HARVEY MUDD COLLEGE

# E4 Major Design Project Final Report

## Section 1, Team 4: Food Transportation

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CLAREMONT CANOPY
HELPING REFUGEES THRIVE

## Abstract

Claremont Canopy sponsored our Harvey Mudd College E4 team to construct them a system for their catering business. The system would need to maintain the temperature and safety of hot and cold foods for up to two and a half hours while they are being transported to catering locations. After following the E4 design process, we created a final prototype consisting of a soft-sided cooler and integrated temperature monitoring system. In order to verify the effectiveness of this design, we conducted tests of the system using thermocouple to track the temperature over time of trays full of hot or cold water. This allowed us to verify both the accuracy of our temperature monitoring subsystem and to quantify the insulation capabilities of the entire system. In the end, we found our devices was able to maintain temperatures above the 57 °C cutoff according to California state regulations as well as the 5°C cutoff per the same regulations better than a tray on its own. Our final prototype increased the amount of time that food would stay out of the temperature danger zone by a factor of 3.03 for hot foods and 3.01 for cold foods.

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## Introduction

Claremont Canopy is a local organisation that works to support refugee families in the Claremont California area. In regards to this specific project, they assist a family operate a catering business that services clients up to 2.5 hours from their home. They serve syrian food of various kinds which comes as hot, cold, and room temperature. They asked us to provide them a system that will help to maintain the temperature of the food while also monitoring the temperature of the food within the device. We expanded this to abide by the regulations in the state of California for foods that are required to be held within a certain range of temperatures.

In talking with Claremont Canopy we connected with Christy Anderson and the family who runs the catering company to discern which details were important to them and what they wanted out of the design to inform our design process.

## **Background**

According to the California Retail Food Code, the specified holding temperatures for retail foods, such as that from a catering company are:

> "Except during preparation, cooking, cooling, transportation to or from a retail food facility for a period of less than 30 minutes, or when time is used as the public health control as specified under Section 114000, or as otherwise provided in this section, potentially hazardous food shall be maintained at or above 135°F, or at or below 41°F." (California Section 113996).

The temperatures in general are specified as above 135 Fahrenheit for hot foods and below 41 Fahrenheit for cold foods, which translates to above 57 Celsius or below 5 celsius. We used these as the targets for our design alternatives, as well as the following information:

> "If it is necessary to remove potentially hazardous food from the specified holding temperatures to facilitate preparation, this preparation shall in no case exceed two cumulative hours without a return to the specified holding temperatures." (California Section 113998).

This sentiment is echoed by the FDA in their regulations. As such, we defined a "danger zone" of the 5 to 57 Celsius range. These regulations mean that at the very least we needed to keep food out of this "danger zone" for at least 30 minutes, as the longest drives Claremont Canopy completes are 2.5 hours in length. This is only required of certain at-risk types of  foods specified in the law, and the others can be stored at room temperature. This also echoes the desire of Claremont Canopy to transport certain foods at room temperature such as breads. Solving this problem is important as the system will increase food safety for the people consuming any food delivered. It also better allows Claremont Canopy to cater events with those longer trips with the peace of mind that their food remained safe the entire trip.

## Methodology

**Original Problem Statement:**

A local catering company has seen increased business in the Los Angeles area. While the business increase has been a positive, it has come with some additional challenges. One of which is the transportation of food such that it remains at the right temperature (and delicious) during the trip through unpredictable Los Angeles traffic. The company needs a way to keep foods the desired temperature during transport to the various sites. Trip duration can be almost a two hour drive in some cases. Current temperature monitoring devices will provide an alert but will not address increases or decreases below the desired temperature. Few systems can monitor or adjust humidity or other factors beyond temperature.

*Figure 1: The Original Problem Statement*

**Revised Problem Statement**

Create a system for maintaining and monitoring the temperature of trays of food. The system should be able to store enough food for up to about 200 people for 2.5 hours. Most of the food will be kept at room temperature, with some food that is kept hot (above 60 degrees C) and some that is kept cold (below 5 degrees C). It must be able to fit within a 2000 Honda Odyssey minivan with room for three people.

*Figure 2: Our Revised Problem Statement*

Our problem statement was created by combining the problem statement we were given by the client with additional, clarifying, and specific information we received during the initial client meeting. We also incorporated the information found for California food safety laws. In our original problem statement, we noticed that there were several instances of an excess of information; we did not need to know the background of the development of the catering company in order to understand what the problem was. As such, we removed this information from our revised problem statement to simplify what we were aiming to achieve through the design of our final project. From the meeting, we received more specifications as to the different foods that our design would be expected to transport and the temperature ranges that they should be stored at, which we included in our revised problem statement. We also learned more about the specifications of where food would be transported and how many people the food would be providing for. Finally, we were told what vehicle the food would be transported in, which we included in our revised problem statement in order to clarify the space requirements of our design.

**Objectives and Constraints**

To determine the objectives and constraints of the given task, we took the specifications outlined by the clients during our preliminary meeting, as well as the physical confinements of the materials we were working with (e.g. the car used and the trays in which the clients store food). Objectives are desired qualities for our device which can be accomplished more or less well. Constraints are the limitations within which our team must design the system, as specified by the clients' needs and materials available (e.g. budget, pre-determined equipment). We went on to specify our objectives and constraints based on what would improve the product and make it more user friendly and safe (both physical and for food). Once we determined the objectives and constraints of the system to be created, we identified functions that would fulfill the objectives and means for the functions that remained within the system constraints.

**Objectives**

- Compatible with trays as similar as possible to currently used foil trays
- Accurate temperature maintenance for both hot and cold items
    - Consistency in ability to maintain temperature
    - Keeps temperature outside of "Danger Zone" provided by FDA and USDA regulations for as long as possible
- Easy to remove food from device
- Cleanable easily
- Efficiency in storage of different types of items together
    - Foods of different temperatures don't cause other foods to change their temperature much more rapidly
    - Overall system is compact regardless of ratio of hot and cold foods
- Easy to install in car and remove when necessary
- Easy and intuitive to operate
    - Easy to learn to use
    - Easy to charge/power (or doesn't require electronics)
- Robust design
    - Easy to fix if necessary without complicated technical knowledge
    - Unlikely to break (become damaged such that it can't maintain temperatures safely)
- Cheap to implement
- Clear and easy temperature reporting to user
    - Easy to read temperature

- Easy to tell which containers are at the wrong temperature
- Minimally distracting to driver

