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EML4551-2

# Team 512: Temperature-Sensitive Medication Storage During Natural Disasters

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**Abstract**

The damage from natural disasters, such as hurricanes, can impact lives long after the storm has passed. Families should only have to worry about rebuilding after a storm, not whether they have the medicine they need to survive. Medical organizations have found the lack of refrigeration to keep insulin, and other medicine, cool as a leading cause of death following hurricanes. Therefore, our team has developed a way to cool insulin and other medication, without the use of grid power.

From its storage instructions, we found that insulin must be kept between 2°C - 8°C (36°F - 46°F) to still be safe. This range can be met using an everyday cooler, but only for a few hours without an added cooling source. Thus, due to the lack of a grid power, using the least power is just as vital as cooling. With this in mind, we found that a thermoelectric unit (TEC) is the best way to keep the internal temperature of the cooler in the desired range. This TEC is powered by a mix of batteries and solar energy. This will keep the medicine in the temperature range for weeks until the power grid is back up.

After trying many ideas, our final design uses a simple cooler body with an attached TEC unit, added insulation, and three airtight locking cylinders. These cylinders both protect and contain each vial separately within the cooler. Our device gives the user peace of mind in times of a natural disaster. It not only spares users the cost of replacing their supply of medicine, but also prevents medical emergencies, and can even save lives.



*Keywords*: list 3 to 5 keywords that describe your project.

## Disclaimer

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## Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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## Chapter One: EML 4551C

### 1.1 Project Scope

1.1.1 Project Description

The proposed project seeks to develop a storage device to keep temperature-sensitive medication cool during natural disasters. The device will specifically benefit those effected by power outages.

1.1.2 Key Goals

In evaluation of conceptual designs, various key goals are included to identify what the design will accomplish. Since the cooler must operate during and after natural disasters, conservation of generated power should be optimized to maintain the viability of the medication. Different medications require varying temperature control to ensure safe storage. For those requiring refrigerated ranges, optimizing heat transfer is important to maintaining such temperatures.

In order to produce a more environmentally sustainable product, renewable energy alternatives will be considered by the group, to reduce resource consumption, environmental impact, and the need for non-renewable energy sources. Since the product is intended for use during and following natural disasters, the design must be durable enough to survive such an event while maintaining functionality. Therefore, the device must be reliable, as the contained medication may be essential for sustaining the user’s life. Since natural disasters come with economic hardship, the cost of obtaining the unit should not significantly inhibit distribution to low income areas. The device will be easily transportable and simple to use.

Summarized Key Goals:

- Conserve energy
- Optimize heat transfer
- Reduce resource consumption/environmentally sustainable
- Cost efficiency
- Reliability
- Portability
- Durability
- Ease of Operation

1.1.3 Market

From the project description, users of temperature-sensitive medicine represent the primary market, as the intended solution is designed to directly benefit these individuals. Multiple secondary markets exist that may find the proposed design appealing. Agencies providing aid following natural disasters, such as FEMA and the Red Cross, may be interested in distributing such a device. In impoverished regions, where grid-power may be unavailable, this device could function as a refrigeration alternative for food storage as well as medication. The military and camping industry could benefit from the product for the same reason. Lastly, companies producing high performance coolers may envision this product as an evolutionary step in cold storage, as ice would be unnecessary.

### 1.1.4 Assumptions

The assumptions made for the project include assessments that deem the project feasible and ensure a successful outcome. The system will meet temperature and time duration needs so that the overall goal is met. The device will be easily accessible in terms of cost and supply. Grid power is not available to power the device, so it cannot depend on conventional refrigeration methods. The device's parts can be made using COE shop machines or be purchased online to ensure the design is possible. The intended solution will not adversely affect the medication. The design will be operated at ambient conditions.

### 1.1.5 Stakeholders

The stakeholders for this capstone project include Dr. McConomy, our professor and project manager, who has direct control over our educational objectives. Our advisor, Dr. Ali, has interest in our project due to the time he is investing to mentor our progress. BowStern Marketing Communications and specifically Tom Derzypolski, who is sponsoring this venture, as well as the Dean's Office of the FAMU-FSU College of Engineering, through Tisha Keller, are collectively investing money into this project and therefore stakeholders as well. Diabetic patients who rely on the temperature sensitive medication, insulin, also are stakeholders since the success of this product could maintain their quality of life following a natural disaster event.

## 1.2 Customer Needs

| Questions | Responses | Interpretation |
|---|---|---|
| Can you describe the intended users of this device? | Chilled medication users in disaster-prone areas. | The device is intended to store and maintain chilled medication. |
| What do you like about existing products? | Existing products keep ice cold, but don't hold the temperature well without ice. | The device sustains a desired temperature without the use of ice. |
| | High end coolers currently on the market are strong. | The device is durable in all environmental conditions. |
| | Many current medication containers can be transported easily. | The device is easily portable. |
| | Many medication containers are lightweight. | The device can be transported by individuals of every age. |
| | Many medication containers show the storage temperature to the user. | The device visually displays the storage temperature to the user. |
| | Many medication containers can be locked. | The device prohibits unauthorized access. |
| What do you dislike about existing products? | Most products require a charger, and don't last long enough in the case of a power outage. | The device generates and uses minimal power to keep the medication refrigerated. |
| Should the device be specialized for a certain medication type? | The medication types that result in the highest death toll. | The device maintains a temperature range suitable for refrigerated medicines. |
| What would you see as the device's main functions and features? | The ability for the product to utilize some form of power generation to keep the medication refrigerated longer. | The device features multiple sources of power generation based on environmental conditions. |
| What type of disasters would you envision this device operating in? | The device should operate in disasters that interrupt power connection to the main grid. | The device will maintain power without being connected to the grid. |

| | | |
|---|---|---|
| What time duration do you envision the device operation? | The device should last up to three months without access to the grid. | The device controls the temperature of the system for at least three months without being plugged into an external power source. |

Table 1: Customer Needs

**Note:**

**Since the sponsor has been unable to meet with the design team, the following customer needs and rationale are determined by the design group based on research, advisor meetings, professor meetings and common, relevant goals for the device. Research references are indicated in the appendix.**

**Question: Can you describe the intended users of this device?**

Answer: Chilled medication users in disaster-prone areas.

Interpreted Need: The device is intended to store and maintain chilled medication.

Rationale: The main implications of this need is the size and temperature of the device. The device will store enough medicine to correspond to the duration of the power outage. Additionally, the internal temperature will fall within a desired temperature range for a refrigerated medication such as insulin.

**Question: What do you like about existing products?**

Answer: Existing products keep ice cold, but don't hold the temperature well without ice.

Interpreted Need: The device sustains a desired temperature without the use of ice.

Rationale: Ice is a common cooling agent used to keep coolers cold without power. However, eventually ice will melt and without grid power, and producing more ice is impossible in a warm climate. Therefore, the interpreted need indicates that the device must maintain a certain temperature without ice.

Answer: High end coolers currently on the market are strong.

Interpreted Need: The device is durable in all environmental conditions.

Rationale: As specified previously in the key goals of the project scope, the device should be durable to survive a natural disaster and continue operating. Therefore, regardless of disaster type and environmental condition, the device is designed to maintain its integrity and avoid damage to the medication stored internally.

Answer: Many current medication containers can be transported easily.

Interpreted Need: The device is easily portable.

Rationale: Evacuations are commonplace proceeding and following natural disasters. To support such movement, keeping the device relatively compact and portable would be optimal to ensure mobility and accessibility.

Answer: Many medication containers are lightweight.

Interpreted Need: The device can be transported by individuals of every age.

Rationale: In tandem of portability, ensuring the device is lightweight enables users of all ages and strength levels to implement the device.

Answer: Many medication containers show the storage temperature to the user.

Interpreted Need: The device visually displays the storage temperature to the user.

Rationale: For many users, chilled medication is essential to maintaining their quality of life. Including a temperature display provides peace-of-mind to the user that the temperature is adequate. It may also indicate a failure in the device if the temperature exceeds the range.

Answer: Many medication containers can be locked.

Interpreted Need: The device prohibits unauthorized access.

Rationale: With many medications being expensive, and dangerous to small children, it is necessary to include a method of securing the medication inside the device so that the medication cannot be unintentionally accessed.

**Question: What do you dislike about existing products?**

Answer: Most products require a charger, and don't last long enough in the case of a power outage.

Interpreted Need: The device generates and uses minimal power to keep the medication refrigerated.

Rationale: In the case of a natural disaster, the device won't be able to use a charger. For the medication to stay cool, the device will need to use minimal energy, whether it generated from a solar panel, batteries etc. In order to keep the temperature under control for a long duration, more simplistic convection processes must be used. A balance must be considered between internal temperature and energy require to keep the internal temperature in between a desired range.

**Question: Should the device be specialized for a certain medication type?**

Answer: The medication types that result in the highest death tool.

Interpreted Need: The device maintains a temperature range suitable for refrigerated medicines.

Rationale: Research indicates that medication requiring specified temperature ranges are divided into two categories: refrigerated or frozen. Medications stored in the freezer are relatively rare and mostly vaccines. Therefore, it is hypothesized that most of the deaths relating to temperature sensitive medication are for those requiring refrigeration. Refrigerated medications are kept in a range of 35-46 degrees F.

**Question: What would you see as the device's main functions and features?**

Answer: The ability for the product to utilize some form of power generation to keep the medication refrigerated longer.

Interpreted Need: The device features multiples sources of power generation based on environmental conditions.

Rationale: Since power from the main grid will be unavailable in event of a natural disaster. Power generation will result from other sources to power the device. Without reliable fuel resupply, renewable sources as well as large quantities of non-renewable sources such as batteries may be considered to provide adequate power. However, with renewable energy generation, environmental variables play a key role in determining effectiveness and efficiency. Therefore, incorporating multiple sources of power generation represents an interpreted need from the customer.

**Question: What type of disasters would you envision this device operating in?**

Answer: The device should operate in disasters that interrupt power connection to the main grid.

Interpreted Need: The device will maintain power without being connected to the grid.

Rationale: Regardless of the region, nearly all parts of the world are susceptible to some form of natural disaster. Some of the most common natural disasters to impact large population areas are hurricanes and snowstorms as they have such a large destructive area. These disasters tend to cause widespread infrastructure damage, as opposed to tornadoes which may cause more catastrophic damage but within an isolated area. Therefore, hurricanes and snowstorms are the primary model for natural disasters in this scenario as they pose the largest risk to power infrastructure.

**Question: What time duration do you envision the device operation?**

Answer: The device should last for up to three months without access to the grid.

Interpreted Need: The device controls the temperature of the system for at least three months without being plugged into an external power source.

Rationale: Research regarding loss of services following Hurricane Maria in Puerto Rico indicates that the average household was without electricity for 84 days. Post-analysis determined that the number of diabetes deaths in September and October (landfall: 9/20/2019) increased 46%, indicating that the inability to cool insulin was a significant cause of mortality. Lack of power identifies a vulnerable population comprised of patients requiring regulated temperature ranges to keep prescription medications cool. Since Hurricane Maria is an extreme example of service loss longevity among recent major hurricanes, it is used to establish a best-case three-month operational device longevity.

## 1.3 Functional Decomposition

### 1.3.1 Introduction to F.D.

The functional decomposition process takes large and relatively complex processes and breaks it down into smaller and simpler functions. This enables the design group to clearly address specific functions while determining relationships between design variables based on previously identified customer needs.

### 1.3.2 Data generation

The data generated for functional decomposition directly relates to the customer needs and the overall scope of the project. This was initiated by asking, "What does the device need to do?" From there, the main systems were composed in conjunction with the overall concept of a temperature-sensitive medication storage device for use during natural disasters. The systems directly related to how the key goals of the device can be accomplished. Additionally, the systems were broken down into smaller functions which clarify what the device is to achieve.

1.3.3 Diagram

Figure 1 below illustrates the functional decomposition flow chart for function breakdown.

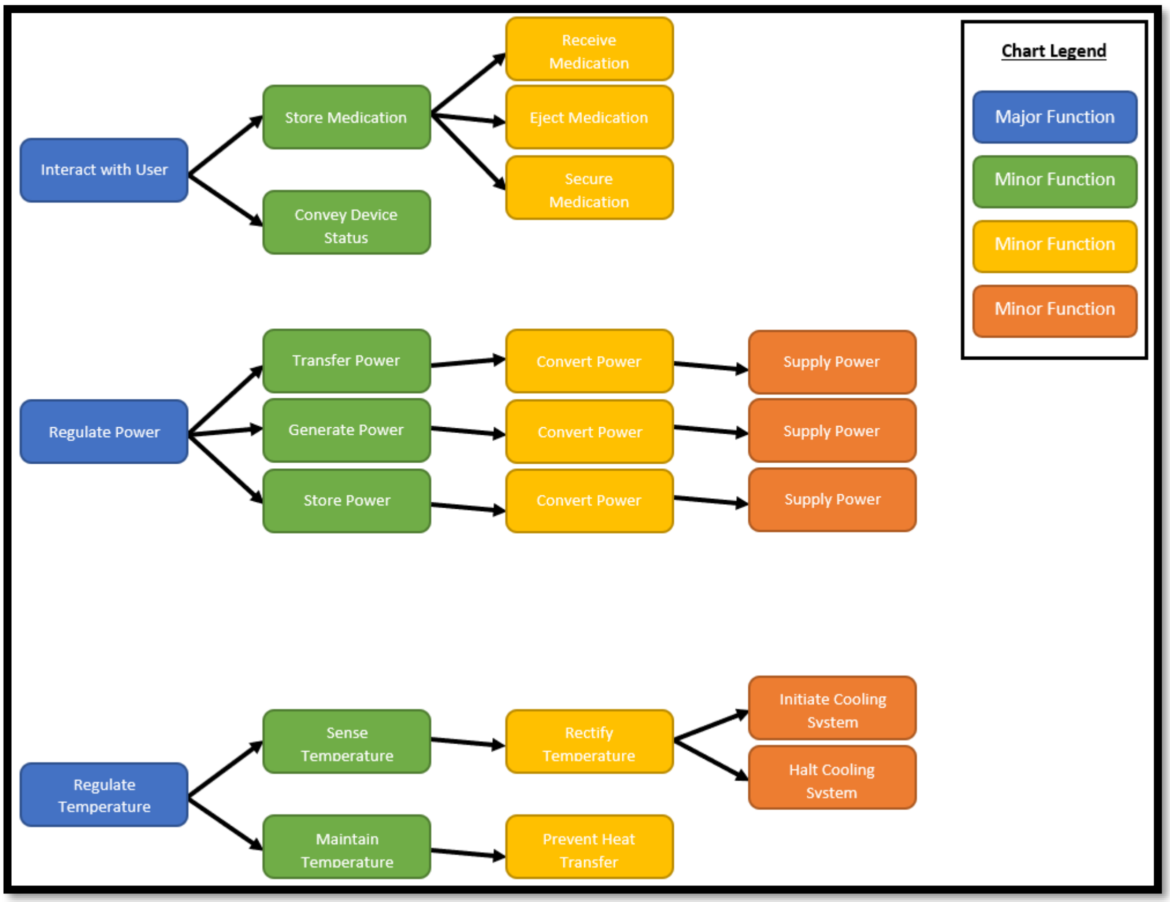



Figure 1: Functional Decomposition Flow Chart

1.3.4 Reasoning

When reviewing the project scope and general premise of our project, it was determined that the major functions the device would be to regulate the temperature within the storage container, to regulate the power within the entire system, and to interact with the user. Interacting with the user is the most structural of the major functions, involving the ergonomics of the device. The subsequent sub functions all involve what the user would need to do to ensure the successful operation of the device. Since this device is used during natural disasters, power regulation is a much more complex function requiring multiple sub functions. The situation may require the device to carry out the function of generating power because grid power is not available, or store power from either internal generation or an external source, or transfer external power to the device from an external source. Regardless of where the power originated, it will need to be converted properly for the device to use it, and then finally will be supplied to the system. In the same way as power regulation, temperature regulation was analyzed and broken down into the necessary components. To regulate temperature, the temperature must be known, maintained, and react to undesirable changes. These components developed into the sub functions: “sense temperature”, “rectify temperature”, “initiate cooling system”, “halt cooling system”, “maintain temperature”, and “prevent heat loss” seen above.

