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Team 523: ESD Temperature Sensitive Medication Storage During Natural Disasters

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Abstract

Our team is designing a portable cooling solution that preserves temperature-sensitive medicine without relying on grid power.

Natural disasters such as hurricanes devastate the world every year and can disable power for weeks at a time. These power outages leave survivors desperate for food and shelter without access to certain critically needed medications. The lack of proper cooling for insulin after these storms causes hundreds of otherwise preventable deaths. People whose entire livelihoods are at risk should not be in fear of losing their lives as well.

Our design consists of a 5-quart cooler with a thermoelectric cold plate powered by two batteries and a solar panel. The storage space will hold three insulin pens at once; the average prescription a user will have available at one time. The cold plate will keep the temperature between 2 to 8 degrees Celsius (35 to 46 degrees Fahrenheit). If insulin reaches 0 degrees Celsius it will freeze. If it goes above 8 degrees Celsius it can expire. The supported temperature range can preserve other supplies, such as vaccines or eyedrops for glaucoma.

The solar panel will supply consistent energy to recharge the batteries during the operation of the device. Employing two batteries allows the user to stagger power draw by alternating the source. While one battery is powering the cold plate, the solar panel is recharging the second battery. This setup will provide 14 days of cooling, average time for power restoration in the United States.

This product can save countless lives. It will protect their medicine when nothing else can and provide invaluable relief to those who need it most.

Acknowledgement

First, our team would like to thank Dr. Shayne McConomy for his mentorship and advice. Along with being our great professor, he was a huge contributor to the success of our team in the development of our project, as well as the InNOLEvation Challenge and the ACC Inventure Prize competition.

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Table of Contents

List of Tables

List of Figures

Notation

AHP	Analytical Hierarchy Process
BPC	Binary Pairwise Comparison
HOQ	House of Quality
TEC	Thermoelectric Cooler

Chapter One: EML 4551C

1.1 Project Scope

1.1.1 Project Description

The project is to develop a device that can store temperature sensitive medication in the event of a natural disaster where power outage is to occur. The device is to maintain a cool temperature for different medications, while also maintaining the integrity of the medications under harsh conditions.

1.1.2 Key Goals

Brainstorming all the possible conditions where this device could be utilized has led to a variety of key goals for the final design. The primary function of this product is to provide storage and power for cooling medication. Thus, optimizing power conservation and heat transfer are paramount to the success of this device. Furthermore, not all medications require the same temperature, so the device must be able to maintain a wide range of temperatures without sacrificing reliability.

Beyond the core functions of the device, the end user also needs consideration. The range of medications this device is intended to preserve means a diverse group of end users would use the device. The device needs to be simple enough for all users, accommodating weaker, older, or otherwise handicapped individuals. With this goal comes the contrasting challenge of durability and portability. The intended environment for this device is hazardous and unpredictable. There is potential for falling debris, extreme heat or cold, dust and ash, and flooding. Further, upholding durability would enable the device to be delivered by air drop, which is a common delivery method in hazardous conditions. It needs to be waterproof and robust enough to withstand those conditions without losing functionality, while maintaining a lightweight and compact design that can easily move with the individual and be carried by a drone if the customer chooses this delivery method. By upholding the device's durability and keeping its weight to a minimum, the device will protect and maintain the medication for a wide variety of deliveries.

Finally, the device needs to be widely accessible. The end users that are intended for this device are people who require temperature sensitive medication to live. Considering our end users already have the economic burden of affording their medication, the cost of the device needs to remain low. This compounds with the limitless damage natural disasters cause and the impoverished conditions that many people living in third world countries endure. The product needs to be low-cost enough for these extraordinarily burdened people to afford, or at least cost effective enough that non-profit disaster relief organizations can afford as many needed to keep people alive.

Summary of Key Goals:

- Conserve energy
- Optimize heat transfer
- Wide temperature range
- Ease of operation
- Durability
- Waterproof
- Reliability
- Portability/lightweight

- Cost efficiency

1.1.3 Market

The primary market is disaster relief organizations, the people responsible for providing care and supplies to those directly impacted by life threatening events. By providing a reliable temperature controlled medication storage unit, these organizations will be able to provide support to individuals who require more care than just clean water and food, and can bear the cost of supplying and maintaining the quality of their medicine for impoverished areas. Moreover, these organizations have the foresight to plan for supplies and services that the survivors will need, while affected peoples usually remain unprepared due to lack of funds or planning.

This leads us to our secondary markets which includes, most namely, the individuals with medical conditions that require lifesaving temperature sensitive medications. While we recognize that most individuals will not feel the need to emergency prep to such an extent, there is a portion of the population who do think ahead about what they would need when disaster strikes. Whether it is individuals who like to be prepared for all situations, or people with such dire need for their medication that they cannot risk going a few days without power, there is a percentage of the population that would purchase such a device directly. Additionally, drug manufacturers and distributors, big box stores, and pharmacies could all benefit. Drug manufacturers and distributors can offer these products in bundles with their medication, as they already target the intended primary market. This product could also be a staple at big box stores such as Walmart or Target, or any other pharmacy where it is a common stop for medication needs, especially during times of natural disaster.

1.1.4 Assumptions

Assumptions for this product begin with providing an efficient temperature control range for sensitive medications for a time such that a more permanent solution can be implemented after power is restored. The device will sustain itself for a minimum of 3 days and we assume it will not be needed for any longer than 1 month of continuous use. The device will operate at ambient conditions. Medication will be placed into the device at sufficient temperature and good quality. We will not be providing any medication or contents for the device.

1.1.5 Stakeholders

Stakeholders for this project include our professor and project manager, Dr. McConomy, who oversees the educational objectives of this project. Our advisor, Dr. Devine, who is aiding the team in the Entrepreneurial aspect of our product, ensuring its viability in the market. Rob McDaniels, senior fellow for the Emergency Management and Homeland Security academic program, as a consultant regarding emergency response and preparedness to help us identify necessary components in our design and target appropriate markets. The InNOLEvation Team for investing their time and resources with their workshops and the overall competition to promote entrepreneurship and professional practice. Diabetic patients and anybody requiring such temperature-controlled medication using this device are directly dependent on its functionality and reliability during disasters. Red Cross and the World Health Organization (WHO) could be future stakeholders if the product is successful as they would be key distributors of this device to those in need.

1.2 Customer Needs

1.2.1 Explanation of Results

To get a general idea of what our customer needs are for a temperature sensitive medication storage device, we did diligent research of what the medical response looks like after a natural disaster. We reached out to Rob McDaniels from FSU Emergency Management and Americares (a non-profit, health-focused organization that helps people affected by poverty or natural disasters) to get some insight on what the current process is for storing and distributing temperature sensitive medication when disaster strikes. We were able to schedule an hour zoom meeting with Rob McDaniels but never received a response from Americares. Further, we had an interview with an individual who uses insulin to get a perspective from a potential end user, and to obtain information on what the needs are for someone who uses temperature sensitive medications.

After gathering sufficient customer data, we have established that the storage device is intended to be used when the location's power grid is down. It will need to keep the medication cool from its own power source, without relying on non-reusable means such as ice, and sustain temperature regulation until a more permanent solution can be implemented. Further, the storage device should light enough for the possibility of an air delivery, while also remaining durable enough to protect the contents inside. The device will also be waterproof to maintain the sterile packaging that the medication comes in as well as the labels to distinguish between types of medicine and instructions that may come with. Moreover, the device needs to be easy to use and transport, such that someone who is elderly can still open the device as well as carry it around using their own strength. Lastly, the storage device needs to be affordable enough such that people will have an incentive to buy it before the power goes out, and also so that non-profit disaster relief organizations can afford it and make it accessible to impoverished peoples in third world countries.

Note: Since our project is entrepreneurship, our team does not have a direct sponsor with a direction for the project in mind. Therefore, several our customer statements were conflicting and provided no interpreted need or interpreted needs that were unhelpful from an engineering perspective and will not be considered in the further progression of the project.

1.2.2 Analysis and Interpretation of Needs

Table 1: Customer Needs Table

Question/Prompt for Insulin User	Customer Statement	Interpreted Need
Have you ever considered what you would do if the power we are to go out and you needed insulin?	I would hope that Walmart has a generator, but I am basically unprepared for that.	Storage device needs to be accessible to the end user after power goes out. Storage device will have its own power source separate from main power grid
How much would you pay for such a device?	Overall, I would not invest a ton, probably only $50 but I could see some diabetics investing much more.	Storage device needs to be very affordable

How big would you prefer such a device to be?	I would want it to hold a 30-day supply of insulin, and be able to hold needles, and a backup test meter.	Storage device is capable of properly storing a 30-day supply per person as well as needles and test meters.
Do you think a natural disaster could happen where the power goes out and your insulin goes bad?	. . . Insulin is good for 3 weeks without a fridge, I think. Supply must be refrigerated but I can take a pen with me to use as long as I'm in A/C, which wouldn't be on in a power outage.	Storage device can store insulin at room temperature for shorter amounts of time.
How much insulin do you have in supply at any given moment?	Usually 2-3 bottles (10mL each) in supply, kept in my fridge.	Storage device can hold 3 10mL bottles of insulin per user of device.

Question/Prompt for Rob McDaniel	**Customer Statement**	**Interpreted Need**
What is the typical response time for first responders after a natural disaster such as a hurricane?	FEMA will tell you we will not even go in there for 3 days. If the state government is any good, which Florida is, they will be there asking questions beforehand, but substantially with resources and medical help, 1 or 2 days.	Device will keep medicine at a proper temperature for an absolute minimum of 3 days.
What is a good way to keep temperature sensitive supplies cold?	Ice is problematic because it is non-reusable and can be very expensive. However, those gel packs that come in food delivery services work a lot better than ice, but the tradeoff is that those gel packs end up being most of the weight.	Storage device will keep contents cold through reusable means. Storage device will keep contents cold through its own power.
What do you think the best market for a temperature sensitive storage device would be?	There is a limited market for such a device in the US since the main priority is to evacuate people out before and after the disaster. Third world countries however could benefit a lot from something like this. Really anywhere where medicine is not easily accessible or	Storage device will be accessible and affordable to third world countries or remote locations where evacuation is not possible

	the people affected cannot easily be evacuated, which is not really the US.	
How is medicine usually delivered to people in need after a disaster?	In the U.S. we would use a helicopter to ship it there quickly. In Africa they are starting to do drone deliveries to drop off medicine, I have seen airdrops with parachutes before too.	Storage device will be light enough to be carried by a drone. Storage device will be durable enough to withstand an airdrop. Storage device will keep contents secure during an airdrop/drone delivery.
What would be the most important physical component considerations?	The most important physical component for the device is that it is lightweight. Since your primary market could be a 3rd world country like Africa, who is working on a delivery system using drones. It would be beneficial to have a storage device that is lightweight. You also have to think about the age of your customer. Your customer could be 90 yrs old, so you have to make sure that the device isn't too heavy and hard to open.	Storage device will be lightweight and easy to carry Storage device will be easy to open or has durable instruction on how to open it Storage device is capable of being delivered by a drone
What is the most common temperature sensitive medications that are distributed to survivors of natural disasters?	The most common medications are ones that need refrigeration such as insulin and certain liquid antibiotics and IVs. Basically, the medications types that result in the highest casualties.	Storage device will maintain quality of insulin, liquid antibiotics/IVs, and medications that cause the highest casualties when not supplied. Storage device will effectively secure and separate different types of medicine to avoid mixing of liquids.

What are some features that you think would be useful for such a storage device?	Someway for the package to be tracked after it is dropped off, labels and labels must survive. Also, you must keep the mediation sterile and have instructions on how to use medication.	Storage device will have a tracking feature to locate package Storage device will be waterproof to maintain labels and instructions inside. Storage device will maintain quality of medications and needles sterilized packaging.

Questions and Answers from Insulin User

The following questions were asked by Andrew to a diabetic friend of his who regularly takes insulin and could be a potential end user for a temperature sensitive medication storage device.

1. Do you think you are prepared for such a disaster and have you ever considered what you would do if it were to happen?
    a. **Answer** - I would hope that Walmart has a generator, but I am basically unprepared for that. Generators would probably be in high demand when the panic sets in. But generators are dependent on fuel, which would also be in high demand, so who knows how long a generator would even be good for if I did have one. A generator is a very important thing to have in Florida, but they cost 12-15k and some people simply cannot afford that. I can afford it and I still do not have one, it’s basically like an insurance policy, you only have it for when it’s needed.

b. **Interpreted Need -** Storage device needs to be accessible to the end user after power goes out because the end user does not think ahead of time on how she/he will properly store medicine.

c. **Interpreted Need -** Storage device will have its own power source.

d. **Rationale -** It is common for people to be unprepared for natural disasters when they occur. However, this device will be easily accessible to the end user because it would either be in the user's possession or given out by first responders. Therefore, the interpreted need indicated that the device must be easily accessible to the end user. Since power will be unavailable during a natural disaster, it will be generated from its own power source to power the storage device.

2. Would you pay money for such a device?

a. **Answer** - It would depend, I do not think there is a huge potential for a major hurricane to come where I live (Odessa, FL). But my medicine is not as critical as some people. If it came down to a dire situation, I could control my carbohydrates and my sugar, so it is not as life and death for me. Full blown diabetics do not have that option and cannot control their carbohydrate intake as easily as I can without adverse health effects. Overall, I would not invest a ton, probably only $50 but I could see some diabetics investing much more.

b. **Interpreted Need -** If sold to a typical insulin user, price needs to be very affordable.

c. **Rationale** - Due to natural disasters occurring almost yearly, insulin users don't expect to be in such situations, so the storage device will need to be affordable to accommodate for emergency spending. When hurricanes occur the number of generators that are bought increases. Therefore, we will sell our product at a more affordable price, so the end user has an incentive to buy our device over a generator.

3. How big would you prefer such a device to be?
    a. **Answer** - I would want it to hold a 30-day supply of insulin, and be able to hold needles, and a backup test meter.
    b. **Interpreted Need -** Device is capable of properly storing a 30-day supply per person as well as needles and test meters.
    c. **Rationale** - When natural disasters occur it could leave users without power for weeks. To support the end user the device will be able to store a 30-day supply per person. It will also include a compartment for needles and test meters, which would provide a peace of mind for the end user as well as a delivery system for the medication.
4. Do you think a natural disaster could happen where the power goes out and your insulin goes bad?
    a. **Answer** -Yes, for the sake of saying yes, but I do not know how long we will be without power. Insulin is good for 3 weeks without a fridge, I think. Supply must be refrigerated but I can take a pen with me to use as long as I'm in A/C, which wouldn't be on in a power outage. A pen of insulin is for convenience, otherwise I would take an injection in the morning and night from my vials at home.
    b. **Interpreted Need -** Storage device can store insulin at room temperature for shorter amounts of time.
    c. **Rationale** - The main implication of this need is its ability to keep insulin in a well-regulated environment. The device will be designed so that it is able to store and maintain a certain temperature range to keep the medicine from spoiling. The device

can also have some leeway in its temperature range, since insulin can survive for shorter amounts of time at room temperature rather than refrigerator ranged temperatures.

5. How much insulin do you typically use in a week?
    a. **Answer** - I use a 10mL bottle about every month and take 2 shots from a needle every day, morning, and night. One shot from the needle is 25 'units. A unit is a measure of how much insulin is packed into each milliliter of the fluid in the vial or pen.
    b. **Interpreted Need -** N/A
6. How much insulin do you have in supply at any given moment?
    a. **Answer** - Usually 2-3 bottles (10mL) in supply, kept in my fridge
    b. **Interpreted Need -** Storage device can hold 3 10mL bottles of insulin per user of device to keep their supply from going bad.
    c. **Rationale** - Since the insulin user emphasized that they carry a limited supply at any given moment, it is important that our device will be able to store at least 3 10mL bottles. Therefore, the end user does not have to waste any of their medication, and they will have at least a 3 months' supply, or a shorter supply for more people.

Questions and Answers from Rob McDaniels

The following questions were asked by Zoe, Andrew, and Keon to Rob McDaniels from FSU Emergency Management via a zoom meeting. Prof. McDaniels has taught emergency management for 23 years at FSU and before that, was the Operations Chief for the Florida Division of Emergency Management.

1. What is the typical response time for first responders after a natural disaster such as a hurricane?

   a. **Answer** - FEMA will tell you we will not even go in there for 3 days. If the state government is any good (Florida is) they will be there asking questions beforehand, but substantially with resources and medical help, 1 or 2 days.
   b. **Interpreted Need -** Device will keep medicine at proper temperature for a minimum of 3 days.
   c. **Rationale** - Since the professor emphasized the fact that the typical response time for natural disasters could take a few days, it is important for the device to be able to keep the medicine at a safe temperature for an absolute minimum of 3 days. Obviously, the device will need to work for longer, but this is the range minimum.

2. What is a good way to keep temperature sensitive supplies cold?
   a. **Answer** - Most people think of ice, but ice is problematic because it is non-reusable and can be very expensive. However, those gel packs that come in food delivery services like HelloFresh work a lot better than ice, but the tradeoff is that those gel packs end up being most of the weight.
   b. **Interpreted Need -** Storage device will keep contents cold through reusable means.
   c. **Rationale** - Ice and gel packs are commonly used to keep items cold when there is no power. However, both ice and ice packs would not work in this situation due to the fact there might be people without power for days or weeks in which ice would melt, not to mention the increased weight. Therefore, the interpreted need indicates that the storage device will maintain the contents inside through using reusable means, using its own power source.

3. What do you think the best market for a temperature sensitive storage device would be?

a. **Answer** - There is a limited market for such a device in the US since the main priority is to evacuate people out before and after the disaster. Third world countries however could benefit a lot from something like this. Really anywhere where medicine is not easily accessible or the people affected cannot easily be evacuated, which is not really the US.

b. **Interpreted Need -** Storage device will be accessible and affordable to third world countries or remote locations where evacuation is not possible

c. **Rationale -** Many people in third world countries cannot afford to get out of harm's way and don't have the infrastructure that developed countries have to mass evacuate people, thus third world countries could benefit from this product, but only if the product is affordable enough.

4. How is medicine usually delivered to people in need after a disaster?

a. **Answer** - In the U.S. we would use a helicopter to ship it there quickly. In Africa they are starting to do drone deliveries to drop off medicine, I have seen airdrops with parachutes before too.

b. **Interpreted Need -** Storage device will be light enough to be carried by a drone

c. **Interpreted Need -** Storage device will be durable enough to withstand an airdrop

d. **Interpreted Need -** Storage device will keep contents secure during an airdrop/drone delivery

e. **Rationale -** The most common way to deliver things in an emergency is through air delivery, since it is safe and efficient, but this would require the device to be lightweight to make delivery easier. Not only that but keeping the weight down will enable future uses by drones. The device could also be dropped from a certain height (from drone, helicopter, parachutes, etc.) so keeping the device durable is critical to keeping the contents inside safe and allowing very versatile means of delivery.

5. What would be the most important physical component considerations?
    a. **Answer** -The most important physical component for the device is that it is lightweight. Since your primary market could be a 3rd world country like Africa, who is working on a delivery system using drones. It would be beneficial to have a storage device that is lightweight. You also must think about the age of your customer. Your customer could be 90 yrs. old, so you must make sure that the device is not too heavy and hard to open.
    b. **Interpreted Need -** Storage device will be lightweight and easy to carry
    c. **Interpreted Need -** Storage device will be easy to open or has durable instruction on how to open it
    d. **Interpreted Need -** Storage device is capable of being delivered by a drone
    e. **Rationale** - An important physical component for the storage device is its weight. The storage device will be designed so that it will meet the requirements for a drone to carry it, but more importantly it needs to be easy to carry such that any aged person can transport it. On the same note, the device needs to be easy to open for elderly people, or have opening instructions on it that wear away in high winds, rushing water, etc.
6. What is the most common temperature sensitive medications that are distributed to survivors of natural disasters?
    a. **Answer** - The most common medications are ones that need refrigeration such as insulin and certain liquid antibiotics and IVs. Basically, the medications types that result in the highest casualties.

b. **Interpreted Need -** The storage device will maintain quality of insulin, liquid antibiotics/IVs, and medications that cause the highest amount when not supplied.

c. **Interpreted Need -** The storage device will effectively secure and separate different types of medicine to avoid mixing of liquids.

d. **Rationale** - Since insulin and other known medications need refrigeration to be maintained, it is pivotal that the storage device is designed with an interior that will allow the medicine to remain the same temperature when it is placed inside. It is also critical to include medications that cause the highest death rates when there's not enough supplies so that the most amount of lives are being saved. The design of the storage device will also need to ensure the medicine is not getting mixed with others while stored, since most temperature sensitive medications are liquid.

7. What are some features that you think would be useful for such a storage device?

a. **Answer** - I think someway for the package to be tracked after it is dropped off or incase it gets lost. You should also keep in mind labeling. Storage devices should be labeled, and labels must survive. Further, the storage device should have delivery systems, like needles. You have to keep those and the mediation sterile and have instructions on how to use medication.

b. **Interpreted Need -** Storage device will have a tracking feature to locate package

c. **Interpreted Need -** Storage device will be waterproof to maintain labels and instructions inside.

d. **Interpreted Need -** Storage device will maintain quality of medications and needles sterilized packaging.

   e. **Rationale** - The storage device could potentially be used to deliver medications in third world countries or remote locations in which some sort of tracking mechanism would be important; however, this would not need to be a feature on every unit. Further, by ensuring the device is waterproof, the device will maintain the integrity of paper labels on the medications as well as the medication's packaging so that the medication remains sterile.

8. How would we ship medicine in the U.S. to people who are unable to be evacuated in a disaster?
   a. **Answer** - Whenever medication is shipped in the US, it is always very quickly via helicopter which can be around $6400-$8400 per hour. We basically solve the problem by throwing money at it and spending whatever is needed.
   b. **Interpreted Need-** N/A
9. What is the typical emergency response structure like as far as most important procedures and getting supplies out to people?
   a. **Answer** - Getting people out of the city is the most important thing, the government is not concerned with getting supplies in unless it is urgent. Throwing money at the situation to evacuate people out is how it is done in the US. I have spent millions to save one person's life before.
   b. **Interpreted Need** – N/A

1.3 Functional Decomposition

1.3.1 Introduction

The functional decomposition breaks down the complete problem into systems designed to perform fundamental actions that come together to complete the objective at hand. In our case, the objective of this project is to develop a device that stores and preserves temperature sensitive medication in the event of a natural disaster that causes power outage to occur. With the use of customer needs, and considering the key goals of the project, the functional decomposition of a storage device for temperature sensitive medication was created with the aid of a hierarchy chart (see Figure 1), and that was diagnosed using the cross-reference chart (see Table 2). We were then able to connect between the systems and their functions and dissect how they are integrated with each other to help us determine what the most important functions and systems are for our project. Thus, we can further narrow down our design process and have a much clearer scope of how we will solve the problem at hand.

