Battery Powered Car Air Conditioning

"The Chilly Dog"

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FINAL REPORT

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FOR

Battery Powered Car Air Conditioning

TEAM <31>

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1. Executive Summary

Our project, Battery Powered Air Conditioning, will allow customers to leave their pets in the car by cooling the car to a safe temperature. Our goal is to construct a device that can cool a crossover SUV without being overly expensive, since most current devices can cost around $500. The device will be controlled with an application that allows the user to adjust and check the temperature in real time while away from the vehicle. To allow for this long-distance control, the device will be equipped with a sim card as we expect that most cars will be parked in a place without a reliable Wi-Fi signal. The A/C is powered by a battery, so the car does not have to be on while the device is in operation. The exhaust air will be pushed out of the car via a hose hooked to the window to ensure that air is circulating properly. We believe this project will be very useful to people who have pets but who often struggle with bringing them places due to extreme temperatures.

2. Introduction

A car parked outside on a sunny, 95-degree Fahrenheit day can reach temperatures of up to 117 degrees Fahrenheit in just 30 minutes. This rapid change in temperature is something many pet owners do not take into consideration when leaving their pets in the car for a seemingly “harmless” trip to the grocery store. We set out to create a device that maintains suitable conditions for man’s best friend inside a parked vehicle without the need to start the engine or use the vehicle's own A/C system. Our battery-powered air conditioning unit will ensure the safety and comfort of the customers pet as well as the peace of mind for the costumer.

2.1. Background

A parked vehicle on a hot day can act like a greenhouse, amplifying the heat in the cabin up to 40 degrees Fahrenheit compared to the temperature outside. A table of estimated vehicle interior air temperature can be seen in Figure 2.1. Cracking the windows has little to no effect on these numbers. While a human may be able to withstand these conditions, dogs have limited ways of regulating their body temperature.

The largest organ in the human body is the skin and one marvelous feature of this organ is its ability to perspire to cool our body temperature. While dogs do have sweat glands, they play a minor role in regulating body temperature. Dogs pant, inhaling cool air and exhaling warm air. This makes our K9 friends more susceptible to heatstroke and even death.

Estimated Vehicle Interior Air Temperature vs. Elapsed Time						
Elapsed Time (minutes)	**Outside Air Temperature (°F)**					
	70	75	80	85	90	95
0	70	75	80	85	90	95
10	89	94	99	104	109	114
20	99	104	109	114	119	124
30	104	109	114	119	124	129
40	108	113	118	123	128	133
50	111	116	121	126	131	136

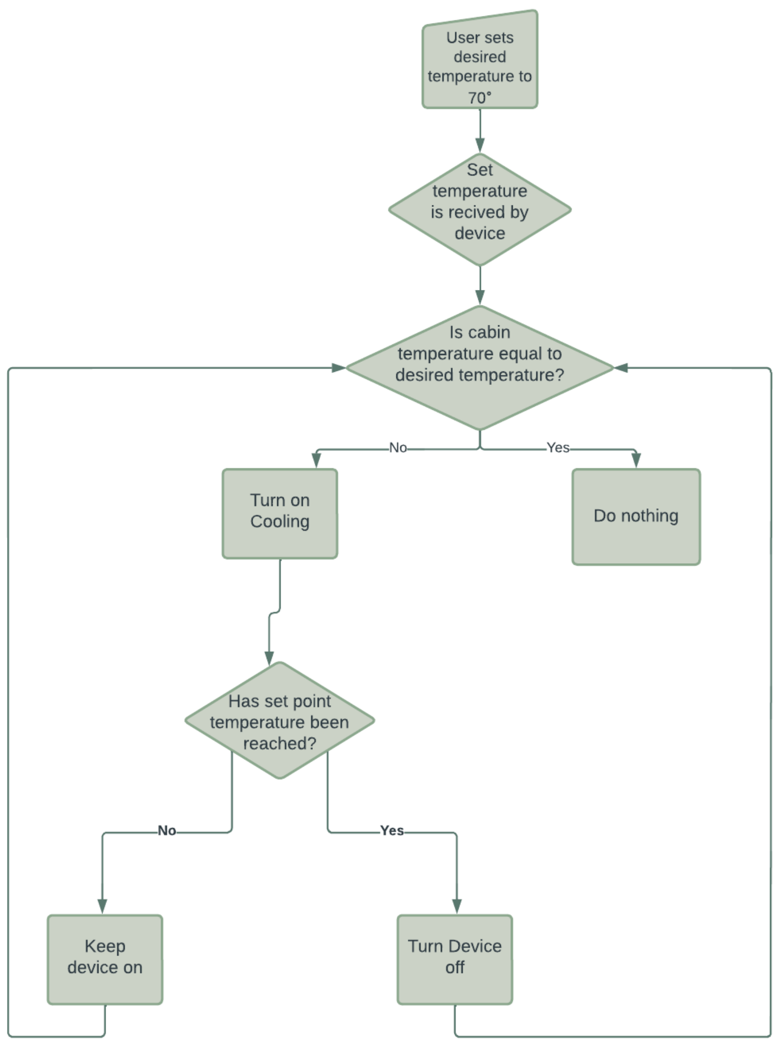
60	113	118	123	128	133	138
>60	115	120	125	130	135	140

Table 2.1. Estimated Vehicle Interior Air Temperature vs. Elapsed Time

2.2. Overview

The Battery Powered Air Conditioning will regulate the temperature in the vehicle to provide optimal conditions for the pet to safely stay in the vehicle unattended. The unit will be powered by a rechargeable battery making it independent and non-reliable on the engine or battery of the car. It will be accessible to the user through an app with features such as increasing or decreasing the climate, real-time readings of the temperature, and turning the device on or off. The internal climate will be read and interpreted by a sensor. That data will be sent and viewed by the user through the application. The user can then set the desired temperature and the A/C unit will output a steady flow of air to match the user's command.

Figure 2.1. Overview Flowchart



2.3. Referenced Documents and Standards

- https://www.akc.org/expert-advice/health/dogs-in-hot-cars/#:~:text=Most%20dog%20owners%20know%20that,at%20risk%20of%20heat%20stroke.&text=The%20answer%20is%20simple%3A%20You,some%20states%2C%20it's%20even%20illegal.
- https://www.akc.org/expert-advice/health/leaving-a-dog-in-the-car-in-winter/
- https://www.animallaw.info/topic/table-state-laws-protect-animals-left-parked-vehicles
- I.R. Dadour, I. Almanjahie, N.D. Fowkes, G. Keady, K. Vijayan, Temperature variations in a parked vehicle, Forensic Science International, Volume 207, Issues 1–3, 2011
- F. Belic, Z. Hocenski and D. Sliskovic, "HVAC control methods - a review," 2015 19th International Conference on System Theory, Control and Computing (ICSTCC), 2015, pp. 679-686, doi: 10.1109/ICSTCC.2015.7321372.
- IEEE 1661-2019 Guide for Test and Evaluation of Lead-Acid Batteries Used in Photovoltaic (PV) Hybrid Power Systems
- IEEE/ASHRAE 1635-2018 Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications

3. Operating Concept

3.1. Scope

The Battery Powered Air Conditioning project was created because of how detrimental it can be for animals to sit in the car during the summer season, where drastic temperature changes occur in a matter of minutes. The objective of this project is to create a machine that can manage the internal temperature of a car using a VAC unit that is controlled by a phone application.

The Battery Powered Air Conditioning will consist of:

- A main unit providing VAC capabilities
- An application that will let the user control the internal temperature
- A microcontroller that receives data from the app and sends signals to the main unit to adjust the temperature based on its temperature sensor
- A battery power supply that can be charged either from the car itself or solar panels

This project will include subsystems consisting of:

- Power supply selection and design – Grant Franklin
- Application development and connection to main unit – Martin Rennaker
- Choosing of VAC system – Yarentzy Magallanes
- Microcontroller design and implementation – Yarentzy Magallanes

3.2. Operational Description and Constraints

The Battery Powered Air Conditioning will be used by any pet owner that needs to leave their animal in their vehicle for a substantial amount of time. Once the customer obtains the product, it will be installed to the floorboard of the back seat. They will install a permanent solar panel to the top of the car (Figure 3.2) as well as an application to their phone. After the installation of the solar panels, the user will plug them into the main device with the use of a power cord. This cord will be fed into the vehicle through a small opening of the backseat window secured by a clip. This gap in the window will also clip the exhaust hose of the main unit. (Figure 3.1) Once the device has power, the user will turn on the unit and connect with their cell phone via a sim card. After the unit is on, the customer will use the application to input the desired temperature, and information on their pet. Recommended settings will then appear and a temperature set point will be chosen. At this point, the user can leave their car and is able to adjust the temperature in the car if needed using the application.

The constraints on the project are listed here:

- The device will have to be pet-friendly so the pet will not injure itself, but sturdy enough that the pet cannot damage it
- The main unit will have to fit within the floorboard and single seat of a medium-sized car
- The time that the car will take to cool will depend on the outside temperature, which varies depending on the location
- The battery will have to last at least two hours so the user will have more than enough time to leave and return to the vehicle

Figure 3.1. Basic Visualization

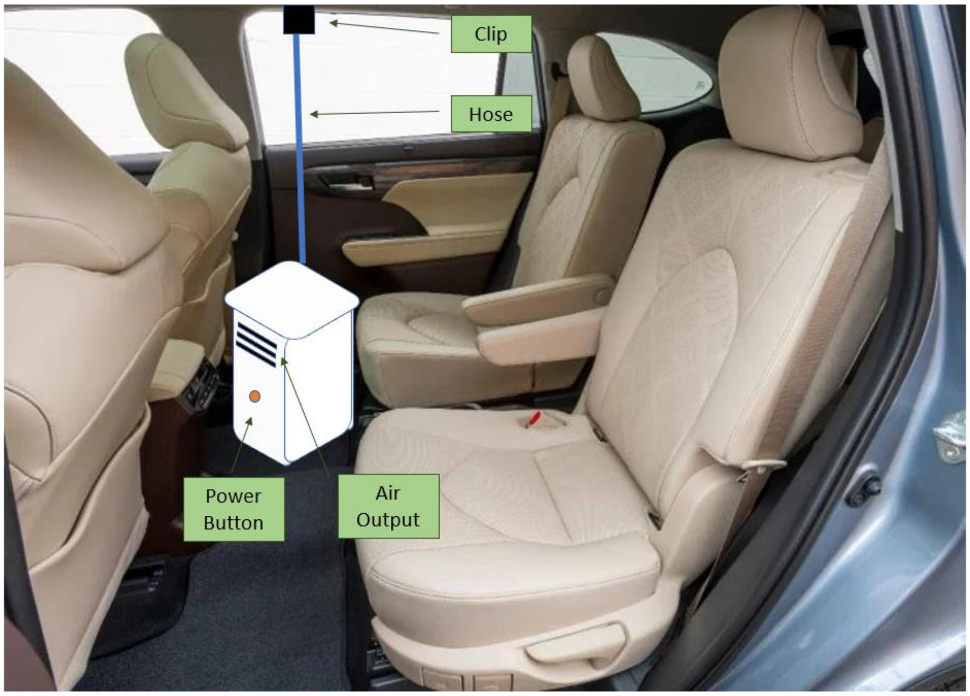
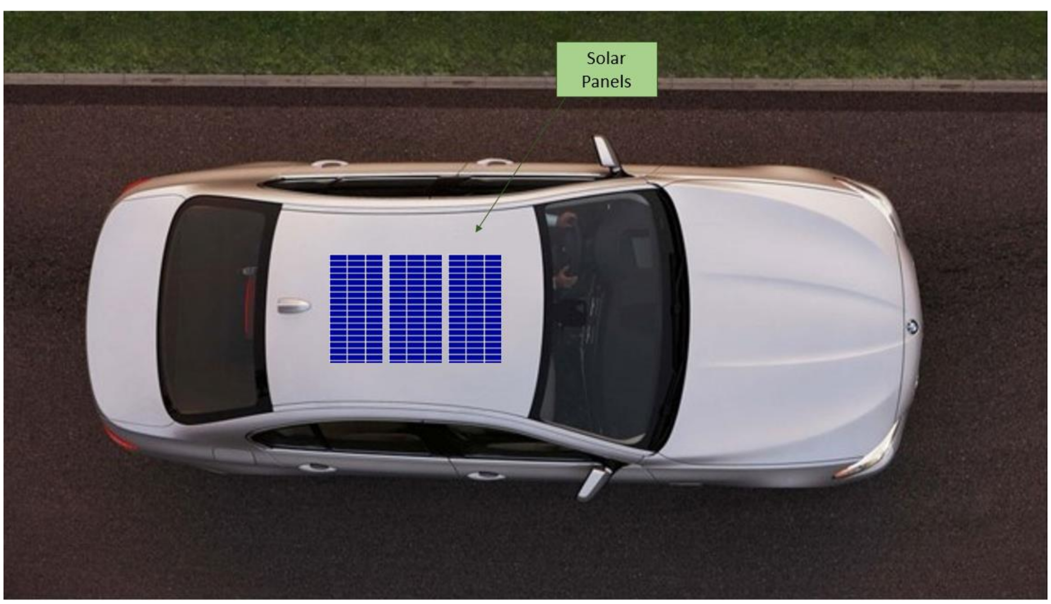


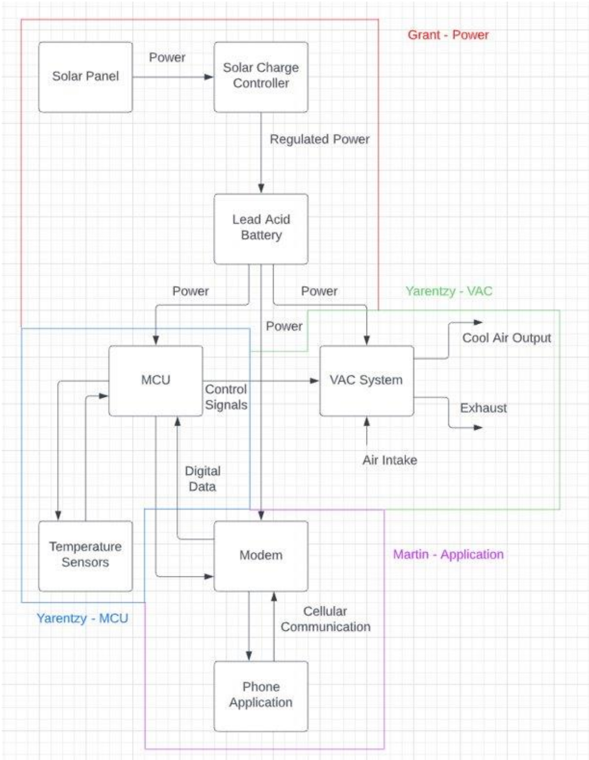
Figure 3.2. Solar Panel Visualization



3.3. System Description

As stated in the scope, the project consists of four subsystems: power supply selection and design, application development and connection to main unit, creation of VAC and microcontroller design and implementation. Figure 3.2 shows how the subsystems will work together.

Figure 3.3. Subsystem Block Diagram



The responsibilities of the different subsystems are:

- Power supply selection and design – Power will be supplied to the main unit using a solar panel. The user will have to install the solar panels on the top of the vehicle.
- Microcontroller design and implementation – The microcontroller system that will take information from the cell phone application and compare it to data that is showing on its temperature sensor. If the car's temperature is higher or lower than the user's desired temperature that is set on the application, the microcontroller will send a signal to the VAC unit to cool or heat the inside of the car.
- Choosing of VAC - The VAC system will be chosen so that the car can be cooled depending on if the current temperature of the car is hotter or colder than the user's desired temperature.
- Application development and connection to main unit – The application will allow the user to interface with the microcontroller and send signals through an internet connection. The user will input data on their pet and the desired temperature for the inside of the car.