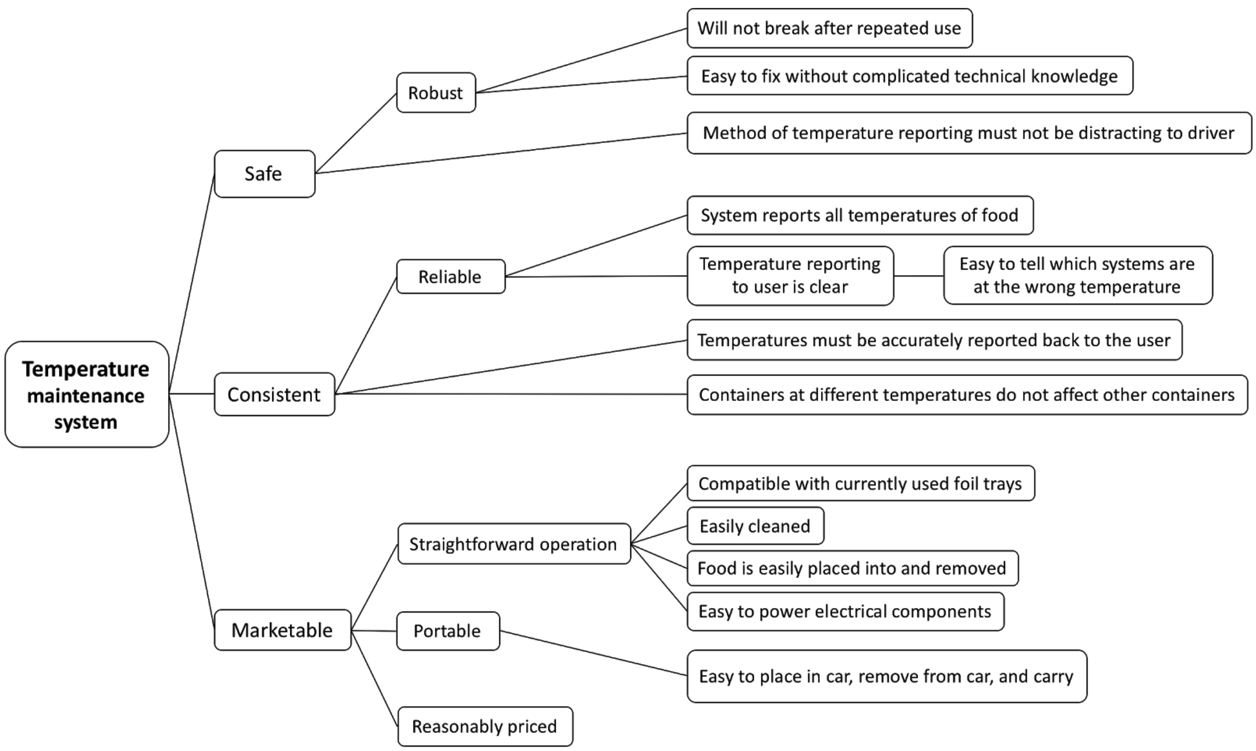


*Figure 3: Objective Tree*

**Constraints**

- Prototyping must cost less than $125 (our budget)
- Must fit within 2000 Honda Odyssey
- Must support weight of trays and food
- System must be able to support both cold and hot food storage
- Must function for at least 2.5 hours without human interaction
- Must abide by all food safety regulations
  - FDA Regulations state that refrigerated foods can only be above 5 °C for a maximum of 2 hours before they are unsafe for consumption
  - USDA: FSIS advisory warnings state that to avoid excessive bacterial growth, food must be kept above 57 °C (135 °F), or below 5 °C (41 °F)

**Functions**

- Monitor/detect temperature
- Report temperature to user
- Insulate/maintain food temperature for hot foods
- Insulate/maintain food temperature for cold foods
- Set desired temperature
- Separate items from different temperature ranges
- Hold food stably
    - Keep food from spilling or tipping in box
    - Support its own weight and resist outside forces

After creating the revised problem statement and identifying objectives and constraints for our design, we created a list of key functions for our food system would be desirable. Organizing the objectives and constraints into a list of functions enabled us to brainstorm different means for accomplishing these functions (using a morphological chart) and thus to create design alternatives for the device or system.

**Morph Chart**

A morphological (or morph) chart is a tool for brainstorming ideas for different means which could be used to accomplish the different functions necessary for a design. The different functions of the device from the list of functions are listed in the left side column. Next, different means are brainstormed to accomplish each function and are listed in the cells to the right of the function. Using a morph chart for brainstorming encourages designers to avoid becoming set on one idea or type of idea too soon (which helps widen the design space), helps designers to think through means for all of the different functions of the device and avoid focusing on only a handful of functions, and spurs creativity and the generation of out-of-the-box and unconventional ideas. After creating a list of means for each function, morph charts can be sorted based on different metrics in order to explore which means might be ideal for a design. For example, the morph chart above is organize in terms of ease of implementation. After completing the morph chart, designers can then select one means from each row and combine them to create a design alternative for the device.

| **Function / Means** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Monitor temperature** | No-Monitoring - "Trust the System" | Human touch (put hand above food to feel) | taste test | provide users with a thermometer to measure temperature upon arrival | hire a person to feel the food occasionally |
| **Report temperature to user** | provide users with a thermometer to measure temperature upon arrival | Lights (Red/ Yellow/ Green) | Gauge | Someone stands by food and yells at the driver if it's the wrong temperature | seven-segment display screen |
| **Insulate/ maintain food temperature (heating)** | Insulated box | styrofoam | packing food closely together | wall insulation | hand warmers |

| | | | | | |
|---|---|---|---|---|---|
| **Insulate/ maintain food temperature (cooling)** | ice packs | Insulated box | styrofoam | Packing food separately | wall insulation |
| **Separate different food items** | Just put everything in the same box | different shelves | different trays | Different drawers | have food items individually wrapped |
| **Set temperature** | Only one temperature setting which cannot be changed | Change amount of ice | Change amount of hot packs or chemicals, etc. | Change amount of salt in ice | Change how close together food is packed |
| **Hold food stably (food doesn't spill in box)** | don't worry about food spilling | tightly packed boxes | Metal Racks to put trays on | Walls to hold trays in place | slots in side of walls of box |
| **Support its own weight and resist forces (box doesn't fall over in car)** | "Hope", no real system. Boxes support themselves | Friction tape on base of device to prevent it from slipping | wedging it between two seats | Strap boxes to floor of vehicle | Wooden Blocks |

*Table 1: The first five columns of our morph chart (which has approximately twenty columns), sorted in terms of ease of implementation*

**Pairwise Comparison Chart**

A pairwise comparison chart is a manner of determining which of the various objectives of our prototype should be prioritized above others. The different objectives of the device are listed on the top (x-axis) and left (y-axis) side of the chart (for readability, we assigned each objective an alphabetical letter and provided a key). Next, we compared the objectives on the y-axis with the ones on the x-axis with the following method: a '1' is placed in cells in which the objective on the y-axis is more important than the one on the x-axis, while a '0' is placed in cells in which the objective y-axis is less important than the one on the x-axis. From there, the entire chart is populated in this binary fashion, and we entered the total number of '1's for each objective in a "Totals" column on the right of the chart. From this we were able to quantitatively see which objectives are of the highest priority, and which are of lower priority.

