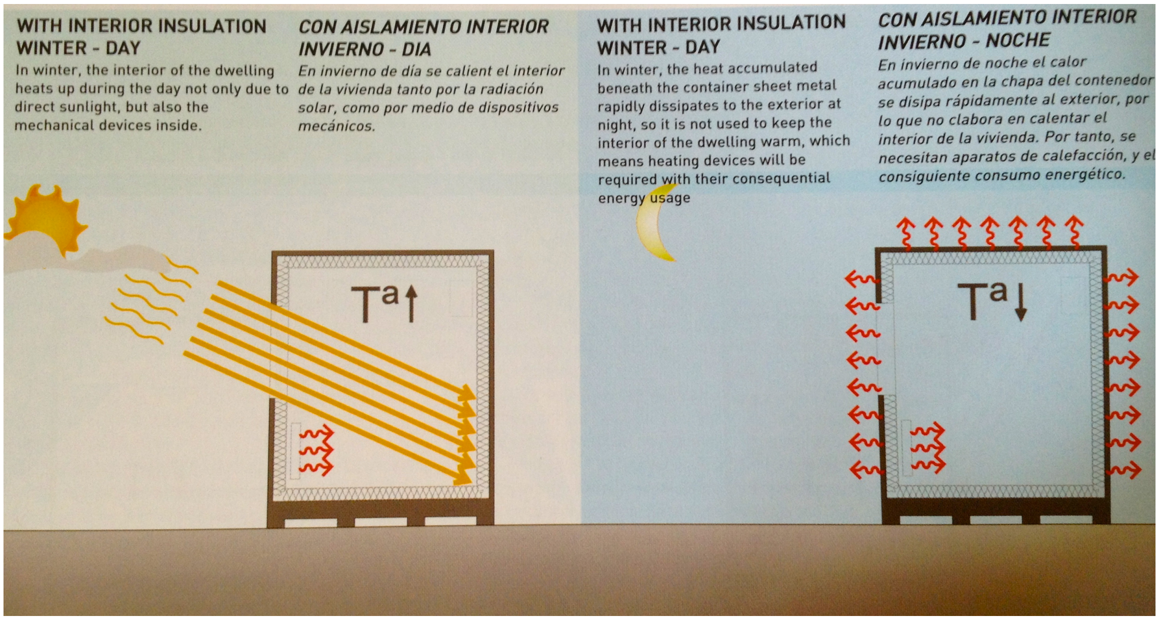

Figure 6.01 – Interior Insulation. Winter. Sustainable Architecture Containers (pp.18)

With Interior Insulation Winter-Day

In the winter, the interior of the dwelling heats up during the day not only due to direct sunlight, but also the mechanical devices inside[18].

With Interior Insulation Winter-Night

In the winter, the heat accumulated beneath the container sheet metal rapidly dissipates to the exterior at night, so it is not used to keep the interior of the dwelling warm, which means heating devices will be required with their consequential energy usage[19].

[18] Sustainable Architecture Containers. (pp.18)

[19] Sustainable Architecture Containers. (pp.18)

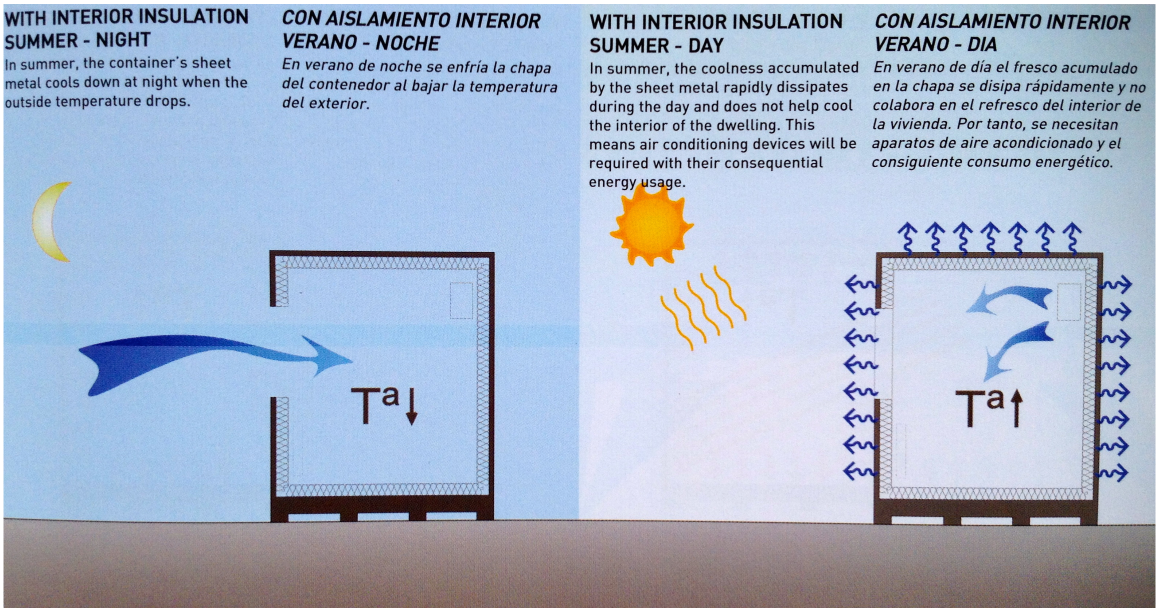

Figure 6.02- Interior Insulation. Summer. Sustainable Architecture Containers (pp.19)

With Interior Insulation Summer-Night

In summer, the container's sheet metal cools down at night when the outside temperature drops[20].

With Interior Insulation Summer-Day

In summer, the coolness accumulated by the sheet metal rapidly dissipates during the day and does not help cool the interior of the dwelling. This means air conditioning devices will be required with their consequential energy usage[21]

[20] Sustainable Architecture Containers. (pp.19)

[21] Sustainable Architecture Containers. (pp.19)

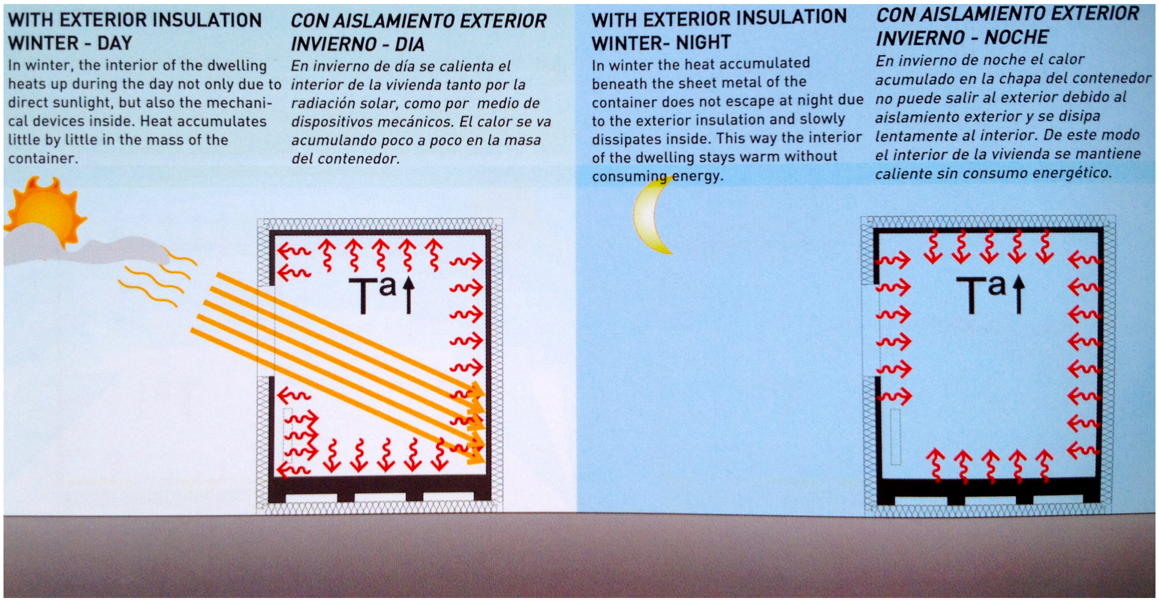

Figure 6.03- Exterior Insulation. Winter. Sustainable Architecture Containers (pp.20)

With Exterior Insulation Winter- Day

In winter, the interior of the dwelling heats up during the day not only due to direct sunlight, but also the mechanical devices inside. Heat accumulates little by little in the mass of the container[22].

With Exterior Insulation Winter - Night

In winter, the heat accumulated beneath the sheet metal of the container does not escape at night due to the exterior insulation and slowly dissipates inside. This way the interior of the dwelling stays warm without consuming energy[23]

[22] Sustainable Architecture Containers. (pp.20)

[23] Sustainable Architecture Containers. (pp.20)

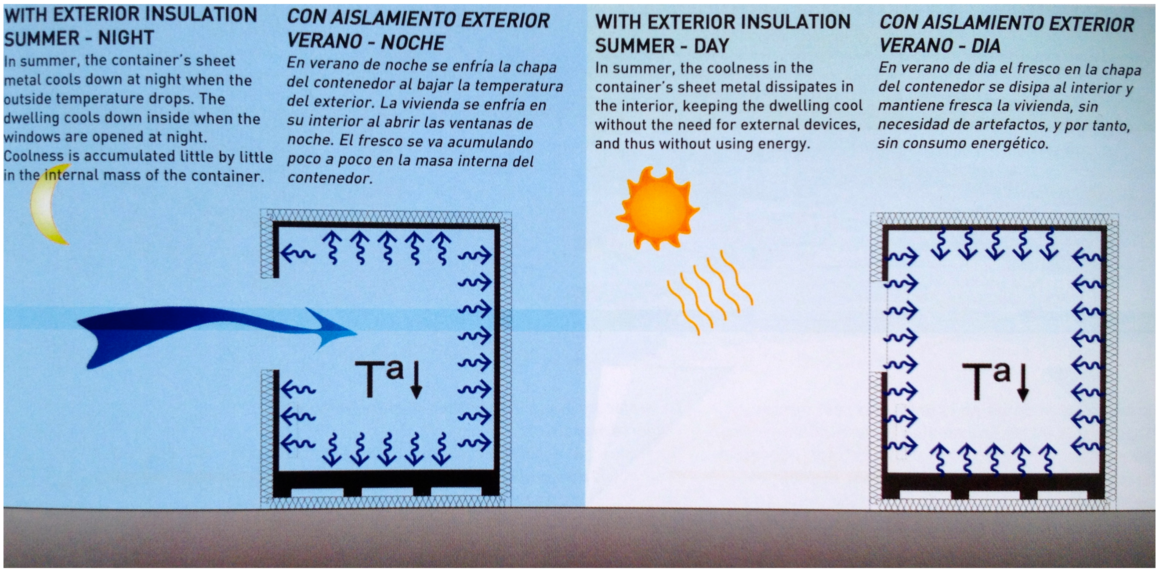

Figure 6.04- Exterior Insulation. Summer. Sustainable Architecture Containers (pp.21)

With Exterior Insulation Summer-Night

In summer, the container's sheet metal cools down at night when the outside temperature drops. The dwelling cools down the inside when the windows are opened at night. Coolness is accumulated little by little in the internal mass of the container[24].

With Exterior Insulation Summer - Day

In summer, the coolness in the container's sheet meal dissipates in the interior, keeping the dwelling cool without the need for external devices, and thus without using energy[25].

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24 Sustainable Architecture Containers. (pp.21)

25 Sustainable Architecture Containers. (pp.21)

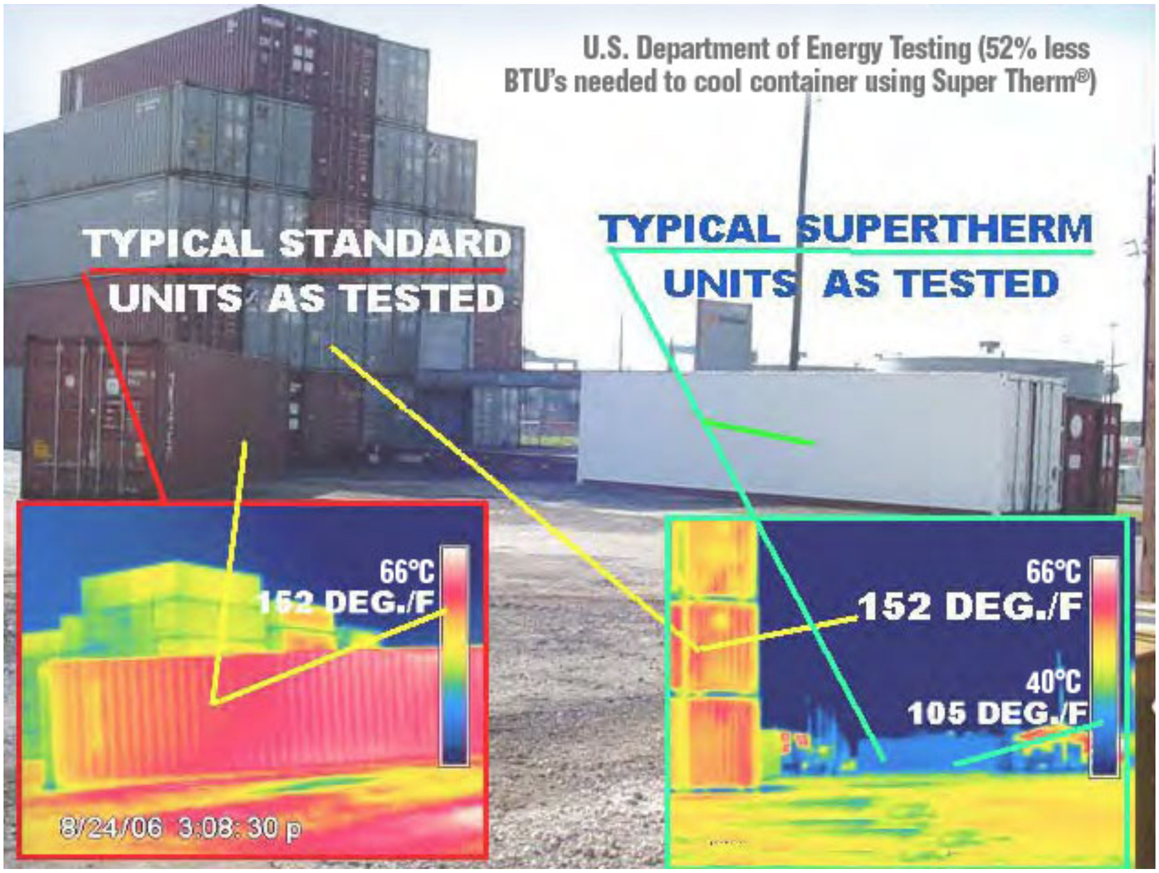

Figure 6.07- Comparison between typical container and supertherm cover container. http://www.superiorcoatings.net.au/images/products/super-therm/Containers-BTU-test.jpg

The best alternative for insulating a shipping container appears to be a product called Supertherm. It has the thinnest application, which is a very important factor when it comes to the limited amount of space that a shipping container offers. Usually insulation ranges from 6-8 inches thick, but with Supertherm, each layer is only 7 mils (0.007 in). With each layer of coating, it has a Flame Test Spread of 0 for both flame and smoke, an R-value of 19, ability to withstand 500°F constant temperature over a long period of time, noticeable sound deadening qualities, and very low VOC (volatile organic compounds). Supertherm is also a good candidate as it can be painted or sprayed on, which makes it easier to get in between the corrugated metal of the container. For more information on the different types of insulation see Appendix B.

Different factors were taken into account when deciding on what type of insulation would be used for the experiments. The following criteria was formulated:

- Easy application
- High R-value
- Low VOC's
- Use of sustainable materials
- Able to be applied to metal surfaces
- Cost-effective
- Availability
- Locally sourced

These were the main characteristics chosen and they were used to find two types of insulation that would be used during the experiment. The following chapter will explore the different types of insulations used as well as the process of setting up the experiments and procuring all the necessary materials and equipment to ensure that the experiment would have valid results.

[EXPERIMENTS]

In order to ensure that the experiments yielded the most accurate results, the selected site would need ample open space to allow for direct sunlight during the day and easy access throughout the day. Also needed would be aquaponic materials and equipment that was accessible, and someone willing to allow these experiments to be conducted on their property. There were a lot of variables to consider and it was a bit overwhelming. After searching for a site that would be suitable for the new project and talking with many different contacts, one was finally found. Hale Tuahine would be the new home to these experiments.

