

DESIGN AND TESTING OF A PROTOTYPE SOLAR SANITIZER

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by

Xiaoying Wang

Dr. Daniel Hassett, Thesis Co-Supervisor

Dr. Luis Occeña, Thesis Co-Supervisor

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The undersigned, appointed by the dean of the Graduate School, have examined the Thesis/Dissertation entitled

DESIGN AND TESTING OF A PROTOTYPE SOLAR SANITIZER

presented by Xiaoying Wang,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Luis Occeña

Professor Daniel Hassett

Professor James Noble

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LIST OF NOTATIONS

ΔT	Difference between final temperature and original temperature
C_p	Specific heat coefficient
M	Material mass
Q	Energy amount
A	Surface Area
$^{\circ}C$	Temperature Degree Celsius
$^{\circ}F$	Temperature Degree Fahrenheit

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Thesis supervisor

ABSTRACT

According to the World Health Organization (WHO), many people die of preventable diseases like diarrhea, cholera, pneumonia, and hepatitis A each year, especially in poor countries, and also after natural disasters like earthquakes, floods, and tsunamis. Diarrheal diseases are the second leading cause of death in children under the age of five (WHO, 2013). These diseases are easily spread through contaminated drinking water. A lack of appropriate water treatment infrastructure, improper waste disposal and inadequate treatment of human waste, especially after natural or civil disasters, are common causes of water contamination. In addition to their severe effects on local populations, similar challenges for preventing diarrheal diseases confronted the United States Army during recent deployments in Iraq and Afghanistan due to a lack of civil infrastructure and the frequent movement of troops to rural areas.

The common ways to treat human waste for the United States Army include burning, chemical disinfection or burying. Burning and chemical disinfection are harmful to the environment; moreover, both are expensive in terms of the fuel and chemicals that are used during waste treatment. Burying waste under the earth is cheaper but, it could possibly stimulate the growth and spread of bacteria in water sources around rivers and wells if done improperly.

Therefore, there is a significant need for an effective low-cost, low-technology solution that prevents the spread of the above-mentioned diseases for civilians in

developing countries, the United States Army and also for natural disaster victims. We have developed and tested a device that meets these needs. The device, which we call the Solar Sanitizer, takes advantage of infrared sunlight to kill the bacteria in human waste. We have prototyped the device using simple readily-available materials. We have also conducted preliminary effectiveness testing of the prototype with positive results. This thesis describes the motivation, design, prototype development, and preliminary testing of the Solar Sanitizer.

Chapter 1

Introduction

1.1 Introduction

There have been reports of soldiers getting sick from drinking contaminated water polluted by human waste in places like Iraq and Afghanistan (WRIISC, 2013). The U.S. army has expressed interest in ways of solving this problem besides using gasoline and chemicals to process human waste. That is why we designed, developed and tested a solar sanitizer. Our prototype is mainly made of plywood and a plexiglass window. The sanitizer is made up of an inner box and an outer box which is separated by insulation. In the desired final product, it is designed to put human waste into a sealed mylar bag and place the bag into the inner chamber under the sun for several hours. After several hours, the bacteria in the human waste will be killed by heat generated by the absorption of solar energy.

The advantages of the device are first, it is cheap to manufacture since it is made of wood and plexiglass and there are no advanced motors, electronic appliances, or any other devices. Second, it is easy to use especially for soldiers; a soldier needs to put the mylar bag of human waste into the inner chamber, close the sanitizer and set it at an appropriate angle towards the sun and walk away. After several hours, the soldier comes back, takes out the mylar bag and buries it under the earth. Soldiers do not need to keep an eye on the device all the time. What they need to do is just set it up then they can go

away to do something else. In a word, the solar sanitizer is a low-cost, low-maintenance alternative for managing human waste in the field that can keep the soldiers from getting sick from contamination and also save the army money.

The practical use of the solar sanitizer will not be restricted to the United States Army; it can also be used by the Red Cross all over the world in the aftermath of disasters like earthquakes, floods, and tsunamis when all the local water and waste treatment infrastructure has been destroyed. In these cases, the solar sanitizer can not only prevent people from getting sick but also save lives. Finally, the solar sanitizer can also be used by residents in some poor places which lack modern hygiene facilities.

1.2 Research Objective

The objectives of this thesis are: (1) to design an actual sanitizer in all aspects, including; the structure of the sanitizer; choosing appropriate materials for construction; calculating the dimensions of all the required pieces, and so on, (2) to manufacture or prototype a real sanitizer based on an original design, and (3) to test the prototype to see whether or not it is effective and to reexamine the design in order to define future improvements.

In Chapter 2 a literature review is provided. This chapter describes the history of solar oven cookers and solar water heaters as an understanding of these devices is important for the development of the solar sanitizer. These two kinds of solar devices use of solar energy to either cook food or heat water and also provide innovative ideas about the design of a solar device.

In Chapter 3, the operational target for all the experiments in this thesis are described, based on solar theory and related formulations. Testing of two competing waste container designs consisting of either a rigid metal bucket or a flexible mylar bag have also been conducted based on solar theory and formulations.

In Chapter 4, the manufacture processes are presented in detail, including all the dimensions, AutoCAD drawings and assembly instructions for the solar sanitizer. Pictures of the manufacturing processes for the sanitizer are also shown in this chapter.

In Chapter 5, the results of laboratory and field testing are shown and followed by detailed analysis to test the efficiency of the sanitizer.

In Chapter 6, the conclusion of all the experiments are presented and also proposed future research including mass manufacturing and human factors design considerations are discussed.

Chapter 2

Literature Review

2.1 Solar Oven Cookers

A solar oven is a device which uses infrared radiation from sunlight to cook food. The first documented effort of using solar energy to prepare food was by the French–Swiss Physicist Horace de Saussure (Cuce, 2013). He reported cooking fruit in 1767 using a sealed window box with five panes of glass stacked one atop another (Saxena A, 2011). Multiple panes of glass reduced heat loss through the window and made the box more efficient at retaining heat. In 1830, Sir John Herschel used a similar device to cook food while aboard a ship on his way to South Africa (Narayanaswamy S, 2001). In August 1866, Augustin Mouchot came up with the idea of using mirrors to focus sunlight in an effort to make solar ovens more efficient. His design was the first description of a parabolic trough solar oven (Gordon, 2001). The first octagonal oven, a device that uses multiple reflective mirrors to focus sunlight onto a fixed point, was developed by W. Adams in 1876. (Narayanaswamy S, 2001).

In the 1960s and 70s, the concept of developing renewable energy technologies became more and more popular all over the world due to increased public awareness of the need to protect our dwindling natural resources (Knudson B, 2004). Since that time, solar cooking technology has been the focus of considerable interest in both developed and developing nations because of the ability of solar ovens to prevent deforestation, reduce local dependency on fossil fuels and reduce a community's carbon emissions (Cuce, 2013).

The first modern book about solar ovens published in the USA was written by Heather Gurley in 1983 and entitled *Solar Cooking Naturally* (Mullick SC, 1987). In 2000, an international standard for solar ovens was finally described (Funk, 2000). Nowadays, solar ovens are widely used in developing nations due to their convenience, cleanliness and low production costs.

There are four main types of solar oven designs: box cookers, paraboloidal reflectors, parabolic troughs, and spherical reflectors (Ashok Kundapur, 2014).

Box cookers

The simplest type of solar oven is a box cooker. As their name implies box cookers are highly insulated cube shaped structures with a single window that allows sunlight to pass into the interior of the cooker. They are usually made of locally sourced materials such as wood, cardboard, mud bricks or stone and have a reflective surface made of polished aluminum or foil on the inside. The cooking vessel is generally a black pot capable of absorbing heat and infrared radiation. The cooking vessel is either placed directly on the floor of the oven or suspended slightly above the cooker floor on a shelf ("How to: Make a cardboard box oven," 2008). A figure of a box cooker is shown below as Figure 1. One of the limitations of a box cooker is that they can only heat a limited amount of food in several hours. However, simple box cookers can reach temperatures of 130 – 150°C well above the minimum temperature of 65°C necessary to kill most pathogenic bacteria. That is to say, most box-type solar ovens are small and designed to heat only small amounts of food therefore, the current commercial designs are not 100% appropriate in terms of the project for The United States Army which is to heat large

quantities of human waste to temperatures that will kill all pathogenic bacteria within several hours.



Figure 1 Box Cooker("How to: Make a cardboard box oven," 2008)

Parabolic Ovens

Parabolic ovens take advantage of the ability of reflective surfaces composed of compound curves to reflect and focus sunlight onto a very small surface area. The advantage of a paraboloidal reflector is that it can generate extremely high temperatures and cook food very quickly. These types of ovens are popular in temperate climates because of their simple design and their ability to cook food on sunny days even when the local temperature is below freezing. However, the sun is constantly moving across the sky, so a major disadvantage of paraboloid ovens is that frequent adjustments are necessary to keep the reflector properly focused on the sun (Williams,2010). A picture of a paraboloidal reflector is shown below as Figure 2. While a paraboloid reflector design would likely be highly efficient at rapidly heating human waste, the need for constantly tracking the sun combined with the fact that the large mirror makes the device highly visible limits the usefulness of these types of devices for the Army.



Figure 2 Paraboloidal Reflector (Wikipedia, 2013)

Parabolic troughs

Another highly efficient method for capturing sunlight is through the use of a parabolic trough. These devices consist of curved mirrors arranged in series. The curvature of the mirrors focuses sunlight onto a fixed point above the mirror surface. While parabolic troughs can be used for cooking food they are more commonly used to heat water or other fluids. Parabolic trough designs have been used to produce electricity on a commercial scale by using mirrors to focus sunlight onto a hollow tubular receiver. Liquid in the receiver can be heated to temperatures well above 100°C. The superheated liquid can then be used to power a turbine generator or steam engine. Although parabolic troughs can be powerful enough to produce steam to run a generator they are bulky and the reflector makes them highly visible (Boukelia, 2013). A figure of a parabolic trough is shown below as Figure 3. The disadvantages of a parabolic trough are its complexity, lack of portability and cost. It consists of multiple mirrors in series and a tube containing the heating fluid suspended over the mirrors at the focal point. If the fluid is used to operate an electrical generator the generator also contributes to the cost. What the army needs is something portable and cheap to build and it is unlikely that a parabolic trough design would meet the needs of soldiers in the field.



Figure 3 Parabolic Trough ("Concentrators vs. Flat Plates", 2013)

Spherical reflectors are similar to paraboloid reflectors and have unique geometric properties for capturing and focusing various forms of radiation including radio and microwaves. This is why these type of devices have been used as wide-angle scanning antennas (Xu, 2009). The temperature of the steam at the focal point of the reflector can reach 150 °C (302 °F) and it can be used not only to cook food, and purify water but also to sterilize medical equipment. Like paraboloid reflectors one of the disadvantages of spherical reflectors is that they also require constant readjustment of the reflector to keep the sun in focus. This is usually accomplished by an electrical actuator and it increases the cost of the device considerably (Xu, 2009). The figure of a spherical reflector is shown below as Figure 4.



Figure 4 Spherical Reflector (Wikipedia, 2013)

As it is discussed above, none of the four types of solar ovens can be directly used by the United States Army due to the limitations in the amount of material that can be heated, the need for constant adjustment towards the moving sun to maximize efficiency, or the complexity and visibility of previous designs. In order to design a device for use in the field there are a lot of things to consider in order to meet the unique operational requirements of the army. For example, glass is commonly used to heat food in fixed location solar box ovens and it works well. However, it is not appropriate for the army due to its fragile nature. Instead, the design of our waste sanitizer utilizes plexiglass as a window material because it is more durable than conventional glass.

2.2 Solar Water Heaters

A solar water heater is a device which uses sunlight to heat water. The first solar water heater in the world was invented in 1760 by a Swiss naturalist who built a rectangular box and had the top covered with glass, and had two smaller boxes painted black placed inside. When this device was exposed to the sun, the inner box could be heated to 228 °F (109°C) which was 16 degrees Fahrenheit above the boiling point of

water (Perlin, 1999) (Ken Butti, 1980). The first record of using solar energy to heat water was in the United States around 20th century. In 1920, solar water heaters were used in Florida and southern California. A surge of interest was risen in North America after oil crisis in 1973 (Perlin, 2013). Nowadays, in Israel and Cyprus, 30%~40% of homes are using solar water heaters (Del Chiaro, 2007). In China, there are at least 30 million households which have a solar water heater (Graham-Harrison, 2005).

There are four main types of designs for solar water heater systems: direct and indirect systems, and active and passive systems. In a direct system potable water is heated and used directly while indirect systems heat a transfer fluid which is then used to heat potable water for use. Active systems use a pump of some kind to move either water or the heating fluid through the system while passive systems rely upon convection currents that arise naturally when a fluid is heated to move liquid through the system. All current solar water heater designs are actually an integration of two of these design types. For example, there are active direct and active indirect systems ("*Heat Your Water with the Sun*", 2003).

Active direct systems physically pump water through the collector into the home. They only work well in places that rarely freeze. The figure of this design is shown in Figure 5 below ("*Heat Your Water with the Sun*", 2003) .

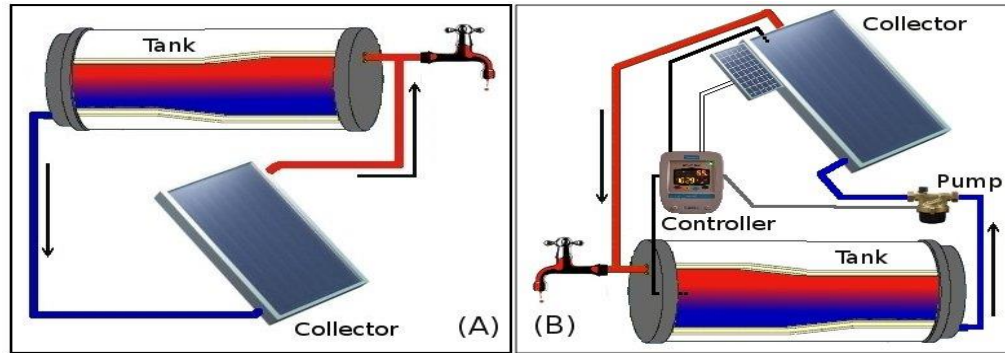


Figure 5 Active Direct System (Wikipedia, 2013)

Active indirect systems pump non-freezing water through the collectors and a heat exchanger. The advantage of an indirect system is that the heating fluid can have a freezing temperature lower than that of water and this makes it possible to use these types of systems during the winter in temperate areas (*"Heat Your Water with the Sun"*, 2003). The figure of an active indirect system is shown below as Figure 6.

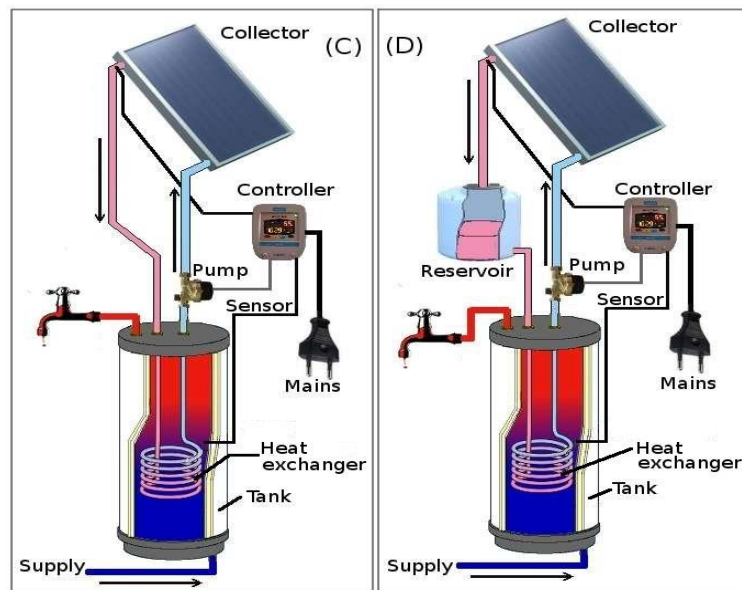


Figure 6 Active Indirect System (Wikipedia, 2013)

In the US, solar water heaters are commonly used to heat swimming pools and water for personal use (*"Heat Your Water with the Sun"*, 2003). Unlike small solar oven

cookers, solar water heaters are designed to heat large amount of water within several hours. However, most solar water heaters are more expensive to build and operate than a simple solar oven, especially for active systems that require electricity driven pumps. The sanitizer for the Amry project needs to be cheap like a solar oven cooker and also able to heat large amounts of human waste at one time like a solar water heater. Although the material of a solar oven cooker is very cheap, many designs require frequent adjustments to follow the daily motion of the sun in order to maximize the amount of captured solar energy. During the proposal phase of the project the Army made it clear that they would prefer to keep the position of the sanitizer static. In this case, the rough idea of the sanitizer would be just a well insulated box with a large window in the front to capture the sunlight. A lot of experiments and tests will be done before the design of the sanitizer is finalized.

