Design Document

Team: NDP

Project: Refrigeration

Date: Summer 2018

1 Table of Contents

2 Revision History

Date	Author	Revisions Made
7/5/18	Harsha Pavuluri	Started the design document for this project. Used previous teams document and added information to be current with the Summer 2018 progress
7/7/18	Mohammed Andejani, Kenzo Kamiya	Began to complete the current design portion of the document, added team Gantt chart, edited sections throughout the document.
7/19/18--7/24/18	Kenzo Kamiya	Beginning the finalization procedures of the document. Updated the current design with the second CAD model and the first prototype. Added experimental data and observations.
7/31/18--8/3/18	Nikita Gaurav	Peltier Module Cooling System Technical Analysis appendix added.Insulation materials and comparison table added. Added thermal cooling circuit diagram.

3 Design Status

Phase 1: Project Identification	**Status:** *Completed* **Semester:** *Spring 2018*
Phase 2: Specification Development	**Status:** *Completed* **Semester:** *Summer 2018*
Phase 3: Conceptual Design	**Status:** *Completed* **Semester**: *Summer 2018*
Phase 4: Detailed Design	**Status:** *In process* **Semester:** *Summer 2018*
Phase 5: Delivery	**Status:** *To be completed*
Phase 6: Service / Maintenance	**Status:** *To be completed*

4 Project Charter

4.1 Description of the Community Partner

Field Ready, a nonprofit humanitarian group, works with many other nonprofit groups, like Humanitarian Makers, to help people in disaster zones. Field Ready seeks to assist those who are harmed in natural disasters, looking at all the different needs that arise in times of crisis. The company takes on many different functions to best combat issues in natural disaster areas. At times Field Ready is an engineering team, testing different designs for use in the field. Other times, Field Ready acts as a social working group, helping people who have recently lost family members and homes.

Field Ready is partnered with Humanitarian Makers, a group of engineers who receive, create, and test innovative designs that could drastically improve the condition of a natural disaster zone. To facilitate ideas, Humanitarian Makers has a list of several challenges, like communication, that it believes are the most pressing needs of people after a disaster that conventional humanitarian assistance does not immediately focus on. Once Humanitarian Makers receives and successfully tests a bright idea, it passes on the design to Field Ready, so it can be implemented in the field.

For the summer 2018 period Field Ready was not directly involved as a project partner. Instead, the NDP team took the previously provided guidance as a base to develop future products.

4.2 Stakeholders

People who have just been through a natural disaster often do not have access to refrigeration to keep medicines and perishables from spoiling. The solution(s) that this team comes up with will impact most, if not all, natural disaster victims that could potentially use the solution. People would have better access to refrigeration to keep medicines cool, and not need to worry about having to walk to the hospital everyday for new medication. Also, hospital employees, like nurses, would not need to carry or hand out as much medicine, because people could store medications in a refrigerator or similar device. And lastly, any humanitarian groups like Field Ready that would be implementing the design would be affected, as they will be purchasing the materials required to make the refrigerators.

4.3 Project Objectives

When a natural disaster passes through a place, affected people often lose access to refrigeration, because of loss of electricity and homes. Without refrigeration, people cannot safely store insulin and so access to these goods dramatically declines. But, many people who have a severe case of diabetes need insulin daily, and lack of refrigeration impairs this. Based on research done on the Virgin Islands and Puerto Rico, many people have a refrigerator, but do not have the electricity needed to use them. As a result, the goal of this project is to provide the best method(s) to keeping insulin between its allowable temperature for prolonged use(2-8 Celsius).

4.4 Outcomes/Deliverables

After this project is done, Field Ready will have a design for an efficient refrigerator that can run in disaster climates. That way people can keep medicines for an extended period of time, without them spoiling in the heat.

4.5 Expected Semester Timeline

By the end of the semester, the team hopes to achieve a prototype with a functioning cooling system and decent insulation. The team expects that the next team would focus on optimizing the box to be more insulated and the determine manufacturing logistics for the product.

5 Semester Documentation

5.1 Team Members

Member	Year	Major	Role	Email
Nawaf Alkeaid	Junior	Industrial Engineering	Project Manager	Nalkeaid@purdue.edu
Harsha Pavuluri	Sophomore	Computer Engineering	Project Archivist	
Mohammed Andejani	Junior	Mechanical Engineering	Design Lead	mandejan@purdue.edu
Kenzo Kamiya	Junior	Mechanical Engineering		kkamiya@purdue.edu
Nikita Gaurav	Senior	Materials Sci. and Engineering		
Ali Alnasser	Sophomore	Computer Science	Webmaster	alnasser@purdue.edu
Harsha Pavuluri	Sophomore	Computer Engineering		

5.2 Current Status and Location on Overall Project Timeline

The project has come to the phase of detailed design and delivery. The group has designed a functional prototype based of the Spring semester team's work and summer research. The group also redefined some constraints to better the product and give a more reasonable design goal. The group began in the first 2 weeks of the semester redefining the constraints and expanding them to give way to more designs and ideas. The 3rd week was spent on deep conceptual design and specifications to get ideas out and discussion to see which was the best idea to follow through on. The team then progressed to prototyping and testing. This is where the team left off.

5.3 Goals for the Semester

By the end of the semester, the team would like to have a functioning prototype with some basic testing done to see how it would react in different climates. The Summer Team would also like to provide blueprints about how the box was built and assembled in hopes that the next team would improve on our methods and come up with a delivery cycle for the boxes and how they would be shipped to areas that are affected.

5.4 Semester Timeline

See Appendix B for detailed version.

Gantt Chart

5.5 Transition Report

5.5.1 Summary of Semester Progress/Comparison of Actual Semester Timeline to Proposed Semester Timeline

So far, the team has accomplished a working prototype that can be tested in different environments. The team has done some testing in very controlled areas but has not progressed to disaster like conditions such as floods or hurricane environments in which areas can be very humid and hot. The team focused mainly on outputting a design that would be functional and working so that the next team can simply improve on the project and come up with ideas about how to deliver or create this box in the disaster area in an efficient way to give maximum relief to those affected. The team followed our timeline nearly exactly with how the team had planned with some minor changes due to products not arriving in the time that the team had expected. Other than that, our Gantt chart was followed well.