3.4. Modes of Operations

The Chilly Dog will have one mode of cooling the interior cabin of a vehicle. Based on the input from the user, and a comparison of the current internal temperature, the VAC system will power up or down.

3.5. Users

The people using our system will primarily be pet owners that have the need to leave their pet in the car for a long amount of time. These customers will most likely be 18+ years old since they must be old enough to drive a car and own a pet. They will not be required to have any training for the installation or operation of our product, since the only thing they will be doing themselves is putting a solar panel on top of their vehicle and downloading and using an application. The information they need will be included in the user's manual.

3.6. Support

Our product will include a user's manual that has a description of the device, gives directions on installation, provides information on where to download the application and how to use it, as well as safety warnings involved with the machine. There will also be a section in the manual that will have common questions and answers to those questions.

4. Scenarios

4.1. Traveling with a Pet

The primary use of the battery powered air conditioning will be to allow pets, specifically dogs, to stay unsupervised and unattended in a vehicle while the driver is away. The battery on the unit will have a duration of 2 hours and will alert the driver when low battery is detected. While conditions are met, the device will cool and heat the car as needed to maintain the ideal temperature for the dog.

4.2. Pre-Boarding Cooling

Another possible application for the project is to pre-cool the vehicle before the driver and passengers enters it. Using the application, the driver can turn on the A/C from virtually anywhere to prepare for their arrival and have the car warmed up or cooled down internally.

4.3. Testing Scenarios

To ensure our device is working properly, we will perform a series of tests. These tests will encompass the full functionality of our device. Listed below are a few.

- Battery Duration: the device will be left on in its cooling state for 1.3 hours
- Temperature Sensing: the device will be placed in a room with known temperature. We will then take a reading from the thermostat within the device to assure it matches

- Wireless Communication: the device will be left in a car parked in a lot and a user with the application will be in a nearby building. Commands will be sent via the app and the device response will be observed
- Cooling: The device will be placed in a hot car and commanded to cool to a certain temperature. Measurements will be made of the temperature of the air being output by the device.
- Drivability: The solar panel will be placed atop the car and driven reaching speeds of up to 60 mph

5. Analysis

5.1. Summary of Proposed Improvements

- The device will have solar panels allowing it to last extended periods of time without charging
- The device will be controlled by an app allowing the user to make temperature adjustments while away from the car as well as check the current car temperature to make sure the environment is safe for their pet
- The device will have multiple temperature sensors reducing the likelihood of a malfunction as it will compare the readings and notify the user if one of them is no longer operating correctly
- The device will be cheaper than the alternatives while having substantial improvements

5.2. Disadvantages and Limitations

Limitations of the device are:

- Power supplied will be from a solar panel, which will not always be active when there isn't sunlight.
- The target car size for cooling will be a crossover sized vehicle, meaning that if the customer wanted to put it in a larger car it may not have the power required to heat/cool that space.
- There will be a decent amount of setup required as the user will have to mount solar panels to their roof rack.
- There is a slight security risk as the window will be cracked for the exhaust system to work properly. However, this is something we are going to work hard to make as minimal as possible.
- The device's charge will last less time the less the sun is out when the device is in operation.

5.3. Alternatives

Alternatives to this device are:

- Leaving the car on with another passenger with the animal
- Leaving the pet at home
- Taking the pet into the store

While these are all possible alternatives each of them has a reason why it could not be a viable replacement for our device. None of these allow the customer to safely leave their animal alone in the car without leaving the car on. There are other battery powered A/Cs available, ours hopes to surpass the competition through the improvements mentioned above and by keeping it inexpensive to reach a larger market. One of the best alternatives to our device is the Icy Breeze, this device is much cheaper than having a full VAC system like our device has. The downside to this, however, is that the Icy Breeze must be filled with ice before every use. Our device, having a full VAC system, will simply work anytime it has power.

5.4. Impact

This device's primary function is to help provide a cool and safe environment for the customer's pet. Our device is sustainable due to our use of solar panels. These solar panels will operate while sunlight is available and will allow the user to go longer stretches of time without charging. This is important because leaving your car on produces CO_2, a greenhouse gas, which contributes to global warming and is generally bad for the environment. The batteries in our device will also be rechargeable to prevent the waste from disposing of batteries in landfills. This device also promotes the companionship between pet owners and their pets by allowing them to take their furry friend wherever they go.

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FUNCTIONAL SYSTEM REQUIREMENTS

FUNCTIONAL SYSTEM REQUIREMENTS

FOR

Battery Powered Car Air Conditioning

PREPARED BY:

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Grant Franklin

Martin Rennaker

02/23/2022

Author Date

APPROVED BY:

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Project Leader Date

02/23/2022

John Lusher, P.E. Date

Sambandh Dhal 02/23/2022

T/A Date

Change Record

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-	2/15/2022	Grant Franklin	Skylar Head	Draft Release
1	04/28/2022	Yarentzy Magallanes	Skylar Head	Update for Final Report Submission

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6. Introduction

6.1. Purpose and Scope

Travelling with pets can be a challenge. The main factor being that there are very few businesses and buildings that are pet friendly. The responsible pet owner cannot just simply leave their pet inside the vehicle since temperature changes in the cabin are drastic and can get hot enough to cause harm to their pet.

Our project, the Chilly Dog, will allow customers to leave their pets in the car unattended by cooling the car to a safe temperature. The Chilly Dog will actively monitor the temperature inside the vehicle using a sensor and microcontroller and send that data via cellular data to an application on the customer’s phone. Through this application, the customer will be able to see the temperature and adjust the VAC system output to their desired setpoint. The microcontroller will receive this input and the VAC unit will output a steady flow of air to match the user's command. The Chilly Dog will be powered by a rechargeable battery making it independent and non-reliable on the engine or battery of the car. This rechargeable battery will have the option of solar charge or charge by the cigarette lighter receptacle. If the battery is running low on charge, the user will be notified to return quickly through the app.

The device is intended to be used inside crossover-sized vehicles with an estimated interior of 110 square feet. It will be placed inside the vehicle and be no bigger than the area of one seat. It will include an exhaust hose to clip to the car window and solar panels that will be installed on the roof of the vehicle. A few possible configurations of installation are shown below.

Figure 1. Seat Placement

Figure 2. Trunk Placement

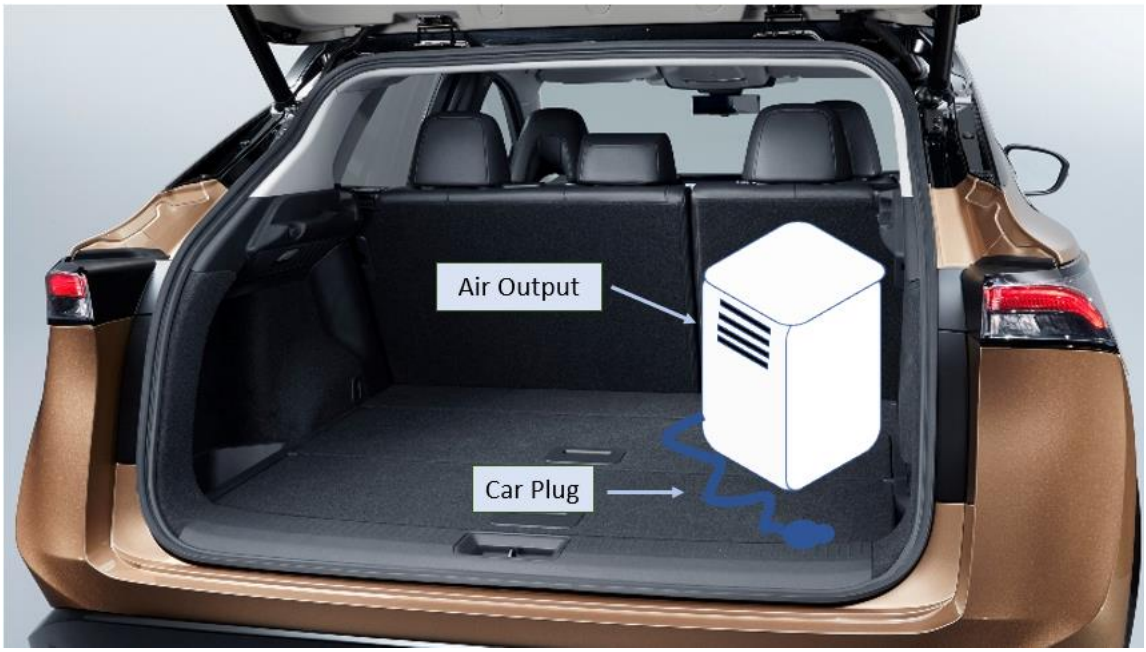
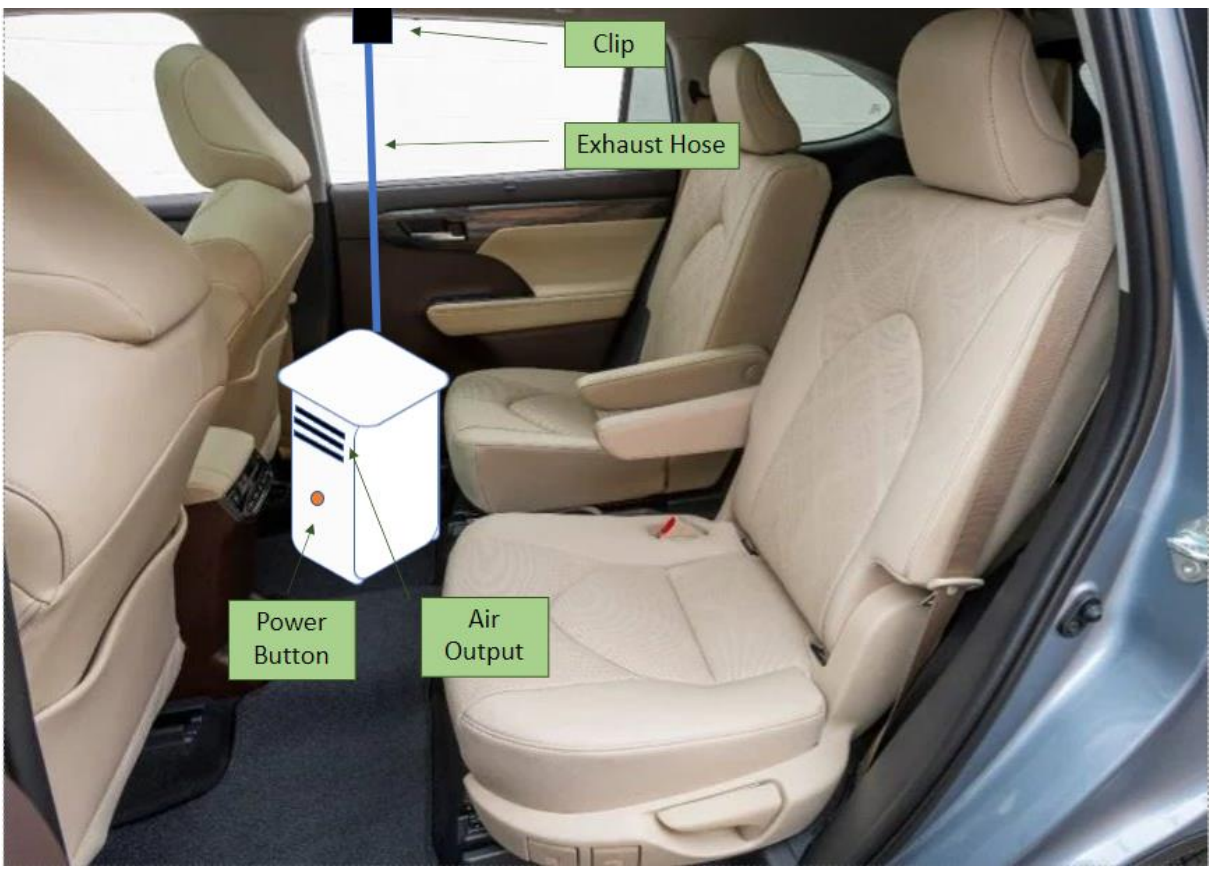


Figure 3. Floorboard Placement



6.2. Responsibility and Change Authority

The team leader, Martin Rennaker, has the responsibility of verifying the project requirements. These requirements can only be changed with the approval of the team sponsor, Skyelar Head, and the team leader. The subsystem breakdown is as follows:

Subsystem	Responsibility
VAC and MCU	Yarentzy Magallanes
Power Supply and Routing	Grant Franklin
Phone App and Interfacing w/MCU	Martin Rennaker

Table 1. Subsystem Leads

7. Applicable and Reference Documents

7.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE 802.15.4-2011	4/2011	IEEE Standard for Local and metropolitan area networks--Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)
IEEE 485-2020	6/2020	IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

Table 2. Applicable Documents

7.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
1	April 2011	Temperature Variations in a Parked Vehicle
2	April 23, 2021	How to calculate battery run-time
3	N/A	How To Maintain Batteries

7.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings, or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

8. Requirements

This section defines the minimum requirements that the development item(s) must meet. The requirements and constraints that apply to performance, design, interoperability, reliability, etc., of the system, are covered.

8.1. System Definition

The Chilly Dog is a battery powered air conditioning unit paired with an application that cools the internal temperature of a vehicle with the purpose of creating a safe environment for a K-9. The Chilly Dog is broken into 4 systems as seen in Figure 3.1. They will all work together to provide sufficient cooling to the vehicle based on the user’s desired temperature. The Chilly Dog is made up by power, microcontroller, VAC, and application subsystems.

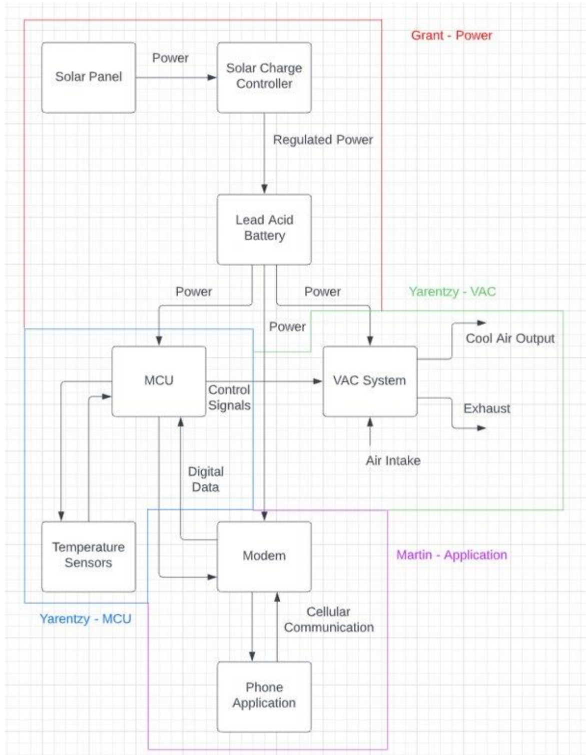


Figure 3.1. Block Diagram of System

The first stage of the block diagram is the power subsystem. Power is routed to the battery from an 18V, 100W solar panel. The solar panel will send power to the battery after going through a solar charge controller while the system is on. The battery will send voltage to the VAC and microcontroller subsystems, after going through converters to give the necessary voltages.

The microcontroller subsystem is in charge of controlling the air output from the VAC system. It will do this by comparing the current temperature in the vehicle from a sensor reading to the data sent from the application. If the two numbers don't line up, the microcontroller will tell the VAC system to either stop blowing air if the car is too cold or to cool the car down if the current temperature is too high. The microcontroller will also read the outside temperature and battery life and send that information to the modem, which will send it to the application.

The VAC subsystem will take the input from the microcontroller and power from the battery and provide necessary cooling to the car. It will require an inverter to convert the battery input to an AC voltage, which is standard in VAC systems. Our VAC system will also handle the exhaust that comes with air conditioners.

The phone application sends data to the microcontroller based on what the user inputs through an internet connection. It will also receive the battery life, current car temperature, and outside temperature from the modem, which gets the data from the microcontroller. On the application, there will be options to input their pet's size and a recommended temperature will appear, but they can set any temperature within a certain range for their dog. This will be the primary interface the user sees, other than the panel on the box with the power button.