1.3.2 Data Generation

To reach our goal, several systems and functions must be defined. Based on the variables identified through our customer needs interviews and our project scope, the team brainstormed the necessary systems and main functions that were needed to achieve our key goals from our project scope. We considered only the customer statements that were helpful and functional such that the interpreted need could be transformed into a function for the device. We identified 3 main functions that satisfied our most important customer needs and broke these down into their lowest forms. The result was a total of 14 fundamental functions (see Figure 1) that the device needs to fulfill to satisfy our customers' needs and fulfill our key goals. The data drawn from customer needs and their functional interpreted need can be seen below:

Question	Customer Statement	Interpreted Need
What is a good way to keep temperature sensitive supplies cold?	Ice is problematic because it is non-reusable and can be very expensive. However, those gel packs that come in food delivery services work a lot better than ice, but the tradeoff is that those gel packs end up being most of the weight	Storage device will keep contents cold through reusable means. Storage device will keep contents cold through its own power.
What are the most common temperature sensitive medications that are distributed to survivors of natural disasters?	The most common medications are ones that need refrigeration such as insulin and certain liquid antibiotics and IVs. Basically, the medications types that result in the highest casualties.	Storage device will maintain quality of insulin, liquid antibiotics/IVs, and medications that cause the highest casualties when not supplied. Storage device will effectively secure and separate different types of medicine to avoid mixing of liquids.
What are some features that you think would be useful for such a storage device? What are some features that you think would be useful for such a storage device?	Labeling for the medicine and the labels must survive. Also, you must keep the mediation sterile and have instructions on how to use medication.	Storage device will be waterproof to maintain labels and instructions inside. Storage device will maintain the quality of the medication's and needle's sterilized packaging.

The customer stated that ice is problematic when it comes to maintaining temperature sensitive supplies since it constantly needs to be replaced. The interpreted need drawn from this was that the device must keep contents cold through reusable means and use its own power. Therefore, the device must perform functions to not only generate, deliver, and store its own power but also have a thermal system. This thermal system must regulate the interior temperature by sensing temperature, activating, and deactivating cooling, and regulating heat transfer via insulation. Our next functional need requires the device to maintain the quality of insulin and other liquid medicine but also to avoid mixing and damage to the medication and other contents. Thus, the device must keep the contents separated through compartments and secured such that the contents will not break from external forces or mix with each other. Our last functional interpreted need states that the device needs to be waterproof to maintain labels, instructions, and the sterilized packaging that the medication and needs come in. This gives way to the function of sealing compartments off from the outside environment so that the contents and their packing and labels remain intact. Based on this data, the team came up with our three main functions of interacting with the user, maintaining the quality of the contents, and regulating power that were then broken down further into more fundamental functions, as shown in Figure 1.

1.3.3 Hierarchy Chart

Using all the data and information listed above, we were able to create a hierarchy chart based on the needed systems and functions. The hierarchy chart is a flow chart starting with our problem and breaking down into systems and fundamental functions that need to be achieved to solve the problem at hand. Below is our hierarchy chart for our objective at hand: storing temperature sensitive medication in the event of a power outage.

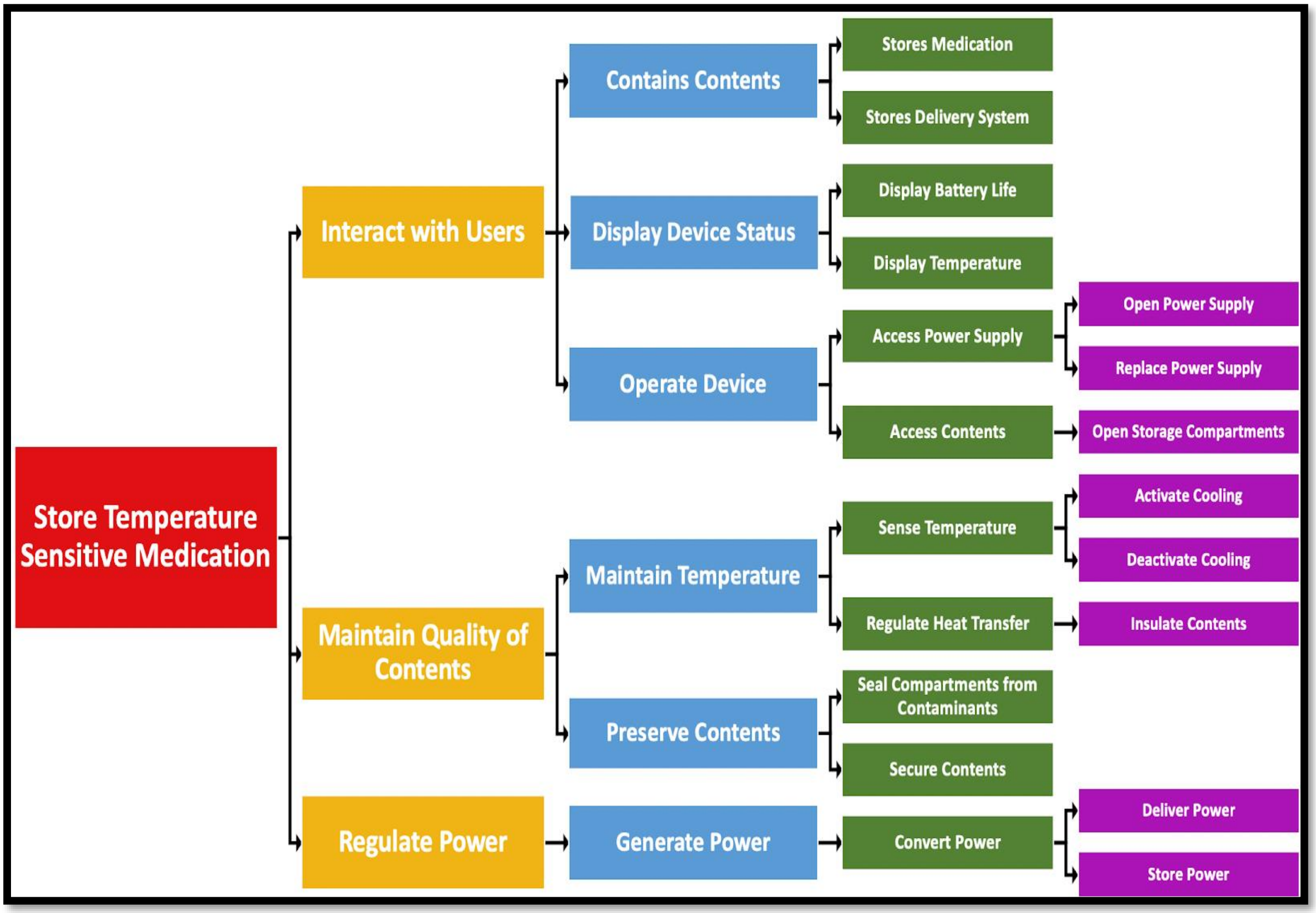

Figure 1: Functional Decomposition Hierarchy Chart

1.3.4 Discussion

The hierarchy chart begins with the ultimate function of the entire project which is storing temperature sensitive medication. This breaks down into the 3 main functions that are needed to achieve this goal: interact with the user, maintain quality of contents, and regulate power. Most importantly, the device must maintain the quality of its contents by not only maintaining the proper temperature but also by preserving the contents from other harmful actions such as outside forces and invading contaminants. To maintain temperature, the device must first sense the temperature inside the storage device, and then activate cooling if the contents have become too warm or deactivate cooling if the contents have become too cold. Further, the device must be able to regulate heat transfer in and out of the device which will be achieved by insulting the inside of the device. Secondly, the device must be able to interact with the user easily so that the user can access the stored contents, understand the status of the device, and operate the device as needed. The device needs to store the medication, but it is also important that the storage device stores delivery systems for the needed medication, such as syringes for the use of insulin. The user must also understand the status of the device so that the user is aware of the temperature that the interior is being maintained at as well as the power left on the device. This goes hand in hand with operating the device, because once the user realizes the power is running low, the user must be able to access the power supply and open it up or replace it as needed**.** On the same token, to properly operate the device, the user must be able to access the contents and compartments easily and quickly in the case of an emergency. This function could adversely affect the aforementioned functions of securing contents and sealing the device from outside contaminates, so it will be important for the team to brainstorm a solution that allows easy access while also effectively sealing off the outside environment and maintaining the durability of the device so that the contents are secured from outside forces. Lastly, the device must regulate power to ensure that all other functions that require power will operate properly. To regulate power, the device must first generate power from some external source, whether that be before the power grid has gone down or via other means that would not require the power grid. Once the power is obtained, it would need to be converted to a suitable form such that the functions on the device (such as displaying temperature, activate/deactivate cooling, etc.) receive the proper power input. Since the device is meant to work on its own power for extended periods of time, it needs to store that power in some way so that it can be delivered to the power-intensive systems and continue operating without an external source of power.

1.3.5 Cross Reference Chart

The cross-reference chart indicates which systems fulfill which of the fundamental functions needed to resolve the problem of the project. For our cross-reference chart, we chose thermal, power, and storage as our systems since all these systems are needed simultaneously to store temperature sensitive medication.

Table 2: Cross-Reference Chart

	Thermal System	**Power System**	**Storage System**
Store Medication			**X**
Store Delivery System			**X**
Display Battery Life		**X**	**X**
Display Temperature	**X**	**X**	**X**
Open Power Supply		**X**	**X**
Replace Power Supply		**X**	**X**

Open Storage Compartments			**X**
Activate Cooling	**X**	**X**	
Deactivate Cooling	**X**	**X**	
Insulate Contents	**X**		**X**
Seal Compartments from Contaminants			**X**
Secure Contents			**X**
Deliver Power	**X**	**X**	
Store Power		**X**	

1.3.6 Connection to Systems

With a general goal to develop a device that can store temperature sensitive medication at a cool temperature while also maintaining the integrity of the medications under harsh conditions, we narrowed down the required attributes of our design and came up with three main subsystems: a thermal system, a power system, and a storage system. While all three systems are integral aspects of our final design, review of the cross-reference chart shows the importance of each individual system in respect to our lowest level functions. The top priority of our design is the storage system, this is confirmed by the fact that 10 of our 14 lowest level functions require this system. For example, the storage system will satisfy our most basic function of storing medication, while also accomplishing a higher-level goal of maintaining quality through functions of securing and insulating contents, while sealing compartments from outside contaminants.

Another aspect of protecting medication, however, is regulating the compartment temperature while external power sources are not available. That leads us to the power system, which satisfies 8 of our lowest level functions including the basic functions of storing and delivering power to activate or deactivate cooling. The importance of the power system is intertwined with that of the thermal system, as it is also necessary to accomplish the task of activating/deactivating cooling. The thermal system will satisfy 5 of our lowest level functions, including accomplishing the function of insulation of the storage compartments which is necessary for maintaining a regulated temperature.

While we have made the assertion here that the priority system is storage followed by power and then thermal as shown by the number of functions requiring each system in the cross-reference chart, it is important to note that the project goal cannot be accomplished without the combined attributes of each system. Most of our lowest level functions, all but six, require the utilization of at least two of these subsystems, with one requiring all three. The successful implementation of all three systems, we believe, will satisfy our top-level functions of interacting with the user, maintaining quality of contents, and regulating power.

1.3.7 Smart Integration

From the cross-reference chart, there are three different systems that makeup the fundamental functions of our device. The thermal system includes coupled components that regulate the temperature inside the device. These components consist of temperature display, de/activating cooling, insulation, and power delivery. The power system involves functions that utilize any electricity from the power source. The storage system incorporates the functions that help store the temperature sensitive medication in the device. These contents include storing, delivering, sealing the device for environmental factors, and securing the medication so it sustains physical damage. The thermal system can complete its functions due to the power system being able to deliver the power needed for the thermal system to operate. The power and thermal systems can fulfill their roles due to the storage system putting them together in the device.

1.3.8 Action and Outcome

This device needs to receive, secure, and store medication while maintaining the constant appropriate temperature, allowing the user to have prolonged access to viable medication when conventional power options are unavailable. The device will open to allow the user to re-supply and receive their medication. The medication will be physically secured and protected from foreign contaminants, debris, and other forces. The user's surroundings may be subject to ash, dust, and flooding, so the device must be sufficiently sealed to preserve its contents. Different medications will require different temperatures, so the device must be capable of accommodating that range. The device will be able to read the current temperature of its contents and adjust its cooling solution to achieve and maintain the temperature set by the user. The device will feature an enclosed power supply that will maintain the systems without access to main power. These functions will be integrated into a compact and portable package, facilitating mobility during times of crisis and accessibility across a wide demographic of users.

1.4 Target Summary

1.4.1 Introduction to Targets and Metrics

Targets and metrics are used to quantify objectives of the functions we have come up with from functional decomposition. Targets are numerical values and units used to design around, while metrics are the methods that are proposed to validate functions. The targets and metrics allow us to quantify and validate the functions and give us a meaningful measure of how well our design is fulfilling our key goals. Our main key goal for our temperature sensitive medication storage are as follows: Maintain quality of the medication for 14 days with a power source that is not reliant on the main power grid. SI Units will be used for the generated targets.

1.4.2 Targets and Metrics Table

Table 3: Targets Catalog (Critical Targets Only)

Specific Function	Metric	Target
*Store Medication	*3 pens/vials of insulin stored	*Stores a 30-day supply of insulin
	*Internal volume	*0.001 - 0.005 m^3
	*External volume	*0.003 - 0.007 m^3
	Time it takes to open storage up	2 seconds
*Sense Temperature	*Number of days temperature is maintained for	*14 days
	*Read medication temperature (thermocouple)	*2°C to 8°C
*Secure Contents	*Number of pens/vials broken or damaged	*0
*Deliver Power	Volts, Amps, Watts (Multimeter)	12V, 6A, 60W (max)
	*Number of days power is delivered for	*14 days

Table 4: Targets and Metrics Beyond Functions

Description	Metric	Target
Weight of Device	Measure weight with a scale	< 10 lbs
Durability	Impact resistance from drop test	27 N
Operating Temperature	Measure temp. of device and surroundings from waste heat	< 45°C

1.4.3 Derivation and Validation of Critical Targets

Our critical targets are the targets that must be achieved to fulfill our project objective. In our case, our critical targets will be as follows: storage of a 30-day supply of medication, maintained temperature of medication between 2°C to 8°C for 14 days, continuous delivery of power for 14 days, and 0 broken contents. If at the bare minimum, all these targets are met, then our project objective will be fulfilled.

Our first critical target, storage of a 30-day supply of medicine, came directly from customer needs in which an interviewed insulin user told us that him and most insulin users only have a 30-day supply of insulin at any given moment. We came up with a measurement to accommodate this target, $0.001m^3$ to $0.005m^3$ for internal storage, based off the average size of insulin vials and pens. To validate this target, we can simply fit a 30-day supply of insulin into the device and confirm that the insulin can fit into the device and be removed without damage to the device or the insulin container.

Our next critical target, temperature maintained between 2°C to 8°C, came from research about temperature sensitive medication. We found that almost all temperature sensitive medication must be kept in this temperature range, but insulin can also be kept at higher temperatures if it is not being stored for longer than 28 days. By restricting the temperature range to 2°C to 8°C, we not only incorporate a factor of safety in our design temperature for insulin, but we also accommodate for other temperature sensitive medications that must remain in the 2°C to 8°C range. This way we can ensure that our largest market, insulin users, can be confident that our device will keep the proper temperature. This critical target also specifies that the temperature must be maintained for at least 14 days, which goes hand in hand with the third critical target: 14 days of continuous power delivery. Both these targets came from background research about mass power outages in the state of Florida. We researched published statistics from power companies and how long it takes to get most of the people's power back, which is where we arrived at the 14-day target. To validate this target, we will set the device up with its power source and allow it to run for 14 days without being touched. We will utilize a thermocouple to read the temperature of the medicine inside and routinely check on the device in 6 hour intervals to ensure the device is still running properly, and the medicine is still at the correct temperature. If we want to solely validate the temperature range target, we will perform the same test but have the device plugged into a power outlet to confirm the thermal system operates properly over our target time range, provided sufficient power is supplied.

Our last critical target is 0 broken contents. The derivation of this target was obvious, we do not want our device to be the reason that a user loses their insulin. To validate this target, we will have the device running and operating with the contents inside and carry it around the college of engineering to simulate how a user might transport the device. If none of the contents end up broken from the motion created by transporting the device, then our target will be met.

1.4.4 Derivation and Validation of Additional Targets

To create a general basis of comparison, the team researched many different personal coolers and their dimensions and specs and arrived at a theoretical benchmark cooler. This is how we derived our targets concerning the interior and exterior volume of the device. The exterior volume ($0.003m^3$ to $0.007m^3$) is an estimated range that most personal coolers come in, and the internal volume ($0.001m^3$ to $0.005m^3$) is that same range with an assumed internal thickness of about 0.002m on all sides to provide insulation. However, these numbers can be played with since we have a range to design from. This target will be tested by simply measuring all dimensions of the interior and exterior to ensure we have met our target range. We will also validate this target by storing the contents and then attempting to remove them to ensure the volume is sufficient. The benchmark cooler could also model the expected heat loss rate without the cooling system.

Knowing our target temperature range, we can approximate the power required to maintain those temperatures. Focusing on insulin, it has a density of $1090kg/m^3$, comparable to that of water. If we then assume it also shares a similar specific heat, we can find the amount of energy required to change the temperature by each degree Celsius. If our cooling cycle is set to 15 minutes, a typical 10 mL vial of insulin would require 50.97mW of power for each degree change. We can optimize our cooling time, and thus power consumed once we have finalized our cooling solution and begin testing.

The time required to access the power supply, as well as replace the power supply was derived through a group consensus. We all decided that replacing the power supply should take no longer than 10 seconds total to ensure ease of operation and an ergonomic design. We also decided on 2 seconds for accessing the contents so that the device is very easy to use and understand and the medicine can be accessed quickly in case of an emergency. All these time-based targets can be validated by allowing someone unfamiliar with the device to open and replace the power supply as well as open the storage compartment on our prototype and time them with a stopwatch.

The most important system in our device is the power system, and thus every target and metric must be thoroughly validated. This can be achieved using a measurement tool such as a multimeter. Since our entire device relies on maximizing what limited power is available, these tests are vital.

There were 3 targets we specified that did not come directly from our targets but needed to be quantified to ensure the device meets our key goals. These targets are as follows: weight of device, impact resistance, and operating temperature. We arrived at our operating temperature by researching what temperatures most batteries can operate at without hurting the batteries life span. We found that most batteries must stay below 45°C, while some can go a little higher. Since we have not decided on what power source we want to use, we decided to go with this operating temperature to allow for a wide array of power options. Our target for weight was decided by researching the weight of various personal coolers as well as thermoelectric cooler modules. Through research and brainstorming, we all converged on a target of 2.75kg for the device, which will be accommodating and easy to control for most people. Our impact resistance was derived from this weight target and agreeing that our device should withstand a drop from the height of a table. We then assumed a height of 1.5m and with our 2.75kg weight target, we arrived at an impact resistance of 27N. We can validate all three of these targets by using the same thermocouple used to measure the medicine temperature, using a digital weight scale, and by performing an impact test (although this test will only be done if we have 2 prototypes).

1.4.5 Discussion of Measurement

The most important measurement needed is temperature inside the device, so a simple thermocouple will be used. For electrical measurements, a multimeter device will be used for measuring voltage and current. To measure length, a simple tape measure will be used to dimension items needed for the device. For length measurements that require a high degree of accuracy, a Vernier digital caliper will be used. To check the volume required for the medication storage device, length measurement tools will be used to find the dimensions for general shapes. To validate our weight target, a digital weight scale will be used. We will also need a stopwatch to validate any targets having to do with time. Any targets requiring a force measurement will either be validated via an impact test (only a length and mass measurement required) or by using a force spring scale.

1.5 Concept Generation

1.5.1 Introduction to Concept Generation

For the final step in our design selection process, we will gather the data from everything we’ve done thus far to come up with 100 concepts for our design and narrow them down to a single design that best fulfills our objective of creating a storage device that stores and maintains the quality of temperature sensitive medication for 14 days. The data we have obtained thus far includes the needs from our customers, the fundamental functions from functional decomposition, and our targets and metrics which will all be the basis of our generated concepts.

1.5.2 Concept Generation Tools

Several different concept generation tools were used to develop our 100 concept designs for our device. We decided to use a morphological chart, which allowed us to generate a lot of different ideas, as well as the Crap Shoot method, the SCAMPER method, and biomimicry. Each method is broken down further in the subsequent sections.

i. Morphological Chart

For 50 of our ideas, we started with a morphological chart. We made the morphological chart by creating subcategories for different components and systems that will be needed to create our storage device. We then thought of potential solutions for these categories as a team and created the ideas by adding together different combinations of items from each column. This morphological chart created 81 ideas, but we only pulled 50 ideas from this method for the purpose of using other methods to give a larger variety of options. All things considered; the morphological approach helped the most with creating many realistic ideas but was not the best for discovering creative ideas like the other approaches were. Shown below in Table 5 is the morphological chart that was used to generate 50 of our concepts.

Table 5: Morphological Chart

Cooling System	Power System	Storage Container	Open Mechanism
Cold plate conductive Peltier module	Solar panel	Hard plastic cooler	Fully opening lid
Convective fan Peltier module	Battery	Soft fabric cooler	Partially opening lid for each medication
Tunnel series heat exchanger with conductive cold plate	Mechanically powered generator	Vacuum sealed cooler	Rubber flaps

ii. Crap Shoot Method

The Crap Shoot method allowed us to generate about 30 different design concepts. Group members got together and launched off a variety of different ideas for either the entire design or different systems. The decision to use the Crap Shoot method was to try and generate diverse design concepts and potentially stumble upon ideas that could be worth exploring. While this method did come up with the most outlandish concepts, it was helpful to think outside of the box and forget about the common methods for cooling that we are all already familiar with.

iii. SCAMPER Method

Our last 8 ideas were created by using SCAMPER which stands for Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, and Rearrange. We utilized this concept generation tool by taking from the ideas we have already generated and using one of the words in SCAMPER to create a new idea. We decided to only use substitute, modify, and combine to create the 8 ideas. All in all, SCAMPER generated some of our best ideas with all the ideas from this tool being feasible and creative (depending on already existing ideas we pulled from).

iv. Biomimicry

For our next couple ideas, we used the concept generation method biomimicry, which is defined as designing systems and processes based on biology. Although this thought process was entertaining, it only provided us with 6 ideas since we started running out of animals and biological entities that could be useful for regulating heat transfer. Altogether, biomimicry created some interesting ideas that were more creative and outside the box but not entirely feasible.

1.5.3 Medium and High-Fidelity Concepts

Concept 1.

High Fidelity

Conductive Peltier cold plate cooling system mounted to the side of a hard-plastic cooler (hot air blows out the side), powered by solar panel battery combination with partially opening lid to pull out individual contents and rubber flaps combination. Must be equipped with a cold plate adapter so medication can still lay flat. This idea came from a combination of utilizing a morphological chart and SCAMPER brainstorming techniques. We feel like the best cooling method available to us is the conductive Peltier plate due to the power consumption it uses, effectiveness of cooling, and affordability. Using a hard-plastic cooler as the storage system provides maximum durability and protection to the contents inside. To maintain cooling for the extended period we are aiming for, we have determined that a combination of rechargeable batteries attached to an external solar power is the best method of power. In addition, to maximize cooling effects and minimize wasted cooling power, the main storage compartment will have a lid that partially opens to provide access to individual contents. To further this, the openings will be fitted with rubber flaps to restrict air escaping.