Chapter 3

Theory and Methodology

The goal of this project is to kill all pathogenic bacteria in human waste by using solar energy. The temperature at which the majority of pathogenic (disease-causing) microbes can be killed is 65 °C (149 °F), while the majority of nonpathogenic bacteria in human waste can be killed at approximately 50 °C (122 °F).

3.1 Solar Energy

This project's solar sanitizer was designed according to the needs of the United States Army for use in tropical and temperate climates like the Middle East. The first task toward achieving this project's goal was to find an economical way to heat human waste. First of all, the sanitizer had to be cheap to operate; hence, solar energy is the best choice. Energy from the sun is absolutely free and was first used for solar oven cookers and solar water heaters in the early 18th century (Saxena A, 2011). Moreover, the Middle East region, especially the Arab Gulf countries, have sufficient solar intensity all year around to operate both solar water heaters and cookers (Yassen, 2013).

3.2 Theory and Formulas

3.2.1 Solar Energy theory and assumptions

Solar energy potential varies seasonally due to the earth's autorotation and revolution around the sun. All field tests described in this thesis were conducted in Missouri in July.

The solar energy striking the surface of the earth in Missouri in July is approximately 6.5 kwhr/m² (Russell, 2010).

There are two assumptions made during the completion of this project related to solar energy: (1) Assuming 30% of the solar energy can be converted to useful heat, then the expected useful solar energy striking the surface of the earth in Missouri in July will be 1.95kwhr/m². (2) Assuming 8 hours of usable sunlight, so the total amount of energy obtainable is 0.24375kwhr/m² per hour.

The sanitizer had to be well designed in order to capture enough solar energy to heat the waste to the temperature necessary to kill pathogenic bacteria.

3.2.2 Calculate Amount of Heat Obtained by Water

All the experiments discussed in this thesis are based on water instead of real human waste because we needed to prove the theory and test the efficiency of the sanitizer before we used real human waste. The energy obtained by water during heating equals the specific heat of water (Cp) multiplied by the mass of the water (M) multiplied by the change in water temperature (ΔT). This equation is represented mathematically below

$$Q = C_p * (M) * (\Delta T) \tag{1}$$

3.3 Operational Target

As noted in the introduction, the majority of disease-causing microbes are unable to survive at 65 °C (149 °F) while the majority of nonpathogenic bacteria in human waste can be killed at approximately 50 °C (122 °F). Because the goal of the project was to reduce disease transmission, the ending target temperature of the solar sanitizer for all the experiments in this thesis is 65°C. It was also assumed that the starting waste temperature

would be approximately room temperature or 25°C (77°F). Therefore, the temperature of the waste needs to increase by 40°C (ΔT) for the machine to be effective. The specific heat of water (C_p) is a constant and equals 4.179 joules/gram/ degree Celsius.

Because the change in waste temperature and the specific heat of the waste are constant the effectiveness of the machine will largely depend upon the mass of the waste that needs to be heated to 65°C. The average human produces approximately 1.95 kg of mixed solid/liquid waste daily and the machine was designed to process the daily waste output of 7 soldiers per day or roughly 14 kilograms. Therefore for the purposes of the initial operational tests we designed the tests to accommodate 15 kilograms of liquid waste ($M=15$ kg).

Each 30"x 20" x 6" Mylar bag used as a waste container in all experiments held 15 liters of water. As stated above we assumed that the starting temperature of the waste would be 25°C. Therefore, the total amount of energy needed to heat 15 liters of liquid waste water from 25 °C to 65 °C is:

From Equation (1) $Q = C_p*(M)*(\Delta T)$

$$Q=4.2\text{kJ}/(\text{kg}/^\circ\text{C})*15\text{kg}*(65-25)^\circ\text{C}$$

$$Q=4.2\text{kJ}/(\text{kg}/^\circ\text{C})*15\text{kg}*40^\circ\text{C}$$

$$Q=2,520\text{kJ}$$

So, each waste container will need to absorb 2,520 kJ of energy to reach an operational temperature capable of sanitizing the waste.

The surface area of each Mylar bag is:

$$A = \text{Length} * \text{Width}$$

$$A = 30" * 20"$$

$$A = 600 \text{ in}^2 \text{ or } 0.375 \text{ m}^2$$

The following calculation is based on Equation (1), the Mylar bag size, and two solar assumptions. The two assumptions are, (1) 30% of the available solar energy can be converted to useful heat and, (2) an average of 8 hours of usable sunlight strikes the surface of the earth per day in the summer.

Using these assumptions lead us to the following equation to calculate the anticipated amount of solar energy available per square meter of surface area per hour in Missouri during the summer months.

6.5 kwhr/m^2 of total energy available per m^2 day X (30% efficiency of energy capture) / 8 hours per day. Therefore, the total amount of energy obtainable is 0.24375 kwhr/m^2 per hour.

The time required to heat the waste in the Mylar bag from 25°C to 65°C equals:

$$2,520\text{kJ} / (0.24375 \text{ kwhr/m}^2)(0.375 \text{ m}^2) * 3600\text{kJ} = 7.6 \text{ hrs}$$

Based on the preceding calculation, the operational target to heat 15 liters of water from 25°C to 65°C during July in Missouri was calculated to be 7.6 hrs. In other words, if the results of the field testing for the sanitizer demonstrate that we can heat 15 liters of

waste to the operational temperature in 7.6 hrs or less then we would consider the theory and the device a success.

3.4 Water Experiments

In order to design experiments that could be conducted in a laboratory setting, we needed to find a suitable replacement for human waste and an appropriate light source to mimic the sun. Water was used to replicate liquid human waste and a halogen tungsten light source used to mimic sunlight. Two experiments preceded the sanitizer's design process. First, testing of the Mylar bag was conducted to test the usability of the material as a waste container. Second, color testing was conducted to decide the best color for absorbing heat. For each experiment, we used 15 liters of water as a substitute for human waste. The light source was placed 7 inches above the surface of the laboratory bench and 12 inches away from a bucket filled with 15 liters of water. Then we recorded temperature changes during experiments.

3.5 Bucket Testing

As discussed in the literature review, the first solar water heater was literally a metal bucket used to heat the water inside by sunlight. The initial design presented to the US Army was a triangular shaped sanitizer capable of accommodating a single 5 gallon metal bucket which served as the waste container. A metal bucket was chosen as the initial waste container because they are cheap and easy to obtain in developing nations. With the addition of an appropriate seat they could also be used directly as a toilet. A further modification was made by including a mylar bag in the bucket to collect the waste with the idea that after the material in the bucket was sanitized the bag with the waste inside could be discarded and the bucket could be reused. After preliminary testing the

bucket waste container concept was discarded in favor of a mylar bag because buckets proved to be more bulky, difficult to store and ship. The large diameter of a 5 gallon bucket also required a much larger sanitizer than one built to accommodate just a mylar bag. However, prior to the redesign of the sanitizer and waste container a series of informative experiments were conducted using the bucket-type waste container and the results are presented in this thesis.

The first set of experiments was to determine how efficiently the bucket waste container without a mylar bag inside could absorb heat during laboratory testing. These experiments tested a bucket coated with a black paint obtained directly from the manufacturer and contrasted it with an identical steel bucket that had the coating removed. For these tests 29 gauge 5 gallon steel buckets with lever lock lids were purchased. A temperature probe was placed in the center of the lid such that it extended 15 cm deep into the waste. For each test the bucket were filled with 15 liters of water at 25°C and then placed exactly 12 inches from the halogen tungsten light source. The light source was placed 12 inches above the surface of the benchtop. The light source was turned on and the temperature of the fluid was recorded every 15 minutes for 4 hours. Because there was some concern about a lack of convection in the waste container and the development of “hot spots” in the fluid the lid was removed and the fluid was stirred 20 times counterclockwise after the last data point was collected after which the final temperature was recorded. Five independent replicates were completed. Data from five tests for uncoated and coated buckets are shown in Tables 1 and 2 respectively.

Replicates	Test #1	Test #2	Test #3	Test #4	Test #5
Origin	23	23	23	23	23

0:15	23	23	23	23	23
0:30	24	24	23	24	23
0:45	24	24	24	24.5	24
1:00	25	25	24	25	24
1:15	25	25	24	25	25
1:30	25	26	25	26	25
1:45	26	26	25	26	26
2:00	26	27	26	27	26
2:15	26	27	26	27	27
2:30	27	27	26	27	27
2:45	27	28	27	28	27
3:00	27	28	27	28	27
3:15	28	29	28	29	28
3:30	28	29	28	29	28
3:45	28	30	28	30	29
4:00	28	30	29	30	29
Final	27	29	28	29	28

Replicates	Test #1	Test #2	Test #3	Test #4	Test #5
Origin	23	23	23	23	23
0:15	23	23	24	23	23
0:30	24	24	24	24	24
0:45	25	25	25	25	25
1:00	25	26	26	25	26
1:15	26	26	27	26	27
1:30	27	27	28	27	27
1:45	28	28	29	28	28
2:00	29	29	30	29	28
2:15	30	29	30	29	29
2:30	30	30	31	30	30.5
2:45	31	31	32	31	31
3:00	32	32	32	31	32
3:15	32	32	33	32	32

3:30	33	33	33	33	33
3:45	33	33	34	33	33
4:00	34	34	34	34	34
Final	33	33	33	33	33

According to the two tables, we can easily calculate the heat absorbance properties for both types of buckets. Figures 7 and 8 show the properties for the uncoated bucket whereas Figures 9 and 10 show the properties for a coated bucket.

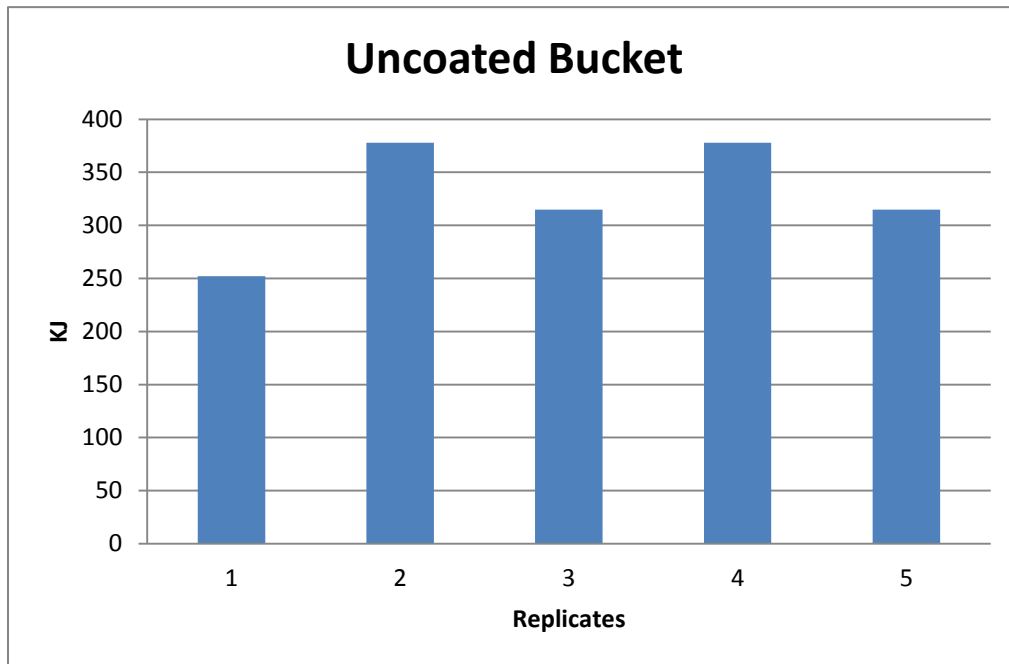


Figure 7 Heat Absorbed for Uncoated Bucket

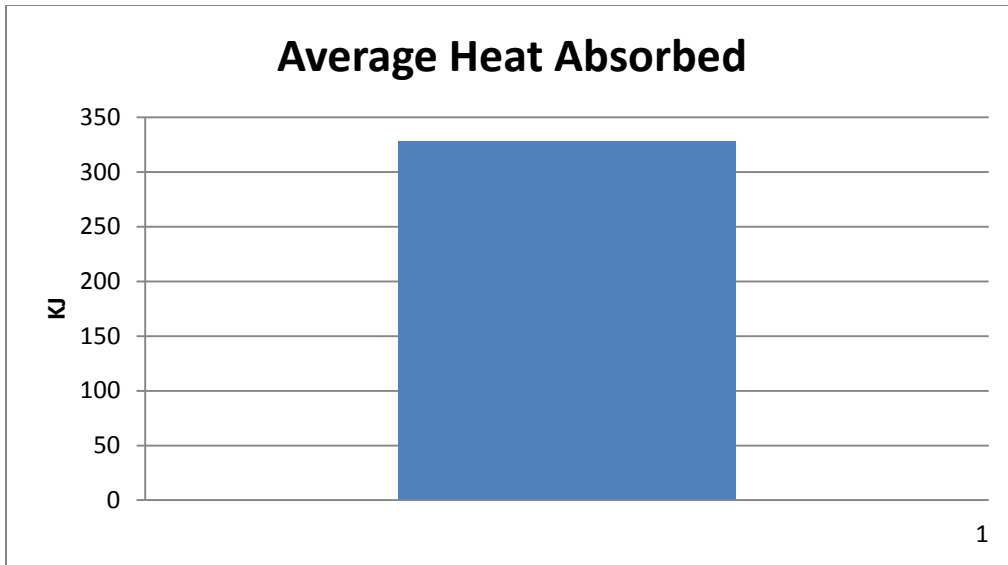


Figure 8 Average Heat Absorbed for Uncoated Bucket

As we can see from the graphs above, the average heat absorbed for an uncoated bucket is around 325 KJ during the four hour testing period.

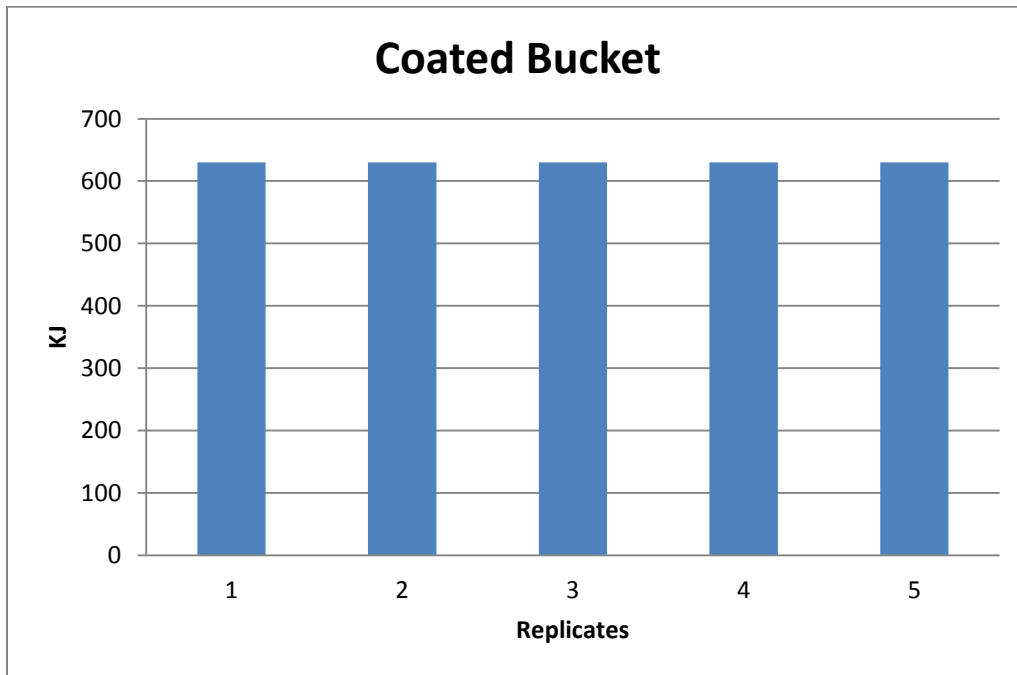


Figure 9 Heat Absorbed for Coated Bucket

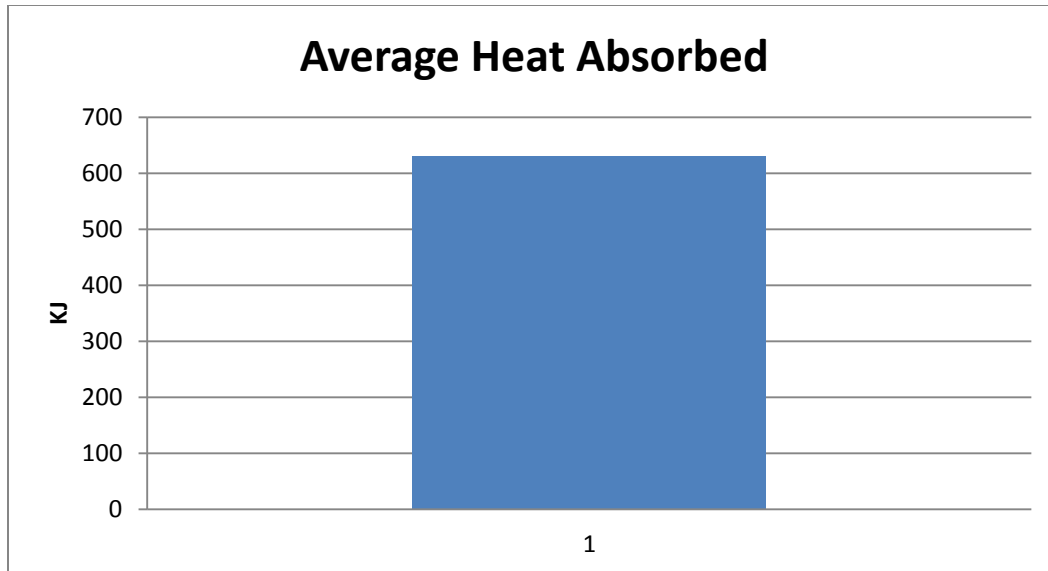


Figure 10 Average Heat Absorbed for Coated Bucket

As we can see from the graphs above shown in Figures 9 and 10, the average heat absorbed for a coated bucket is above 600KJ in the four hour testing period. As expected a black coated bucket absorb considerably more heat than an uncoated bucket. In fact, the data show that the inclusion of a black coating resulted in an 80% increase in the amount of energy absorbed by the waste container during the 4 hour testing period.