### 1.3.5 Function relationships

Moving from left to right in the figure above, the functions are organized by hierarchy. The first column of boxes represents major functions such as “regulate power”. The subsequent column of boxes corresponds to minor functions, which in the case of “regulate power” could be “generate power”. To the right of that minor function can be another minor function which relates to the previous one, falling under the hierarchy of the overall main function. For instance, “convert power” falls after “generate power”. Additionally, another minor function can follow, which represents the smallest scale function of the system. This can be something such as “supply power”.

1.3.6 Connection to Systems

The first function corresponds to the interaction with the user. The primary subsystem corresponds to storing the medication through the device. For the medicine to be stored, the user must interact with the device so that the device can receive the medication. When the medicine is needed, the user can interact with the device to eject the medicine for use. While the medicine is in the device, the medicine will be secured to prevent damage to the containers or vials. The device will also interact with the user on the subsystem level to display the device's status. This subsystem relates to the subsystem of generating power to make the user aware of the current state in the instance that additional power must be produced for the system. If more power has been generated, the device will interact with the user to transfer this power.

The regulate power function begins with the concept of power generation. By creating power through multiple possible sources, the function can be used to convert the power to usable energy. The usable energy is then supplied to the cooling system. Additionally, the power generated can be stored if needed. In order to monitor the power levels to determine if more is needed to be generated or accessed, the flow continues to the subsystem used to display the device status. Similarly, the power will be supplied to the temperature sensing device, as well as its display counterpart. Based on the temperature sensing feedback, the flow continues to supply power back to the cooling system in order to adjust or maintain the temperature.

The regulate temperature function directly relates to the power cooling systems as it is needed to provide cool air. Subsequently, the regulate temperature function is initially sensed and rectified if deemed necessary. For this subsystem, the cooling system will then be initiated.

Once the temperature is controlled, the function will halt the cooling process. In the instance an acceptable temperature is sensed, the temperature is then maintained. Through the subsystem of preventing heat transfer, the temperature is maintained.

### 1.3.7 Integration

The first integration between subsystems is through the device status. This will interact with the user in order to determine if more power is needed to be generated. Additionally, the subsystem conveys to the user if more cooling mechanisms are needed in order to regulate the temperature of the device. The device interacts with the user across subsystems to regulate power in terms of transferring power and generating power.

### 1.3.8 Action and Outcome

This device needs to enable temperature-sensitive medication users to store their medication at the proper temperature in the situation where normal refrigeration units are not an option. It will take in a medication, keep it at the appropriate temperature, prevent damage, and safely eject whenever the user needs it.

| | Interact with User | Regulate Power | Regulate Temperature |
|---|---|---|---|
| Store Medication | X | | |
| Receive Medication | X | | |
| Eject Medication | X | | |
| Secure Medication | X | | |
| Convey Device Status | X | | |
| Transfer Power | | X | |
| Generate Power | | X | |
| Store Power | | X | |
| Convert Power | | X | |
| Supply Power | | X | |
| Sense Temperature | | | X |
| Rectify Temperature | | | X |
| Initiate Cooling System | | | X |
| Halt Cooling System | | | X |
| Maintain Temperature | | | X |
| Prevent Heat Transfer | | | X |

Table 2. F.D. Cross reference Table

### 1.4 Target Summary

SI Units will be used for the generated targets. Critical functions, targets, and metrics are designated by (*). The catalog of targets can be found in Appendix C.

1.4.1 Method of Validation

A large majority of our metrics can be validated by simply measuring the dimensions stated in the metric, such as surface area, medicine storage internal volume, total internal volume, and wall thickness.

Internal temperature can be tested using a simple experiment with a benchmark cooler and a temperature sensor such as a thermopile or thermocouple. As our device is aimed to be relatively inexpensive, a benchmark cooler could be a good example of our probable heat loss rate without our cooling system.

The durability of the device can be determined through an impact test where the load will be dependent upon the mass of the device, gravity, and a common height that our device might fall from. With the height being 1.5m and a rough estimate of our device mass being 2.75 kg, the estimated impact force would be 27 N with an energy of 40.5 Nm. These targets will then be used in material selection, further in the design process, to narrow the potential materials to those within the optimal ranges specified by these targets. Once the impact testing of our prototype is performed, the device would also be visually inspected for any deformations or shortcomings caused by the impacts.

Additionally, electrical management is a very important component to this device, and therefore, the targets and metrics regarding the current, voltage, and electrical conversion must be validated. This validation will be carried out by doing simple tests using a measurement tool like a multimeter. While these tests are very simple, they are still extremely important, since our power supply is limited and optimization of power usage is crucial to our device.

1.4.2 Critical Targets

The most critical metrics for our device's successful operation are the heat transfer rate through the container, the cooling rate of our cooling system, and the cooling time. The target each of these revolve around is the temperature range of 3.5 to 6 degrees Celsius. Initially, the temperature must be sensed with a critical accuracy of plus or minus 0.25 degrees through the thermocouple. Too large of a deviation can result in a loss of excess power, or a temperature outside of the desired range. In a necessary instance, and in normal conditions, the cooling time will be less than 15 minutes to regain an acceptable temperature. If we model insulin as a water-like substance, because it has a similar density of 1090 kg/m3, then at the mean of our temperature range it has a specific heat of 4208.45 J/kg°C. Combining these values with a 15 minute time, each 10mL vial of insulin will require 50.97 mW of power for every degree Celsius we wish to change the temperature. This is accomplished through the optimized heat transfer rate, which is determined through the cooling time and the temperature difference from the surroundings in normal conditions. Additionally, the design of the device will consist of materials and an optimized structure that will minimize the heat transfer rate. By taking into consideration the surrounding temperature in a natural disaster situation, the insulation of the device will provide a net equilibrium of heat transfer. In this case, less energy is consumed in cooling the system, as heat is prevented from entering the boundary layer.

Additionally, other critical metrics are the medicine storage internal volume and the voltage and current of the system; these directly factor into the critical targets. For instance, the internal volume affects the cooling rate and cooling time of the system. Likewise, the voltage is measured through the thermocouple, which then is translated into the internal temperature.

1.4.3 Derivation of Targets/Metrics

Many of our targets and metrics were derived from background research and the customer needs generated by the team, with the most critical targets/metrics being derived directly from the functions in the functional decomposition. The targets for the temperature range were determined through recommended medication storage temperatures. This temperature then factors into the necessary cooling rate and cooling time; as well as the heat transfer rate, which directly corresponds to the cooling rate through the energy balance equation. The targets/metrics related to the functions that power the device were derived from research on common power supplies, which consisted of common battery voltages, such as 1.5V and 3V, and standard power outlets present in the market; as such the targets of the power functions were chosen to reflect these results.

1.4.4 Discussion of Measurement

Multiple measurement tools are required to adequately illustrate the targets previously mentioned. For length measurements, a standard tape measure will be used for dimensioning items greater than 15cm and smaller items that do not require a high degree of accuracy. For length measurements less than 15cm, a Vernier digital caliper will be implemented. To identify the volume required for medication storage, length measurement tools are used to find applicable dimensions for common shapes. If the generated designs do not comply with traditional shaping, water displacement using graduated cylinders is used to measure the volume. A force of impact equation was utilized to identify the impact resistance of the device, to be confirmed using a physical sensor at a later date.

Of utmost importance within the device is ensuring the internal temperature is kept to applicable ranges. Therefore, temperature sensors will be used to display its value to the user. To identify service life longevity time, a stopwatch will be used.

## 1.5 Concept Generation

In order to generate 100 different design concepts, various techniques were employed, rather than the traditional brainstorming methods. These generation processes include the Morphological Chart, Brainstorm SCAMPER list, and Biomimicry. A list of additional concepts is provided in Appendix E.

### 1.5.1 Morphological Chart

The morphological chart process began with the minor functions previously determined through functional decomposition. These subsystems were used as the sub-problems for the design concept. From there, various solutions were generated for each subsystem. Once the individual sub-problems were accounted for, the ideas were then combined, moving from left to right, to create an overall concept for the design. For instance, one complete concept that was generated was for a double walled traditional cooler, which included a refrigeration system, thermopile, LCD display, and lithium battery.

| Receive Medication | Eject Medication | Secure Medication | Convey Device Status | Transfer Power |
|---|---|---|---|---|
| Single locking cylinder mechanism | Single locking cylinder mechanism | Small feet at the base of vials to ensure stability | LCD display | 120 Volt plug |
| A small drawer with rigid mesh sides and solid front and back. Would seal off inside from the environment | A small drawer with rigid mesh sides and solid front and back. Would seal off inside from the environment | Vertical rods to which the medication vials would be clamped onto | Red and green LEDs | 230 Volt plug |
| Hatch on top of device | Hatch on top of device | Vials placed in padded sleeves before entering the device | Speaker that will sound an error, warning of device failure | |
| Individual airtight tubes for medication vials | Individual airtight tubes for medication vials | Vials placed in small nets hanging from the inside of the container | Analog thermometer to display internal temperature | |
| Individual sliding cylinders | Individual sliding cylinders | | | |
| Vacuum sealed individual cylinders | Vacuum sealed individual cylinders | | | |
| Rectangular compartments with individual lids | Rectangular compartments with individual lids | | | |

| Supply Power | Rectify Temperature | Initiate Cooling System | Halt Cooling System | Prevent Heat Transfer |
|---|---|---|---|---|
| Separate power storage from cooling system, requiring the power to be manually plugged into the cooling system | Miniaturized standard refrigeration system | Feed forward control | Feed forward control | Standard cooler design. Interior and exterior hard shell with Styrofoam in between |
| Cooling system and power storage are integrated | Compressed gas used as cooling system | Feedback control | Feedback control | Double walled casing with vacuum space in between |
| Utilize a conventional generator | Chemical reaction cold packs or ice packs | Arduino | Arduino | |
| | Fan to circulate air over cooling packs within the device | Manual | Manual | |
| | No cooling device, rely solely on fluid diffusion | | | |
| | Evaporative cooling | | | |

Table 3. Morphological Chart

### 1.5.2 Brainstorm SCAMPER List

The SCAMPER list takes traditional brainstorming and breaks it down into seven types of change: substitute, combine, adapt, modify, put others to use, eliminate, and rearrange. This process assists in analyzing current systems or concepts and differentiating particular elements of the system. For instance, in order to adapt a mini-fridge, one idea was to provide multiple power sources such as a car adapter, solar energy, human created power etc. This brainstorming process shifts the view through different components of the overall design concept and invokes creativity along the lines of improving current systems.

| Proposed Change | Idea |
|---|---|
| Substitute | Substitute a mini-fridge outlet with a long-lasting battery. |
| Combine | Combine a fan with ice/icepack inside of a cooler. |
| Adapt | Multiple power generation methods such as generator plug, car adapter, solar panel, hand crank etc. for a mini-fridge. |
| Modify | Thickened walls of a traditional cooler for better insulation. |
| Put Others to Use | |
| Eliminate | Eliminate a traditional lid in order to compartmentalize the device with individual chambers. |
| Rearrange | A lid on the side of the device to rearrange the flow of heat when opened. |

Table 4. SCAMPER List

1.5.3 Biomimicry

The design concept process of biomimicry directly correlates to mimicking biological nature. By observing natural techniques and behavior patterns, unique design concepts can be generated. Biological systems have already proven to work, and even more so, can be adapted to fit various sorts of needs in all aspects of the design world.

- Stegosaurus – Cooling Fins
    - Many paleontologists theorize that the main purpose of the large plates on the back of a stegosaurus were to assist the animal in regulating their body temperature. These plates had blood vessels running through them and as air flowed around the plate the blood would be cooled. Modern animals such as the

elephant also carry out this convection cooling through their large ears which contain a large amount of blood vessels and draw a lot of heat from the animal's blood. This idea of convection cooling can be applied to our project by considering adding a large array of cooling fins which will draw heat away from our cooling fluid which can then be circulated back towards the medicine vials.

- Tortoise – Hard Shell
  - Like the shell on a tortoise or turtle, we want our device to have a hard, outer shell to protect the vital internal components. However, in the same way that a turtles shell does not transfer impact force to its vital organs due to the tissue separating the two, our device needs to also have a method of ensuring that any impact force that the device might encounter will not be directly transferred to the vials of medication, or the other vital components inside. This can be done through many different methods, easiest of which is to have a secondary layer of impact absorbing material behind the hard, outer shell such as rubber or foam.
- Humans – Sweating – Evaporative Cooling
  - In the same way that we humans excrete water and salt from glands onto the surface of our skin, which is then evaporated and cools the skin in the process, we could adapt the concept of evaporative cooling to our device. "Cool towels" are a newer invention which are made of materials which retain a large amount of water and allow for the evaporative process to last a long time and provide noticeable cooling for a notable amount of time. These towels, or at least this material, can be applied to create sleeve for the medication to sit in which will

draw heat away from the medication without the need of power. Additionally, this technology could be combined with the aforementioned cooling fins to further increase the effectiveness of the fins cooling power.

- Reptiles – Shade/Burying - Reducing External Heat Transfer
    - Reptiles, which are cold blooded animals, cannot regulate their body temperatures as we humans do, so they cleverly adapted to their environments to ensure that they are not exceeding their survivable body temperatures. Many reptiles will seek shade in hot climates/direct sunlight to keep cool. Although this cannot be adapted to be a component of our device, we can incorporate in our user manual that the device should be kept out of direct sunlight and away from other sources of direct heat such as fires and motors. Additionally, some reptiles have been known to bury themselves to keep cool. Given the right scenario (that there is not flood water which would drown and destroy the device), the device could be built so that it could be buried. Ground temperatures vary much less than air temperatures and could greatly assist in regulating the external temperature of our device. Finally, although most reptiles are not white, because it would be a disadvantage and opt for having natural camouflage, many desert reptiles are lightly colored which assist in heat regulation. However, we can paint the exterior of our device white, since white absorbs the least amount of heat out of all colors, to aid in ensuring that our device absorbs the least amount of external heat as possible, thus reducing the amount of cooling our cooling system would need to do, and reducing the amount of electrical power our device would need.