Site

Hale Tuahine is located in the Manoa Valley and can be found at 2768 Woodlawn Drive. Schools, libraries, restaurants, grocery stores and residential homes can be found in the surrounding area. Hale Tuahine is part of the University of Hawai'i at Manoa College of Tropical Agriculture and Human Resources (CTAHR). In 2012, 10,000 square feet of land from the Magoon Research Facility in Manoa was obtained. The site, lead by Dr. Clyde Tamura, is a place where research is conducted on plants grown by aquaponic systems compared to traditional soil grown plants. The site is also shared with a group of high school students along with their mentors, who have created a Community Support Agriculture farm for the students and community[26].

Figure 7.00- Location of Hale Tuahine. http://maps.google.com

[26] https://sites.google.com/site/fetchhi/where-we-work/hale-tuahine

The facility is growing many different plant types using aquaponics. It is an inspiring site to see. All the plants are fed water that comes from fish tanks below them and the water is filtered and returned back to the tanks. The yield from the aquaponic plants compared to soil grown plants is astounding. There is a clear difference in size and rate of growth between the two, as shown in Figure 7.01

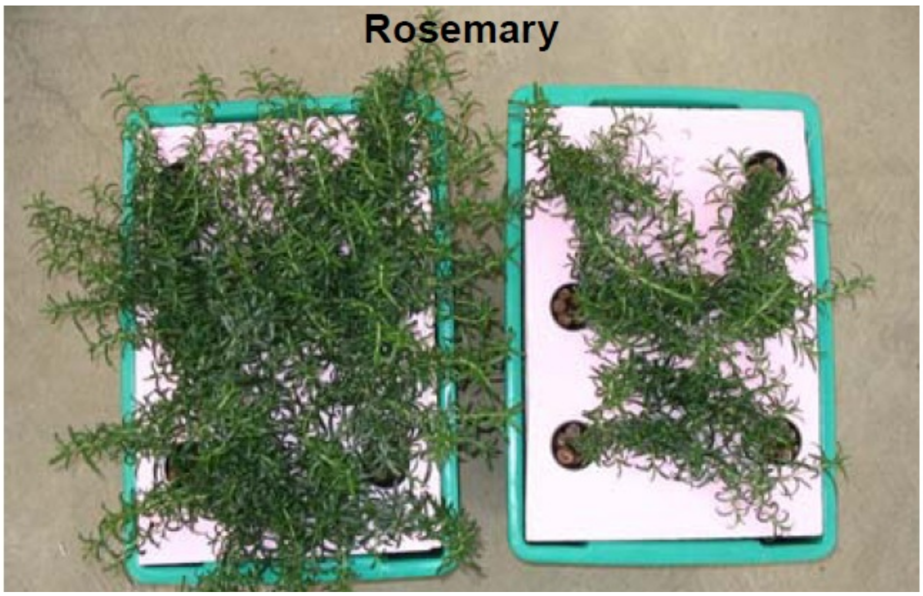

Figure 7.01- Comparison between aquaponics and soil.
http://aquaponicsplan.com/wp-content/uploads/2013/05/aquaponics-hydroponics-4.jpg

Site Selection

RuthEllen Kilnger-Bowen is the current director at Hale Tuahine. She and Bradley Fox were very instrumental in making things happen and allowing the experiments to take place at Hale Tuahine. They allotted space where the experiments could take place as well as making available all the materials and equipment needed for an aquaponic system. They were both very interested in the project and that helped get the process started. The project was beneficial for them, as they would be able to learn from my experiments and use the information for studies they will be conducting. There was ample space at the site and the experiments were not in the way or interfering with any other studies. It was also out in the open, giving the site a lot of sun exposure, which is exactly what was needed for the study.

Figure 7.02- Aquaponic materials and equipment. Photograph by Richard E. Mead III

Experiments

Originally, testing was going to be done on four container pieces. They would be standalone pieces and only one side would have the different types of insulation applied. After thinking it over with the committee, it was decided that it would be better if the testing were done on boxes, each having four sides, a top and a bottom that were sealed. This would provide much more accurate results and would also allow for sensors to be installed that would monitor temperature and relative humidity measurements.

Figure 7.03- HOBO data logger for interior temperature and relative humidity sensor. HOBO onset exterior temperature sensor. Photograph by Richard E. Mead III

Process- Container Boxes

The process of getting the container boxes together and ready for testing had to be one of the most challenging ordeals experienced during the project. There were a lot of problems with communication, scheduling and timing. Many of these things could have been avoided with careful and deliberate planning. This was a very valuable lesson learned and will help with projects in the future.

It was very difficult obtaining the container pieces. There were a few companies that would scrap their cutouts when modifying containers. Chris Thometz was contacted at Container Storage Company Hawaii and was asked if he had any scraps available. He said at the time that he had just thrown away a large bin of them and to come back next week and he would have more. When the end of the week arrived, a trip was made down to Sand Island in hopes of getting scraps. There were maybe a few cutouts and a very large piece that would not fit in a truck or be manageable to carry. Chris sent an email later saying they would be starting a large job where they would be cutting out 3' x 3' pieces for windows from 187 containers. This would be perfect because the pieces would all be relatively the same size and shape and there would be a large quantity of them. It took about 3 weeks to actually get enough to work with.

Figure 7.04-Pieces cut from shipping container to be welded together. Photograph by Richard E. Mead III

From there the pieces were taken to a welder where they were turned into the boxes needed for the experiment. When it came time to pick them up, there was another challenge presented. The boxes had only been tack welded together and the top piece was not in the right place. They were supposed to be seam welded so that it would be sealed and the top was supposed to be recessed about 6 inches down from the top of the side pieces so there wouldn't be any openings.

Figure 7.05- 3' x 3' welded container boxes. Photograph by Richard E. Mead III

This was a big setback because the boxes would have to be sealed and this would delay the start of the testing. A lot of different theories on how to seal these boxes were thought of and then thrown out. Finally, after much deliberation, it was decided that spray foam would be the best alternative

Figure 7.06- Process of sealing container boxes. Taping voids. Photographs by Richard E. Mead III

Cans of the spray foam can be found at most hardware stores such as Home Depot, Lowes, City Mill, etc. It is a very simple product to use. Simply spray the foam into the cracks and it expands and fills the void. The excess foam can then be trimmed off with a serrated blade.

Figure 7.07- Materials used to seal the box and the process of taping the gaps to keep the foam in. Photographs by Richard E. Mead III

After the foam was given time to cure (24 hours according to the directions on the can), it was stable enough to cut and trim off the excess. The tape was also ready to come off, and after doing so it revealed a nice, clean, even finish. The seals were inspected to ensure that all gaps or openings were covered.

Figure 7.08- Result of spray foam. Smooth finish with all the voids sealed properly. Photographs by Richard E. Mead III

After the interior was sprayed with foam, plywood was applied to the bottoms of each box, and sealed with spray foam as well. The spray foam was very successful and all the boxes were sealed and ready for the next phase.

Reflection

This stage had to have been the most challenging and stressful part of the whole experiment. As difficult as it may be to try and coordinate with contacts that don't follow through, it the student invaluable experience that not only taught him how to deal with difficult situations, but also allowed him to test his problem solving capabilities. The student was faced with many different obstacles and each one needed to be approached in a different manner. In the end, each problem had a solution, some of which were easier to find than others. As each problem was solved, the task became easier and the goal became clearer.

Process- Spray Foam Insulation Application

There was much deliberation on which insulations were to be used in the experiments. Of the many different types that are available, foam-in-place insulations seemed to be a good fit when it came to applying them to the side of a shipping container. These foams are applied by using a pressurized applicator, giving an even and consistent coating on the surface.

Chad Johnston, one of the doctorate committee members, was able to put the student in contact with Bob Johnson, President of Pacific Industrial Coatings. They specialize in spray-applied polyurethane foam for roofing and interior insulation. He informed the student by saying:

> "there are basically two types of spray applied foam for insulation, there is open cell and closed cell. The open cell has no structural strength and has an r-value of 3.5 to 4.2 per inch applied. For your type of project it must be protected with drywall or it would get damaged and should only be applied to the inside. Closed cell foam can be walked on and can be applied to the outside or inside. If applied to the outside only regular coating is needed to protect the foam. If applied to the inside it should be protected by drywall or an intumescent coating must be applied for fire code regulations."

After going back and forth with emails, Bob was able to get in contact with his partner, Red Coleman, who would be able to meet at their location where they would apply the spray foam. They are located in Sand Island, close to the Coast Guard station. The box was dropped off and Red was informed to spray the 4 sides of the box with 2" thick closed cell foam and the top with 3" thick foam. The moment the foam is sprayed onto a surface, it takes approximately 6-10 seconds for it to rise and be tack-free and is fully cured in 4 hours[27]. Gaco 183M is a two component HFC-blown (zero ozone-depleting) liquid spray system that cures to a medium-density rigid cellular polyurethane insulation material. Gaco 183M contains polyols derived from naturally renewable oils, post-consumer recycled plastics, and

[27] http://www.gaco.com/products/Brochure_PDS_183M_w.pdf

pre-consumer recycled materials. This closed cell foam is designed to provide: excellent thermal performance, air impermeable insulation, and an integral part of an air barrier assembly [28].

Figure 7.09 – Information on closed cell spray foam. Pacific Industrial Coatings.

[28] http://www.gaco.com/products/Brochure_PDS_183M_w.pdf

GacoWallFoam
SPRAY POLYURETHANE FOAM INSULATION

System 183M Two Pound Closed Cell Foam Product Data Sheet

183M is an HFC-blown (zero ozone-depleting) liquid spray system that cures to a medium-density rigid polyurethane insulation material. It contains polyols derived from naturally renewable oils, post-consumer recycled plastics, and pre-consumer recycled materials. 183M does not contain CFC's, HCFC's or other gases harmful to the environment. This system can be sprayed on clean, dry substrates down to 35°F (2°C). It is a class I fire rated foam that meets the requirements of ICC-ES AC377 Acceptance Criteria for Foam Plastic Insulation. 183M meets the requirements of AC377 Appendix X for use in attic and crawl spaces without an additional ignition barrier.

TECHNICAL INFORMATION — To ensure optimum performance, a minimum pass thickness of 3/4" (1.9 cm) is recommended with the maximum not to exceed 2" (5.1 cm) per pass. For typical equipment settings, consult Gaco Western's GacoFoam Spray Guide.

PROPERTY	TEST TEMPERATURE	ASTM TEST	UNIT	VALUE
Nominal Density (Sprayed In Place):	77°F (25°C)	D-1622-03	lbs/ft³	1.8 - 2.2
R-Value *See Note Below	75°F (23.9°C)	C-518	h · ft² · °F/Btu h · ft² · °F/Btu	R 6.4 at 1" R 23.3 at 3.5"
Compressive Strength (Parallel to Rise):	77°F (25°C)	D-1621-04a	psi	32
Tensile Strength:	77°F (25°C)	D-1623	psi	64
Water Absorption:	77°F (25°C)		%	0.45
Water Vapor Transmission:	77°F (25°C)	E-96-05	perm-in	1.12
Dimensional Stability (7 Days):	158°F (70°C) / 95% RH	D-2126-99	% linear. change	L=6%, W=5%, T=3%
Recommended Service Temperature Range:	77°F (25°C)		°F / °C	-40°F to 200°F (-40°C to 93°C)
Closed Cell Content:	77°F (25°C)	D-6226-05	%	97.8
Air Permeance @ 75Pa (Infiltration/Exfiltration)	77°F (25°C)	E-283-04	L/s/m²	0.000 / 0.000 (@ 1" thickness)

* NOTE: Federal Trade Commission regulations published in the Federal Register 16 CFR Part 460 require that R value testing of polyurethane foam insulation must be conducted on aged samples at a 75°F mean test temperature. Failure to comply can result in substantial fines by the FTC.

SURFACE BURNING CHARACTERISTICS — ASTM E84-05 (Also known as ANSI 2.5, NFPA 255, UBC 8-1 (42-1) and UL 723)

SYSTEM	THICKNESS	FLAME SPREAD INDEX	SMOKE DEVELOPED INDEX
WallFoam 183M	4" (10.2 cm)	10	400

ROOM CORNER FIRE TESTING — NFPA 286 (AC377 Appendix X)

LOCATION	FOAM THICKNESS
Walls	Up to 9.5" (24.13 cm)
Ceiling	Up to 11" (27.94 cm)

TYPICAL LIQUID CHEMICAL PROPERTIES — "A" Component contains polymeric isocyanate. "B" Component contains polyol, catalysts and blowing agents.

PROPERTY	TEST TEMPERATURE	ASTM TEST	UNIT	VALUE
Viscosity – "A" Component: Viscosity – "B" Component:	77°F (25°C)	D-2196-68	cps	180 ± 20 750 ± 50
Specific Gravity – "A" Component: Specific Gravity – "B" Component:	77°F (25°C)	D-1638-70	S.G.	1.22 1.20
Weight/Gallon – "A" Component: Weight/Gallon – "B" Component:	77°F (25°C)		lbs/gal	10.2 10.0
Mixing Ratio – "A" & "B" Component	77°F (25°C)		By volume	1:1
Stability When Stored at 50°F to 70°F (10°C to 21°C)			Months	"A" Component: 1 year "B" Component: 6 months

EQUIPMENT SETTINGS

SETTING	VALUE
Pre-Heat: Iso (A)	115°F - 130°F (46.1°C - 54.4°C)
Pre-Heat: Poly (B)	115°F - 130°F (46.1°C - 54.4°C)
Hose Heat	115°F - 130°F (46.1°C - 54.4°C)
Recommended Spray Pressure	1,200 - 1,400 psi (dynamic)

PRODUCT CHARACTERISTICS

CHARACTERISTIC	VALUE
Cream Time	0 - 1 sec
Rise Time	3 - 5 sec
Tack Free Time	3 - 5 sec
Cure Time	4 hours

The information herein is believed to be reliable but unknown risks may be present.
ALL WARRANTIES OF ANY KIND, EXPRESSED OR IMPLIED, INCLUDING WARRANTIES OF FITNESS FOR A PARTICULAR PURPOSE AND THAT GOODS ARE OF MERCHANTABLE QUALITY, ARE SPECIFICALLY DISCLAIMED. See Gaco Western for information concerning its limited warranty and its availability.

GWFDS1 0913

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Figure 7.10 – Technical Information on closed cell spray foam. Pacific Industrial Coatings.

According to the information packet that was given by Bob Johnson (Figure 7.08), the R-value of the closed cell foam is 6.4 at 1" thickness and 23.3 at 3.5". For the side walls at a 2" thickness the R-value would be 13.3 and the top at a 3" thickness would be 19.9. Fiberglass batt insulation at a 6" thickness has an R-value of approximately 19[29]. The same R-value can be obtained by using half the thickness of material needed for fiberglass batt. This decreases the overall amount of material needed to complete a job and saves the owner time and money.

The box was sprayed and ready to be picked up later that afternoon. It was impressive how fast they were able to complete the job. For the amount of foam that was applied to the box, it was surprisingly light, but sturdy enough to be able to withstand the weight of a person as they walked on top of the box. The box was then installed at the Hale Tuahine site and nothing else needed to physically be done to the box. All that was left to do was to add the temperature sensor to the interior and seal it up.

Figure 7.11- Closed cell spray foam box. Strong enough to hold up my weight while standing on top. Photograph by Richard E. Mead III

Reflection

This was the easiest box to install. The only thing that took some time was coordinating a time and day in which the box could be dropped off and sprayed. Pacific Industrial Coatings was very helpful and key to getting this insulation installed. Bob Johnson was generous enough to do the job at no charge. All he

29 http://www.bobvila.com/articles/395-ceramic-coatings-for-increased-insulation/#.U0-fLOZdVr4

asked was that the data be shared with him. They had planned on doing a similar test with shipping containers and this project was a way for both of us to get what we needed.

Process- Elastomeric Paint Application

While researching the many different types of insulation, elastomeric paint was a type that could easily be applied to the container boxes. This is not an ordinary paint that you get from the hardware stores. It has special insulating ceramic additives that are mixed into the paint. The microspheres in the insulating ceramic additive have compressive strengths up to 6,000 psi, a softening point of about 1800° C., and they are fairly chemical resistant, with low thermal conductivity of 0.1 W / m / Deg.C[30]. The scientific process went one step farther and improved on the ceramic microspheres by removing all the gas inside which created a vacuum.