5.5.2 Draft Timeline for next semester and relationship to overall project timeline.

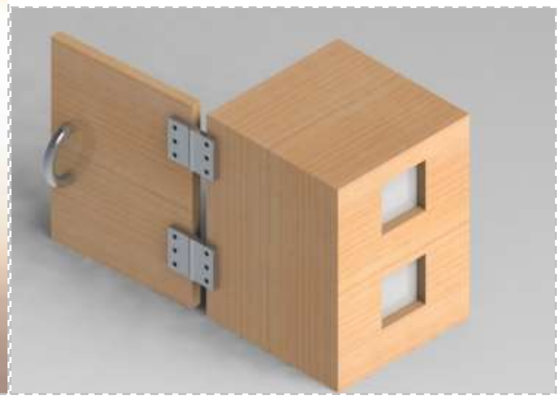
The next semester team should focus on continuing testing the prototype to get a good benchmark on how much power the combined box is drawing as well as creating a more finalized design in which the box will be the most efficient in the most types of different climates. If the next team believes there is a better way to cool the insulin vials, then these options should be explored to provide a more overarching solution to the problem. The next team should also be focusing on how to deliver the product to these disaster areas and more defined calculations in a matrix with minimal variables.

6 Current Design

6.1 Design Iterations

The current stage of the design is the *Detailed Design Phase*. As the semester has progresses the team has begun to produce a number of preliminary designs. The initial discussion began with the possibility of using either evaporative cooling or energy based cooling systems. After a period of discussion and weighing the benefits of both sides the team has proceeded to side with using the active cooling systems.

Design #1

This iteration of the design can be broken into a number of parts: housing, insulation, and Peltier module mount. Each of these parts require numerous factors to consider before coming to a conclusion.

Housing

The initial design was inspired by the modern refrigerator. We Took the design and shrunk it down to a product that is more useful within this situation. The common place design would ensure that users would not be confused as to how to use it.

The door is attached to the rest of the device via two hinges allowing for controlled movement. On the door a knob will be attached so that it can be opened easily.

The housing had a number of objectives to complete. First, it had to keep the entire module safe and functional. Second, it had to be aesthetically pleasing. Third, it had to allow for the Peltier modules to be mounted. Of the three, the most important is ensuring the module does not break. Initially we were planning to have the housing just be the insulator and leave it at that. I, however, had some concerns about that. Depending on the insulator the housing could be easily damaged and thus be unable to function properly. The wood not only acts as a good insulator, but it also protects the rest of the product from damage. This will ensure that the product would be able to work for an extended amount of time with little to no repairs. The additional fact that wood is a decent insulator adds to the benefits it brings to the table.

Insulation

While the material we will be using the insulation is not clear, We have number of possible candidates for this position. Here is a list of a number of materials and their thermal conductivity. From the table below it would be best to choose from the following materials: Styrofoam, fiberglass, wood, wool, and polyurethane. All of these are great insulators and would be able to function for an extended period of time.

We, however, pushed towards supporting a foam based solution compared to any other. This is based on the merits of three points: price, durability, and thermal conductivity.

Price is critical when designing a product for disaster release. It would make no sense to force people who are in need to pay a significant amount to get help. By reducing the cost it will be possible to maximize the amount of community influence the product could have. Styrofoam is very cheap when compared to the alternatives.

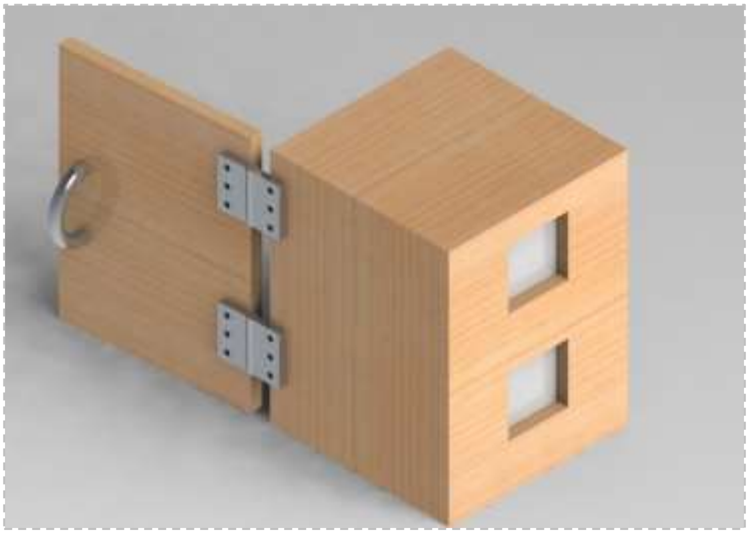
Having loose material like with wool would be of great detriment when building a product that would last for an extended period of time. Should the housing be damaged the loose material would spill everywhere.

While this is liable to change if future information comes up We would like to stick to Styrofoam for the now.

Material	Thermal Conductivity (W/m K)
Styrofoam	0.033
Fiberglass	0.04
Wood	0.12-0.04
Wool	0.04
Polyurethane	0.02

Source: http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html

Peltier Module



The Peltier module is the most important part of the entire build. Without it the box becomes a glorified shoebox. Figuring out a way to stick the module on without sacrificing insulation capability was complicated. We accounted for this issue by doing a number of design choices. First, We cut out a hole in the back of the refrigerator where the module can be mounted. This square holes are then connected to an aluminum plate which could transfer the work done by the module effortlessly. This entire plate would then be surrounded by an insulator like Styrofoam to minimize the surface area that could cause the cooled air to leave the system.

Bill of Materials (BOM)

Material	**Cost**
Temperature Controller 10A 1 Relay with Sensor bayite AC 110V Fahrenheit Digital	$17.90
Qianson Thermoelectric Peltier Refrigeration Cooling System Cooler Fan TEC1-12706 DIY Air Conditioner	$29.89
Door Hinge (3-pack)	$7.98
Styrofoam Cube 9.9 Inch x 9.9 Inch x 9.9 Inch	$17.42

6061 T6 Aluminum Sheet 12" x 12"	$12.98
Sanded Plywood (1/2 in. x 2 ft. x 4 ft)	$12.07
TOTAL	**$98.24**

Design #2

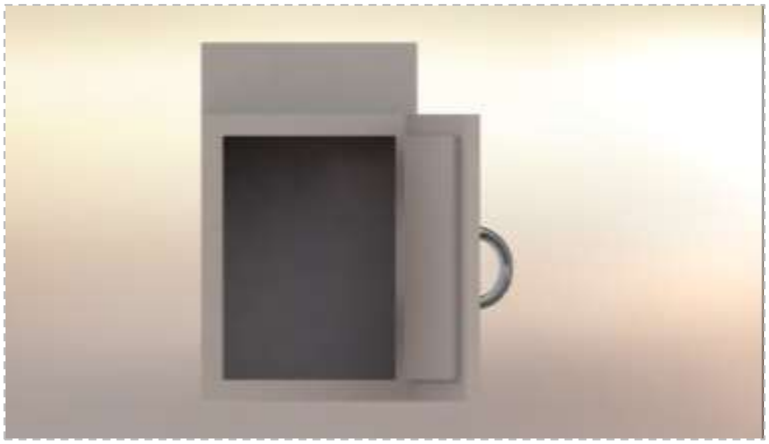
The midterm review provided the team with professional feedback in terms of design and what would be expected of the final product. This gave the team the opportunity to improve the design significantly.