8.2. Characteristics

8.2.1. Functional / Performance Requirements

8.2.1.1. Frequency of Temperature Measurements

Each temperature sensor in the Chilly Dog shall take a measurement every minute.

Rationale: This frequency is expected to report accurate temperature readings to the customer while avoiding recording excessive amount of data that could become difficult to manage. This frequency will also provide sufficient time for the customer to act if the temperature rises above the predetermined safe range.

8.2.1.2. Accuracy Of Measurements

The Chilly Dog sensors will report accurate data.

Sensor	Accuracy
Cabin and Outside Temperature	+ or - 1 ° C
Battery Life	+ or - 1 %

Rationale: These are standard values that most sensors of decent quality can achieve. Accuracy of measurements is key in Chilly Dog as the health and comfortability of the customers pet is of essence.

8.2.1.3. Device Environment

The components of the Chilly Dog shall function in ambient temperatures of up to 130 degrees Fahrenheit.

Rationale: The Chilly Dog must be able to withstand extreme heat as it will be placed inside a vehicle.

8.2.1.4. Battery Operating Time

The Chilly Dog shall perform its entire functionality for a span of 1.3 hours.

Rationale: Per customer request. To provide the customer sufficient time to perform their tasks while their pet is in the vehicle.

8.2.1.5. Communication from Device to Application

Every minute The Chilly Dog will send updates to the app on cabin temperature, outside temperature, and current battery remaining. The app will send any updates the user makes on desired temperature within 5 seconds of them being made. These packets will be maximum 16 bits in size. As the device will be using cellular data as long as both the phone and device are connected to a cell signal it should work from any range, but the goal will be 500 yards for testing purposes.

Rationale: The goal is to keep the user as informed as possible so they can be sure that their pet is safe in the car.

8.2.1.6. Output Temperature Ranges

The Chilly Dog shall assume the car had been recently turned off and has an internal temperature of up to 85 degrees Fahrenheit before the device is powered. The Chilly dog shall then be able to output air with a minimum temperature of 62 degrees Fahrenheit.

Rationale: The average car air conditioner has a cooling power of 17,000 BTU. This allows the car to cool quickly. The Chilly Dogs cooling power is 5,000 BTU maximum. The Chilly Dog shall be used for the sole purpose of maintaining the cabin temperature assuming it is less than 85 degrees Fahrenheit.

8.2.2. Physical Characteristics

8.2.2.1. Mass

The mass of the total Chilly Dog battery powered air conditioning unit shall be less than or equal to 127.8 pounds. This does not include the weight of the switchover circuit, microcontroller, or temperature sensor, which will affect the total weight minimally.

Current Component Mass Breakdown:

- AC Unit: 47.4 lbs
- Battery: 63.9 lbs
- Solar Panel:14.3 lbs
- Inverter: 2 lbs
- Microcontroller: 0.05 lbs
- Temperature Sensor: 0.007 lbs
- Buck Converter (Total): 0.0708 lbs
- Solar Charge Controller: 0.27 lbs
- Modem: .089 lbs

Rationale: The Chilly Dog will have a wide mass range to work with thanks to the carrying capacity of a crossover vehicle. It will encompass the seat of one passenger. With this said, the Chilly Dog shall weigh less than the average passenger which weighs 136 pounds. Each physical component will be less than 65 pounds. This is to avoid the need for machinery during installation.

8.2.2.2. Volume Envelope

The volume envelope of the Chilly shall be less than or equal to 26 inches in height, 14 inches in width, and 14 inches in length. The Chilly Dog will only occupy the area of one seat but can be placed on the floorboard, or the trunk if desired. More detail can be found in the ICD.

Rationale: This is a requirement specified by our customer due to the limitation of the cabin space inside a vehicle. The customer expects sufficient room for their pet even after the Chilly Dog has been installed.

8.2.2.3. Mounting and Installation

The mounting information for the Chilly Dog System shall be captured in the ICD.

Rationale: The Chilly Dog includes the VAC unit, the exhaust hose, the connecting wires, and the solar panels. These details will be described in the ICD.

8.2.2.4. Material

The material of the Chilly Dog will be “pet friendly” meaning it will be made of nontoxic material to both the pet and the human, sturdy enough to resist accidental nudging, but shall not be expected to withstand chewing of cables and any other improper use.

8.2.2.5. Exhaust

The VAC unit will also have a hose connected to the window that will push the warm air outside of the car.

8.2.3. Electrical Characteristics

8.2.3.1. Inputs

The electrical inputs for the Chilly Dog consist of the power from the solar panel, the temperature data gathered by the sensor on the microcontroller, and the user's input information sourcing from the phone application.

8.2.3.1.1 Power Consumption

The maximum peak power of the system shall not exceed the available power coming from the battery, which outputs 1200WH and consumes 803.825WH at maximum power consumption.

Rationale: The solar panel recharging time would be drastically reduced if a larger wattage panel is used or if some other form of charging can be found.

8.2.3.1.2 Input Voltage Level

The input voltage level for the battery will be 14V, as is needed for the battery to recharge. The microcontroller will take 3.3V, the modem will take 5V at 50mA, and the VAC system will take 115V at 7.19A.

Rationale: The battery powered car air conditioning will need to power the microcontroller and the VAC components with enough voltage for the amount of time the unit will need to be running.

8.2.3.1.3 Modem Inputs

The modem will receive desired temperature data from the application, as well as the current temperature and battery life from the microcontroller.

8.2.3.1.4 Microcontroller Inputs

The microcontroller will receive inputs from temperature sensors and the modem. The temperature data from the sensors will be compared to the desired temperature data coming from the modem. If the actual temperature inside the vehicle is different than the desired temperature, the microcontroller will command the VAC system to output cool air.

Rationale: The microcontroller will oversee regulating the amount and the temperature of air that is output into the vehicle.

8.2.3.1.5 Application Inputs

The application will receive the current temperature data for the inside of the vehicle, as well as outside, and battery life from the modem.

Rationale: The app will need to display to the user the current internal car temperature, outside temperature, and battery life.

8.2.3.1.6 Air Conditioning Inputs

The VAC will receive commands from the microcontroller to turn/off its cooling.

8.2.3.2. Outputs

8.2.3.2.1 Modem Outputs

The modem will send the current temperatures and battery level to the application using cellular data.

8.2.3.2.2 Microcontroller Outputs

The microcontroller will send the current temperatures and battery level to the modem.

8.2.3.2.3 Application Outputs

The Application will send the user's desired temperature to the modem. The application will also push notification banners to the phone to alert the user to low battery.

Rationale: The MCU will need the desired temperature from the app to know what temperature to set the car at. The app will need to notify users if there is danger to their animals

8.2.3.2.4 Air Conditioning Outputs

The unit will provide enough cool air that will bring the inside temperature of the car to the desired temperature input by the user.

Rationale: The unit will need to cool the car down fast enough so the pet inside the car will not overheat. It will also need to blow the hot air out of the car using an exhaust hose.

8.2.3.2.5 Cellular Outputs

The MCU will send both the current temperature and battery level to the app via cellular data.

Rationale: Allows the user to quickly check if the unit is operating correctly while away from the car, as well as informing them of the current battery life of the unit.

8.2.4. Environmental Regulations

The Chilly Dog will need to withstand various climates and temperature ranges since its function is to keep the pet inside the vehicle safe while the weather is dangerous outside.

Rationale: This is a requirement specified by our customer due to constraints of their system in which the Chilly Dog is integrating.

8.2.4.1. Animal Activity

The Chilly Dog will be constructed to be resistant to animals biting or scratching it. It will also, as mentioned previously, be made out of nontoxic materials to prevent poisoning an animal that does bite or scratch it.

Rationale: This is to prevent injuries to animals in the car with the device as well as protecting the device from animals.

8.2.4.2. Weather Conditions

The only component that will be exposed to varying weather conditions will be the solar panel and the wires leading to the main unit. It will have to withstand weather conditions such as rain, humidity, etc. to satisfy the claim that it can run and charge a battery in all conditions.

8.2.5. Failure Propagation

The Chilly Dog shall not allow propagation of faults beyond the Chilly Dog interface.

8.2.5.1. Battery Input Regulation

Since the voltage coming from a solar panel is more than required to charge the battery, we regulate it with a solar charge controller to eliminate overcharging.

8.2.5.2. Battery Output Regulation

There is a chance that the current will be too high between the load converters/inverter, so fuses are needed. These will be implemented in the wired connections from the converters/inverter to the battery.

8.2.5.3. Connection Lost Between Modem and App

If the Modem and app lose connection, an attempt will be made 5 times, once per minute, to reestablish connection. If connection is not made and the phone can still connect to cellular data itself the app will send a banner notification to the phone informing them that connection has been lost and they need to return to their car. If the phone itself is unable to connect to cellular data, it is likely that the device is still functioning, and the app will simply send a notification every 5 minutes informing the user of how long it has been since a connection has been made.

9. Support Requirements

9.1.1. Android Device with Cellular Data

To Communicate with the Chilly Dog via the application, the customer will need access to an android device with cellular credit

Rationale: Other forms of accessing the information from the system are outside of the scope of this project.

9.1.2. Cellular Reception

The customer must have reliable cellular reception in the area where the Chilly Dog will be placed and where the customers phone will be located.

Rationale: The app and the device communicate through cellular signals.

9.1.3. Crossover Sized or Smaller Vehicle

The customer must have a car that spans 179 inches (14 feet) in length or less.

Rationale: The use of the Chilly Dog in larger vehicles will not cool as expected and could result in the cabin being unfit for pets.

9.1.4. Rolling Window

The customers crossover or smaller vehicle must have fully functioning windows that roll up and down.

Rationale: The Chilly Dog has an exhaust hose used to dispose of hot air. The exhaust hose configuration is only supported via a clip that attaches to a standard roll up window. Other configurations are not in the scope of this project.

9.1.5. Provided

- (1) VAC unit
- (1) Rechargeable Battery
- (1) MCU
- (1) Cigarette Lighter Receptacle Plug in
- (1) Surface Mount Solar Panel
- (1) User Manual and Warnings
- (1) Installation Manual

Appendix A: Acronyms and Abbreviations

lbs	Pounds
ft	Feet
in	Inches
GUI	Graphical User Interface
AC	Air Conditioning
Hz	Hertz
V	Volts
A	Amps
kHz	Kilohertz (1,000 Hz)
mA	Milliamp
MCU	Microcontroller Unit
MHz	Megahertz (1,000,000 Hz)
mW	Milliwatt
VAC	Ventilation and Air Conditioning

Appendix B: Definition of Terms

Battery Powered Car Air Conditioning

“The Chilly Dog”

Grant Franklin

Martin Rennaker

Yarentzy Magallanes

INTERFACE CONTROL DOCUMENT

INTERFACE CONTROL DOCUMENT

FOR

Battery Powered Air Conditioning

PREPARED BY:

Marrtin Rennaker

Grant Franklin

Yarentzy Magallanes

Author Date

APPROVED BY:

Martin Rennaker

Project Leader Date

John Lusher II, P.E. Date

Sambandh Dhal

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	02/15/2022	Grant Franklin		Draft Release

List of Tables

List of Figures

10. Overview

The Interface Control Document or ICD discusses in depth the methods in which the subsystems of the Chilly Dog function as individuals and interact. In this document we can see what will be done in order to produce what has been described in the Concept of Operations, Functional System Request, and Validation Plan.

11. References and Definitions

11.1. References

IEEE Standard for Local and metropolitan area networks--Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Document IEEE 802.15.4-2011

11.2. Definitions

ConOps	Concept of Operations
FSC	Functional System Requests
ICD	Interface Control Document
CCA	Circuit Card Assembly
GSM	Global System for Mobile Communications
VAC	Ventilation, and Air Conditioning
mA	Milliamp
MCU	Microcontroller Unit
mW	Milliwatt
MHz	Megahertz (1,000,000 Hz)
SUV	Sport Utility Vehicle
TBD	To Be Determined
TTL	Transistor-Transistor Logic
V	Volts
VME	VERSA-Module Europe
WPAN	Wireless Personal Area Network

12. Physical Interface

12.1. Weight

The weight of the power supply will contain the heaviest components, since it uses a solar panel, marine battery, and a VAC system. The parts can be removed and installed individually, since they will be almost immobile together. The total weight of the system is estimated to be

Component	Weight	Estimate
Solar Panel	14.3 lbs	No
Battery	63.9 lbs	No
VAC system	47.4 lbs	No
Inverter	2 lbs	No
Microcontroller	0.00441 lbs	Yes
Buck Converter	0.0708 lbs	No
Solar Charge Controller	0.27 lbs	No
Modem	.089 lbs	No
Temperature Sensor	0.00661 lbs	Yes
Solar Panel	14.3 lbs	No
Battery	63.9 lbs	No

Table 1: Weight of System

12.2. Dimensions

12.2.1. Dimensions of System

The dimensions of the Chilly Dog components will be mostly confined to the back seat of a mid-sized SUV. The solar panel will need to fit on the roof of the car, while the rest of the components will be small enough to be placed in the floorboard behind the passenger seat, with the possible exception of the VAC unit.

Component	Length	Width	Height
Solar Panel	42.2”	19.6”	1.38”
Battery	12.09”	6.65”	8.48”
VAC system	12.56”	24.96”	12.96”
Inverter	8.75”	4.5”	2.5”
Microcontroller	TBD	TBD	TBD
Modem Buck Converter	2”	1”	0.47”
MCU Buck Converter	0.47”	0.3”	0.43”
Solar Charge Controller	4.7”	3”	1.1”
Modem	3’’	2’’	3.5’’
Temperature Sensor	2’’	0.5’’	0.5’’

Solar Panel	42.2”	19.6”	1.38”

Table 2: Dimensions of System

12.3. Mounting Locations

12.3.1. Mounting of Solar Panel, Charge Controller, and Battery

The solar panel will be mounted on the roof of the vehicle. The solar charge controller and battery will be placed inside of the car on the floorboard of the back seat. Possible ola

13. Thermal Interface

Provide detail on any thermal interfaces that your project may have. Do you need cooling and air circulation? Do you need heatsinks? If you use a heatsink, does it need a cold wall?

14. Electrical Interface

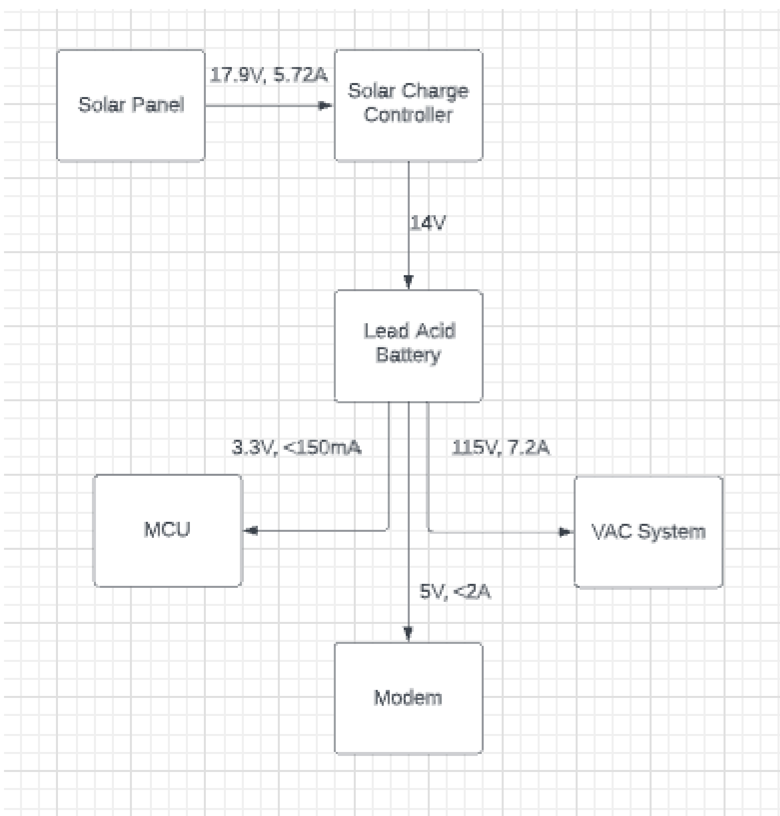


Figure 1: Power Supply System

14.1. Primary Input Power

All power to the battery powered car air conditioning will be supplied by a 100W solar panel, which will be used to charge a 100Ah car battery. This battery will power the microcontroller and VAC subsystems for 1.3 hours. The voltage will be stepped up and down and regulated by buck converters and an inverter. The buck converters providing power to the microcontroller and the modem, and the inverter changing the power to AC and routing power to the VAC system.