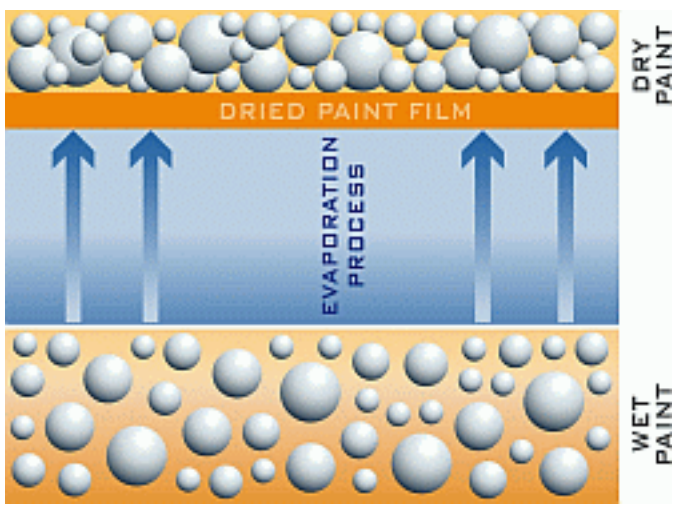

Figure 7.12- Illustration of elastomeric bonds. http://www.hytechsales.com/insulating_paint_additives.html

Physics law states that nothing can move by conduction through a vacuum, since it represents an absence of matter. In effect we have a miniature thermos bottle… a

[30] http://www.hytechsales.com/insulating_paint_additives.html

microscopic hollow vacuum sphere that resists thermal conductivity and reduces the transfer of sound[31]. The painted surface dries to a tightly packed layer of the hard, hollow "microspheres. The tightly packed film reflects and dissipates heat by minimizing the path for the transfer of heat. The ceramics are able to reflect, refract and block heat radiation (loss or gain) and dissipate heat rapidly preventing heat transfer through the coating with as much as 90% of solar infrared rays and 85% of ultra violet-rays being radiated back into the atmosphere[32].

At 8' wide, shipping containers are already short on space. Adding bulky insulation reduces the already limited amount of useable space. When measuring the thickness of paint, mils are used to represent a thickness.
1 mil = .001 inches or a thousandth of an inch[33]. When applying elastomeric paint, the wet film thickness (when applied) is 10 mils and the dry film thickness (when dried) is 4 mils. Two coats of the ceramic compound is recommended for best results which gives you a wet film thickness of 20 mils and a dry film thickness of 8 mils[34]. This converts into .008 inches or eight thousandths of an inch, which is very miniscule when compared to 6" of fiberglass batt insulation. The paint can also be mixed to any color desired by the user.

When doing research on where to find these paints, there were many stores online selling them, but they would not ship to Hawai'i. Eventually, a local company here in O'ahu was found. The Cool Roof Store specializes in waterproofing and elastomeric paints. After speaking with one of their representatives about the project and what was needed, they invited the researcher to come by and, if they had any opened 5-gallon buckets, they would give him a sample from it. When arriving at the store, they took the student to the back where they stored buckets of paint that were being used for various jobs. At first they thought of the student as

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31 http://www.hytechsales.com/insulating_paint_additives.html
32 http://www.hytechsales.com/insulating_paint_additives.html
33 http://dictionary.reference.com/browse/mils
34 http://www.coolroofstore.net/wp-content/uploads/2013/07/crs-nxt.pdf

someone who was just trying to get free handouts. After they had learned that these paints were for a doctorate project, they realized the benefits of the project and were happy to donate what they could. In the end they were able to donate a bucket of elastomeric patching that is used to seal cracks and joints, a bucket of the NXT Cool Zone paint, which was about ¼ full and a bucket of their Silicone paint for waterproofing, which was also about ¼ full. They were very generous and supplied the project with everything that was needed.

Figure 7.13 – NXT Cool Zone elastomeric paint and elastomeric patching compound. Photograph by Richard E. Mead III

The elastomeric patching compound was used on the areas where the foam was exposed and also on the seams where the pieces of the container joined together. The compound was very thick and would ensure that the box was sealed. After the compound was applied, the paint was then brushed onto each side as well as the top. A white primer was applied and two coats of the NXT Cool Zone paint were applied as recommended. The paint was a thick slurry so there was not any worry that the paint would not adhere to the metal surface. It went on very smoothly and was tack free after approximately an hour. Results depend on the working conditions whereby the hotter it is, the faster it will dry.

Figure 7.14–Apply patching compound, primer and elastomeric paint. Photograph by Richard E. Mead III

Reflection

Locating this product was not a simple task. It would seem that here in Hawai'i there would be a demand for this type of product with all the sun exposure we get. Coating roofs and exterior walls would greatly reduce heat gain and reduce the need for cooling systems. The paint-on application is also a great way to apply a finish to the exterior using any color to match your project. It was a very easy product to use and that is what makes this product a great alternative for the do-it-yourself type of person. No complicated equipment is required and can be applied with a simple paintbrush or roller.

The Living wall portion of the experiment is the main reason behind this project. There were many obstacles during the construction of the Living Wall box. There were also many mistakes made. From the experiences, valuable knowledge was gained and helped to make the process smoother as it progressed. There were many living wall designs already out there. There was not enough time or money to purchase one of these systems as they were all sourced from the mainland, and they were very expensive. Realizing this, the researcher came up with his own design to overcome this problem. There were many, many trial and errors that helped the resaecher to gain a better understanding of what needed to be done and how to do it.

The first thing that needed to be done was to waterproof the exterior of the box. Spray on waterproofing that came in spray paint cans was an option, but proved too expensive in the end. Waterproofing membrane was another option, but again that, too, was expensive and the rolls contained far more material than what was needed. Luckily, upon visiting The Cool Roof Store, they were able to donate a silicone paint that was used for waterproofing roof decks and could also be applied to exterior siding.

Figure7.15- Silicone waterproofing paint. Photograph by Richard E. Mead III

The paint itself was very, very thick. It was a little difficult to apply with a roller, but once that initial layer was applied, it was easier to roll on. Two coats were applied to the box and were allowed to cure for 24 hours. The layer of silicone paint had a latex quality that would ensure that water would not get through to the interior. After the waterproofing was done, the next step was to assemble the Living Wall. The first step was to decide what would hold the plants and provide enough coverage. From the many different systems that were researched, the tray system seemed to be the best option. While looking at Home Depot, planter box liners became a possibility. These liners are long black plastic containers that measure 5.6" W x 31" L x 4.9" H. These were perfect for my project because they were just long enough to span the length of the container box. 12 liners were purchased, 3 for each side.

After the spacing was figured out, holes needed to be drilled into the liners to allow for drainage. A ¼" drill bit was used to drill a hole every 2 inches. Once the holes were drilled, the liners could be mounted onto the container box. Self-tapping metal roof screws were used because they had a self-sealing washer that would ensure that there would be no leaks in the box. After the liners were mounted, the PVC pipe could then be measured and cut to form the watering system.

Figure 7.16- PVC watering system ready to be drilled. Photograph by Richard E. Mead III

The same ¼" bit was used to drill the holes with 2" spacing just like the liners. Once the holes were drilled, the water pump was connected and tests were done to ensure that the system would work. After the pump was plugged in, the water began to flow and it was an even and steady flow from the top where the PVC pipe released the water to the very bottom of the liner. It was amazing to see. Something had finally worked out and it was just thrilling to see that something with so much effort put into it was working so well. However, this only lasted a short while. The rate of flow was too fast and the water was not draining fast enough to keep up.

Figure 7.17-Testing of watering system. Photograph by Richard E. Mead III

Because the flow rate was too fast, the liners started to overflow with water and the cinder and plants started to fall out. Somehow the flow rate needed to be slowed down. Not only was the flow rate too fast, only two sides were getting the full amount of water through the pipes. It was not an even flow to all four sides. This was a problem because some plants would be getting more water than others and results would be affected. The researcher had never done any kind of plumbing work so this was all very new to him and there were a lot of variables that needed to be addressed. This was a very important learning process for the researcher. From the mistakes made and help from others at Hale Tuahine the problem was fixed. It became apparent that one pump was not sufficient to deliver water to both sides. Two pumps would be needed so an even flow rate could be achieved.

Instead of having the water pump into a pipe going straight up to one side, the flow was split into a T and directed into two pipes, one going to each side. This configuration was done on each pump. In order to slow down the flow rate, ball valves were installed on each vertical pipe so that the desired flow rate could be achieved. Four more ball valves were used to cap off the water so that it would only flow into the desired pipes.

Figure 7.18- Tee joint and ball valve pipefittings that were used in the set up.
Photograph by Richard E. Mead III

This design was very effective, but from all of these modifications, the levels on each side were slightly off so one side would be sloping one way and only a portion of the liner was getting watered. To fix this, wood shims were placed around the pipes to ensure that every side was even and the whole liner was getting water. After the watering system was figured out, the plants were transplanted to their new home. Where each plant would go was decided by a lottery system. Each plant had a letter assigned to it and written down on a piece of paper. There were 7 different types of plants and 64 plants in all. A piece of paper was picked out of a box and the order was decided in that fashion. There are 16 plants on each side of the box with 5-6 plants in each liner. This ensured that there was a mixture of every type of plant on each side.

Figure 7.19- Plants after being transplanted to liners. Photograph by Richard E. Mead III

One criterion for what types of plants would be used in the experiment was that the plant needed to have a wide spread, so that each one would cover a significant portion of the exterior wall. Plants that needed 6 hours or more of direct sunlight were also chosen because they would be exposed for most of the day. The next step was to assess what plants would be best to use and where they could be found. Many nurseries were called and unfortunately they either didn't have the type of plants the student was looking for or if they did have them, they only had a few. The student was put in contact with Professor Ted Radovich from the Tropical Plants and Soil Sciences (TPSS) department and he told the student if he had been contacted earlier, he could have started growing what was needed. Unfortunately, there wasn't much time and the plants needed to be ready to plant and have enough coverage for the experiment. After many challenging weeks of calling and trying to find plants, Home Depot ended up having plants that met the criteria.

The following plants were chosen: Mint, Romaine Lettuce, Redbor Kale, Wautoma Pickling Cucumber, Cheery Tomato, Greek Mini Window herb, and bedding flowers.

Figure 7.20- Plants bought from Home Depot for experiment. Photograph by Richard E. Mead III

Looking back, more flowers should have been used than herbs and vegetables. The reason for this is that flowers provided a better coverage. Marigolds and other flowers that grow in clusters would have been better suited. This was another learning curve that would have to be dealt with during the experiment. The bedding flowers could have been a good choice if a large quantity were planted together side by side. They have the height to cover the wall, but not the horizontal coverage needed to fill out a side. Once the plants were in, the fish could be transferred to their new home as well. 25 Tilapia were taken from a nearby tank and transferred into the tank where the living wall would be. A ½ kilo of fish per 10 gallons of water is recommended. There was 250 gallons of water in the tank, which translated to 25 lbs of fish. Each fish weighed approximately 1 pound and therefore, 25 fish were needed. The process was actually quite fun because it required you to get in the tank where all the fish were, and by using two nets, try and herd them into one of the nets. Only 4-5 could be caught at a time because the transfer bucket was very small. After about 6-8 trips, all the Tilapia were caught and transferred. These fish would provide nutrients for the plants and in turn the plants would filter the water for the fish.

Figure 7.21- Golden and grey Tilapia fish that are held in the aquaponics tank. Photograph by Richard E. Mead III

When the plants were first transplanted, they were very droopy and unhappy. With fingers crossed, the water was turned on and with nothing left to do on the project for that day the plants were left alone. There was much excitement and anxiety before arriving to the site the next day to check on how everything went. Everything looked good from afar, but with closer inspection, some of the liners were starting to overflow. They were not overflowing as much as the first trial, and the plants were all there. Some minor adjustments to the ball valves needed to be made and overflowing stopped. The fish needed to be fed everyday. After they were fed, photographs were taken each day. Shots were taken from each side at relatively the same angle each time. For the first 4 days, minor adjustments needed to be made to the system, but afterwards the system seemed to work well and there were few problems.

Figure 7.22- South facing wall Day 1 compared to Day 6. Photograph by Richard E. Mead III

Each day the plants grew and looked better than they did on day 1. After closer inspection, some of the plants were not doing as well as the others. These plants were directly under the drip point and were getting too much water and were starting to wilt. Adjustments were made to prevent this from happening again. As seen in figure 7.21, the plants perked up and began to grow much better, resulting in more coverage of the exterior walls. The plants continued to grow bigger and wider as the experiment progressed. The Redbor kale, tomatoes and cucumbers seemed to do the best in the growing conditions provided. The north, east and south sides were doing very well and most of the wall was being covered by the plant growth. The plants on the west side of the wall were not doing very well. The west wall did not get much sunlight until around 3 pm and once the sun set, it only got approximately 3-4 hours of direct sunlight. This was important information that was gathered as the experiment progressed. For future studies, this information can be used to choose plants that don't need as much sunlight and would provide better results for the west facing walls. By the time the experiment came to a completion, the north, east and south walls were almost completely covered by the plants. The west wall plants were not doing as well as the others and covered approximately 50% of the wall. The following pictures illustrate the differences between day 1 and day 16 of the experiment on the north, east, south and west facing walls.

Figure 7.23- North wall Day 1 compared to Day 16. Photograph by Richard E. Mead III

Figure 7.25- West wall Day 1 compared to Day 16. Photograph by Richard E. Mead III

There was a lot of materials and equipment used during the process of this experiment. The following foldout is a table of all the materials and equipment used to build this project, including cost, name of item, quantity used, total cost of each and the grand total of the entire project.

**Figure 7.24-Top row from left to right: South and East walls Day 1.
Bottom row from left to right: South and East walls Day 16.
Photographs by Richard E. Mead III**

Reflection

Of all the boxes that were worked on, this aspect was by far the most challenging, yet the most rewarding. The design was completely the researchers own and it was a struggle to figure how to make it work. By doing this, it gave the researcher invaluable experience that can be used in future designs or projects. What worked and what did not work gave the resaercher a better idea of what needs to be changed in the design and how it can be approved. The researcher will be staying on at Hale Tuahine to further his research and to better the living wall design. There were many suggestions made by everyone at Hale Tuahine that will help to improve and better the design. This project has been a great passion of the students and there is much excitement to be able to continue to work on a design that could hopefully, one day, be part of a home.

Data Gathering

At the end of Day 16, the sensors were taken out from each box and the data was collected. There were 1570 data entries from each sensor for a total of 7850 data entries. The reason why there were so many entries is because the sensors would take a reading every 15 minutes. The duration of the experiment started on 4/12/2014 at 6:00 AM and ended on 4/28/2014 at 1:30 PM. There were a total of five sensors that were used. Four of these sensors were HOBO data loggers that recorded interior air temperatures as well as relative humidity and one was a HOBO pendant that measured exterior air temperatures. An infrared temperature gauge was used to measure exterior surface temperatures of each box and a thermal infrared imaging camera was used to document the surface temperatures of the boxes. The following is a list of the equipment used to record the data:

- 4- HOBO data loggers temp/RH/light/ext channel
- 1- HOBO pendant exterior temperature sensor
- FLIR Infrared thermal imaging camera
- Ryobi Infrared thermal gauge

This equipment was an integral part of the experiment. Without it, there would be no data to analyze and be able to give a result as to which insulation performed the best. While the HOBO sensors were placed in the interior of the boxes, exterior temperatures were taken using the infrared equipment. Using the infrared gauge, surface temperatures were recorded for a period of 7 days at approximately the same time during each day. Measurements were recorded on the north, east, west and south facing walls, as well as the roof of the box. Table 7.00 shows temperatures recorded as well as the time and dates.