3.6 Mylar Bag Testing

The first design of the container to hold replicated human waste was a 12"x 17" black bucket. The sanitizer was designed to accommodate at least one bucket to enable users (soldiers or disaster victims) to treat their waste. After the waste has been completely heated, users are still expected to take their sanitized waste and bury it. Furthermore, the handling of this waste before and during burial has proven to be unacceptable by some who are opposed to both seeing and handling feces in a field situation. Heating such a large bucket and even larger sanitizer (especially in desert areas where the heat level is already extreme) is also problematic because the surrounding air

or environment is also heated in addition to the waste. A better idea was developed as this project progressed. The new design required users to eliminate waste right into a Mylar bag placed inside of one bucket and then transfer the bag into a sanitizer rather than the bulky bucket. After killing all the bacteria, users can remove the bag from the sanitizer and then bury it without ever having to view the waste directly. The whole process is more convenient than emptying and reusing the bucket, moreover users are not able to see their waste through the bag because the bag is not transparent.

The material of this special bag needed to meet certain requirements. It must be airtight and it must be a poor insulator so that heat from the surface of the bag can be rapidly transferred to the waste. It should have a large surface area with a dark coating to absorb heat rather than reflect heat. Last but not least, it must be able to stand high temperatures of up to 150° C. The Mylar bag meets all these requirements. It was originally designed for use in the food industry. It is airtight and able to stand high temperatures up to 210° C. Mylar is actually a polyester film that is lightweight and flexible. It has also been defined as polyethylene terephthalate or BoPET. It has high tensile strength, chemical and dimensional stability, reflectivity, gas barrier properties and electrical insulation properties. Because of its properties, it is widely used to produce bags, tubes, sheets and rolls for a variety of uses (Corporation, 2013). Although Mylar meets most requirements, further tests are needed to determine its ability to absorb heat instead of reflecting heat.

	Test #1	Test #2	Test #3	Test #4	Test #5
Origin	23	23	23	24	23
0:15	23	23	23	24	23

0:30	23	24	24	24	24
0:45	24	25	25	25	25
1:00	24	25	25	26	25
1:15	25	26	26	27	26
1:30	25	27	26	28	27
1:45	26	28	27	28	28
2:00	26	28	27	30	28
2:15	27	29	28	31	29
2:30	27	30	28	31	30
2:45	27	30	29	32	30
3:00	27.5	31	29	32	31
3:15	28	31	30	33	31
3:30	28.5	32	30	34	32
3:45	29	33	31	34	32
4:00	29	33	31	35	33
Final	28.5	32	31	34	32

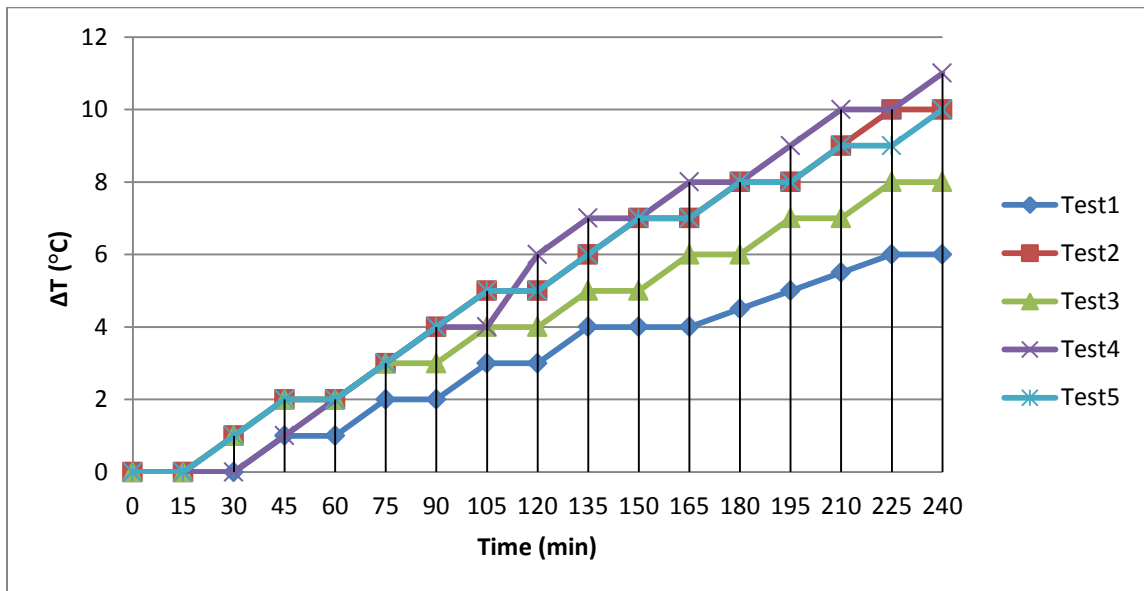


Figure 11 Mylar Bag Testing

Table 3 shows the ΔT of five tests which were labeled as 5.5, 9, 8, 10 and 9, respectively. However they are designated as Tests 1-5 here. Figure 11 shows the graph for the change in temperature (ΔT). The testing methodology was followed as closely as

possible to the methodology used for the bucket tests. The bag was filled with 15 liters of water partially sealed and then placed in a black bucket. A temperature probe was placed 15 cm deep into the center of the waste and the starting temperature was recorded. The bucket containing the bag was then heated for 4 hours and the temperature was recorded every 15 minutes. The average ΔT was 8.3 °C with an average final temperature of 31.5°C. Because the mylar bag was placed in a coated bucket it is appropriate to compare the average ΔT of the mylar bag tests to the coated bucket tests. The increase in temperature was 10 °C for the coated bucket tests and only 8.3°C for the buckets containing a mylar bag. This means the bag is clearly acting as an insulator and it is more efficient to use a bucket without a mylar bag as the waste container. However, most people would not want to view the waste directly or clean the bucket so, in this instance, human factors considerations outweigh efficiency concerns.

Chapter 4

Development and Manufacture

4.1 Design of the Sanitizer

A disposable 30"x20" mylar bag was chosen to be the container to hold the waste. The color of the mylar bag needs to be black in order to more efficiently absorb infrared radiation. The next step in the process was to design the sanitizer. The sanitizer is made of an inner shell and outer shell with foiled polystyrene insulation between the shells to reduce heat loss by the sides, back and top of the machine. The choice of insulation was made based upon the relative R values of insulation material commonly available for the construction industry. R value is a measure of thermal resistance, the higher the R value the more efficient the material is in retaining heat (Desjarlais, 2008). However, there is a tradeoff between the R value and the size of the sanitizer, the thicker the insulation, the bigger the R value but the larger the sanitizer. Ultimately, an R value of 10 and the thickness of $1\frac{1}{2}$ " of foiled polystyrene insulation were decided upon. In order to reach the thickness and R value requirement, two pieces of $\frac{3}{4}$ " foiled polystyrene insulation were glued together. The inner shell and the outer shell of the prototype are both made of $\frac{1}{4}$ " plywood because it is very light and convenient to obtain. However, a more lightweight molded plastic shell would probably be used if the device were to be mass produced.

Since this sanitizer is designed for the Army, it is not suitable to use glass as a window material because it is fragile, heavy and inconvenient to move it around. In the case of the prototype, $\frac{1}{8}$ " plexiglass was chosen as a substitute for pure glass.

4.2 Window Design

As calculated above, the energy of the sun hitting the surface of the earth per unit area per hour on a bright sunny day is about $4.9 \times 10^3 \text{ kJ/m}^2\text{h}$. Assuming the efficiency of solar energy capture is approximately 30% then the energy of the sun captured in one hour by a solar sanitizer with a surface window of 1 meter square would be $1,470 \text{ kJ/m}^2\text{h}$.

Our goal is to heat human waste in a 30"x20" black mylar bag to at least 65°C in less than a single day. In order to calculate the size of a window necessary to accomplish that goal we needed to first specify design parameters needed to adequately heat the waste. Each mylar bag can accommodate 15 liters of mixed solid and liquid waste. We assume that the mixed waste would have heating properties similar to water and that the starting temperature of the waste would be 25°C , normal room temperature. Therefore, the difference between the final and starting temperatures (ΔT) is $65^\circ - 25^\circ\text{C} = 40^\circ\text{C}$. The specific heat (c_p) of water is $4.2 \text{ kJ/kg } ^\circ\text{C}$. The energy (Q) needed to heat 15 liters of water from 25°C to 65°C in a four hour periods is described by the equation: $Q = C_p \times M \times \Delta T$ or $4.2 \text{ kJ/kg } ^\circ\text{C} \times 15 \text{ kg} \times 40^\circ\text{C} = 2,520 \text{ kJ}$. So to heat 15 liters of water from 25°C to 65°C in 4 hours 630 kJ of energy need to be captured per hour ($2,520 \text{ kJ total} / 4 \text{ hours} = 630 \text{ kJ/hour}$). As stated previously, each meter of the earth's surface receives on average $4.9 \times 10^3 \text{ kJ/h}$ of energy and we assume a 30% capture efficiency such that each meter of window can capture and retain $1,470 \text{ kJ}$ of energy per hour. Under these conditions, to meet our design requirements we calculate a minimum window area of 0.43 m^2 is needed ($630 \text{ kJ/h} / 1470 \text{ kJ/m}^2\text{h} = 0.43 \text{ m}^2$).

Since this sanitizer utilizes nothing but solar energy, it is also important to consider the motion of the sun as it travels from east to west during the day. In order to

limit the need to re-position the device during the day a rectangular window shape was adopted instead of a square window. Figure 12 and 13 below shows different configurations of a rectangle window. It is better to choose the rectangle window on the left rather than the one on the right because the shape on the left can capture more sunlight as the sun moves across it.



Figure 13 The Shape of the Window (Left)

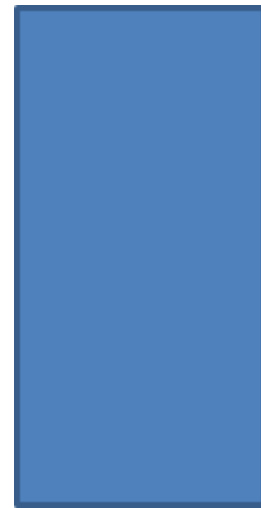


Figure 12 The Shape of the Window (Right)

4.3 Sanitizer Lid Design

From a human factors point of view, there are three possible designs for getting things into and out of the sanitizer; (1) loading from the front by opening the window; (2) loading from the rear by including a door; (3) or loading from the top. Most of the heat loss from the sanitizer is anticipated to be from the surface of the window and from around the seals associated with the opening mechanism. A front loaded machine would be attractive from an ergonomic point of view but would result in a large seal that could allow significant heat to escape. A rear door or a top loading machine would require a much smaller seal and theoretically allow less heat loss during operation. In the end it

was decided that it would be more convenient to open the sanitizer from the top than from the rear to place the mylar bag inside.

4.4 Dimensions of the Sanitizer

The sanitizer is made up of inner and outer shells surrounded by insulation. Both shells are made of 5 pieces of plywood: a front piece containing a cutout for the window, a back piece, right and left pieces and bottom piece. As discussed above, the area of the window must be at least 0.43m^2 which means the area of the inner shell front piece must be greater than 0.43m^2 . Another restriction is that the interior space of the inner shell which must be wide and tall enough to accommodate at least one mylar bag. According to these restrictions, the final dimensions of the sanitizer are listed below in tables 4, 5 and 6. The units are all in inches.

<i>Table 4 Inner Shell Dimensions</i>			
	Length	Width	Height
Front Piece	34.5	0.25	24.5
Rear Piece	34.5	0.25	24.5
Right Piece	6.75	0.25	24.5
Left Piece	6.75	0.25	24.5
Bottom Piece	34	6.75	0.25

<i>Table 5 Outer Shell Dimensions</i>			
	Length	Width	Height
Front Piece	38	0.25	26.25
Rear Piece	38	0.25	26.25

Right Piece	10.25	0.25	26.25
Left Piece	10.25	0.25	26.25
Bottom Piece	37.5	10.25	0.25

<i>Table 6 Insulation Dimensions</i>			
	Length	Width	Height
Front Piece	37.5	1.5	24.5
Rear Piece	37.5	1.5	24.5
Right Piece	7.25	1.5	24.5
Left Piece	7.25	1.5	24.5
Top Piece	37.5	10.5	2.75

In order to manufacture the sanitizer prototypes, parts drawings and assembly drawings needed to be done carefully. Two software programs were used to do the drawings, 2D representations and the final assembly drawings were done in Auto CAD software (Auto CAD, 2007). A 3D picture of the lid, a sanitizer without the lid and the final assembly drawing were done in Solid Works software (Solid Works, 2007). 2D drawings in Auto CAD helped to define how much material was needed to construct each piece of the device while 3D drawings in Solid Works helped to see the parts and the final product assembly more directly than the 2D drawings. Figures 14 through 33 below show the individual 2D parts drawings in Auto CAD. Figure 34 shows the 2D assembly drawing in Auto CAD. Figures 35 through 37 show 3D drawings in Solid Works.