Exterior

A significant critique brought up during the review revolved around the materials used during the design. The wooden exterior, while stylish, is not practical in any real sense. Not only does the wood not have a high R-value, but it also added to the bulk of the product. The result is a cooler that is not only heavier and less effective, but also more expensive. As it is the wood is more of an aesthetic choice than a practical one. Therefore, the materials that made up the box had to change.

The new design now uses an exterior made exclusively of Styrofoam. Not only would this reduce the weight of the product significantly, but it would also provide a higher level of thermal resistance. The only concern the team has in regards to the design choice is whether or not the product would be able to withstand wear and tear over a long period of time.

Interior



With the numerous changes made with the exterior its clear to us that many of the elements used to facilitate the effectiveness of the peltier module is no longer necessary. First, the aluminum plate used as a method of conduction has been removed from the design. This was due to the method used to mount the peltier changing. This change in design eliminated the need to have a conductor. This design choice lowered the amount of weight the object has and improves the overall transportability of the product.

Peltier Module

The position the team had intended to mount the module was brought under scrutiny during the review. The previous position, the side, made it so that the device was imbalanced and easy to tip. To resolve this problem the team agreed that it would be better to mount the module on the top of the device.This is where the extrusion on the top comes into play. This is made as a support for the module and a small battery. There is a rectangular hole cut into the top where the module can now be mounted onto. This should improve the stability of the design since it would be less prone to tipping.

6.2 Peltier Module Calculations

The calculations were determined from the Electrical Properties of Materials Textbook and they can also be found online. They are essentially common knowledge since the Peltier system has been around since the 1840's. Peltier effect, the cooling of one junction and the heating of the other when an electric current is maintained in a circuit of material consisting of two dissimilar conductors; the effect is even stronger in circuits containing dissimilar semiconductors. In a circuit consisting of a battery joined by two pieces of copper wire to a length of bismuth wire, a temperature rise occurs at the junction where the current passes from copper to bismuth, and a temperature drop occurs at the PN junction where the current passes from bismuth to copper. This effect was discovered in 1834 by the French physicist These modules are solid-state devices and do not have any moving parts, therefore they are less likely to have anything go wrong than a normal refrigerator.

Here are some more examples of the many benefits of thermoelectric coolers that use the Peltier effect:

• No refrigerants, such as chlorofluorocarbon (CFC), make these devices more environmentally friendly and safer to be around

• Modules that are small and lightweight are easily adaptable to whatever room or device they are aiding

• With less moving parts, these devices provide a faster, more dynamic response than larger cooling generators

- **Total Heat Transfer Rate from the Peltier Cell through the Copper Plate**

$$q = \frac{kA}{L} (T_h - T_c)$$

- **Heat Rate = Peltier Cooling Effect – Joule Heating –Heat Conduction**

$$Qc \cong -S\,I\,T_c + \frac{1}{2} I^2 R + k\,\frac{A}{L}\,(T_h - T_c)$$

- **Heat on cold side of the Peltier Cell**

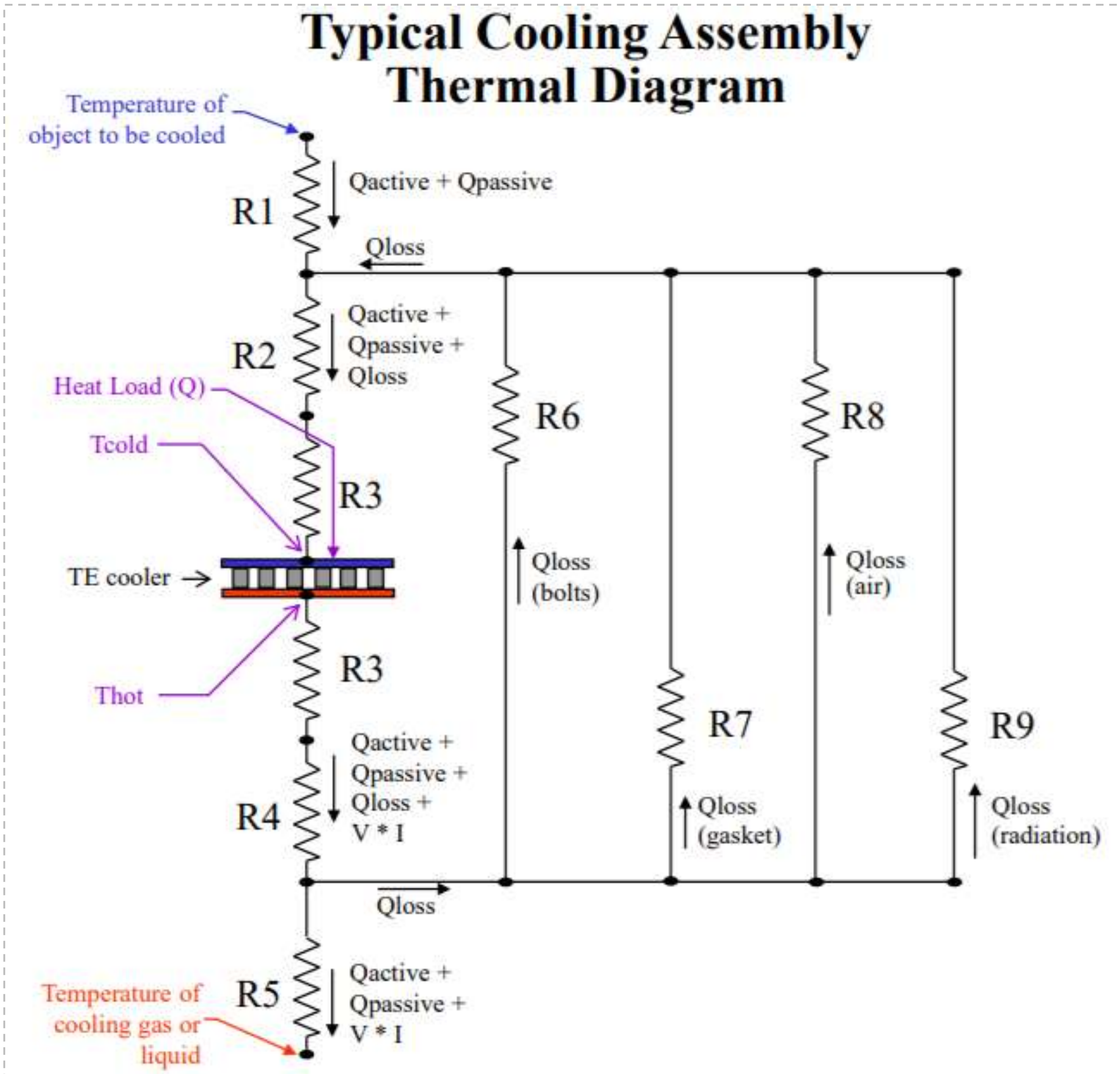
$$q_c = \frac{(T_{Bulk\ Fluid} - T_{Peltier\ Cell\ Cold})}{\frac{1}{h_{Cooling\ Block} A_{Cooling\ Block}} + \frac{L_{Copper\ Plate}}{k_{Copper\ Plate} A_{Copper\ Plate}}}$$