Concept 2.

High Fidelity

Conductive tunnel heat sink cooling system powered by solar panel battery combination with partially opening lid and rubber flaps combination. The Tunnel Series heat exchangers utilizes convection to provide cooling, championing a design that pulls air through the heat exchanger to maximize heat transfer. This design is compact enough to be fitted with a standard hard-top plastic cooler but offers enough performance to achieve our cooling needs. To minimize power usage, medication will be stored in 3 individual slots with their own lid, and rubber (or another form of insulation) will separate the compartments to minimize heat lost during medicine retrieval.

Concept 3.

Medium Fidelity

Liquid heat exchanger that continuously pumps a low conductive fluid through a cold plate, powered by a solar panel and battery combination with a partially opening lid and a vacuum sealed container. This design was chosen as medium fidelity as it has the potential to cool the device very effectively with the caveat that liquid heat exchangers tend to be too large for such a compact design and they are pricey.

Concept 4.

Medium Fidelity

Convective fan Peltier cooling system powered by a battery solar panel combination, stored in a hard-plastic cooler with a partially opening lid. This design was chosen as medium fidelity as it is simple and cost effective. However, based on previous research in convective cooling might not be able to achieve as desirable of a cooling effect. In order to overcome this, it would require additional methods of cooling.

Concept 5.

Medium Fidelity

Combination of a liquid compressor heat exchanger to cool contents while the device is plugged into an external power source then switching to a cooling system that requires less power such as conductive Peltier plate to maintain function for longer period of time from solar panel. This medium fidelity design seeks to capitalize on the resources available before a power outage occurs. Using a liquid compressor heat exchanger will allow the device to cool itself quickly and effectively at these advantageous moments, and once power is lost, the system will transition to the less power-consuming Peltier cooling plate. To further extend the systems use time, a solar panel will be used to generate more power for the device. This design comes with the burden of increased financial cost utilizing two cooling solutions, when the compressor alone is already extremely expensive. In addition, this adds weight and bulk to a product we want to be compact and portable.

Concept 6.

Medium Fidelity

Conductive Peltier cold plate with attached cold plate adapter that has thin pieces of aluminum mesh meant to cover medication and increase contact area. Powered by battery and solar panel in a hard-plastic cooler with partially opening lid. This design was deemed medium fidelity as it contains some of the aspects already deemed to be of higher fidelity such as the Peltier plate, battery solar panel combo, and hard plastic cooler with partially opening lid. This design also includes the use of mesh aluminum to surround the contents to maximize the surface area directly in contact with a cooled material.

Concept 7.

High Fidelity

Conductive Peltier cold plate cooling system mounted to the side of a hard plastic cooler (hot air blows sideways), powered by solar panel and battery combination with fully opening lid and straps over the cooling plate to hold contents in place. This idea came from a combination of utilizing a morphological chart and SCAMPER brainstorming techniques. We feel like the best cooling method available to us is the conductive Peltier plate due to the power consumption it uses, effectiveness of cooling, and affordability. It will be attached to an extended metal plate laying horizontally with semi-cylindrical cutouts that allow for more surface contact between the medications and the plate. In addition, we will include straps to hold the medications in place. Using a hard-plastic cooler as the storage system provides maximum durability and protection to the contents inside. To maintain cooling for the extended period we are aiming for, we have determined that a combination of rechargeable batteries attached to an external solar power is the best method of power. We will be attaching a compartment to the underside of the cooler for the battery to be included in the main body of the design.

Concept 8.

Medium Fidelity

Conductive Peltier cold plate cooling system powered by external mechanical generator with partially opening lid to pull out individual contents and rubber flaps combination. This is a medium fidelity concept as portable generators are a great option already widely available during power outages and would meet our power requirements. However, it is not as portable and compact as some other design options.

1.6 Concept Selection

1.6.1 Concept Selection Tools

From all our concepts that were generated, we narrowed them down to 8 concepts of medium and high fidelities (listed in section 1.5.2). We used a more analytical approach to decide which of these 8 concepts was the best idea. To do this, we utilized House of Quality (HOQ), Pugh Chart, Binary Pairwise Comparison (BPC), and the Analytical Hierarchy Process (AHP). The HOQ and AHP were used to determine our most important engineering characteristics which will help us decide which idea is best based on how well it fulfills the most important requirements. A Pugh chart was used to compare our concepts with similar cooling methods to an outside competitor, and then with one of our own concepts, to decide which of our concepts were better. Then, the AHP was used to compare concepts that were promising as well as concepts that used different methods for cooling.

1.6.2 Binary Pairwise Comparison

The Binary Pairwise Comparison table can be seen in Appendix F as Table F.1.

Binary pairwise comparison (BPC) is used to create the important weight factor for the HOQ. Customer Requirements are used in this graph. Throughout the design process we have re-examined and refined these needs into the list shown below in our BPC chart. Appropriate temperature is a need stating that the device needs to cool to an effective temperature range as defined by our target (8°C to 10°C). Securing medication refers to ensuring the contents of the device are safe and preserved in means other than temperature, such as being restricted from movement inside the device or being crushed by outside force. Self-contained power means the source of power utilized is physically attached or contained within the device itself rather than being a separate entity. The need for portability requires a weaker individual be able to move the device around their home. The device must be able to store power to operate during a power outage, which is integral to the device's design. Ease of operation is a need to ensure that anyone who requires medication will be able to access the contents of their device without strain. Finally, displaying status allows the product user to ensure their device is the correct temperature and has sufficient battery life. Customer requirements represent both the columns and rows. In this process, the importance of a row is compared to a column. If a row is more important, a value of 1 is assigned, if not a value of 0 is assigned. The sum of a given row and the corresponding column is taken to verify the data of the table. The sum is equal to n-1, n being the number of customer requirements. Since the number of customer requirements for this project is 7, the sum must be 6, which it is. This proves that the binary chart is theoretically correct.

1.6.3 House of Quality

The House of Quality Chart can be seen in Appendix F as Table F.2.

The house of quality (HOQ) translates customer requirements into quantifiable data. Rows of the HOQ represents customer needs while engineering characteristics represents the columns. An exaggerated weight from 0 to 9 is used as follows.

0 - Blank (Not Important)

1- Weak (Relatively unimportantly)

3- Medium (Average Importance)

9- High (Very Important)

HOQ allows us to mathematically find the most important engineering characteristics of the design process so that when we compare concepts with each other, we will know which concepts best fulfill our most important customer needs. The results of our HOQ chart proved that access power supply was our most important engineering characteristic. The five other important engineering characteristics were to activate cooling, access contents, regulate power, insulate compartments, and cost. All six of these engineering characteristics have a relative weight greater than 10% so we will keep these throughout our concept selection process by using them in the Pugh chart and AHP. All other engineering characteristics will be removed as they have a relative weight less than 10%.

1.6.4 Pugh Chart

The Pugh Charts can be seen in Appendix F as Table F.3.

Pugh charts are a method of identifying the most promising concept from the alternatives. We took the most important engineering characteristics (found from

HOQ) and used these to evaluate our concepts. The concepts are benchmarked against a datum selected, based on engineering characteristics of the designs. The criteria are as follows.

+ : Better than the datum

S : Same as the concept

- : Weaker than the datum

To get a better result, a 2-step process is used. First, the 8 concepts selected were benchmarked against an outside competitor. The competitor that was selected for benchmarking was the HomeCare Portable Medicine Refrigerator, which is basically a small refrigerator meant for one insulin pen and can only be cooled by being plugged into a wall. It is powered by convection and has a hard-plastic cover without much insulation, but also has a screen and buttons to adjust temperature and settings.

From the initial comparison (Table F.3.1), it was found that concepts 1, 2, 6, and 7 all had the highest number of plusses in the chart. Concepts 3, 4, 5 and 8 had less plusses and more minuses, so they were removed for the second comparison. We used Concept 2 as the datum for the next Pugh chart as concept 2 was the only concept that made it to the next round and was not tied with the other three concepts.

After filtering out some concepts in the initial comparison, the concept with the least positives, and most negatives was eliminated, which was concept 6. The remaining concepts are concept 1 and 7. The results are shown in Table F.3.2.

1.6.5 Analytical Hierarchy Process

The AHP tables can be found in Appendix F as Tables F.4.

Each of the final 3 concepts were concepts 2, 5, and 7. Although concepts 1, 2, and 7 were shown to be the better concepts through the Pugh charts, we decided to use concept 5 instead of concept 1 so there would be more diversity when comparing concepts designs and therefore a more definite concept selection. All three concepts were compared using the weighted design criteria. Using the HOQ, the top six engineering characteristics were access power supply, activate cooling, regulate power, access contents, insulate compartments, and cost. These engineering characteristics were compared to each other to determine their respective weights which then became criteria for rating each of the three design concepts.

All three concepts were compared to each other with each of the top six engineering characteristics. During the AHP, consistency checks for each of the engineering characteristics were completed to ensure that each criteria was properly weighted to prove there was no bias introduced for any of the designs.

The final concept selection was reached by creating a criteria comparison matrix for the functions and then using the sums, we create a normalized matrix. The normalized matrix is used to find the criteria weight for each function. This process is used for all the functions. We then created design alternative matrices which we used to find normalized matrices of the three concepts that we chose. The normalized alternative concept matrices are used to form the final rating matrix.

1.6.6 Final Selection

The selection process using HOQ, Pugh Chart, and AHP determined that concept design 7 would be the best fit, as it maintained the highest overall performance amongst all the selection criterion.

Concept 7 was the hard-plastic cooler with a fully opening lid with a conductive Peltier plate module attached to the side. The cold plate from the Peltier module will be attached to an aluminum adapter that will clamp horizontally to a metal cold plate with semi-cylindrical grooves for medicine placement. In Figures 2-4, the Peltier plate module and adapter are shown in yellow. The fan compartment shown in red will be attached to the side of the cooler, and a fan (not shown in model) will be attached to the heat sink from the Peltier module. In addition to the grooved cold plate (shown in blue) we have decided to include 2 elastic straps to extend over the contents on the plate to keep the medicine in place. The design will be powered by a rechargeable lithium ion battery that will be placed inside the battery mount (shown in teal) at the bottom of the device. Further, a solar panel will be connected to the battery for maximum power longevity. Both power sources will work with a control system that detects the temperature inside the device and only uses power when the temperature range is not between 2°C and 8°C.

This design performed comparatively with high fidelity concept number 1 in the Pugh chart, both receiving four pluses, one minus, and one same. In comparison with high fidelity concept 1, a major difference in this design is the fully opening lid in comparison to the partially opening lid. We found the fully opening lid to be a more practical design for our application compared to a partially opening lid with compartments for a multitude of reasons. Primarily, we do not want to narrow our scope to be limiting to the type or size of medication that can be stored in our device. We want to accommodate for both insulin vials and insulin pens and having a partially opening lid that takes out the medicine without fully opening the device makes it difficult to accommodate for both. Additionally, keeping a generic lid simplifies the design and requires less modifications to the cooler shell. Less modifications means we lower the cost of the design, the time to build our prototype, and lower risk of leaks in insulation.

Furthermore, the AHP showed that concept 7 was determined to be better than concepts 2 and 5 in 4 of the 6 engineering characteristics that were used for evaluation. The four characteristics were access power supply, regulate power, access contents, and cost. These also happen to be our most vital characteristics to our design as the goal of our design is to be cost effective, accessible, and have enough power to last an extended period time as well as have a power supply that can be accessible to change if necessary. Overall, concept 7 came out on top in 4 out of 6 of the engineering characteristics and close to the top in the other 2. Improvements will be made to our design to ensure that it achieves its maximum capabilities in all of the engineering characteristics. Below are the CAD models for design concept 7.

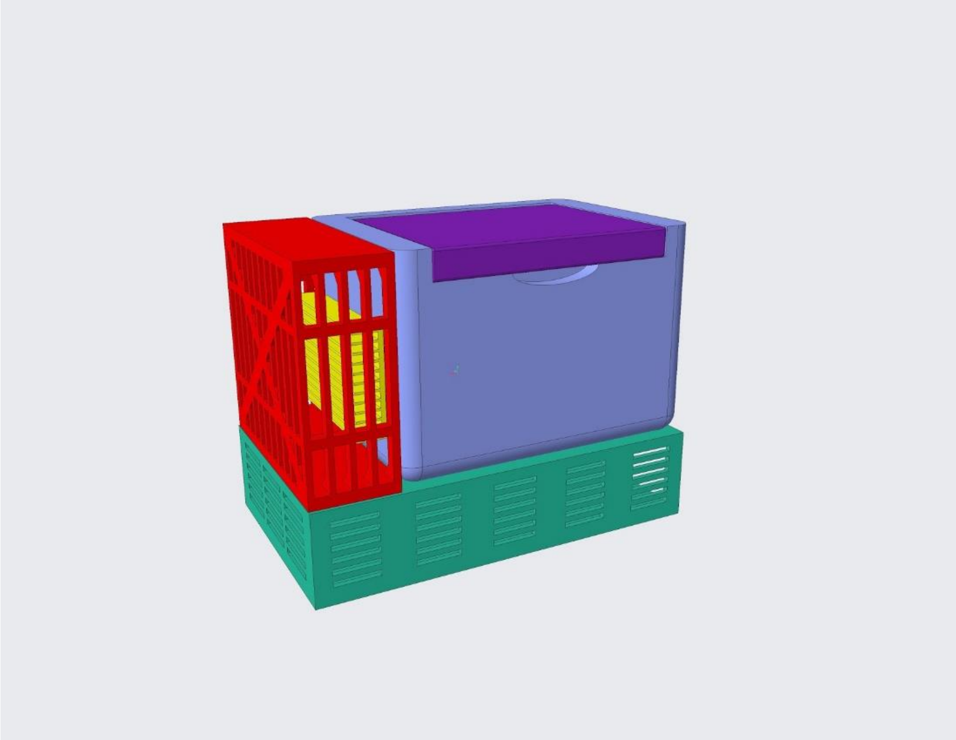

Figure 2: Concept 7 Assembly

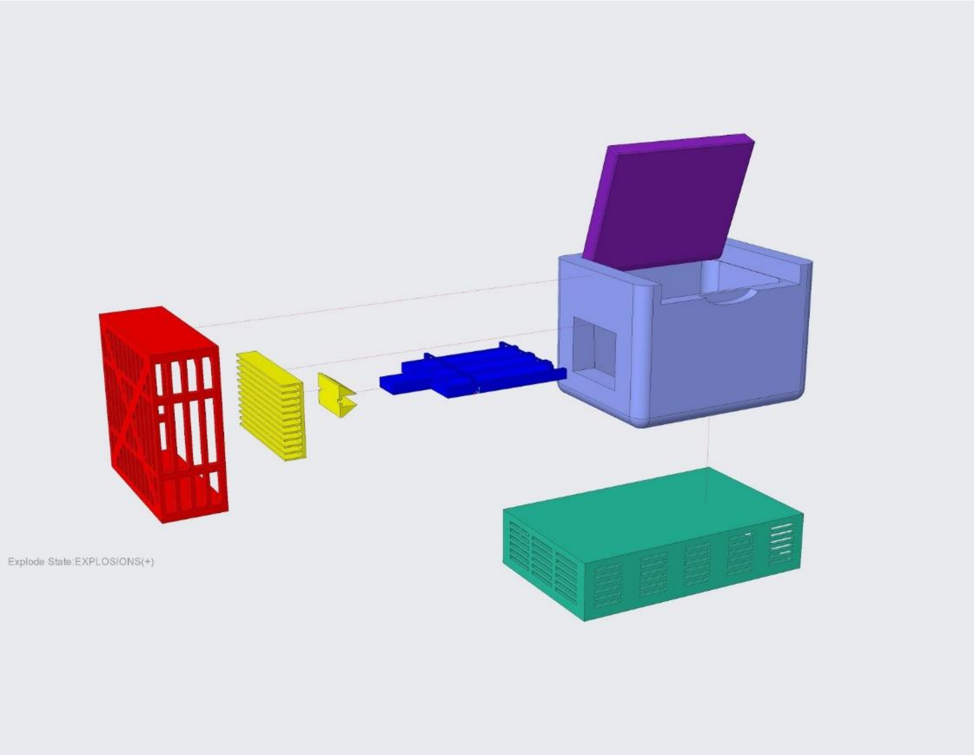

Figure 3: Exploded View of Concept 7

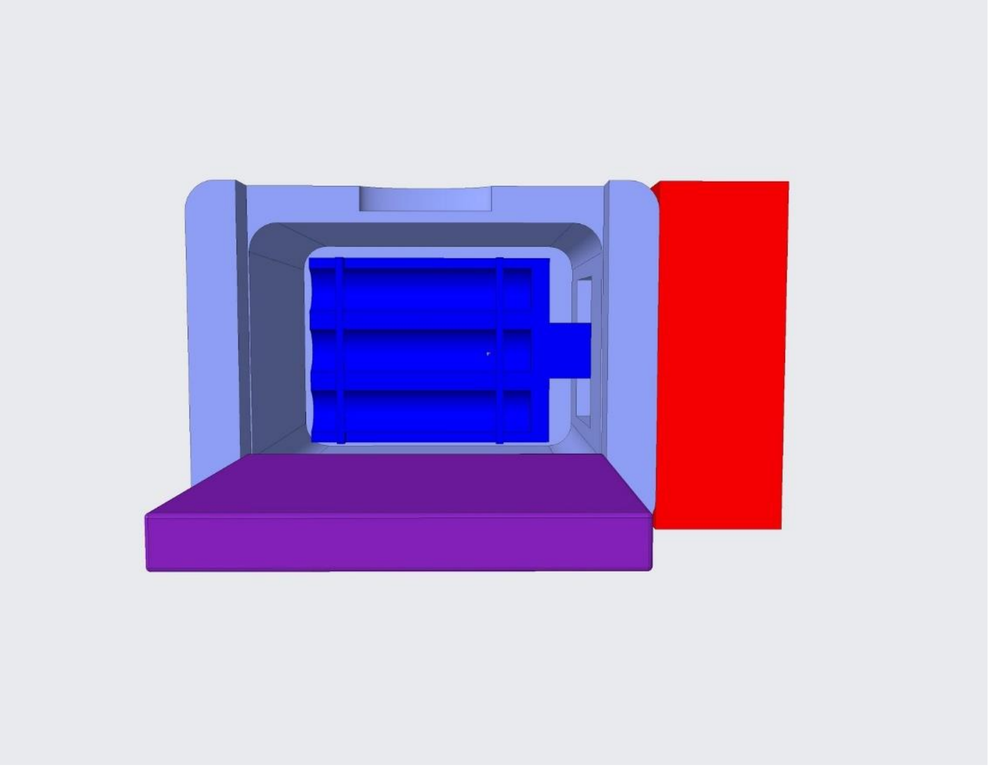

Figure 4: Top View of Concept 7

Chapter Two: EML 4552C

2.1 Restated Project Charter

2.3.1 Project Scope

The project is to develop a device that can store temperature sensitive medication in the event of a natural disaster where power outage is to occur. The device is to maintain a cool temperature for different medications, while also maintaining the integrity of the medications under harsh conditions.

2.3.2 Key Goals

Brainstorming all the possible conditions where this device could be utilized has led to a variety of key goals for the final design. The primary function of this product is to provide storage and power for cooling medication. Thus, optimizing power conservation and heat transfer are paramount to the success of this device. Furthermore, not all medications require the same temperature, so the device must be able to maintain a wide range of temperatures without sacrificing reliability.

Beyond the core functions of the device, the end user also needs consideration. The range of medications this device is intended to preserve means a diverse group of end users would use the device. The device needs to be simple enough for all users, accommodating weaker, older, or otherwise handicapped individuals. With this goal comes the contrasting challenge of durability and portability. The intended environment for this device is hazardous and unpredictable. There is potential for falling debris, extreme heat or cold, dust and ash, and flooding. Further, upholding durability would enable the device to be delivered by air drop, which is a common delivery method in hazardous conditions. It needs to be waterproof and robust enough to withstand those conditions without losing functionality, while maintaining a lightweight and compact design that can easily move with the individual and be carried by a drone if the customer chooses this delivery method. By upholding the device's durability and keeping its weight to a minimum, the device will protect and maintain the medication for a wide variety of deliveries.

Finally, the device needs to be widely accessible. The end users that are intended for this device are people who require temperature sensitive medication to live. Considering our end users already have the economic burden of affording their medication, the cost of the device needs to remain low. This compounds with the limitless damage natural disasters cause and the impoverished conditions that many people living in third world countries endure. The product needs to be low-cost enough for these extraordinarily burdened people to afford, or at least cost effective enough that non-profit disaster relief organizations can afford as many needed to keep people alive.

Summary of Key Goals:

- Conserve energy
- Optimize heat transfer
- Wide temperature range
- Ease of operation
- Durability
- Waterproof
- Reliability

- Portability/lightweight
- Cost efficiency

2.1.3 Market

The primary market is disaster relief organizations, the people responsible for providing care and supplies to those directly impacted by life threatening events. By providing a reliable temperature-controlled medication storage unit, these organizations will be able to provide support to individuals who require more care than just clean water and food and can bear the cost of supplying and maintaining the quality of their medicine for impoverished areas. Moreover, these organizations have the foresight to plan for supplies and services that the survivors will need, while affected peoples usually remain unprepared due to lack of funds or planning.

This leads us to our secondary markets which includes, most namely, the individuals with medical conditions that require lifesaving temperature sensitive medications. While we recognize that most individuals will not feel the need to emergency prep to such an extent, there is a portion of the population who do think ahead about what they would need when disaster strikes. Whether it is individuals who like to be prepared for all situations, or people with such dire need for their medication that they cannot risk going a few days without power, there is a percentage of the population that would purchase such a device directly. Additionally, drug manufacturers and distributors, big box stores, and pharmacies could all benefit. Drug manufacturers and distributors can offer these products in bundles with their medication, as they already target the intended primary market. This product could also be a staple at big box stores such as Walmart or Target, or any other pharmacy where it is a common stop for medication needs, especially during times of natural disaster.

2.1.4 Assumptions

Assumptions for this product begin with providing an efficient temperature control range for sensitive medications for a time such that a more permanent solution can be implemented after power is restored. The device will not be required to operate for more than 14 days. ~~sustain itself for a minimum of 3 days and we assume it will not be needed for any longer than 1 month of continuous use.~~ The device will be used indoors or under some sort of shelter and not submerged in water. ~~The device will operate at ambient conditions~~. Medication will be placed into the device at sufficient temperature and good quality. We will not be providing any medication or contents for the device. The batteries will be charged before the end user needs the product.

2.1.5 Stakeholders

Stakeholders for this project include our professor and project manager, Dr. McConomy, who oversees the educational objectives of this project. Our advisor, Dr. Devine, who is aiding the team in the Entrepreneurial aspect of our product, ensuring its viability in the market. Rob McDaniels, senior fellow for the Emergency Management and Homeland Security academic program, as a consultant regarding emergency response and preparedness to help us identify necessary components in our design and target appropriate markets. The InNOLEvation Team for investing their time and resources with their workshops and the overall competition to promote entrepreneurship and professional practice. Diabetic patients and anybody requiring such temperature-controlled medication using this device are directly dependent on its functionality and reliability during disasters. Red Cross and the World Health Organization (WHO) could be future stakeholders if the product is successful as they would be key distributors of this device to those in need.