Inner Shell
Bottom
Piece

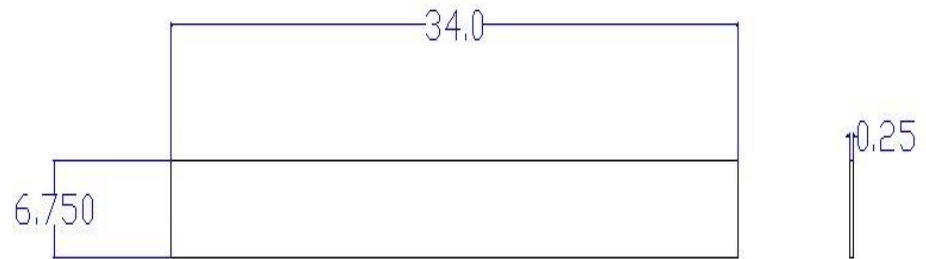


Figure 14 Inner Shell Bottom

Inner
Shell
Front
Piece

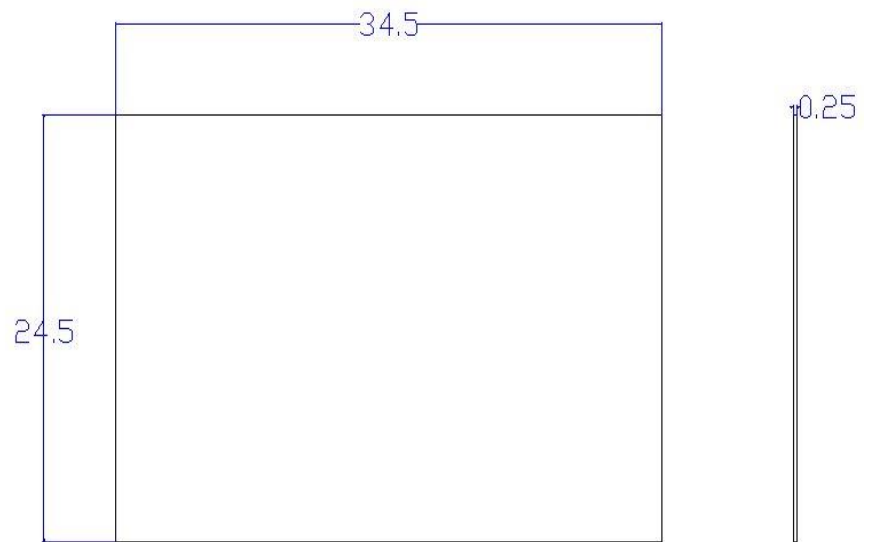


Figure 15 Inner Shell Front

Inner Shell
Left Piece

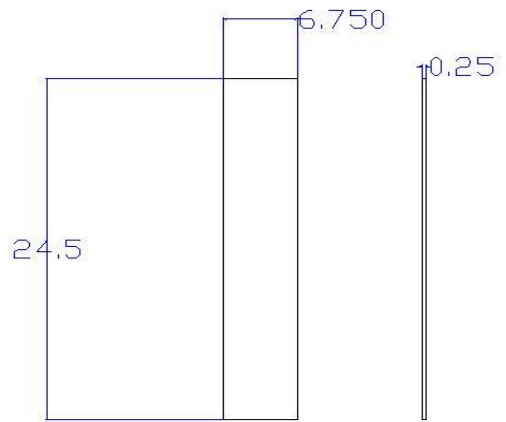


Figure 16 Inner Shell Left

Inner
Shell
Rear
Piece

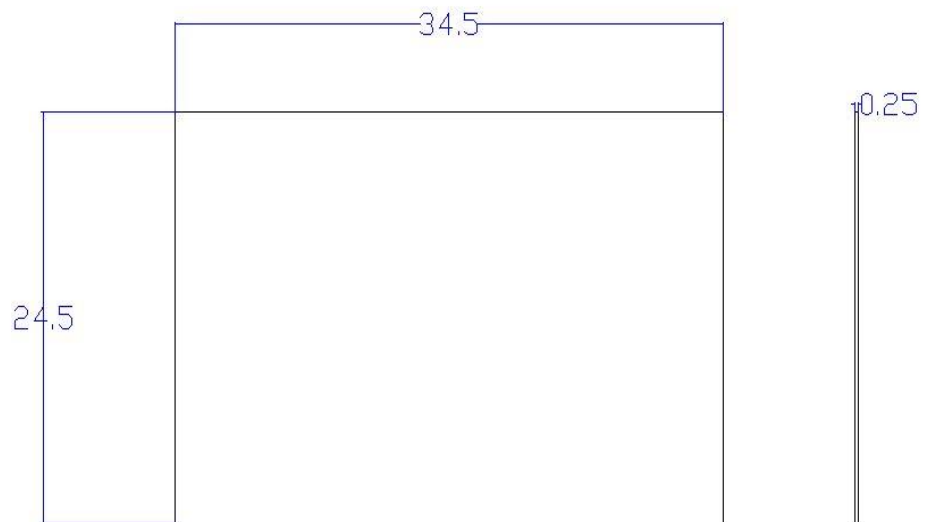


Figure 17 Inner Shell Rear

Inner Shell
Right Piece

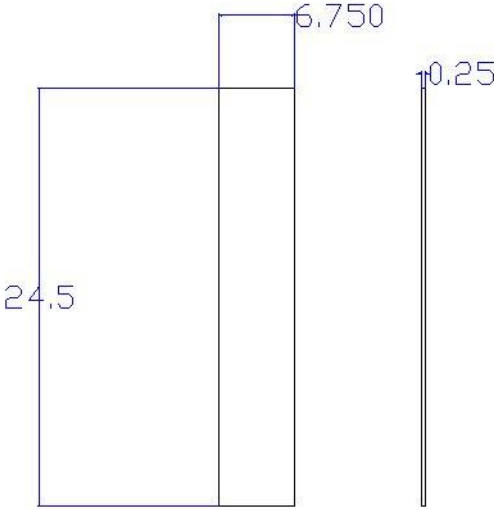


Figure 18 Inner Shell Right

2 sheets of 0.75 inch
aluminized
insulation:
Bottom Piece

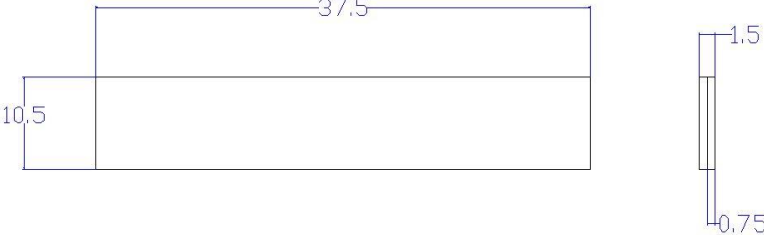


Figure 19 Insulation Bottom

2 sheets of
0.75 inch
aluminized
polystyrene
insulation:
Front Piece

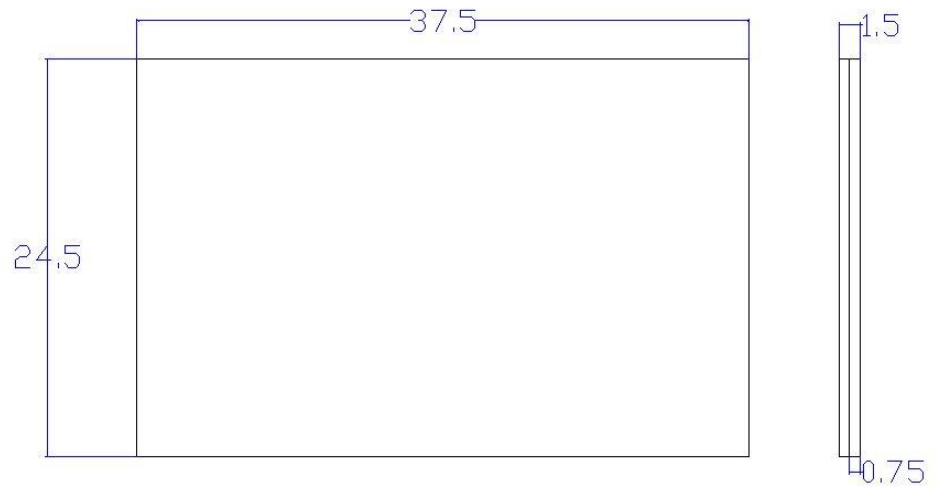


Figure 20 Insulation Front

2 sheets of 0.75 inch
aluminized
insulation:
Left Piece

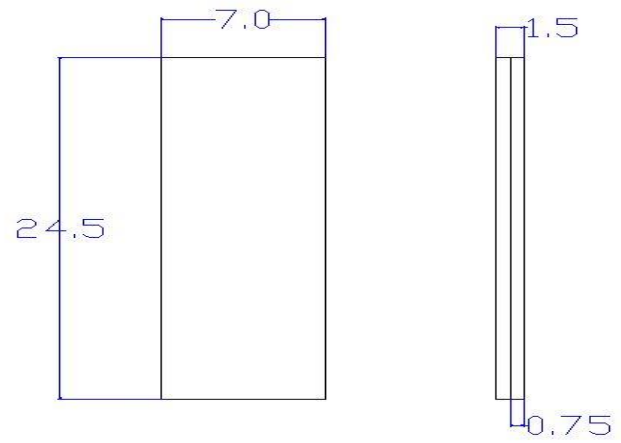


Figure 21 Insulation Left

2 sheets of
0.75 inch
aluminized
polystyrene
insulation:
Rear Piece

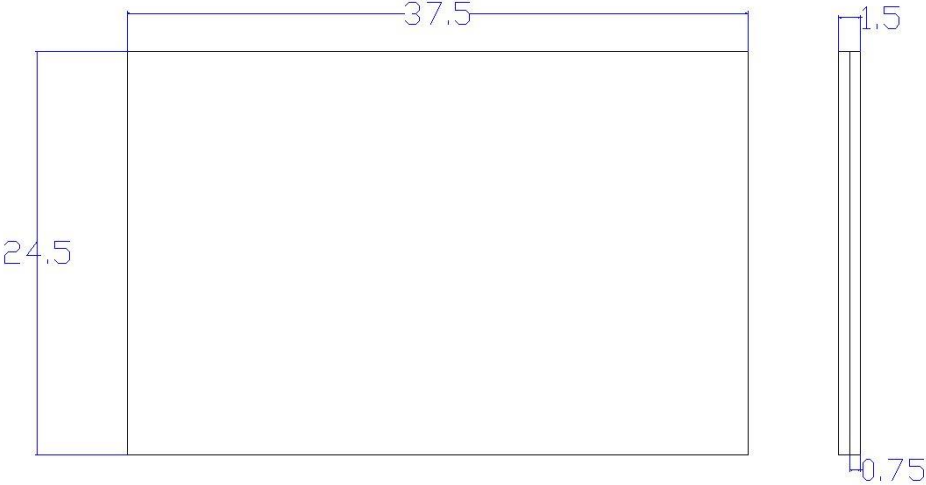


Figure 22 Insulation Rear

2 sheets of 0.75 inch
aluminized
insulation:
Right Piece

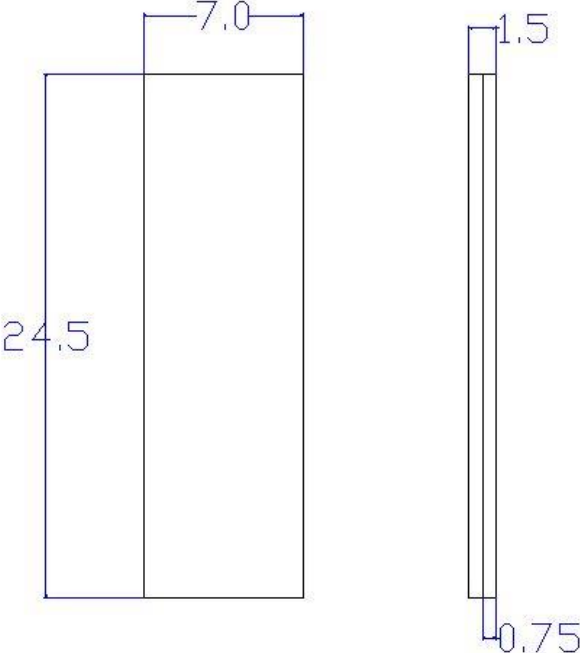


Figure 23 Insulation Right

Outer Shell
Bottom Piece

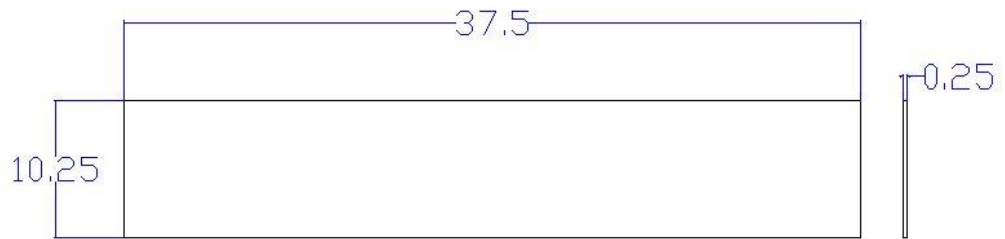


Figure 24 Outer Shell Bottom

Outer
Shell
Front
piece

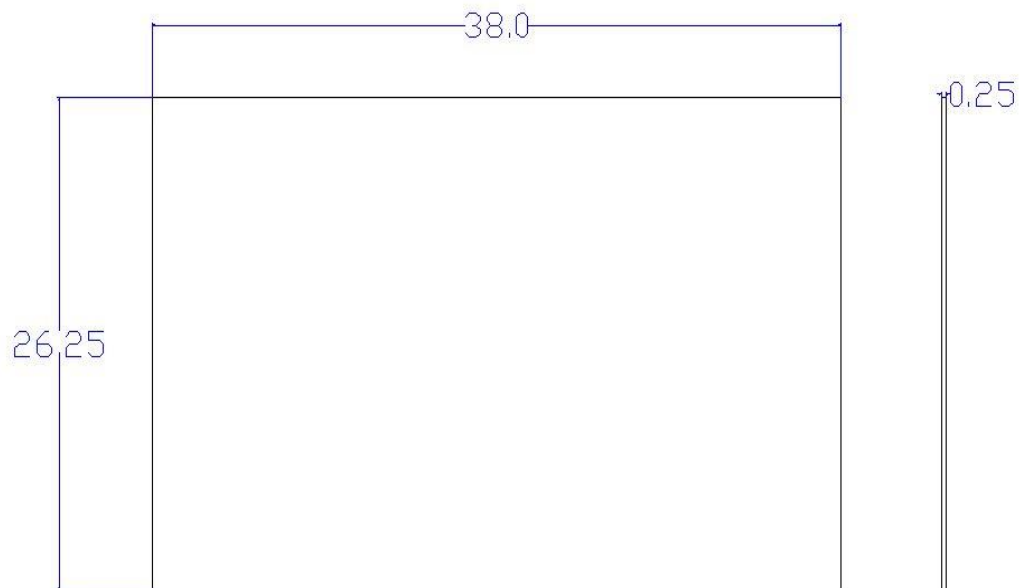


Figure 25 Outer Shell Front

Outer Shell
Left Piece

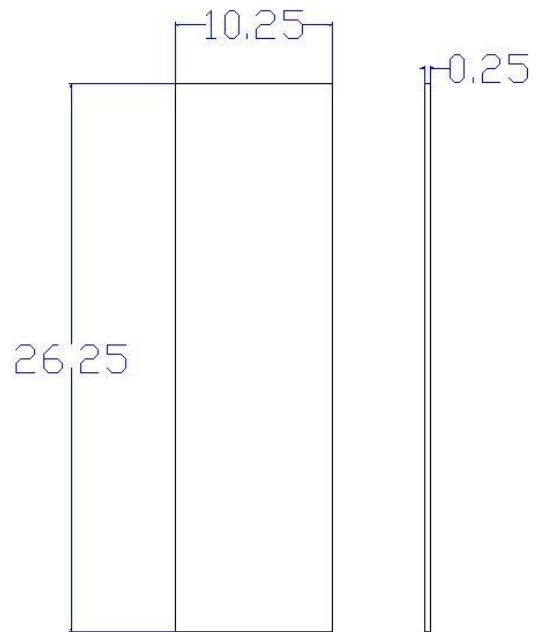


Figure 26 Outer Shell Left

Outer
Shell
Rear
piece

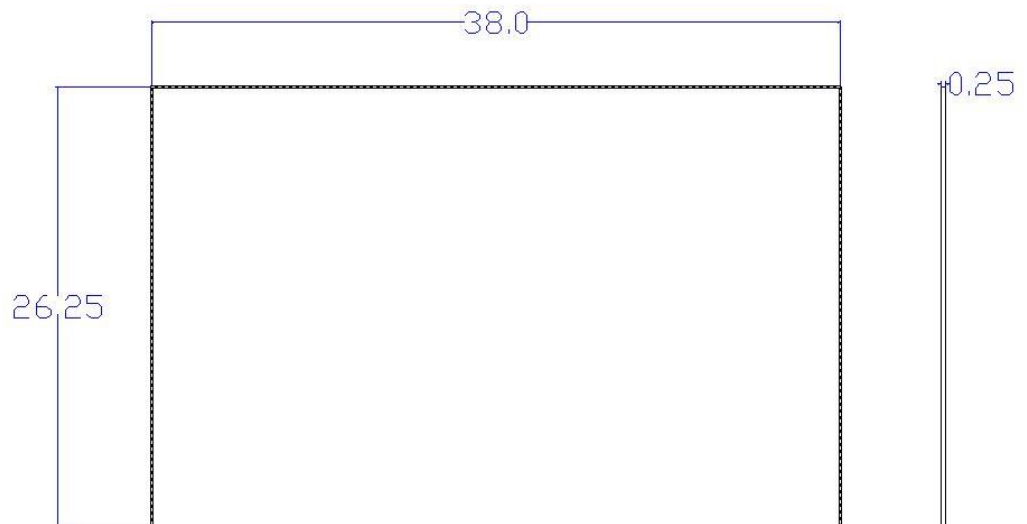


Figure 27 Outer Shell Rear

Outer Shell
Right Piece

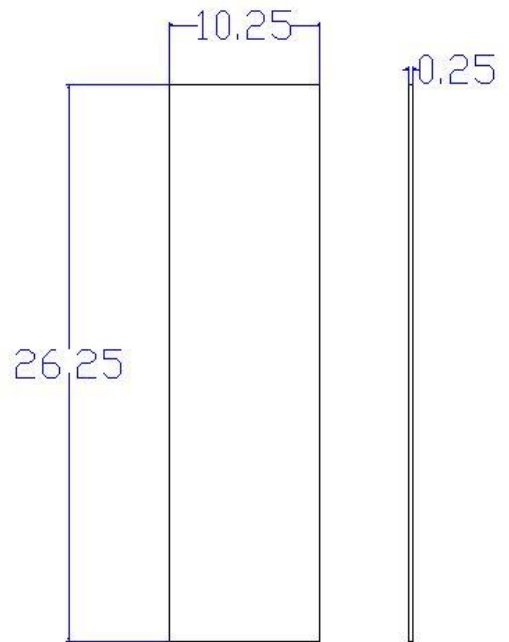