- **Heat on the hot side of the Peltier Cell**

$$q_h = \frac{(T_{Peltier\ Cell\ Hot} - T_{Ambient\ Air})}{\frac{L_{Copper\ Plate}}{k_{Copper\ Plate} A_{Copper\ Plate}} + \frac{1}{h_{Heat\ Sink} A_{Heat\ Sink}}}$$

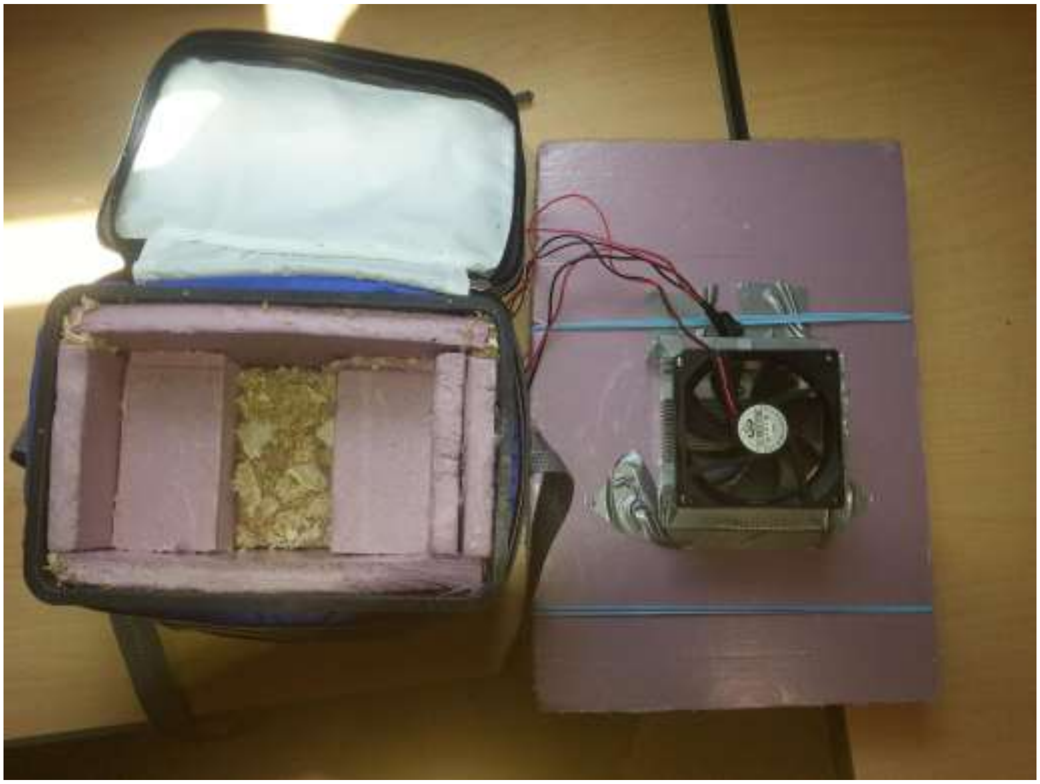
Surface area	1600mm^2
Peltier Power	48 Watts
Delta T	*10 K*

Thickness(L)	3.9 mm
Thermal Conductivity of Styrofoam	.033 W/mK
Thermal Conductivity of copper (k)	401 W/mK
Resistance(R)	1.98 Ohm
Test Peltier + insulation heat transfer rate at room temperature	0.838 W/m^2*C



6.3 Rapid Prototypes Iterations

Iteration 1:



Using a store bought Ozark Trail cooler as the base, the team has designed and produced an effective prototype for the purposes of testing. The internal dimensions are 4 cm H x 17.5 cm W x 10cm D. External dimensions are 15 cm H x 22 cm W x 13 cm D. The weight is .85 kg without a car battery.

When testing, the foam cover is put on top of the box to prevent air from leaking out. Over the course of all the experiments this iteration of the prototype has seen many changes. After each experiment the members improved the design by changing around the dimensions of the doam and closing up the various holes the system has between the cuts of foam.