2.2 Results

2.3.1 Data Collection and Analyzation

Testing early on in prototype development consisted of only relatively short-term tests such as the 30-minute temperature differential test. For this test, two thermistors from our temperature control switches were used, one on either end of the aluminum cold plate to record the temperature extremes and ensure the entire cold plate is within our target temperature range. It is important to note that while the temperature control switches were used to get temperature readings, the switch was not being used to turn the system in or off in our early tests. Data collection consisted of manually recording both temperatures every 30 seconds until test completion.

As we looked towards longer tests our data acquisition methods had to become more automated but remained consistent. Since the temperature of the system varied significantly over short time periods, it was extremely important to continue to record data in small regular intervals of 30 seconds. Previously, the temperature control switches were used during testing only to read temperatures, but in our long-term tests, the control switch was used to control the power system and enter power saving mode at 3.5°C. To accomplish this in our multi-hour tests we utilized two additional thermistors, both located in the exact middle of the aluminum cold plate for a total of four thermistors: one closest to the thermoelectric cooling module, one furthest, one in the middle, and another thermistor in the middle acting as the sensor for the control switch. The other 3 thermistors not attached to the temperature control switch were connected to a breadboard circuit and an Arduino that was running a code to take temperature readings at the front, middle, and back of the cold plate every 30 seconds. As previously stated, the control switch was set to turn off the Peltier plate at 3.5°C and turn back on at 8°C. This allowed us to observe temperatures across the cold plate for extended use and ensure that our device and control system performs optimally. Data analysis for each test consisted of plotting the temperature data against time to observe trends including cool down time, amount of time spent in power saving mode, and any instances where the device's temperature went out of range.

2.3.2 Data

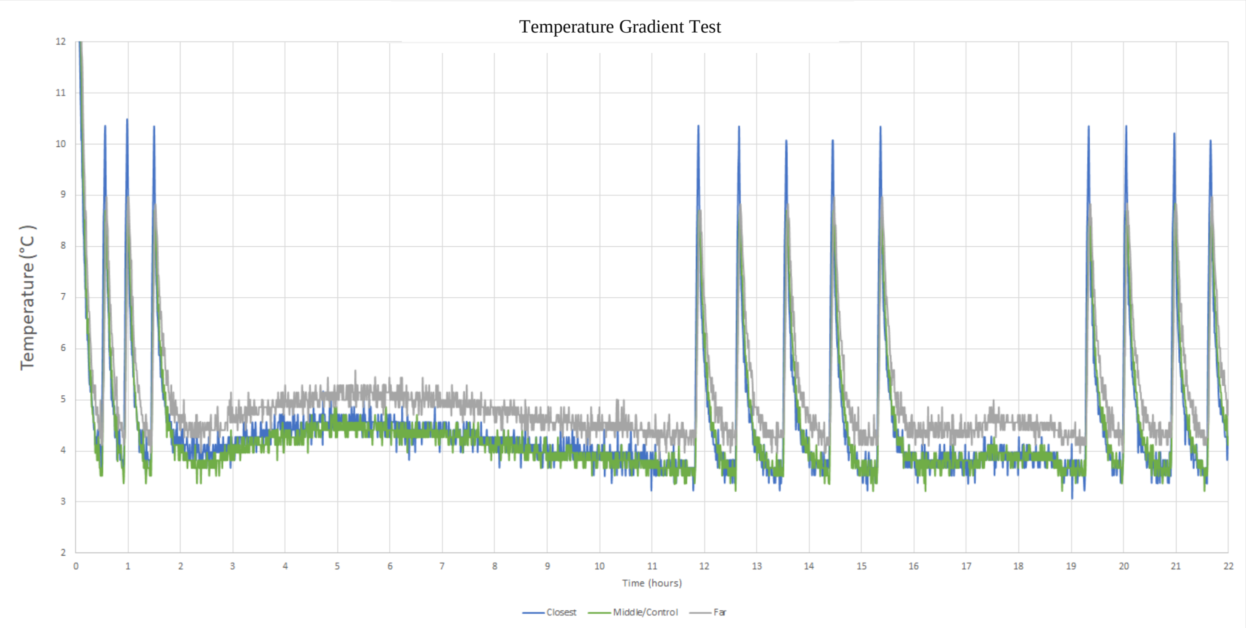

Figure 5: Temperature Gradient Test with old cold plate and buck converter

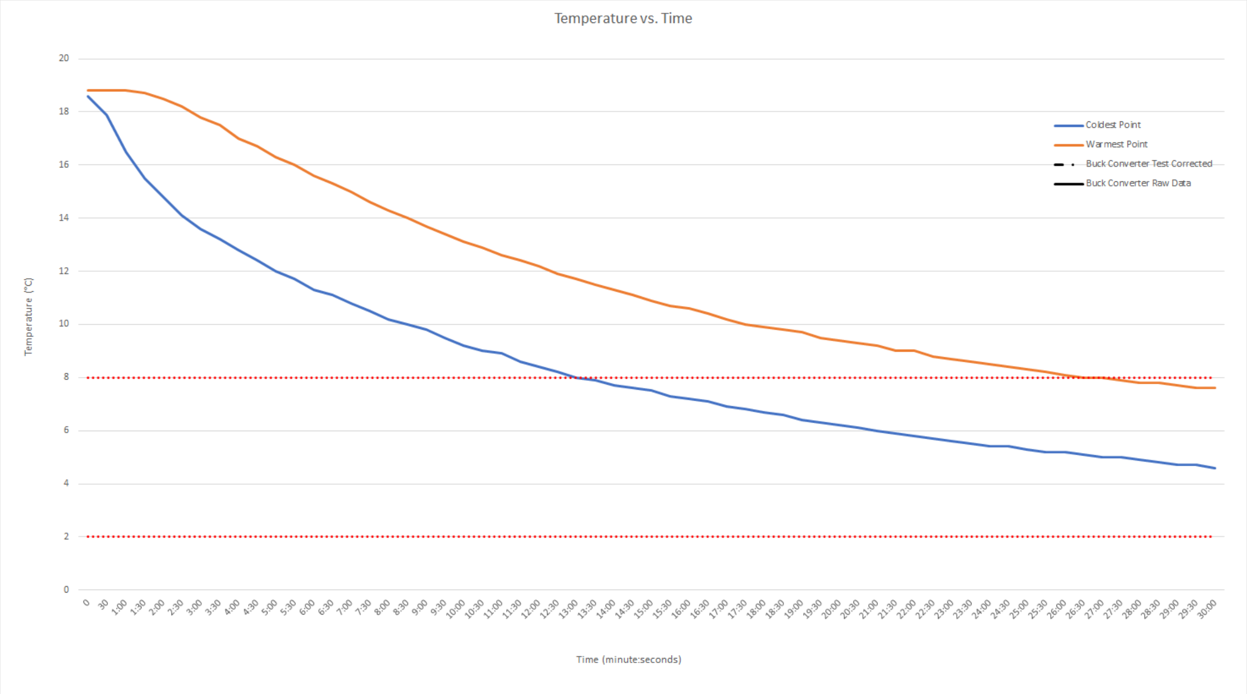

Figure 6: 22-hour test with small fan and buck converter

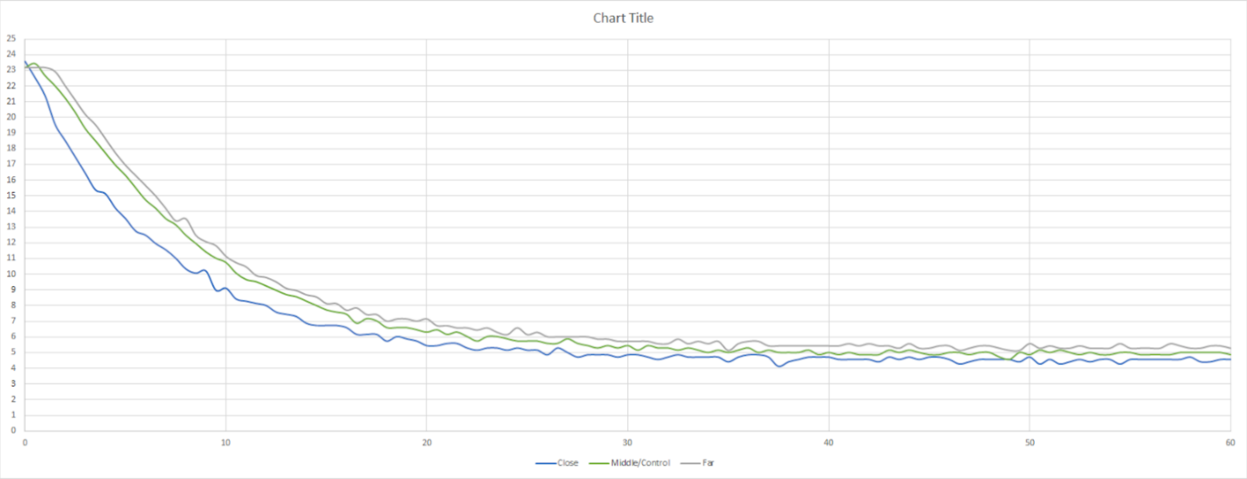

Figure 7: Test with big fan and buck converter

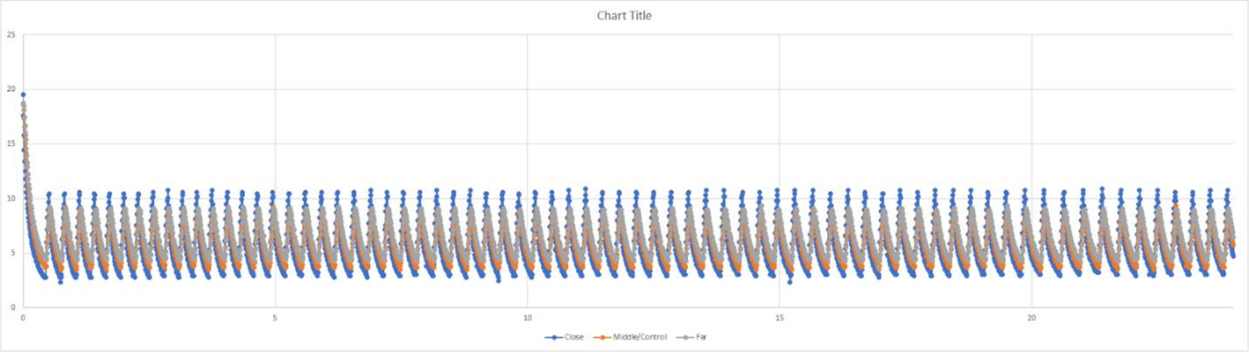

Figure 8: Long term test with small fan and no buck converter

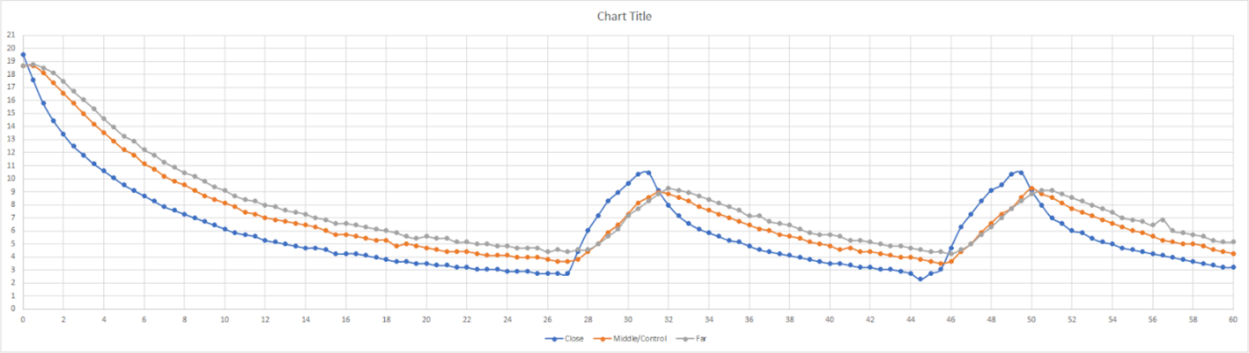

Figure 9: Test with small fan and no buck converter

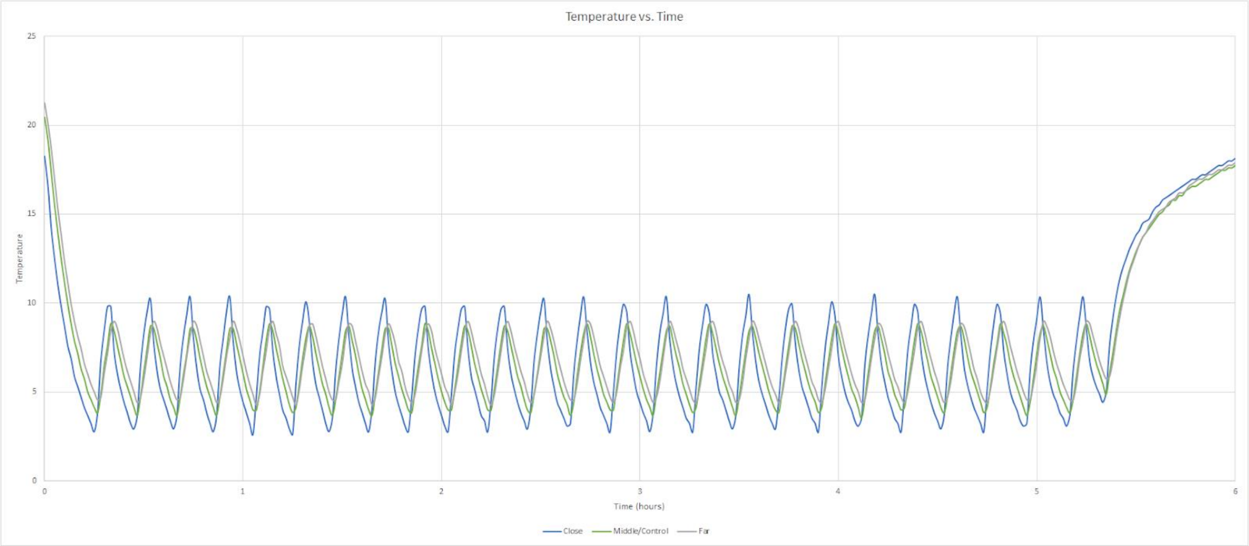

Figure 10: Test with single battery w/ small fan & no buck converter test

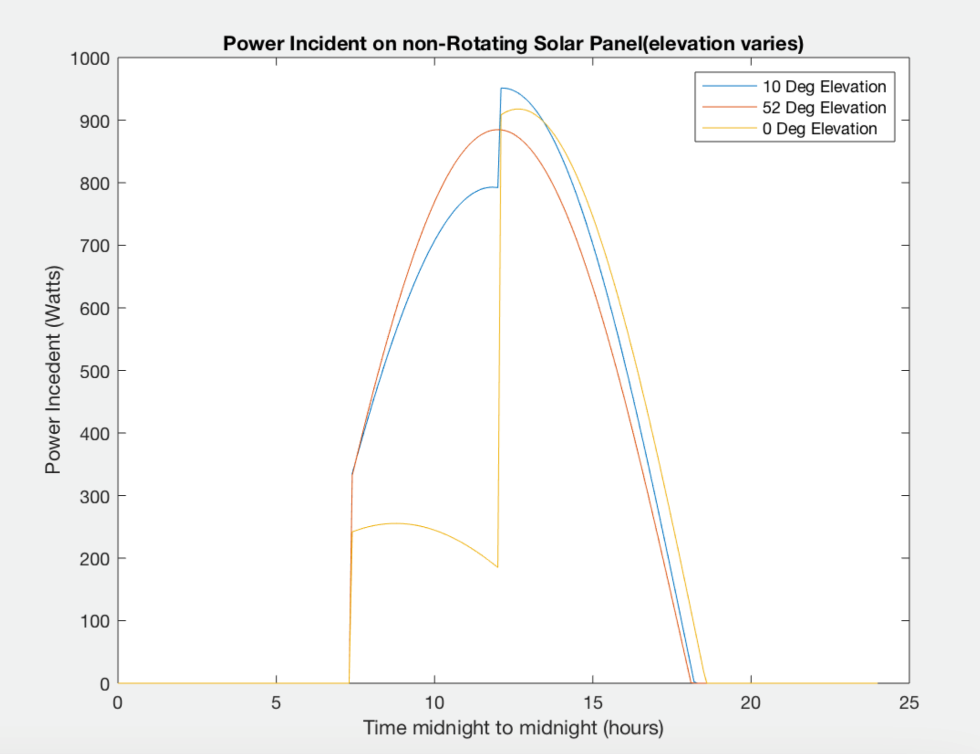

Figure 11: Power incident on solar panel during daylight hours

Found a solar panel at an elevation of 10 degrees could provide an average of 80 W to the system on a day in September.

2.3 Calculations

To determine the amount of power available via our solar panel in conditions like those that our device would encounter when in use, we completed theoretic calculations using earth-sun geometry for the month of September. These calculations include the following assumptions: the test day is September 13th, the location latitude is 30.44°N, the sun rises at 98.2° measured clockwise from North, there is a constant solar irradiance of 1000W/m^2, and the solar panel has an efficiency of 20%.

First, the declination angle is calculated for the specific day of the year and is defined as the angle between the sun-earth centerline and equator. This calculation is shown below.

$$\delta = 23.44 \sin\left[360\left(\frac{d-80}{365.25}\right)\right] \quad \text{degrees}$$

where del is the declination angle and d is the day of the year.

Next, we obtain the hour angle which describes the sun position at any given time throughout the day. The hour angle is calculated as

$$\alpha \equiv \frac{360}{24}(t-12)$$

where t is time in hours beginning at midnight.

Continuing, the zenith angle gives us the location of the sun between the local vertical and the line from the observer and is calculated by:

$$\cos\chi = \sin\delta\sin\lambda + \cos\delta\cos\lambda\cos\alpha$$

where del is the declination angle, lambda is the latitude of the observer, and alpha is the hour angle.

Finally, the solar azimuth is the sun's location measured clockwise from north and the equation is shown below.

$$\tan\xi = \frac{\sin\alpha}{\sin\lambda\cos\alpha - \cos\lambda\tan\delta}$$

These equations give a full picture of the location of the sun at any given time and can be used to calculate the percentage of solar irradiance directly incident on a panels surface using the following equation,

$$P = P_S[\cos\epsilon\cos\chi + \sin\epsilon\sin\chi\cos(\xi-\zeta)]$$

where P_s is the solar irradiance, 1000 W/m^2 at any given time.

2.4 Discussion

2.3.1 Temperature Gradient Test

The first test performed was to establish the temperature gradient that exists across our initial cold plate. As the plate is being cooled from one extreme end, the opposite end is expected to have higher temperatures. The device was receiving constant power from a local power supply. The results showed a 4°C temperature difference as the system was cooling down, which settled to a 3°C difference once the plate was within the temperature range. This gradient confirmed our cooling solution was viable since our targeted range is 2°C - 8°C, which has a 6°C difference. This test confirmed that a second TEC would not be required, and furthermore, that the placement of the TEC was sufficient for our purposes.

2.3.2 Cold Plate Redesign and Buck Converter

The second test implemented a buck converter and a new and slimmer cold plate design that incorporated the plate and adapter into a single piece. The reduced volume of the new cold plate directly translates to an increase in performance, as there is less physical material to cool.

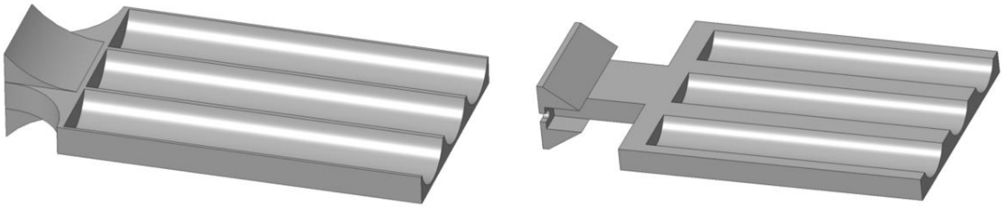

Figure 12: New cold plate (left) vs. old cold plate (right)

The buck converter was implemented to increase the current being delivered to the TEC. Doing this will decrease the time required to cool the system while not consuming additional power. This test was run for 22-hours to observe more long-term performance of the system. Temperature was monitored using the four thermistors described in the previous section, and the system was powered with a DC power supply.

Figure 13: Thermistor locations for long-term test

The combination of the new cold plate and buck converter cut the cooldown time to 12.5 minutes, which was twice as fast as the previous configuration. Once within range, the cold plate began a series of fluctuations between 3.5°C and 10.5°C as the TEC switched on and off. In between these fluctuations are long periods of relatively constant temperature. Although it stabilized within our target range during these times, the plate never reached our minimum temperature target and thus the TEC was constantly consuming max power and did not enter power saving mode periodically as we had hoped. Altogether, the system only entered power saving mode 12 times during the 22-hour test for approximately 7.5 minutes each. Our system was consuming max power over 93% of the test duration.

Additionally, the responses from the thermistors revealed unique temperature differences during the two distinct system responses. During periods of steady temperature, the thermistor furthest from the TEC had the higher temperatures, as anticipated. However, when the system was fluctuating, the thermistor closest to the TEC had the higher temperatures. There are two reasons for this behavior. First, the cut out made in the cooler for the cooling module was not properly sealed during this test, thus the thermistor closest to the TEC is subsequently closest to the unsealed portion of the cooler. The second reason compounds with this, and it is caused by the unexpected heat dissipation from the buck converter. Thermal imaging revealed the capacitors on the component reached over 90°C, and due to its close proximity to the heat sink, this heat would travel upward, back into our system. Accordingly, the closest sensor would be most impacted by this heat.

One final point of interest is that excess condensation built-up within the system by the end of the test, to the point where pools of water could be seen resting within the grooves of the cold plate. Improper sealing is the most prominent cause of this, but the cooler was also packed with 1” thick wool insulation in attempts to improve cooling. This material choice retained moisture, crumbled when adjusted, and had the potential to foster bacteria in an environment intended to be sterile. Wool was originally selected for its thermal properties, but its physical properties prove it to be ineffective and potentially detrimental for this system.

2.3.3 Large Fan Test

To offset the heat from the buck converter, a larger fan was swapped into our cooling system. This fan was large enough to cover the entire heatsink and overlap to cover the buck converter as well and cool both components simultaneously.

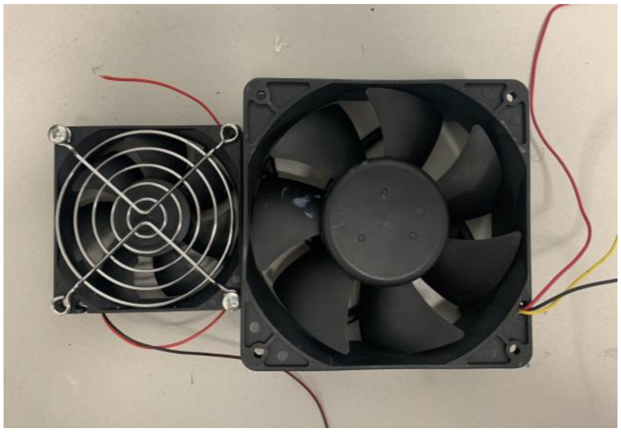

Figure 14: Small fan vs. big fan

This fan drew 0.6 A compared to the small fan's 0.2 A, but it was hypothesized that the increased air flow over the heatsink and electric components will improve cooling enough to offset the increased current draw. Further sealing was done prior to this test as well by adding spray foam insulation into all holes in the cooler.