14.2. Signal Interfaces

The Chilly Dog will receive and transmit wireless signals between the phone app and MCU. This communication will occur through GSM cell band, the cellular modem being used can accept 850, 900, 1800, or 1900 MHz signals, so the chosen cell carrier must support one of these frequencies of GSM. The cell signals will transmit and receive temperature information for the MCU. This information transfer will need to be at a rate of 16 bits in 5 seconds to allow quick changes.

14.3. User Control Interface

The primary way that users will interface with The Chilly Dog will be the app. This app will allow the user to change the desired temperature of the device, manage multiple devices if they have them, and see the current temperature inside the car.

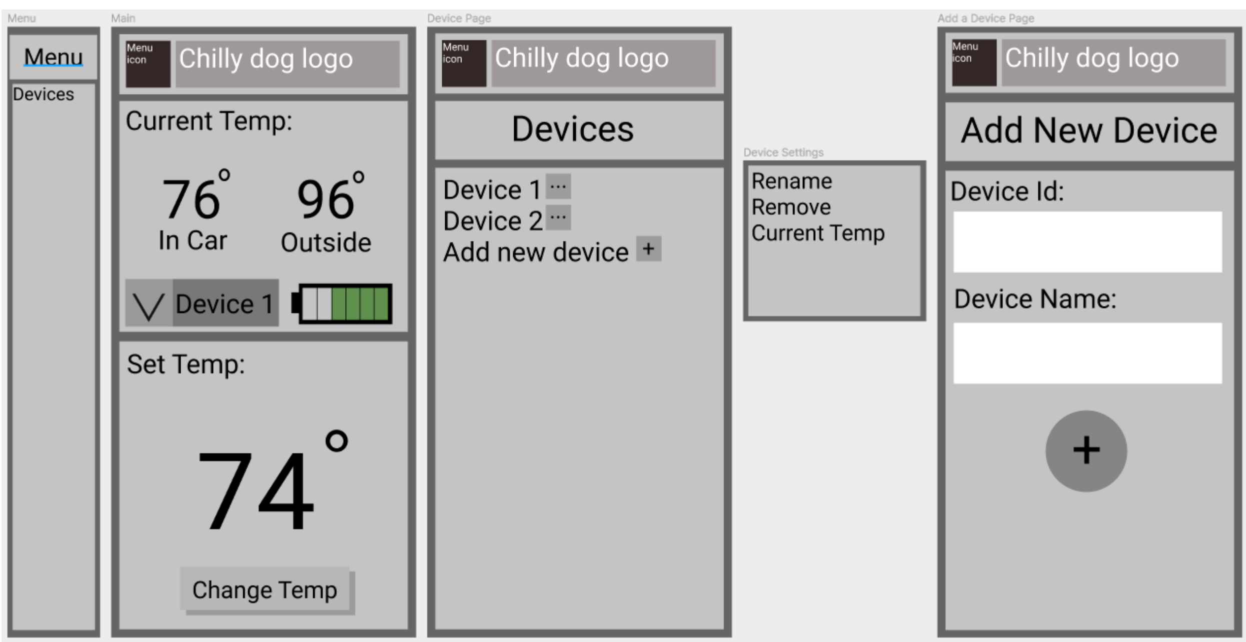


Figure 2: Preliminary Application Design

14.4. Voltage and Current Levels

The voltage and current going through the system will be regulated by the converters that are sending power to the VAC and the microcontroller. When the Chilly Dog is turned on, the microcontroller will be receiving 5V, the modem will be receiving 5V at 50mA, and the VAC will consume 115V at 7.2A. The 18V, 100Ah battery will be able to power these components at these values for 1.3 hours.

These are the maximum voltage and current inputs for each part of the power subsystem:

	Max. Voltage (V)	Max. Current (A)	Max. Power (W)
Battery	15	27	405
Microcontroller	3.3	0.25	0.825
Modem	5	2	10
VAC	115	15	793

Table 3: Maximum Voltage Inputs of System

These are the minimum voltage and current inputs for each part of the power subsystem:

	Min. Voltage (V)	Min. Current (A)	Min. Power (W)
Battery	12.9	0.1	1.29
Microcontroller	1.8	N/A	N/A
Modem	4.8	N/A	N/A
VAC	110	13	790

Table 4: Minimum Voltage Inputs of System

15. Communications / Device Interface Protocols

15.1. Wireless Communications (Cellular Data)

This device will have wireless communication via cellular data utilizing the IEEE 802.15.4-2011 standard for WPAN. This connection will be used to send temperature data between the app and the device

Chilly Dog

Battery Powered Car Air Conditioner

Martin Rennaker

Grant Franklin

Yarentzy Magallanes

SUBSYSTEM REPORTS

REVISION – 1

30 April 2022

SUBSYSTEM REPORTS

FOR

Chilly Dog

Battery Powered Car Air Conditioning

TEAM <31>

APPROVED BY:

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Sambandh Dhal 02/09/2022

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1. Introduction

The Chilly Dog will create a safe, cool environment for pets inside a car during the hot Texas summer. The system will take in the user's inputted data on the application and send that data to the MCU to be interpreted. The MCU will determine whether or not the car is currently cool enough and if not, it will send a command to the VAC system to cool the car. The system will be powered by a lead acid battery and stepped up and down to the various loads using DC-DC converters and an inverter.

2. Power Supply Subsystem Report

The power supply subsystem consists of a 12V lead acid battery that is charged with a 100W solar panel, after going through a solar charge controller. The battery powers two buck converters that step down voltage to an MCU and modem, as well as an inverter that steps up the voltage to a portable VAC system.

2.1. Power Subsystem Block Diagram

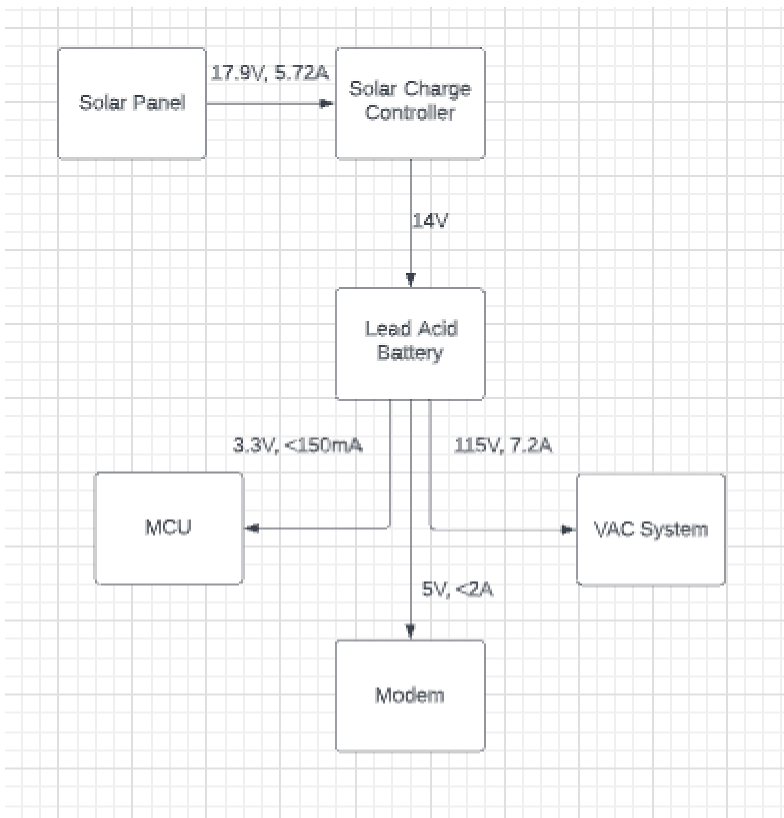

Figure 1. Power Block Diagram

2.2. Buck Converters

2.2.1. MCU Converter

The DC-DC Buck converter leading to the MCU successfully stepped down the 12V of the battery to ~3.32V at <150mA. The circuit consists of an isolated Buck converter with an inductor and 4 capacitors that regulate the voltage coming in and out of it. The converter did not have a sound data sheet and therefore no simulation was able to be made due to difficulties in finding suitable models. Due to this, validation on the breadboard and Perfboard was done to confirm correct operation of the circuit. It passed and gave valid outputs as seen in section 3.6.1. Over the summer, research and simulations into a non-isolated DC-DC converter will be done so the user can have more flexibility in the output voltage and current going to the MCU.

2.2.2. Modem Converter

The DC-DC Buck converter leading to the modem successfully stepped down the 12V of the battery to ~5V at <2A. The circuit consists of an isolated Buck converter with all the voltage regulation required for the circuit already inside of it. The converter did not have a sound data sheet and therefore no simulation was able to be made due to difficulties in finding suitable models. Due to this, validation on the Perfboard was done to confirm correct operation of the circuit. It passed and gave valid outputs as seen in section 3.6.2. Over the summer, research and simulations into a non-isolated DC-DC converter will be done so the user can have more flexibility in the output voltage and current going to the Modem.

2.3. Inverter/VAC

The lead acid battery is connected to the inverter using an o-ring connector with a fuse. The portable VAC system plugs into the female wall outlet port on the inverter and receives the stepped up 115V at ~7.2A.

2.4. Solar Panel Charging

The solar panel charging system consists of a 100W solar panel, a solar charge controller, and the battery that gets charged. The solar panel provides a nominal voltage and current of 17.9V and 5.72A respectively, however it can provide a maximum voltage and current of 21.6V and 6.24A. The solar charge controller regulates the voltage to ~14V to give enough power to charge the battery, without overloading it.

2.5. Solar Switching Circuit

Another part of the power supply that was not able to be validated was the solar switching circuit. This circuit was created to determine whether the solar panel was creating enough output to charge the battery, and if not, allow the 12V car outlet to provide charging. This circuit can be seen below.

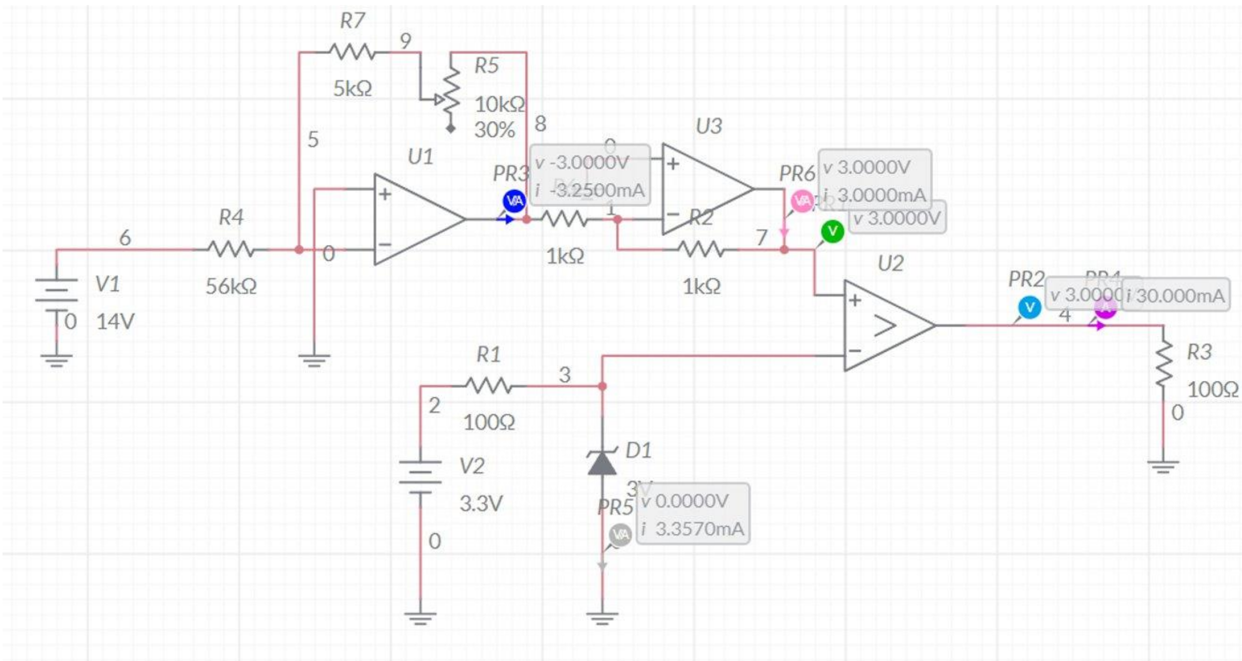

Figure 2. Switching Circuit Simulation

2.6. Subsystem Validation

2.6.1. MCU Converter

To validate the MCU DC-DC converter, an initial test for operation, as well as line and load regulation tests were performed on the circuit. The circuit took in 12V from the bench power supply to simulate the battery and outputted 3.32V as seen in Figure 3.

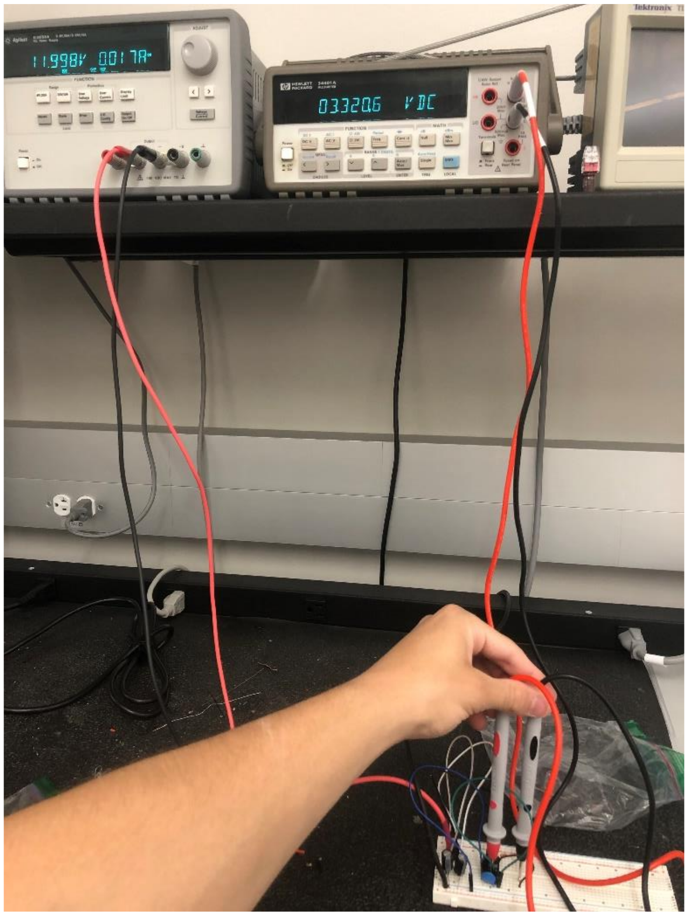

Figure 3. MCU Multimeter Output

The load regulation test was conducted by hooking up an e-load to the output nodes of the circuit and measuring the change in load voltage after changing the current draw from 0A to 250mA (Figure 3). The line regulation test stepped up the input voltage from 11.4V to 12.8V, measuring the change in the load voltage (Figure 4). The converter had an acceptable 7.03% load regulation and very good line regulation of 0.003%.