- Blubber – Insulation
  - Many animals, especially those in the artic such as polar bears and beluga whales, have a layer of blubber. Blubber is a fat rich, collagen fiber laced layer of skin that these mammals have which insulates them from the cold temperatures of their environment. Although our device is not operating in the frigid cold of the artic, insulation is still crucially important to our project. Instead of keeping heat in, like these mammals' blubber does, our insulation needs to keep the cold temperatures of the inside of our device from transferring out. The more effective our insulation is, the less our cooling system will have to work, and the less power we will need to generate and store.

1.5.4 Concepts

Listed below are eight concepts our group determined to be of reasonable fidelity.

**Concept 1.**

*Medium Fidelity*

Ranque-Hilsch vortex tube takes compressed air from a compressor and induces a vortex to separate a cold and hot fluid stream. Cold air provides cooling to the medications while hot air is expelled outside of the storage container. A single large internal rechargeable lithium battery will power the LCD display, thermocouple sensor, and a miniaturized refrigeration system. Device will have a cord to plug into various power generation sources.

**Concept 2.**

*Medium Fidelity*

Standard cooler (double walled insulated) with a controls system that cools the system via compressed air and a fan that are activated when the temperature is sensed to be out of range via a thermocouple. Additionally, the system will be powered through a large external battery.

**Concept 3.**

*Medium Fidelity*

Create a cool sleeve with small tubes to place the vials of medication in; these tubes will be connected to a liquid cooling system which will circulate coolant or water through the sleeve to cool it. The water or coolant will then be pumped through external fins which employ evaporative cooling to chill the water or coolant back down to an acceptable temperature. The internal device volume will be evacuated to a safe level, to reduce the volume of air inside the container and reduce the ability of convection heat transfer to warm the medication. Each vial of medication will have its own vacuum chamber and its own cooling sleeve to ensure that if one vial is retrieved for use, the others are not affected in any way. The cooling system will be powered by an internal rechargeable battery, with integrated solar panels and wired in hand cranks.

**Concept 4.**

*Medium Fidelity*

Use an immersion cooling system to circulate coolant around vacuum sealed vials which will be kept in 3 locking cylinders and held in place with netting. The coolant will be cooled below normal system temperatures with an incorporated coolant cooling system. The immersion cooling system would not draw power but the coolant cooling system would be powered by an external battery pack. The external battery pack can have conventional batteries placed in it, and those batteries can be recharged using a power generation source such as solar panels or hand cranks.

**Concept 5.**

*Medium Fidelity*

Standard cooler (double walled insulated) with a large solar panel array which powers a miniaturized refrigeration system. The device would also have an internal rechargeable battery to collect the excess energy created from the solar panel. The solar panel and/or battery would also power a thermocouple and LCD display, and the entire system would utilize a feedback control. The vials of medication would be placed in protective padded sleeves which would be kept in a small drawer with rigid mesh sides that seals itself off during opening and closing of the device.

**Concept 6.**

*High Fidelity*

Standard cooler (double walled insulated) with a miniaturized refrigeration system which, along with an LCD and a thermocouple, will be powered by a single, large, internal, rechargeable lithium battery. Vials will be kept in 3 locking cylinders which will have zip-tie like clamps which will keep the vials secure inside the device. The device will have a cord which can be plugged into a large external emergency battery or another power generation source.

**Concept 7.**

*High Fidelity*

Standard cooler (double walled insulation) with a large compressed liquid mixture ($N_2$, $CO_2$) cylinder. A large internal rechargeable battery powers a thermocouple, LCD display, and a servo which regulates the flow of the compressed liquid. Since the liquid is maintained at an extremely cold temperature in its compressive state, the valve is opened to release the fluid into the storage section and cool the medication.  Vials are wrapped in sleeves made of "cool towel" material and placed in individual locking cylinders.

**Concept 8.**

*High Fidelity*

Double walled vacuum sealed cooler, with vacuum sealed individual cylinders for each vial. Cylinders will be insulated as well. An endothermic chemical reaction will be used to chill the internal system. Using a control feedback system, a thermocouple will measure the internal temperature, and if it is out of the desired range the system will lower the temperature by activating the reaction. Furthermore, a fan will assist in this process to cool the medication by convection. The device will be powered through a battery, as well as include a cord that allows for it to be plugged into other power sources. Additionally, the medication will be dispensed out in such a fashion that the cylinders twist and lock to provide an airtight seal, while not releasing any atmospheric air into the control space.

### 1.6 Concept Selection

For the selection process, our team decided to focus on the five concepts we determined to be the most feasible. Those concepts are as follows;

**Concept 1**: Standard cooler (double walled insulated) with a miniaturized refrigeration system which, along with an LCD and a thermocouple, will be powered by a single, large, internal, rechargeable lithium battery. Vials will be kept in 3 locking cylinders which will have zip-tie like clamps which will keep the vials secure inside the device. The device will have a cord which can be plugged into a large external emergency battery or another power generation source.

**Concept 2**: Standard cooler (double walled insulation) with a large compressed liquid mixture (N2, CO2) cylinder. A large internal rechargeable battery powers a thermocouple, LCD display, and a servo which regulates the flow of the compressed liquid. Vials are wrapped in sleeves made of "cool towel" material and placed in individual locking cylinders.

**Concept 3**: Double walled vacuum sealed cooler, with vacuum sealed individual cylinders for each vial. Cylinders will be insulated as well. An endothermic chemical reaction will be used to chill the internal system. Using a control feedback system, a thermocouple will measure the internal temperature, and if it is out of the desired range, the system will lower the temperature by activating the reaction. Furthermore, a fan will assist in this process to cool the medication by convection. The device will be powered through a battery, as well as include a cord that allows for it to be plugged into other power sources. Additionally, the medication will be dispensed out in such a fashion that the cylinders twist and lock to provide an airtight seal, while not releasing any atmospheric air into the control space.

**Concept 4**: Standard cooler (double walled insulated) with a TEC (thermoelectric cooling) system to cool the interior of the device and thus cool the medication. The vials will be held in individual locking cylinders with zip-tie like clamps to secure the vials. The TEC system, along with an LCD display and thermocouple, will be powered by a single large, external emergency battery. The battery will be connected to a large solar panel, which will charge the battery.

**Concept 5**: Ranque-Hilsch vortex tube takes compressed air from a compressor and induces a vortex to separate a cold and hot fluid stream. Cold air provides cooling to the medications while hot air is expelled outside of the storage container. A single large internal rechargeable lithium battery will power an LCD display, and a thermocouple sensor. Device will have a cord to plug into various power generation sources.

1.6.1 Introduction

In continuation of the design process, the conceptual selection process receives high and medium fidelity concepts identified in the concept generation phase, and evaluates such designs using multiple selection tools to identify the optimal design. The House of Quality (HOQ), Pugh Chart, and Analytical Hierarchy Process (AHP) are examples of such tools used to identify which design is most feasible and addresses customer needs most adequately. While the elimination of certain design ideas occurred within the concept generation phase by reducing the number of initial ideas through feasibility analysis, concept selection seeks to identify which of the most viable designs the team should select to begin detailed design.

The HOQ seeks to compare customer needs to specific engineering characteristics using a weighted scale. The purpose of this is to identify which engineering characteristics are most important to address given customer needs. Customer needs are arranged in the first column while engineering characteristics are arranged along the first row. An importance weight factor using a pair-wise comparison is used to determine the importance weight factor per customer need. Such weighting factors determine which need the customer values more highly in relation to the others. Following this, the relationship matrix is completed by moving from row to row in order to identify how significantly the engineering characteristic contributes to fulfilling the corresponding customer need. If a cell is left blank, the engineering characteristic does not address the need. However, if a 9 is inserted, the engineering characteristic significantly contributes to the need. 1 – 9 may be used to indicate very weak to very strong correlation. The highest-ranked characteristics form constraints, or design variables, that must be prioritized when evaluating the high and medium fidelity concepts from concept generation. As a result, lower ranking characteristics are not as critical when determining how well a design complies with the interpreted customer needs.

Further analysis can be implemented to eliminate less feasible options, in the form of a Pugh Chart. This tool compares each design concept on a relative basis to one another as well as a datum benchmark currently available on the market. It assigns a plus sign, minus sign, or 0 within the matrix to identify whether the given concept is better than, worse than, or relatively equal to the referenced design forming the datum. To accomplish this, a selection criterion is developed consisting of the engineering characteristics previously implemented in the HOQ and arranged in the first column. Next, the benchmark concept is inserted in the second column to establish the datum by which the other designs will be evaluated against. Each design concept is arranged along the first row and the matrix is evaluated by analyzing each concept against the datum, in relation to the engineering characteristics. The sum of pluses and minuses for each concept is calculated and presented in the bottom row of the graph. Concepts with substantial minuses and few pluses may be eliminated. A second Pugh Chart is established using the reduced number of concepts. However, instead of the benchmark being the datum concept, one of the design concepts with relatively equal number of pluses and minuses is used. Once the sum of pluses and minuses are obtained from each design concept, a decision among the team is made to select the most feasible remaining concepts to transition in the AHP.

Following the implementation of the Pugh Chart, only the most feasible concepts remain among the initially proposed designs. To identify which of these designs is optimized in relation to the customer needs, an AHP chart is implemented. To begin an AHP diagram, a pairwise comparison matrix must be formed, using a scaling system to develop the respective criteria weights. The scale will implement odd number values from 1-9 and be normalized to develop the corresponding criteria weight. For each engineering characteristic, separate comparison matrices are developed in which designs are compared with each other to determine rating values per engineering characteristic. The resulting tables are once again normalized, and row values are averaged to develop the design alternative priority values. Consistency checks are implemented for each iteration to ensure that unintentional bias is not being introduced within the AHP evaluation. The design alternative priority values for each engineering characteristic are finally averaged among each design to determine the alternative value. The design with the highest alternative value is identified as the most optimal as determined through the AHP analysis tool.

### 1.6.2 House of Quality

The HOQ table can be found in Appendix F.

The HOQ is a comparison chart used to analyze how the engineering requirements satisfy the given customer needs; thus each of the customer needs were given an importance factor to weigh their relations based upon their own importance. For instance, the customer need of "the device maintaining the desired temperature for the medicine" was assigned the highest weight, at 11. This directly represents how important this customer need is in relation to the overall design. The weights for each customer need were determined using a binary pairwise comparison chart which compares each customer need against each other, in the method of column versus rows. If the customer need at the top of the column was more important than the customer need in the row, it got a 1, if it was less important then it got a 0. The totals for each row and column were taken and the sum at the bottom of the table was the importance weight factor for that customer need.

Following that, the engineering characteristics were analyzed in conjunction to each of the customer requirements. It is evident that power consumption and power generation were the most important of the engineering characteristics for this requirement, which relates to how the two targets directly affect the ability of the device to cool medication; being followed in importance by "Heat Transfer Rate", "Cooling Time" and "Cost". These five highest ranked characteristics will be used in the development of the Pugh chart and AHP tables.

1.6.3 Pugh Chart

The Pugh chart can be found in Appendix F.

The Pugh chart is a decision-making matrix which compares the design criteria against the top selected designs. Each concept is ranked on a positive note (+1) or a negative note (-1) depending upon how the concept satisfies the selection criteria. The selection criteria were determined through the engineering characteristics which most greatly affected the customer requirements. In the case of this design, the high-ranking engineering characteristics were determined to be generated power, power consumption, heat transfer rate, cooling time, and cost.

The five concepts were weighed against the criteria, and then the process was narrowed down further to the final 3. For instance, Design 3 didn't pass the first round due to the high amount of negative values; this concept in particular received negative values due to its slow cooling time and high cost. Once the final comparison was complete, Concept 2 was shown the be the most promising of the choices due to the high number of positives the design had in comparison to the other two concepts.

1.6.4 AHP

The AHP tables can be found in Appendix F.

Through the AHP matrices, each of the final concepts can be compared through the weighted design criteria. During this process, consistency checks are made for each criteria matrix, ensuring each criterion is properly weighted and bias is not being introduced. The final output is an alternative value table, in which Design 2 received the overall highest value.

In the criteria comparison matrix, the top five engineering characteristics from the HOQ are compared against each other to generate their respective weights. These engineering characteristics are now the criteria for the following sections, to which the five designs are compared against each other.

For the consideration of power generation, all our concepts will include some form of power generation source. Therefore, this criterion is primarily regarding how easily the power generation source can be integrated into the system. Design 4 stands out the most out of the other designs in this category because it is the only design with an external emergency battery. The company which makes the most popular emergency batteries, and is most likely going to be our source for this type of battery, also makes various size and power solar panels. Therefore, the integration of this power generation source is the most easily achieved.

Since each of the five designs have different cooling systems, they each have very different power requirements, and thus different power consumptions. Design 2 draws the least amount of power since it relies solely on compressed gas to provide cooling and would only need to power a thermocouple, LCD display, and a servo motor to control the flow of the compressed gas. Additionally, Design 3 requires the second least amount of power because it only needs power for a fan, dispenser, thermocouple, and microcontroller. Design 1 requires the most power as it involves a compressor, fan, microcontroller, and various other sensors and components present in a refrigeration system.

An important factor for each concept is the heat transfer rate. This concept not only relates to the size capability of the system, but the outcome of the desired temperature ranges. Designs 1, 4 and 5 all ranked the highest for this criterion due to the size and power of the cooling systems in each. On the contrary, Design 3 had the lower heat transfer rate due to the constraints with the system; it incorporates a chemical reaction, so increasing the heat transfer rate directly affects the material consumption. Additionally, the cooling system is rather simple, and only employs a fan in addition to the chemical reaction.

The cooling time of the system plays a key role in how long the system can initially lower the temperature. Even after the temperature is met initially, the cooling rate factors into the equation throughout the duration of the power outage if the selected concept implements a control-feedback system. Under this circumstance, if the device must awaken to lower the internal temperature, the cooling rate can affect the power consumption in the process. For instance, Design 2 has the fastest cooling rate, as the compressed gas is naturally very cold and only needs to spread throughout a small volume of space. Subsequently, Design 1 includes the longest cooling time due to the refrigeration like design.

In addition to causing a large variation in power consumption, the five different cooling systems of the five designs results in a large variation in cost. Since Design 1 has the most power consumption, and would therefore require the most power, and involves multiple expensive components, it has been rated to have the highest cost out of all the designs. On the opposite end of the spectrum, Design 2 involves the least number of components and power, and from previous research and product sourcing it was found that the compressed gas, which is one of the most expensive components of the cooling system, is relatively affordable.

#### 1.6.5 Final Selection

The selection process using HOQ, Pugh Chart, and AHP determined that Design 2 would be the best fit, as it maintained the highest overall performance amongst all the selection criterion. Design 2 includes a compressed gas cooling system used to lower the internal temperature of the device. However, this concept has been deemed to be not fully feasible given the circumstances of this project. The main concerns stem from the compressed gas, which not only is difficult to acquire, but provoke significant safety concerns. Due to this, the 2nd place concept will be the selected design.