Exterior Surface Temperature, °F						
Date & Time	Type	North	East	South	West	Top
4/22/14	Control	90.4	89.2	84.3	80.6	N/A
8:35 AM	Closed Cell	86	83.2	79.3	80.6	N/A
	Elastomeric	87.4	86.8	82.2	83.7	N/A
	Living Wall	78	77.1	74.8	75.2	N/A
4/23/14	Control	106.5	108	104.1	105.6	140.6
12:34 PM	Closed Cell	103.3	108	105.2	104	121.7
	Elastomeric	99.1	102.5	100	99.4	117.5
	Living Wall	84.6	83	81.1	82.9	90.9
4/23/14	Control	106.4	106.7	116.2	110.7	138.2
2:11 PM	Closed Cell	96.2	97.1	106.4	107.4	126.2
	Elastomeric	103.7	102.3	112.3	106.6	115.1
	Living Wall	90.2	87.6	86	90.1	91.7
4/24/14	Control	109.5	112.1	104.5	107.2	142.2
11:15 AM	Closed Cell	111.5	114.1	98.5	103	133.4
	Elastomeric	103.9	104.9	101	101.4	110.1
	Living Wall	89.2	84.8	80.3	84.6	91
4/25/14	Control	90.6	92.1	91	89.8	102.5
12:07 PM	Closed Cell	84.3	88.7	84.2	86.4	99
	Elastomeric	88.2	90.5	89.3	88.5	92.2
	Living Wall	77.9	75.6	75.6	77	79.8
4/27/14	Control	85.2	83.4	81.7	83.5	85.3
11:33 AM	Closed Cell	83.8	82.6	80.7	77.4	79.3
	Elastomeric	82.9	81.1	80.5	81.7	78.5
	Living Wall	70	68.3	67.4	68.2	71.3
4/28/14	Control	104.6	109.8	119.5	110.5	144.9
1:30 PM	Closed Cell	99.3	107.9	114.1	109.5	131
	Elastomeric	102.5	104.7	115.6	106.4	116.4
	Living Wall	89.4	86.9	89.1	89.8	98.8
	Average	93.0	93.5	93.0	92.6	108.2
	Max	111.5	114.1	119.5	110.7	144.9
	Min	70	68.3	67.4	68.2	71.3

Table 7.00-Infrared exterior air temperature recordings taken from 4/22-4/28.

Without seeing the recordings from the interior sensors, it was very clear from the exterior recordings how each box was performing. The control had the highest recordings out of all the boxes, which was to be expected. It was interesting to see how much the temperatures differed from the control box as well as from each other. The closed cell spray foam box and elastomeric box were relatively close to the control, sometimes having surface temperatures that were higher than what the control recorded. The living wall was significantly lower in temperature than all three of the other boxes sometimes having temperatures on the sides that were 20 degrees cooler than the control and almost 47 degrees cooler on the rooftop than the control. Infrared thermal images were taken once each week on the same day, which was a Friday at approximately the same time. The reason behind this was to allow the plants time to grow in order to get more accurate results. The thermal images match the surface temperatures that were taken with the infrared gauge as far as which box was the hottest and which one was the coolest. The control was had the highest temperature reading and the living wall had the lowest, which can be seen in figures 7.27 and 7.28.

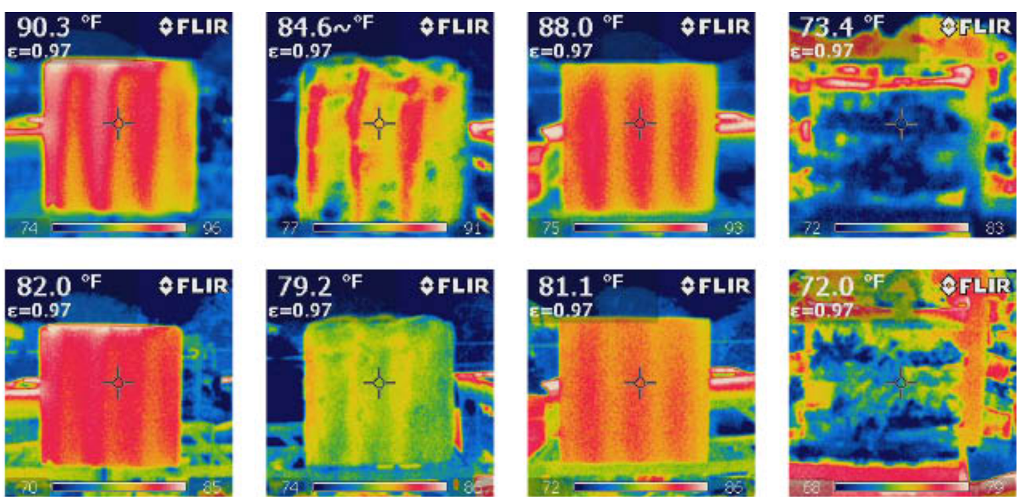


Figure 7.25-Top row 4/18/2014 10:58 AM North facing sides from left to right: Control, Closed Cell, Elastomeric, Living wall. Bottom row 4/25/2014 11:57 AM North facing sides from left to right: Control, Closed Cell, Elastomeric, Living wall. Photographs by Richard E. Mead III

The living wall is significantly cooler than the control as well as the other boxes with a 7-18 degree difference. The interior recordings were also closely matched to the exterior recordings. On 4/18 at 11:00 AM, interior readings show that the control was at 86.98°, closed cell spray foam was at 77.37°, elastomeric was at 82.88° and the living wall was at 75.02°. On 4/25 at 12:00 PM, interior readings show that the control was at 82.79°, closed cell spray foam was at 79.48°, elastomeric was at 80.80° and the living wall was at 74.46°.

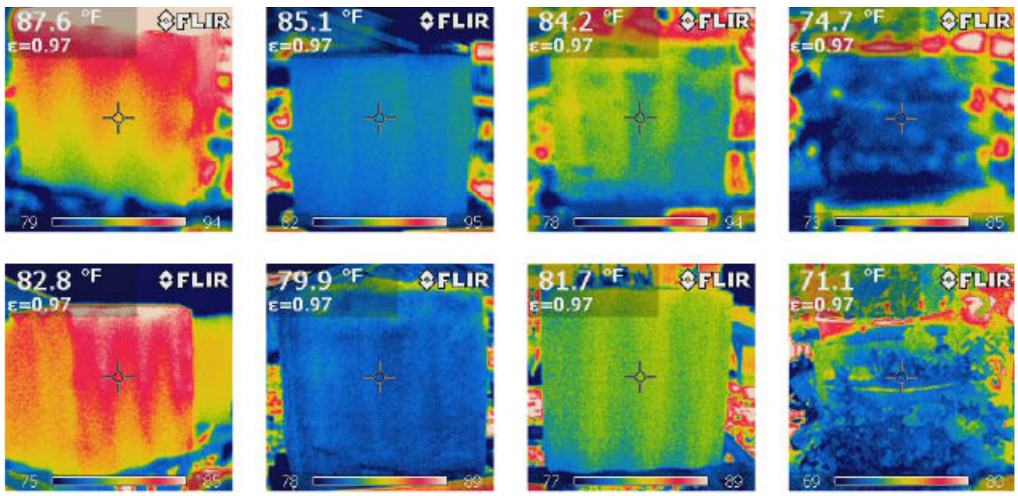
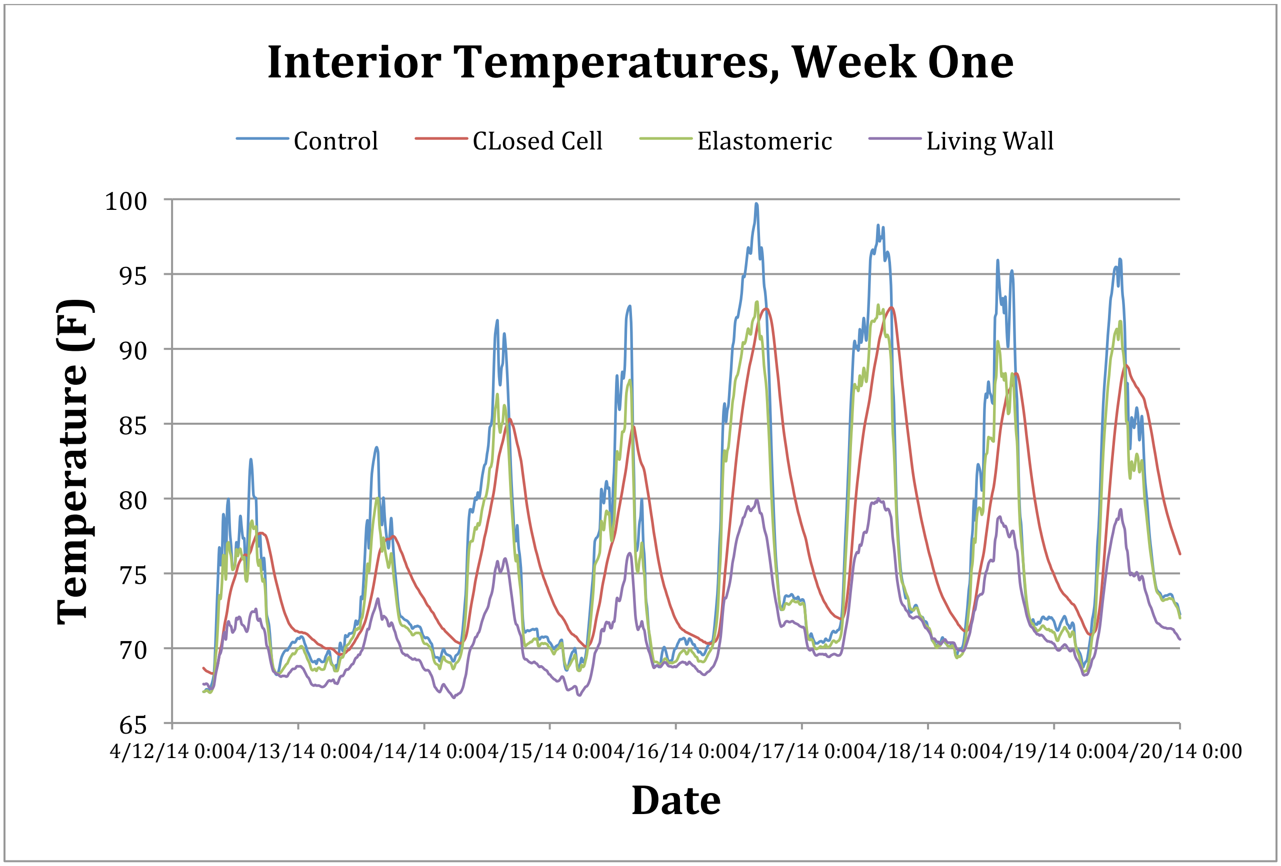


Figure 7.26- Top row 4/18/2014 10:58 AM South facing sides from left to right: Control, Closed Cell, Elastomeric, Living wall. Bottom row 4/25/2014 11:57 AM South facing sides from left to right: Control, Closed Cell, Elastomeric, Living wall. Photographs by Richard E. Mead III

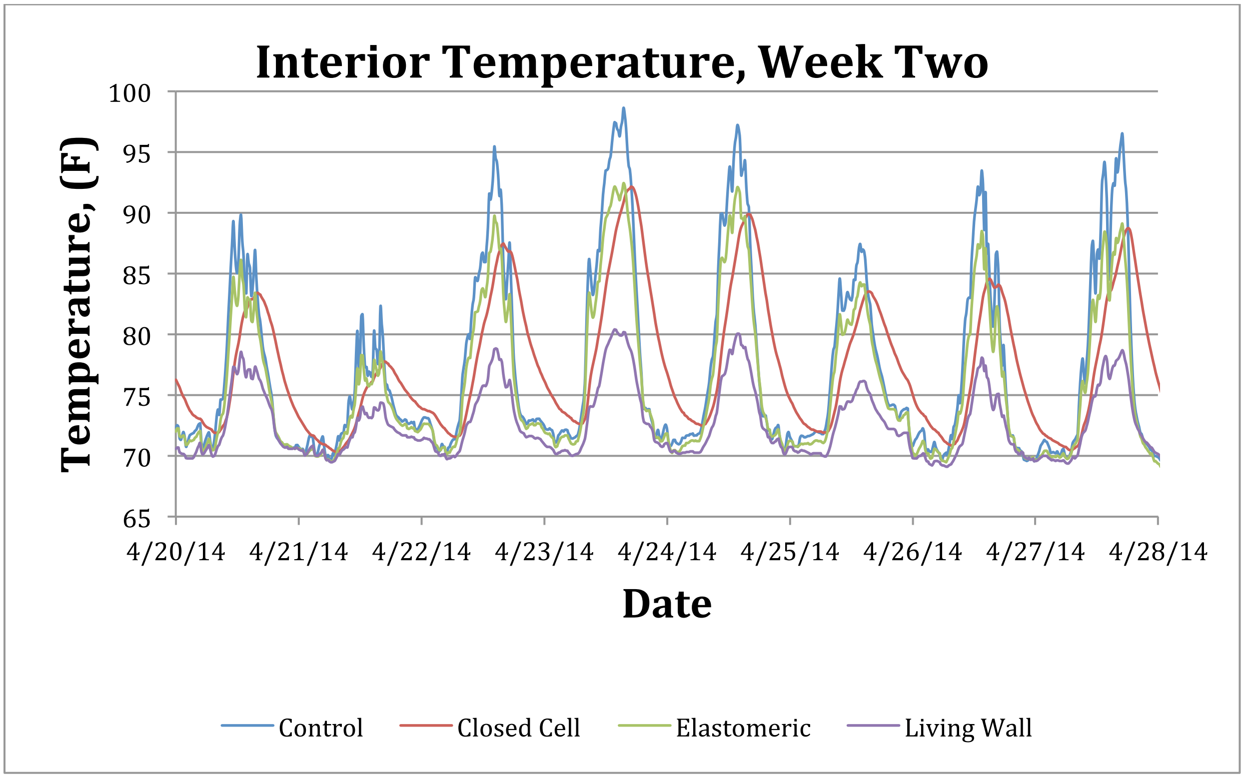
Once the interior sensors were pulled, the data was collected and put into an excel format. By using Excel, the average, maximum and minimum temperatures were calculated. This helped to gain a better understanding of what was happening inside the boxes. Excel was also able to take the large number of data entries and graph it into a scattered line graph. The graph helps to visually show where each box was as far as temperature and how they compared to each other. After analyzing the data, four graphs were produced from the interior temperature data. The graphs were of the highest and the lowest recorded temperatures in one day as well as a graph for each week of the experiment.

The following tables and graphs are meant to be visual aids to better understand all the data collected. An interesting observation when looking at the graphs is that the closed cell series have a much smoother and steadier line than the others do. There were no drastic spikes in temperatures and it rose and fell at a steady rate.



Graph 7.00-Interior temperatures from each day of the first week. Created by Richard E. Mead III.

Graph 7.00 shows what the interior temperatures were like during the first week of the experiment. The living wall series had spikes in temperature just like the control and elastomeric boxes had. The plants were still in the early stages of growing and had yet to provide enough coverage on the exterior walls. Graphs 7.00 and 7.01 reveal that temperatures in the living wall box never rose above 80° F. Even on the hottest day where temperatures rose to almost 100° F, temperatures inside the living wall box stayed under 80° F.



Graph 7.01- Interior temperatures from each day of the second week. Created by Richard E. Mead III.

During the two-week testing period, there was a range of different temperatures due to the changing weather conditions. This was helpful because it illustrated how the boxes did on hot and cold days and also showed if the boxes were able to mitigate heat gain in the day and keep a steady temperature though the night.