Figure 28 Outer Shell Right

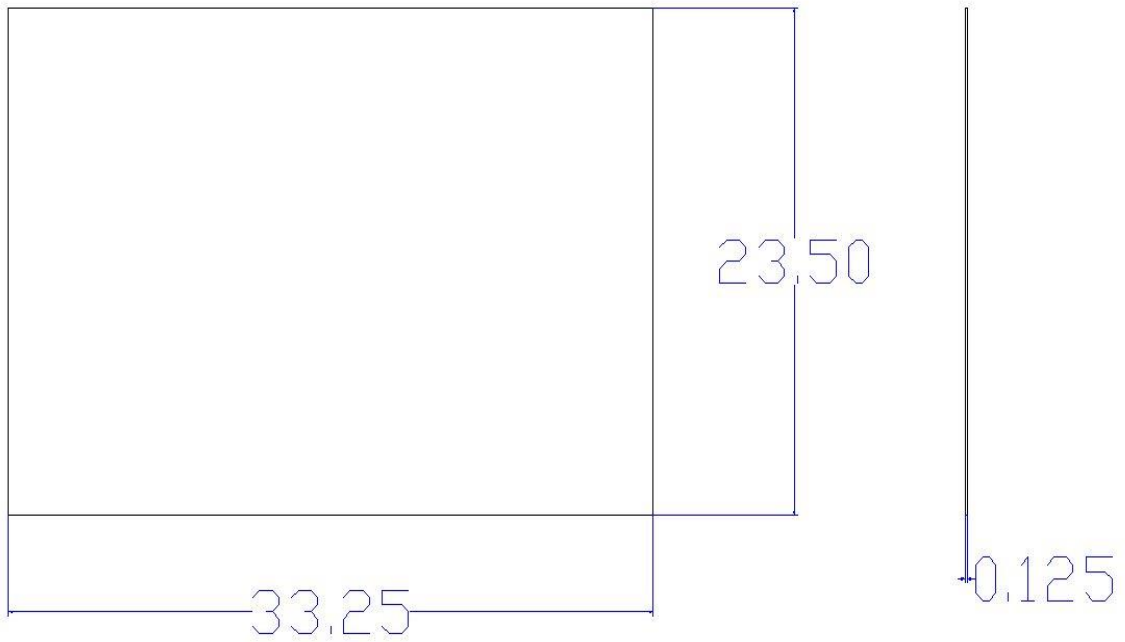


Figure 29 Plexiglass Window

Inner Shell Lid

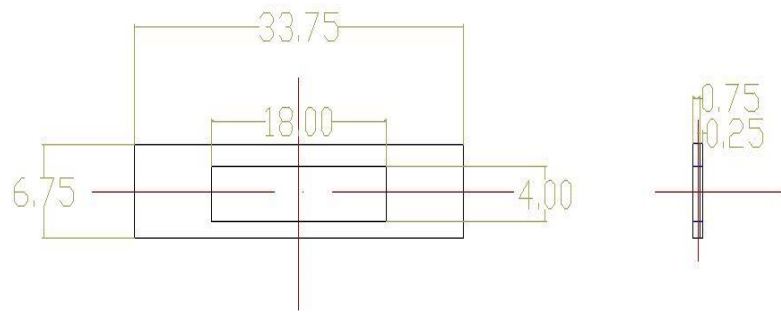


Figure 30 Inner Shell Lid

Outer Shell Lid Unit CM

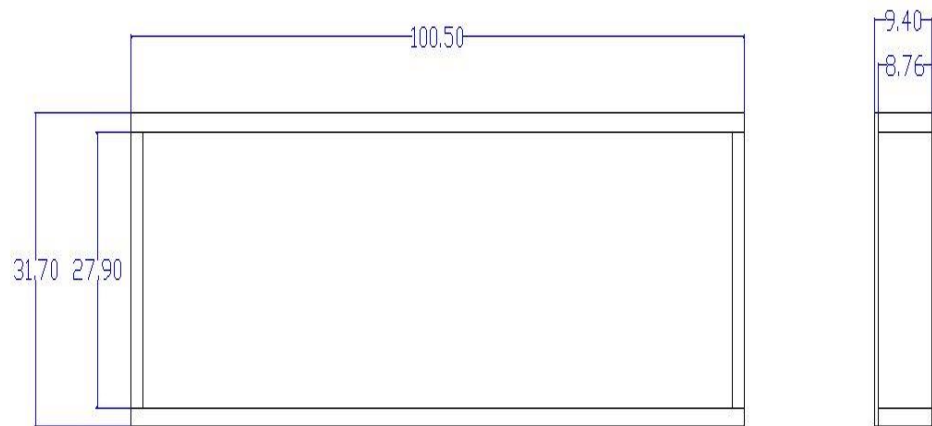


Figure 31 Outer Shell Lid

Medal
Plate

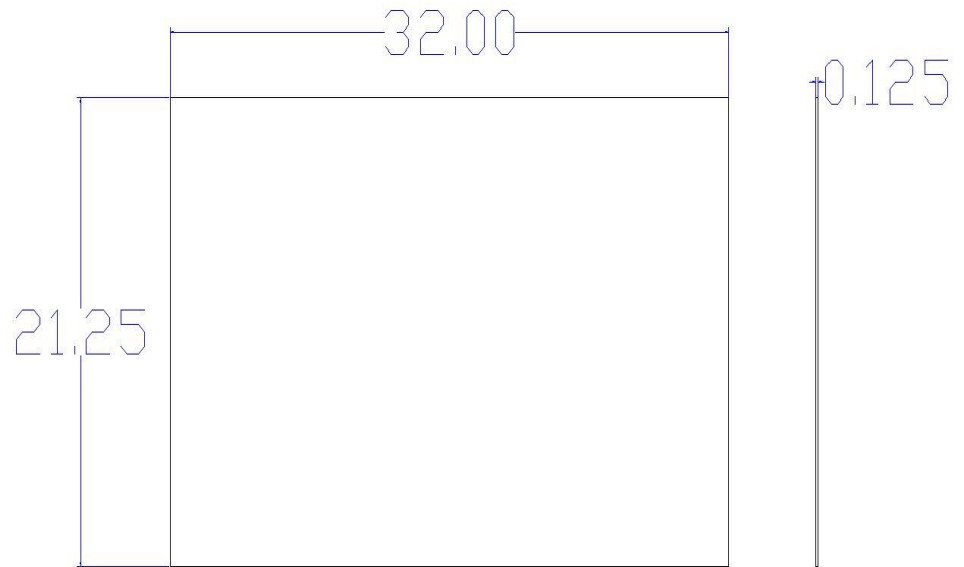


Figure 32 Metal Plate

Cage
Frame

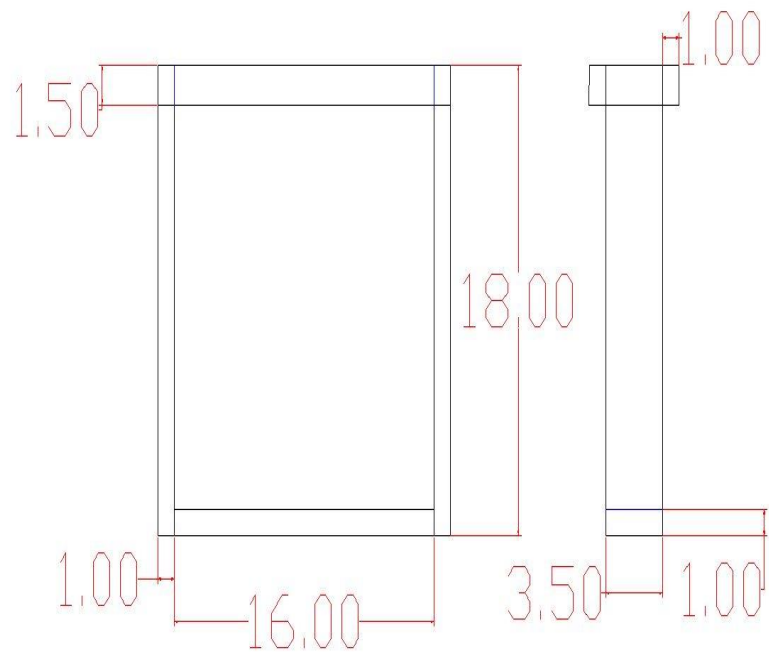


Figure 33 Cage Frame

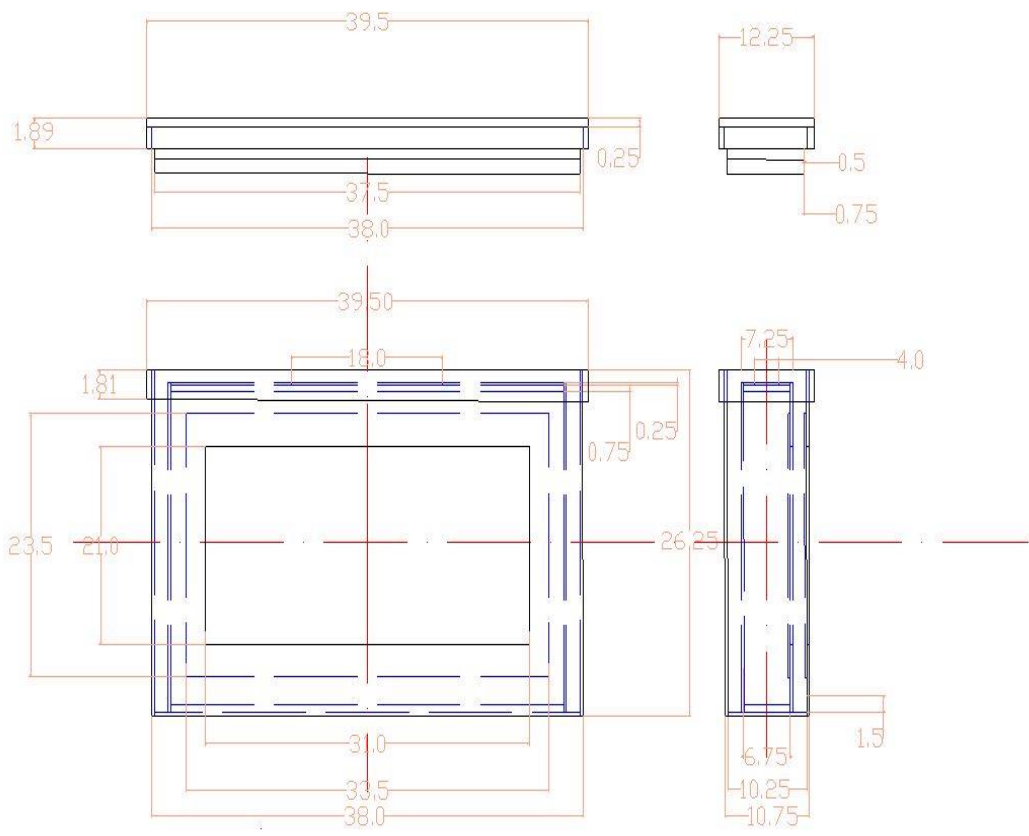


Figure 34 Assembly

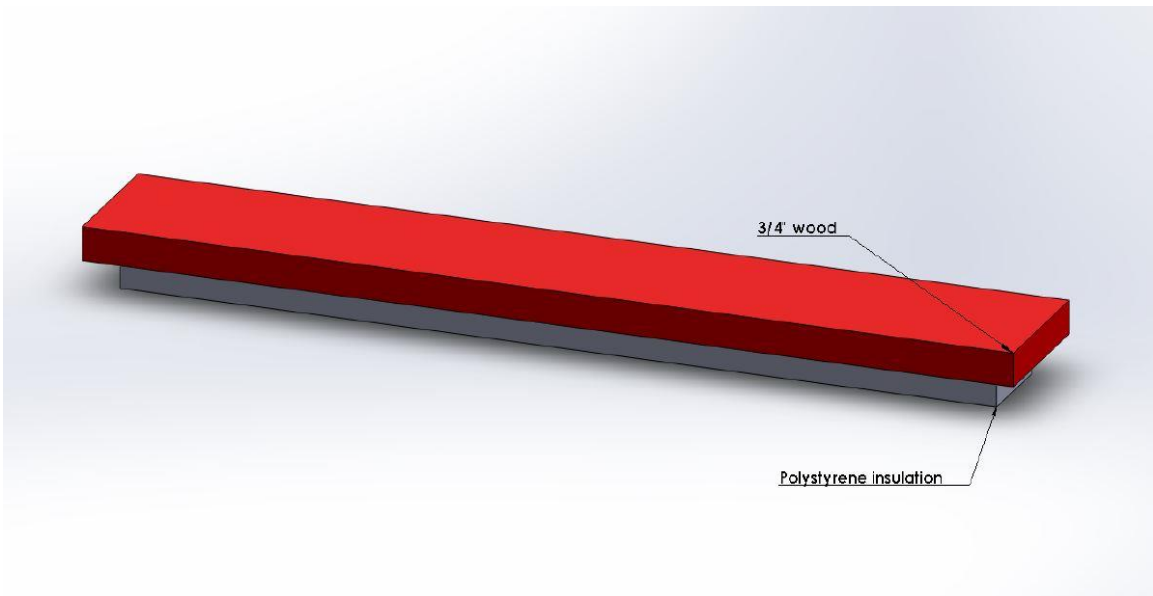


Figure 35 3D Lid



Figure 36 3D Front View

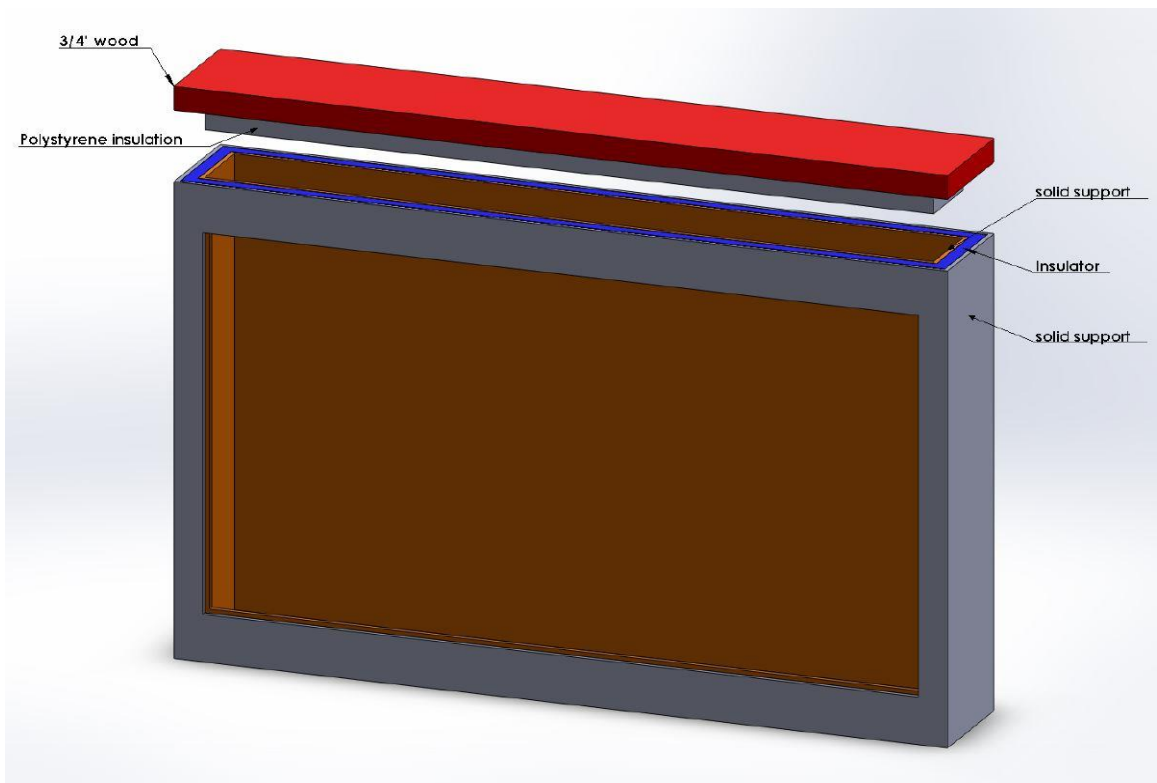


Figure 37 3D Assembly

4.5 Description of Construction

The structure of the sanitizer is not very complicated and was specifically designed to be made of readily available construction materials. It consists of plywood, polystyrene insulation and plexiglass. In order to construct this sanitizer according to the drawings above, a rough order of manufacture was decided as follows: First, all the pieces of plywood for the inner and outer shells were cut and pieced together. Second, the back, sides and bottom of the inner and outer shells were glued together and the seams were sealed with flexible silicone caulk. Third, insulation pieces were cut and glued together to a final thickness of 1 ½ inches. Each piece was then placed in its proper place in between the inner and outer shells. Fourth, window frames for the inner and outer shells were cut out of plywood and the plexiglass windows were secured to each frame. Fifth, a hinged lid was manufactured out of plywood and 1"x3" boards.