<u>Objectives:</u>

Key:

A. Accurate temperature maintenance for both hot and cold items
B. Containers at different temperatures do not affect other containers
C. Easy and intuitive to operate
D. Clear and easy temperature reporting to user
E. Robust design
F. Food is easy to place into and removed from device
G. Easily cleaned
H. Compatible with trays as similar as possible to currently used foil trays
I. Easy to place in car, remove from car, and carry when necessary
J. Cheap to implement

| Objectives | A | B | C | D | E | F | G | H | I | J | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **A** | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| **B** | 0 | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| **C** | 0 | 0 | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 |
| **D** | 0 | 0 | 0 | - | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **E** | 0 | 0 | 0 | 0 | - | 1 | 1 | 1 | 1 | 1 | 5 |
| **F** | 0 | 0 | 0 | 0 | 0 | - | 1 | 1 | 1 | 1 | 4 |
| **G** | 0 | 0 | 0 | 0 | 0 | 0 | - | 1 | 1 | 1 | 3 |
| **H** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 1 | 1 | 2 |
| **I** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 1 | 1 |
| **J** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 |

*Table 2: Pairwise comparison chart*

From our pairwise comparison chart, we can see that our most important objective is accurate temperature maintenance. From there, we rearranged the objectives on the chart itself to reflect their score ranking, which proceeds as follows:

1. Accurate temperature maintenance for both hot and cold items□
2. Containers at different temperatures do not affect other containers
3. Easy and intuitive to operate
4. Clear and easy temperature reporting to user
5. Robust design
6. Food is easy to place into and removed from device
7. Easily cleaned
8. Compatible with trays as similar as possible to currently used foil trays
9. Easy to place in car, remove from car, and carry when necessary
10. Cheap to implement

From this, we have an order with which to identify the most optimal design alternatives, based on how effectively they are able to implement the objectives specified above. The priorities of each will help us to compare similar designs, however all of the identified objections are central to our system, and so are still all heavily considered when creating and selecting design alternatives.

## Design Alternatives

In the process of deciding on a final design alternative, we split the product into three main subsystems: Structure/Insulation, Temperature Monitoring, and Temperature Modulation. These systems did not depend on each other so we could mix and match different means to complete each subsystem separately. After employing our best of class charts and pairwise comparison chart, we were able to decide on a final design that fit best within the budget, was most feasible with our skillset, and best accomplished the objective, functions, and constraints developed based on the problem statement.

### Structure and Insulation Design Alternatives:

For the structure and insulation of the food we considered various different alternative means. After researching the problem, we realized that a multitude of existing solutions were present for holding and insulating trays of food. As a result, we concluded that it would be more effective in terms of both performance and cost to use one of these existing solutions for this element of our design than to design it from scratch. We organized these solutions into two basic categories of design alternatives: rigid containers and soft-sided containers. The rigid coolers provided structure to the stack of trays inside, were easily cleaned, and could sometimes have wheels already attached. The soft coolers relied on the structure of the trays to support the weight of the stack but were overall very light and collapsible for storage or for smaller stacks of trays.

<u>Insulation and Structure Design Alternative 1: Hard Material Container</u>

Using a hard material cooler would cause our device to maintain temperature better and be easier to clean, but would be significantly more expensive.

*Figure 4: An Insulated Container for Trays made with Hard Material*

<u>Insulation and Structure Design Alternative 2: Soft-Faced Container</u>

Using a soft-faced material cooler wouldn't maintain temperature quite as well, but would be significantly less expensive and would be easier to store and remove from the car.

*Figure 5: An Insulated Container for Trays made with Soft Material*

Best of Class Chart for Insulation and Structure:

| Design Constraints and Objectives | Alternative 1: Rigid Cooler | **Alternative 2: Soft Cooler** |
|---|---|---|
| C: cost less than $125 to prototype | ✓ | ✓ |
| C: supports weight of food | ✓ | ✓ |
| C: fits in Honda Odyssey | ✓ | ✓ |
| C: works for both hot and cold food | ✓ | ✓ |
| C: function for at least 2.5 hours | ✓ | ✓ |
| C: doesn't cause a breach in food safety regulations | ✓ | ✓ |
| O: Stable and accurate temperature maintenance | 1 | 2 |
| O: Efficiency in storage of items of different temperatures | 1.5 | 1.5 |
| O: Easy and intuitive to operate | 1.5 | 1.5 |
| O: Robust design | 1.5 | 1.5 |
| O: Easy to remove food from device | 1.5 | 1.5 |
| O: Easily cleanable | 1 | 2 |
| O: Compatible with trays as similar as possible to currently used foil trays | 1.5 | 1.5 |
| O: Easy to install in and remove from car | 2 | 1 |
| O: Cheap to implement | 2 | 1 |

*Table 3: Best of Class Chart for Insulation and Structure*

A best of class chart (BOC) is a chart that allows the engineers to look at several different design alternatives and determine whether each alternative is able to fit the relevant constraints. It also allows the engineer to rank the various design alternatives in terms of how well they accomplish different objectives. If an alternative does not fit one of the constraints that was given, then either the alternative needs to be revised or cannot be selected. For our best of class chart we compared different ways of displaying the temperature to the user. The constraints we considered were costing less than $125 (our budget), fitting in the 2000 Honda Odyssey, supporting the weight of trays and food, working with both cold and hot food, working without human interaction for at least 2.5 hours, and abiding by all food safety regulations. None of our alternatives violated any of these constraints. We then ranked them under the following objectives which were related to insulation and structure: stable and accurate temperature maintenance, efficiency in storage of items of different temperatures, easy and intuitive to operate, robust design, easy to remove food from device, easily cleanable, compatible with trays as similar as possible to currently used foil trays, easy to install in and remove from car, and cheap to implement.

From looking at our BOC, we determined that Alternative 2 was the best for this project. Although alternative 1 provided better temperature maintenance, the tremendous difference in cost (approximately ten times more expensive) as well as the fact that the soft-faced cooler was easier to remove from the car and store outweighed this benefit. While it may not support the weight of the trays directly, the stack of trays contained within the walls allows the trays to remain stable in transport. It also allows the trays to insulate each other as well as providing additional insulation in the walls of the cooler.

Temperature Reporting Design Alternatives:

For the temperature reporting subsystem of our design, we considered three different design alternatives. We used a standard temperature thermocouple probe for measuring the temperature of food for all three alternatives, and focused on the way we reported the temperature to the user. The three alternatives we considered were using text alerts to notify the user of food entering the temperature danger zone, using a display to communicate the temperature of the food and the time that the food had been in the danger zone with a buzzer that makes a sound when the food enters the danger zone, and using a display to communicate temperature and time information with lights that turn on when the food enters the danger zone.