The cooldown time was approximately 15 minutes and the system never entered power saving mode for the entire duration of the 27-hour test. This meant that the fan was consuming too much power, such that the TEC was unable to get the cold plate down to the minimum target temperature of 3.5°C and never entered power saving mode.

2.3.4 Small Fan without the Buck Converter

The unsatisfactory results with the large fan led the team to resort back to the small fan and experiment excluding the buck converter entirely. Running a test mirroring the previous test procedure, these changes resulted in a cooldown time of 12 minutes and the return of the periodic temperature fluctuations resulting from the Peltier plate turning off once the temperature control switch reaches 3.5°C. This meant the system was getting to the minimum target and entering power saving mode in regular intervals. Additionally, this test had no periods of constant temperature, affirming that the improvements made to the cold plate and sealing rendered the buck converter unnecessary. The test ran for about 25 hours and entered power saving mode 71 times for 7.5-minute intervals. This translates to nearly 9 hours with the TEC turned off and our system at max power consumption for 64.5% of the test.

2.3.5 Single Battery Test

The final test performed was targeted at establishing the practical operation time provided by one battery. Theoretical calculations suggested that the system consumed 43,425 mAh of power over a 22-hour period, whereas our dual battery system supplied 23,680 mAh of power. This means that our theoretical operation time was 13 hours, or 6.5 hours per battery. These calculations exclude any potential recharging from the solar panel.

After completing this single battery test, the system ran for 5 hours and 20 minutes, with a cooldown time of 10 minutes. This test was performed in the controlled environment of the Senior Design Lab at constant room temperature, which is considered ideal conditions for this device. Even in this environment, both batteries would only last approximately 10 hours and 40 minutes.

2.3.6 Solar Panel

The solar panel was included in the design to prolong device operation. Preliminary calculations found that it required 8 hours of constant sunlight to recharge one battery.

Even in the unlikely situation where sunlight was constant and unobstructed, this current configuration would result in 3 hours of no power before another battery was fully recharged. This excludes factors such as cloud cover, dust settlement on the solar panel, and night fall. To reach our target operation time of 14 days, the team needs to consider expanding the battery supply, the solar panel count, and improve the cooler insulation to prolong the time the TEC stays in power saving mode.

2.3.7 Packaging

One of our main priorities of this project was to package the device sch that is all held together as one cohesive unit. Shown below in Figure 14, is an updated model of our CAD model (concept 7) and the actual assembly of the device. We were able to 3D print battery compartments and electrical equipment compartments and mount everything to the main body of the cooler. Wiring was a bit exposed on the outside of the cooler but that is something that can be accounted for in the future if the device were to be redesigned and manufactured.

Figure 15: Updated CAD model (left) and the actual assembly (right)

2.5 Conclusions

In conclusion, our device was able to achieve most of the benchmarks required to successfully prevent diabetes related deaths connected to natural disasters. The first goal required the device to reach the targeted temperature ranging from 2°C and 8°C. We were able to fulfill this goal with a temperature gradient test along our cold plate. The results proved that our cooling system was viable. Moving forward, we faced many challenges attempting to reach our second goal, which requires the device to maintain power for 14 days. The biggest problem encountered throughout the project was optimizing power consumption throughout the equipment. In most of our tests the TEC module was consuming max power, causing the system to never enter the minimum temperature target, which allows the system to enter power saving mode. After performing a single battery test, it was found that one battery would last for 5 hours and 20 minutes. Utilizing both batteries only lasted 10 hours and 40 minutes, which is not sufficient to fulfill an operation time of 14 days. The third goal required the device to be portable enough so the user can travel as needed. We were able to achieve this goal by packaging all our components onto a standard 5-quart cooler. Lastly, our team was able to secure the contents inside the device by utilizing a fabricated cold plate and a Velcro strap.

After completing the project, we learned several significant lessons. We encountered our first problem while using the temperature control switch during a long-term test. During testing the temperature control switch would easily break, causing a delay in testing our device throughout the semester. In addition, temperature readings would differ approximately around 1°C-2°C. Since we are dealing with temperature sensitive medication, it is critical for the equipment to achieve accurate temperature readings. Next, it goes without saying that we should have begun prototyping much earlier. Our original cad was over-simplified, and tunnel visioned on our cooling method. Not enough attention was given to the supplemental components that make the entire device function, which includes wiring and other extra CAD components. Our next lesson learned was that we needed a better method to collect data for our tests. While performing our long-term tests we ended up losing critical data due to computers malfunctioning. In the future we need a more secure way to acquire data so that this problem does not occur. Lastly, we encountered problems with the buck converter when performing tests. During testing the buck converter would overheat causing the system to never enter power saving mode. We also learned that the buck converter did not improve the overall system performance.

2.6 Future Work

There are several steps that can be taken to improve upon our current design and completely satisfy our goal of providing temperature regulation for 14 days. The most notable being continued research and testing on the solar panel-battery combination. First, the current battery selection should be reconsidered now that there is sufficient information on the cooler’s power requirements. At minimum, the batteries should be able to maintain cooling throughout a full night as this time is guaranteed to lack power from the solar panel. Based on current testing the two batteries will only supply power for up to ten hours. We suggest addition of two more batteries so that at any given time there is almost a full day of power available. Another approach would be determining a battery option that provides more power while maintaining the portability of the cooler, however the size restriction makes this a more complex.

Additional testing needs to be completed to analyze the solar panel's capabilities regardless of the battery decision. This testing needs to be completed during hurricane season, late summer to early fall, to gain accurate insight into conditions for which this device is being designed for. It would be interesting to approach the solar panel testing via two different methods. First, power the cooler solely by the batteries only utilizing the solar panel to charge the batteries when they run out of power. This approach simplifies the overall design minimizing the additional components it requires to complete the wiring. However, it also creates limitations as batteries will be draining during the day while solar power is readily available. For this reason, it will be beneficial to also test a configuration where the solar panel is directly powering the device during the day and supplying power to charge the batteries so that they can be fully charged for nighttime power.

In addition to further testing on the power system, the device could benefit from slight design modifications. First, as discussed as a lesson learned the wool insulation should be replaced with foam or equally water resistant and durable insulation. Additionally, the prototype was created out of a generic hard foam cooler for simplicity's sake. When designing for scaled production, it would be beneficial to minimize the cooler housing size so that the thermoelectric cooler has a smaller volume to keep cool.

Finally, an issue the most detrimental to the project was the lack of consideration for component heat generation while running the device for extended periods of time. Further testing is needed on methods to alleviate heat from the heat sink attached to the thermoelectric cooler so that less heat dissipates back into the system during power saving mode.

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Appendices

Appendix A: Code of Conduct

Mission Statement

Team 523 aspires to work and communicate efficiently as a team to get all deliverables and assignments done properly and professionally while also treating every group member with respect and giving every group member's ideas and opinions equal consideration.

Team Roles

Project Manager and Research Engineer – Travis Amaral

The project manager's main objective is to ensure the team assignments are completed to the best of their ability and in a timely manner. Along with overseeing the well-being of the team and keeping records, the project manager is also the lead communicator with advisors and all relevant faculty. The role of the research engineer is to research, source, and distribute relevant information to team members.

Systems Integration Engineer – Zoe Dillehay

The systems integration engineer is responsible for ensuring compatible integration of mechanical and electrical components without compromising the needs of the customer and objectives of the project.

Design Engineer – Nick Georgevich

The design engineer is responsible for the design of all housing for components to ensure a cohesive, accessible, and functional product. He is responsible for minimizing cost of production and assembly without compromising structural integrity and functionality of product.

Entrepreneurial Leader and Research Engineer – Keon Glass

The entrepreneurial leader/research engineer is tasked with creating and analyzing a commercialization plan for our product, along with researching relevant information for the entire project.

Electrical Engineer – Diego Mendoza

The electrical engineer's main role will be to analyze and develop a power system that will be able to generate and store enough power to complete the task.

Quality Control Engineer – Andrew Sayers

The quality control engineer is responsible for ensuring that the quality of the design meets target metrics and that the product is easy to use, durable, and can be used in all anticipated environments. Most importantly, ensure the product effectively maintains the quality of the medicine inside.

Note: Not one individual is responsible for doing all the work on a system or topic alone, everyone is responsible for everything. Team roles indicate who is the go-to person to answer questions on such topics/systems. All team members must have a firm understanding on the project. Team roles can be changed and morphed throughout the project.

Communication

All vital information pertaining to the project will be recorded in Basecamp. Primary communication should be done either through email or the GroupMe chat created. Team members are expected to respond to any forms of communication from group members within the allocated amount of time:

- During business hours (M-F 9am - 8pm) members must respond at a maximum of within 6 hours, preferably earlier.

- Outside of business hours group members must respond within 12 hours.

Phone numbers as well as primary and secondary emails for group members are as follows:

- Travis Amaral
    - email: travisjamaral@gmail.com, tja16@my.fsu.edu, phone: (646) 734-0137
- Zoe Dillehay
    - email: zoedillehay@gmail.com, zcd15@my.fsu.edu, phone: (407) 592-0313
- Nick Georgevich
    - email: ndgeorgevich@gmail.com, ndg14b@my.fsu.edu, phone: (727) 410-3717
- Keon Glass
    - email: glasskeon@gmail.com, keon1.glass@famu.edu, phone: (850) 443-2507
- Diego Mendoza
    - email: diego.mendozaa414@gmail.com, dm17b@my.fsu.edu, phone: (973) 902-

      3837
- Andrew Sayers
    - email: asayers3@verizon.net, aes17d@my.fsu.edu, phone: (813) 428-3112

Work Schedule & Meeting Times

Tuesdays and Thursdays will be definite meeting times during the scheduled time block for Senior Design. Friday meeting time will be between 1:00 PM and 4:00 PM. Monday’s and Wednesday’s meeting time will be between 6:30 PM and 8:00 PM. Weekend meetings will be scheduled as needed.

Note: These meeting times reflect availability in our schedules, and they can be adjusted, as *necessary. Meetings are also able to surpass allotted time if necessary.*

Dress Code

Wear whatever you want, its Zoom. For presentation dress business casual. Guys will wear suit and tie with white buttoned-down shirt underneath. Ladies will wear blouse and or/ a suit. Team members must be clean cut and look professional on days of presentations.

Attendance Policy

Team members are expected to be present for every scheduled meeting.

Should an event arise, the Project Manager should be informed at least 24 hours before the scheduled meeting time. During the time at which an urgent event occurs within 24 hours of a meeting, Project Manager should still be informed, and a separate, smaller—not all group members need to be present—meeting should be held to bring conflicted parties up to speed with current tasks.

In addition, for impromptu meetings, at least most group members (4) should be present.

All team members should record their own notes for every meeting that includes the date, time, and the members who attended that meeting. Project Manager will keep attendance based on notes and keep record on an Excel Spreadsheet. The spreadsheet will be used in conjunction with meeting notes to account for attendance of meetings.

Conflict Resolution

Minor conflicts (between two members) should attempt resolution independent of the entire group. Should a resolution not be found between the two in conflict, the conflict will pass to the entire team. Major conflicts (involving 3 or more members) should be brought to the attention of the entire team and a full team meeting should be scheduled to address the issue. Documentation needs to be provided describing the conflict for record keeping and points of reference during the discussion. Should a resolution not be found during a group meeting, the conflict shall then be brought to the attention of Dr. Shayne McConomy to further assess the situation and aid in resolving the conflict.

Decision Making

All major decisions made about the project should have a 5-1 ruling for the decision to be accepted. In the case that anything other than a 5-1 ruling occurs, there should be more discussion to meet a common ground, compromise, or convince other group members to change their vote. If the vote is still not 5-1, the idea should be brought to the advisor (Dr. Shayne McConomy) for further advice. If a non 5-1 vote persists, Dr. McConomy's vote wins over.

Team Rules

No final draft of any assignment will be submitted by any member without each team member having the opportunity to review the final product.

Each team member should take notes during all meetings, the minimum requirement being recording group attendance (in conjunction with the excel attendance record).

Earnings

If the team wins any money from the success of this project through any means, the money should be split evenly (6 ways) such that all team members get equal amounts. In the event that a team member is undeserving of the prize money due to lack of participation, effort, communication, or attendance (provided that the proper documentation displaying their absence in meetings, lack of communication, and/or lack of participation in the needed tasks is shown) then that team member shall first be warned that they are in jeopardy of not receiving their portion of the prize money. If the same behavior still persists, then that team member shall not receive their portion of the prize money, if and only if, all other group members and Dr. McConomy agrees that the accused group member did not contribute enough to the group's success to warrant receiving any money.

Amendments

If an amendment is deemed necessary, all team members must be present and in accordance with the change. A vote of (6/6) is required to amend the Code of Conduct.

Statement of Understanding

All team members agree to have read and understood the contents of the Code of Conduct, and verify this by signing and dating below:

DocuSigned by:
Travis Amaral: Travis Amaral Date: 9/10/2020
7151D81CEC0A417...

DocuSigned by:
Zoe Dillehay: Date: 9/10/2020
1964A0055A0E45D...

DocuSigned by:
Nick Georgevich: Nicholas Georgevich Date: 9/10/2020
5EC44571674746E...

DocuSigned by:
Keon Glass: Keon Glass Date: 9/10/2020
CC919AD2BECF40F...

DocuSigned by:
Diego Mendoza: Diego Mendoza Date: 9/10/2020
D5B7EC27E85A4BD...

DocuSigned by:
Andrew Sayers: Andrew Sayers Date: 9/10/2020
BEC0D56A1EEE428...

Appendix B: Functional Decomposition

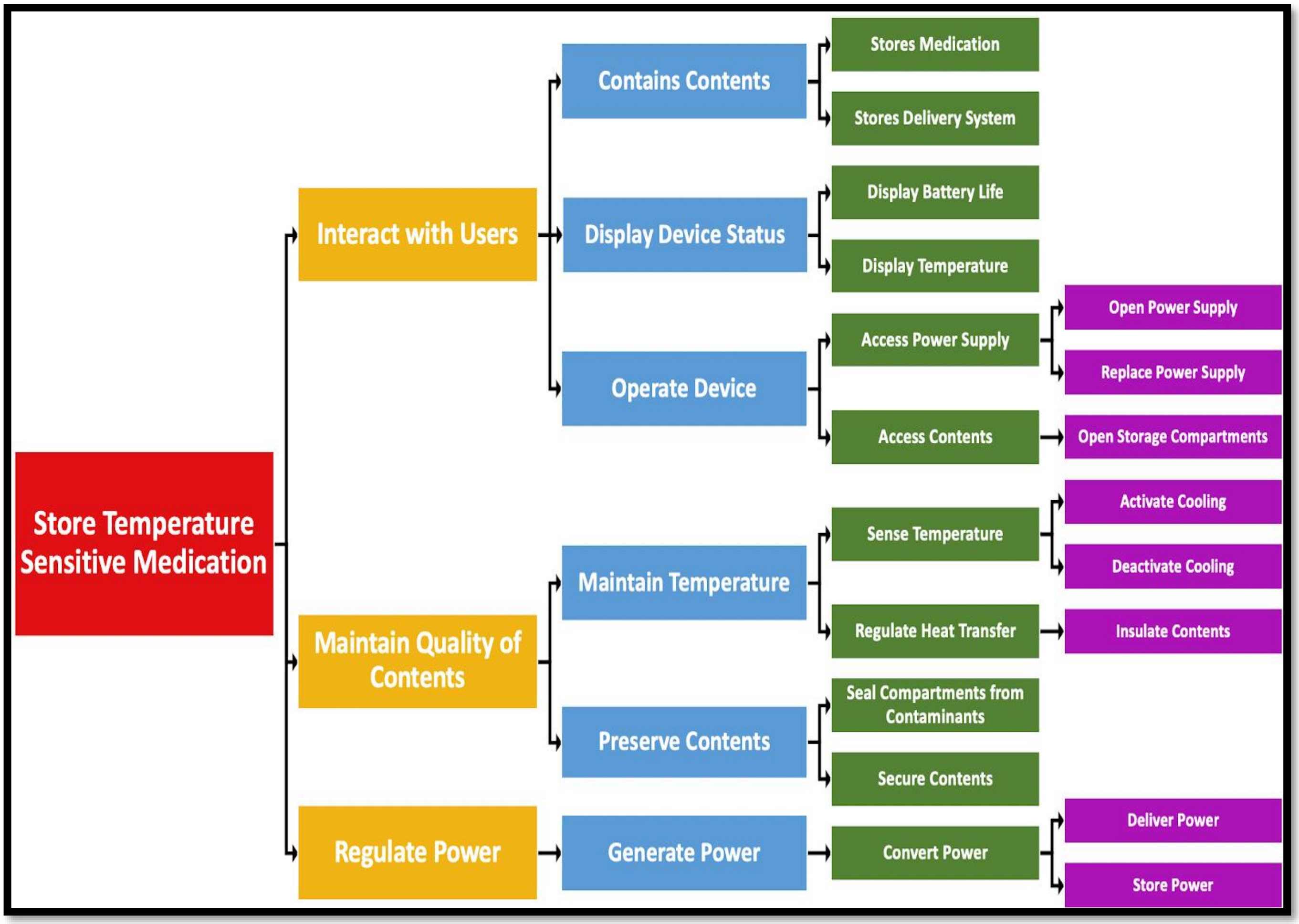


Figure 1: Hierarchy Chart

	Thermal System	Power System	Storage System
Store Medication			X
Store Delivery System			X
Display Battery Life		X	X
Display Temperature	X	X	X
Open Power Supply		X	X
Replace Power Supply		X	X

Open Storage Compartments			X
Activate Cooling	X	X	
Deactivate Cooling	X	X	
Insulate Contents	X		X
Seal Compartments from Contaminants			X
Secure Contents			X
Deliver Power	X	X	
Store Power		X	

Table 2: Cross-Reference Chart

Appendix C: Target Catalog

Table 3: Targets Catalog

Specific Function	Metric	Target
*Store Medication	*3 pens/vials of insulin stored	*Stores a 30-day supply of insulin
	*Internal volume	*0.001 - 0.005 m^3
	*External volume	*0.003 - 0.007 m^3
Store Delivery System	Number of syringes stored	≥ 1 syringe
Display Battery Life	Alert user when power is low (10% of power or less)	Yes
Display Temperature	Alerts user when storage is not between 2-8°C	Yes
Open Power Supply	Time it takes to locate and open power supply	3 seconds
Replace Power Supply	Time it takes to replace power supply	7 seconds
Open Storage Components	Force required to open storage	< 2N
	Time it takes to open storage up	2 seconds
*Sense Temperature	*Number of days temperature is maintained for	*14 days
	*Read medication temperature (thermocouple)	*2°C to 8°C
Activate Cooling	Total time for cooling system to reach target range (stopwatch)	≤ 15 minutes
	Cooling rate, power required per degree change	50.97 m·W/°C
	Cooling system activates when temperature exceeds target range (On/Off)	On
Deactivate Cooling	Cooling system deactivates when target range is achieved (On/Off)	On

Insulate Components	Net heat transfer rate going into and out of medication compartment	$\Delta\dot{Q} = 0W$
Seal Compartments from Contaminants	Number of pens/vials contaminated	0
*Secure Contents	*Number of pens/vials broken or damaged	*0
*Deliver Power	Volts, Amps, Watts (Multimeter)	12V, 6A, 60W (max)
	*Number of days power is delivered for	*14 days
Store Power	Watt-hour	~240 W·h

Table 4: Targets and Metrics Beyond Functions

Description	Metric	Target
Weight of Device	Measure weight with a scale	10 lbs.
Durability	Impact resistance from drop test	27 N
Operating Temperature	Measure temp. of device and surroundings from waste heat	< 45°C

Appendix D: Operations Manual

Project Overview

Our team is designing a portable cooling solution that preserves temperature-sensitive medicine without relying on grid power, named Medi-Kool. Natural disasters such as hurricanes devastate parts of the world every year and can disable power for weeks at a time. These power outages leave survivors desperate for food and shelter without access to critically needed medications. The lack of proper cooling for temperature sensitive medication after these storms causes hundreds of otherwise preventable deaths. People whose entire livelihoods are already at risk should not be in fear of losing their lives as well.

Our design consists of a 5-quart cooler with a thermoelectric cold plate powered by two batteries in conjunction with a solar panel. Employing two batteries will allow the device to operate for a minimum of 14 days, which is the average time for power restoration after a natural disaster. The solar panel will be able to charge one of the batteries that is not being used if power has not been restored within the expected time. The cooler is big enough so that the storage space will hold our fabricated cold plate, additional insulation, and three insulin pens/vials at once--the average prescription a user will have available at one time. A hook and loop Velcro strap will secure the pens in the grooves cut into the cold plate, holding them in the ideal position for cooling. The cold plate will keep the temperature between 2 to 8 degrees Celsius (35 to 46 degrees Fahrenheit). This temperature range can preserve several different medications other than insulin, such as various vaccines, glaucoma eye drops, and more.

This product can save countless lives. It will protect their medicine when nothing else can and provide invaluable relief to those who need it most.

Component/Module Description

Medi-Kool will consist of three important functionalities: store medication, sense and maintain temperature, and generate as well as store power. The main component of the device is a 5-quart hard plastic cooler. This serves to hold and secure the medication, along with providing a good starting point for maintaining temperature. The cooler utilized for our prototype can be seen in figure 1 below:

Figure 1: 5-qt. Personal Plastic Cooler

The interior dimensions for the cooler are roughly 8.5” x 6.5” x 6” and the exterior dimensions are 10.125’’ x 7.5” x 7.3125”, allowing it to be exceedingly portable. Additional insulation was added to the inside of the cooler wall to enhance its ability to maintain temperature. The insulation used for the device was Mineral Wool High Temperature Insulation.

Mounted to the front and back sides of the cooler are 3D printed battery storage compartments. These compartments are screwed into the cooler and are used to provide an accessible storage spot for the batteries. Another 3D printed storage compartment was created to hold other relevant electronics, like the temperature sensors and buck converter, and that is also mounted on the side of the cooler. Also mounted to the cooler is another 3D printed storage compartment to hold the solar panel. These compartments are shown in figures 2, 3, and 4 below.