4.6 Construction of Shells and Insulation

Materials were purchased and cut according to the dimensions shown in the drawings above. The inner shell was constructed first by gluing up the back piece to the bottom piece and the side pieces to the bottom and back pieces. The front piece, which is composed of the window frame, was not attached yet. The glue was allowed to dry for two hours and the interior of the inner shell was painted flat black. The reason for painting the interior black was to decrease the amount of light reflected by the inner chamber and increase the amount of heat absorbed. After the paint dried all the seams were sealed with a silicone caulk to reduce the amount of heat lost through convection of air escaping from the inner to the outer chamber. The caulk was allowed to dry for at

least one day before doing anything to the inner shell box. Figure 38 shows the inner shell after the application of the silicon.



Figure 38 Inner Shell

As it is shown in Figure 33 silicon was used to seal the seams in the inside of the box. To further reduce convective heat loss it was also important to seal the outer seams. To do this, we used Pella SmartFlash™ self-sealing door and window flashing tape. The tape consists of an aluminized sheet with a butyl rubber adhesive backing. The adhesive creates a tight seal that resists the transfer of air and moisture. Figure 39 shows the exterior of the taped inner box.



Figure 39 Inner Shell with the Tape

The outer shell was manufactured according to the same construction process as the inner shell. Next, all the needed polystyrene insulation was cut according to the dimensions shown in the drawings. Figure 40 shows the outer shell box.



Figure 40 Outer Shell and Insulation

4.7 Window Construction

To create the inner and outer shell windows two pieces of plexiglass were cut to 33.5"X 23.5". A hole was cut in the front piece of the inner and outer shells to dimensions of 31"X 21" to create a frame for the plexiglass. Figure 41 below shows the outer shell window frame.



Figure 41 Outer Shell Window Frame

The plexiglass was then positioned on the back of the inner shell window frame leaving a half inch overlap on all four sides. In order to place the plexiglass in the right position and to reduce heat loss around the edge it was necessary to tape the plexiglass to the window frame with window flashing tape. A template for drilling evenly spaced holes through the plexiglass window was next constructed out of plexiglass with holes spaced every 1 inch apart. Aluminum bolts (0.5”) were then used to secure the plexiglass to the window frame. Window flashing tape was then applied to the perimeter of the window to reduce convective heat loss. Figures 42 and 43 below show the inner shell plexiglass with frame.



Figure 42 Inner Shell Window With Frame



Figure 43 Inner Shell Window With Frame

The construction of the window for the outer shell had one more step than the inner shell window. The bolts around the inner shell window and the outer shell window were really long and they totally went through the wood frames. Since there was nothing inside the inner shell, there was no need to worry about those long bolts. For the outer

shell window it was necessary to think about them because they would definitely damage the front insulation. In order to solve this problem, we trimmed the ends of each bolt and placed an additional layer of window flashing tape to the rear surface of the window frame. Figure 44 and Figure 45 show the picture for the outer shell window. Figure 46 shows a picture of the outer shell window with tape covering the bolts.



Figure 44 Outer Shell Window With Frame



Figure 45 Outer Shell Window With Frame



Figure 46 Outer Shell Window with Covers

4.8 Construction of the Lids

Since heat rises, it is important to seal the top of the sanitizer well. In an attempt to minimize heat loss the inner and outer shells were designed as completely separate boxes. There were also two separate lids: one for the inner shell lid and one for the outer

shell lid. The inner shell lid consisted of a $\frac{1}{4}$ " thick plywood covered with $\frac{3}{4}$ " polystyrene insulation. First, a piece of plywood was cut with dimension of $33\frac{3}{4}$ " X $6\frac{3}{4}$ ". The design called for placing the mylar bag into the sanitizer from the top, so an opening was cut in the inner shell lid of sufficient size to allow insertion of the mylar bag. The width of an empty mylar bag is 17" so the length of the hole in the lid was constructed to be 18" wide. The thickness of a mylar bag containing 15 liters of liquid is approximately 5 inches. Since a bag containing 15 liters is not completely full and is capable of being deformed to allow insertion, it was decided to make the width of the hole in the inner shell 4 inches wide. The lid was used as a template to produce an identical piece of insulation which was then glued to the inner surface of the lid. After the glue dried the lid was fitted to the top of the inner shell and glued and taped in place.

The outer shell lid was much more complicated to construct than the inner shell lid. The outer shell lid needed to be very well insulated and the hinged lid needed to access the interior of the sanitizer needed to seal very tightly. A frame was created out of 4 pieces of 3" X $\frac{1}{2}$ " pine whose inner dimension exactly matched the outer dimension of the outer shell. A piece of $\frac{1}{4}$ " plywood was secured to the top of the frame with finish nails and glue and then the frame was cut in half using a table saw. This created two identically matched pieces that were secured to each other with a 24" brass piano hinge. Insulation was fitted to the top of the lid, glued in place and then caulk was used around the edges to fill in the gaps. Figure 47 shows the outer shell lid.



Figure 47 Outer Shell Lid

4.9 Sanitizer Assembly

As discussed above, the inner shell, the bottom piece, both side pieces and the back piece were glued together. For the plexiglass window, we took off the inner plexiglass sheet protector before taping the window and the inner shell together. The reason we did not use glue was because that it was really hard to glue well since the window would be glued to three pieces: right piece, left piece and bottom piece and it was also better to use tape in terms of creating an airtight seal. After that stage was completed we put the outer shell and the back insulation in and then put the inner shell inside of the outer shell and removed the outer plexiglass protector. When everything was nice and tightly sealed the front insulation pieces for the outer shell were installed. Then the inner shell lid was put into place. For the outer shell plexiglass window, the inner protector was removed before using Pella tape to secure it to the outer shell. After it was well taped, we took off the outer protector.

It was very important to assemble the lid well. First the top of the lid was secured to the lid frame with a hinge. After that, the lid could be opened and closed. Next, the lid frame was glued to the outer frame of the box and then screwed in place. Twelve screws were used to secure the lid to the outer box; 5 screws on the front side, 5 screws on the back side, 1 screw on the left side and 1 screw on the right side. In order to minimize heat loss through the lid 5 latches were used to secure the top of the lid to the lid frame. Three latches were used in the front and one latch was used on each side. After putting latches on there were still gaps between the top lid and the outer frame. The way this problem was solved was to use flexible weather stripping between the top of the lid and the lid frame. The wood would press on the weather stripping which would prevent air flow between outside and inside of the lid. Instead of using nails staples were used to connect the weather stripping to the outer lid frame. Staples were placed every 2 inches on the weather stripping to make sure it was nice and tight. With the help of both latches and weather stripping, the top lid and the outer frame would close as tightly as possible.

Chapter 5

Results and Discussions

5.1 Laboratory Tests

As preparations for the field tests a series of laboratory tests were performed to see how various parameters and modifications affected the sanitizer and waste container. For the sanitizer, heat accumulation and heat loss were determined with and without insulation. Additional heat accumulation and heat loss tests were also conducted to determine how the inclusion of a metal plate in the inner chamber would affect the sanitizer's performance. The idea was that a black metal plate might increase the efficiency of the device by absorbing more infrared radiation than the wooden interior of the sanitizer. Theoretically, this could result in producing super heated air in the interior of the sanitizer which could transfer heat to the waste container by convection. The heated metal plate could also transfer heat to the back of the waste container by conduction. Laboratory tests were also conducted with the mylar bag waste container. Heat absorption and loss was determined using aluminized mylar bags received directly from the manufacturer and compared to two different black spray coatings, one applied with glue and one sprayed on to the bag surface directly.

5.1.1 Outer Shell Insulation

The first thing tested was to determine the ability of the assembled sanitizer to capture heat. To do this the temperature of the air inside the inner chamber was monitored with a temperature probe. The changes in temperature before and after exposure to a light source was determined with and without insulation to understand the

process of heating and cooling. A tungsten halogen light source was set up 1 meter from the outer window of the sanitizer and the sanitizer was placed on a table which was 73 centimeters (cm) above the ground. This height was chosen because it allowed the light source to shine directly into the center of the outer window. The first experiment was a heating and cooling test with insulation in an empty sanitizer. The test started at 9:30 am and ended at 12:30 pm July 2nd 2013 for replicate number one. Replicate number two was done on July 3rd 2013 from 10:00 am to 1:00 pm. The temperature probe was inside the inner shell and measured the air temperature every 15 minutes. In the heating test the light source was kept on for two hours. In the cooling tests the light was turned off and the temperature within the chamber was measured every 15 minutes for one hour. The data collected is shown in the table below.

Table 7 Heating and Cooling Test With Insulation

	Rep1	Delta 1	Heat	Rep2	Delta 2	Heat
	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)
Heating Origin	23.5	0	0	25	0	0
0:15	32	8.5	535.5	37	12	756
0:30	36	12.5	787.5	40	15	945
0:45	40	16.5	1039.5	45	20	1260
1:00	44	20.5	1291.5	49	24	1512
1:15	48	24.5	1543.5	52	27	1701
1:30	49	25.5	1606.5	54	29	1827
1:45	51	27.5	1732.5	56	31	1953

2:00	52	28.5	1795.5	57	32	2016
Cooling Origin	52	0	0	57	0	0
0:15	44	8	504	49	8	504
0:30	40	12	756	45	12	756
0:45	38	14	882	43	14	882
1:00	33	19	1197	40	17	1071

As we can see from the table above, for replicate number one, the temperature went up 28.5°C in two hours and went down 19°C in one hour. For replicate number two, the temperature went up 32°C in two hours and went down 17°C in one hour. The average temperature increase was 30.25 °C which the average temperature decrease was 18°C.

It was obvious that there was a huge temperature drop in one hour which meant after the light source was turned off, there would be significant heat loss probably primarily through the plexiglass and lid. The same experiment was repeated after removing all of the insulation from inside the sanitizer. The test was started at 9:30 am and ended at 12:30 pm July 2nd 2013 for replicate number one. Replicate number two was done on July 3rd 2013 from 10:00 am to 1:00 pm. The data is shown in the table below.

<i>Table 8 Heating and Cooling Test without Insulation</i>						
	Rep 1	Delta 1	Heat	Rep 2	Delta 2	Heat
	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)
Heating	25	0	0	22	0	0

Origin						
0:15	34	9	567	29	7	441
0:30	38	13	819	35	13	819
0:45	41	16	1008	39	17	1071
1:00	43	18	1134	42	20	1260
1:15	44	19	1197	43	21	1323
1:30	45	20	1260	44	22	1386
1:45	45	20	1260	44	22	1386
2:00	46	21	1323	45	23	1449
Cooling Origin	46	0	1323	45	0	1449
0:15	37	-9	756	36	-9	882
0:30	35	-11	630	34	-11	756
0:45	30	-16	315	30	-15	504
1:00	29	-17	252	27	-18	315

As we can see from the table above, for replicate number one, the temperature went up 21°C in two hours and went down 17°C in one hour. For replicate number two, the temperature went up 23°C in two hours and went down 18°C in one hour. The average temperature increase was 22 °C while the average temperature decrease was 17.5°C. Comparing both tables it is clear that the insulation had a significant effect on heat gain but only a minimal impact on heat loss as shown by the average temperature increase with insulation is 30.25°C whereas without insulation was 22°C. Figure 48 below shows the comparison in a graph.

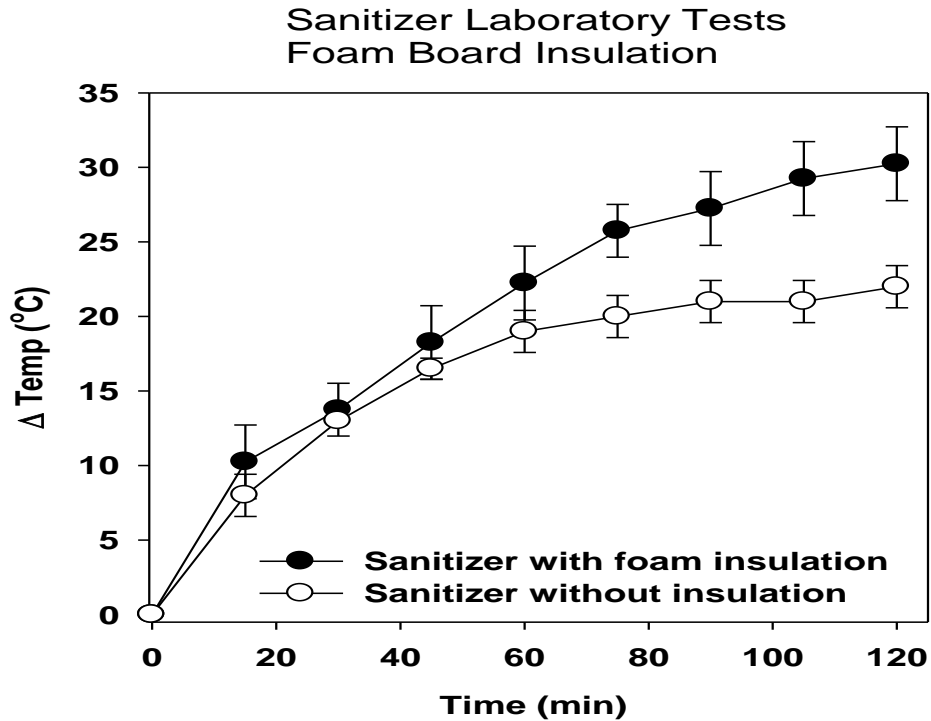


Figure 48 The Effect of Foam Insulation

As we can see from the graph, from 0 minutes to 60 minutes the increases in temperature at each time point are similar with differences only being noticeable after the 60 minute point. That is because in the first hour the box is absorbing heat pretty fast and the air temperature in the box goes up with minimal heat loss. It is only after the temperature inside the box increases by about 15°C that it starts to emit significant heat and that is when the insulation starts to have an effect. Please go to Appendix A for detailed statistical analysis.

5.1.2 Inner Shell Metal Plate

The main source of heat used to heat the waste within the waste container was theorized to be the conversion of infrared radiation from sunlight that directly strikes the mylar bag. The bag has a limited surface area and it will probably be more efficient if we could create another way for the bag to absorb heat. A metal plate on the back of the

inner shell may help to create another way of conducting heat into the waste. Water inside the waste container can be heated up both by radiation from the light source and conduction through the metal plate. A 1/8 inch thick steel plate was purchased from the Columbia Welding Company, sanded smooth and painted black using heat stable paint. The dimension of the plate are shown below as Figure 49.

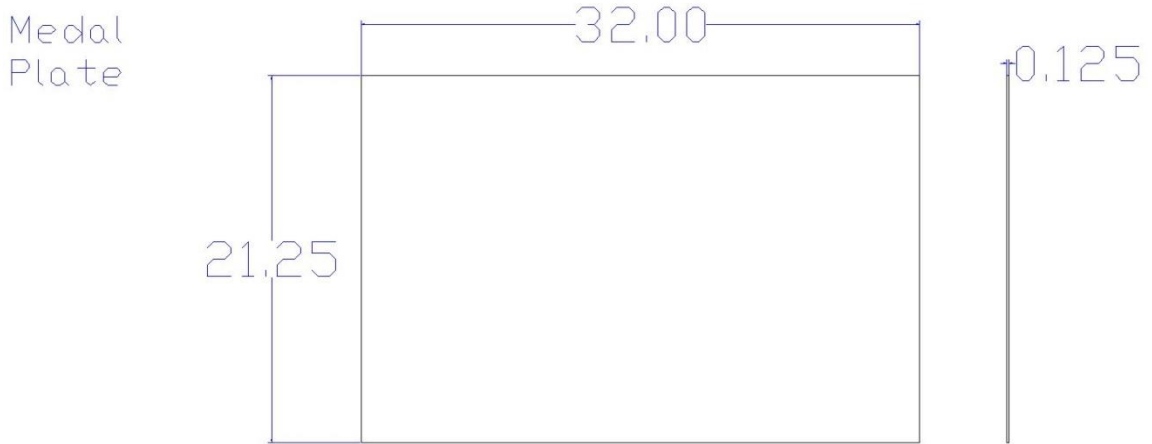


Figure 49 Metal Plate

In order to test how the metal plate affected the sanitizer the plate was placed inside the inner box and heating and cooling tests were conducted in the laboratory. The sanitizer was exposed to the light source for two hours and the air temperature in the inner chamber was measured using a temperature probe every 15 minutes. Test replicate 1 started from 10:30 am and ended at 1:30 pm July 5th 2013 while replicate 2 started from 2:33 pm and ended at 5:33 pm on July 10th 2013. The table below shows the results of these experiments.