The 2nd ranked design is concept 4, which is based around a standard cooler (double walled insulation) equipped with a thermoelectric cooling (TEC) system. It includes an LCD display, and zip-tie locking cylinders to contain the medicine within the container. This concept meets all the criteria, as it is the least expensive method, and consumes the least power all while still being able to maintain the desired temperatures. Subsequently, the lower tier engineering characteristics factored into this design decision as well. For instance, the TEC system provides one of the smallest, and lightest overall assemblies, which greatly benefits the weight reduction of the design. Additional reasons for the selection of concept 4 are due to the multiple factors that attribute to the heat transfer rate. Most of the other concepts solely depended upon the power supplied to the system, which was often a high amount. The TEC system, on the other hand, can operate on AA batteries. This grants ability to manipulate the power in terms of the capacity, while leaving the potential for the user to have easier access to the power supply. Furthermore, the heat transfer rate of the TEC system is also dependent upon the heat sink. This allows for natural cooling methods to be explored, in order to optimize the cooling process, while using minimal energy. Below are the CAD drawings developed for this design.

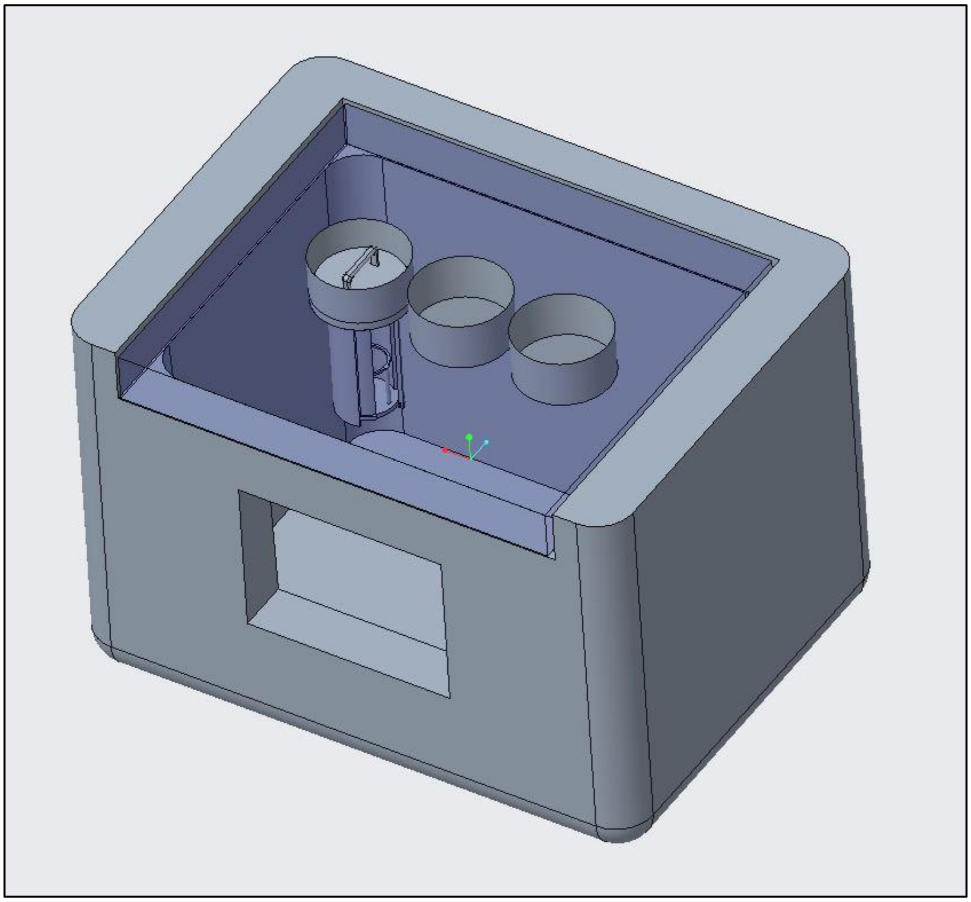


Figure 2. Final Design

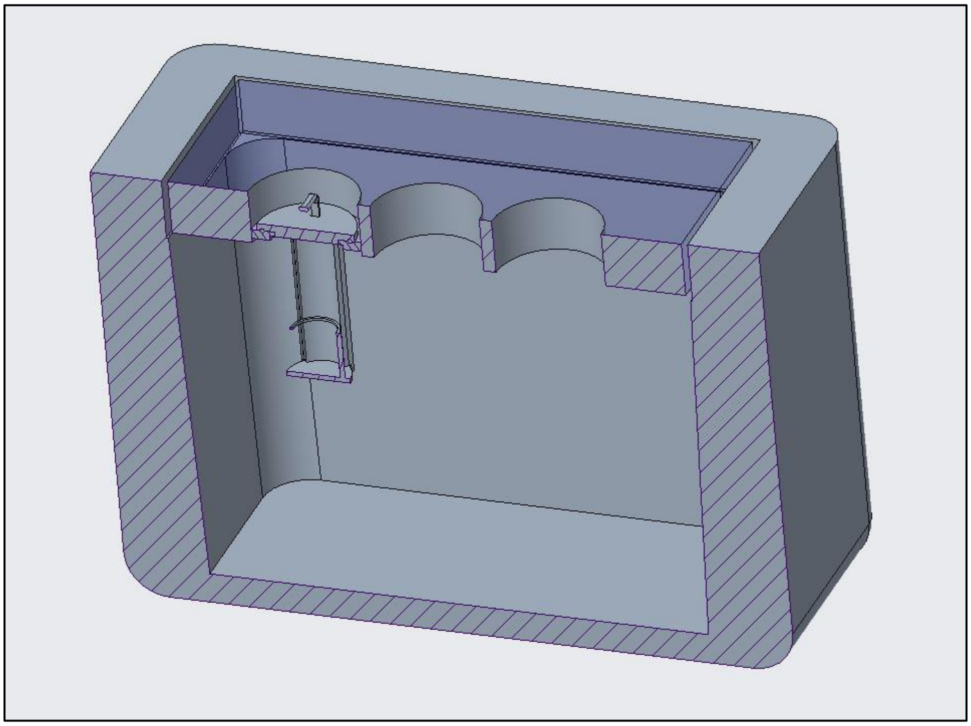


Figure 3. Cross-section of Final Design

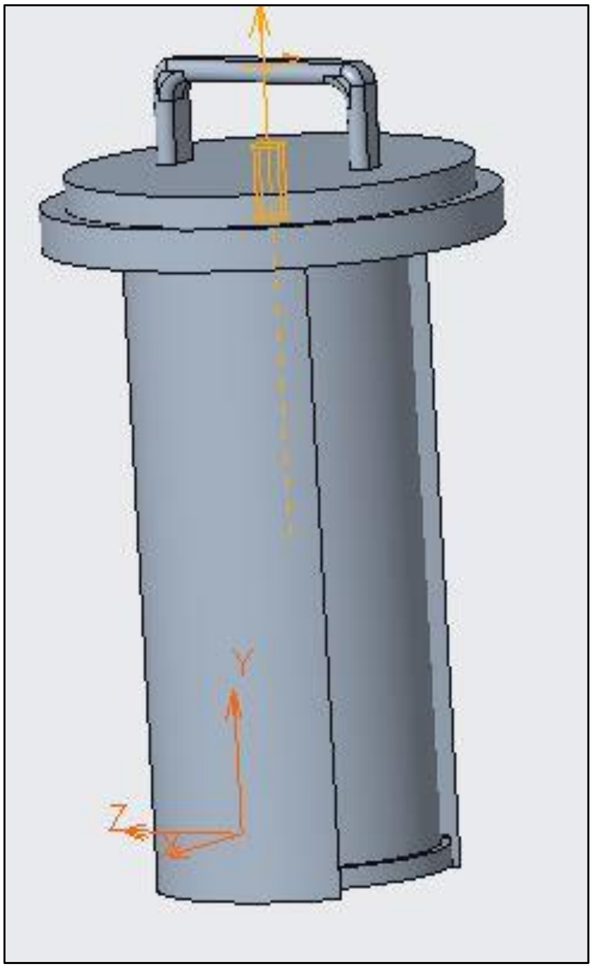



Figure 4. Locking Cylinder (closed)

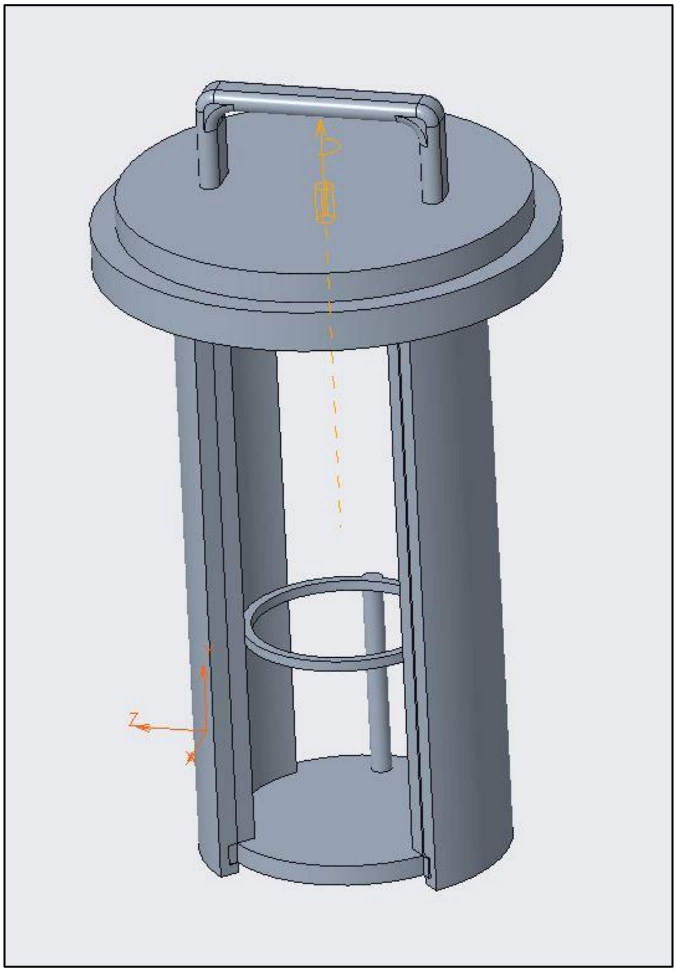


Figure 5. Locking Cylinder (opening)

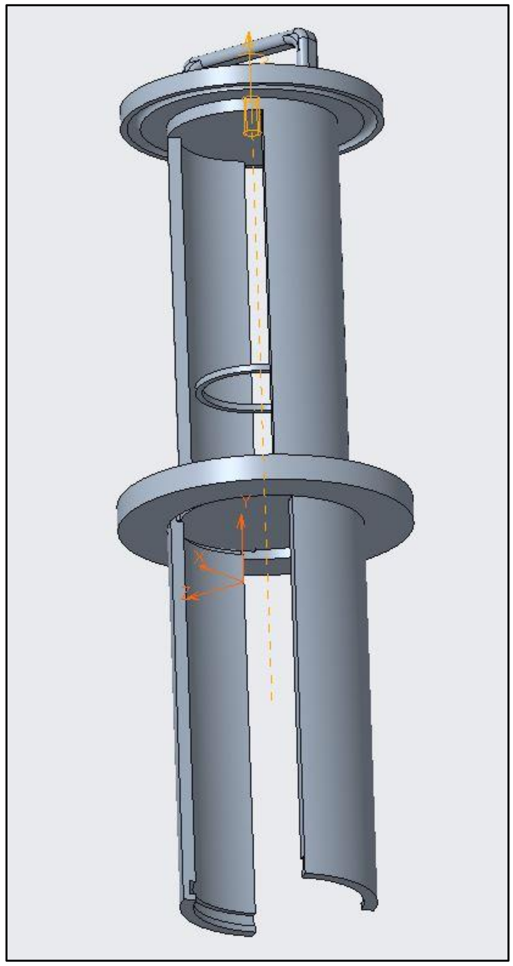


Figure 6. Locking Cylinder (fully open)