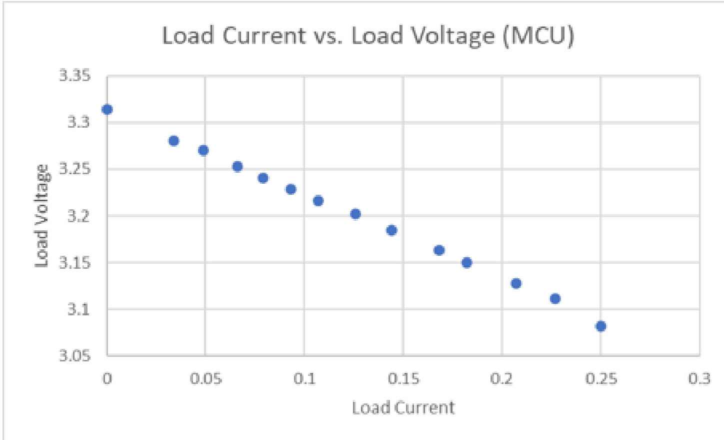

Figure 4. Load Regulation Test Results

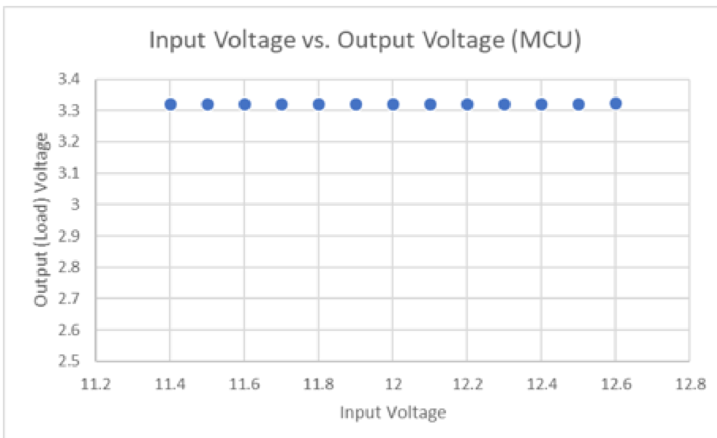

Figure 5. Line Regulation Test Results

2.6.2. Modem Converter

To validate the Modem DC-DC converter, an initial test for operation, as well as line and load regulation tests were performed on the circuit. The circuit took in 12V from the bench power supply to simulate the battery and outputted 5V as seen in Figure 5.

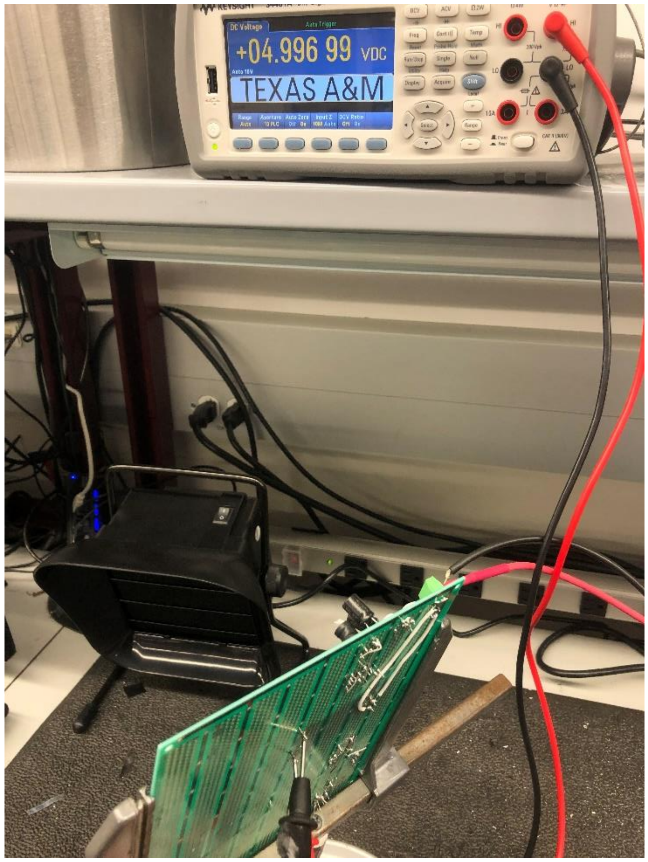

Figure 6. Modem Multimeter Output

The load regulation test was conducted by hooking up an e-load to the output nodes of the circuit and measuring the change in load voltage after changing the current draw from 0A to 2A (Figure 6). The line regulation test stepped up the input voltage from 11.4V to 12.8V, measuring the change in the load voltage (Figure 7). The converter had an acceptable 2.14% load regulation and very good line regulation of 0.006%.

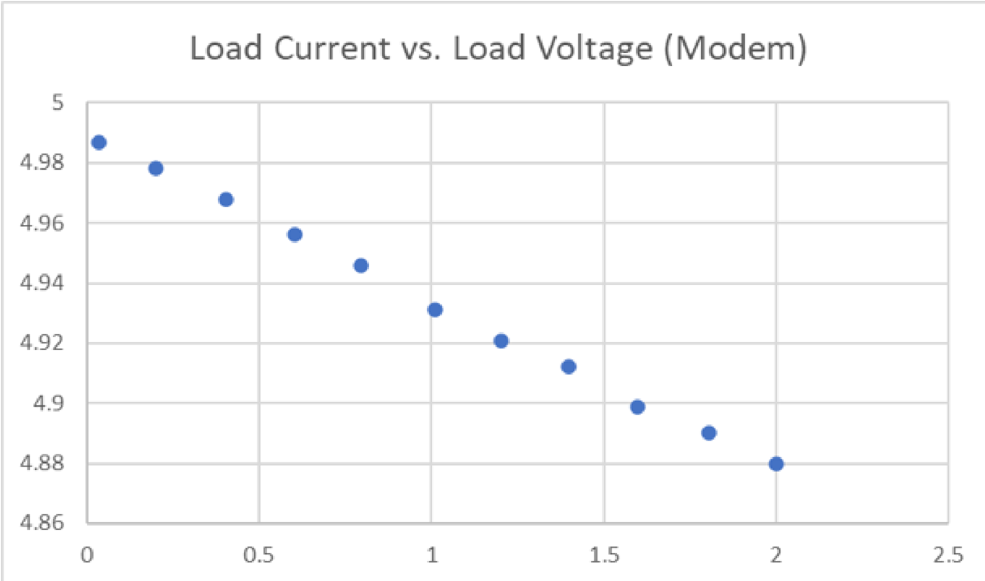

Figure 7. Load Regulation Test Results

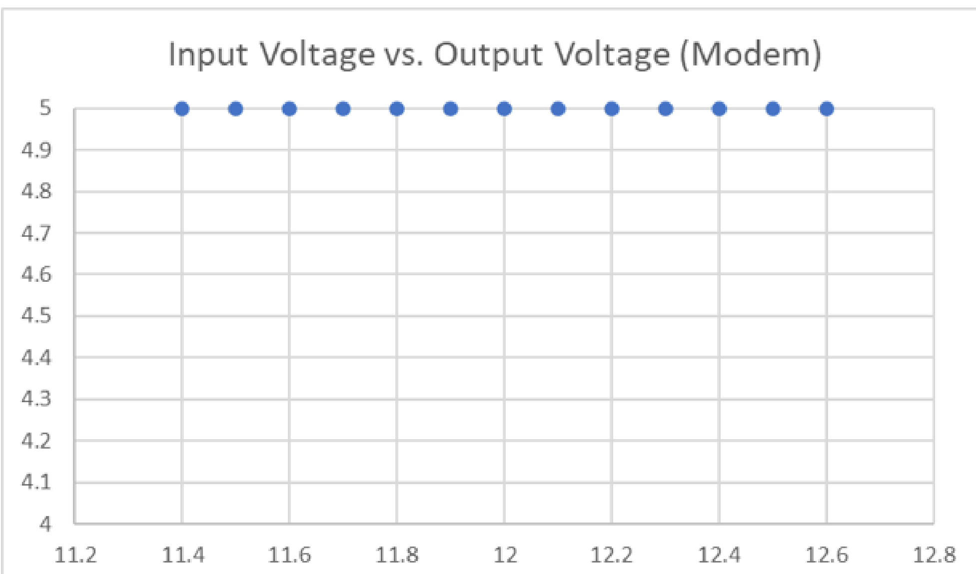

Figure 8. Line Regulation Test Results

2.6.3. Inverter/VAC

The inverter/VAC portion of the power supply subsystem was tested for functionality, since all the associated products were purchased, not made. The battery connected to the inverter through an O-ring with a fuse, and the VAC plugged into the inverter's wall socket. The device turned on and was able to operate when the temperature was changed from the minimum to the maximum value.

2.6.4. Solar Panel Charging

The charging of the battery is handled by the 100W solar panel. Since the panel outputs more than 14V needed for charging, the voltage is regulated by the solar charge controller. This can be seen in Figures 9 and 10, where the solar panel is outputting 19.1V and the battery is charging from the output of the charge controller while at a voltage of 12.6V.

Figure 9. Solar Panel Output Voltage to Controller

Figure 10. Current Battery Voltage

2.7. Subsystem Conclusion

Each part of the power supply system operated as designed. The DC-DC converters outputted their respective voltages at a current regulated for their loads. The inverter successfully takes the DC battery voltage and changes it to an AC voltage for the VAC to use and operate within the range of operating temperatures. The solar panel gives a high enough voltage for the controller to step down and charge the battery. Moving forward, changes to the DC-DC converters will be made for more flexibility with loads, as well as implementation of a switching input system to provide a 12V car outlet as a secondary charging source.

3. Microcontroller Subsystem

The microcontroller subsystem serves as the control center of the Chilly Dog. It is responsible for reading temperature sensors and interpreting the battery life of the system outputting the data to the user's application. It will receive a temperature set point by the user and control the on/off status of the VAC system. It will also alert the user when the temperature of the cabin has varied far from what the user sent. The Chilly Dog as a whole was created to maintain safe conditions for a pet inside a vehicle. It is critical that these sensors and responses are executed in a timely manner. For this reason, the functionality of each part of the microcontroller subsystem was thoroughly validated to meet our requirements.

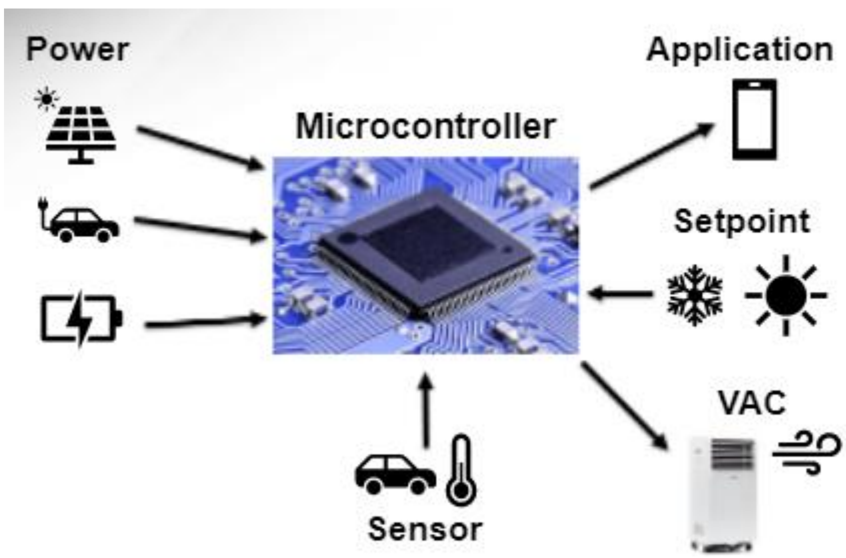

Figure 11. Inputs and Outputs of the Microcontroller

3.1 Microcontroller

The selected microcontroller for the Chilly Dog was the PIC24FJ128GA204. The PIC24FJ is a flexible, cost-effective, low-power microcontroller equipped with innovative peripherals and plenty of flash program memory. Some of the key characteristics that led to the selection of this MCU include:

- 44 I/O Pins
- UART Serial Communication
- 12 Bit Analog Input Channels for A/D Conversion
- 5 Timers

- Mplab X IDE
- Programmed in C code
- Mplab Code Configurator
- Sufficient and Extensive Documentation

3.2 Temperature Sensor

The temperature sensor used for the data collection of the internal cabin, and outdoor conditions is the DHT22. Due to the limited charge of the battery and our goal of having the device cool for a minimum of 2 hours, power is a precious resource. The selection of this sensor revolved around its low power consumption as summarized in the table below.

	Condition	Minimum	Typical	Maximum
Power Supply	DC	3.3 V	5 V	6 V
Current Supply	Measuring	1 mA	1.3 mA	1.5 mA
Current Supply	Stand-by	40 uA	Null	50 uA

Table 1. Power Consumption of DHT22

3.2.1 Communication Method

A one wire bus is used for communication between the MCU and the DHT22. To begin data transmission, the sensor first waits for a low pulse of at least 1ms from the MCU followed by a high pulse for 40us. Once the signal is received the sensor will respond with a low pulse of 80us and a high pulse of 80us as illustrated below.

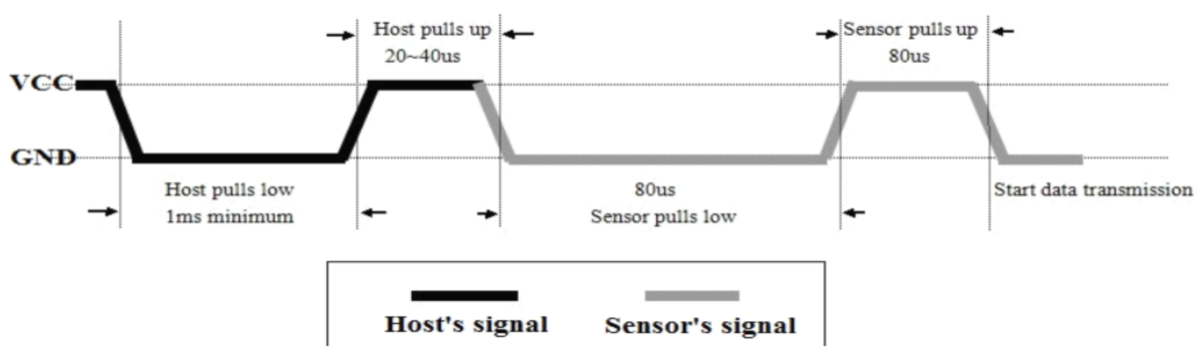

Figure 12. MCU DHT22 Signal Exchange

Upon established connection, the data is sent through the bus in 40 bits. The right most 16 bits are allocated for the relative humidity data, followed by another 16 bits for the temperature data and the last 8 bits being the check sum. An example of data transmission can be seen below.

0000 0010 1000 1100	0000 0001 0101 1111	1110 1110
16 bits humidity	16 bits temperature	8 bits check sum

Humidity = 65.2%

Binary to Decimal

0000 0010 1000 1100 -> 652

Divide by 10

652/10 = 65.2

Temperature = 35.1 ℃

Binary to Decimal

0000 0001 0101 1111 - > 351

Divide by 10

351/10 = 35.1

Check Sum = 1110 1110

Humidity	0000 0010 1000 1100
+	+
Temperature	0000 0001 0101 1111
Check Sum	1110 1110

Once the 40 bits of data are sent, the sensor will again wait for the pulses of the MCU to take another reading.

3.2.1 Accuracy

The DHT22 temperature and humidity sensor is capable of reading data every two seconds with an accuracy of +- 0.5 degrees Celsius and a resolution sensitivity of 0.1 degrees Celsius with a long transmission distance of up to 100 meters. This accuracy was critical for the scope of the Chilly Dog as we will provide the most accurate up to date temperature data possible to the user and alert them in real time when conditions fall below the desired setpoint temperature.