<i>Table 9 Metal Plate Test with Insulation</i>									
	Rep1	Delta 1	Heat	Rep 2	Delta 2	Heat	Rep 3	Delta 3	Heat
	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)

Heat	24	0	0	29	0	0	29	0	0
0:15	33	9	567	34	5	315	31	2	126
0:30	38	14	882	40	11	693	40	11	693
0:45	42	18	1134	46	17	1071	44	15	945
1:00	44	20	1260	49	20	1260	49	20	1260
1:15	47	23	1449	51	22	1386	53	24	1512
1:30	50	26	1638	53	24	1512	56	27	1701
1:45	52	28	1764	55	26	1638	58	29	1827
2:00	53.5	29.5	1858 .5	57	28	1764	60	31	1953
Cool	53.5	29.5	1858 .5	57	28	1764	60	31	1953
0:15	47	23	1449	52	23	1449	55	26	1638
0:30	44	20	1260	49	20	1260	51	22	1386
0:45	42	18	1134	46	17	1071	48	19	1197
1:00	39	15	945	43	14	882	48	19	1197

As we can see from the heating and cooling tests with the insulated sanitizer shown in Table 7, the average temperature increase was 30.25°C while the average temperature decrease was 18°C. In the metal plate tests, the average temperature increase was only 28.75°C while the average temperature decrease was 14.25°C. Therefore, it was concluded that inclusion of the metal plate resulted in a reduction in the air temperature inside the inner chamber. Furthermore, the change in temperature during the cooling experiment with the metal plate was lower than the one without metal plate. It was explained that the metal plate absorbed a lot of heat in the heating experiment so that the air temperature was not as high as the one without the metal plate. Also, the metal plate

radiated a lot of heat into the air in the inner chamber during the cooling phase which was why the change in temperature during the cooling test was lower than tests conducted without the metal plate. According to the results from the metal plate test, it was possible that a metal plate could be used as a good heat conductor to heat waste in the waste container in future field experiments with the sanitizer.

5.1.3 Laboratory Tests of the Waste Container

Tests were designed to determine the effects of various outer coatings on the ability of the mylar bag waste container to absorb infrared radiation and heat water contained within the bag. However, the water filled mylar bag deforms easily and is difficult to handle. Therefore, a cage was constructed to contain the bag in a position that was similar to the position the bag would adopt when in the inner chamber of the sanitizer

The first step to making an appropriate cage to hold the mylar bag was to design the dimensions of the cage frame as shown below as Figure 50.

Cage
Frame

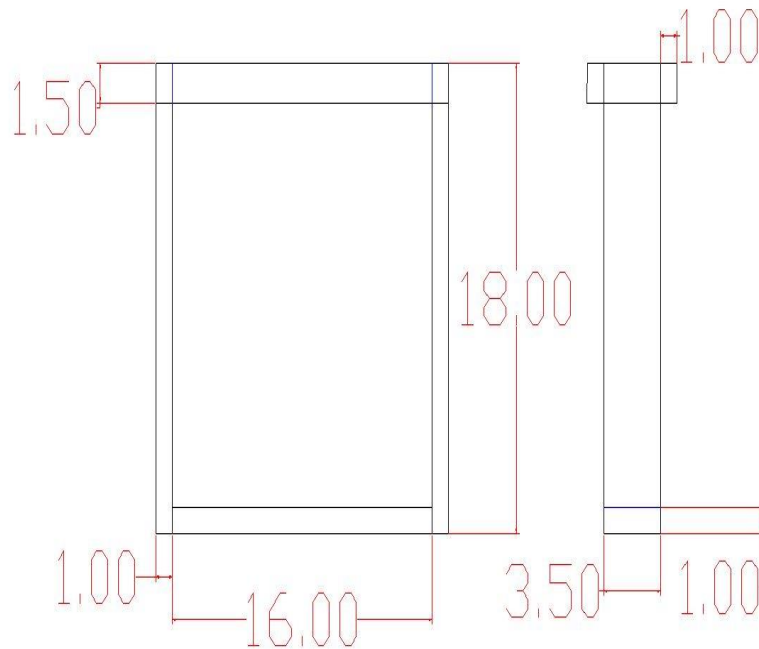


Figure 50 Cage Frame

The frame was made of plywood and the front and back of the frame was covered in $\frac{1}{2}$ by $\frac{1}{2}$ inch galvanized hardware cloth that was stapled into place. A mylar bag filled with 15 liters of water could then be placed inside the cage frame. The mylar bag was placed 1 meter from the light source and positioned so that the light source illuminated the center of the bag. A temperature probe was placed at a depth of 4 inches into the water and the bag was sealed. To ensure that the probe was always in the same depth for each test it was secured to the inner surface of the bag with tape. The bag was exposed to the light source for 2 hours and the temperature was recorded every 15 minutes as shown in the table below. The first tests used an aluminized mylar bag with no additional coating. Replicate 1 was done from 10:00am~12:00pm on July 5th 2013 while replicate 2 was done from 9:30am~11:30am on July 10th 2013.

	Rep 1	Delta 1	Heat	Rep 2	Delta 2	Heat	Rep 3	Delta 3	Heat
	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)
Heat	30	0	0	28	0	0	29	0	0
0:15	30	0	0	28	0	0	29	0	0
0:30	30	0	0	28	0	0	30	1	63
0:45	30	0	0	29	1	63	30	1	63
1:00	30	0	0	29	1	63	30	1	63
1:15	30	0	0	29	1	63	30	1	63
1:30	30	0	0	29	1	63	31	2	126
1:45	30	0	0	29	1	63	31	2	126
2:00	30	0	0	29	1	63	31	2	126

As we can see from table 10, for replicate 1, the temperature didn't go up even 1°C during the two hour test. For replicate 2, the temperature only increased 1 degree during two hours.

The next series of tests used a mylar bag that had been coated with a heat stable black paint. The initial tests were conducted with bags in which the black paint was sprayed directly onto the aluminized surface of the bag (Table 11). The paint on these bags didn't stick well and quickly peeled off. Further tests were conducted with bags that had been precoated with a glue containing diphenylmethane isocyanate before being spray painted black (Table 12). Precoating the surface allowed the black paint to adhere more efficiently to the outer surface of the bag and resulted in minimal peeling of the paint.

Table 11 below shows the data collected with bags that were painted with black spray paint. Replicate 1 was conducted from 5:31 pm ~7:32 pm July 5th 2013; replicate 2 was done from 9:58 am~12:00 pm July 8th 2013. Replicate 1 of the sprayed bag tests lasted from 12:11 pm~2:16 pm July 8th 2013 and replicate 2 was done from 2:33 pm~4:34 pm July 8th 2013. The third replicate was completed between 11:00 am~1:00 pm on July 23th 2013.

<i>Table 11 Spray Painted Mylar Bag Test</i>									
	Rep1	Delta1	Heat	Rep 2	Delta2	Heat	Rep3	Delta 3	Heat
	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)	(°C)	(°C)	(KJ)
Heating	29	0	0	23	0	0	31	0	0
Origin									
0:15	29	0	0	23.5	0.5	31.5	31	0	0
0:30	30	1	63	24	1	63	32	1	63
0:45	31	2	126	25	2	126	32	1	63
1:00	31	2	126	26	3	189	33	2	126
1:15	32	3	189	26	3	189	33	2	126
1:30	32	3	189	27	4	252	34	3	189
1:45	32	3	189	27	4	252	34	3	189
2:00	33	4	252	27	4	252	35	4	252

The average temperature increase of 15 liters of water during the two hour test was only 0.5°C when silver mylar bags were used but it was 4°C when the spray painted mylar bags were tested. When compared to a silver mylar bag, adding a coating of black

paint to the bag resulted in significant increase in heat absorption. Please go to Appendix B for detailed statistical analysis.

Table 12 Coated, Painted Mylar Bag Test

	Rep 1 (°C)	Delta 1 (°C)	Heat (KJ)	Rep 2 (°C)	Delta 2 (°C)	Heat (KJ)	Rep 3 (°C)	Delta 3 (°C)	Heat (KJ)
Heating Origin	27	0	0	28	0	0	30	0	0
0:15	27	0	0	28	0	0	31	1	63
0:30	28	1	63	29	1	63	32	2	126
0:45	29	2	126	29	1	63	32	2	126
1:00	29	2	126	30	2	126	33	3	189
1:15	30	3	189	30	2	126	33	3	189
1:30	30	3	189	31	3	189	34	4	252
1:45	31	4	252	31	3	189	34	4	252
2:00	31	4	252	31	3	189	35	5	315

The average temperature increase during the two hour test using a mylar bag precoated with glue and then painted black was 3.5°C. There was no significant differences between mylar bags that had been painted directly and those which were pretreated with glue and then painted. But there were significant differences between black and uncoated aluminized mylar bags. Please go to Appendix B for detailed analysis. As expected the black coating worked much better than silver surface in terms of absorbing heat but it didn't matter how the coating was applied.

5.2 Field Tests

After completion of the laboratory tests, we knew that insulation played an important role in retaining heat inside the inner shell; that a black mylar bag was more efficient than an aluminized mylar bag in terms of absorbing heat, and that a metal plate was a good heat conductor that could be used to speed the heating of the air in the inner chamber. There were several field tests designed to confirm the laboratory observations and to determine how well the sanitizer and the waste container worked in real situations. These tests were 1) exposure of an empty sanitizer with a metal plate inside to sunlight, 2) Exposure a black painted mylar bag to sunlight inside of a sanitizer with a metal plate, and 3) comparing the heating properties of a black mylar bag to an aluminized mylar bag inside of a sanitizer containing a metal plate.

5.2.1 Field Test with Empty Sanitizer with Metal Plate

A wooden support was built for the sanitizer so that it could be tilted at an appropriate angle towards the sun. A temperature sensor was placed in the inner shell in indirect sunlight and the air temperature in the inner chamber was monitored for two hours. The test was done on July 9th 2013 from 10:00 am~12:00 pm. The air temperature outside was 89°F (32°C). The table below is the data collected.

<i>Table 13 Field Test with Metal Plate</i>	
	Temperature (°C)
Heating Origin	32
0:30	53
0:60	84

1:15	91
1:30	94
1:45	89
2:00	91

As shown in Table 13, the air temperature increased 59°C in two hours time. The final temperature was 91°C which is approximately 196°F. This test showed that the air inside the sanitizer we designed and built could easily get up to 91°C when exposed to natural sunlight for a short amount of time. In this case, it was reasonable to continue the tests and run several additional tests with a full waste container inside the sanitizer.

5.2.2 Field Test with Metal Plate and Black Sprayed Painted Waste Container

Then next experiment was done to determine if waste container could be heated in a sanitizer to 65°C using only sunlight. For these tests the sanitizer contained a black metal plate and a spray painted black waste container loaded with 15 liters of water was used. Replicates 1 was done on July 11th 2013 from 9:34 am~6:19 pm. The outside temperature at the beginning of the test was 30°C (86°F). Replicate 2 was completed on July 12th 2013 from 9:00 am~6:00 pm. The outside temperature on this day was about 28°C (83°F). Replicate 3, was done on July 19th 2013 from 9:03 am~7:03 pm with a beginning outside temperature of 23°C (73°F). The data is shown below in Table 14.

	Rep1	Delta 1	Rep 2	Delta 2	Rep 3	Delta 3
	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)
Origin	27	0	28	0	25	0

0:15	27	0	28	0		
0:30	28	1	28	0	26	1
0:45	28	1	29	1		
1:00	29	2	29	1	27	2
1:15	31	4	31	3		
1:30	32	5	32	4	30	3
1:45	33	6	33	5		
2:00	34.5	7.5	35	7	36	9
2:15	35	8	36	8		
2:30	38	11	37	9	38	11
2:45	39	12	37	9		
3:00	41	14	39	11	45	18
3:15	42	15	40	12		
3:30	44	17	42	14	49	22
3:45	46	19	43	15		
4:00	48	21	46	18	53	26
4:15	50	23	47.5	19.5		
4:30	51	24	49	21	57	30
4:45	53	26	51	23		
5:00	56	29	52	24	60	33
5:15	58	31	54	26		
5:30	59	32	55	27	63	36
5:45	61	34	57	29		

6:00	62	35	58	30	65	38
6:15	63	36	59	31		
6:30	64	37	60	32	67	40
6:45	65	38	61	33		
7:00	66	39	62	34	69	42
7:15	66	39	63	35		
7:30	67	40	64	36	68	41
7:45	67	40	64	36		
8:00	67	40	64	36	68	41
8:15	68	41	65	37		
8:30	67.5	40.5	65	37	67	40
8:45	67	40	65	37		
9:00			65	37	66	39
9:15						
9:30					65	38
9:45						
10:00					63	36

For replicate 1, the temperature reached 65°C after 6 hours and 45 minutes of exposure to sunlight which was a 38°C increase when compared to the starting temperature. The temperature continued to increase for an additional hour and a half until reaching a high of 68°C well beyond the temperature needed to kill pathogenic bacteria in the waste container. For replicate 2, the final temperature reached was 65°C after 8 hours and 15 minutes of sun exposure. This is a 37° increase compared to the starting

temperature. The third replicate began with the lowest waste temperature of 25°C but reached the highest final temperature of 69°C. Figure 51 below shows the graphical relationship between these three replicate tests. From the graph it doesn't appear that there is any difference between these three replicates. However, it is important to note that all three tests confirmed that waste within a fully loaded waste container could be heated to temperatures that are capable of killing pathogenic bacteria after exposure to sunlight in a solar sanitizer. For detailed statistical analyses please go to Appendix C.

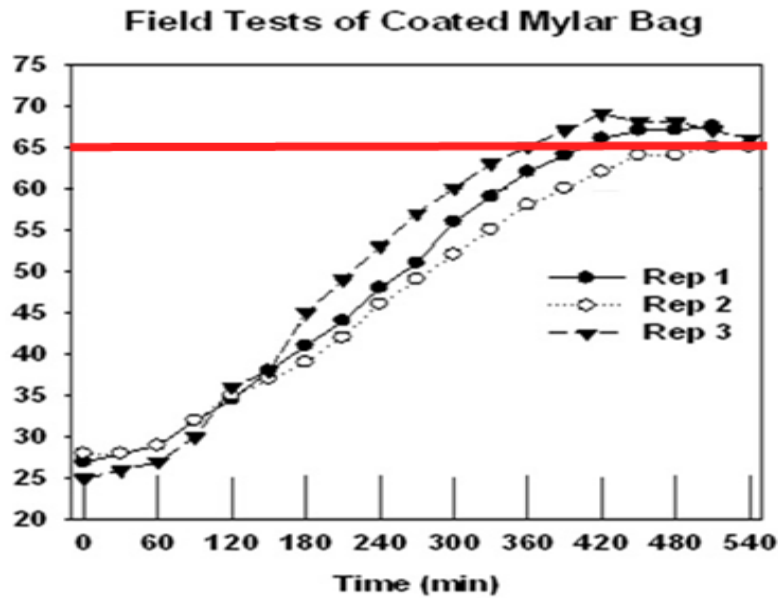


Figure 51 Field Test of Sprayed Coated Bag

5.2.3 Field Test with Metal Plate and Silver Bag

In the laboratory test, there was a clear difference in the heat absorbing properties of black sprayed coated mylar bags and aluminized non-coated mylar bags. However, it was still of interest to field test the aluminized mylar bags. Therefore, 4 replicate tests of a sanitizer loaded with a full aluminized waste container were conducted. Replicate 1 lasted from 9:03 am~4:33 pm on July 15th 2013 with an outside air temperature of 32°C

(89°F). Replicate 2 was done from 9:10 am~5:10 pm on July 16th 2013 with an outside air temperature of 32°C (90°F). Replicate 3 was done from 9:04 am~6:04 pm on July 17th 2013 with an outside temperature of 34°C (93°F). Finally, Replicate 4 was done from 9:06 am~ 6:08 pm on July 22th 2013 and the outside temperature was 23°C (73°F). The data for these four tests are shown below in Table 15.