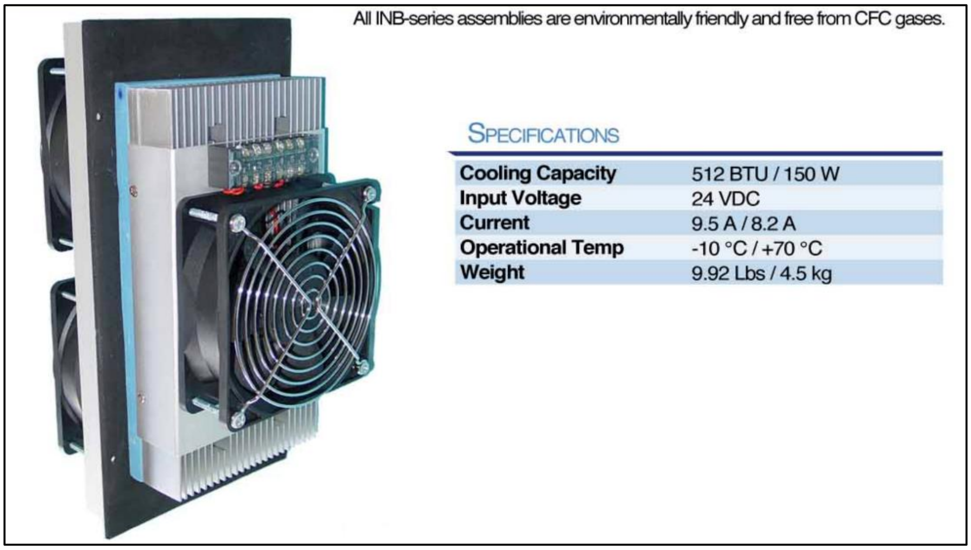



Figure 7. Thermoelectric Cooling (TEC) System

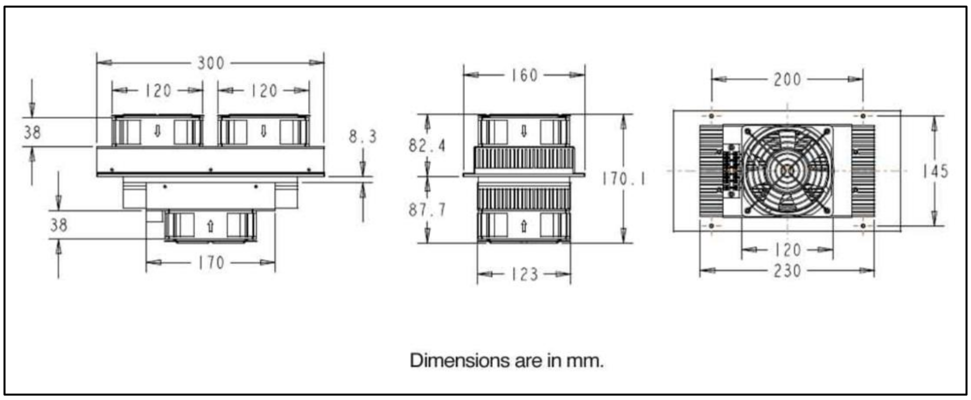



Figure 8. TEC Dimensions

## 1.8 Spring Project Plan

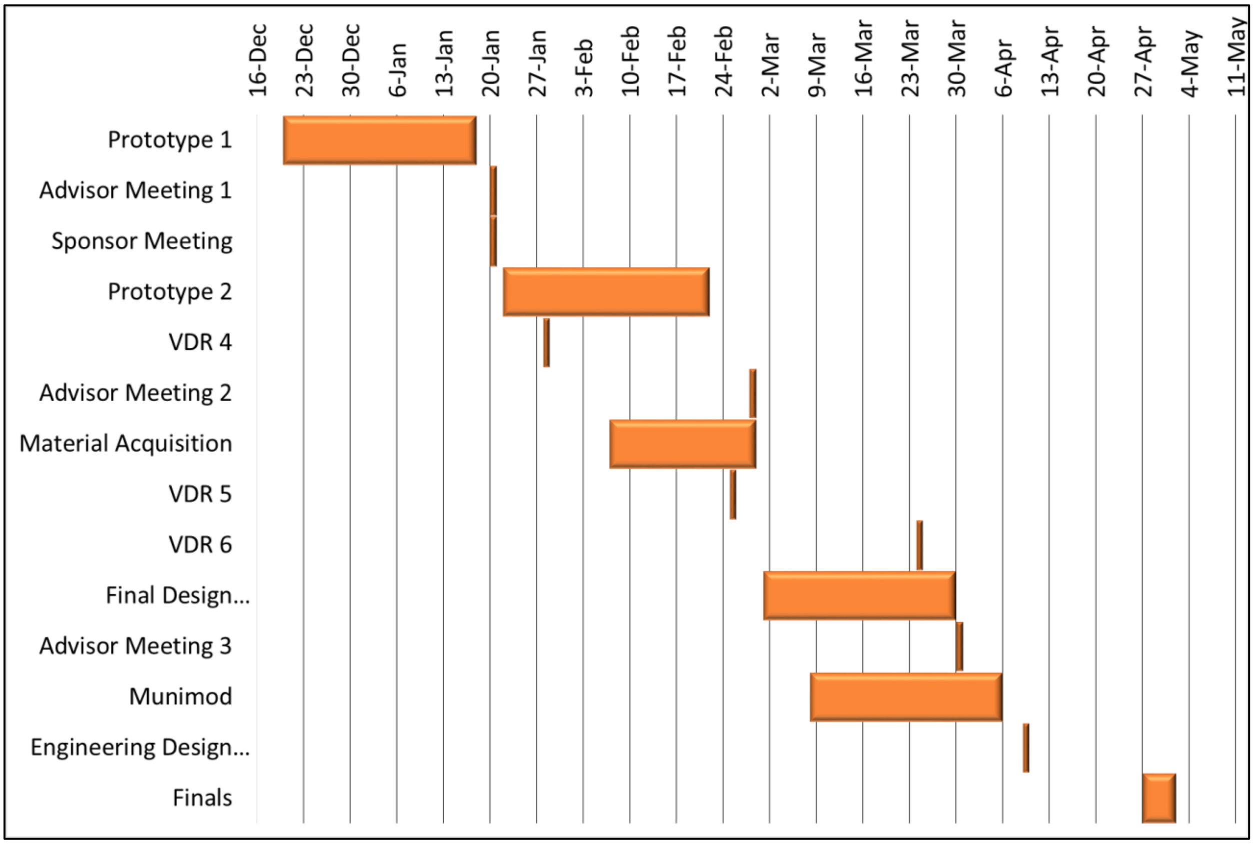



Figure 9. Spring Project Gantt Chart

Below is a breakdown of the upcoming date and milestones for the spring semester.

| Task | Due Date | | Color Code Key |
|---|---|---|---|
| **1. Prototype I** | | | Set Date |
| 1.1 Order Additional Materials | 12/20/2020 | | Subject to Change |
| 1.2 Machine/Fabricate/Assemble Necessary Parts | 1/10/2020 | | Strictly an Estimate |
| 1.3 Conduct Tests | 1/12/2020 | | |
| 1.4 Analyze Data from Testing | 1/17/2020 | | |
| | | | |
| **2. Advisor/Sponsor Meetings** | | | |
| 2.1 Meet with Sponsor | 1/20/2020 | | |
| 2.2 Meet with Advisor | 1/20/2020 | | |
| | | | |
| **3. Prototype II** | | | |
| 3.1 Order Additional Materials | 1/22/2020 | | |
| 3.2 Trial 1 Begins (Length of 3 days) | 1/30/2020 | | |
| 3.3 Assesment and Modification from Trial 1 | 2/5/2020 | | |
| 3.4 Trial 2 Begins (Length of 7 days) | 2/9/2020 | | |
| 3.5 Assement and Modification from Trial 2 | 2/21/2020 | | |
| | | | |
| **4. VDR 4** | 1/28/2020 | | |
| | | | |
| **5. Meet with Advisor** | 2/28/2020 | | |
| | | | |
| **6. Material Acquisition** | 2/28/2020 | | |
| 6.1 Compile Final Bill of Materials | 2/7/2020 | | |
| 6.2 Determine Arrival Time of Materials | 2/7/2020 | | |
| 6.3 Complete Orders for Raw Materials | 2/13/2020 | | |
| 6.4 Complete Orders for Remaining Materials | 2/21/2020 | | |
| 6.5 Machine/Fabricate any Raw Materials | 2/28/2020 | | |
| | | | |
| **7. VDR 5** | 2/25/2020 | | |
| | | | |
| **8. VDR 6** | 3/24/2020 | | |

| | |
|---|---|
| **9. Final Design Assembly** | 3/29/2020 |
| 9.1 Construct Device | 3/1/2020 |
| 9.2 Machining/Fabricating to Join Parts | 3/1/2020 |
| 9.3 Testing of Final Design (Length of 14 days) | 3/8/2020 |
| 9.4 Iteration (if necessary) | 3/29/2020 |
| | |
| **10. Meet with Advisor** | 3/30/2020 |
| | |
| **11. Munimod** | 4/4/2020 |
| 11.1 Begin Working on Presentation | 3/8/2020 |
| 11.2 Finalize Presentation | 3/27/2020 |
| 11.3 Rehearse Presentation | 3/29/2020 |
| 11.4 Competition Starts | 4/4/2020 |
| 11.5 Competition End | 4/5/2020 |
| | |
| **12. Engineering Design Day** | 4/9/2020 |
| | |
| **13. Finals** | 4/27/2020 |
| 13.1 Start of Finals Week | 4/27/2020 |
| 13.2 End of Finals Week | 5/1/2020 |
| | |
| **14. Graduation** | 5/2/2020 |
| 14.1 Engineering Ceremony (9:00am) | 5/2/2020 |

# Chapter Two: EML 4552C

## 2.1 Spring Plan

### Project Plan.

### Build Plan.

**Appendices**

## Appendix A: Code of Conduct

1.2.1 Mission Statement

The team will maintain professionalism and apply technical knowledge in order to effectively communicate with stakeholders and ensure a successful design outcome. In addition, the team will produce high quality work which, in turn, will benefit the members on an educational level.

1.2.2 Team Roles

**Design Engineer: Jesse Arrington**

The Design Engineer has the responsibility of leading the team through the design process and developing innovative designs. They are tasked with design ideation and researching preexisting benchmarks that can benefit the design of the final product. The Design Engineer will work with all members of the team through the design process and ensure that the final design includes the best thermal properties possible, an ideal energy balance, and is realistic and producible.

**Technical Engineer: Christian Torpey**

The Technical Engineer is responsible for quality control, both design itself, and the work produced through the design process. The Technical Engineer will be responsible for reviewing all calculations, designs, and deliverables that the team produces to maintain a high standard of excellence throughout. The Technical Engineer oversees keeping all meeting minutes for any advisor and sponsor meetings, as well as creating the meeting agendas prior to each meeting. Additionally, this member will be the designated "Web Master" and will manage team web page content.

**Thermal Process Engineer: Matthew Israel**

The Thermal Process Engineer oversees the heat exchange process of the product to ensure that all heat transfer within the system is accounted for. They will also be the lead engineer responsible for selecting the materials used in the final design and will work closely with the Production Engineer throughout this process to maintain cost effectiveness while optimizing thermal properties. The Thermal Process Engineer will also work with the Energy Systems Engineer to control the flow of energy throughout the device.

**Energy Systems Engineer: Tyler White**

The Energy Systems Engineer has the responsibility of managing the energy consumption of the system. The Energy Systems Engineer will work alongside the Thermal Process Engineer to monitor the power generation and consumption of the device to ensure its overall efficiency. Additionally, the Energy Systems Engineer will work with the Production Engineer to source the components necessary to allow the final design to operate at an ideal efficiency.

**Production Engineer: Timothy Willms**

The Production Engineer is responsible for creating the 3D CAD models for the parts and assemblies of all prototypes and the eventual final product. Additionally, the Production Engineer will take lead on material sourcing and pricing throughout the duration of the project. The Production Engineer will work closely with the Design Engineer to develop the design concept into a physical, producible product. The Production Engineer will also work closely with the Thermal Process Engineer and Energy Systems Engineer when selecting materials in order to balance optimum thermal properties with cost effectiveness.

1.2.3 Methods of Communication

Communication is a vital component of effective team operation; therefore, the following section details how communication will be carried out within the team and with advisors and sponsors. Within the team, communication will be done using GroupMe and email. The primary location for daily communication will be on GroupMe, and members are expected to check the GroupMe at least 3 times a day. When an assignment is submitted, the person who submitted it is expected to send a photo of the successful Canvas submission in the GroupMe. Email will be used for official communication, such as communication with Dr. McConomy, our advisor Dr. Ali, or our sponsors. All emails will have every team member CC'd on them, and team members are expected to keep up to date on reading emails, even if they are not the point of contact. Any direct email from Dr. McConomy, Dr. Ali, or our sponsors should be replied to in a professional manner and in an appropriate time. Professional emails will have a detailed subject line, greeting, professional email signature, properly formatted, and will be sent from only school email addresses. Emails should ideally be responded to within 3 hours, or at least by the end of that business day.

1.2.4 File Management

All team members are expected to submit their designated component of the assignment to the Technical Engineer at least 17 hours before the assignment is due. Ideally, for assignments due by Friday at 5pm, all members will aim to send their work to the Technical Engineer by midnight the Thursday prior. The Technical Engineer will then edit, format, and compile the final

document for submission and submit it. All files, including the evidence book will be stored on the team OneDrive and will be updated as frequently as possible. Only the Technical Engineer will make edits to the evidence book unless an unexpected situation requires another member to make edits because the Technical Engineer cannot.

1.2.5 Dress Code

Dress code is implemented to ensure team appearance is appropriate based on respective situations. Through the course of the project, the group will hold meetings and give presentations requiring different levels of formality. Since all group members are male, the following generalized dress code is applicable to all members.

For team meetings, advisor meetings, professor meetings and class lectures, casual attire is acceptable, as member functionality is of chief concern. Casual clothing refers to comfortable and informal dress. However, common-sense standards are still required, and clothing should not be offensive or distracting to others.

Business casual attire will be worn by all attending team members during meetings with the sponsor. Business casual includes dress shoes, dress socks, dress slacks and button-up collared shirts. Dress shoe color will be either brown or black. Dress slacks will be grey, tan, navy or black. Sock color must match pant color. Button-ups will be a light color such as white, light blue, or light grey.

For virtual design review presentations, business formal attire is required by all team members. Business formal attire will include a one-, two-, or three-button suit in either grey, navy, or black. Dress shoe color shall be brown or black. Sock color must match pant color. Button-ups will be a light color such as white, light blue, or light grey. Tie patterning will be conservative and bowties are not acceptable.

1.2.6 Attendance Policy

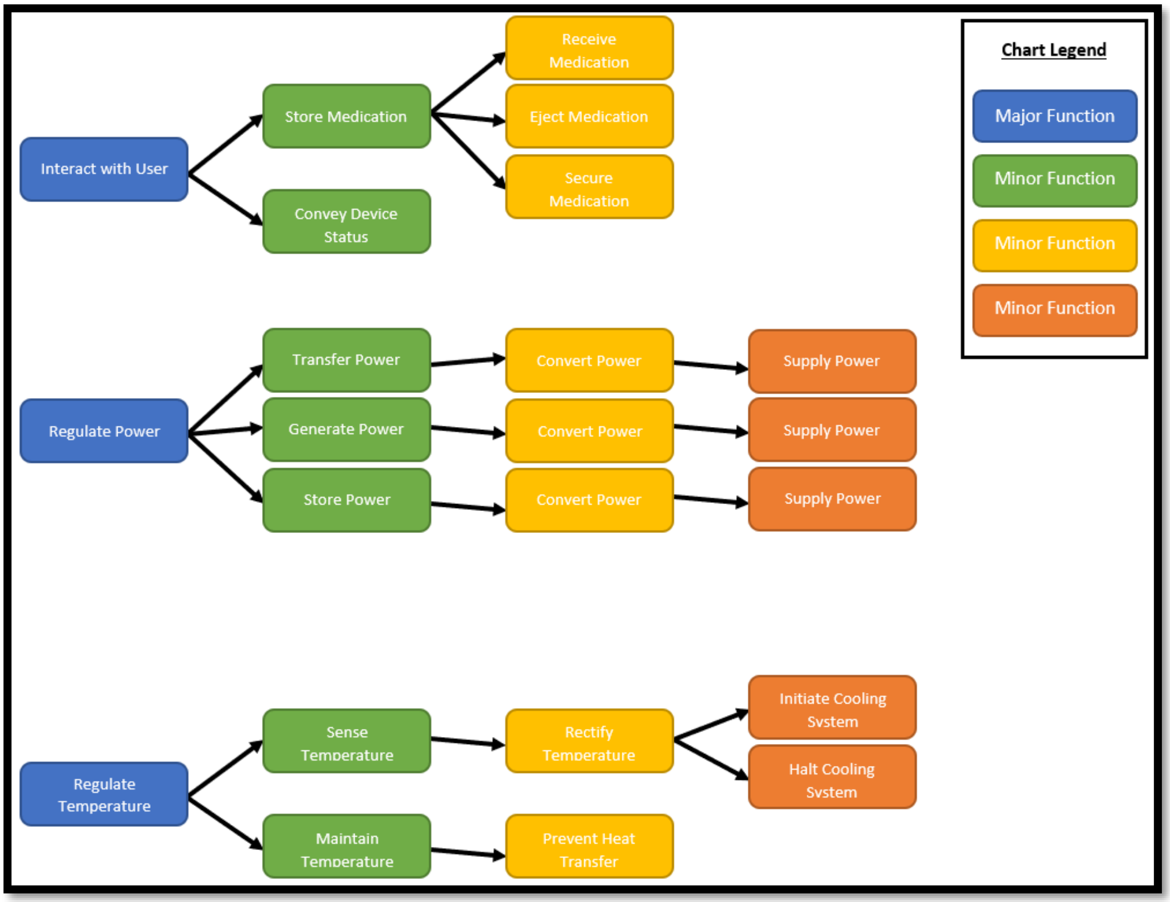
Attendance to mandatory and non-mandatory events will be crucial to the success of this team project. That said, for mandatory and non-mandatory events, any team member projected to miss must notify the team at the date and time of the scheduled event, except in emergency situations. At all mandatory and non-mandatory events, there will be at least 4 of the 5 team members present. To ensure accountability among group members, an excel spreadsheet detailing the meeting date and attendance will be kept throughout the process. If a team member fails to notify the team of their absence—up to two times--before any mandatory or non-mandatory events, the issue will be resolved amongst the team. If it happens a third time, the team will notify Dr. McConomy of the non-compliance.