Figure 2: Battery Storage Compartment

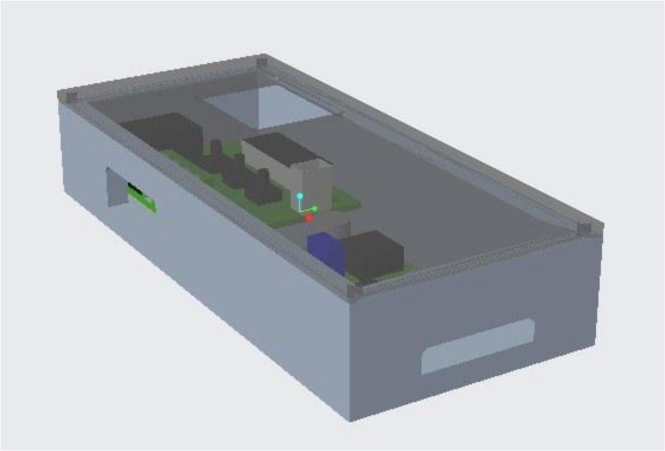


Figure 3: Electronic Storage Compartment

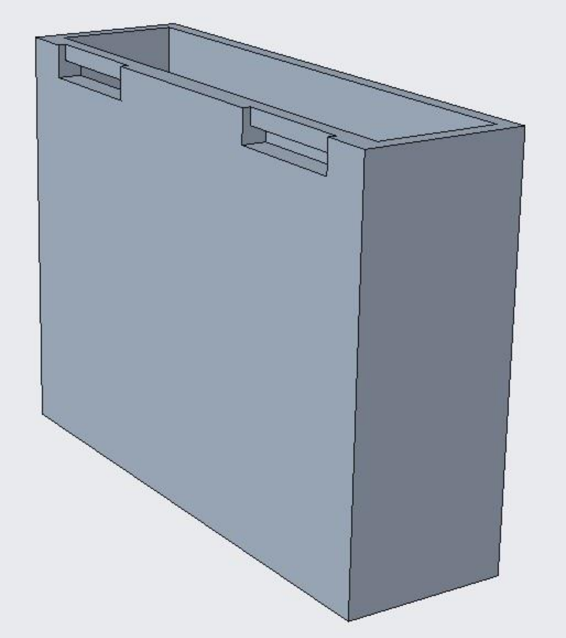


Figure 4: Solar Panel Storage Compartment

For cooling, the device uses thermoelectric cooling technology to achieve the necessary temperature range that the medication needs to be stored at. The TEC module utilizes the Peliter effect, which sends current through alternating semiconductors creating a temperature differential, thus generating a cooling on one side and heat on the other. If there is enough power generated the TEC module is capable of cooling far below ambient temperatures. The TEC module includes six different components and a schematic can be seen below in figure 5.

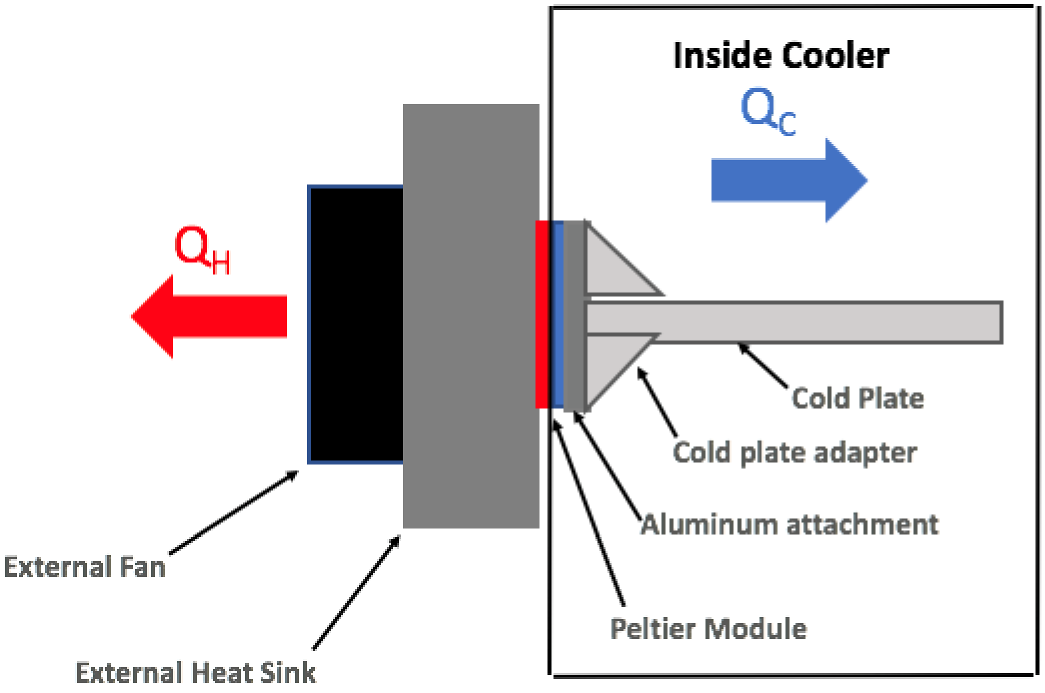


Figure 5: Thermoelectric Module Diagram

The TEC module is in charge of creating the temperature difference when power is supplied from the combination of a solar panel and lithium batteries. With that being said, the TEC module alone isn't capable of maintaining low temperatures due to its lack of ability to dissipate the heat from the hot side of the module. To help dissipate the heat throughout the system an external heat sink and external fan are included with the TEC module. These two are used to gather heat from the module and transfer it to the surrounding environment.

Attached to the thermoelectric cooling module is a custom fabricated aluminum cold plate (Al-6061). It was designed to store three insulin vials/pens. The CAD model for the cold plate can be seen in figure 6.

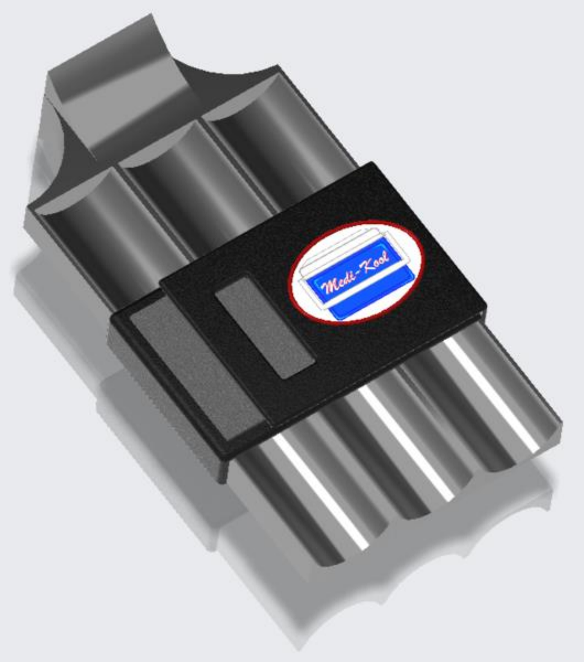


Figure 6: Fabricated Cold Plate

After purchasing the material, the cold plate was fabricated in the FAMU-FSU College of Engineering Machine Shop. We also 3D printed a table-like support (Figure 7) to place inside the cooler, to reduce stress on the screws that attach the cold plate to the thermoelectric cooling module.

Figure 7: Cold Plate Support

To sense and maintain the temperature throughout the cooler there are three main components required: temperature control switch, TEC unit, and insulation. These three components work together to ensure that the medication is adequately cooled to the required temperature ranges. The temperature control switch operates by turning the TEC unit on or off at discrete temperature ranges. Figure 8 displays the temperature control used for our device.

Figure 8: W1209 Temperature Control Switch

When the temperature inside the cooler reaches 8°C it communicates to the TEC unit that it needs to be cooled. When the temperature inside the cooler reaches 3.5°C the temperature control switch will automatically turn off the TEC unit. This component is crucial to the success of our device, because if the inside of the cooler reaches a temperature of 0°C the insulin would be frozen and be of no use.

Power is generated through a photovoltaic system that converts sunlight into electricity within the device. There are two main components that are required to complete this system, which includes the solar panel and two Lithium batteries. The solar panel used in our design is the Pi-Supply 22 W Solar panel. This solar panel was the most compatible for our design due to its ability to fold and be easily attached to our cooler. It also has a nominal value of 5.5V, which correlates best with the batteries.

The purpose of the batteries are to store energy for the power system. The batteries selected for the device were the PB120B1 TalentCell Lithium batteries. These batteries have a nominal value of 12V, which is sufficient enough to hold power when solar energy isn't available.

Integration

The integration of all of the previously mentioned components creates this CAD modeled assembly (Figure 9).

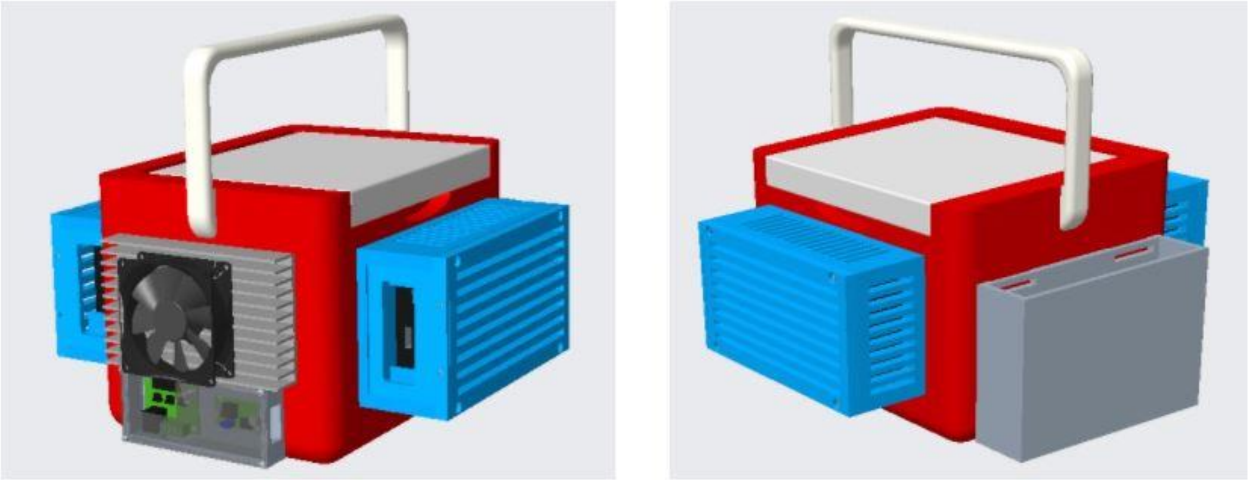


Figure 9: Assembled Cooler (left image: front left view; right image, front right view)

This assembly was used as the final design of our device. Excluding wiring from the CAD model was intentional, but the wiring will be securely wrapped and attached to the sides of the cooler, connecting all necessary components. This prototype was thoroughly tested and found to be functional as well as hitting our targets and goals. A main goal in this project was to create something that was packageable, in other words, develop a design that can hold all of the aforementioned components in one cohesive unit, and Figure 9 is a clear representation of that goal being met.

Operation

When providing the initial setup, the first thing to consider is the charge of the batteries. The battery storage compartments, located on the front and back side of the cooler, have a hole conveniently located such that the power button, and battery life can easily be seen (Figure 11). It is important that the batteries are fully charged before initial operation.

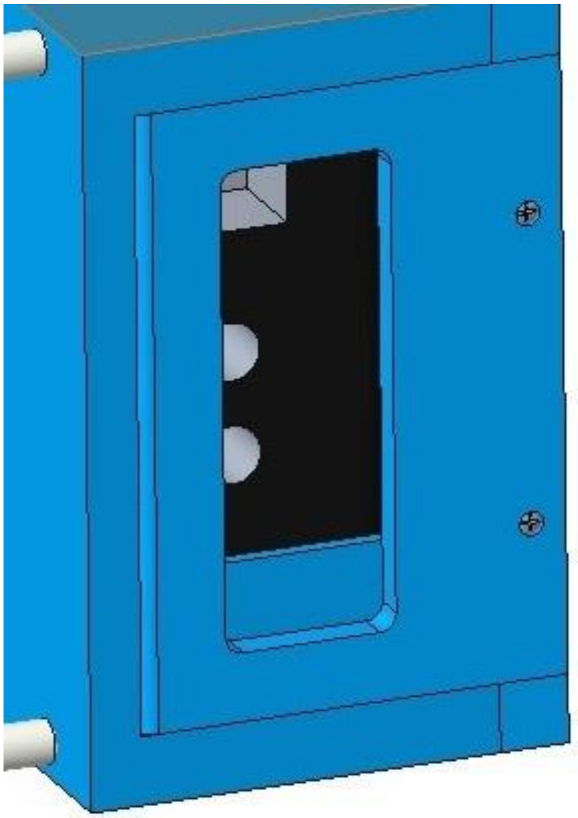


Figure 11 : Battery Power Location

The lid of the cooler can then be opened and medication can be placed in the grooves of the cold plate. Then, attach the velcro strap to the cold plate by wrapping the strap around the plate and over the medicine. Tighten the strap to ensure the medicine is secure and close the lid.

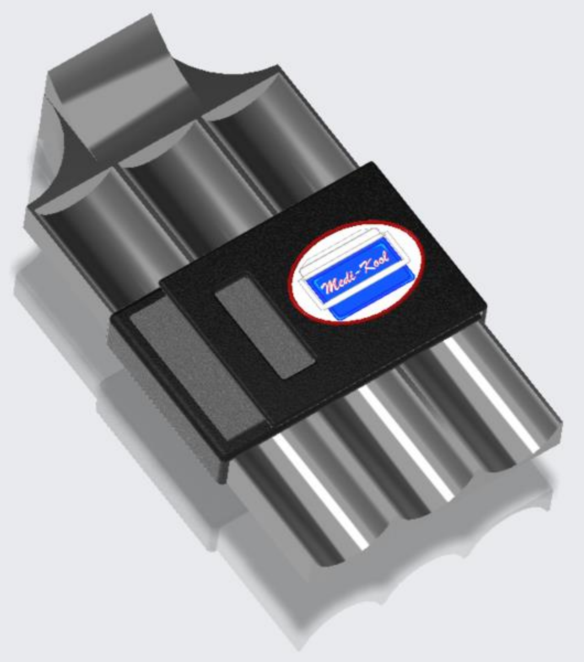


Figure 12: How to place medication and attach velcro strap

Once the battery power is confirmed, a simple flip of the power switch on a battery will turn the system on. The power is supplied to the thermoelectric cooling module and the cooling process will begin. The medication will be cooled to the required temperature range within a short period of time.

The temperature sensor will be able to control the temperature inside the cooler. Once the temperature is within range, the sensor will turn the power off to conserve battery power. As the temperature increases while the power is off, the temperature sensor will turn back on and cool the system again. During this process, the user should check on the power level of the battery (refer to Figure 11). As the power gets low on one of the batteries, the wire can be flipped to the other battery by removing the power cord from the low battery to the other fully charged battery. The power cord should be connected to the port indicated as “OUT”.

The dead battery can then be connected to the solar panel. The cord from the solar panel should be connected to the port indicated as "IN" on the dead battery. Then, the solar panel should be unfolded and placed in a sunny location so that the battery can be re-charged.

This cycle of operation can be carried out as long as it takes until the power gets restored. For simplicity, here is a breakdown of the steps required to operate the device:

1. Check power levels on batteries (refer to Figure 11).
2. Place the device in a secure location.
3. Place medicine in the cooler and secure using the velcro strap (refer to Figure 12).
4. Turn battery on.
5. Allow system to cool down.
6. Check power level on battery periodically.
7. Connect the solar panel to the battery that needs to be re-charged.
8. Remove medicine as needed by opening lid and removing velcro strap.

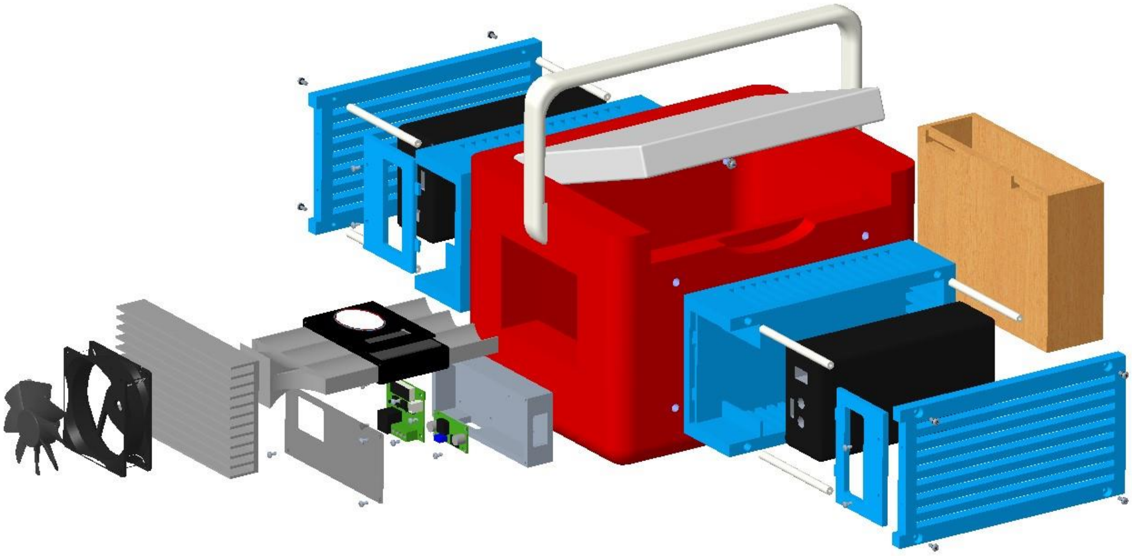
Troubleshooting

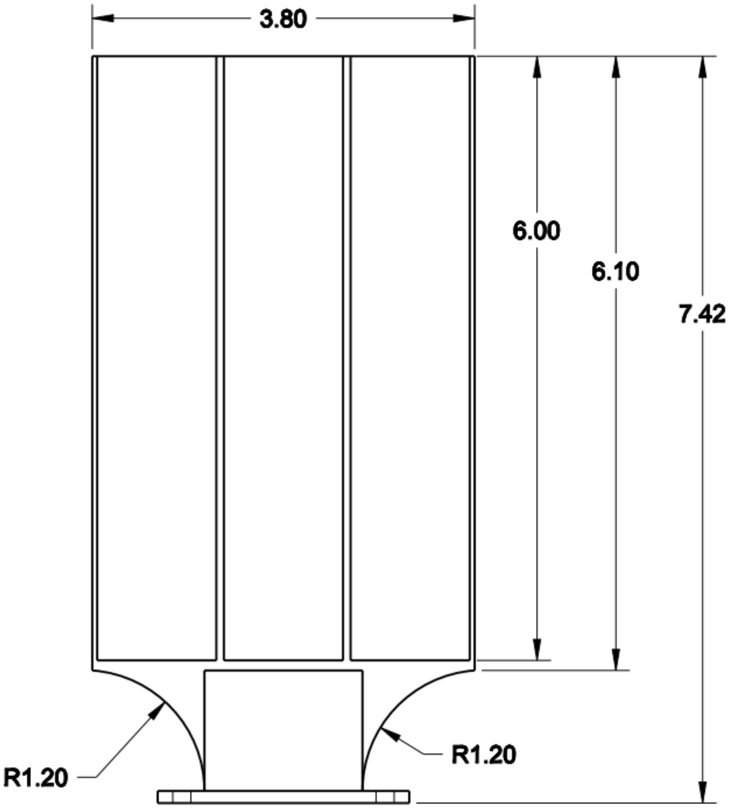
In the event that the temperature sensor fails, an analog thermometer will be included with the device. The thermometer should be placed at the indicated area on the device so that the temperature of the device can be accurately read. This will require extra attention as the power will need to be manually turned on and off when the temperature begins to exceed the required temperature range.

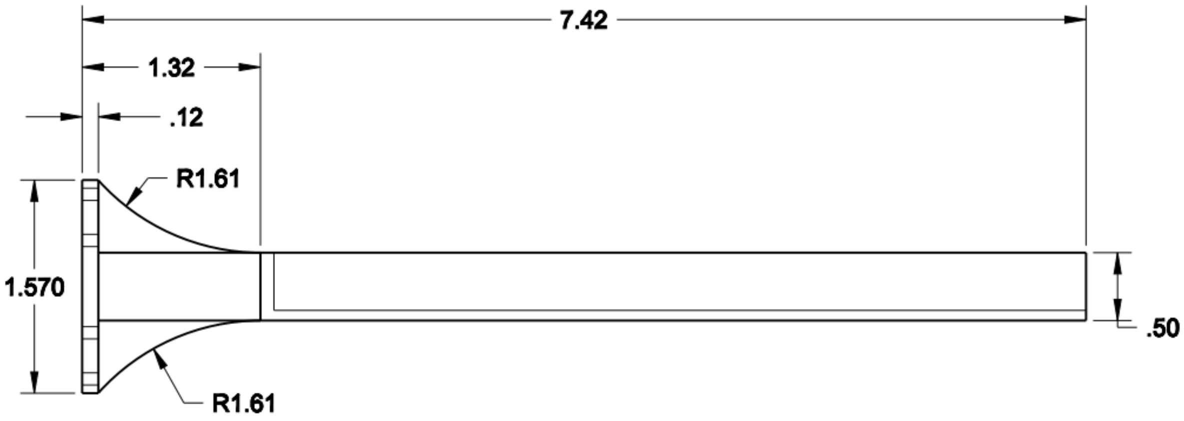
In regards to the solar panel, if the battery is not being charged quick enough, or at all, try moving the solar panel to an alternate location where the solar panel is exposed to the sun for the longest period of time. Sun exposure is the only way the solar panel will be able to work and by putting it in a location where exposure is greatest, the battery will be able to charge better.

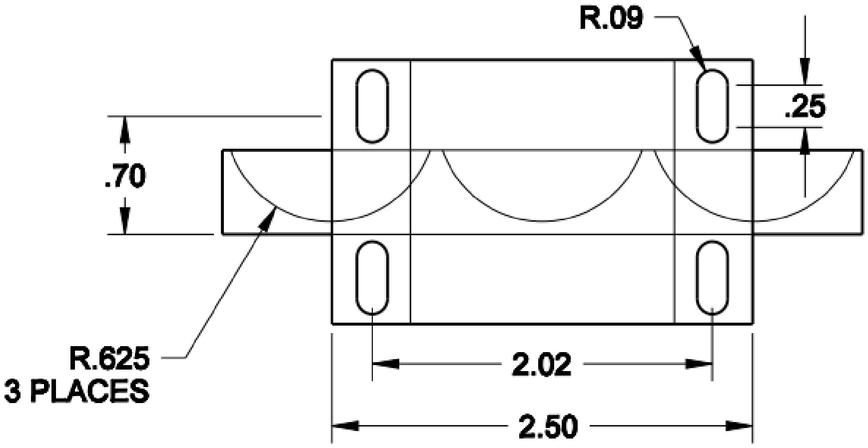
If a velcro strap fails, attach the extra velcro straps included with the device. The velcro strap does not require any other material to attach to the device. Simply slip the tag end of the velcro through the loop of the strap and wrap it around whatever needs to be secure.