Best of Class Chart for Temperature Reporting:

| Design Objectives | Alternative 1: Text alerts | Alternative 2: Beep with display on box | Alternative 3: Light with display on box |
|---|---|---|---|
| O: easy to read temperature | 1 | 2.5 | 2.5 |
| O: easy to tell when containers are at the wrong temperature (and which container) | 2 | 3 | 1 |
| O: minimally distracting to driver (safe) | 3 | 2 | 1 |
| O: robust design | 3 | 1.5 | 1.5 |
| O: cheap to implement | 3 | 1.5 | 1.5 |
| O: easy to learn to use | 3 | 1 | 2 |
| O: easy to charge and power | 2 | 2 | 2 |

*Table 4: Best of Class Chart for Reporting Temperature*

We next evaluated our three alternatives for temperature reporting using a best of class chart. Similarly, the constraints we considered were costing less than $125 (our budget), fitting in the 2000 Honda Odyssey, supporting the weight of trays and food, working with both cold and hot food, working without human interaction for at least 2.5 hours, and abiding by all food safety regulations. None of our alternatives violated any of these constraints. We next identified which of our objectives applied to the temperature reporting. After analyzing these objectives, we decided not to use text alerts because we were concerned about the robustness of this solution, the fact that it would be difficult to educate the client on how to repair, and the possible difficulty of switching between phones for the client.

After eliminating the text alerts, we decided upon using the LEDs with a digital readout because it was easier to discern which specific box, if there were several, was out of the acceptable range of holding temperatures. The lights were also less likely to surprise and distract the driver than a buzzer. This is reflected in the best of class chart for these two design alternatives.

<u>Temperature Modulation Design Alternatives:</u>

For modulating the temperature we considered various methods. Initially we figured we could use some sort of heating coils system integrated with a custom box design or implanted in the base of the cooler along with a battery and control circuit. We also considered using large heat storing objects for the hot foods, such as hot rocks or plates, and ice for the cold foods in the form of one tray carrying ice or a custom "ice pack". The final main option we considered was relying solely on pure insulation, which we would test given our selected type of cooler or box. However, after we began testing of the insulated boxes we selected as part of our storage and insulation design alternatives, we realized that we did not need to supply additional heat regulation in order to assure that the food stayed out of the danger zone for at least half an hour. If the system we provided was able to keep food out of the danger zone for more than half an hour, it would ensure that it would be safe when Claremont Canopy arrived at their destination, given the 2.5 hour radius that the client told us.

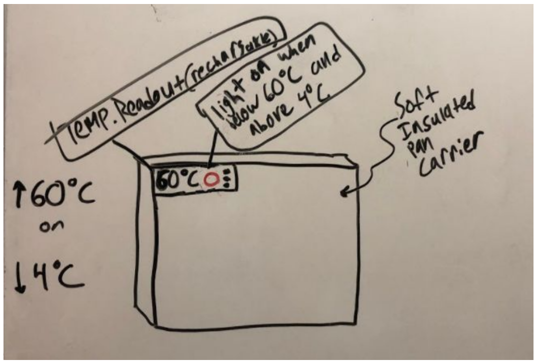


*Figure 6: Original Drawing of Complete System of Selected Alternatives*

*Figure 7: Photo of Complete System Prototype*

**Complete System**

From our selected design alternatives for the different subsystems we have created a complete system for our client. This includes the soft-sided cooler and 7-segment LED display connected to a temperature probe and control circuit. The control circuit is stitched into the lining of the cooler along with wires running to the LEDs which are mounted at the top four corners of the box. It is also connected to a temperature probe that is fed into the box and to be placed in the most-temperature sensitive tray. The probe is washable and can be put in a tray of food; we outline which tray is best for putting the probe in for hot and cold foods in the client user manual. When the device detects that the food is outside of the danger zone, the LEDs will be turned off and the device will display the current temperature (in degrees Celsius) on the 7-segment display screen. When the food enters the danger zone, the LEDs will turn on to notify the client and the LCD will alternate between displaying the temperature for three seconds and displaying the total time that the device has been in the danger zone (in minutes). The main electronics board has a small case and all wires are braided and protected wherever possible to improve the robustness of the device. The entire system is powered using three AA batteries, which can be easily accessed and changed by the user. Our mathematical calculations (using the fact that power equals voltage multiplied by current) indicate that the device should last for approximately seven or eight trips (or 20-25 hours of usage) before the batteries will need to be swapped. The device also features a convenient power switch for turning it on and off.

**Validation and Testing Procedure**

To validate the insulation subsystem we ran a series of tests involving heating and cooling trays of water then measuring the change in temperature over time when placed in open air and in the designed system. Water is an acceptable analog to the food as it has a precisely known specific heat capacity of 4.148 J/g/°C. Specific heat is a measure of how much energy is needed to change a gram of the material by one degree Celsius. In essence, it correlates to how well the substance maintains a temperature. The higher the specific heat, the better it will retain its temperature. The value for water is around what we see in that of food where cooked rice is around 5 J/g/°C and chicken is 3.35 J/g/°C. We used a thermocouple to measure the temperature changes and plotted them over time to find the worst insulated tray in both hot and cold applications as well as tracking how well the system insulated the trays. We also ran a control test with a tray out in the open air and tracked the temperature change over time using the same thermocouple. This allowed us to compare the performance of our system with a standard tray exposed to the open air as a control.

To test the acquired temperature monitoring subsystem we created, we measured various things such as body temperature, tap water, and open air with both the thermocouple and our temperature monitoring subsystem and found them to give the same readings.

# **Results and Findings**

Hot Testing:

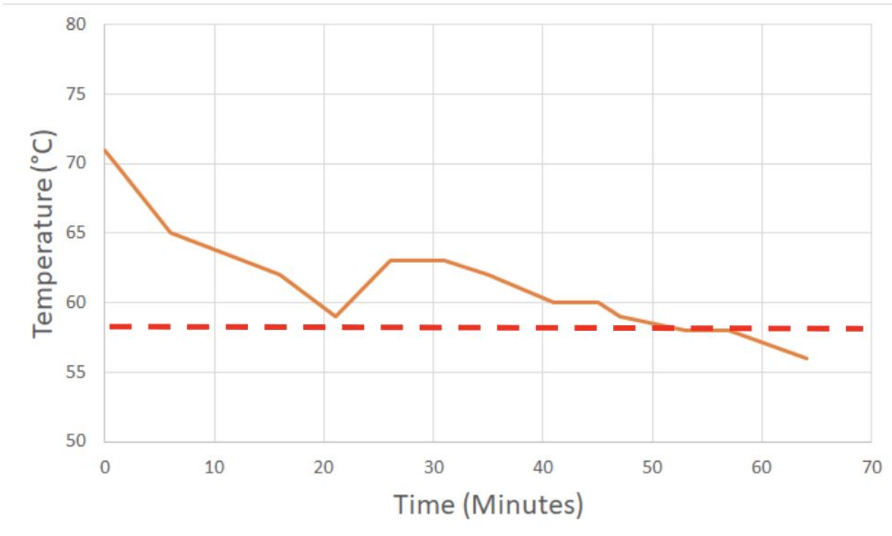


*Figure 8: Control Testing of Hot Trays - (-11.2 ºC per hour)*

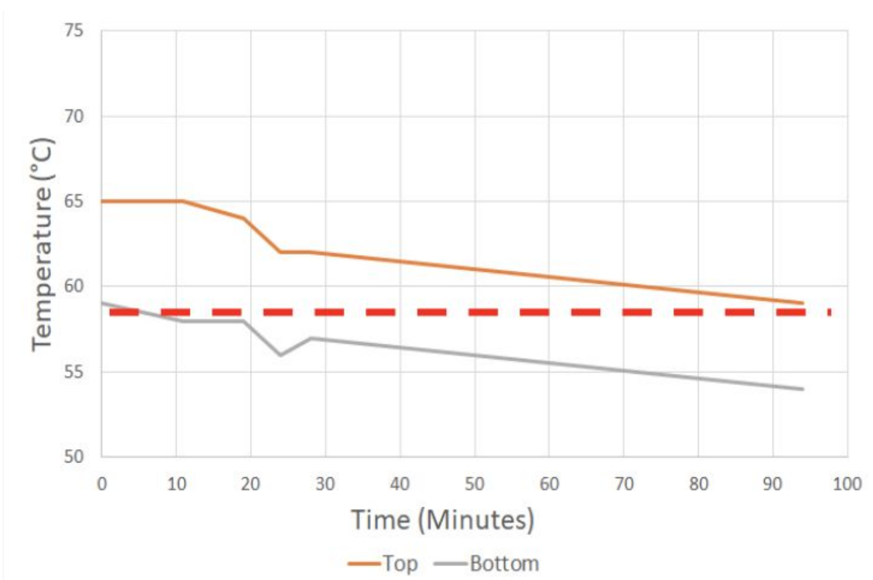


*Figure 9: Proof of Concept Testing (Hot) Trial 1*

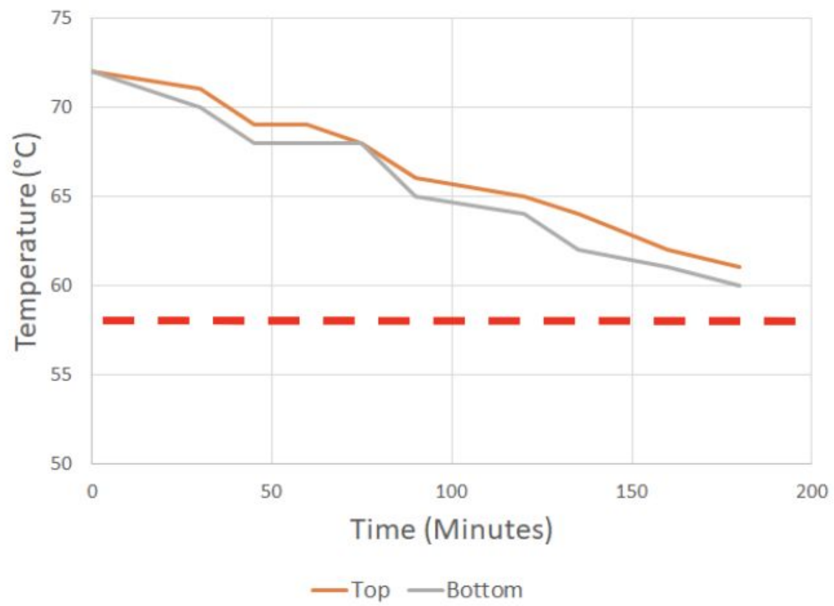


*Figure 10: Proof of Concept Testing (Hot) Trial 2*

<u>Cold Testing:</u>

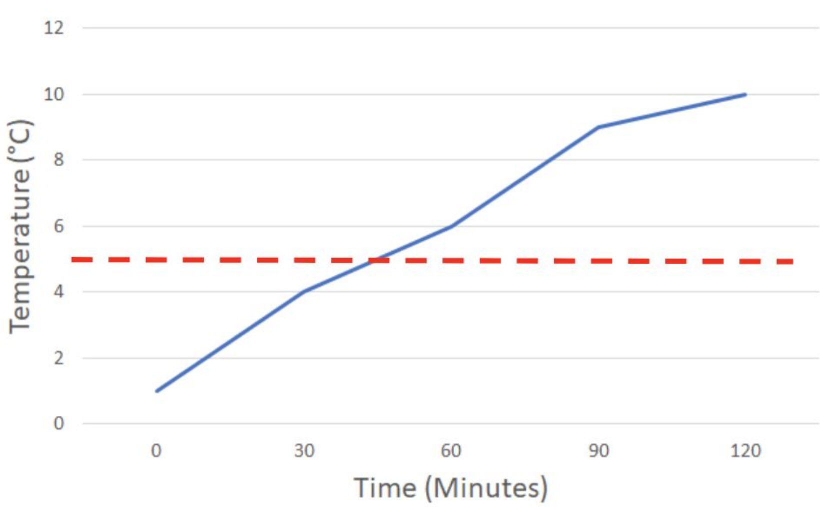


*Figure 11: Control Testing of Cold Trays (+4.6ºC per hour)*

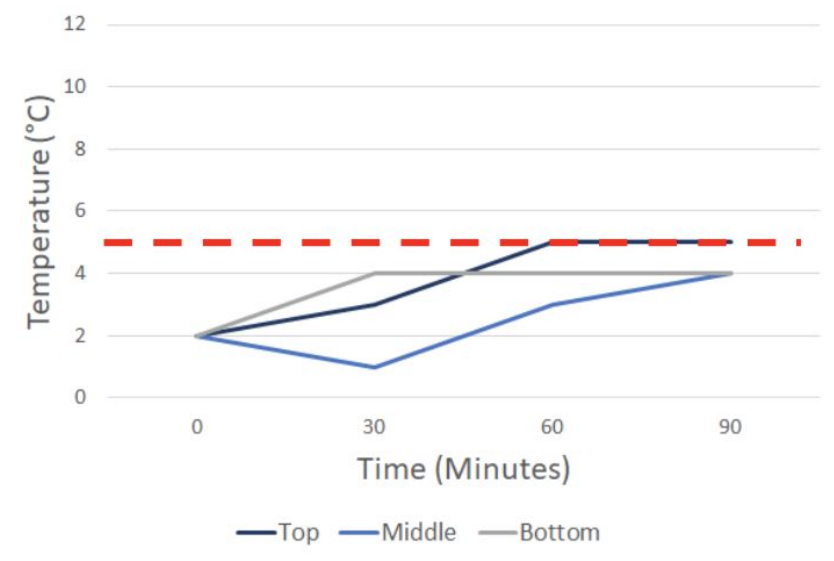


*Figure 12: Proof of Concept (Cold) Trial 1*

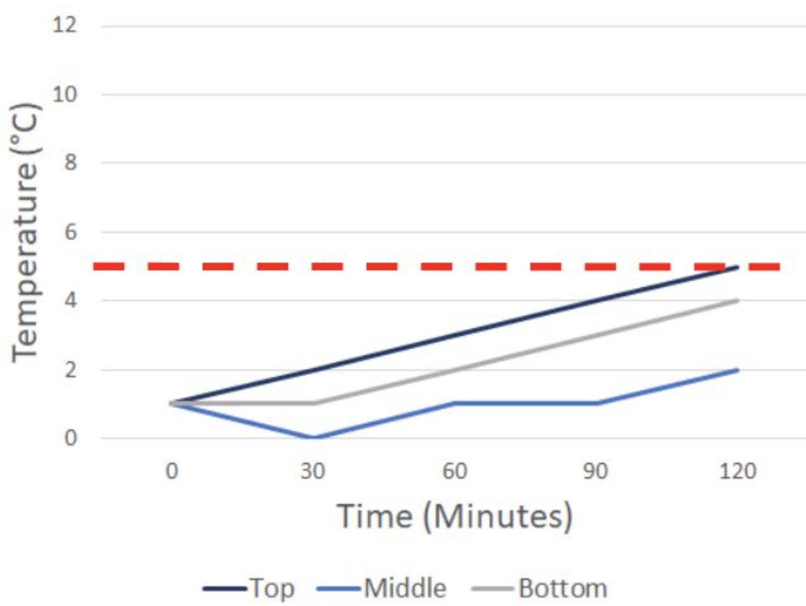


*Figure 13: Proof of Concept (Cold) Trial 2*

The trials showed an average of -3.7 ºC per hour change in temperature when hot foods were placed within the system in comparison to the -11.2 ºC per hour change in the open air control. This is a 3.03 times improvement in the temperature rate of change for the average of all trays.

The cold trials show that there was a change of +1.53ºC per hour when the trays were placed in the designed system compared to the +4.6ºC per hour when the tray was in the open air. This is a 3.01 times improvement in the temperature rate of change for the average of all trays.

We found that our device was able to store food much more safely that a tray on its own. It slows the rate of temperature change by a factor of ~3 for both hot and cold foods which would help Claremont Canopy to safely transport both types of food for their long drives. We recommend that the user places the most temperature-sensitive foods in the middle of the stack of trays within the cooler. The most temperature-sensitive foods being those that would be most likely to spoil such as dairy or meats. The least temperature-sensitive foods should go on the bottom for hot and top for cold applications. As these are the least worst insulated spots in the stack for hot and cold, the temperature probe should be placed in the bottom tray for hot and top tray for cold. This follows logically as hot air rises and cold air sinks. The middle trays remains best insulated as they are  insulated on both top and bottom by other trays rather than the walls of the cooler, which allow some amount of heat to escape to the outside which is of a different temperature.

## **Recommendations**

While our device does well to accomplish our objectives and meet the constraints we set out to accomplish, there are some modifications that could be made to increase performance.

We could integrate some phase-change materials or objects that retain heat with our final prototype to help the entire system retain heat better than it already does. This would allow the company to go on drives even longer than they currently do.

If this were to go into a more commercial production we would like to do more testing. This could include many many more trials starting from a variety of different temperatures with actual food or different objects with known specific heats. This would allow us to better validate the system with the specific types of food a customer was looking to transport.