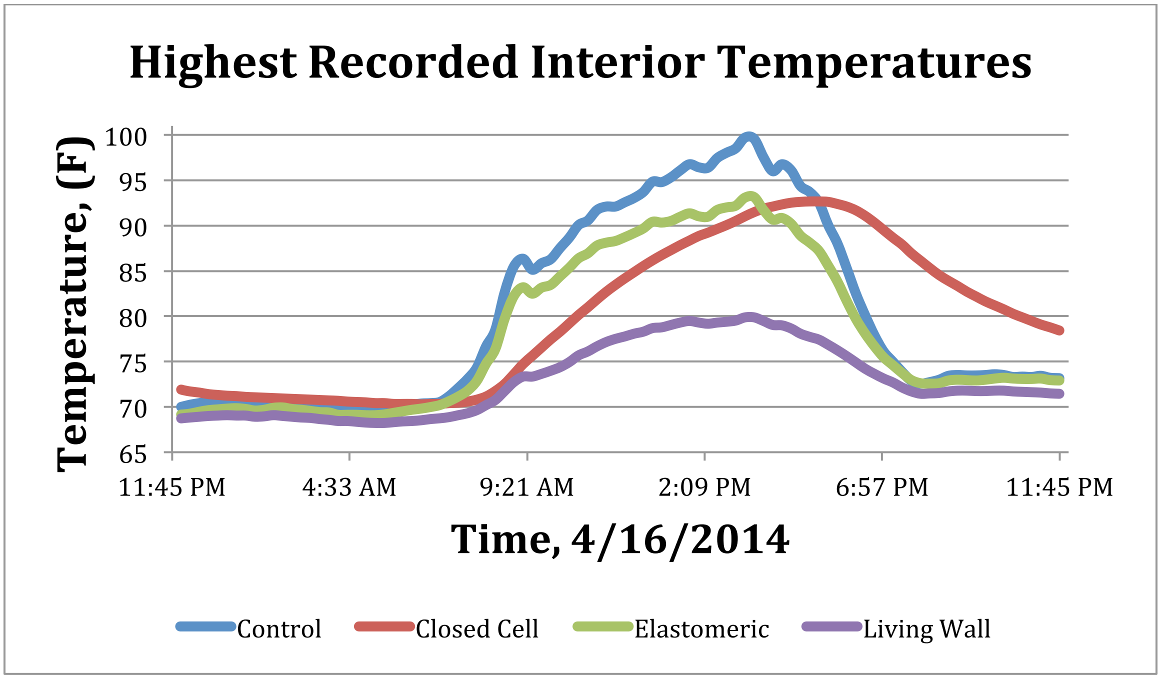
Date Time, GMT-10:00	Interior Temp, °F			
	Control	Closed Cell Spray Foam	Elastomeric Paint	Living Wall
4/16/14 0:30	70.416	71.577	69.471	68.913
4/16/14 0:45	70.587	71.404	69.643	68.999
4/16/14 1:00	70.587	71.317	69.728	69.042
4/16/14 1:15	70.63	71.231	69.814	69.085
4/16/14 1:30	70.673	71.19	69.858	69.042
4/16/14 1:45	70.543	71.103	69.771	69.042
4/16/14 2:00	70.243	71.06	69.6	68.913
4/16/14 2:15	70.372	71.017	69.685	68.956
4/16/14 2:30	70.63	70.974	69.901	69.085
4/16/14 2:45	70.587	70.93	69.942	68.999
4/16/14 3:00	70.416	70.887	69.771	68.913
4/16/14 3:15	70.243	70.846	69.685	68.828
4/16/14 3:30	70.243	70.803	69.557	68.785
4/16/14 3:45	69.985	70.759	69.427	68.657
4/16/14 4:00	69.985	70.716	69.386	68.571
4/16/14 4:15	69.728	70.673	69.129	68.443
4/16/14 4:30	69.771	70.587	69.129	68.443
4/16/14 4:45	69.685	70.543	69.129	68.356
4/16/14 5:00	69.557	70.502	69.085	68.27
4/16/14 5:15	69.557	70.416	69.085	68.227
4/16/14 5:30	69.685	70.416	69.17	68.227
4/16/14 5:45	69.901	70.329	69.343	68.313
4/16/14 6:00	70.115	70.329	69.514	68.4
4/16/14 6:15	70.243	70.329	69.685	68.443
4/16/14 6:30	70.372	70.286	69.814	68.527
4/16/14 6:45	70.416	70.329	69.985	68.657
4/16/14 7:00	70.543	70.329	70.201	68.742
4/16/14 7:15	71.19	70.416	70.63	68.871
4/16/14 7:30	72.093	70.459	71.146	69.085
4/16/14 7:45	73.083	70.587	71.791	69.3
4/16/14 8:00	74.338	70.803	72.869	69.643
4/16/14 8:15	76.681	71.146	74.77	70.201
4/16/14 8:30	78.514	71.748	76.375	70.759
4/16/14 8:45	82.62	72.523	79.7	71.748
4/16/14 9:00	85.487	73.602	82.218	72.739
4/16/14 9:15	86.346	74.727	83.199	73.342
4/16/14 9:30	85.127	75.637	82.486	73.342
4/16/14 9:45	85.849	76.55	83.154	73.645
4/16/14 10:00	86.301	77.464	83.467	73.99
4/16/14 10:15	87.528	78.296	84.407	74.381
4/16/14 10:30	88.671	79.216	85.352	74.943
4/16/14 10:45	90.055	80.139	86.391	75.681
4/16/14 11:00	90.565	80.978	86.936	76.114
4/16/14 11:15	91.729	81.864	87.802	76.681
4/16/14 11:30	92.104	82.708	88.122	77.16
4/16/14 11:45	92.104	83.467	88.306	77.509
4/16/14 12:00	92.574	84.182	88.718	77.77
4/16/14 12:15	93.045	84.857	89.177	78.076

Table 7.00- Data entries from 1:30 AM - 23:45 PM on 4/16/2014. Table by Richard E. Mead III.

4/16/14 12:30	93.706	85.532	89.685	78.296
4/16/14 12:45	94.849	86.164	90.424	78.69
4/16/14 13:00	94.8	86.754	90.333	78.777
4/16/14 13:15	95.328	87.3	90.518	79.041
4/16/14 13:30	96.096	87.847	90.982	79.304
4/16/14 13:45	96.773	88.351	91.355	79.48
4/16/14 14:00	96.435	88.855	91.029	79.304
4/16/14 14:15	96.386	89.224	90.982	79.173
4/16/14 14:30	97.452	89.638	91.729	79.304
4/16/14 14:45	98.038	90.055	92.01	79.392
4/16/14 15:00	98.528	90.518	92.197	79.524
4/16/14 15:15	99.712	91.029	93.092	79.876
4/16/14 15:30	99.563	91.495	93.139	79.876
4/16/14 15:45	97.551	91.87	91.729	79.48
4/16/14 16:00	95.999	92.104	90.657	79.041
4/16/14 16:15	96.773	92.338	90.844	78.996
4/16/14 16:30	96.096	92.527	90.194	78.645
4/16/14 16:45	94.372	92.62	88.902	78.076
4/16/14 17:00	93.706	92.667	88.122	77.727
4/16/14 17:15	92.527	92.667	87.21	77.421
4/16/14 17:30	90.055	92.62	85.577	76.854
4/16/14 17:45	88.03	92.386	83.824	76.246
4/16/14 18:00	85.307	92.104	81.687	75.594
4/16/14 18:15	82.486	91.683	79.7	74.899
4/16/14 18:30	80.096	91.076	78.076	74.206
4/16/14 18:45	77.902	90.333	76.681	73.645
4/16/14 19:00	76.114	89.499	75.463	73.126
4/16/14 19:15	74.986	88.671	74.597	72.696
4/16/14 19:30	73.861	87.894	73.731	72.136
4/16/14 19:45	72.869	86.936	72.955	71.704
4/16/14 20:00	72.567	86.119	72.61	71.447
4/16/14 20:15	72.739	85.307	72.567	71.49
4/16/14 20:30	72.997	84.542	72.61	71.533
4/16/14 20:45	73.429	83.914	72.912	71.704
4/16/14 21:00	73.515	83.332	72.997	71.791
4/16/14 21:15	73.472	82.708	72.955	71.791
4/16/14 21:30	73.472	82.175	72.912	71.748
4/16/14 21:45	73.515	81.642	72.997	71.748
4/16/14 22:00	73.602	81.199	73.126	71.791
4/16/14 22:15	73.515	80.757	73.213	71.791
4/16/14 22:30	73.299	80.272	73.126	71.704
4/16/14 22:45	73.342	79.876	73.083	71.661
4/16/14 23:00	73.299	79.48	73.083	71.62
4/16/14 23:15	73.429	79.084	73.126	71.577
4/16/14 23:30	73.213	78.777	72.955	71.49
4/16/14 23:45	73.17	78.427	72.912	71.447

Table 7.01- Continuation of data entries from 1:30 AM - 23:45 PM on 4/16/2014. Table by Richard E. Mead III.

Graphs of the highest and lowest recorded temperatures in a day were created to form the data entries as shown in Tables 7.00-7.03. How each box did in these conditions, how fast temperatures raised, trends, and how fast temperatures fell are some of the things illustrated by graphs 7.02 and 7.03.



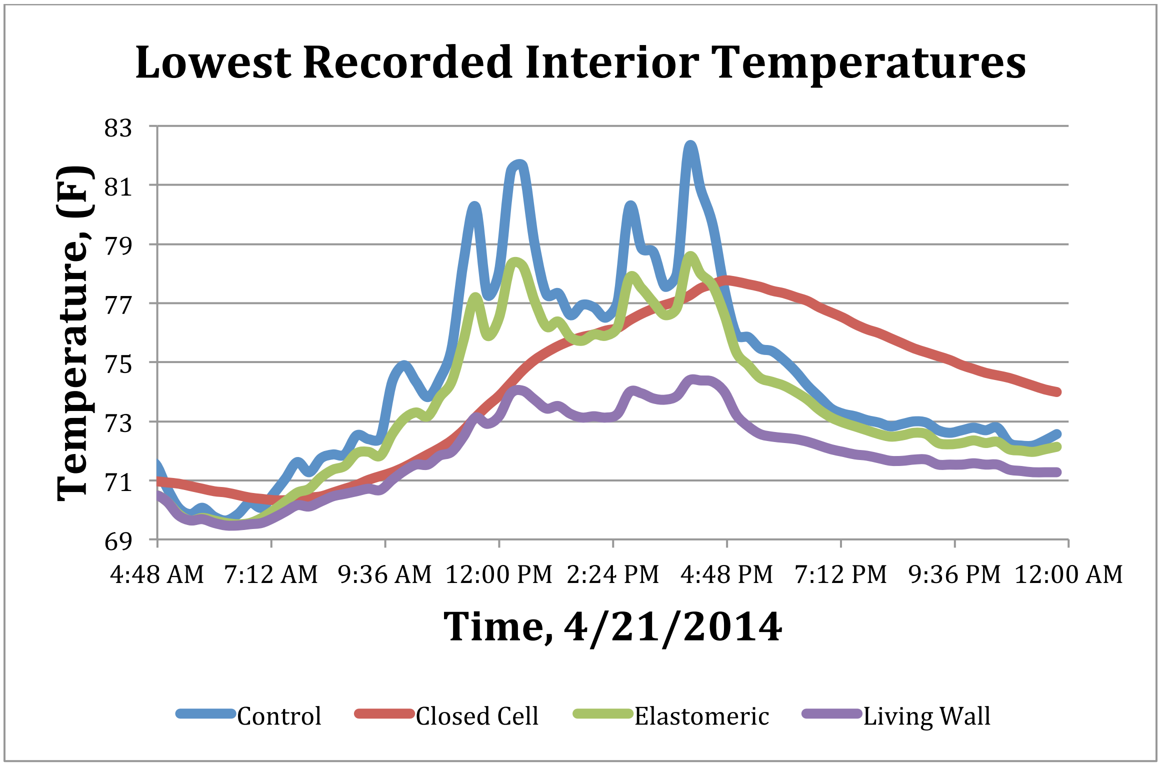
Graph 7.02-Highest recorded interior temperatures in one day. Created by Richard E Mead III.

Date Time, GMT-10:00	Interior Relative Humidity, °F			
	Control	Closed Cell Spray Foam	Elastomeric Paint	Living Wall
4/21/14	70.759	73.213	70.63	70.543
4/21/14 0:15	70.63	73.04	70.587	70.459
4/21/14 0:30	70.543	72.869	70.543	70.416
4/21/14 0:45	70.587	72.696	70.502	70.459
4/21/14 1:00	70.416	72.523	70.372	70.286
4/21/14 1:15	70.072	72.351	70.072	70.029
4/21/14 1:30	70.502	72.178	70.072	70.115
4/21/14 1:45	70.93	72.05	70.201	70.286
4/21/14 2:00	71.447	71.92	70.329	70.459
4/21/14 2:15	71.704	71.791	70.459	70.63
4/21/14 2:30	71.577	71.704	70.543	70.759
4/21/14 2:45	71.533	71.661	70.716	70.846
4/21/14 3:00	70.759	71.62	70.416	70.459
4/21/14 3:15	70.115	71.49	69.985	70.029
4/21/14 3:30	70.115	71.361	69.942	69.985
4/21/14 3:45	70.286	71.274	69.942	70.029
4/21/14 4:00	70.759	71.146	70.029	70.115
4/21/14 4:15	71.06	71.06	70.072	70.201
4/21/14 4:30	71.404	71.017	70.243	70.329
4/21/14 4:45	71.577	70.974	70.502	70.502
4/21/14 5:00	70.759	70.93	70.286	70.286
4/21/14 5:15	70.072	70.887	69.858	69.814
4/21/14 5:30	69.858	70.803	69.643	69.643
4/21/14 5:45	70.072	70.716	69.728	69.685
4/21/14 6:00	69.771	70.63	69.643	69.557
4/21/14 6:15	69.643	70.587	69.557	69.471
4/21/14 6:30	69.858	70.502	69.514	69.471
4/21/14 6:45	70.243	70.416	69.557	69.514
4/21/14 7:00	70.072	70.372	69.728	69.557
4/21/14 7:15	70.543	70.329	69.985	69.728
4/21/14 7:30	71.06	70.329	70.286	69.942
4/21/14 7:45	71.62	70.372	70.587	70.158
4/21/14 8:00	71.274	70.416	70.716	70.115
4/21/14 8:15	71.748	70.459	71.103	70.286
4/21/14 8:30	71.877	70.587	71.361	70.459
4/21/14 8:45	71.877	70.716	71.49	70.543
4/21/14 9:00	72.523	70.846	71.92	70.63
4/21/14 9:15	72.394	71.017	71.964	70.716
4/21/14 9:30	72.437	71.146	71.834	70.673
4/21/14 9:45	74.338	71.274	72.567	71.017
4/21/14 10:00	74.899	71.447	73.083	71.317
4/21/14 10:15	74.338	71.661	73.299	71.533
4/21/14 10:30	73.818	71.877	73.17	71.533
4/21/14 10:45	74.424	72.093	73.818	71.834
4/21/14 11:00	75.463	72.351	74.338	71.964
4/21/14 11:15	78.382	72.696	75.724	72.48

Table 7.02- Data entries from 1:00 AM - 23:45 PM on 4/21/2014. Table by Richard E. Mead III.

4/21/14 11:30	80.272	73.126	77.203	73.126
4/21/14 11:45	77.292	73.515	75.898	72.912
4/21/14 12:00	78.076	73.861	76.507	73.17
4/21/14 12:15	81.466	74.295	78.296	73.947
4/21/14 12:30	81.642	74.727	78.251	74.034
4/21/14 12:45	78.996	75.074	77.072	73.731
4/21/14 13:00	77.292	75.333	76.203	73.429
4/21/14 13:15	77.335	75.551	76.375	73.515
4/21/14 13:30	76.593	75.724	75.853	73.256
4/21/14 13:45	76.942	75.853	75.724	73.126
4/21/14 14:00	76.854	75.942	75.942	73.17
4/21/14 14:15	76.507	76.071	75.898	73.126
4/21/14 14:30	77.072	76.158	76.203	73.256
4/21/14 14:45	80.272	76.419	77.859	73.99
4/21/14 15:00	78.865	76.636	77.509	73.947
4/21/14 15:15	78.733	76.811	77.029	73.774
4/21/14 15:30	77.553	76.942	76.593	73.731
4/21/14 15:45	78.033	77.072	76.854	73.861
4/21/14 16:00	82.263	77.247	78.559	74.381
4/21/14 16:15	80.845	77.509	77.99	74.381
4/21/14 16:30	79.655	77.639	77.596	74.338
4/21/14 16:45	77.464	77.77	76.593	73.99
4/21/14 17:00	75.942	77.727	75.333	73.213
4/21/14 17:15	75.853	77.639	74.899	72.826
4/21/14 17:30	75.463	77.553	74.467	72.567
4/21/14 17:45	75.376	77.421	74.338	72.48
4/21/14 18:00	75.074	77.335	74.206	72.437
4/21/14 18:15	74.683	77.203	73.99	72.394
4/21/14 18:30	74.206	77.072	73.731	72.307
4/21/14 18:45	73.818	76.854	73.386	72.178
4/21/14 19:00	73.429	76.681	73.126	72.05
4/21/14 19:15	73.256	76.507	72.955	71.964
4/21/14 19:30	73.17	76.289	72.826	71.877
4/21/14 19:45	73.04	76.114	72.696	71.834
4/21/14 20:00	72.955	75.985	72.567	71.748
4/21/14 20:15	72.826	75.81	72.48	71.661
4/21/14 20:30	72.912	75.637	72.523	71.661
4/21/14 20:45	72.997	75.463	72.61	71.704
4/21/14 21:00	72.955	75.333	72.567	71.704
4/21/14 21:15	72.696	75.204	72.264	71.533
4/21/14 21:30	72.61	75.074	72.221	71.533
4/21/14 21:45	72.696	74.899	72.264	71.533
4/21/14 22:00	72.783	74.77	72.351	71.577
4/21/14 22:15	72.696	74.64	72.264	71.533
4/21/14 22:30	72.783	74.554	72.307	71.533
4/21/14 22:45	72.264	74.467	72.05	71.361
4/21/14 23:00	72.178	74.338	72.007	71.317
4/21/14 23:15	72.178	74.206	71.964	71.274
4/21/14 23:30	72.351	74.077	72.05	71.274
4/21/14 23:45	72.567	73.99	72.136	71.274

Table 7.03- Continuation of data entries from 1:00 AM - 23:45 PM on 4/16/2014. Table by Richard E. Mead III.