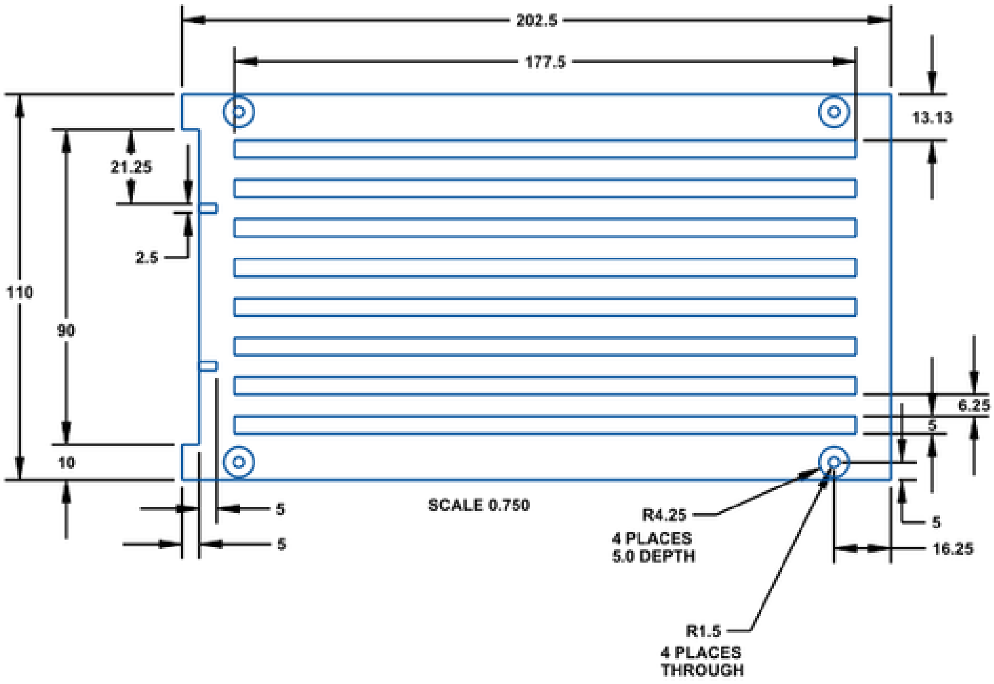
Appendix E: Engineering Drawing

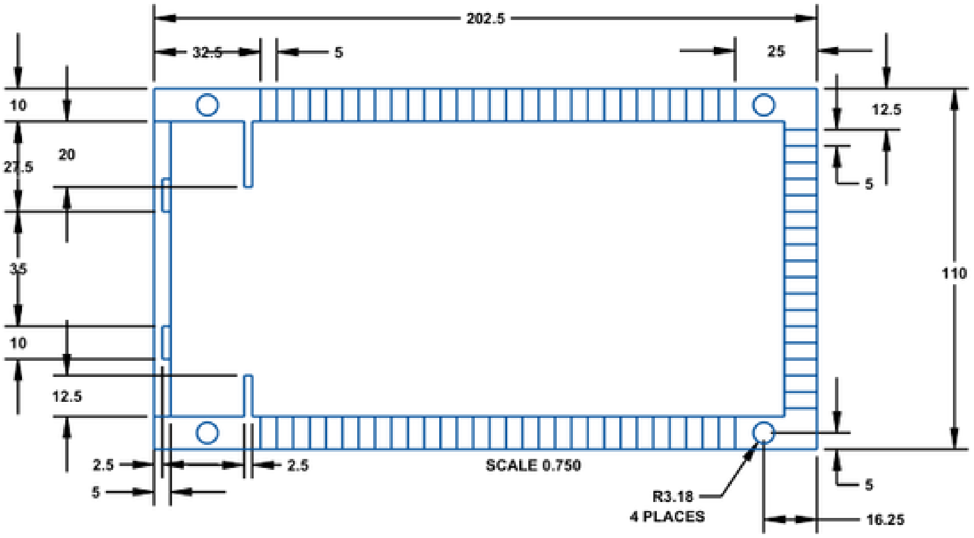


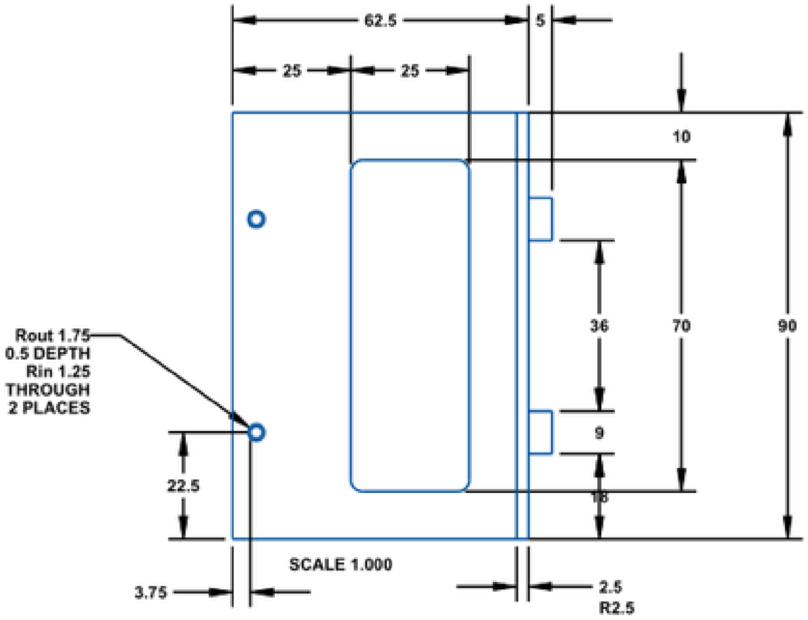



7.42
1.32
.12
R1.61
1.570
R1.61
.50


R.09
.25
.70
R.625
3 PLACES
2.02
2.50


202.5
177.5
13.13
21.25
2.5
110
90
10
6.25
5
5
5
SCALE 0.750
R4.25
4 PLACES
5.0 DEPTH
5
16.25
R1.5
4 PLACES
THROUGH


202.5
32.5
5
25
10
12.5
20
27.5
5
35
110
10
12.5
2.5
2.5
5
SCALE 0.750
R3.18
4 PLACES
5
16.25


62.5
5
25
25
10
36
70
90
9
18
Rout 1.75
0.5 DEPTH
Rin 1.25
THROUGH
2 PLACES
22.5
SCALE 1.000
3.75
2.5
R2.5

Appendix F: Calculations

Solar power calculations:

22 watt w/ 20% efficiency

Total power supplied by solar panel=Solar Panel Wattage*Avg. hrs sunlight*80% (accounts for outside variables)
= (22)*(6)*(80%) = 105.6 Watt-hour .... (1)

Battery capacity is 38,400 mAh @3.7 V = 142.08 Watt-hour

Calculating hours of sunlight to charge single battery using equation 1:
142.08 W-h = (22)(hours of sunlight)(80%)
=> avg. hours of sunlight = 8.07 hrs

Battery is running @12V so the total capacity turns into 11,840 mAh when running device
Total battery capacity @12V is 23,680 mAh

How much power the solar panels provide
How much power the device takes:

Peltier ON = 2.1 A
Peltier OFF, Power saving mode = 250 mA

Total power through power saving = (250 mA)(1.5 hr) = 375 mAh
Total power when ON = (2,100 mA)(20.5 hr) = 43,050 mAh
Total Power = 375 + 43,050 = **43,425 mAh**

Total device weight: 9.47 lbs.

Device capacity: 3 pens or vials (1-month prescription)

Arduino Code:

```
//Thermometer with thermistor

/*thermistor parameters:
 * RT0: 10 000 Ω
 * B: 3977 K +- 0.75%
 * T0:  25 C
 * +- 5%
 */

//These values are in the datasheet
#define RT0 10000   // Ω
#define B 3977      // K
//--------------------------------------



#define VCC 3.3    //Supply voltage
#define R 10000  //R=10KΩ

//Variables
float RT, VR, ln, TX, T0, VRT, RT2, VR2, TX2, VRT2, ln2, RT3, VR3, TX3, VRT3, ln3;

void setup() {
  Serial.begin(9600);
  T0 = 25 + 273.15;
  Serial.println("Temperature:\t\tTemperature 2:\t\tTemperature 3:"); //Temperature T0 from datasheet, conversion from Celsius to kelvin
}

void loop() {
  VRT = analogRead(A0);              //Acquisition analog value of VRT
  VRT = (5.0 / 1023.00) * VRT;      //Conversion to voltage
  VR = VCC - VRT;
  RT = VRT / (VR / R);               //Resistance of RT

  ln = log(RT / RT0);
  TX = (1 / ((ln / B) + (1 / T0))); //Temperature from thermistor

  TX = TX - 272.15;                 //Conversion to Celsius

  VRT2 = analogRead(A1);              //Acquisition analog value of VRT
  VRT2 = (5.0 / 1023.00) * VRT2;      //Conversion to voltage
  VR2 = VCC - VRT2;
  RT2 = VRT2 / (VR2 / R);               //Resistance of RT
```

```
 ln2 = log(RT2 / RT0);
 TX2 = (1 / ((ln2 / B) + (1 / T0))); //Temperature from thermistor

 TX2 = TX2 - 272.15;
//Conversion to Celsius

 VRT3 = analogRead(A2);              //Acquisition analog value of VRT
 VRT3 = (5.0 / 1023.00) * VRT3;      //Conversion to voltage
 VR3 = VCC - VRT3;
 RT3 = VRT3 / (VR3 / R);              //Resistance of RT

 ln3 = log(RT3 / RT0);
 TX3 = (1 / ((ln3 / B) + (1 / T0))); //Temperature from thermistor

 TX3 = TX3 - 272.15;

 //Serial.println("Temperature:\t\tTemperature 2:\t\tTemperature 3:");
 //Serial.print("\t\t");
 Serial.print(TX);
 Serial.print("\t\t\t");
 Serial.print(TX2);
 Serial.print("\t\t\t");
 Serial.println(TX3);


 delay(60000);

}
```

Appendix G: Risk Assessment

FAMU-FSU College of Engineering
Project Hazard Assessment Policy and Procedures

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.
5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.
6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).

7. PI/instructor must ensure that approved methods and precautions are being followed by :
    a. Performing periodic laboratory visits to prevent the development of unsafe practice.
    b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
    c. Assigning a safety representative to assist in implementing the expectations.
    d. Etc.
8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Dr. Shayne McConomy	Phone #: (850) 410-6624	Dept.: Mechanical Engineering	Start Date: 12/01/2020	Revision number: 0
Project: Team 523: Temperature Sensitive Medication Storage for Natural Disasters			Location(s): FAMU-FSU College of Engineering, FSU Innovation Hub	
Team member(s): T. Amaral, Z. Dillehay, N. Georgevich, K. Glass, D. Mendoza, A. Sayers			Phone #: (646) 734-0137	Email: tja16@my.fsu.edu

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
3D Printing	FSU Innovation Hub	Nick Georgevich	Inhaling toxic fumes/COVID	All Innovation Hub rules will be followed precisely.	N/A	N/A	HAZARD: 2 CONSEQ: Negligible Residual: Low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.

Cutting	FAMU-FSU College of Engineering Senior Design Lab	Travis Amaral	Eye damage/sight impairment/ splinters/ lacerations/particle inhalation COVID	Any cutting not done by the machine shop will be done in the Senior Design Lab and will be carried out following the lab procedure.	Long Pants, close-toed shoes, eye protection, gloves, masks	N/A	HAZARD: 2 CONSEQ: severe Residual: medium	Safety controls are planned by both the worker and supervisor. A second worker must be in place before work can proceed (buddy system). Proceed with supervisor authorization.
Electrical Operation Testing	FAMU-FSU College of Engineering Senior Design Lab	Diego Mendoza	Electrocution/ Electrical burns/COVID	Current testing procedures for using the power regulator will be followed, including connecting terminals while the device is off. Additionally, the manufacturer’	N/A	My	HAZARD: 1 CONSEQ: Moderate Residual: medium	Safety controls are planned by both the worker and supervisor. Safety controls are planned by both the worker and supervisor

				s guidelines for maximum input voltage and current for the modules will be followed.				
Gluing	FAMU-FSU College of Engineering Senior Design Lab	Andrew Sayers	Toxic Fume Inhalation/Skin Irritation/Eye Damage/COVID	Manufacturer recommendations will be followed. All adhesives will be applied in a well-ventilated area. User will wear gloves while handling and wash hands before and after use. Any containers with torn or damaged labels will be	Gloves/protective eye wear/masks	Leftover adhesive will be stored in a proper location recommended by manufacturer.	HAZARD: 1 CONSEQ: negligible Residual: low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.

				relabeled with the brand, product, and/or chemical name. All containers will be labeled with the date of purchase and last use.				
Machining	FAMU-FSU College of Engineering Machine Shop	Keon Glass	Lacerations/ Crushed Appendages/Eye Damage/ Contusions/ COVID	All metal machining of components from raw material will be carried out by the COE Machine Shop only, not a team member.	Work Gloves/ Eye Protection / Long Pants/Closed -Toed Shoes/No Loose Clothing	N/A	HAZARD: 3 CONSEQ: Severe Residual: Med High	After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA. A written Project Hazard Control is required and must be approved by the PI and the Safety Committee

								before proceeding. Two qualified workers must be in place before work can proceed. Limit the number of authorized workers in the hazard area.
Applying Spray Foam Insulation	FAMU-FSU College of Engineering Senior Design Lab	Zoe Dillehay	Toxic Fume Inhalation/Skin Irritation/Eye Damage/ COVID	Spray foam will only be applied in a well-ventilated area and with at least one other team member present. Spray foam will only be handled by team members and approved supervisors.	Gloves/protective eye wear/masks	N/A	HAZARD: 3 CONSEQ: negligible Residual: low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.

Electrical Assembly/Soldering	FAMU-FSU College of Engineering Senior Design Lab	Diego Mendoza	Electrocution/ Toxic Fume Inhalation/Skin Burns/COVID	A power supply will never be connected to any component while any assembly is occurring, even if it is not the component being worked on at the time. Soldering will only be done in a well-ventilated workstation and the operator must notify team members of hot components. All power leads will be taped over with red electrical tape and labeled while electrical	Protective eyewear/ masks	Lead solder must be disposed in correct waste baskets.	HAZARD: 1 CONSEQ: minor Residual: Low med	After approval by the PI, a copy must be sent to the Safety Committee. A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee. A second worker must be in place before work can proceed (buddy system). Limit the number of authorized workers in

				components are being worked on.				the hazard area.
Hardware/Final Assembly	FAMU-FSU College of Engineering Senior Design Lab	Nick Georgevich	Contusions/Lacera Tions/COVID	Any tools required in the final assembly will be handled according to lab safety guidelines. Assembler must be supervised by other team members during operations.	Work Gloves /Closed Toed Shoes/No Loose Clothing	N/A	HAZARD: 2 CONSEQ: moderate Residual: low	Safety controls are planned by both the worker and supervisor. Proceed with supervisor authorization.
Thermo-electric cooler testing	FAMU-FSU College of Engineering Senior Design Lab	Travis Amaral	Burns/ COVID	Handle thermo-electric cooler with care by avoiding direct contact with the cold/hot sides of the thermo-electric cooler during operation.	Gloves/mask/Closed Toed Shoes/No Loose Clothing	N/A	HAZARD: 3 CONSEQ: minor Residual: Low-med	After approval by the PI, a copy must be sent to the Safety Committee. A written Project Hazard Control is required and must be approved by the PI

								before proceeding. A copy must be sent to the Safety Committee. A second worker must be in place before work can proceed (buddy system). Limit the number of authorized workers in the hazard area.

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	**Signature**	**Date**	**Name**	**Signature**	**Date**

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	**Signature**	**Date**	**Name**	**Signature**	**Date**
Travis Amaral	*Travis Amaral*	12/1/2020	*Zoe Dillehay*	Zoe Dillehay	12/1/2020
Nick Georgevich	*Nick Georgevich*	12/1/2020	Keon Glass	*Keon Glass*	12/1/2020
Diego Mendoza	*Diego Mendoza*	12/1/2020	Andrew Sayers	*Andrew Sayers*	12/1/2020

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DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone"*. A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.
2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
Familiarity Level	Very Familiar	1	2	3
	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.
    a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
    b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
    c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
    d. Significant: severe injuries requiring hospitalization.
    e. Severe: death or permanent disability.
3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 2. Residual risk assessment matrix.

ssessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High

2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Appendix A: Hazard types and examples

Types of Hazard	**Example**
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body

	Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn
Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.
Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.
Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.
Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or down stairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects
Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic

	response.

Project Hazard Control- For Projects with Medium and Higher Risks

Name of Project:		**Date of submission:**
Team member	**Phone number**	**e-mail**
Travis Amaral	(646) 734-0137	Tja16@my.fsu.edu
Zoe Dillehay	(407) 592-0313	Zcd15@my.fsu.edu
Nick Georgevich	(727) 410-3717	Ndg14b@my.fsu.edu
Keon Glass	(850) 443-2507	Keon1.glass@famu.edu
Diego Mendoza	(973) 902-3837	Dm17b@my.fsu.edu
Andrew Sayers	(813) 428-3112	Aes17d@my.fsu.edu
Faculty mentor	**Phone number**	**e-mail**
Dr. Shayne McConomy	(850) 410-6624	smcconomy@eng.famu.fsu.edu
Dr. Jerris Hooker	(850) 410-6463	hooker@eng.famu.fsu.edu

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

Within the design process, multiple experimental steps representing various residual risks are identified to ensure proper safety measures are taken. While most of the steps involve low to low-medium risk, there are a few steps of medium and medium-high risk included within this section.

Cutting, indicated as having medium risk, will be used to modify cooler and insulation, vital to accurately construct prototype concepts and the final design. Multiple physical health consequences may result from improper use including eye damage, sight impairment, splinters, lacerations, and particle inhalation. Safety measures for this procedure require that all lab safety guidelines be strictly followed by any team member who operates such device. In addition, supplemental rules established by the team prohibit the user from operating cutting tools without team member supervision or approval. When cutting, the operating team member will wear protective eye wear, gloves, masks, close-toed shoes, pants, and tight-fitted clothing.

Electrical operation testing presented itself as a medium residual risk activity. Handling electrical equipment before or during the testing procedures have been completed has innate risk involved. Individuals performing tests and handling equipment have the risk of being electrocuted and/or suffering electrical burns. Individuals will only handle electrical equipment after reviewing safety procedures. Current testing procedures for using the power regulator include only connecting terminals while the device is off and also following manufacturer's guidelines for maximum voltage and current for the modules. In addition, individuals will read and adhere to any additional safety information/procedures included with any devices used throughout the prototyping process.

Machining, indicated as having medium high risk, will be used to fabricate grooved cold plate and cold plate adapter. Mutiple physical health consequences may result from improper use including lacerations, crushed appendages, eye damage, and contusions. Safety measures for this procedure require that all machine shop and lab safety guidelines be strictly followed by any team member who operates such device. In addition, supplemental rules established by the team prohibit the user from operating cutting tools without team member supervision or approval/supervision from faculty members. When machining, team member will wear gloves, eye protection, long pants, close-toed shoes, and tight fitted clothing.

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

- Remove injured from location of accident
- Call appropriate authority (supervisor, FSUPD, 911 dependent on severity)
- Shut down/close off source of injury if safely possible
- Isolate scene until responding authority arrive
- Ensure responding authority has all necessary information on the situation and assist them however they may need
- Compose an incident report with all team members present following the conclusion of the incident
- Share incident report with Faculty mentor

List emergency response contact information:

- Call 911 for injuries, fires or other emergency situations
- Call your department representative to report a facility concern

Name	Phone number	Faculty or other COE emergency contact	Phone number
Kelly Williamson	(678) 308-3827	Dr. Shayne McConomy	(850) 410-6624
Sidney Dillehay	(407) 592-0787	Donald Hollet	(850) 410-6600
Kristin Georgevich	(727) 642-1298	Sahar Mohammadi	(850) 410-6623
Ryan Glass	(850) 459-6258	Jeremy Phillips	(850) 410-6613
Susana Laguna	(973) 902-7879		
Rebeca Sayers	(813) 966-5762		

Safety review signatures

Team member	Date	Faculty mentor	Date
Travis Amaral	12/01/2020		
Zoe Dillehay	12/01/2020		
Nick Georgevich	12/01/2020		
Keon Glass	12/01/2020		
Diego Mendoza	12/01/2020		
Andrew Sayers	12/01/2020		

Report all accidents and near misses to the faculty mentor.

Appendix H: Generated Concepts

Crap Shoot

1. Big aluminum box with vacuum sealed walls (like a yeti) and gel packs to keep interior cold.
2. Large tank with massive fans and misters that are pumping cold water and blowing at maximum speed
3. Velcro sealed thin tall pouch with conductive plates on both sides
4. Small plastic box with insulation and a large fan (large enough to get desired temperature) attached to one end with a heat sink, powered by a gasoline engine
5. Create a vacuum sealed environment with little to no particles inside so that heat transfer is minimal and cold temperatures are easier to reach, powered by gasoline
6. A very tall, contractible tower that goes high enough to place a cooler (with medicine inside) to a high enough altitude for correct temperature range
7. Compressive cooling insulated cooler with multiple solar panels
8. Conductive Peltier plate where entire exterior of cooler is made of individual fans
9. Conductive Peltier plate with gel top to maximize surface area available to contents
10. Multiple lead acid batteries and electric cooler already available on the market
11. Mini fridge made of solar panels
12. Use a fluid heat exchanged that continuously pumps water to take away excess heat from the inside of the cooler
13. Use a fluid heat exchanged but utilize a fluid with much higher thermal conductivity to transfer heat away more efficiently from medication

14. Have medication packaging directly immersed in fluid that is continuously being pumped around the medication through a liquid heat sink module
15. Cryogenic cooler powered by a massive solar roof on top of the users’ house
16. Compressive cooler powered by a small generator
17. Insulated storage container continuously fed an irresponsible amount of dry ice
18. Wrap medication packaging in aluminum mesh that is attached to a Peltier cooling plate to maximize cooling rate
19. Maximized surface area grooved Peltier plates
20. Custom machined cooling plates for each major temperature sensitive medication which maximize surface area contact for each type (multiple models available)
21. Combined compression cooling while using external power source and conductive once power goes out
22. A small personal cooler with an entire bottom surface made of Peltier plates with heatsinks and fans attached to the outside to create a large heat difference
23. Human hamster wheel used to power a generator that creates electricity to power Peltier plates and fans attached to heat sinks
24. Human hamster
25. Assuming user has access to a fast-moving body of water, supply a turbine to generate hydroelectric power to supply device
26. Air screen to minimize air escape
27. Rubber siding/sealant for keeping environment cooled while accessing medications
28. UPS battery attached to cooler
29. 2 UPS batteries attached to cooler with wheels

30. 2 rechargeable lithium batteries attached to cooler
31. Pump liquid nitrogen into storage compartment to ensure that the medication inside remains cold and bacteria-free
32. Create a cooler that incorporates the use of a drilling mechanism to bury itself deep into the ground to remain cool
33. Insert chemicals into the device that allow for an endothermic reaction, pulling the heat out of its surroundings aka the medication
34. Like drilling concept but create a watertight container that has some sort of propeller system and operates as a submarine. Throw the container into a lake and control it to dive down to the bottom of the lake to keep cool
35. Attach wings to the outside of the container and fly it up to the top of a mountain to achieve a cold ambient temperature thus keeping the inner compartment cooler

Biomimicry

36. Gel (ice pack) insulation around all sides of the cooler like blubber in animals
37. Honeycomb cell shaped (hexagonal) storage compartments inside cooler
38. Suction cup like lid for the cooler like animals with adhesive toe pads
39. Use an ice block in a bucket to cool the medication
40. The use of blubber off animals, such as whales, to insulate the inner storage compartment
41. Create our container out of materials that make up turtle shells to ensure strength

Morphological Chart

42. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a hard-plastic cooler, with a fully opening lid.