6.4 Experimentation/ Data

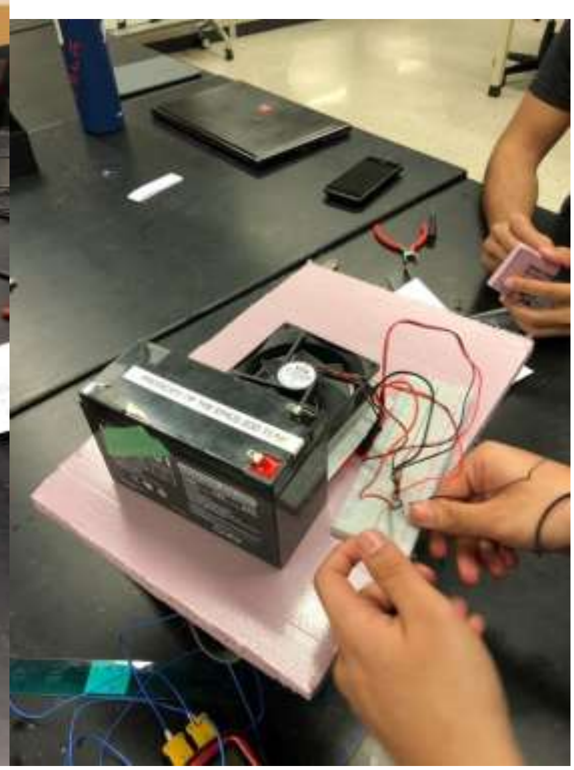
Experiment #1:

The first experiment used minimal insulation and limited power. By using a E3631A Triple Output Power Supply, the team provided the peltier setup with 6V and 2A.

Experiment #2:

The second trial instead used a battery that outputted 12V and 2.4A. While this added to the amount of work the system was able to do, the temperature only went down to 12.4C. The problem is likely due to the both the lack of insulation with the module and the throttled power all the parts recieve.

Experiment #3:

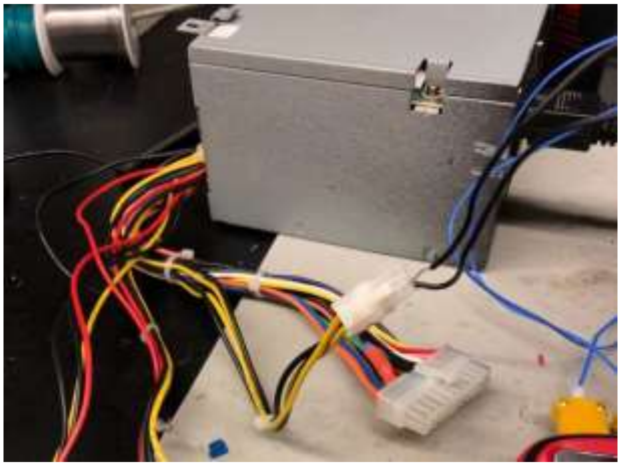


The third experiment introduced a new prototype insulating box that will be used for all future testing. At the time the inside of the box had no foam based insulation. Instead, it elected to just use the box at its natural state.

The data is shown in appendix D, experimentation data. The results are worse than the previous experiment, capping out at 17.9 C. This various is likely due to two key variables. First, the amount of energy left within the lead based battery was lower than the previous day. The lack of energy prevented the model from working at max efficiency. Second, the larger size of the box made it more difficult for the module to have an immediate effect on the system.

For testing purposes it would be better if a steady power source is used to get consistent results. Also, future iterations of the rapid prototype should have foam installed to increase insulation and lower the volume the module has to do work on.

Experiment 4:



The goal of this experiment is to figure out whether the disappointing performance was due to the lack of energy. To test this hypothesis the team used a PC power supply to provide the system with 12V and 6A in a consistent manner. The extra energy allowed for the system to work on full power and the cooling was significantly faster than the previous experiment. However, the power supply fused out during our test and the team had to cancel this experiment.

Experiment 5:

The prototype has been significantly improved through the modification of the design. First, styrofoam has been added to the system to improve its capacity to keep cool. Second, the internal layout of the system was improved to lower the amount of cracks and empty space within the object. Finally, vacuum grease was used to secure the sealing of the foam without permanently sealing the system.

This experiment's purpose is to both understand how the module reacts to an improved power source and measure if there are points of leakage within the construction. The peltier module and the two fans in total draw 12V and 4A from the power source. As a whole it uses 48 Watts.

In 6 minutes the peltier module managed to lower the temperature of the system to 1.9C. This is lower than the required benchmark of 5 C for insulin. While this is a point to celebrate, the moment the system was disconnected ot the power source the internal temperature increased significantly. The amount of effect this could have to the overall efficiency of the product has to be measured.

Points of leakage has been identified using a infrared camera. These points need to be improved to provide a better result for the final product.

Experiment 6:

A new insulator, mycelium foam, had been added to the box to improve the the system. Silicone adhesive was added to seal off the previously identified leakage points. The mycelium foam could be an interesting alternative to foam since it is biodegradable and would not damage the environment.

All the collected data is shown in the appendix D subsection experiment 5. The experiment can be separated into two types of motion, periods where the power source is on and periods where it is not. Initially, the team allowed for the cooler to run for 10 minutes. Once it hit this point the power source was removed and the team observed how long it took to heat back up. In the minute the system was turned off the temperature of the peltier module increased from 4.4 to 9.1 C. Near the end of the experiment the power was turned off again and in the span of four minutes the temperature increased from 2.4 to 16 C.Evidently, this quick increase in temperature is going to be a significant issue that the NDP team has to overcome to make a successful product.

In order to solve this problem there are a number of methods the team has proposed. First, the team could add a thermal conductor within the system to maintain the cool temperature for longer periods. Second, the team could add a way to lower the temperature of the heatsink or limit its temperature increase.

Appendix A: Overall Project Design

A.1 Project Identification

Phase 1: Project Identification	Status:	Evidence can be found:
Goal is to identify a specific, compelling need to be addressed		
· Conduct needs assessment (if need not already defined)	Complete	Defined at start of project
· Identify stakeholders (customer, users, person maintaining project, etc.)	Complete	Stakeholders document
· Understand the Social Context	Complete	Social Context document
· Define basic stakeholder requirements (objectives or goals of projects and constraints)	Complete	Stakeholders document
· Determine time constraints of the project	Complete	Gantt chart

The project identification phase progressed quickly, as it does not have significant research or development included. Defining the scope of the project was the most difficult part of this phase.

A.2 Specification Development

Phase 2: Specification Development	Status:	Evidence can be found:

Goal is to understand “what” is needed by understanding the context, stakeholders, requirements of the project, and why current solutions don’t meet need, and to develop measurable criteria in which design concepts can be evaluated.		
· Understand and describe context (current situation and environment)	Complete	Stakeholders and Social Context documents, notes on Puerto Rico and USVI research

We have not completed most of the actual steps in this design phase, because most of our efforts have been focused on researching refrigeration, Puerto Rico, and the US Virgin islands. We plan on moving forward through the rest of this design phase quickly to continue in conceptual design.