3.2.2 Validation

The sensor was implemented into the MCU and tested thoroughly with the use of redundancy. Two DHT22 temperature sensors were placed side by side and readings were collected. The results of this cross examination can be seen below.

DHT22 Sensor #1	DHT22 Sensor #2
73.6 °F	73.6 °F
73.5 °F	73.5 °F
73.5 °F	73.5 °F
73.4 °F	73.4 °F
73.4 °F	73.5 °F
73.2 °F	73.2 °F
73.2 °F	73.2 °F

Table 2. DHT22 Sensor Comparison

Warm air was then blown on the sensors and an increase was detected and recorded.

Validation of the speed of data transmission was also conducted by redirecting the output signal of the sensor to an oscilloscope and taking measurements between data transmission beginning and end.

3.3 UART Serial Protocol

The microcontroller of the Chilly Dog will be responsible for transmitting and receiving data to and from the user application. The means of this communication will be done through the serial communication protocol UART or Universal Asynchronous Receiver/Transmitter.

3.3.1 Validation

UART has been used extensively within the microcontroller subsystem. The Chilly Dog MCU can receive and send data between MCU and MCU, and between MCU and console. One of the most useful purposes being redirecting print function to the console. Using this feature, debugging of code was simplified and used for incremental coding.

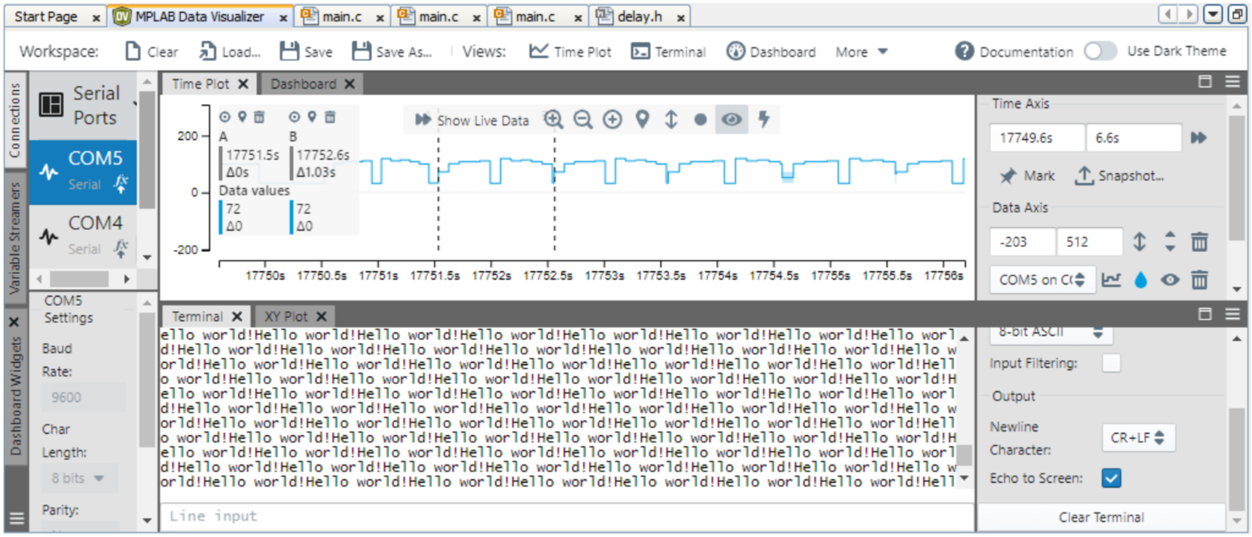

Figure 13. UART Print

3.4 Relay Control

The MCU of the Chilly Dog will turn on and off the VAC system according to the cabin temperature and the temperature set by the user. This will be done using a relay.

3.4.1 Validation

The validation of the MCUs responsibility of controlling the on/off status of the VAC system was completed using a Songle 5V electromagnetic relay. The relay was implemented using the circuit below. (Note: The PICFJ24 was not supported by this simulation software so an Arduino Nano is shown. This, however, was implemented using the PIC24FJ and its respective I/O pins.)

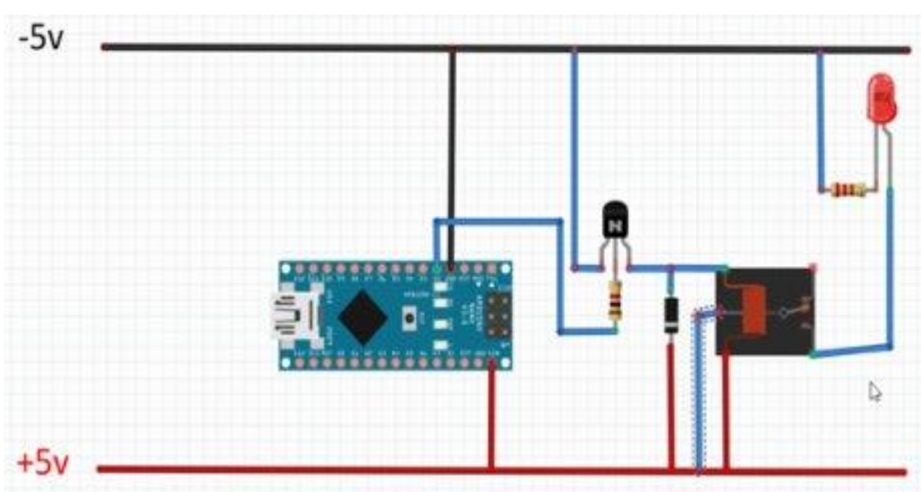

Figure 14. Relay Circuit

This circuit consists of the relay, an NPN transistor, two resistors, an LED, and a diode connected across the electromagnetic coil to prevent against a voltage spike or a backward flow of current.

3.5 AC Input

Another function of the Chilly Dogs MCU is outputting the devices battery percentage. The MCU will be receiving a scaled down voltage from the battery and expected to interpret that voltage into a percentage of battery life.

3.5.1 Validation

The scope of validation for this function in 403 revolved around being able to configure the MCU to receive an AC voltage and output it. This was completed using a potentiometer and a flashing LED. The potentiometer varied the resistance and therefore the voltage seen by the input pin in the arrangement of a voltage divider. The position of the potentiometer controlled the speed at which the LED toggled.

3.6 Microcontroller Subsystem Summary

The PIC24FJ128GA204 fits and exceeds the needs of the Chilly Dog. It has been configured to read and process temperature data, communicate from MCU to MCU and from MCU to console, turn on or off a load, and receive and interpret AC voltages. Looking forward to ECEN 404, a relay capable of controlling a higher current will be necessary to power the VAC system, code will be written to manage alert cases, the PIC will communicate via UART with the application subsystem and the AC voltage will be received from the power subsystem in order to output battery percentage.

4 Application and Modem Subsystem

The Application and Modem Subsystem has the goal of keeping the user informed that their pet is alive and well in the car. The app also serves as the method of controlling the set temperature of the VAC unit allowing the user to control the speed at which the car is cooled down. The modem allows the Chilly Dog to rely on cellular data which while not available all the time is more reliable than Wi-Fi or Bluetooth. This makes the Chilly Dog's range theoretically infinite in the US if both the device with the app and The Chilly Dog are both within range of a cell tower. The app is also for error detection and has notifications to alert the user of malfunctions within The Chilly Dog, prolonged temperature discrepancies, or low battery. The following sections will go more in depth into the construction of each subsystem and then how each were validated.

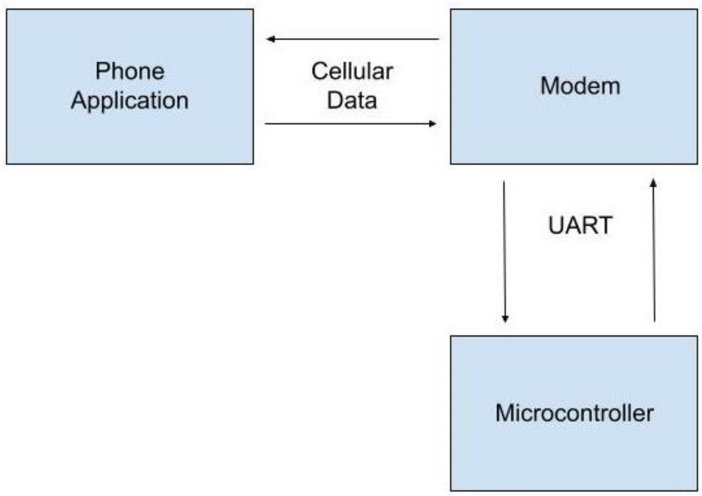

Figure 15 App and Modem Block Diagram

4.1 Android App

The application was constructed using Android Studio meant for an Android device, this was chosen due to IOS being more difficult to work with and Android allowing developers more ready access to features like texting. At its core the app is a SMS platform that is made to send and accept text messages from a specific user defined phone number, this being The Chilly Dog.

After install on first startup the app will ask the user for permission to send and receive text messages and will store this permission. The app will open to a not filled in home screen and the device status will read “Device Not Connected”. The user will have to navigate to the Add Device page and enter The Chilly Dog's phone number. This will prompt the app to send a SMS to The Chilly Dog that reads “test” from here the app will wait until it receives a response from the phone number it messaged. If it does the connection status will be updated, this is handled internally as a Boolean. Once the connection is established the app will wait to receive messages from the connected device formatted with the prefix corresponding to the prefixes seen if figure 15, these will tell the app which section to put the received data. The Add a Device button has been made so it will only accept 10-digit entries which is the length of a phone number, anything else and it will simply inform the user that the entered value is invalid. Once a device is connected if the user attempts to connect another device the user will be told that a device is already connected and if they wish to add a new one, they must press the button again to confirm. In the future the app will be able to hold multiple devices.

The home screen on the app was designed so the most important information for the user is the most visible on startup, that is the internal car temperature, the outside temperature, and the battery remaining. These sections will be filled in by the texts received from the connected device and will update both when the app is in the foreground and background. At the bottom of the home page is the editable text box for the user to enter a desired set temperature for the VAC system. This box will only accept numbers and if the number is out of the range 40 – 90 the user will be asked to confirm that they wish to send this temperature. The temperature range is to help prevent the user from accidentally entering an extreme temperature, however they may wish to send that temperature, so they simply must confirm.

The last main feature of the app are the notifications, the app must notify the user of malfunction or battery issue to keep the user’s pet safe. The notifications page is simply a page full of toggles to different notifications. Currently the device only notifies if the battery reaches a certain percentage, and the corresponding notification is turned on. In the future however there will be more notifications this was more of a proof of concept to show that the app can send notifications. These notifications work both in when the app is in the foreground and background, will only be received if the condition is met and the toggle is on, and when tapped will navigate the user back to the app.

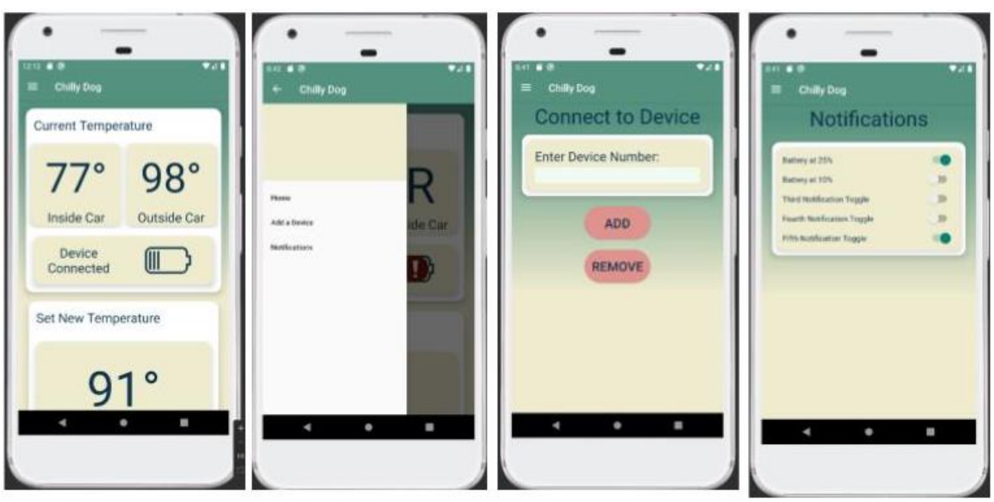

Figure 16 App Screens, left to right: Home, Menu, Add Device, and Notifications

Figure 17 Message Prefixes

4.2 Modem

The Modem is the middleman between the phone app and the microcontroller, this means that it receives a text from the app indicating the user's desired temperature and sends texts to the app indicating the car's internal temperature, the temperature outside the car, and the current battery remaining in The Chilly Dog. This modem will communicate to the microcontroller via UART and currently has been communicating to a laptop via built in UART to USB through PuTTY. The serial communication transmits AT commands which are commands made for COMS and can be used to configure the modem and send and receive text messages.

The modem was going to communicate with a Raspberry Pi which was then going to communicate with the microcontroller, however the Pi wasn't cooperating, and it is more efficient if in the final design the modem simply communicates directly with the microcontroller. On startup the microcontroller will send the commands "AT" and "AT+CMFG" which establish the initial handshake and set the SMS format to text as opposed to hex code, the other at commands used are shown in figure 17. The device will then wait until the "test" SMS is received and then it will send the updated in temperature, out temperature, and battery percentage. From here it will sit idle waiting for either an updated temperature for the VAC from the app or in, out temperatures, and battery percentage to send to the app.

AT Commands (at+)	
cmgd=index,(1)	Delete message, at index or all read
cmgr=index	read message at index
cmgf=1	set message format to text
cmgs="+phonenum"	sends message to the number, send with ctr+z cancel with del
at	initial handshake

Figure 18 AT commands used to communicate with the modem

4.3 Validation

Testing these systems was interesting as they are both completely on the computer or on a mobile device meaning there aren't many numeric results and instead differ. In Appendix A more detailed results will be shown this section will go over all the tests and how they were conducted, where the appendix will have the pictures as proof and those will simply have flowchart style explanations of what is happening.

4.3.1 Android App

The testing of the app was the more extensive of the two as it has the most failure states. First the permissions request was verified, this was done by simply uninstalling and reinstalling the app and verifying that the app requested if it could have permission to send and receive text messages. The second conducted test was over the receiving of the temperature data and battery data. To do this, a device was connected to the app, in this case it was simply a cell phone, and from that device the text “itemp:78” was sent to the phone with the app. Then the app was checked to see if the inside temperature then displayed 78 degrees. These messages do not need to be checked if they are something other than a temperature as they will come from The Chilly Dog and therefor will not be anything other than what they are supposed to be. This test was repeated for the other two pieces of data that will be received from The Chilly Dog. The next test was the sending of a temperature to The Chilly Dog, to test this a temperature was entered into the box and then the send button was pressed. Then it was checked that the phone had sent a text to the connected device’s phone number that read “utemp:[temperature entered]”. This step also included some validation of making sure that the value the user entered was a valid number within the range 40 – 90. To test this, first a word was entered and then verified that the app responded by not sending the message and informing the user that it is an “Invalid Input”. Second a number out of range was sent and it was verified that the app responded by not sending the message and asking the user to confirm the entered temperature. Then the button was pressed again, and it was verified that it sent the out of range temperature because the user confirmed it.

The next set of tests conducted were on the notifications. To test these the 25% battery notification was toggled on, and the phone was sent the message “bat:25” which tells the app that the battery is at 25%. Then it was verified that this triggered the app to send a notification to the phone. This same test was conducted again however this time google chrome was opened to simulate the app being in the background, and the same result was verified, when send that the battery was at 25% the app would notify the phone. Both tests were conducted again although this time the 25% notification was toggled off and it was verified that both when in foreground and background when sent the 25% battery message the app did not notify the phone.