Finally, it would be ideal if electronics woven into the box could be made entirely waterproof so the box could be sprayed out to be washed, rather than needing to be hand washed with a rag as it currently is. The temperature probe and wires themselves are not prone to water damage but the overall circuit is not entirely resistant to submersion as it would be ideally if we could make it waterproof.

## Conclusions

For our final prototype, we created four insulated boxes capable of each holding five pans of food. Each bag can be used to store either hot or cold foods. Based on our testing, we determined that for half-full bags (two trays) the temperature of hot food (60 to 70 degrees Celsius) would drop approximately 3.7 degrees Celsius in temperature per hour. We determined that partly-full trays of cold food (-5 to 5 degrees Celsius) would increase in temperature by approximately 1.53 degrees Celsius per hour. In comparison, the control trays (uninsulated, single trays) had rates of temperature change of 4.6 degrees Celsius per hour and 11.16 degrees Celsius per hour for the cold and hot trays respectively. As an additional safety measure, we installed temperature monitoring devices in each bag. Each device has a waterproof, sterilizable probe which can be placed in whichever tray is the least insulated and thus the most likely to enter the "danger zone" of temperatures first (i.e. the topmost tray for cold foods and the bottom tray for hot foods), and which will alert the user by turning on a red light when the temperature becomes too cool or too warm. The device also contains a microcontroller which keeps track of how long the food has been outside the desired range, which is displayed on a screen.

## **References**

Advanced Cooling Technologies, Phase Change Technology; https://www.1-act.com/pcmselection/

Amazon, Car and RV Lunch Box With 12 Volt Powered Stove – Plugs Into Car Cigarette Lighter Or Any 12V Source – Quickly Heats Food Up To 300-Degrees Fahrenheit: https://www.amazon. com/dp/B071K6WGVC/ref=asc_df_B071K6WGVC5427780/

California State, Legislature. Senate Bill 144. *California Retail Food Code.* 1 Jan. 2018. https://www.cdph.ca.gov/Programs/CEH/DFDCS/CDPH%20Document%20Library/FDB/FoodSafetyProgram/RetailFood/CRFC.pdf

Claremont Canopy Homepage: https://www.claremontcanopy.org/

"DS18B20 Waterproof Digital Temperature Sensor." *RobotShop*, www.robotshop.com/en/ds18b20-waterproof-digital-temperature-sensor.html.

Facebook, Claremont Canopy Company: https://www.facebook.com/Canopy-Catering-Company-194447967235809/

Hot Logic: https://hotlogicmini.com/products/hot-logic-mini-multiple-colors?gclid=EAIaIQobChMI073eh6yh2gIVBJR-Ch0FmgEYEAQYASABEgKZoPD_BwE

Instructables. "2 Digit Seven Segment Display." Instructables.com, *Instructables*, 11 Oct. 2017, www.instructables.com/id/2-Digit-Seven-Segment-Display/.