1.2.7 Statement of Understanding

By signing this document below, we the members of Senior Design Team 512 agree to all the previous terms and agree to abide by this Code of Conduct.

| **Name** | **Signature** | **Date** |
|---|---|---|
| Matthew Israel | Matthew Israel | 1/10/2020 |
| Timothy Willms | [illegible] | 1/10/2020 |
| Tyler White | [illegible] | 1/10/2020 |
| Christian Torpey | C. Torpey | 1/10/2020 |
| Jesse Arrington | [illegible] | 1/10/2020 |

# Appendix B: Functional Decomposition



## Appendix C: Target Catalog

| Function | Metric | Target |
|---|---|---|
| * Receive Medication | * Medicine storage internal volume | * Height = 50mm Diameter = 22mm |
| | Wall thickness | Thickness <= 0.05 meters |
| | Total external size | Volume = 0.0625 - 0.25 $meters^3$ |
| * Eject Medication | * Dimensions for device that removes the medication from the device body | * Height = 50mm Diameter = 22mm |
| * Secure Medication | * Number of medication vials broken | * Vial number = 0 |
| | Impact resistance | Force = 27N |
| Convey device status | The user is notified whether the device is operating properly | Yes |
| Transfer power | Voltage | 120V and/or 240V outlets |
| Generate power | Voltage | 1.5V, 9V, 3V, 3.7V |
| Store power | Voltage | 1.5V, 9V, 3V, 3.7V |
| * Convert power | * Voltage | * 1.5V, 9V, 3V, 3.7V |
| * Supply power | * Voltage | * 1.5V, 9V, 3V, 3.7V |
| * Sense temperature | * Medication temperature | * T = 3.5-6 °C |
| * Rectify temperature | * Medication temperature | * T = 3.5 or 6 °C |
| | * Container cooling time | * Time <= 15 minutes |
| | * Cooling rate | 50.97 mW/°C |
| Initiate cooling system | On/Off | On |
| Halt cooling system | On/Off | On |
| * Prevent heat transfer | * Net heat transfer rate going into and out of the container | * ΔQdot = 0W |

## Appendix D: Work Breakdown Structure

| Task | Assigned to: |
| --- | --- |
| **1. Project Charter** | **Jesse** |
| 1.1 Project Scope | Jesse |
| 1.1.1 Refine project description | Tyler |
| 1.1.2 Determine project goals | Tyler |
| 1.1.3 Research applicable markets | Tim |
| 1.1.4 Consider stakeholders and possible assumptions | Matthew |
| 1.2 Code of Conduct | Tim |
| 1.2.1 Meet with team to discuss conduct | Tyler |
| 1.2.2 Determine member roles/titles | Matthew |
| 1.2.3 Choose method of communication | Tyler |
| 1.2.4 Discuss appropriate dress code and attendance | Tim |
| 1.2.5 Write Statement of Understanding | Jesse |
| 1.3 Edit & Format deliverable | Christian |
| 1.4 Submit | Christian |
| 1.4.1 Notify Team of Submission | Christian |
| **2. Work Break Down Structure** | **Christian** |
| 2.1 Start an Evidence Book for the project | Jesse |
| 2.1.1 List Milestones with due dates | Jesse |
| 2.2 Decompose milestones into small tasks | Matthew |
| 2.2.1 Assign each task to a member | Tyler |
| 2.3 Edit & Format deliverable | Christian |
| 2.4 Submit | Christian |
| 2.4.1 Notify Team of Submission | Christian |
| **3. Customer Needs** | **Tyler** |

| | |
|---|---|
| 3.1 Meet with sponsor to discuss needs | Tyler |
| 3.1.1 Identify unique and repeated statements | Tyler |
| 3.2 Analyze statements given by customer | Matthew |
| 3.2.1 Assign each unique customer statement to an interpreted need | Matthew |
| 3.3 Explanation of Results | Christian |
| 3.3.1 List of questions group asked the customer | Tyler |
| 3.3.2 List statements provided by the customer in relation to each statement | Tim |
| 3.3.3 Identify customer needs in relation to each customer statement | Jesse |
| 3.4 Edit & Format deliverable | Christian |
| 3.5 Submit | Christian |
| 3.5.1 Notify Team of Submission | Christian |
| **4. Functional Decomposition** | **Matthew** |
| 4.1 Discuss and determine Each Low Level Function | All |
| 4.2 Begin a chart/diagram for FD | Tyler |
| 4.3 Explanation of Results | Tim |
| 4.3.1 Discuss Data | Jesse |
| 4.3.2 Discuss Graphics | Matthew |
| 4.3.3 Discuss Methods used for FD | Christian |
| 4.4 Breakdown of Sub functions | Tyler |
| 4.4.1 Describe relation between rows and columns | Tim |
| 4.4.2 Describe relationship between Sub functions | Jesse |
| 4.4.3 Discuss Subsystem Relationships | Matthew |
| 4.5 Actions and Outcomes | Christian |
| 4.5.1 Use physics to explain outcome | Tyler |
| 4.5.2 Describe the physical action of the project | Tim |
| 4.6 Ensure functional resolution is adequate | Jesse |
| 4.7 Edit & Format deliverable | Christian |
| 4.8 Submit | Christian |

| | |
|---|---|
| 4.8.1 Notify Team of Submission | Christian |
| **5. Targets** | **Tim** |
| 5.1 Assign 1 Target/Metric to each Function | Christian |
| 5.2 Generate more Targets/Metrics than Functions | Tyler |
| 5.3 Method of Validation | Tim |
| 5.3.1 Detail method used to determine each target/metric | Jesse |
| 5.4 Discussion of Targets/Metrics | Matthew |
| 5.4.1 Clearly identify the Targets/Metrics | Christian |
| 5.4.2 Determine the Critical Targets/Metrics | Tyler |
| 5.5 Summarize and catalog targets/metrics | Tim |
| 5.6 Edit & Format deliverable | Christian |
| 5.7 Submit | Christian |
| 5.7.1 Notify Team of Submission | Christian |
| **6. Concept Generation** | **Jesse** |
| 6.1 Brainstorm over 100 concepts | Christian |
| 6.1.1 At least 5 Medium Fidelity Concepts | Tyler |
| 6.1.2 At least 3 High Fidelity Concepts | Tim |
| 6.2 Assemble Document | Jesse |
| 6.3 Edit & Format deliverable | Christian |
| 6.4 Submit | Christian |
| 6.4.1 Notify Team of Submission | Christian |
| **7. Concept Selection** | **Jesse** |
| 7.1 Generate House of Quality | Tyler |
| 7.2 Generate Pugh Chart | Matthew |
| 7.3 Generate AHP | Matthew |
| 7.4 Decide on main concept | Tim |

| | |
|---|---|
| 7.5 Edit & Format deliverable | Christian |
| 7.6 Submit | Christian |
| 7.6.1 Notify Team of Submission | Christian |
| **8. Bill of Materials** | **Tim** |
| 8.1 Determine best materials to be used | Matthew |
| 8.2 Research Sourcing & Pricing | Christian |
| 8.3 Generate table of materials and prices | Tyler |
| 8.4 Edit & Format deliverable | Christian |
| 8.5 Submit | Christian |
| 8.5.1 Notify Team of Submission | Christian |
| **9. Risk Assessment** | **Christian** |
| 9.1 Gather all Project Information | Jesse |
| 9.2 Describe project | Jesse |
| 9.3 Detail the Steps of Project | Tim |
| 9.3.1 Analyze Steps of Project to Predict Possible Accidents | Christian |
| 9.3.2 Research Accidents That Have Occurred with Project Materials | Christian |
| 9.3.3 Generate Statements of How to Avoid Hazardous Situations | Christian |
| 9.3.4 Describe Measures to Mitigate Each Hazard | Matthew |
| 9.3.5 Rewrite Project Steps to Include Safety Measures | Jesse |
| 9.3.5 Describe Emergency Response Procedures to Use | Tim |
| 9.4 List Emergency Response Contact Information | Tyler |
| 9.5 Gather Safety Review Signatures | Tyler |
| 9.4 Edit & Format deliverable | Christian |
| 9.5 Submit | Christian |
| 9.5.1 Notify Team of Submission | Christian |
| **10. Spring Project Plan** | **Tyler** |

| | |
|---|---|
| 10.1 Initialize Milestones | Tim |
| 10.2 Work Backwards | Tyler |
| 10.3 Develop Plan for Spring | Matthew |
| 10.4 Edit & Format deliverable | Christian |
| 10.5 Submit | Christian |
| 10.5.1 Notify Team of Submission | Christian |

## Appendix E: Generated Concepts

1. Standard cooler (double walled with insulation), with a miniaturized conventional refrigeration system, LCD display, a thermopile to measure temperature, and a cord to plug into the power source. A large external rechargeable lithium battery, and/or another power generation source can be plugged into to power the device. Vials contained in 3 locking cylinders which can be pulled out from the top, with zip-tie like clamps attached to the cylinders that will secure the vials in place.
2. Double walled vacuum sealed shell with a miniaturized conventional refrigeration system, LCD display, a thermopile to measure temperature, and a cord to plug into the power source. A large external rechargeable lithium battery, and/or another power generation source can be plugged into to power the device. Vials contained in 3 locking cylinders which can be pulled out from the top, vials will be placed in small nets and will hang from the top of the cylinder to keep them from hitting the sides of the container.
3. Standard cooler with sealed rubber gasket (double walled with Styrofoam insulation), with a miniaturized conventional refrigeration system, LCD display, a thermopile to measure temperature, and a single large internal rechargeable lithium battery directly wired to the cooling system and cord to plug into various power generation sources. Vials contained in 3 locking cylinders which can be pulled out from the top, with small feet at the base of the cylinder which cup the vials and hold them in place.
4. Standard cooler (double walled with Styrofoam insulation) with a small drawer with rigid mesh sides to allow air flow that will hold 3 vials that will be placed in padded sleeves prior. A single large internal rechargeable lithium battery will power the LCD display,

thermocouple sensor, and a miniaturized refrigeration system. Device will have a cord to plug into various power generation sources.

5. Standard cooler (double walled with Styrofoam insulation) with a very large cylinder of compressed nitrogen gas, and the release of the nitrogen gas into the cylinder will provide cooling. A mercury thermometer will display the temperature to the user, and a thermocouple will supply temperature information to the microcontroller which will actuate the valve controlling the flow of the gas. The vials will be contained in 3 locking cylinders and will be secured using the zip-tie like clamps.
6. Ranque-Hilsch vortex tube takes compressed air from a compressor and induces a vortex to separate a cold and hot fluid stream. Cold air provides cooling to the medications. A single large internal rechargeable lithium battery will power the LCD display, thermocouple sensor, and a miniaturized refrigeration system. Device will have a cord to plug into various power generation sources.
7. Standard cooler (double walled with Styrofoam insulation) with a medium sized compressed air cylinder and a small compressor, LCD display, and a thermocouple. Multiple small rechargeable batteries (internal) which can be replaced and charge from an external source (either a large external emergency battery or a generation source). Vials will be contained in a small drawer with rigid mesh walls and will be placed in padded sleeves prior to being placed in the drawer.
8. Standard store-bought cooler with hinge opening at the top. A small fan will be placed inside and powered by an external emergency battery and will blow air through a meshed container that will hold multiple chemical reaction cold packs. A thermocouple and an

LCD will also be powered by the battery and the LCD will notify the user when the temperature is getting too high and they need to place more chemical reaction cold packs inside.

9. Standard cooler (double walled with Styrofoam insulation) with a large compressed gas ($N_2$, $CO_2$, air) cylinder. A large internal rechargeable battery powers a thermocouple, LCD display, and a servo which regulates the flow of the compressed gas. Vials are wrapped in sleeves made of “cool towel” material and placed in individual locking cylinders.
10. Double walled vacuum sealed cooler, with vacuum seals individual cylinders for each vial. Cylinders will be insulated as well. Chemical reaction cold packs will be placed into the container using an airlock.
11. Standard cooler (double walled with Styrofoam insulation) with a Ranque-Hilsch vortex tube inside and a small compressed gas storage cylinder and a small compressor. Additionally, a resistance temperature detector and 2 LED external lights will be powered by a large internal rechargeable battery. The battery will be recharged from a large emergency battery and a solar panel that will be directly wired to the device. Vials will be kept in a rigid mesh drawer.
12. Standard cooler (double walled with Styrofoam insulation) with a large evaporative cooling system with external fins which draw heat from the internal section of the device. Vials will be kept in a mesh drawer and will be wrapped in cold towels.
13. Standard cooler (double walled with Styrofoam insulation) with 3 locking cylinders that will have the vials vacuum sealed in a protective bag. Inside the device, the vials will be

submerged in coolant that will have a feed section at the top and bottom of the cooler. Hotter coolant at the top of the container will be circulated through a cooling system (evaporative cooling or some other method) and cooled coolant will be pumped into the bottom of the device. Thermocouple will be located near the vials to ensure accurate temperature readings and will enable the system to not have to operate continuously. Power will be supplied by an external emergency battery.

14. Using CO2 fire extinguishers to create dry ice and then put the dry ice into a cooler with the medication to keep it cool. Dry ice sublimates completely roughly in 24 hours, so multiple fire extinguishers would be needed.
15. Underground storage container utilizing geothermal energy to power an internal chilling refrigeration to maintain temperature levels.
16. Cryogenic fluid control.
17. Utilize a normal refrigeration cycle, with a coolant such as R135a, but where a compressor would normally go, and be powered by electricity, a positive displacement pump and a gate valve would go in its place. The positive displacement pump would be hand powered. Once the coolant is fully depressurized and cooled, the coolant would be allowed to travel back to the evaporator and absorb heat from the inside of the device and away from the medication.
18. Install a large rain barrel system which will store all of the rain produced during the hurricane, and then a hydroelectric generator will utilize the stored water to power a small refrigerator for the medication.

19. Use zeer pots method, which is a multi-layer clay pot design with sand between the layers of clay pots, which operates under the premise of evaporative cooling. This design is ancient but still very effective and is used to this day in primitive regions of the world.
20. Immersion cooling system (similar to those used in large servers) that uses a coolant to maintain the medicine at the required temperature.
21. Bury a high-quality cooler filled with ice underground in a well shaded area to limit heat exposure and heat loss.
22. Running cool water through a double walled cooler to minimize heat loss due from surrounding conditions.
23. Koozie insulation coverings for individual medication vials to prevent heat transfer and maintain temperature.
24. Kinetic energy reaction packs to cover the vials in, so the user can shake the vials to cause a cooling reaction.
25. A cooler with a mechanical, human powered pressurized device that cools the internal state through convection.
26. Solar powered mini-fridge.
27. Multilayered cooling system that incorporates normal ice and dry ice in a layering effect to prevent heat losses.
28. A cooler that the inside is layered like an ice pack, containing a much smaller storage area. The cooler will be left in the freezer prior to the power outage so that the cold packs are frozen.