Finally, the device connection was tested this began with entering a phone number and verifying that the message “Connection Attempted” appeared and the attempted device received the “test” text message. Then from the device the temperature and battery information were sent to the phone, and it was verified that as soon as the first message was received the connection status was updated. Then the remove a device functionality was tested by pressing the remove button and verifying that the connection status was updated, and that the device information was removed. The text box then needed to be tested as it needs to only accept 10-digit numbers, this box was tested with words, improper length numbers, and floats and it was verified that each time the app returned “Invalid Input”. Finally, the app was connected to a device and another device was attempted to be connected to and it was verified that the app responded by informing the user that there already was a device connected and to confirm that they wanted to connect a new device by pressing the button again. Upon the press of the button again it was verified that the device attempted to establish a new connection with the new device.

4.3.2 Modem

The testing of the modem had fewer components than the phone app as all that needed to be verified was the power consumption, and the send and receive SMS capability. To test the power requirement both micro-USB ports on the modem were utilized, those being the micro-USB power port and the micro-USB to UART port. The UART port was connected to the computer and interfaced with using PuTTY, while the power port was connected to a 5V 1A brick and then to the wall socket. The rest of the tests were then conducted using this setup to verify that the power requirements were met, and the modem was functioning properly using the desired power setup. The next test that was conducted was verifying the send text functionality. To do this the commands in order that were send were “at (enter) at+cmfg=1 (enter) at+cmgs=”+17372106468” (enter) test (Ctrl + Z)”. These commands, set up the initial handshake, configure the SMS mode to text, start a send text prompt to the entered phone number, and then send “test” the Ctrl + Z being the key combo to send the text. This phone number was used because it is Martin’s who was the person conducting the test. Then it was verified that these texts were received by the target phone. Finally, from the phone the message “Test” was sent back to the modem and using the command “at+cmgr=0” which reads the text in index 0 it was verified that the message “Test” was received from the correct phone number.

4.4 Application and Modem System Summary

The phone app and modem function as intended and are ready to be integrated into the main system next semester. Remaining tasks are beautifying the app, adding more detailed notifications, adding multiple device functionality, and integrating the modem with the microcontroller. Overall, however the app is safe from misinputs and displays the information properly to the user in a form that is easy to read. The modem is configured to send and receive text messages and is ready to connect to the microcontroller that code simply must be written.

5. Appendix - A

Phone App and Modem Validation Images

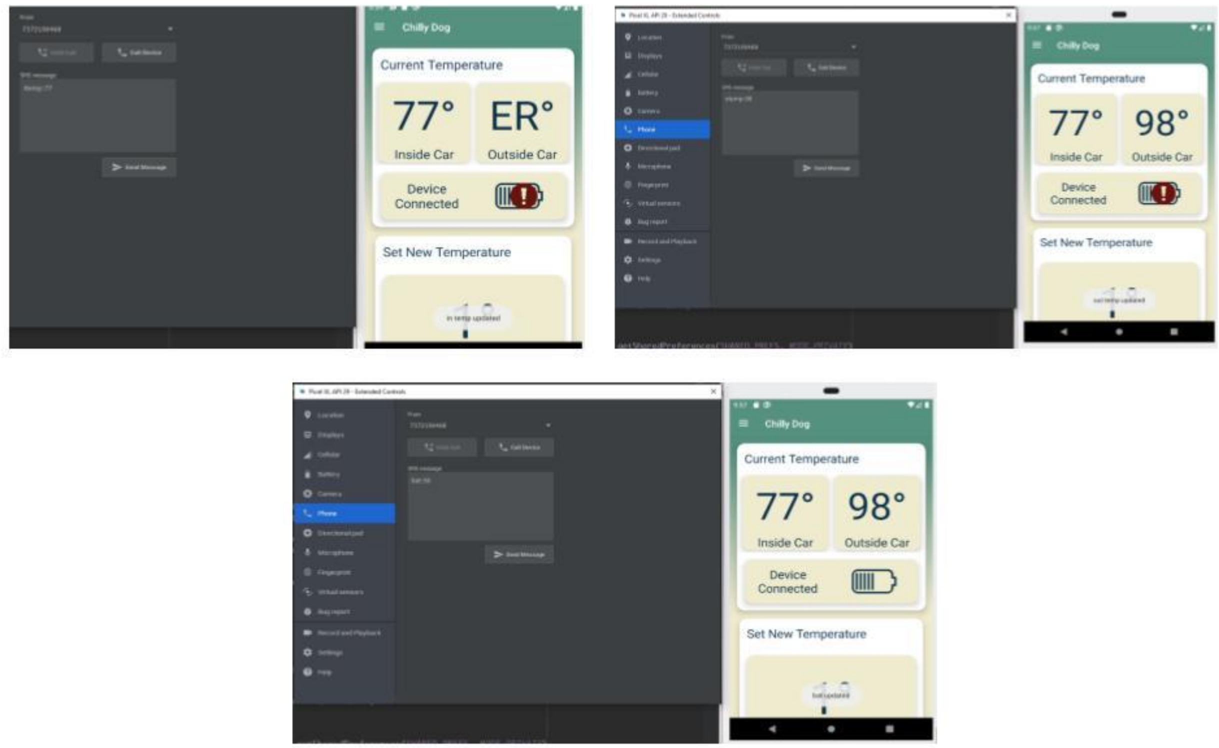

Figure A.1 connected to virtual device in android studio and sending texts from it to update in temp, out temp, and battery life (top left, top right, bottom respectively)

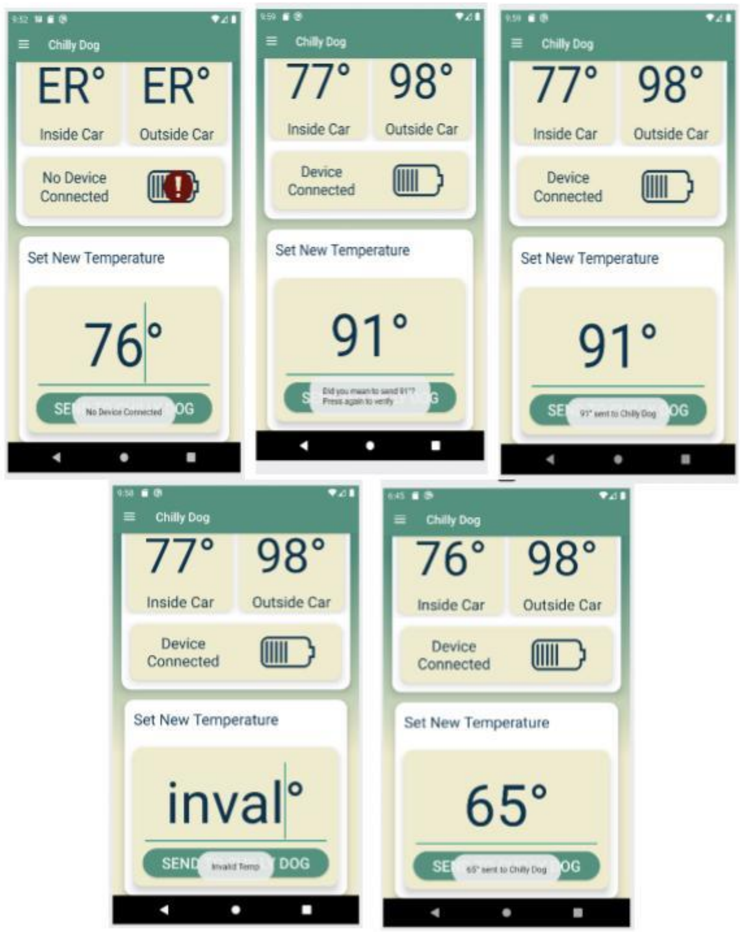

Figure A.2 These are the tests for sending a temperature, with no device connected (top right), non-number value (bottom left), temp out of range (two top right), correct entry (bottom right)

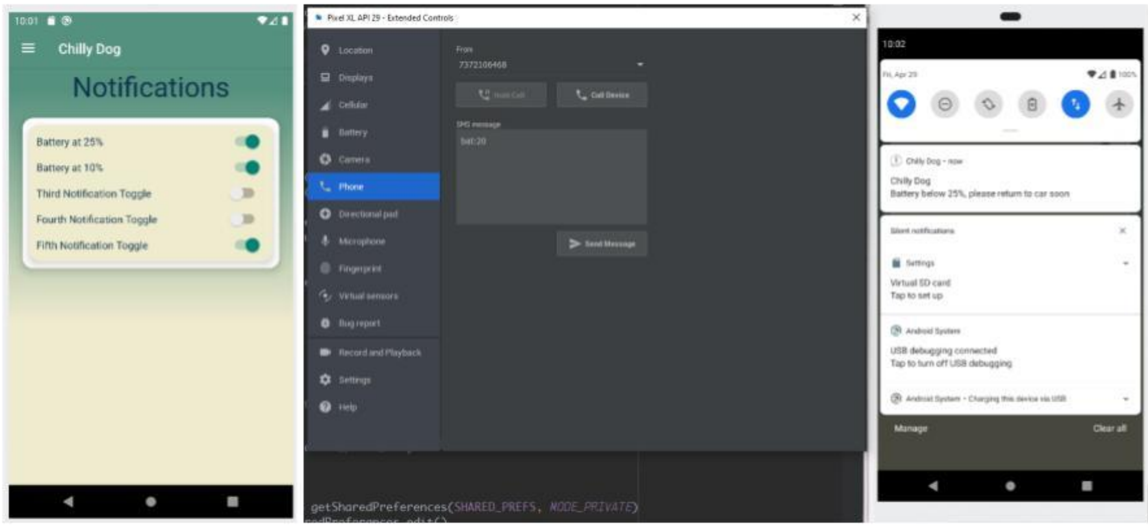

Figure A.3 This is showing that the notification will work when toggled on and sent the correct message.

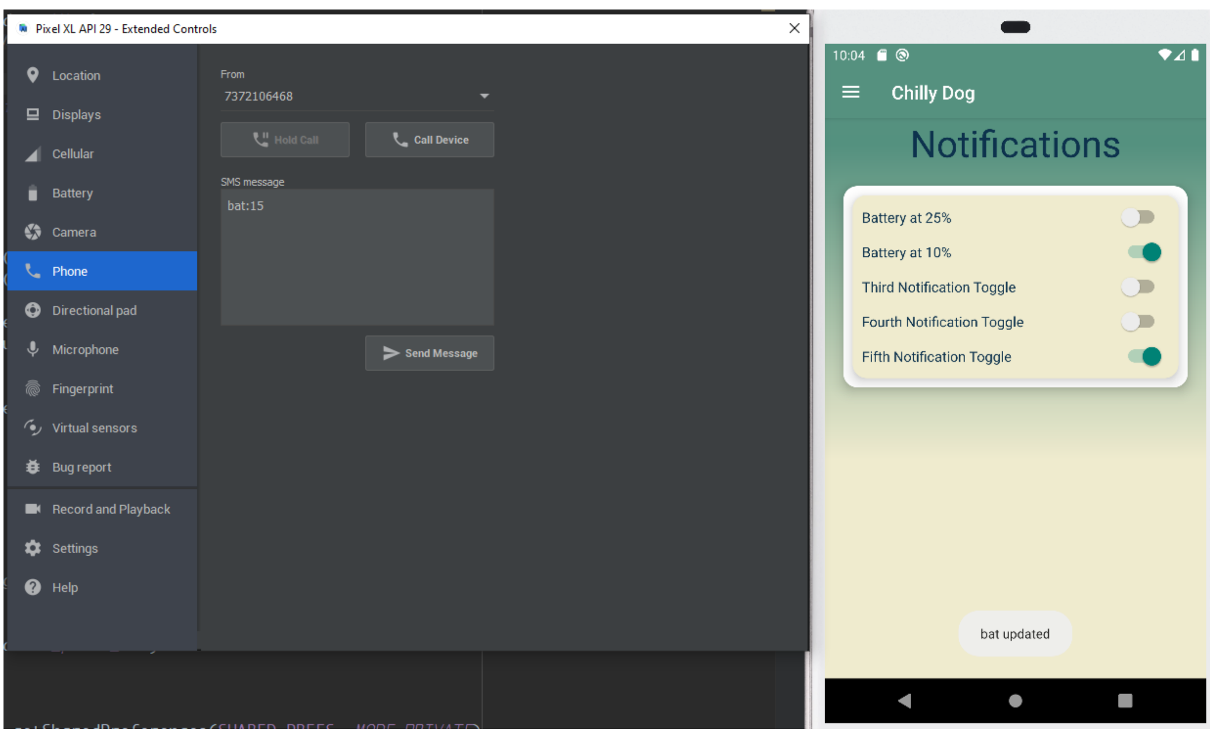

Figure A.4 This is showing the battery being updated correctly but no notification because it is toggled off

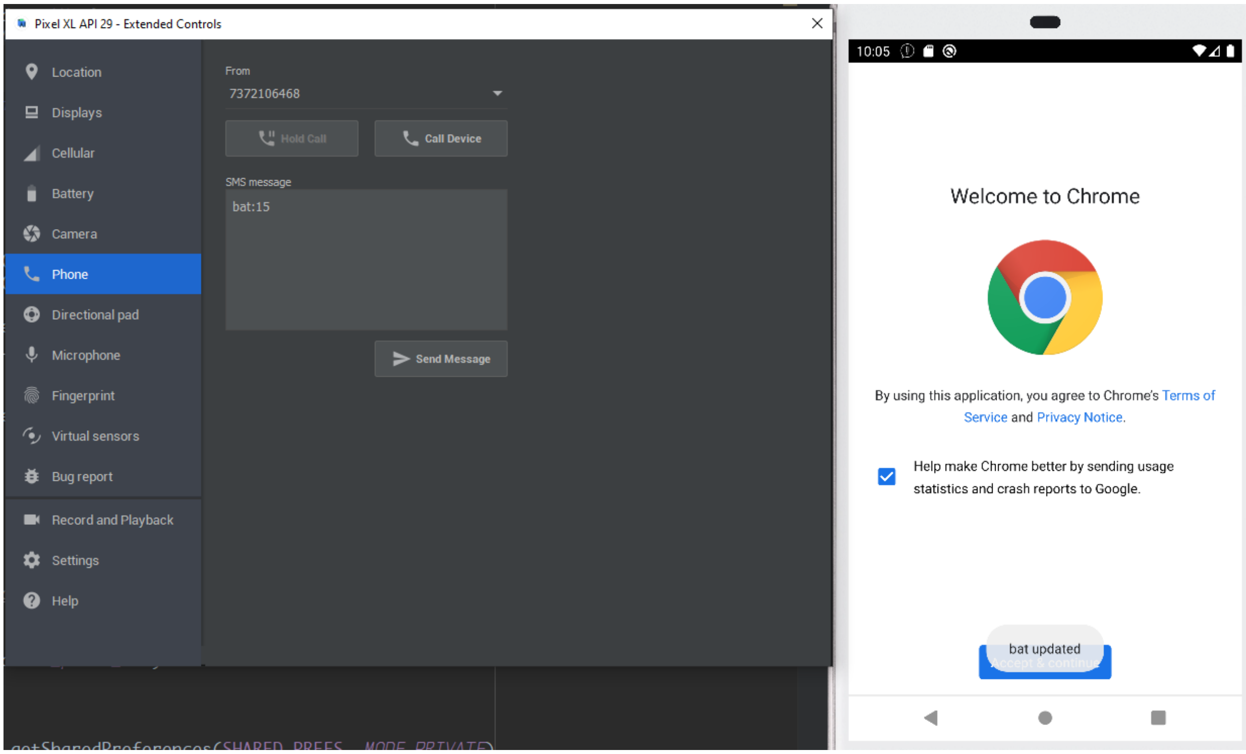

Figure A.5 Showing that the app is in the background and the battery updated and the notification has popped up (the speech bubble with an exclamation point in the top)