Koripalli, Srihari. "DS18B20 (Digital Temperature Sensor) and Arduino." *Arduino Project Hub*, create.arduino.cc/projecthub/TheGadgetBoy/ds18b20-digital-temperature-sensor-and-arduino-9cc806.

Rechargeable phase change material unit and food warming device, https://patents.google.com/patent /US5884006

Sams Club, Small Thermal Catering/Delivery System (Heated or Cooled): https://www.samsclub.com/sams/sm-heated-cater-bag-sm-size-hot-or-cold/prod20952703.ip?&source=ifpla&CAWELAID=730010300000962705&pid=_CSE_Google_PLA_1013572000&wl0=&wl1=g&wl2=c&wl3=239353345156&wl4=pla-301256252291&wl5=9031212&wl6=&wl7=&wl8=&wl9=pla&wl10=1247713&wl11=online&wl12=479677&wl13=&wl15=52655939747&wl17=1o1&veh=sem&source=ifpla

Walmart, Igloo 48-Qt Island Breeze Cooler: https://www.walmart.com/ip/Igloo-48-Qt-Island-Breeze-Cooler/23735484?wmlspartner=wlpa&selectedSellerId=0&wl13=3796&adid=22222222227017351844&wl0=&wl1=g&wl2=c&wl3=41080991552&wl4=pla-78912333272&wl5=9031212&wl6=&wl7=&wl8=&wl9=pla&wl10=8175035&wl11=local&wl12=23735484&wl13=3796&veh=sem

Webstaurant Store, Cambro UPC300158 Ultra Pan Carrier Hot Red Front Loading Insulated Food Pan Carrier with Handles:https://www.webstaurantstore.com/cambro-upc300158-ultra-pan-carrier-hot-red-front-loading-insulated-food-pan-carrier-with-handles/214UPC300RD.html

Webstaurant Store, Choice Insulated Food Delivery Bag / Pan Carrier, Red Nylon, 23" x 13" x 15": https://www.webstaurantstore.com/choice-insulated-food-delivery-bag-pan-carrier-red-nylon-23-x-13-x-15/124FCARRRD.html?utm_source=Google&utm_medium=cpc&utm_campaign=GoogleShopping&gclid=EAIaIQobChMIo6H3v6mh2gIV0oV-Ch0i_A69EAYYAyABEgJ5YvD_BwE

## Appendix A - Work Breakdown Structure

A work breakdown structure functions to divide up the parts of the process that when completed will necessarily indicate we have solved the problem statement and fulfilled necessary criteria. In breaking down the design portion of the project we started by combining the revised problem statement and out determined objectives, constraints, and functions. We planned on all members of the team working on each of the different aspects in the work breakdown structure. We mapped the process we would logically follow to determine what different design alternatives or ideas we would have. From there, given we had picked a final design we mapped the different main subsystems and what was needed to complete them. We then created a plan to test the system and how well it accomplished those objectives and whether or not it met the constraints. In terms of creating a final presentation and paper, we planned to write the report sections as the different pieces were completed, rather than writing it all at the end. We then laid out the steps needed to plan and practice an effective presentation.

Work Breakdown Structure:

1. Design overall system
    a. Define Objectives - All
    b. Define Constraints - All
    c. Define Functions - All
    d. Pairwise Comparison Chart - All
    e. Create Alternative Means
        i. Morphological Chart - All
        ii. Best of Class Chart - All

    f. Do any low resolution prototyping and decide on final design
        i. Prototype Temperature Reporting System - All

2. Support and transport system
    a. Determine type of trays to use for food - All
    b. Create system that can stably hold trays
        i. Ensure that device is removable from car - All
        ii. Ensure that food is easy to remove from device - All
3. Maintain food temperature
    a. Research existing solutions - All
    b. Test abilities of existing solutions to maintain food temperature - All
    c. Identify possible/necessary improvements to existing solutions - All
    d. Create final prototype for maintaining temperature
        i. Acquire cooler needed for prototyping - Caleb
        ii. Run hot trials using thermocouple - Kyle
        iii. Run cold trials using thermocouple - Oliver
        iv. Create charts of results for these trials - Martha
4. Monitor food temperature
    a. Determine necessary characteristics to monitor - All
    b. Determine optimal area of device for measuring temperature
        i. Does the device need a probe in one of the trays? - All
        ii. If so, which tray would be best? - All
    c. Purchase materials for temperature monitoring device - Caleb

d. Construct device for monitoring temperature - Caleb

e. Test functionality of device

i. Use a standard thermocouple thermometer to test accuracy of readings - All

5. Test system

a. Quantify temperature changes over time for foods of different temperatures with device - All

b. Quantify temperature changes over time without device - Kyle/Oliver

c. Make changes if device does not meet constraints - All

d. Evaluate safety and effectiveness of design using statistics - All

6. Paper and presentation

a. Write report sections as steps completed - All

b. Revise and edit report - All

c. Create PowerPoint - All

d. Create presentation script - All

e. Practice presentation - All

f. Give presentation - All

# Appendix B - User Manual

**Project Team Recommendations for Product Use:**

Hot food operation:

- Be very cautious of spillage when loading the the carrier with trays
- Ensure that food is above 70ºC before placing in carrier
- Remove most perishable food from heat source last/cook the most perishable food last before putting it in the carrier
- Place the tray containing the most perishable food in the topmost position (load last, remove first)
- Place the temperature probe in the bottommost tray
    - It is likely that the system will trip and lights will go on at the start until the temperature probe adjusts to the temperature of the food. It should turn off after a few minutes if the food is truly outside the danger zone.

Cold Food operation:

- Be very cautious of spillage when loading the the carrier with trays
- Ensure that food is as close to 0ºC as possible before placing in carrier
- Remove most perishable food from cold storage last/prepare the most perishable food last before putting it in the carrier
- Place the tray containing the most perishable food in the bottommost position (load first, remove last)
    - Is could also be beneficial to place a tray of ice at the top of the stack to help maintain the temperature of the entire cooler.
- Place the temperature probe in the topmost tray
    - It is likely that the system will trip and lights will go on at the start until the temperature probe adjusts to the temperature of the food. It should turn off after a few minutes if the food is truly outside the danger zone.