Graph 7.03- Lowest recorded interior temperatures in one day. Created by Richard E Mead III.

Results/Reflection

Interior relative humidity was also recorded and similar graphs were produced to illustrate week one, week two and highest and lowest recorded temperatures with reference to relative humidity. Since each box was completely sealed, there was no way for any air circulation to pass through. Because of this, the boxes would heat up inside and this would cause the relative humidity to be at a higher percentage than it would be if there were air circulation. The purpose of this experiment was to measure interior temperatures and heat gain. Therefore, the relative humidity information is not relative to this experiment because the results were not accurate due to the lack of air circulation. The next step in this experiment would have been to make scaled cutouts from the boxes to represent windows and doors, which would allow for air to circulate through the boxes.

Insulation Technical Specifications			
Type	Thickness	R-value	Cost/sf
Closed Cell Spray Foam	2" sides 3" top	2"-13.3 3"-19.9	$4.51 $5.99
Elastomeric Paint	2 coats Wet Film- 20 mils (.020") Dry Flim- 8 mils (.008")	N/A	$0.22 - $0.36
Living Wall	5.6"	N/A	$5.64

Table 7.04-Specifications on the type of insulation used, thickness, R-value and the cost per square foot. Created by Richard E Mead III.

Table 7.04 shows each insulation type, the overall thickness, R-value and cost per square foot. The elastomeric paint and living wall did not have an R-value that could be calculated because there was not sufficient information to calculate one. The elastomeric paint seemed to be the most cost-effective, but the data showed that it did not perform as well as the living wall and closed cell boxes. Data shows that the elastomeric paint was only a few degrees off from the control box and was not able to mitigate heat gain as well as the closed cell spray foam and the living wall. With all these factors, elastomeric paint is the easiest out of the three to install. It requires a minimal amount of equipment and preparation and anyone who can use a paintbrush or roller can do it, which gives the user the option to do it themselves rather than pay for professional application. Overall, the elastomeric paint is easy to use and is cheaper and can be any color the user desires. It is also a very easy form of insulation for a shipping container because of its ease of application and the corrugation can be a problem because of its challenging surface.

The closed cell spray foam offered better results and although the cost is a little expensive, ranging from $4.51-$5.99, it offers a more controlled environment on the interior. Graphs 7.02 and 7.03 illustrates how the closed cell spray foam took longer to heat up than the control and elastomeric paint did and it also took longer to dissipate the heat gained during the day. This type of insulation would do well in higher elevations where it gets a little cooler during the night and would offer warmer temperatures through the night. This type of insulation requires a professional to apply it and heavy equipment and chemicals need to be mixed before it is ready to be applied. This is one negative about this type of insulation. The amount of time and equipment needed is far more that what the other types require. The great thing about closed cell spray foam is that it takes about 5 seconds to go from being a liquid to a solid, tack free surface in about 5 seconds and also has the fastest cure time of 4 hours. After the spray foam is applied and cured, an exterior finish can then be applied to meet the needs of the user. This also seals the foam and ensures that it will not be exposed to sunlight or water. Overall, this was a great product to use and would be a possible form of insulation for a shipping container.

The control box performed as expected. Both interior and exterior temperatures got to be very high with surface temperatures reaching almost 150° F and interior temperatures reaching almost 100° F. This would offer a very uncomfortable environment and the use of insulation is an absolute requirement in order to make it a livable space. It was interesting to see how hot the container box got. Most of the time, the box was too hot to touch and could easily cause burns.

[LESSONS LEARNED]

Looking back, it is hard to believe everything that has happened. It started as a very ambitious idea and filled with excitement and inspiration, the student thought he could possibly build a full-scale container home by the time he was ready to graduate. The student could not have been greener around the ears. He was advised that he was being too ambitious and that he would have to focus on a small topic rather than the broad one that he had originally planned to do. He had to consider how much time he had, the resources that were available to him, and if he would have the funding required to make this project a reality. With the help of the students committee, they were able to set him on the right direction and although they were skeptic and doubtful at times, they were behind the student and believed that he could do it.

The student learned that having people who believe and support them 100% makes the difference in a project. There were a lot of times where the student felt he had taken on too much and that he would be unable to finish. This project was a roller coaster of emotions, but the people the student had along the way helped him to get back on his feet and give him the inspiration he needed to push forward.

To whomever is reading this, whether it be just to glance at or to reference for your doctorate project, there are a few things the student would like to share to help you along the way and to help you try and avoid the costly mistakes the student had made.

First of all, plan everything out months in advanced. It may be hard to think that far ahead, but doing so will help you to see the bigger picture and will help you realize what your goals are. Do not wait until the last minute to make contact with a company, contact or supplier. Establish these relationships early so that the people have time and can plan ahead for anything you might need. Be persistent with them and do not take no for an answer. If they say they cannot do something for you, think of a way that would be convenient for them or some type of situation that would be beneficial to them. A lot of the materials that were used in this project were donated because they felt that the information gathered during the course of the project would benefit them and they can use the info to improve their understanding. Do not be afraid to mention that you are a doctorate candidate. People love to hear what your topic is and often want to help you out, whether it be donating materials or sharing their knowledge with you. These contacts will become very important to your project so make sure you stay in touch and inform them along the way so they do not feel like they were just being used.

Record everything you do, whether it be written or photographed. Be sure to cite everything that is not yours and give credit where credit is due. One last thing, make a back up of all your files related to your project. Back it up online using Dropbox or any other storage site, on a zip drive every night or when you turn your computer off and any other way you can.

[CASE STUDIES]

There have been many buildings and structures that have been built around the world with shipping containers. These are a selection of projects that have been built that have qualities that could be integrated into the container design. Each design is unique in its own way through aesthetics, usability, functionality, and sustainability.

Port-a-bach
Atelier Workshop

Project location	Various
Estimated use	Mobile home
Container type	20' Freight container

Figure 8.00- Fold down balcony
http://www.port-a-bach.com

The Port-a-bach (pronounced "batch") was created from a single 20-foot container with an additional roofed area of 14 square meters (150 ft^2). When folded out, the inner room is supplemented with a terrace that runs along the longitudinal side of the structure and with balcony-like reclining surfaces at one if the container's open ends. Flexible furnishings can be stored in the wall. This and other efficiencies of organization mean that four people (two adults and two children) can comfortably inhabit Port-a-bach despite its minimal floor space. The house can operate in a stand-alone manner from a technical point of view; however, it can also be connected to existing public utilities (electricity, water, sewage) if necessary[35].

[35] Container Atlas (pp.50)

Figure 8.02 & 8.03- Interior and Exterior shots
http://www.port-a-bach.com/

This was a case study with design features that the student had envisioned the final product to have. The mobility, space efficiency, sustainability, and flexibility made this project stand out. Its so simplistic and yet it is able to provide the necessary comoditites to allow for a comfortable living space. The way the furnishings can be moved when they are not in use and the multi-functionality of the space are examples of clever and effiecient use of space. Opening the doors and providing a reading nook not only gives the user a place to read or nap, but it also opens up to allow natural lighting and ventilation. The same can be said about the fold out balcony. When this is opened it allows the home to double its size, allowing the users more space so that they don't feel like they are confined to the walls of the container. The fold out balcony can be covered to allow a more private setting as well as shelter from the outside elements, which is a good feature when entertaning guests. Living walls can also be applied to the south and east facing walls.

Ecopods
ecopods.ca

Project location	Various
Estimated use	Mobile home
Container type	20’ Freight container

Figure 8.04- Exterior view of Ecopod
http://ecopods.ca/

The single ecopod as designed provides excellent short-term accommodation that has great benefits as a product showroom or as an accessory building in conjunction with existing buildings. Operating with an 80-watt solar panel and minimal electrical needs there is no need to run power lines or trench power cables to the unit, it’s ready to use minutes after setup. The secure nature of the ecopod when in the closed position provides protection against vandals and works excellent in areas where extreme weather conditions exist. The ecopods are quick to set up and easily transported with all unit modifications re-surveyed to international transportation standards[36]. According to ecopods.ca, their objective is to create a design with a low environmental footprint, minimal operating cost and high quality at an affordable price. They use recycled materials such as post-

[36] Ecopods http://ecopods.ca/products.php

consumer tires for the floors and a product called Magnesiacore, which is an environmentally friendly board and core material for the walls.

Figure 8.05 & 8.06- Ecopod for residential use
http://tinyhouseblog.com/pre-fab/ecopods/

This project has all the design elements that are necessary to achieve a net zero energy design. This design was thought out and every aspect was looked at. They were able to create a unit that can be self-sufficient and can be used as a standalone or combined with others to create a complex. Electricity, water, sewage, insulation, recycled materials; these are all components that make up a comfortable and efficient home and they have figured out the right match for each component. This design is similar to Port-a-bach with is fold down balcony that offers the users more space and can be closed up when the unit is not in use to prevent vandalism and protection from storms and hurricanes. The price for one of these units is $26,650 CND or $26,232.51 US.

These case studies are an excellent source of information and give inspiration to a design that can be sustainable as well as aesthetically pleasing. Living walls have the potential to be applied to these designs, not only providing insulation, but a garden on the side of your home. There is much potential when designing with shipping containers.

[CONCLUSION/REFLECTION]

By comparing all of the data collected, it was concluded that the living wall did in fact perform better than the control, closed cell spray foam and elastomeric paint. This experiment began with the goal of testing whether or not living walls could be an alternative to standard insulation. The results show that it is in fact a better insulator and was able to cool the interior on days with high temperatures. Given more time, the researcher would have liked to explore and test other types of insulations such as fiberglass batt insulation. Only two types of insulations were tested and there is not enough conclusive data to prove that a living wall is the best insulator. These tests do show that it is in fact a better insulator than closed cell spray foam and elastomeric paint.

The living wall portion of the experiment had two purposes. The first was to test if it was a better insulator than other types of insulation. The second was to test if the plants would be able to grow in the environment they were put in and if they would provide enough coverage on the exterior to have any effect. In just two weeks, the plants grew large enough to cover the whole exterior face of the wall. The cucumbers, tomatoes and kale had amazing growth and they continue to grow up the wall on onto the top of the box. A bamboo trellis was constructed and placed on top of the box to provide the cucumbers and tomatoes an area that they could grow on and be able to spread their vines.

Fishing line was also used to direct the plants upwards because they were growing to large and were starting to lean over the planter boxes they were growing in. These results were very unexpected, but came with a breath of relief. The goal of the experiment was achieved after all of the hard work and challenges that came with it.

Photof bamboo trellis constructed to alow the plants more space to grow. Photo by Richard E Mead III.

This project became the researchers life. The researcher worked at the site from 8 am-7 pm for 3 weeks straight, trying to get everything constructed and working. This had to be one of the most challenging moments in the researchers school career, but in the end, it was one of the most rewarding moments in the researchers life and was very proud of the work that had been accomplished. The directors and caretakers of Hale Tuahine were very impressed with the project and they all gave praise to the work that was done. They enjoyed having the project there because they felt that the living wall was very meditative. The watering system that was created had a waterfall effect and was very calming and peaceful while observing it. The researcher will be staying on at Hale Tuahine to further his research on living walls and aquaponic systems with hopes of creating an integrated system that can be applied to homes. There is no end result or conclusion to this project, only a direction that will allow the researcher to further my knowledge in this field and apply it to an affordable, net zero energy design for future homes. With the invaluable list of contacts and wealth of information that was accumulated during this project, the researcher hopes to use them to make this container housing design a reality and be able to provide affordable, sustainable homes for the people of Hawaiʻi.

One month since initial planting. Plants have covered almost 100% of exterior sides. Photograph by Richard E. Mead III

[APPENDIX A]

The diagrams and information below illustrates the various parts of a container and what their function is.

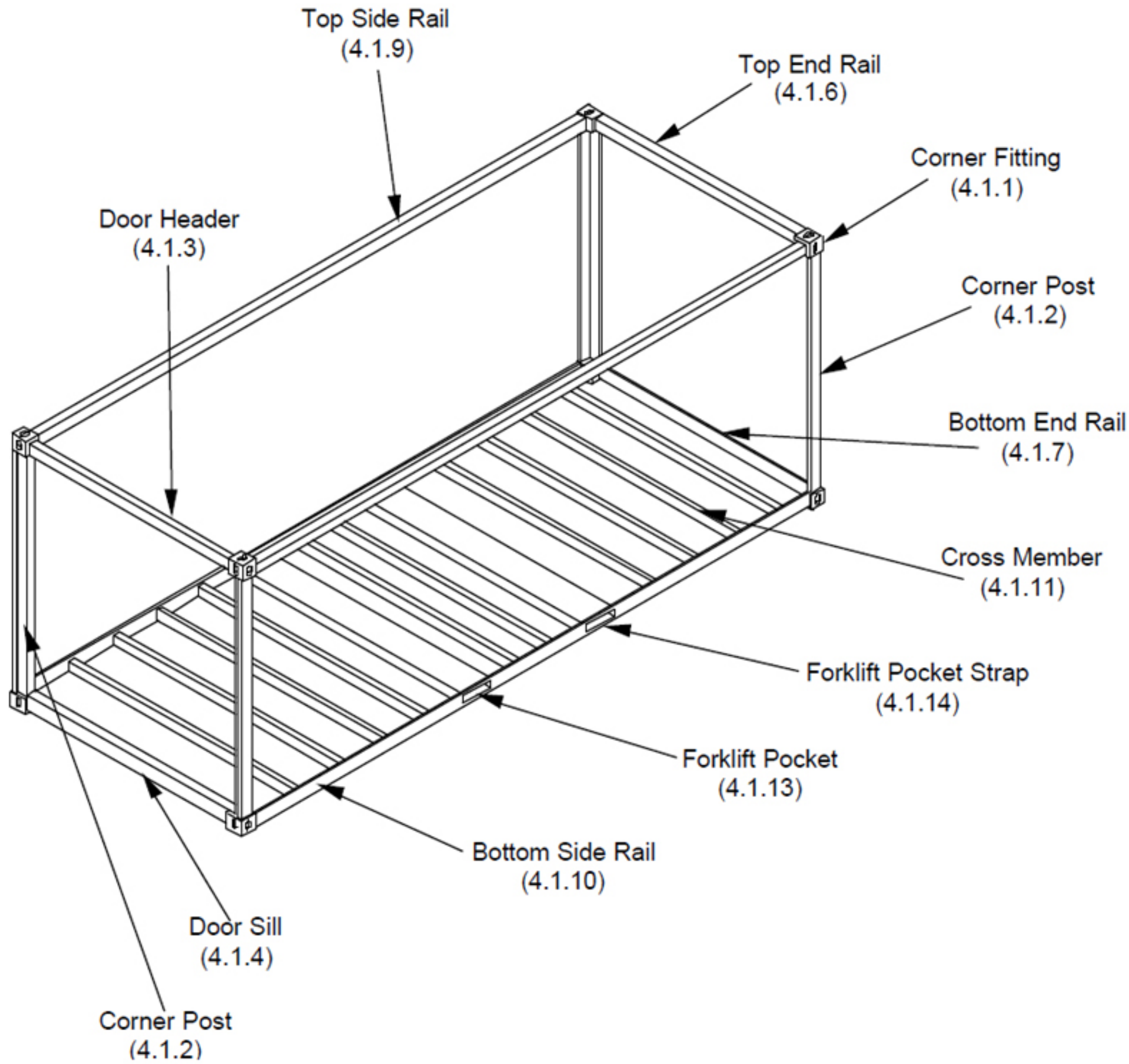


Figure 9.01 SHIPPING CONTAINER STRUCTURAL COMPONENTS AND TERMINOLOGY
http://www.residentialshippingcontainerprimer.com/

- 4.1.1 Corner Fitting. Internationally standard fitting (casting) located at the eight corners of the container structure to provide means of handling, stacking and securing containers. Specifications are defined in ISO 1161.
- 4.1.2 Corner Post. Vertical structural member located at the four corners of the container and to which the corner fittings are joined.
- 4.1.3 Door Header. Lateral structural member situated over the door opening and joined to the corner fittings in the door end frame.
- 4.1.4 Door Sill. Lateral structural member at the bottom of the door opening and joined to the corner fittings in the door end frame.