Table 15 Field Test With Sanitizer Containing Metal Plate and Aluminized Waste Container

	Rep1 (°C)	Delta 1 (°C)	Rep 2 (°C)	Delta 2 (°C)	Rep 3 (°C)	Delta 3 (°C)	Rep 4 (°C)	Delta 4 (°C)
Origin	28	0	26	0	27	0	28	0
0:30	28	0			29	2	31	3
1:00	29	1	28	2	32	5	32	4
1:30	30	1			35	8	35	7
2:00	31	2	31	5	36	9	36	8
2:30	32	4			40	13	39	11
3:00	34	5	36	10	42	15	42	14
3:30	36	6			43	16	45	17
4:00	37	7.5	40	14	47	20	48	20
4:30	39	8			48	21	52	24
5:00	41	11	45	19	50	23	54	26
5:30	42	12			53	26	58	30
6:00	43	14	51	25	56	29	59	31
6:30	44	15			58	31	59	31

7:00	46	17	52	26	59	32	60	32
7:30	47	19			60	33	61	33
8:00			53	27	60	33	61	32
8:30					58	31	59	31
9:00					57	30	59	31
9:30					56	29		

When an aluminized mylar bag was used as a waste container the temperature of the material in the container reached the target temperature of 65°C in none of the 4 replicates. While it is obvious from the table above that the final temperature of the material in the waste container was much higher than the initial starting outside temperature for all four tests, indicating that the material in the waste container was being heated, it was not being heated as efficiently as material in a black waste container. Compared with the data from black sprayed painted mylar bag tests, the temperatures of silver mylar bag tests are lower than those of the tests using black spray painted mylar bag tests. Figure 52 below shows the relationship between these four replicates of the aluminized mylar bags. But there is not a significant difference in statistics between black sprayed mylar bag and silver mylar bag. Please go to Appendix D and Appendix E for detailed statistical analysis.

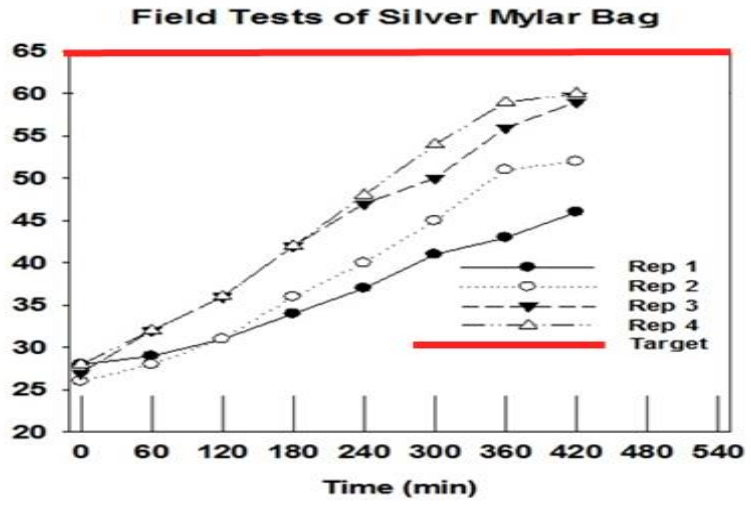


Figure 52 Field Test of Silver Mylar Bag

Chapter 6

Conclusions and Future Research

6.1 Conclusions

In this thesis, a goal has been presented which is to develop a machine that can heat human waste to 65°C using nothing but sunlight. The design of the Solar Sanitizer was based upon previous designs that utilized a simple sealed box with a window to capture solar energy for cooking food. However, most of these devices are very small and capable of cooking only small amounts of food. In addition, in general solar cookers are not well insulated and valuable heat is lost to the environment during the cooking process. The design criteria specified for the Solar Sanitizer was to be able to heat 15 liters of mixed solid/liquid waste to 65°C within a single day. In contrast, most solar cooker designs are capable of heating only 1 or 2 liters of food per day. The necessity of heating such a large amount of waste required a fairly large window for capturing an adequate amount of sunlight and considerable insulation to minimize heat loss during operation. In order to test the theory, a prototype sanitizer and waste container was designed including specifications for all the dimensions, materials for construction, assembly considerations, and so on was completed to prepare fully for building a working prototype. After the design phase a real sanitizer based on the drawings produced for the prototype was developed and manufactured. In order to manufacture the whole sanitizer, all the materials for the inner and outer shells and windows were cut to size and assembled. Although most solar ovens use plate glass as the material for the window our design required us to use plexiglass as it is less likely to break during use. Pieces of foam board

insulation were cut to fit really tight between the inner and outer shells to minimize heat loss during operation. Close fitting latches were used to close the top lid really tight to the wood body and weather stripping was added around the perimeter of the lid to minimize heat loss. Besides that, we also prepared all the tools which were needed during the whole manufacturing processes; a circular saw to cut the plywood, a table saw to cut all the insulation, clamps to stabilize the wood during gluing and a tape measure to measure all the dimensions. Black paint was used to paint the inside of the sanitizer to seal the wood and minimize heat loss and increase absorption of infrared radiation.

After manufacture of the sanitizer was finished, a lot of tests were conducted to determine if the sanitizer met the design criteria and also how to determine how efficient it was by comparing different colors of mylar bags in both laboratory tests and field tests. We had also tested the effect of insulation in laboratory tests which showed that the insulation did help to minimize the escape of air hot air from inside of the sanitizer. Also in preliminary laboratory tests, including a metal plate in the sanitizer did not reach our high expectation of speeding up the heating process of the air in the inner chamber. In laboratory tests, we also tested three different modifications of the mylar bag waste container, the first was the original aluminized mylar bag, the second was a mylar bag spray painted black and the third one was a mylar bag precoated with a material that allowed the black spray to stick efficiently to the aluminized surface. In all of the tests in both the laboratory and the field, black colored bags performed much better than aluminized bags. In the field test, with limited time, we tested two scenarios a sanitizer containing a black metal plate and a black spray painted waste container and a sanitizer with a black metal plate and an aluminized silver waste container. It turned out that the

black waste container again performed better than the silver container. It can be concluded that black color performs better than silver color in terms of the speed to get to the required temperature which is 65°C. It is also concluded that the theory can be proved by our field testing. It is obvious that liquid material within a waste container can reproducibly reach the target temperature during a single day when a black mylar bag is used as the waste container.

6.2 Future Research

6.2.1 Test Material

Water was used as the test fluid in all of the experiments because of limited time. In order to get more precise and convincing testing results in the future we will use synthetic urine to replace water and repeat the laboratory and field tests to see whether the synthetic urine can reach 65°C during the daytime. If it does, we will begin to add vegetable solids which mimic human fecal material. This will most likely involve adding increasing amounts of rabbit food to synthetic urine to replace just synthetic urine to do the same tests. Finally, if the synthetic urine with solids can reach our target temperature, we will then test the device with real human waste. It is also essential that we continue making improvements of our prototype sanitizer as we test different materials including alternative insulators, more efficient closures and sealants to minimize heat loss from the outer chamber. Any design improvements that can result in reducing heat loss or which will speed up the heating process should be implemented or tested immediately so that by the time we test on real human waste, we can settle down on a final version of the prototype.

6.2.2 Human Factor

Because of the nature of the device there are a lot of human factor issues that need to be addressed before we are able to use real human waste in the sanitizer. Surveys were planned to poll a number of potential users on the operability of the sanitizer and waste container. When these surveys are completed the results will be analyzed and used to make decisions about the final design.

In using the device a subject will first place a mylar bag into a camp toilet and then evacuate their waste into the bag. When the bag is full the waste container will be sealed and placed into the inner chamber of the sanitizer. Finally the operator will close the sanitizer top lid tightly and place the sanitizer towards the sun. Then the operator can return at the end of the day. By that time, the free solar energy will have killed all the bacteria which cause disease in human waste.

After a subject finishes all the processes above, he or she will be given a written survey to complete. There are a lot of human factors involved in the whole process and these are the points that we could address and possibly improve our sanitizer a lot into a more user friendly device. For example, by asking questions on the survey about the height of the bucket that people evacuate their waste into. Doing so we could then collect all the data that subjects provided to us and learn that some people might like a taller bucket because they were relatively taller and some people might like a shorter bucket because they were relatively shorter. Ideally we would end up with an average height that could accommodate 95% of the people in the United States. Secondly, we could also survey on the height of the sanitizer because people will eventually need to open the lid of the sanitizer and insert and later remove the mylar bag. Likewise, we would end up

with a height of the sanitizer lid that was comfortable for 95% of the people in the United States. We could also ask subjects how they feel about the way to open and close the top lid of the sanitizer. If the majority of the subjects are satisfied with the way it opens and closes, it means it is well designed. If the majority of the subjects are not satisfied or even dissatisfied with the way it opens and closes, it would be obvious to us that we need to consider a redesign. We could also redesign the lid and then survey on subjects with the new design, in this way, we could not only get an effective device but also one that users are satisfied with so that more users would be likely to use the device. In a word, our ultimate goal is to make the sanitizer acceptable and welcome to all the people who need it.

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Appendix A

Since the purpose of this test was to see the effect of the insulation, the data used for statistical analysis started from the 60 minute time point instead of the 0 minute time point. It was not appropriate to begin from the 0 minute time point because the box hadn't been heated up and the insulation hadn't started to function yet.

↓	C1	C2-T
	Average Temperature	Insulation
1	19.00	N
2	20.00	N
3	21.00	N
4	21.00	N
5	22.00	N
6	22.25	Y
7	25.75	Y
8	27.25	Y
9	29.25	Y
10	30.25	Y

Figure 53 Data Sets for Foam Insulation (Heating)

Two-Sample T-Test and CI: Average Temperature, Insulation

Two-sample T for Average Temperature

Insulation	N	Mean	StDev	SE Mean
N	5	20.60	1.14	0.51
Y	5	26.95	3.15	1.4

Difference = mu (N) - mu (Y)
 Estimate for difference: -6.35
 95% CI for difference: (-9.81, -2.89)
 T-Test of difference = 0 (vs not =): T-Value = -4.23 P-Value = 0.003 DF = 8
 Both use Pooled StDev = 2.3717

Figure 54 T test for Foam Board Insulation (Heating)

According to the results above, it was concluded that there was a huge difference between the box with insulation in it and the box without the insulation in it with a P value of $0.003 < 0.05$.

Appendix B

The data used for analysis both the aluminized mylar bag, the spray painted mylar bag and the coated, spray painted mylar bag is:

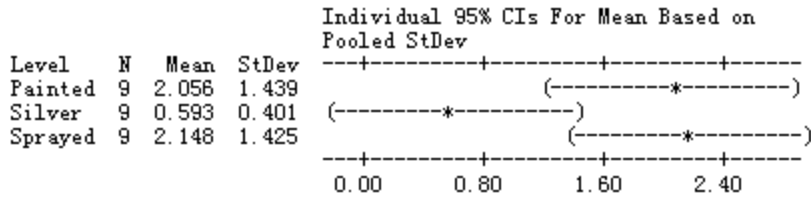
↓	C1	C2-T
	Average Temperature	Kind
1	0.00000	Silver
2	0.00000	Silver
3	0.33333	Silver
4	0.66667	Silver
5	0.66667	Silver
6	0.66667	Silver
7	1.00000	Silver
8	1.00000	Silver
9	1.00000	Silver
10	0.00000	Sprayed
11	0.33333	Sprayed
12	1.33333	Sprayed
13	1.66667	Sprayed
14	2.33333	Sprayed
15	2.66667	Sprayed
16	3.33333	Sprayed
17	3.66667	Sprayed
18	4.00000	Sprayed
19	0.00000	Painted
20	0.16667	Painted
21	1.00000	Painted
22	1.66667	Painted
23	2.33333	Painted
24	2.66667	Painted
25	3.33333	Painted
26	3.33333	Painted
27	4.00000	Painted

Figure 55 Silver Bag VS Spray Painted Bag VS Spray Painted, Coated Bag

One-way ANOVA: Average Temperature versus Kind

Source	DF	SS	MS	F	P
Kind	2	13.71	6.85	4.83	0.017
Error	24	34.09	1.42		
Total	26	47.79			

S = 1.192 R-Sq = 28.68% R-Sq(adj) = 22.73%



Pooled StDev = 1.192

Grouping Information Using Fisher Method

Kind	N	Mean	Grouping
Sprayed	9	2.148	A
Painted	9	2.056	A
Silver	9	0.593	B

Means that do not share a letter are significantly different.

Figure 56 Result for silver bag VS painted bag VS sprayed bag

It is obvious that there is a significant difference between the aluminized bag and the spray painted bag. There is also a significant difference between the aluminized bag and spray painted, coated bag. There is no a significant difference between spray painted and spray painted, coated bags.

Appendix C

Data used for analysis is:

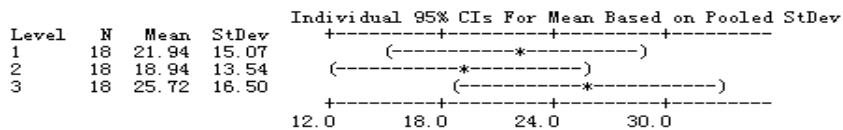
Replicate1	Replicate2	Replicate3
0.0	0	0
1.0	0	1
2.0	1	2
5.0	4	5
7.5	7	11
11.0	9	13
14.0	11	20
17.0	14	24
21.0	18	28
24.0	21	32
29.0	24	35
32.0	27	38
35.0	30	40
37.0	32	42
39.0	34	44
40.0	36	43
40.0	36	43
40.5	37	42

Figure 57 Data for Spray Painted Bag Field Test

One-way ANOVA: Average Temperature versus Replicate

Source	DF	SS	MS	F	P
Replicate	2	415	208	0.91	0.408
Error	51	11602	227		
Total	53	12017			

S = 15.08 R-Sq = 3.46% R-Sq(adj) = 0.00%



Pooled StDev = 15.08

Grouping Information Using Fisher Method

Replicate	N	Mean	Grouping
3	18	25.72	A
1	18	21.94	A
2	18	18.94	A

Means that do not share a letter are significantly different.

Fisher 95% Individual Confidence Intervals
All Pairwise Comparisons among Levels of Replicate

Simultaneous confidence level = 87.93%

Figure 58 Result for Spray Painted Bag Field Test

It is obvious that there is no detectable difference between the three replicates with the P value being 0.408. Also, by using Fisher's Method, there is also no detectable difference since all of the three replicates share the same alphabet A for grouping.

Appendix D

Data for the Aluminized mylar bag field test is as below:

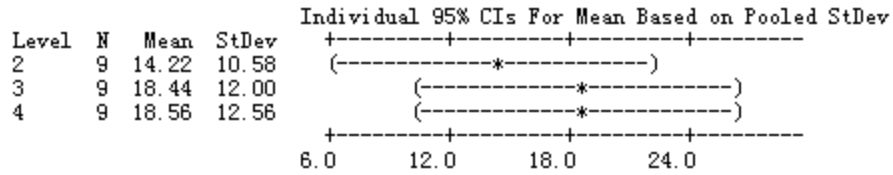
	Temperature	Replicate
1	0	2
2	2	2
3	5	2
4	10	2
5	14	2
6	19	2
7	25	2
8	26	2
9	27	2
10	0	3
11	5	3
12	9	3
13	15	3
14	20	3
15	23	3
16	29	3
17	32	3
18	33	3
19	0	4
20	4	4
21	8	4
22	14	4
23	20	4
24	26	4
25	31	4
26	32	4
27	32	4

Figure 59 Field Test Aluminized Mylar Bag

One-way ANOVA: Temperature versus Replicate

Source	DF	SS	MS	F	P
Replicate	2	110	55	0.40	0.676
Error	24	3310	138		
Total	26	3420			

S = 11.74 R-Sq = 3.21% R-Sq(adj) = 0.00%



Pooled StDev = 11.74

Grouping Information Using Fisher Method

Replicate	N	Mean	Grouping
4	9	18.56	A
3	9	18.44	A
2	9	14.22	A

Means that do not share a letter are significantly different.

Figure 60 Result for Field Test of Aluminized Mylar Bag

With a p value of 0.67 it is obvious that there is not a significant difference between these three replicates.

Appendix E

Data for silver aluminized mylar bag VS spray painted mylar bag is shown below:

↓	C1	C2-T
	Average Temperature	Kind
1	0.0000	Silver
2	3.6667	Silver
3	7.3333	Silver
4	13.0000	Silver
5	18.0000	Silver
6	22.6667	Silver
7	28.3333	Silver
8	30.0000	Silver
9	30.6667	Silver
10	0.0000	Sprayed
11	1.6667	Sprayed
12	7.8333	Sprayed
13	14.3333	Sprayed
14	21.6667	Sprayed
15	28.6667	Sprayed
16	34.3333	Sprayed
17	38.3333	Sprayed
18	39.0000	Sprayed

Figure 61 Field Test Aluminized Mylar Bag vs Spray Painted Mylar Bag

Two-Sample T-Test and CI: Average Temperature, Kind

Two-sample T for Average Temperature

Kind	N	Mean	StDev	SE Mean
Silver	9	17.1	11.7	3.9
Sprayed	9	20.6	15.4	5.1

Difference = mu (Silver) - mu (Sprayed)
 Estimate for difference: -3.57
 95% CI for difference: (-17.23, 10.08)
 T-Test of difference = 0 (vs not =): T-Value = -0.55 P-Value = 0.587 DF = 16
 Both use Pooled StDev = 13.6620

Figure 62 Result for Field Test Aluminized Mylar vs Spray Painted Mylar Bag

It is obvious that there is not a significant difference between the aluminized bag and spray painted bag during the field tests due to a P-Value=0.587>0.05.