Cleaning the Carriers:

- For light use:
    - Remove all food trays and battery
    - Wipe down with wet cloth (**do not soak**)
    - Leave open to air dry
    - Reinstall battery
- For heavy use:
    - Remove all food trays and battery
    - Use a sponge or cloth to scrub with mild dishwashing detergent
    - Wipe down with damp cloth (**do not soak**)
    - Repeat scrub and wipe as necessary
    - Leave open to air dry
    - Reinstall battery

## Appendix C - Code for Temperature Monitoring

The program for our device runs on an Arduino Pro Mini. It can be flashed to a mini using the standard Arduino software (we used Arduino 1.8.4). It also requires the OneWire code library, which can be found in the documentation files from the DS18B20 temperature sensor we used (https://www.robotshop.com/en/ds18b20-waterproof-digital-temperature-sensor.html#Supplier-Product-Code). Our code is shown below:

```
#define minHotTempC 57
#define maxColdTempC 5

#define LEDPin1 8
#define LEDPin2 9
#define LEDPin3 10
#define LEDPin4 7

#define screenD1 4
#define screenD2 3

#define AA 17
#define BB 6
#define CC 18
#define DD 19
#define EE 14
#define FF 15
#define GG 16

#include <OneWire.h>

int DS18S20_Pin = 2;
//Temperature chip i/o
OneWire ds(DS18S20_Pin);

float timeOut = 0;
unsigned long lastTime = 0;

void setup(void)
{
  //Serial.begin(9600);
  pinMode(LEDPin1, OUTPUT);
```

```
  pinMode(LEDPin2, OUTPUT);
  pinMode(LEDPin3, OUTPUT);
  pinMode(LEDPin4, OUTPUT);
  pinMode(screenD1, OUTPUT);
  pinMode(screenD2, OUTPUT);
  pinMode(AA, OUTPUT);
  pinMode(BB, OUTPUT);
  pinMode(CC, OUTPUT);
  pinMode(DD, OUTPUT);
  pinMode(EE, OUTPUT);
  pinMode(FF, OUTPUT);
  pinMode(GG, OUTPUT);
  lightsOn();
  getTemp();
  delay(3000);
  lightsOff();
  screenOff();
  lastTime = millis();
}

void loop(void)
{
  unsigned long thisTime = millis();
  float temperature = getTemp();
  //Serial.println(temperature);
  if(temperature > maxColdTempC and temperature < minHotTempC)
  {
   timeOut = (thisTime - lastTime) + timeOut;
   lightsOn();
   //display temp
   show(round(temperature), 3000);
   showTime(500);
  }
  else
  {
   lightsOff();
   //display temp
   show(round(temperature), 3000);
  }
```

```
  lastTime = thisTime;
}

////////////////LEDs for danger zone//////////////////////////////////

void lightsOn(void)
{
  digitalWrite(LEDPin1, HIGH);
  digitalWrite(LEDPin2, HIGH);
  digitalWrite(LEDPin3, HIGH);
  digitalWrite(LEDPin4, HIGH);
}

void lightsOff(void)
{
  digitalWrite(LEDPin1, LOW);
  digitalWrite(LEDPin2, LOW);
  digitalWrite(LEDPin3, LOW);
  digitalWrite(LEDPin4, LOW);
}

/////////////////temperature sensor/////////////////////////////////////

float getTemp()
{
  //returns the temperature from one DS18S20 in DEG Celsius
  byte data[12];
  byte addr[8];

     if ( !ds.search(addr)) {
       //no more sensors on chain, reset search
       ds.reset_search();
       return -1000;
     }

     if ( OneWire::crc8( addr, 7) != addr[7]) {
       Serial.println("CRC is not valid!");
       return -1000;
     }
```

```
  if ( addr[0] != 0x10 && addr[0] != 0x28) {
    Serial.print("Device is not recognized");
    return -1000;
  }

  ds.reset();
  ds.select(addr);
  ds.write(0x44,1); // start conversion, with parasite power on at the end

  byte present = ds.reset();
  ds.select(addr);
  ds.write(0xBE); // Read Scratchpad


  for (int i = 0; i < 9; i++) { // we need 9 bytes
   data[i] = ds.read();
  }

  ds.reset_search();

  byte MSB = data[1];
  byte LSB = data[0];

  float tempRead = ((MSB << 8) | LSB); //using two's compliment
  float TemperatureSum = tempRead / 16;

  return TemperatureSum;
}

////////////////LED display/////////////////////////////

//7-seg display
const int segs[7] = { AA, BB, CC, DD, EE, FF, GG };

const int numbers[10][7] =
  {//A,B,C,D,E,F,G
   {1,1,1,1,1,1,0}, //0
   {0,1,1,0,0,0,0}, //1
```

```
    {1,1,0,1,1,0,1}, //2
    {1,1,1,1,0,0,1}, //3
    {0,1,1,0,0,1,1}, //4
    {1,0,1,1,0,1,1}, //5
    {1,0,1,1,1,1,1}, //6
    {1,1,1,0,0,0,0}, //7
    {1,1,1,1,1,1,1}, //8
    {1,1,1,1,0,1,1}  //9
  };

void screenOff()
{
  digitalWrite(AA, LOW);
  digitalWrite(BB, LOW);
  digitalWrite(CC, LOW);
  digitalWrite(DD, LOW);
  digitalWrite(EE, LOW);
  digitalWrite(FF, LOW);
  digitalWrite(GG, LOW);
  digitalWrite(A7, LOW);
  digitalWrite(screenD1, LOW);
  digitalWrite(screenD2, LOW);
}

void lightDigit1(int number)
{
  digitalWrite(screenD1, LOW);
  digitalWrite(screenD2, HIGH);
  lightSegments(number);
  screenOff();
}

void lightDigit2(int number)
{
  digitalWrite(screenD1, HIGH);
  digitalWrite(screenD2, LOW);
  lightSegments(number);
  screenOff();
}
```

```

void lightSegments(int n)
{
 for (int i = 0; i < 7; i++)
 {
  digitalWrite(segs[i], numbers[n][i]);
 }
}

void twoDigitsTime(int n1, int n2, int t)
{
 for(int i = 0; i < t; i++)
 {
  lightDigit1(n1);
  if (n2 != 0) { lightDigit2(n2); }
  delay(1);
 }
}

void show(int n, int t)
{
 int n2 = (n / 10) % 10;
 int n1 = n % 10;
 twoDigitsTime(n1, n2, t);
}

void showTime(int t)
{
 int mins = round(timeOut / 60000);
 show(mins, t);
}
```

# Appendix D - Revising Problem Statement

Correcting for implied solutions and biases:

- Implemented information from the initial sponsor meeting to clarify the problem
    - Found humidity was not required by the client
    - Client does not expect temperature modulation
        - Only requested food temperature maintenance
    - Defined client specific physical design space
        - Food transported in a 2000 Honda Odyssey minivan, along with three people
    - Range of potential event scope is ~2.5 hours
    - The upper bound of the number of people served in one event is approximately 200
- Adjusted for state (California) and national (USDA: FSIS, FDA) guidelines for food safety:
    - While the taste of food may change with temperature change, the greatest incentive for proper food maintenance is to guarantee food safety (minimal bacteria growth)
    - Identified what is known as the “Danger Zone” for food
        - Cold foods may not be above 5ºC for more than 2 hours
        - Hot foods may not be below 57ºC for more than 2 hours
- Other edits:
    - Simplified the wording and phrasing of the parts of the statement