- 4.1.5 Rear End Frame. The structural assembly at the rear (door end) of the container consisting of the doorsill and header joined at the rear corner fittings to the rear corner posts to form the door opening.
- 4.1.6 Top End Rail. Lateral structural member situated at the top edge of the front end (opposite the door end) of the container and joined to the corner fittings.
- 4.1.7 Bottom End Rail. Lateral structural member situated at the bottom edge of the front end (opposite the door end) of the container and joined to the corner fittings.
- 4.1.8 Front End Frame. The structural assembly at the front end (opposite the door end) of the container consisting of top and bottom end rails joined at the front corner fittings to the front corner posts.
- 4.1.9 Top Side Rail. Longitudinal structural member situated at the top edge of each side of the container and joined to the corner fittings of the end frames.
- 4.1.10 Bottom Side Rail. Longitudinal structural member situated at the bottom edge of each side of the container and joined to the corner fittings to form a part of the understructure.
- 4.1.11 Cross Member. Lateral structural member attached to the bottom side rails that support the flooring.
- 4.1.12 Understructure. An assembly consisting of bottom side and end rails, door sill (when applicable), cross members and forklift pockets.
- 4.1.13 Forklift Pocket. Reinforced tunnel (installed in pairs) situated transversely across the understructure and providing openings in the bottom side rails at ISO prescribed positions to enable either empty capacity or empty and loaded capacity container handling by forklift equipment.
- 4.1.14 Forklift Pocket Strap. The plate welded to the bottom of each forklift pocket opening or part of bottom side rail. The forklift pocket strap is a component of the forklift pocket.
- 4.1.15 Gooseneck Tunnel. Recessed area in the forward portion of the understructure to accommodate transport by a gooseneck chassis. This feature is more common in forty foot and longer containers[37].

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[37] SHIPPING CONTAINER STRUCTURAL COMPONENTS AND TERMINOLOGY
http://www.residentialshippingcontainerprimer.com

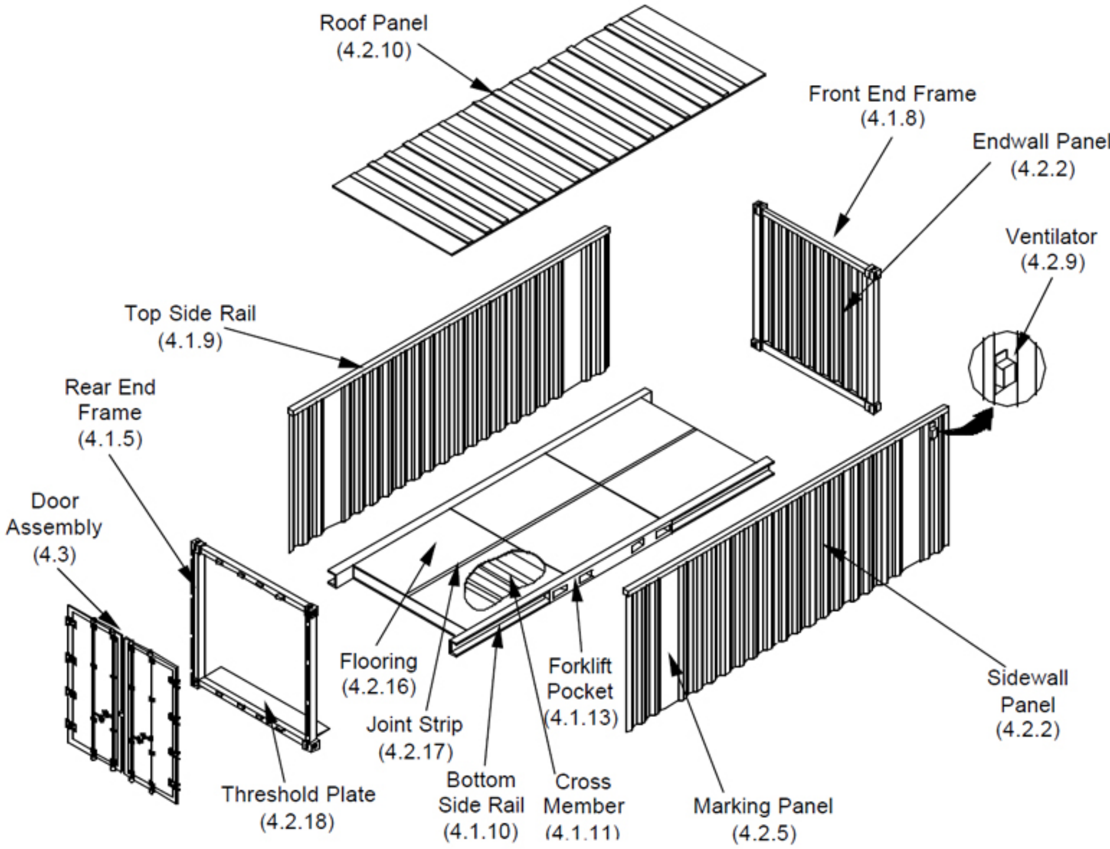

Figure 9.02 SHIPPING CONTAINER STRUCTURAL COMPONENTS AND TERMINOLOGY
http://www.residentialshippingcontainerprimer.com/

- 4.2 **Walls, Roof, and Floor.** Refer to Figure 4.2A
- 4.2.1 **Fiberglass Reinforced Plywood (FRP).** A material constructed of laminates of fiberglass, polyester resins, and plywood, also known as sandwich panel.
- 4.2.2 **Wall Panel.** Corrugated or flat sheet steel, a riveted or bonded aluminum sheet and wall post assembly, FRP, foam and beam, aluminum, or honeycomb material that forms the side wall or end wall.
- 4.2.3 **Wall Post.** Interior or exterior intermediate vertical component to which sheet aluminum or steel is riveted or welded to form a wall panel.
- 4.2.4 **Wall Beam.** Encapsulated vertical component to which sheet aluminum or steel is bonded to form a wall panel. This is found in foam and beam panels.
- 4.2.5 **Marking Panel.** A sidewall panel of a corrugated steel configured with a flat portion used for the display of markings and placards. (4.2A)
- 4.2.6 **Lining.** Plywood or other like material attached to the interior side and end wall to protect the walls and/or cargo and facilitate loading operations.

- 4.2.7 Lining Shield. A strip of thin metal installed at the bottom of the interior walls to protect the lower portion of the lining from damage by materials handling equipment during loading or unloading operations.
- 4.2.8 Kick Plate. A common name for a lining shield installed on the lower portion of the interior front-end wall.
- 4.2.9 Ventilator. Two or more devices permanently attached to the side or end wall panel that provides openings for the exchange of air (but not water) between the outside and the container interior. (4.2A)
- 4.2.10 Roof Panel. Corrugated or flat sheet steel, sheet aluminum, FRP, or foam and beam and aluminum honeycomb panel that forms the top closure of the container. (4.2A,)
- 4.2.11 Roof Bow. Lateral non-structural member attached to the topside rails and supporting the underside of the roof panel. Roof bows used with removable cover (tarp) assembly are unattached. Not all container designs require roof bows.
- 4.2.12 Roof Beam. Encapsulated horizontal component to which sheet aluminum or steel is bonded to form a roof panel.
- 4.2.13 Roof Reinforcement Plate. An additional metal plate on the interior or exterior of the roof panel adjacent to the top corner fittings that provides protection of the roof panel or top rail components from misaligned handling equipment.
- 4.2.14 Tarp. Jargon for "tarpaulin" which is a waterproof and flexible fabric used for covering the top of an open-top container. This covering is referred to as a "Tilt" in some countries.
- 4.2.15 TIR Cable. Plastic sheathed wire rope that is designed in accordance with TIR customs convention (Refer to paragraph 4.5.6) and is threaded through the welded loops on the sides, end panels and door panels of an open-top container to secure the tarp.
- 4.2.16 Flooring. Material that is supported by the cross members and bottom rails to form a load-bearing surface for the cargo. The flooring is usually constructed of laminated wood planks, plywood sheets, or other composition material and is screwed or bolted to the cross members. Some containers have welded steel or aluminum flooring, sandwich panels or a combination of metal and wood. (4.2A)
- 4.2.17 Joint Strip. A formed steel or aluminum strip (usually hat-shaped section) installed between joints of the plywood sheet flooring or joints of the plywood sheet lining to help integrate and support the edges of the plywood. (4.2A)
- 4.2.18 Threshold plate. Plate forward of the doorsill to protect the entrance area of the container floor. This plate is commonly referred to as a crash plate.
- 4.2.19 Steps. Folding steps are found on some ISO Shelters and are used to gain access to the roof. They must be folded up prior to transporting shelter.
- 4.2.20 Sandwich Panel. A type of fixed or removable panel construction used in ISO Shelters consisting of a thin inner and outer sheet aluminum skin, bonded or fastened to a core constructed of either honeycomb or structural foam and aluminum beams.

- 4.2.21 Striker Plate. An additional metal plate on the exterior of the roof panel adjacent to the top corner fittings that provides protection to the roof panel or top rail components from misaligned handling equipment.
- 4.2.22 Sling Pad. An additional metal plate on the exterior of the roof panel located in the center of the roof panel that provides protection to the panel from lowered handling equipment[38].

[38] SHIPPING CONTAINER STRUCTURAL COMPONENTS AND TERMINOLOGY
http://www.residentialshippingcontainerprimer.com/

[APPENDIX B]

The following information is about insulation and the different options that are available. It has been taken from:
http://www.residentialshippingcontainerprimer.com/insulation

Insulation's job is to slow down the transfer of heat. R-value is a measurement of a material's ability to resist the transfer of energy; as we all know, the higher the R-value, the more effective the insulation. By doubling the thickness of an insulating material, we can double its R-value, cutting energy transfer in half; however, the law of diminishing returns means that the same resources applied over again yield half the net change. Looking at a complete wall assembly design and its energy analysis is the only way to find the right balance between construction cost, long-term energy savings, and overall environmental impact.

Below is a brief review of the major types of insulation, from simplest to more complex and from least cost to most. Remember: As we improve our thermal enclosure, we also can reduce the complexity and size of our heating and cooling systems. This reduces first cost and saves on long-term operating cost. In a Life Cycle Assessment of this approach, higher-performing insulation will result in the best choice.

BATTS: If you are considering using batt insulation, select high-density batts with a higher insulating value. Remember that careful installation is vital; too often, poor installation techniques, design complexities, framing challenges, and other factors can cause gaps and voids between and around batts, seriously deteriorating their performance over time.

LOOSE-FILL SPRAY: Fibrous spray insulations are an innovative use of some traditional blown insulation products or recycled materials all using low-toxicity binders. These loose-fill solutions can be sprayed when mixed with moisture or binding agents. Some are intended for filling cavities while others are designed to adhere to exposed surfaces such as joists and floor pans. Correct installation requires careful management of moisture content and carefully watching the installed density. Cellulose-based solutions such as Green Fiber's Cocoon System are made from recycled newspaper and incorporate EPA-registered fungicide. Some companies are fine-tuning their blends to emphasize fireproofing and acoustical attenuation along with energy-saving insulation.

SPRAY FOAM: Foam-in-place technology is playing an increasingly important role in establishing a tight building envelope. Historically, most of these products utilized high-density, closed-cell polyurethanes, which involved exposure to potentially hazardous chemicals during application. Today they usually flash their VOCs quickly and become fairly innocuous after a short time. Closed-cell foams are very effective at managing air leakage and can have high R-values of up to 7 per inch. Unfortunately, most still use HCFCs as blowing agents (with some notable exceptions such as SuperGreen).

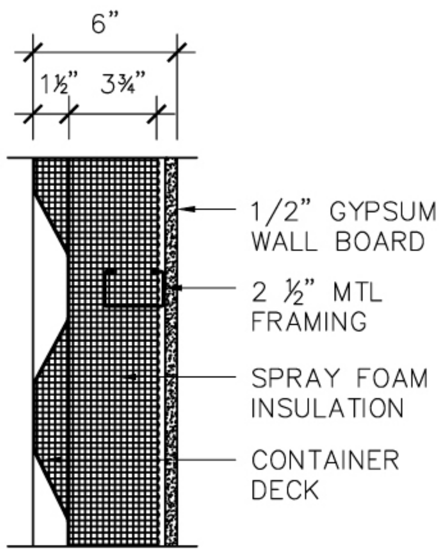

Figure 10.01-Typical Exterior Wall
http://www.residentialshippingcontainerprimer.com/

But there are now a number of non-ozone-depleting, open-cell products available. These open-cell foams have lower R-values, but manufacturing them requires fewer hydrocarbon resources. Some are managing to replace petrochemicals with bio-based raw materials. The Icynene insulation system has a very long track record and is the most widely installed open-cell foam used today. BioBased 501 is polyurethane foam with a soybean-oil base that uses carbon dioxide as a blowing agent. These products seem to be gaining rapid acceptance as builders look for alternatives to traditional insulation.

SIPS: An alternative to installing traditional insulation, Structural Insulated Panels (SIPs) are typically constructed of OSB sandwiching a foam core. Pros appreciate the ease of assembly and the improved performance SIPs can provide. Typical wall system R-values are from 22 to 30; these walls actually perform remarkably well as they have less framing materials thus reducing thermal bridging. This would eliminate the conventional framing approach and provide a faster and very tight enclosure. Still, these are not perfect either and require some training to install them correctly.

Framing Details

Regardless of the system you choose, remember that structural framing has a significant impact on insulation performance. The space between the studs may be R-22, but the studs, trimmers, headers, and rim joists themselves are only R-7 or R-8. Also remember that complex framing designs increase the building envelope's surface area, and more surface area means more energy loss. Design the building shell with less surface area, and you'll be miles ahead before you even start thinking about insulation.

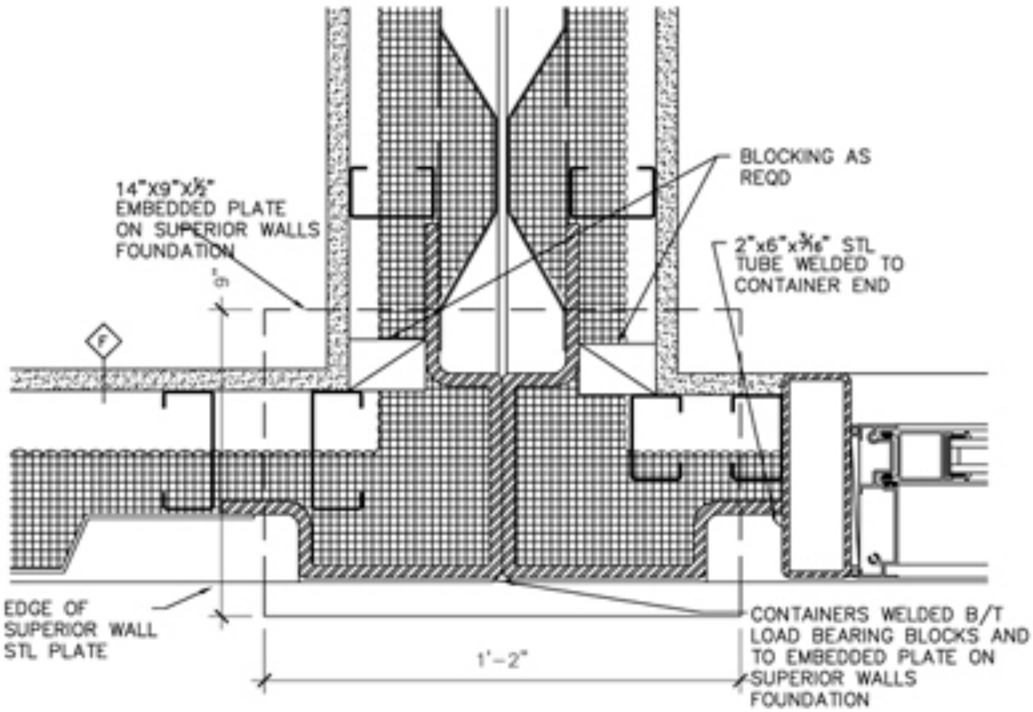

Figure 10.02- Section of interior and exterior walls of container
http://residentialshippingcontainerprimer.com/

Most wall insulation is traditionally installed in wood stud cavities, but adding insulation on the outside of the frame can significantly improve building performance if traditional framing is used. Besides adding additional insulation value, insulating the exterior of the enclosure also reduces dew-point potentials in cold climates and condensation potentials in high latent-load cooling climates. Exterior insulation also reduces the thermal bridging effect that studs have in a wall.