Appendix B: Semester Timeline

Action	Time to be Completed
Project Identification Phase (Covering Previous team’s progress and making modifications when needed)	
Needs assessment	Week 1-Week 2
Identify stakeholders	Week 1
Social context	Week 1
Basic constraints	Week 1

Specification Development Phase (Covering Previous team's progress and making modifications when needed)	
Define Constraints and Customer requirements	Week 3
Evaluating benchmark products	Week 1-2
Conceptual Design Phase	
Brainstorm possible solutions	Week 2
Functional decomposition	Week 3
Prototyping	Week 4 – Week 6
Test Prototype, experiment, and optimize	Week 6 - 8
Final Presentation and Preparation of transition documents	Continually

Appendix C: Peltier Module Cooling Calculations

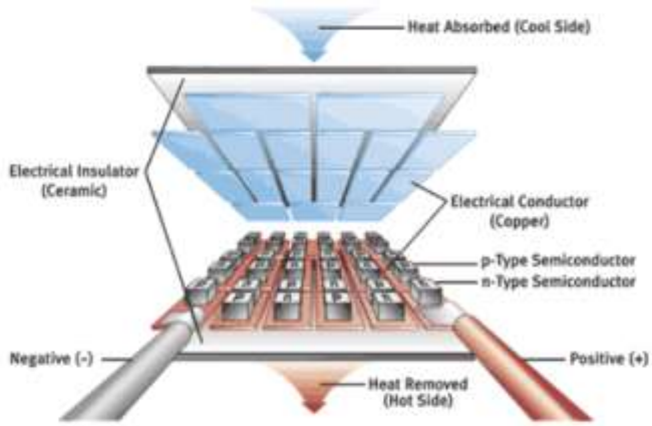
Peltier Module Cooling System Technical Analysis Report

1. Heat Transfer from the Peltier Cell through the Copper Plate through conduction

$$q = \frac{kA}{L}\,(T_h - T_c)$$

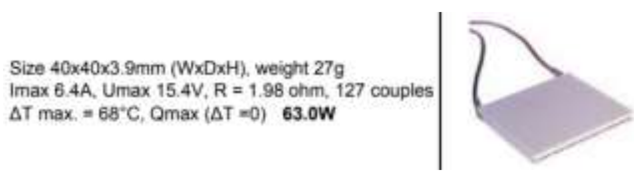
Equation 1

Where q is the total heat transfer rate, Tc is the thermal conductivity of the material, Th is the thickness of the material, A is the heat transfer surface area of the plate, is the hot side temperature of the plate, and is the cold side temperature of the plate.



The heat transfer is a function of the temperature difference between the two sides of the plate, the plate's material properties (k) and the plate's geometry. The plate and its material properties and geometry are controlled variables. To maximize q, a copper plate was used because of its high thermal conductivity (k), and designed to have large surface area (A), and a small thickness (L).

Thermal contact resistance, or the resistance to heat transfer caused by air small air pockets that exist between the surfaces of two rough, touching materials, has been ignored for this analysis. All thermal mated surfaces have you been coated with a highly thermally conductive silicon thermal paste to reduce contact resistance. Based on Equation 1 and the assumption of negligible conductive contact resistance, if (the Peltier Cold Side temperature) or the heat flux through the system is known, the heat transfer through the block and into the fluid can be determined.



2. Heat Transfer and Heat Production in the Peltier Cell

Inside of the Peltier Cell, the Peltier Effect or Thermoelectric Effect produces a thermal differential from a temperature differential. The major challenge in using a Peltier Cell is managing the heat produced by the hot side of the Cell. If heat is not removed sufficiently fast enough, then the Peltier Cell will begin to heat, increasing the temperature of the cold side and decreasing cooling. The heat balance is represented by the following equation:

Heat Rate = Peltier Cooling Effect – Joule Heating – Heat Conduction from Hot Side

These three terms are governed by the symbolic equation for the cold side of the Peltier:

$$Qc \cong -S\,I\,T_c + \frac{1}{2}\,I^2R + k\,\frac{A}{L}\,(T_h - T_c)$$ Equation 2

Where Qc is the heat transfer rates on the cold side of the Peltier Cell, S is the Seebeck Coefficient (a factor which indicates the effectiveness of the Peltier Cell at creating a temperature differential), I is the electrical current powering the Peltier Cell, is the cold side temperature, R is the electrical resistance of the Peltier Cell (a term which will affect the amount of joule heating which occurs in the cell during operation), and a conductive heat transfer equation

To maximize heat removal, the first term must be maximized and the second two terms must be minimized. The Peltier Cells used in the prototype are designed to run at full power while using 50 watts.

$$Re_{Heat\ Sink} = \frac{\left(\frac{\dot{V}_{fan}}{A_{heat\ sink}}\right)d_{heat\ sink}}{\nu_{air}}$$

https://wiki.ece.cmu.edu/ddl/images/Thermal_Analysis2.pdf

Calculating the Peltier Cell Cold Side Thermal Circuit

The thermal circuit on the cold side of the Peltier Cell (top of the Peltier Cell), was composed of the convective heat transfer term that related the heat transfer channel surface temperature and the bulk water temperature and the conductive term of heat transfer through the bottom copper plate that was connected to the cold side of the Peltier Cell. The thermal circuit for those two terms is shown below:

$$R1 = \frac{1}{h_{Cooling\ Block}A_{Cooling\ Block}} \quad \text{and} \quad R2 = \frac{L_{Copper\ Plate}}{k_{Copper\ Plate}A_{Copper\ Plate}}$$

Using the Thermal Resistance models previously explained, the heat transfer on the cold side of the Peltier Cell can be expressed as:

$$q_c = \frac{(T_{Bulk\ Fluid} - T_{Peltier\ Cell\ Cold})}{\frac{1}{h_{Cooling\ Block}A_{Cooling\ Block}} + \frac{L_{Copper\ Plate}}{k_{Copper\ Plate}A_{Copper\ Plate}}}$$

Calculating the Peltier Cell Hot Side Thermal Circuit

The thermal circuit on the cold side of the Peltier Cell (top of the Peltier Cell), was composed of the convective heat transfer term that related the heat transfer channel surface temperature and the bulk water temperature and the conductive term of heat transfer through the bottom copper plate that was connected to the cold side of the Peltier Cell. The thermal circuit for those two terms is shown below:

$$R3 = \frac{L_{Copper\ Plate}}{k_{Copper\ Plate}A_{Copper\ Plate}} \quad \text{and} \quad R4 = \frac{1}{h_{Heat\ Sink}A_{Heat\ Sink}}$$