29. A device with a cooling system that uses the reaction from ammonium nitrate and water to cool the system.
30. A high humidity state material doubled with a convection process from the outside air to circulate in cooler air to the system.
31. A device that maintains the internal temperature through the use of refrigeration system powered by the Rankine cycle via propane.
32. A cooler with an A/C system running off the house's supply of natural gas.
33. Separate insulated blocks per vial that connect to a grid like system that can cool the medication, and as each block is removed for use, the other blocks remained seals. Additionally, less power is consumed with less vials being connected.
34. A storage device equipped with a compressor in which the user can mechanically compress a liquid through human power which then circulates within the device to lower the temperature.
35. A double walled cooler lined with dry ice packs that maintains the internal temperature by preventing convection losses due to the ambient conditions.
36. A device that can cooling the medication in storage through a manually operated fan.
37. Generate power with a person running on a treadmill
38. Use combination of rock salt and ice to provide greater cooling for the medication
39. Use a water wheel and a series of gears to provide the rotational motion for a cooling fan
40. Use lemons to generate enough electricity to power a cooling system
41. Burn wood to heat water into steam to drive a turbine and power a cooling system
42. Use highly reflective paint on the outside of the device to reduce absorbed solar radiation

43. Burn gunpowder to produce the necessary heat to drive a steam engine
44. Cover house in solar panels and be off the grid!
45. Install a large wind turbine on residential property to generate enough energy to power a traditional refrigeration unit
46. Miniaturized fission nuclear pressurized water reactor converting radioactive decay into thermal energy to produce steam that drives a turbine to power an A/C system.
47. Molten salt reactor converting radioactive decay into thermal energy to produce steam that drives a turbine to power an A/C system.
48. A cooler featuring a reaction between potassium chloride and water to keeping the internal temperature within the desired range.
49. Exothermic chemical reaction producing thermal energy to produce steam that drives a turbine to power an A/C system.
50. A dual humidity and fan-controlled device that uses temperature circulation methods through the energy of 2 AA batteries.
51. A liquid nitrogen system that initially begins at a subzero temperature, and then distributes the "warming" gas, which will then be at an appropriate temperature for the medicine, at a periodic rate. At the same time, the tank continues to contain much colder than desired nitrogen.
52. A refrigeration system used to cool the device, that's power by a sterling engine, which generates power via a candle.
53. An ice bath cooling system that flows through the walls of a cooler, in which case ice is needed less frequently.

54. A system based on a chemical reaction that induces a current to power a cooling system for the device.
55. Utilize a lightning rod to capture the energy from lightning and store it for later use in a battery
56. A mini-fridge device with a long wired solar panel used for power. In these conditions, the solar panel can be left outside while the mini-fridge remains inside. Under these conditions the solar panel can be smaller or the mini-fridge can be bigger.
57. Endothermic chemical reaction lowers the temperature of the surroundings creating a net cooling effect within the device.
58. Utilize the premise of a potato clock, but on an industrial size. So, create a fuel cell array of many potatoes in parallel to create a high enough voltage and current to power a very small refrigeration system.
59. A vacuum sealed primary layer with an insulated internal layer around the medication. The vacuum sealed portion will remove many heat losses associated with convection by the surrounding air.
60. A cooler with an outside layered pressurizing system that takes in air and uses geometric pressurizing techniques to provide cooler air to the inside of the container.
61. Create individual containers for each vial of medication made of aerogel. These containers will then be place inside a high-quality cooler.
62. Use a hand crank powered Van de Graaff generator which will produce static electricity which can then be collected and used to charge batteries which will then power a miniaturized refrigeration system. The hand crank will have an attached gear box with a

high ratio so that the user will not have to crank very fast but the end result will have a very high angular velocity.

63. Utilize natural springs to provide cold water to cool the medication, medication would simply be placed in a vacuum sealed bag and then would be placed in a protective container that is connected to an already tapped natural spring such as the Crystal Springs which Zephyrhills uses for their bottling plant.
64. Utilize an electrolytic cell and human urine to produce hydrogen which can be used to power a generator and create electricity to power a small refrigeration system.
65. Generate power by burning various fuels in a furnace and generate electricity from that process to power the household refrigerator.
66. Induce electromagnetic induction using two magnets and coiled wire to produce an electric field that can be harnessed to convert to electrical power

# Appendix F: Concept Selection Methods

## F.1 Binary Pairwise Comparison Chart of Customer Requirements

Binary Pairwise Comparison Chart of Customer Requirements

| | The device is intended to store and maintain chilled medication. | The device sustains a desired temperature without the use of ice. | The device is durable in all environmental conditions. | The device is easily portable. | The device can be transported by individuals of every age. | The device visually displays the storage temperature to the user. | The device prohibits unauthorized access. | The device generates and uses minimal power to keep the medication refrigerated. | The device maintains a temperature range suitable for refrigerated medicines. | The device features multiple sources of power generation based on environmental conditions. | The device will maintain power without being connected to the grid. | The device controls the temperature of the system for a target of three months without being plugged into an external power source. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| The device is intended to store and maintain chilled medication. | — | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| The device sustains a desired temperature without the use of ice. | 1 | — | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 4 |
| The device is durable in all environmental conditions. | 1 | 1 | — | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 6 |
| The device is easily portable. | 1 | 1 | 0 | — | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 5 |
| The device can be transported by individuals of every age. | 1 | 1 | 1 | 1 | — | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 8 |
| The device visually displays the storage temperature to the user. | 1 | 1 | 1 | 1 | 1 | — | 0 | 1 | 1 | 0 | 1 | 0 | 8 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **The device prohibits unauthorized access.** | 1 | 1 | 1 | 1 | 1 | 1 | \| | 1 | 1 | 1 | 1 | 1 | 11 |
| **The device generates and uses minimal power to keep the medication refrigerated.** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | \| | 1 | 0 | 1 | 0 | 3 |
| **The device maintains a temperature range suitable for refrigerated medicines.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | \| | 0 | 0 | 0 | 0 |
| **The device features multiple sources of power generation based on environmental conditions.** | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | \| | 1 | 0 | 8 |
| **The device will maintain power without being connected to the grid.** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | \| | 0 | 2 |
| **The device controls the temperature of the system for a target of three months without being plugged into an external power source.** | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | \| | 10 |
| **Total** | 10 | 7 | 5 | 6 | 3 | 3 | 0 | 8 | 11 | 3 | 9 | 1 | |
| **Check (TRUE if properly filled out)** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | **TRUE** | |

F.2 House of Quality

| Key | | |
|---|---|---|
| | 1 | Weak Relationship |
| | 3 | Moderate Relationship |
| | 9 | Strong Relationship |

| | | Engineering Characteristics | | | | | |
|---|---|---|---|---|---|---|---|
| Improvement Direction | | ↑ | ↑ | ↓ | ↓ | ↑ | ↓ |
| Units | | Wh | W | W | m3 | # | kg |
| **Customer Requirements** | **Importance Weight Factor** | **Power Capacity (Storage)** | **Generated Power** | **Power Consuption** | **External Size** | **Number of Power Generation Sources** | **Weight** |
| The device is intended to store and maintain chilled medication. | **10** | | | 1 | | 3 | |
| The device sustains a desired temperature without the use of ice. | **7** | | 9 | 1 | | 3 | |
| The device is durable in all environmental conditions. | **5** | | | | 1 | | 1 |
| The device is easily portable. | **6** | | | | 9 | | 9 |
| The device can be transported by individuals of every age. | **3** | | | | 9 | | 9 |
| The device visually displays the storage temperature to the user. | **3** | 1 | 1 | 3 | | | |

| Heat Transfer Rate | Cooling Time | Excess Internal Volume | Cost | Number of Vials Stored | Durability (Impact Resistance) | Ease of Operation | Safety of Medication |
|---|---|---|---|---|---|---|---|
| W | sec | m3 | $ | # | N | ---- | ---- |
| ↓ | ↓ | ↓ | ↓ | ↑ | ↑ | ↑ | ↑ |
| 9 | 9 | 3 | 9 | 1 | | | |
| 9 | 1 | 1 | | 1 | | | |
| | | | 3 | | 9 | 3 | 3 |
| | | | 1 | 9 | 1 | 9 | |
| | | | | | 1 | 9 | |
| | | | 1 | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **The device prohibits unauthorized access.** | **0** | | | | | | |
| **The device generates and uses minimal power to keep the medication refrigerated.** | **8** | 3 | 9 | 9 | | 3 | |
| **The device maintains a temperature range suitable for refrigerated medicines.** | **11** | 3 | 9 | 9 | | | 1 |
| **The device features multiple sources of power generation based on environmental conditions.** | **3** | 3 | 9 | 3 | | 9 | |
| **The device will maintain power without being connected to the grid.** | **9** | 9 | 9 | 9 | | 9 | |
| **The device controls the temperature of the system for a target of three months without being plugged into an external power source.** | **1** | 9 | 9 | 9 | | 3 | |
| **Raw Score** | **2276** | 159 | 354 | 296 | 86 | 186 | 97 |
| **Relative Weight %** | | 6.985940246 | 15.55360281 | 13.00527241 | 3.778558875 | 8.172231986 | 4.261862917 |
| **Rank Order** | | 7 | 1 | 2 | 11 | 6 | 9 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | 3 |
| 3 | 9 | 1 | 1 | | | | |
| 9 | 9 | | 1 | 3 | | | 3 |
| | | | 9 | | | | |
| | | | 3 | | | | 0 |
| 9 | 9 | 1 | 1 | | | | 0 |
| 285 | 277 | 46 | 188 | 104 | 54 | 96 | 48 |
| 12.52196837 | 12.17047452 | 2.021089631 | 8.260105448 | 4.569420035 | 2.37258348 | 4.21792619 | 2.108963093 |
| 3 | 4 | 14 | 5 | 8 | 12 | 10 | 13 |

F.3 Pugh Chart

| Pugh Chart | | | | | | |
|---|---|---|---|---|---|---|
| Selection Criteria | Datum | Concepts | | | | |
| | Dcol Battery Powered Insulin Cooler | 1 | 2 | 3 | 4 | 5 |
| Generated Power | 0 | 1 | 1 | 1 | 1 | 1 |
| Power Consuption | 0 | -1 | 1 | 1 | S | S |
| Heat Transfer Rate | 0 | 1 | 1 | 1 | 1 | 1 |
| Cooling Time | 0 | S | 1 | -1 | S | S |
| Cost | 0 | -1 | -1 | -1 | -1 | -1 |
| **# of pluses** | 0 | 2 | 4 | 3 | 2 | 2 |
| **# of minuses** | 0 | 2 | 1 | 2 | 1 | 1 |

| Selection Criteria | Datum | Concepts | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Generated Power | 0 | S | S | S |
| Power Consuption | 0 | 2 | 2 | 1 |
| Heat Transfer Rate | 0 | S | S | S |
| Cooling Time | 0 | 1 | -1 | S |
| Cost | 0 | S | S | S |
| **# of pluses** | 0 | 3 | 2 | 1 |
| **# of minuses** | 0 | 0 | 1 | 0 |
| Sum | 0 | 3 | 1 | 1 |

| Criteria Comparison Matrix [C] | | | | | |
|---|---|---|---|---|---|
| | Generate Power | Power Consumption | Heat Transfer | Cooling Time | Cost |
| Generate Power | 1 | 3 | 5 | 5 | 0.333333333 |
| Power Consumption | 0.333333333 | 1 | 3.000000003 | 5 | 0.333333333 |
| Heat Transfer | 0.2 | 0.333333333 | 1 | 3 | 0.2 |
| Cooling Time | 0.2 | 0.2 | 0.333333333 | 1 | 0.2 |
| Cost | 3 | 3 | 5 | 5 | 1 |
| Sum | 4.733333333 | 7.533333333 | 14.33333334 | 19 | 2.066666666 |

| Normalized Criteria Comparison Matrix [NormC] | | | | | | |
|---|---|---|---|---|---|---|
| | Generate Power | Power Consumption | Heat Transfer | Cooling Time | Cost | Criteria weights {W} |
| Generate Power | 0.211267606 | 0.398230089 | 0.348837209 | 0.263157895 | 0.161290322 | 0.276556624 |
| Power Consumption | 0.070422535 | 0.132743363 | 0.209302326 | 0.263157895 | 0.161290322 | 0.167383288 |
| Heat Transfer | 0.042253521 | 0.044247788 | 0.069767442 | 0.157894737 | 0.096774194 | 0.082187536 |
| Cooling Time | 0.042253521 | 0.026548673 | 0.023255814 | 0.052631579 | 0.096774194 | 0.048292756 |
| Cost | 0.633802817 | 0.398230089 | 0.348837209 | 0.263157895 | 0.483870968 | 0.425579795 |
| Sum | 1 | 1 | 1 | 1 | 1 | 1 |

| Consistency Check | | |
|---|---|---|
| {Ws}=[C]{W} | {W} | Cons={Ws}./{W} |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 1.572967881 | 0.276556624 | 5.687688322 |
| 0.88945515 | 0.167383288 | 5.313882645 |
| 0.423287518 | 0.082187536 | 5.150264105 |
| 0.249592543 | 0.048292756 | 5.168322611 |
| 2.409800994 | 0.425579795 | 5.662395206 |

| 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 |

| | |
|---|---|
| Average consistency | 5.396510578 |
| Consistency Index | 0.099127644 |
| Consistency Ratio | 0.089304184 |

| Generate Power [C] | | | | | |
|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 |
| Design 1 | 1 | 0.333333333 | 1 | 0.2 | 1 |
| Design 2 | 3 | 1 | 3 | 0.333333333 | 3 |
| Design 3 | 1 | 0.333333333 | 1 | 5 | 1 |
| Design 4 | 5 | 3 | 0.2 | 1 | 5 |
| Design 5 | 1 | 0.333333333 | 1 | 0.2 | 1 |
| Sum | 11 | 5 | 6.2 | 6.733333333 | 11 |

| Normalized Generate Power Comparison [NormC] | | | | | | |
|---|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 | Design Alternate Priorities {Pi} |
| Design 1 | 0.090909091 | 0.066666667 | 0.161290323 | 0.02970297 | 0.090909091 | 0.087895628 |
| Design 2 | 0.272727273 | 0.2 | 0.483870968 | 0.04950495 | 0.272727273 | 0.255766093 |
| Design 3 | 0.090909091 | 0.066666667 | 0.161290323 | 0.742574257 | 0.090909091 | 0.230469886 |
| Design 4 | 0.454545455 | 0.6 | 0.032258065 | 0.148514851 | 0.454545455 | 0.337972765 |
| Design 5 | 0.090909091 | 0.066666667 | 0.161290323 | 0.02970297 | 0.090909091 | 0.087895628 |
| Sum | 1 | 1 | 1 | 1 | 1 | |

| Consistency Check | | |
|---|---|---|
| {Ws}=[C]{Pi} | {Pi} | Cons={Ws}./{Pi} |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 0.559111059 | 0.087895628 | 6.361079276 |
| 1.587207108 | 0.255766093 | 6.205697913 |
| 2.181380332 | 0.230469886 | 9.464925645 |
| 2.030321303 | 0.337972765 | 6.007351814 |
| 0.559111059 | 0.087895628 | 6.361079276 |

| | |
|---|---|
| Average consistency | 6.880026785 |
| Consistency Index | 0.470006696 |
| Consistency Ratio | 0.068314661 |