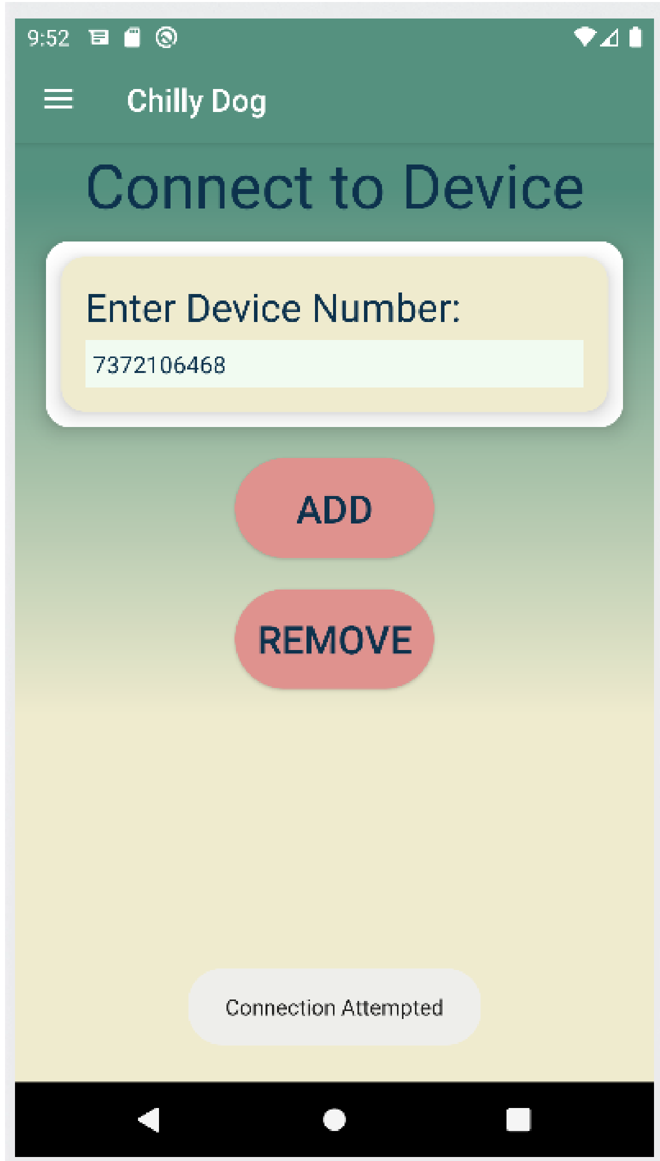

Figure A.6 Showing that when a correct number is entered the device attempts a connection

Figure A.7 showing the add a device does not accept incorrect types and will only accept a 10-digit value

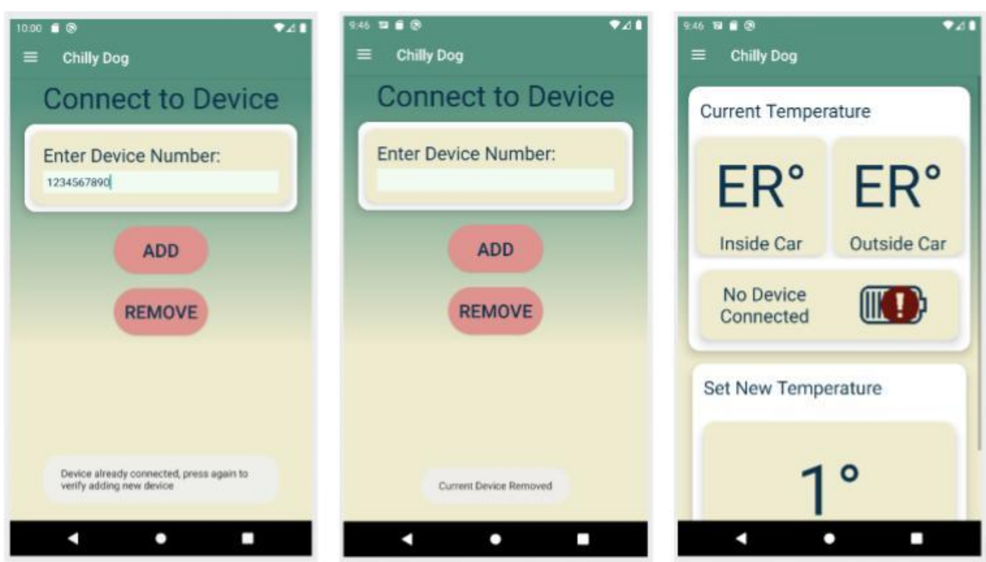

Figure A.8 adding a new device while a device is already connected (left) and removing the device showing that it also wipes the device info (right)

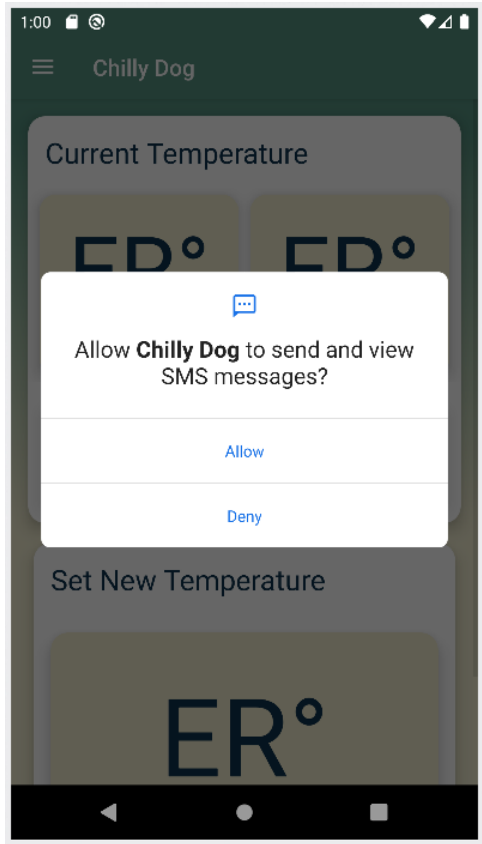

Figure A.9 Initial startup asking for permissions

```
at+cmgr=0
at+cmgr=0
+CMGR: "REC READ","+17372106468","","22/04/12,21:33:59-20"
Test

OK
```

Figure A.10 Receiving a text on PuTTY

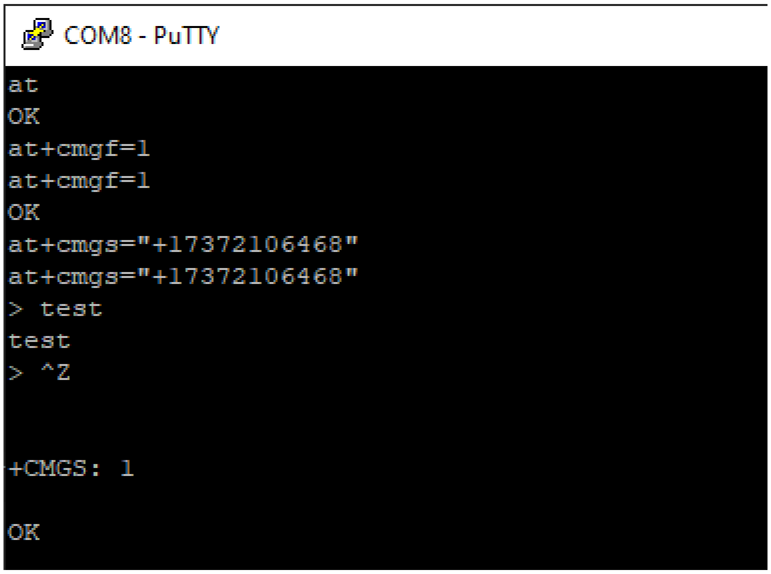

Figure A.11 sending a text message via PuTTY on the modem

Battery Powered Car Air Conditioning

“The Chilly Dog”

Grant Franklin

Martin Rennaker

Yarentzy Magallanes

EXECUTION

	1/24/2022	1/31/2022	2/7/2022	2/14/2022	2/21/2022	2/28/2022	3/7/2022	3/14/2022	3/21/2022	3/28/2022	4/4/2022	4/11/2022	4/18/2022	4/25/2022	5/2/2022	Owner	Date Completed
Assigned Project and Team																All	1/24/2022
Sponsor Introduction																All	1/25/2022
Brain Storm Stage										Not started						All	1/31/2022
Distribution of Subsections										In Progress						All	1/28/2022
Concept of Operations										Completed						All	2/19/2022
Research										Behind Schedule						All	2/21/2022
Research and Choose AC Unit																All	2/21/2022
Research Microcontroller Requirements																Yarentzy	2/21/2022
Choose Microcontroller																Yarentzy	2/21/2022
Download and begin testing with Android Studio																Martin	2/21/2022
Submit Preliminary Parts Request																All	2/22/2022
App layout and acquire cellular modem, sim, and antenna																Martin	2/22/2022
Functional System Requirements																All	2/23/2022
Interface Control Document																All	2/23/2022
Midterm Presentation																All	2/23/2022
Download MPLAB Software and Obtain Access to Debugger																Yarentzy	2/21/2022
Familiarize myslef with MCC																Yarentzy	2/28/2022
Configure System																Yarentzy	3/7/2022
Configure I/O pins																Yarentzy	3/14/2022
Create a Blinking LED																Yarentzy	3/21/2022
Configure UART Serial Communication																Yarentzy	3/28/2022
UART Serial Communication and PC Communication																Yarentzy	4/10/2022
Design PCB and schematic for circuit																Grant	4/18/2022
Order components and parts for power supply																Grant	4/8/2022
Develop app to modem communication system																Martin	3/20/2022
Configure MCU and ambient temperatrue sensor																Yarentzy	4/11/2022
Make connection between app and modem																Martin	3/30/2022
Test VAC side of power supply circuit																Grant	3/22/2022
Solder and test MCU/control components																Grant	
Validate the modem is able to send and receive the correct data																Martin	4/4/2022
Implement Relay to control a large current load																Yarentzy	4/18/2022
Establish AC Inputs																Yarentzy	4/11/2022
Progress Update Presentations																All	3/14/2022
Validate and test full power supply circuit																Grant	4/20/2022
Implement GUI over the app																Martin	4/12/2022
Validate the whole cellular subsystem is working together																Martin	4/11/2022
Accept Input from PC																Yarentzy	4/11/2022
Final Presentation																All	4/13/2022
Subsystem Presentations																All	4/24/2022
Final Report																All	4/30/2022

Battery Powered Car Air Conditioning
“The Chilly Dog”

Grant Franklin
Martin Rennaker
Yarentzy Magallanes

VALIDATION

Item Testing	Success Criteria	Methodology	Status	Responsible Engineer(s)
Battery Output	The battery will output a DC voltage of +12V for a specified run time on the specified loads.	Set up the battery with the inverter and VAC since it is the largest load and test operation.	Tested	Grant Franklin
MCU Input	The +12V DC from the battery will be stepped down to 3.3V for the temperature controlling MCU system.	Create an input voltage and current that mimics the battery and use a multimeter to assure that the output of the Buck converter is 3.3V.	Tested	Grant Franklin
Modem Input	The +12V DC from the battery will be stepped down to 5V for the modem.	Create an input voltage and current that mimics the battery and use a multimeter to assure that the output of the Buck converter is 5V.	Tested	Grant Franklin
Inverter Output	The inverter correctly changes the +12V DC from the battery to 110V AC that will route to the VAC.	Create an input voltage and current that mimics the battery and use a multimeter to assure that the output of the inverter is an AC 110-115V.	Tested	Grant Franklin
Solar Panel Charging	The mounted solar panel will provide sufficient charging for the battery at ~14V.	Use a multimeter to check that power coming from the solar panel and solar charge controller is a DC 14V.	Tested	Grant Franklin
12V Outlet Charging	The +12V DC from the car outlet will provide sufficient charging for the battery at ~14V.	Use a multimeter to check that power coming from the 12V car outlet is a DC 14V when the car is on.	Untested - 404	Grant Franklin
Input Power Switching	The control circuit will be able to correctly choose which power source to use.	When the solar panel relay receives a control signal, the connected relay should be outputting 14W to charge the battery. Repeat for the car outlet.	Untested - 404	Grant Franklin
Solar Panel Circuit Functionality	The circuit will correctly step down the voltage to a value within the specifications of the MCU. If this value is >=13.9V, the output is 3V to the MCU. Otherwise output 0V.	Set up the circuit with inputs higher, lower and at the threshold voltage and record output values with a multimeter.	Untested - 404	Grant Franklin
App Receiving	App can recieve temp data and battery data via cellular data	Change the displayed in and out temps in the app with a text message	Tested	Martin Rennaker
modem Transmitting	Can send texts from the modem via at commands	use Putty to send at commands to the modem to send a text and verify that it send	Tested	Martin Rennaker
App sending	App can send a desired temp based on user input	enter a temp into the app, press a send button and check that the message was recieved by the target device	Tested	Martin Rennaker
modem Receiving	can recieve and read texts on the modem	send a text to the modem and using putty and at commands read the text	Tested	Martin Rennaker
Notification	The app can send notifications to the phone, the user can toggle on or off different notifications and the app will react and not send or send a notification based on the toggled state	toggle on a battery life notification, send the app a corresponding battery update, check if notification was received. toggle off battery life notification, repeat and verify the notification was not recieved.	Tested	Martin Rennaker
Modem Power	The modem's power consumption will not exceed the 5V at 1 A	modem will be powered using a usb 1A wall plug, so as long as it is operating correctly with this power it is under the power requirement	Tested	Martin Rennaker
correct entry verification	app will only accept temperatures in the send to device box and phone numbers in the add a device box	if an invalid entry is entered into the box the app will not crash it will simply notify the user of the incorrect entry	Tested	Martin Rennaker
out of range temp detection	will double check with the user if the entered desired temp is less than 40 deg F or higher than 90 deg F	if the user enters a temp out of range ask the user to press the button again to verify	Tested	Martin Rennaker
change device verification	if the user tries to add another device while one is connected it will verify with the user	if a device is connected and the user tries to add another device ask the user to press the button again	Tested	Martin Rennaker
device removal	if a device is removed the app should remove all current data and display that a device is not connected	connect a device and send all the information then disconnect the device and verify that the info was removed from the app	Tested	Martin Rennaker
device connection	when adding a device app will attempt to make a handshake with a test message and once a response is recieved will update the connection status on the home page	attepmt to add phone as device and wait for the test text message, then send info to update app and verify that the status is updated and the connection status is updated	Tested	Martin Rennaker
Backgroud data parsing and notifications	The app will update the information while in the background and send notifications based on that data and the noification toggle status	open another app while the app is in the background, and send the phone text updates and verify that the app will still send notifications based off the data sent and the status of the toggle	Tested	Martin Rennaker
Startup Permissions	The app will ask the user permission to send and receive text messages on initial startup	Will uninstall and reinstall the app and verify that it has a SMS permission popup	Tested	Martin Rennaker
VAC Cooling Specifications	The VAC's minimum temperature output is 62 degrees fahrenheit	VAC unit will be placed in a crossover vehicle and data of the maximum cooling capacity capabillity will be collected	Tested	Yarentzy Magallanes
Temperature Sensor	Both temperature sensors report the same measurement	Redundancy will assure accuracy. Two temperature probes will be taking ambient readings. A comparison of these inputs will assure functionality.	Tested	Yarentzy Magallanes
MCU UART Data Receiving	The MCU can receive a setpoint and react to given setpoint	This will test the functionallities of the UART communication between the MCU and a PC. The MCU will recive input from the PC and toggle an LED accordingly	Tested	Yarentzy Magallanes
MCU Data Transmitting	The MCU shall output temperature readings to be received by the application	Temperature will be read using the probes and interpreted into digital signals to them be outputted to the console.	Tested	Yarentzy Magallanes
Measurement Periods	The MCU shall receive and output the temperature to the application every 2 seconds	The temperature sensor data wil be redirected to an output pin which will then be measured by an oscilliscope to determine the frequency of full data transmission	Tested	Yarentzy Magallanes