Because steel-stud exterior walls lose much more heat than wood-framed walls, they have the additional need to be sheathed in extruded or expanded polystyrene. The Department of Energy specifies the application of a minimum 1- to 2-inch layer over steel framing members to prevent thermal transfers that bypass the insulated cavities. In most climates, I would recommend installing at least 2 to 3 inches of foam if steel studs are being used. Enclosing the box with rigid insulation also can tighten up the envelope and will keep framing materials warmer and drier. Remember, in all but the most extreme climates a house enclosed in foam sheathing should not have an interior polyethylene vapor barrier. (More on this topic in the next issue.)

Put It All Together

With all of these approaches, real success comes from paying attention to the details. When wall and roof assemblies effectively connect with improved insulation products, we achieve synergistic gains. As our industry increases understanding of and respect for the fundamentals of building science, it is leading to many significant product innovations. Keep your eyes and knowledge tuned to improving our buildings' performance.

INSULATION: PRODUCT REVIEW

Sometimes finding the right insulation can be extremely tricky. Fernando Pages Ruiz wrote a great article for ecohome magazine that lays a comprehensive list and product review of most insulation available:

Insulation represents an inherently green building material because it is designed to save energy. Still, while any insulation is better than none, the many choices present a broad range of benefits, with certain products inherently more ecological than others.

Here is a sampling of the major types of insulation, their properties, and their sustainability beyond simply saving energy.

Fiberglass

Ubiquitous and economical, fiberglass represents the largest share of the market, comprising more than 50% of the insulation installed in the U.S. in 2007, according to the North American Insulation Manufacturers Association (NAIMA). It's available in loose form for blown-in installation and in blankets, rolls, and batts for compression installation. Depending on density, both blown and stuffed fiberglass products provide R-13 to R-15 in a 2×4 wall cavity. Medium-density fiberglass designed for 2×6 constructions now provides R-21. In a 9?1/2-inch (2×10) cavity, high-density fiberglass can deliver a whopping R-38.

All fiberglass insulation manufacturers use 25% to 40% recycled glass in their products, according to Paul Bertram, director of environment and sustainability for NAIMA. The balance is sand, an abundant natural resource, with chemical binders added to create loft and a cohesive mat in the case of batt-style insulation.

One ecological issue with fiberglass is that glass and sand have to bake at extremely high temperatures to produce fibers. On the flip side, a typical pound of fiberglass insulation "saves 12 times as much energy in its first year in place as the energy used to produce it," says Bertram.

Most of the health concerns and allegations made about fiberglass insulation have been retracted or disproved. The National Academy of Sciences (NAS) reported in 2000 that epidemiological studies of glass-fiber manufacturing workers indicate, "glass fibers do not appear to increase the risk of respiratory system cancer." NAS now supports the exposure limit of 1.0 f/cc that has been the industry recommendation since the early 1990s. And as of 2001, the International Agency for Research on Cancer (IARC), on which the California standards for Proposition 65 are based, no longer classifies fiberglass as a human carcinogen.

Perhaps the biggest objection to fiberglass batts in green building circles comes from the binders used to glue the glass fibers into a cohesive mat. These binders usually contain formaldehyde, a chemical known to cause sensitivity in certain people and classified as a human carcinogen by the IARC and as a probable human carcinogen by the EPA.

Most manufacturers insist that the low levels of formaldehyde used in manufacturing fiberglass batts makes any health concern exaggerated when compared to many other building products and naturally occurring off-gassing from raw materials, such as wood. In fact, some fiberglass batt insulation with added formaldehyde has gained Greenguard certification.

But if you are concerned, loose fill or blown fiberglass insulation requires no binder, which means no formaldehyde. For those using batts, Johns Manville offers the only fiberglass batt product line with no added formaldehyde. "We don't consider the formaldehyde binders in insulation to be a big contributor to indoor air pollution, but since we can use alternatives without formaldehyde, why not do our little part to improve the environment?" explains Erick Olson, a senior technical product specialist for Johns Manville.

Any stuffed insulation requires excellent on-site quality control to perform at its rated R-value. A few missed cuts, gaps, or cracks left between batts, and the R-value plummets. Blown and foamed insulation usually provide a more foolproof system to prevent air infiltration, but an excellent sealing job using a well-aimed caulk gun and a few cans of foam sealant coupled with
a craftsmanlike batt installation can yield low-cost insulation results comparable to the blown systems.

Non-Fiberglass Batts

Non-fiberglass batts can be made of cotton, sheep's wool, or mineral (rock or slag) wool. All of the alternative batt insulation products are made almost entirely from recycled or renewable materials. They offer similar thermal performance as fiberglass but at a slight cost premium. They come unfaced and need the addition of a separate vapor retarder in extreme-cold climate zones.

To make them fire resistant and prevent mold and insect infestation, most alternative batt (and cellulose) insulation fibers are coated with ammonium sulfate or borate. Although one manufacturer advertises its product as so safe a child could eat it, both sulfates and borate are used as pesticides and have toxic properties. At a minimum, a respirator should be worn when installing any kind of insulation.

Cellulose

Although the broad category of cellulose insulation includes a variety of products such as granulated cork, hemp fibers, straw, and grains, the most common and readily available cellulose insulation is made almost entirely from recycled newspapers, cardboard, waste paper, and wood pulp. Cellulose insulation is perhaps the best example of a significant recycled product in widespread use. Most is approximately 90% post-consumer recycled waste paper, with fire-retardant chemicals and, in some products, acrylic binders added.

“Mineral fiber materials take at least 25 to 30 times more energy to make than cellulose of equivalent R-value,” says Daniel Lea, executive director of the Cellulose Insulation Manufacturers Association, citing cellulose’s low-intensity manufacturing process and high-recycled content.

Nowadays, blown cellulose is applied dry or merely damp, eliminating the extended drying times required for older, “wet” applications. Because of its relative high density and fire suppressants, this recycled newsprint product increases the fire resistance of building assemblies by 22% to 55%, per the Canadian National Research Council. It also provides a better air seal than fiberglass because of its higher density and slight dampness when applied, which tend to push the material into framing member penetrations.

As with cotton and wool, cellulose is an organic and flammable product that requires added biocides and flame-retardants, usually borate and ammonium sulfate. Most cellulose installations are done by contractors using special equipment, but loose fill is also available that anyone can simply pour out of a bag. As with all other insulation products, installers should wear proper respirators as recommended by the manufacturer, especially since some people have sensitivity to newsprint ink. Foam

Although R-values remain close to equivalent across all insulation products, expanding foam has an added benefit because of the excellent air seal it provides. Foams are two-part products that are mixed through a blowing mechanism and sprayed into the framing cavity. The two chemicals react and expand. As the foam expands, it fuses tightly around all pipes, ducts, and wires, creating an airtight seal that yields much higher thermal performance than R-value alone would suggest.

The adhesive quality of foam offers another benefit rarely associated with insulation: High-density foam insulation provides improved structural integrity that helps make a building a little stronger. Nowadays, most foams use HCFCs as blowing agents, which are less destructive to the ozone layer than the old, and now banned, CFCs but still considered environmentally detrimental. Foams that do not use ozone-depleting blowing agents include Icynene, which uses carbon dioxide and water; Air Krete, foam produced from magnesium oxide (derived from sea water) and compressed air; and BioBased, which uses compressed air.

As a builder of low-cost houses, I look for the least expensive option to achieve the best possible results. For this reason, I often use high-density fiberglass batts coupled with an excellent sealing job. But when my company set out to build a LEED for Homes–certified demonstration house, we chose BioBased insulation as a high-performance alternative.

Depending on market niche, the variety of insulation products available lets a builder distinguish his house as a comfortable, energy-efficient, and environmentally safe place to call home.

Owens Corning. The manufacturer says its entire line of fiberglass insulation products has been certified by Scientific Certification Systems to contain an average of 35% recycled content, 5% of which comes from post-consumer sources. ProPink fiberglass insulation carries Greenguard certification, including its highest-level with Greenguard Children & Schools product emission standards. 800.438.7465. www.owenscorning.com.

Demilec. Sealection Agribalance open-cell, semi-rigid, polyurethane spray-foam insulation contains more than 10% renewable, agriculture-based products, says the firm. The material expands to fill the cavity, sealing cracks, gaps, and voids. It provides an R-value of 4.45 per inch. 877.336.4532. www.demilecusa.com.

CertainTeed. Designed for attic areas, InsulSafe SP blown-in fiberglass insulation is manufactured with no formaldehyde and is Greenguard certified. The product offers up to 20% better coverage versus competitors, the company says, with one bag covering up to 67 square feet. InsulSafe SP installed in the attic at 113/4 inches is R-30 and 141/2 inches is R-38. 800.233.8990. www.certainteed.com.

Advanced Fiber Technology. AFT cellulose insulation is made from 85% post-consumer recycled newspaper and cardboard. The pulp is ground into a fine, fluffy powder, and then treated with primarily boric acid and borax to render it fire resistant. The higher density of this cellulose insulation makes for a tight seal, second only to foam products in blocking air infiltration and sound deadening, says the company. The blown-in insulation provides an R-value of 3.8 per inch. 419.562.1337. www.advancedfiber.com.

Thermafiber. Thermafiber mineral wool insulation is made with up to 90% post-industrial recycled content. It exceeds the California purchase specifications for total volatile organic compounds and general emissions with formaldehyde concentrations of 12 ppb, exceeding the California standard of 20 ppb maximum for formaldehyde concentration. Thermafiber can provide high sound-transmission coefficients that improve indoor environmental quality. The product also offers fire resistance of more than 2,000 degrees F for more than five hours, the maker says. 888.834.2371. www.thermafiber.com.

Air Krete. The company's magnesium silicate, cement-based insulation is foamed or pumped into closed cavities. This insulation is purportedly hypoallergenic and popular with chemically sensitive people, the company claims. Since it is not temperature sensitive, it can be installed indoors under any weather conditions and tolerates contact with high-heat sources, such as exhaust pipes, without concerns for combustion. The product is fully recyclable and can be used for soil enrichment. AirKrete has an R-value of about 3.9 per inch. 315.834.6609. www.airkrete.com.

Icynene. Icynene water-blown foam insulation expands to 100 times its volume to fill cracks and crevices and minimize air leakage. It carries an R-value of 3.6 per inch. The product also is available in a pour-fill variation that expands upward to 60 times its original volume; it will not expand outward and damage the wall. The pour-fill version has an R-value of 4 per inch. 800.758.7325. www.icynene.com.

Johns Manville. Formaldehyde-free MR faced fiberglass batts use a water-based acrylic binder that meets California's Section 01350 standards. The facing serves as an integral vapor retarder chemically protected against potential fungi growth. The company claims to obtain its sand from sources close to the manufacturing plant to reduce transportation impacts, and 20% of its recycled content is post-consumer. 800.654.3103. www.jm.com.

Second Nature. Sheep's wool is an insulation product commonly used in Europe and available in the United States through the Internet. A natural insulator, wool has a slightly higher R-value per inch than fiberglass and does not lose its insulating property when wet. It has inherent properties that resist both flame and many insects, but remains susceptible to moths, so it is treated with boron.

Thermafleece comes in 2-inch-thick batts cut to friction fit within 16- and 24-inch stud spacing. They carry an R-value of 3.8 per inch and can be layered to achieve the desired total R value. www.secondnatureuk.com.

BioBased 1701 BioBased Insulation. Unlike some traditional spray-foam insulation products that are petroleum-based and use HCFCs as blowing agents, BioBased 1701 is a soy-based, 100% water-blown, closed-cell polyurethane insulation. It has earned the Greenguard air quality certification. BioBased 1701 has an R-value of 19 at 3-1/2 inches. 800.803.5189. www.biobased.net.

Bonded Logic. Ultra Touch cotton friction-fit batt insulation can be used for 16- and 24-inch spacing. The product is made with 85% post-industrial recycled content. The line includes an R-30 batt that fits into 2×6 walls or joist cavities. Cotton insulation offers acoustic properties 36% higher than fiberglass, says the company, only slightly less than mineral wool[39].

Supertherm

SUPERTHERM ® is a unique single component combination of high performance aliphatic urethanes, elastomeric acrylics, standard acrylics and resin additives in a

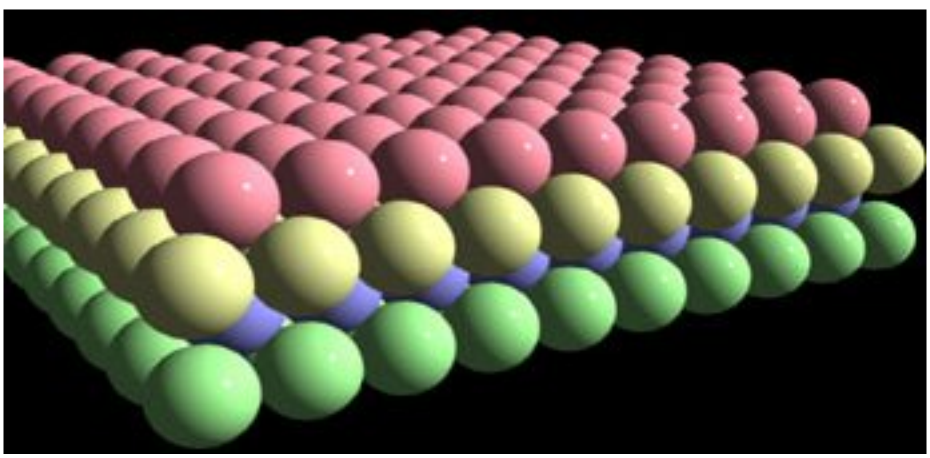

Figure 10.03- Molecular structure of Supertherm.
http://www.residentialshippingcontainerprimer.com/insulation

[39] http://www.residentialshippingcontainerprimer.com/insulation

water borne formula. No co-solvents are present and will dry by evaporation. Due to the unique combination of acrylics and urethanes, SUPERTHERM ® cures out completely in 14 - 21 days to an extremely tough, durable, non-yellowing, water resistant coating that also provides flexibility, water proofing and UV stability. SUPERTHERM ® has passed 2000 hours of salt spray testing which equals marine specifications and in fact has DNV certification. SUPERTHERM ® was built to meet the requirements of industrial uses which required a tough surface, and provide flexibility against stresses of contraction and expansion. Also, unlike all other "reflective" paints on the market which offer only a single reflective ceramic to provide heat reflection, SUPERTHERM ® is designed with four separate ceramic compounds for insulation from radiant heat, reflection, conduction and convection. SUPERTHERM ® ceramics are not the rough multifaceted type as the one found in other coatings, SUPERTHERM ® ceramics are ground to form microscopic spheres. The spherical shape permits the 4 types of ceramics to settle very tight together, not allowing air to interact between the ceramics; thus "plating". SUPERTHERM ® multi-ceramic insulation coating blocks 96% of the three sources
of heat -
visual light, ultra violet rays and infrared rays.

Therefore, SUPERTHERM ® is a true " insulating " coating and not just a reflective paint as are all the competing formulas in the market. Also tested by the Thermo Physical Research Laboratory for comparative R19 equivalent insulation factor SUPERTHERM ® blocked 92% of the heat. No other R19 equivalent insulator can claim that!. No Fiberglass, No Foam, No Cellulose, No other single ceramic paint!

~ Two ceramic compounds are primarily to repel radiation and offer reflective abilities. These two ceramics repel better than 95% of the sunlight and radiant heat (short wave).

~ The third ceramic compound is to stop 92% heat and / or cold conduction by hollow sphere technology which is not glass.

~ The fourth ceramic compound is designed specifically for stopping infrared radiated heat. This ceramic blocks 99.5% of Infrared Radiation (long wave) to control the heat gain or loss to the envelope of buildings or equipment. This new compound was introduced in February 2000 as part of our continued research in controlling heat transfer.

~ The combination of acrylics provide elasticity and adhesion while the urethane adds toughness, binds the acrylics and compounds and also provides a moisture barrier. The fourth resin additive is what makes the complete resin blend to combine into a single component and extends the life of the coating. This resin / ceramic combination has been shown to repel both heat and fire, withstand elements for 30 to 40 years, endure 180 degree bend without cracking, resist water, acid rain and ultraviolet light. SUPERTHERM ® is a permanently flexible "breathable" membrane that stops water penetration and prevents corrosion and surface deterioration[40].

[40] http://ecopods.ca/gogreen.php

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