Using the Thermal Resistance models previously explained, the heat transfer on the hot side of the Peltier Cell can be expressed as:

$$q_h = \frac{(T_{Peltier\ Cell\ Hot} - T_{Ambient\ Air})}{\frac{L_{Copper\ Plate}}{k_{Copper\ Plate}A_{Copper\ Plate}} + \frac{1}{h_{Heat\ Sink}A_{Heat\ Sink}}}$$

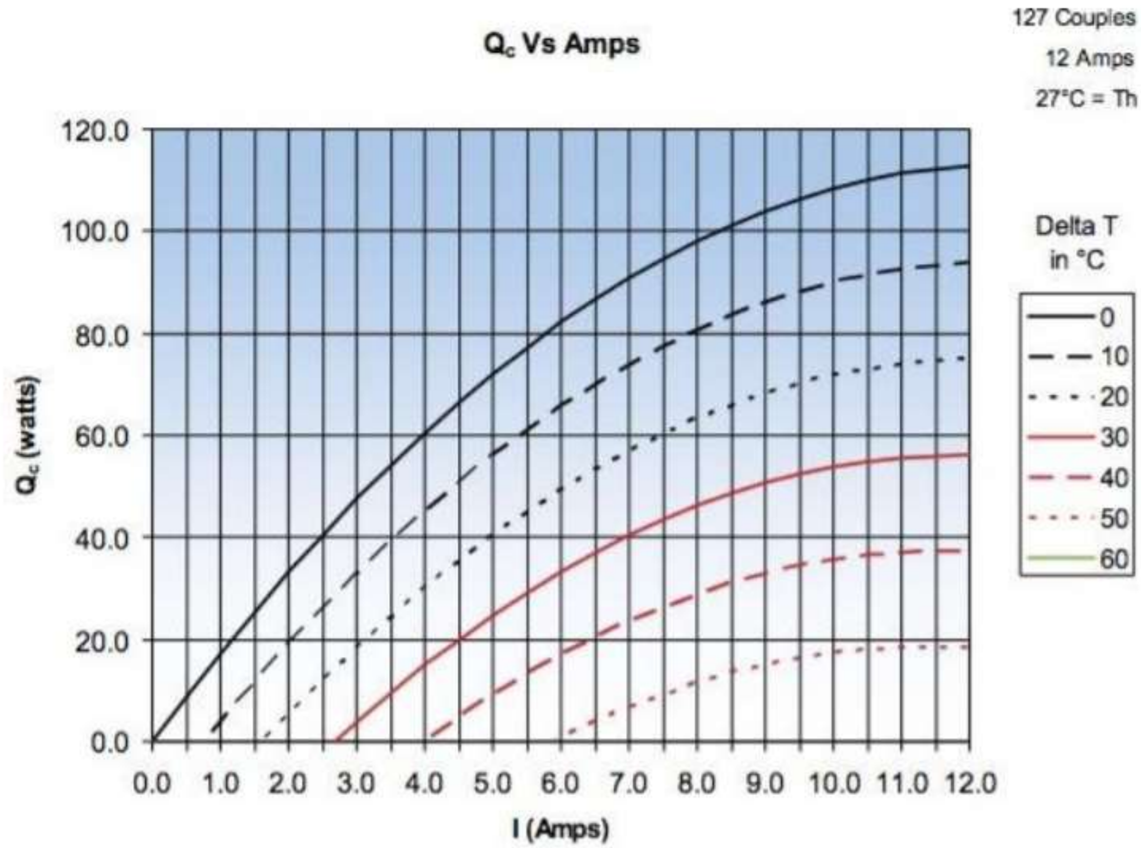
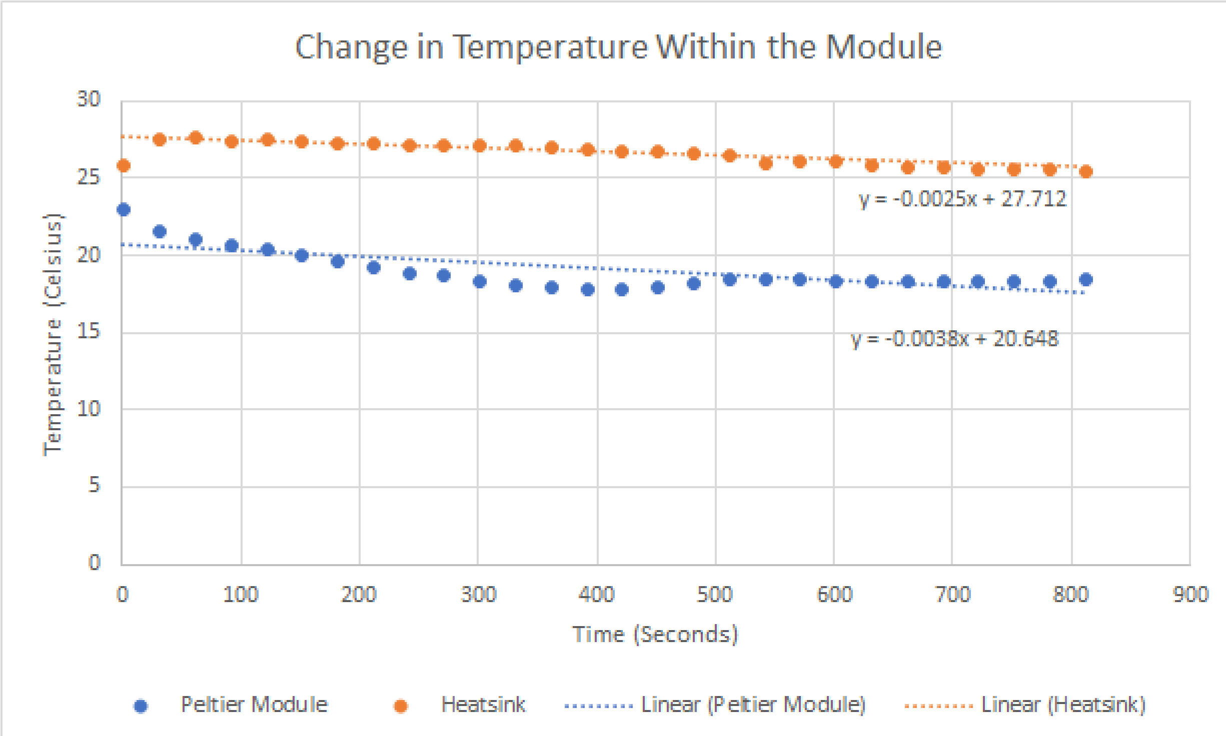


Figure 3. Chart of Peltier Cell Performance

Appendix D: Experimentation Data

Experiment 3:

This experiment used the peltier module covered by a small cardboard box and a battery (12.6V and 4.5 Ah) with a maximum of 1.35A.