| Power Consumption [C] | | | | | |
|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 |
| Design 1 | 1 | 0.142857143 | 0.2 | 0.333333333 | 1 |
| Design 2 | 7 | 1 | 3 | 3 | 5 |
| Design 3 | 5 | 0.333333333 | 1 | 3 | 5 |
| Design 4 | 3 | 0.333333333 | 0.333333333 | 1 | 1 |
| Design 5 | 1 | 0.2 | 0.2 | 1 | 1 |
| Sum | 17 | 2.00952381 | 4.733333333 | 8.333333333 | 13 |

| Normalized Power Consumption Comparison [NormC] | | | | | | |
|---|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 | Design Alternate Priorities {Pi} |
| Design 1 | 0.058823529 | 0.071090047 | 0.042253521 | 0.04 | 0.076923077 | 0.057818035 |
| Design 2 | 0.411764706 | 0.497630332 | 0.633802817 | 0.36 | 0.384615385 | 0.457562648 |
| Design 3 | 0.294117647 | 0.165876777 | 0.211267606 | 0.36 | 0.384615385 | 0.283175483 |
| Design 4 | 0.176470588 | 0.165876777 | 0.070422535 | 0.12 | 0.076923077 | 0.121938596 |
| Design 5 | 0.058823529 | 0.099526066 | 0.042253521 | 0.12 | 0.076923077 | 0.079505239 |
| Sum | 1 | 1 | 1 | 1 | 1 | |

| Consistency Check | | |
|---|---|---|
| {Ws}=[C]{Pi} | {Pi} | Cons={Ws}./{Pi} |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 0.299970661 | 0.057818035 | 5.188184993 |
| 0.299970661 | 0.457562648 | 0.655583804 |
| 0.299970661 | 0.283175483 | 1.059310143 |
| 0.299970661 | 0.121938596 | 2.460014076 |
| 0.299970661 | 0.079505239 | 3.772967241 |

| | |
|---|---|
| Average consistency | 2.627212052 |
| Consistency Index | -0.593196987 |
| Consistency Ratio | -0.225789535 |

| Heat Transfer [C] | | | | | | |
|---|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 | |
| Design 1 | 1 | 0.333333333 | 0.2 | 1 | 1 | |
| Design 2 | 3 | 1 | 0.5 | 3 | 3 | |
| Design 3 | 5 | 2 | 1 | 5 | 5 | |
| Design 4 | 1 | 0.333333333 | 0.2 | 1 | 1 | |
| Design 5 | 1 | 0.333333333 | 0.2 | 1 | 1 | |
| Sum | 11 | 3.999999999 | 2.1 | 11 | 11 | |

| Normalized Heat Transfer Comparison [NormC] | | | | | | |
|---|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 | Design Alternate Priorities {Pi} |
| Design 1 | 0.090909091 | 0.083333333 | 0.095238095 | 0.090909091 | 0.090909091 | 0.09025974 |
| Design 2 | 0.272727273 | 0.25 | 0.238095238 | 0.272727273 | 0.272727273 | 0.261255411 |
| Design 3 | 0.454545455 | 0.5 | 0.476190476 | 0.454545455 | 0.454545455 | 0.467965368 |
| Design 4 | 0.090909091 | 0.083333333 | 0.095238095 | 0.090909091 | 0.090909091 | 0.09025974 |
| Design 5 | 0.090909091 | 0.083333333 | 0.095238095 | 0.090909091 | 0.090909091 | 0.09025974 |
| Sum | 1 | 1 | 1 | 1 | 1 | |

| Consistency Check | | |
|---|---|---|
| {Ws}=[C]{Pi} | {Pi} | Cons={Ws}./{Pi} |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 0.451457431 | 0.09025974 | 5.001758593 |
| 1.307575758 | 0.261255411 | 5.004971002 |
| 2.344372294 | 0.467965368 | 5.009713228 |
| 0.451457431 | 0.09025974 | 5.001758593 |
| 0.451457431 | 0.09025974 | 5.001758593 |

| | |
|---|---|
| Average consistency | 5.003992002 |
| Consistency Index | 0.000998 |
| Consistency Ratio | 0.000199441 |

| Cooling Time [C] | | | | | |
|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 |
| Design 1 | 1 | 0.142857143 | 0.333333333 | 0.142857143 | 3 |
| Design 2 | 7 | 1 | 5 | 3 | 9 |
| Design 3 | 3 | 0.2 | 1 | 0.333333333 | 5 |
| Design 4 | 5 | 0.333333333 | 3 | 1 | 7 |
| Design 5 | 0.333333333 | 0.111111111 | 0.2 | 0.142857143 | 1 |
| Sum | 16.33333333 | 1.787301587 | 9.533333333 | 4.619047619 | 25 |

| Normalized Cooling Time Comparison [NormC] | | | | | | |
|---|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 | Design Alternate Priorities {Pi} |
| Design 1 | 0.06122449 | 0.079928952 | 0.034965035 | 0.030927835 | 0.12 | 0.065409262 |
| Design 2 | 0.428571429 | 0.559502664 | 0.524475524 | 0.649484536 | 0.36 | 0.504406831 |
| Design 3 | 0.183673469 | 0.111900533 | 0.104895105 | 0.072164948 | 0.2 | 0.134526811 |
| Design 4 | 0.306122449 | 0.186500888 | 0.314685315 | 0.216494845 | 0.28 | 0.260760699 |
| Design 5 | 0.020408163 | 0.062166963 | 0.020979021 | 0.030927835 | 0.04 | 0.034896396 |
| Sum | 1 | 1 | 1 | 1 | 1 | |

| Consistency Check | | |
|---|---|---|
| {Ws}=[C]{Pi} | {Pi} | Cons={Ws}./{Pi} |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 0.324250369 | 0.065409262 | 4.957254635 |
| 2.731255389 | 0.504406831 | 5.414786681 |
| 0.693038179 | 0.134526811 | 5.151673289 |
| 1.403797829 | 0.260760699 | 5.383471638 |
| 0.176901578 | 0.034896396 | 5.069336557 |

| | |
|---|---|
| Average consistency | 5.19530456 |
| Consistency Index | 0.04882614 |
| Consistency Ratio | 0.009398129 |

| Cost [C] | | | | | |
|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 |
| Design 1 | 1 | 0.2 | 0.333333333 | 0.2 | 1 |
| Design 2 | 5 | 1 | 3 | 1 | 5 |
| Design 3 | 3 | 0.333333333 | 1 | 0.333333333 | 5 |
| Design 4 | 5 | 1 | 3 | 1 | 5 |
| Design 5 | 1 | 0.2 | 0.2 | 0.2 | 1 |
| Sum | 15 | 2.733333333 | 7.533333333 | 2.733333333 | 17 |

| Normalized Cost Comparison [NormC] | | | | | | |
|---|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 | Design Alternate Priorities {Pi} |
| Design 1 | 0.066666667 | 0.073170732 | 0.044247788 | 0.073170732 | 0.058823529 | 0.063215889 |
| Design 2 | 0.333333333 | 0.365853659 | 0.398230088 | 0.365853659 | 0.294117647 | 0.351477677 |
| Design 3 | 0.2 | 0.12195122 | 0.132743363 | 0.12195122 | 0.294117647 | 0.17415269 |
| Design 4 | 0.333333333 | 0.365853659 | 0.398230088 | 0.365853659 | 0.294117647 | 0.351477677 |
| Design 5 | 0.066666667 | 0.073170732 | 0.026548673 | 0.073170732 | 0.058823529 | 0.059676066 |
| Sum | 1 | 1 | 1 | 1 | 1 | |

| Consistency Check | | |
|---|---|---|
| {Ws}=[C]{Pi} | {Pi} | Cons={Ws}./{Pi} |
| Weighted Sum Vector | Criteria Weights | Consistency Vector |
| 0.321533923 | 0.063215889 | 5.08628331 |
| 1.839873203 | 0.351477677 | 5.234680101 |
| 0.896499142 | 0.17415269 | 5.147776602 |
| 1.839873203 | 0.351477677 | 5.234680101 |
| 0.298313565 | 0.059676066 | 4.99888117 |

| | |
|---|---|
| Average consistency | 5.140460257 |
| Consistency Index | 0.035115064 |
| Consistency Ratio | 0.006831113 |

| Final Rating Matrix | | | | | |
|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 |
| Generate Power | 0.087895628 | 0.255766093 | 0.230469886 | 0.337972765 | 0.087895628 |
| Power Consumption | 0.057818035 | 0.457562648 | 0.283175483 | 0.121938596 | 0.079505239 |
| Heat Transfer | 0.09025974 | 0.261255411 | 0.467965368 | 0.09025974 | 0.09025974 |
| Cooling Time | 0.065409262 | 0.504406831 | 0.134526811 | 0.260760699 | 0.034896396 |
| Cost | 0.063215889 | 0.351477677 | 0.17415269 | 0.351477677 | 0.059676066 |

| [Final Rating Matrix]^T | | | | | |
|---|---|---|---|---|---|
| | Design 1 | Design 2 | Design 3 | Design 4 | Design 5 |
| Generate Power | 0.087895628 | 0.057818035 | 0.09025974 | 0.065409262 | 0.063215889 |
| Power Consumption | 0.255766093 | 0.457562648 | 0.261255411 | 0.504406831 | 0.351477677 |
| Heat Transfer | 0.230469886 | 0.283175483 | 0.467965368 | 0.134526811 | 0.17415269 |
| Cooling Time | 0.337972765 | 0.121938596 | 0.09025974 | 0.260760699 | 0.351477677 |
| Cost | 0.087895628 | 0.079505239 | 0.09025974 | 0.034896396 | 0.059676066 |

| Concept | Alternative Value |
|---|---|
| Design 1 | 0.071466316 |
| Design 2 | 0.34273508 |
| Design 3 | 0.230210274 |
| Design 4 | 0.283471966 |
| Design 5 | 0.072116363 |

## Appendix G: Bill of Materials

# Bill of Materials - T512

| KEY: | Do not order - more information needed | Do not order - free from school | In stores | Recieved |
|---|---|---|---|---|

| Project Maturity: | 5.0% |
|---|---|

| T512 Part | Item | Description | Quantity | Manufacturer | Supplier |
|---|---|---|---|---|---|
| 1 | Void-Filling Spray Foam Insulation | 1.8lbs./cu. ft Density. Heat Flow Rate: 0.16 Btu @ 75F | 1 | n/a | McMaster-Carr |
| 2 | Buna-N O-Ring | 34mm ID, 2mm Thickness, 38mm OD | 1 | n/a | McMaster-Carr |
| 3 | Legend 6-Can Cooler | 5 qt cooler | 1 | Igloo | Igloo |
| 4 | Explorer 240 Portable Power Station | 240Wh (14.4V, 16.8Ah). Charging Input:12V-30V(42W Max). DC Output: 13.3V, up to 10A. USB Output: 5V 2.4A | 1 | Jackery | Jackery.com |
| 5 | Explorer 50W Solar Panel | Equipped with 1* USB-A output port (5V/2.4A) and 1*USB-C output port (5V/3A) in addition to 1* DC port (16.2V/3.15A/50W) | 1 | Jackery | Jackery.com |
| 6 | Super Silicone Sealant | 3oz Tube. Temperature Range: -75F to 400F. 325 psi Tensile Strength. 24hr Hardening Time | 1 | 3M | McMaster-Carr |
| 7 | Mini Nano V3.0 ATmega328P Microcontroller Board | Arduino Nano. Digital I/O Pins 14 (of which 6 provide PWM output). Flash Memory 32 KB (ATmega328) of which 2 KB used by bootloader | 1 | Makerfire | Amazon.com |
| 8 | USB Battery Pack | 2200mAh Capacity. 5V 1A Output | 1 | Adafruit | Adafruit |
| 9 | USB Male to Male Cable | USB 2.0 Cable, 45.7cm Long | 1 | Monoprice | Amazon.com |
| 10 | Large Sized Heat Sink set | 12V Thermoelectric Peltier Cooler Refrigeration Cooling System Heat Sink Conduction Module | 2 | n/a | Amazon.com |
| 11 | Digital Thermocouple | Proster Digital Thermocouple Temperature Thermometer with Two K-Type Thermocouple | 1 | Proster | Amazon.com |
| 12 | Locking Cylinders | SLA Printed | 3 | Ciscor | n/a |
| 13 | xterior Protective Grat | ABS Printed In Sections | 1 | Innovation Hub | n/a |

| Unit Weight | Specifications | Unit Cost | Cost | Total Cost | Shipping times |
|---|---|---|---|---|---|
| 1.04 kg | 1.04 kg can | $40.00 | $40.00 | $40.00 | |
| n/a | Pack of 50 | $10.23 | $10.23 | $50.23 | |
| 1 kg | EXT DIM: 27.5*20.5*18.7 cm. INT DIM: Top: 21.6*16.2*14.9 cm. Bottom: 20.5*15.2*14.9 cm | $22.49 | $22.49 | $72.72 | |
| 3 kg | 13.2*23.1*19.6 cm | $249.99 | $249.99 | $322.71 | |
| 2.46 kg | 56.5*39.5*1 cm | $199.99 | $199.99 | $522.70 | |
| n/a | 88.72 mL Tube | $11.60 | $11.60 | $534.30 | |
| 0.0227 kg | 3.3*1.8 cm | $8.29 | $8.29 | $542.59 | |
| 0.073 kg | 2.5*91*2.5 cm | $14.95 | $14.95 | $557.54 | |
| 0.0045 kg | 45.7 cm | $4.94 | $4.94 | $562.48 | |
| 354.88 mL | 14.9 x 13.9 x 8.9 cm | $23.49 | $46.98 | $609.46 | |
| 236.59 mL | -200℃ to 1372℃ | $22.99 | $22.99 | $632.45 | |
| n/a | 4.5 cm OD, 7.0 cm Length | $0.00 | $0.00 | $632.45 | |
| n/a | 20.0 cm Width, 12.5 cm Height, 2.5 cm Depth | $0.00 | $0.00 | $632.45 | |

| Purchase | Ordered | Arrived | Unit | Project Weight | Unit Total | Link |
|---|---|---|---|---|---|---|
| NO | NO | NO | 0% | 5% | 0.0% | |
| NO | NO | NO | 0% | 1% | 0.0% | |
| NO | NO | NO | 0% | 30% | 0.0% | |
| NO | NO | NO | 0% | 12% | 0.0% | |
| NO | NO | NO | 0% | 4% | 0.0% | |
| NO | NO | NO | 0% | 3% | 0.0% | |
| NO | NO | NO | 0% | 5% | 0.0% | https://www.amazon.com/ATmega328P-Microcontroller-Board-Cable-Arduino/dp/B00NLAMS9C/ref=asc_df_B00NLAMS9C/?tag=hyprod- |
| NO | NO | NO | 0% | 5% | 0.0% | https://www.adafruit.com/product/1959 |
| NO | NO | NO | 0% | 5% | 0.0% | https://www.amazon.com/dp/B009GUXG92/ref=psdc_464394_t2_B015OMSQWM |
| NO | NO | NO | 0% | 21% | 0.0% | https://www.amazon.com/dp/B079QWMCW3/ref=psdc_2998409011_t2_B078T7J3SF |
| YES | YES | YES | 100% | 5% | 5.0% | https://www.amazon.com/gp/product/B071V7T6TZ/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1 |
| NO | NO | NO | 0% | 3% | 0.0% | |
| NO | NO | NO | 0% | 1% | 0.0% | |

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