43. Conductive Peltier module with a cold plate, powered by a battery, stored in a soft fabric cooler, with a partially opening lid for each medication
44. Conductive Peltier module with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
45. Convective Peltier module with a fan, powered by a solar panel, stored in a hard-plastic cooler, with a fully opening lid
46. Convective Peltier module with a fan, powered by a battery, stored in a soft fabric cooler, with a partially opening lid for each medication
47. Convective Peltier module with a fan, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
48. Conductive tunnel heat sink with a cold plate, powered by a solar panel, stored in a hard-plastic cooler, with a fully opening lid
49. Conductive tunnel heat sink with a cold plate, powered by a battery, stored in a soft fabric cooler, with a partially opening lid for each medication
50. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
51. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a hard-plastic cooler, with a fully opening lid
52. Convective Peltier module with a fan, powered by a solar panel, stored in a soft fabric cooler, with a partially opening lid for each medication
53. Conductive tunnel heat sink with a cold plate, powered by a solar panel, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in

54. Conductive Peltier module with a cold plate, powered by a battery, stored in a hard-plastic cooler, with a fully opening lid
55. Convective Peltier module with a fan, powered by a battery, stored in a soft fabric cooler, with a partially opening lid for each medication
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57. Conductive Peltier module with a cold plate, powered by a mechanically powered generator, stored in a hard-plastic cooler, with a fully opening lid
58. Convective Peltier module with a fan, powered by a mechanically powered generator, stored in a soft fabric cooler, with a partially opening lid for each medication
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64. Convective Peltier module with a fan, powered by a battery, stored in a soft fabric cooler, with a partially opening lid for each medication

65. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a soft fabric cooler, with rubber flaps that keep the cold air in
66. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a vacuum sealed cooler, with a fully opening lid
67. Convective Peltier module with a fan, powered by a battery, stored in a vacuum sealed cooler, with a partially opening lid for each medication
68. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
69. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a hard-plastic cooler, with a fully opening lid
70. Convective Peltier module with a fan, powered by a battery, stored in a soft fabric cooler, with a fully opening lid
71. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with a fully opening lid
72. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a hard-plastic cooler, with a partially opening lid for each medication
73. Convective Peltier module with a fan, powered by a battery, stored in a soft fabric cooler, with a partially opening lid for each medication
74. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with a partially opening lid for each medication
75. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a hard-plastic cooler, with rubber flaps that keep the cold air in

76. Convective Peltier module with a fan, powered by a battery, stored in a soft fabric cooler, with rubber flaps that keep the cold air in
77. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
78. Conductive Peltier module with a cold plate, powered by a battery, stored in a hard-plastic cooler, with a partially opening lid for each medication
79. Convective Peltier module with a fan, powered by a solar panel, stored in a soft fabric cooler, with a fully opening lid
80. Convective Peltier module with a fan, powered by a mechanically powered generator, stored in a soft fabric cooler, with rubber flaps that keep the cold air in
81. Conductive tunnel heat sink with a cold plate, powered by a battery, stored in a vacuum sealed cooler, with a partially opening lid for each medication
82. Conductive Peltier module with a cold plate, powered by a solar panel, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
83. Convective Peltier module with a fan, powered by a battery, stored in a hard-plastic cooler, with a fully opening lid
84. Convective Peltier module with a fan, powered by a battery, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
85. Conductive tunnel heat sink with a cold plate, powered by a solar panel, stored in a vacuum sealed cooler, with a fully opening lid
86. Conductive Peltier module with a cold plate, powered by a mechanically powered generator, stored in a hard-plastic cooler, with rubber flaps that keep the cold air in

87. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a vacuum sealed cooler, with a fully opening lid
88. Conductive tunnel heat sink with a cold plate, powered by a mechanically powered generator, stored in a hard-plastic cooler, with rubber flaps that keep the cold air in
89. Conductive tunnel heat sink with a cold plate, powered by a solar panel, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
90. Convective Peltier module with a fan, powered by a battery, stored in a vacuum sealed cooler, with a fully opening lid
91. Conductive tunnel heat sink with a cold plate, powered by a battery, stored in a vacuum sealed cooler, with rubber flaps that keep the cold air in
92. Conductive tunnel heat sink with a cold plate, powered by a solar panel, stored in a vacuum sealed cooler, with a partially opening lid for each medication

SCAMPER

93. Conductive Peltier cold plate cooling system mounted to the side of a hard-plastic cooler (hot air blows out the side), powered by solar panel battery combination with partially opening lid to pull out individual contents and rubber flaps combination. Must be equipped with cold plate adapter so medication can still lay flat.
94. Conductive tunnel heat sink cooling system powered by solar panel battery combination with partially opening lid and rubber flaps combination
95. Liquid heat exchanger that continuously pumps a low conductive fluid through a cold plate, powered by a solar panel and battery combination with a partially opening lid and a vacuum sealed container

96. Convective fan Peltier cooling system powered by a battery, stored in a hard-plastic cooler with a partially opening lid.
97. Combination of use of a liquid compressor heat exchanger to cool contents while device is plugged into external power source then switching to cooling system that requires less power such as conductive Peltier plate to maintain function for longer period of time from solar panel
98. Conductive Peltier cold plate with attached cold plate adapter that has thin pieces of aluminum mesh meant to cover medication and increase contact area. Powered by battery and solar panel in a hard-plastic cooler with partially opening lid
99. Conductive Peltier cold plate cooling system mounted to the bottom of a hard-plastic cooler (hot air blows downward), powered by solar panel battery combination with partially opening lid to pull out individual contents and rubber flaps combination
100. Conductive Peltier cold plate cooling system, powered by external mechanical generator with partially opening lid to pull out individual contents and rubber flaps combination

Appendix I: Concept Selection Methods

Table F.1: Binary Pairwise Comparison Chart

	1	2	3	4	5	6	7	**Total**
1. Appropriate Temperature for Extended Time	–	0	1	1	0	1	1	4
2. Securing Medication	1	–	1	1	0	1	1	5
3. Self-Contained Power	0	0	–	1	0	0	0	1
4. Portable	0	0	0	–	0	0	0	0
5. Store Power	1	1	1	1	–	1	1	6
6. Ease of Operation	0	0	1	1	0	–	1	3
7. Display Status	0	0	1	1	0	0	–	2
Total	2	1	5	6	0	3	4	

Table F.2: House of Quality

Improvement Direction														
Units		mm^3	Yes/No	°C	sec	sec	Yes/No	mW/°C, sec	ΔQ	ppm	N	V, A, W, Day	kg	$
Customer Requirements	Importance Weight Factor	Storage Volume	Display Battery Life	Display Temperature	Access Power Supply	Access Contents	Sense Temperature	Activate Cooling	Insulate Comparments	Seal Off from Contaminents	Durability	Regulate Power	Weight of Device	Cost
Appropriate Temperature for Extended Time	4	1		3		9	9	9	9			3		3
Securing Medication	5	3				3			3	3	9		1	
Self Contained Power	1		1		9				1		3	1	1	
Portable	0	9			3				3		9	1	9	
Store Power	6	3	1	1	9			9	3			9	1	9
Ease of Operation	3	3			9	9							9	
Display Status	2		9	9	1		3					3		1
Raw Score	654	46	25	36	92	78	42	90	70	15	48	73	39	68
Relative Weight %		7.03	3.82	5.50	14.07	11.93	6.42	13.76	10.70	2.29	7.34	11.16	5.96	10.40
Rank Order		8	12	11	1	3	9	2	5	13	7	4	10	6

Tables F.3: Pugh Charts

Table F.3.1: Pugh Chart with All Fidelity Concepts

Selection Criteria	Datum	Concepts							
	HomeCare Portable Medicine Refrigerator	1	2	3	4	5	6	7	8
Access Power Supply		S	-	S	S	-	S	S	-
Activate Cooling		+	+	S	-	+	+	+	+
Regulate Power		+	+	+	+	+	+	+	-
Access Contents		+	+	+	+	S	+	+	+
Insulate Compartments		+	+	+	+	+	+	+	+
Cost		-	-	-	-	-	-	-	-
# of pluses		4	4	3	3	3	4	4	3
# of minuses		1	2	1	2	2	1	1	3
# of S		1	0	2	1	1	1	1	0

Table F.3.2: Pugh Chart with Narrowed Down Fidelity Concepts

Selection Criteria	Datum	Concepts		
	Concept 2	1	6	7
Access Power Supply		S	S	S
Activate Cooling		+	+	+
Regulate Power		+	+	+
Access Contents		S	-	S
Insulate Compartments		S	S	S
Cost		+	+	+
# of pluses		3	3	3
# of minuses		0	1	0
Sum		3	2	3

Tables F.4: Analytical Hierarchy Process

Criteria Comparison Matrix [C]						
	Access Power Supply	Activate Cooling	Regulate Power	Access Contents	Insulate Compartments	Cost
Access Power Supply	1.00	0.14	0.20	0.33	0.20	3.00
Activate Cooling	7.00	1.00	0.33	0.33	0.33	7.00
Regulate Power	5.00	3.00	1.00	0.20	0.33	7.00
Access Contents	3.00	3.00	5.00	1.00	3.00	7.00
Insulate Compartments	5.00	3.00	3.00	0.33	1.00	9.00
Cost	0.33	0.14	0.14	0.14	0.11	1.00
Sum	21.33	10.29	9.68	2.34	4.98	34.00

Normalized Criteria Comparison Matrix [NormC]							
	Access Power Supply	Activate Cooling	Regulate Power	Access Contents	Insulate Compartments	Cost	Criteria Weights {W}
Access Power Supply	0.0468750	0.0138889	0.0206693	0.1422764	0.0401786	0.0882353	0.0586872
Activate Cooling	0.3281250	0.0972222	0.0344488	0.1422764	0.0669643	0.2058824	0.1458199
Regulate Power	0.2343750	0.2916667	0.1033465	0.0853659	0.0669643	0.2058824	0.1646001
Access Contents	0.1406250	0.2916667	0.5167323	0.4268293	0.6026786	0.2058824	0.3640690
Insulate Compartments	0.2343750	0.2916667	0.3100394	0.1422764	0.2008929	0.2647059	0.2406594
Cost	0.0156250	0.0138889	0.0147638	0.0609756	0.0223214	0.0294118	0.0261644
Sum	1	1	1	1	1	1	1

Consistency Check		
{Ws} = [C]{W}	{W}	Cons={Ws}./{W}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.36042012	0.05868724	6.14137066
0.99622428	0.14581985	6.83188383
1.23168035	0.16460010	7.48286505
2.70571981	0.36406902	7.43188689
1.82219150	0.24065937	7.57166249
0.16882232	0.02616441	6.45236458

RI Values for Consistency Check	
# of Criteria	RI Value
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.4
9	1.45
10	1.49
11	1.51
12	1.54

Average Consistency	6.98533891
Consistency Index	0.19706778
Consistency Ratio	0.15765423

Access Power Supply [C]			
	Design 2	Design 5	Design 7
Design 2	1.00	3.00	0.33
Design 5	0.33	1.00	0.20
Design 7	3.00	5.00	1.00
Sum	4.33	9.00	1.53

Normalized Access Power Supply Comparison [NormC]				
	Design 2	Design 5	Design 7	Design Alternate Priorities {Pi}
Design 2	0.2307692	0.3333333	0.2173913	0.2604980
Design 5	0.0769231	0.1111111	0.1304348	0.1061563
Design 7	0.6923077	0.5555556	0.6521739	0.6333457
Sum	1	1	1	

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.790082167	0.2604980	3.0329688
0.31965812	0.1061563	3.0112019
1.945621206	0.6333457	3.0719734

Average Consistency	3.03871468
Consistency Index	0.01935734
Consistency Ratio	0.01548587

Activate Cooling [C]			
	Design 2	Design 5	Design 7
Design 2	1.00	0.33	3.00
Design 5	3.00	1.00	5.00
Design 7	0.33	0.20	1.00
Sum	4.33	1.53	9.00

Normalized Activate Cooling Comparison [NormC]				
	Design 2	Design 5	Design 7	Design Alternate Priorities {Pi}
Design 2	0.2307692	0.2173913	0.3333333	0.2604980
Design 5	0.6923077	0.6521739	0.5555556	0.6333457
Design 7	0.0769231	0.1304348	0.1111111	0.1061563
Sum	1	1	1	

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.790082167	0.2604980	3.0329688
1.945621206	0.6333457	3.0719734
0.31965812	0.1061563	3.0112019

Average Consistency	3.03871468
Consistency Index	0.01935734
Consistency Ratio	0.01548587

Regulate Power [C]			
	Design 2	Design 5	Design 7
Design 2	1.00	3.00	0.33
Design 5	0.33	1.00	0.20
Design 7	3.00	5.00	1.00
Sum	4.33	9.00	1.53

Normalized Regular Power Comparison [NormC]				
	Design 2	Design 5	Design 7	Design Alternate Priorities {Pi}
Design 2	0.2307692	0.3333333	0.2173913	0.2604980
Design 5	0.0769231	0.1111111	0.1304348	0.1061563
Design 7	0.6923077	0.5555556	0.6521739	0.6333457
Sum	1	1	1	

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.790082167	0.2604980	3.0329688
0.31965812	0.1061563	3.0112019
1.945621206	0.6333457	3.0719734

Average Consistency	3.038714681
Consistency Index	0.01935734
Consistency Ratio	0.015485872

Access Contents [C]			
	Design 2	Design 5	Design 7
Design 2	1.00	3.00	0.33
Design 5	0.33	1.00	0.33
Design 7	3.00	3.00	1.00
Sum	4.33	7.00	1.67

Normalized Access Contents Comparison [NormC]				
	Design 2	Design 5	Design 7	Design Alternate Priorities {Pi}
Design 2	0.23076923	0.42857143	0.20000000	0.28644689
Design 5	0.07692308	0.14285714	0.20000000	0.13992674
Design 7	0.69230769	0.42857143	0.60000000	0.57362637
Sum	1	1	1	

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.897435897	0.2864469	3.1329923
0.426617827	0.1399267	3.0488656
1.852747253	0.5736264	3.2298851

Average Consistency	3.13724767
Consistency Index	0.06862383
Consistency Ratio	0.05489907

Insulate Compartments [C]			
	Design 2	Design 5	Design 7
Design 2	1.00	1.00	3.00
Design 5	1.00	1.00	3.00
Design 7	0.33	0.33	1.00
Sum	2.33	2.33	7.00

Normalized Insulate Compartments Comparison [NormC]				
	Design 2	Design 5	Design 7	Design Alternate Priorities {Pi}
Design 2	0.4285714	0.4285714	0.4285714	0.4285714
Design 5	0.4285714	0.4285714	0.4285714	0.4285714
Design 7	0.1428571	0.1428571	0.1428571	0.1428571
Sum	1	1	1	

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
1.285714286	0.4285714	3
1.285714286	0.4285714	3
0.428571429	0.1428571	3

Average Consistency	3
Consistency Index	0
Consistency Ratio	0

Cost [C]			
	Design 2	Design 5	Design 7
Design 2	1.00	3.00	0.33
Design 5	0.33	1.00	0.29
Design 7	3.00	7.00	1.00
Sum	4.33	11.00	1.62

Normalized Cost Comparison [NormC]				
	Design 2	Design 5	Design 7	Design Alternate Priorities {Pi}
Design 2	0.2307692	0.2727273	0.2058824	0.2364596
Design 5	0.0769231	0.0909091	0.1764706	0.1147676
Design 7	0.6923077	0.6363636	0.6176471	0.6487728
Sum	1	1	1	

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons={Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.797019973	0.2364596	3.3706388
0.378951114	0.1147676	3.3019002
2.16152475	0.6487728	3.3317130

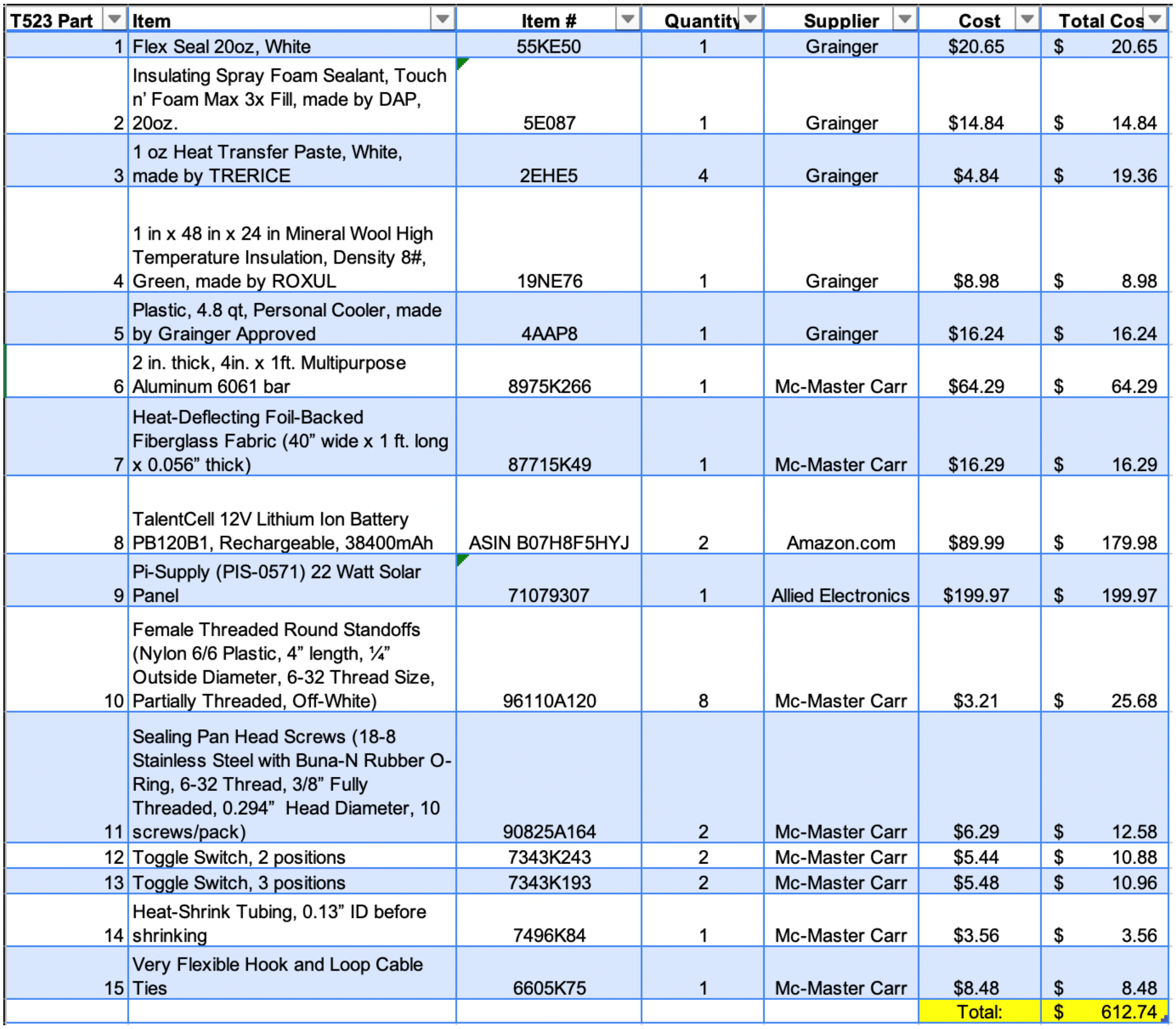
Average Consistency	3.33475068
Consistency Index	0.16737534
Consistency Ratio	0.13390027

Final Rating Matrix			
	Design 2	Design 5	Design 7
Access Power Supply	0.2604980	0.1061563	0.6333457
Activate Cooling	0.2604980	0.6333457	0.1061563
Regulate Power	0.2604980	0.1061563	0.6333457
Access Contents	0.2864469	0.1399267	0.5736264
Insulate Compartments	0.4285714	0.4285714	0.1428571
Cost	0.2364596	0.1147676	0.6487728

[Final Rating Matrix]^T					
0.260497956	0.2604980	0.2604980	0.2864469	0.4285714	0.2364596
0.106156324	0.6333457	0.1061563	0.1399267	0.4285714	0.1147676
0.63334572	0.1061563	0.6333457	0.5736264	0.1428571	0.6487728

Concept	Alternative Value
Design 2	0.3097647
Design 5	0.2731433
Design 7	0.4170920

Appendix J: Bill of Materials



T523 Part	Item	Item #	Quantity	Supplier	Cost	Total Cos
1	Flex Seal 20oz, White	55KE50	1	Grainger	$20.65	$ 20.65
2	Insulating Spray Foam Sealant, Touch n' Foam Max 3x Fill, made by DAP, 20oz.	5E087	1	Grainger	$14.84	$ 14.84
3	1 oz Heat Transfer Paste, White, made by TRERICE	2EHE5	4	Grainger	$4.84	$ 19.36
4	1 in x 48 in x 24 in Mineral Wool High Temperature Insulation, Density 8#, Green, made by ROXUL	19NE76	1	Grainger	$8.98	$ 8.98
5	Plastic, 4.8 qt, Personal Cooler, made by Grainger Approved	4AAP8	1	Grainger	$16.24	$ 16.24
6	2 in. thick, 4in. x 1ft. Multipurpose Aluminum 6061 bar	8975K266	1	Mc-Master Carr	$64.29	$ 64.29
7	Heat-Deflecting Foil-Backed Fiberglass Fabric (40" wide x 1 ft. long x 0.056" thick)	87715K49	1	Mc-Master Carr	$16.29	$ 16.29
8	TalentCell 12V Lithium Ion Battery PB120B1, Rechargeable, 38400mAh	ASIN B07H8F5HYJ	2	Amazon.com	$89.99	$ 179.98
9	Pi-Supply (PIS-0571) 22 Watt Solar Panel	71079307	1	Allied Electronics	$199.97	$ 199.97
10	Female Threaded Round Standoffs (Nylon 6/6 Plastic, 4" length, ¼" Outside Diameter, 6-32 Thread Size, Partially Threaded, Off-White)	96110A120	8	Mc-Master Carr	$3.21	$ 25.68
11	Sealing Pan Head Screws (18-8 Stainless Steel with Buna-N Rubber O-Ring, 6-32 Thread, 3/8" Fully Threaded, 0.294" Head Diameter, 10 screws/pack)	90825A164	2	Mc-Master Carr	$6.29	$ 12.58
12	Toggle Switch, 2 positions	7343K243	2	Mc-Master Carr	$5.44	$ 10.88
13	Toggle Switch, 3 positions	7343K193	2	Mc-Master Carr	$5.48	$ 10.96
14	Heat-Shrink Tubing, 0.13" ID before shrinking	7496K84	1	Mc-Master Carr	$3.56	$ 3.56
15	Very Flexible Hook and Loop Cable Ties	6605K75	1	Mc-Master Carr	$8.48	$ 8.48
					Total:	$ 612.74