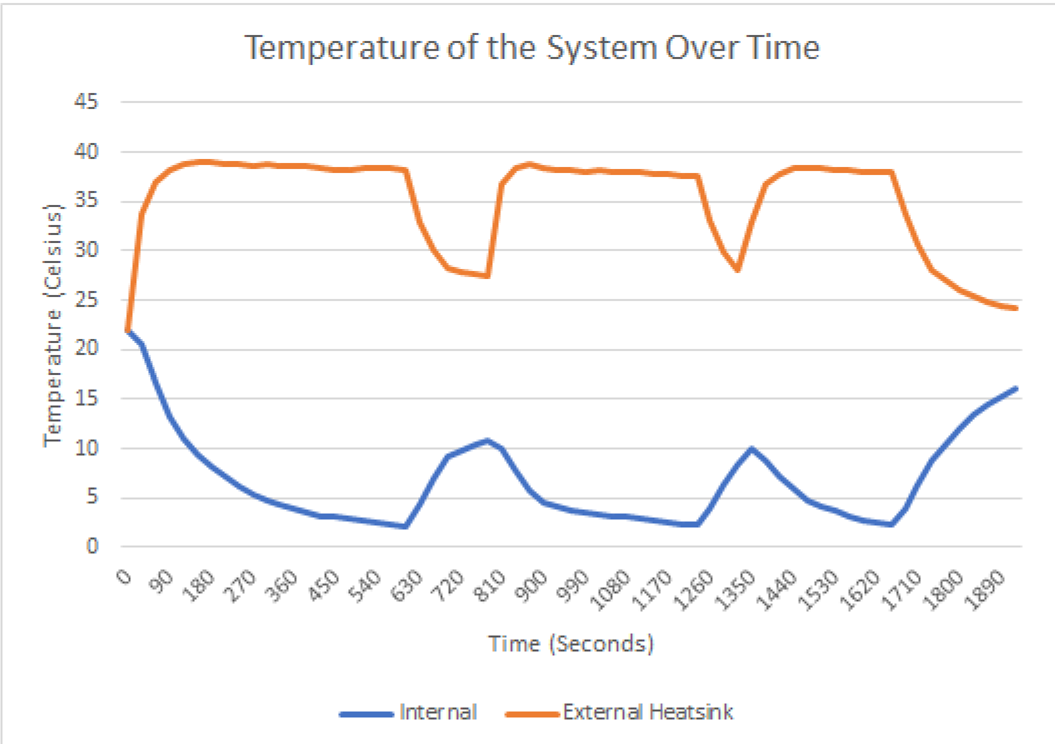
Data Points

Time (Second)	Peltier Module	Heatsink
0	23.1	26
30	21.7	27.6
60	21.1	27.8
90	20.8	27.5
120	20.5	27.6
150	20.1	27.5

180	19.8	27.4
210	19.4	27.4
240	19	27.3
270	18.8	27.2
300	18.5	27.2
330	18.2	27.2
360	18.1	27.1
390	17.9	27
420	17.9	26.9
450	18.1	26.8
480	18.3	26.7
510	18.6	26.6
540	18.6	26.1
570	18.6	26.2
600	18.5	26.2
630	18.5	26
660	18.4	25.8
690	18.4	25.8
720	18.4	25.7

750	18.4	25.7
780	18.5	25.7
810	18.6	25.6

Experiment 6:



It takes our latest protype 10 minutes to achieve a temperature of 2 deg C, and it takes it about a minute and half to get back to 8 deg C. Be sure to measure the temperature of the Insulin and not the air when conducting future tests.

Data Points

	Internal	External Heatsink
Time	Temperature (C)	Temperature (C)
0:00:00	22	22

0:00:30	20.6	33.8
0:01:00	16.7	36.9
0:01:30	13.3	38.2
0:02:00	11.1	38.7
0:02:30	9.4	38.9
0:03:00	8.2	38.9
0:03:30	7.1	38.7
0:04:00	6.1	38.7
0:04:30	5.4	38.6
0:05:00	4.8	38.7
0:05:30	4.4	38.6
0:06:00	4	38.6
0:06:30	3.6	38.6
0:07:00	3.2	38.4
0:07:30	3	38.2
0:08:00	2.8	38.2
0:08:30	2.6	38.3
0:09:00	2.4	38.3

0:09:30	2.3	38.3	
0:10:00	2	38.2	Power Off
0:10:30	4.4	33	
0:11:00	6.9	30	
0:11:30	9.1	28.3	Power On
0:12:00	9.8	27.9	Human Error Occurrence
0:12:30	10.3	27.6	
0:13:00	10.8	27.4	
0:13:30	9.9	36.8	
0:14:00	7.8	38.4	
0:14:30	5.8	38.7	
0:15:00	4.6	38.4	
0:15:30	4.2	38.2	
0:16:00	3.8	38.2	
0:16:30	3.5	38	
0:17:00	3.3	38.1	
0:17:30	3.1	38	
0:18:00	3	37.9	
0:18:30	2.9	37.9	

0:19:00	2.6	37.8	
0:19:30	2.5	37.8	
0:20:00	2.3	37.6	
0:20:30	2.3	37.5	Power off
0:21:00	4	33.2	
0:21:30	6.4	29.8	
0:22:00	8.4	28	Power On
0:22:30	9.9	33	
0:23:00	8.8	36.8	
0:23:30	7.2	37.8	
0:24:00	6	38.3	
0:24:30	4.8	38.3	
0:25:00	4.2	38.3	
0:25:30	3.7	38.1	
0:26:00	3.2	38.1	
0:26:30	2.7	38	
0:27:00	2.5	38	
0:27:30	2.3	38	Power off
0:28:00	3.9	33.7	

0:28:30	6.4	30.6
0:29:00	8.7	28
0:29:30	10.5	27
0:30:00	12	26
0:30:30	13.4	25.4
0:31:00	14.4	24.8
0:31:30	15.3	24.4
0:32:00	16	24.1