Smart Cooler

Group 23

Senior Design 2 Final Paper

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I Executive Summary

There is much to be said about the power of convenience propagating throughout the world right now, as its hold on everyday pedestrians grows stronger and keeps us wanting more. From working remotely for jobs, to getting groceries delivered to your home in a matter of clicks, there is a high degree of satisfaction that comes with being able to do so much with so little effort. This project stems from that idea and uses it as motivation for satiating that need. Sometimes situations warrant having such convenience because it can prevent mishaps and human error in day-to-day activities. A big part of college-life is tailgating for sporting events like football or basketball, where you bring food and drinks to socialize with friends before the actual event. An event like this can take place for hours on end, therefore people bring many different commodities to keep busy, ranging from hotdogs to cook on the grill to water bottles to stay hydrated. This requires bringing many different appliances, which can be heavy and quite cumbersome to drag back and forth. The world needs an item to help lighten the load for all parties involved because we deserve that quality of life and convenience.

Our project aimed to create a smart cooler that would have many different functionalities to help combat such hindrances. One of the main features is to introduce a partial lid that is made out of smart glass. Smart glass is a type of glass material that changes its light transmission properties once light, heat, or voltage is introduced to it. It would be powered by a battery that is charged through a solar panel attached to the other lid of the cooler. The smart glass is our solution to a few problems with a cooler: cold loss mitigation and privacy. A portable cooler is usually made cold through ice or ice packs, but everytime someone wants to check what is inside of the cooler, they have to open it and the cooler begins to release the cold air it has trapped inside. This begins to melt the ice, and the problem further develops as the day progresses. This feature would allow you to see the cooler’s contents without opening it to help mitigate some temperature loss by not having it open while deciding what you want to grab. Rather than normal glass, the smart glass can turn clear to opaque through the aforementioned processes and give privacy to the cooler’s contents when needed. This would be handled through a switch to apply voltage when flipped on.

Another component for our cooler’s functionality would be introducing usb ports for the many devices people have with them. Its main purpose would be for charging since dead devices seem to be a common occurrence for outdoor activities. This not only helps with convenience, but safety concerns when left with a powerless device. We attempted to introduce more miscellaneous components, but the project mainly focused on implementing these for the consumer.

The end goal for this project is to provide a stable, efficient, and low cost cooler that can help supplement people’s many life activities. We brought in different functionalities to make one that is refreshing to have and pleasant for the average consumer. From here, there are endless other ideas we can employ, but we have only scratched the surface.

II Project Description

The chapter goes over the main ideas of the project such as discussing the features of the project, possible implementations, basic block diagrams, etc. The goal of this section is to propose our idea of a potential project that would improve the quality of life for coolers. This technology is implemented for mainly recreational usage but potential features in the future can expand the targeted audience.

II.i Features

Basic:

- PDLC Smart Glass
- PV Panel
- LED Lights
- Temperature Sensor

Advanced:

- USB Ports
- Rechargeable battery
- Graphical Interface
- Adjustable transparency

Stretch Goals:

- Camera
- Bluetooth Speakers
- Mobile application

II.ii Possible Project Constraints

- New design of the cooler lid must be able to fit properly back onto the cooler to insure the cooler is still effective

- Electrical components contained within the cooler should not be disturbed by other items put inside the cooler (i.e. food, drinks, ice, etc.)

- Electrical components contained within the cooler should take up as little space as possible

- Electrical components, when power, should not change the temperature of the cooler by a large amount

- Components exposed on the outside of the cooler should be okay when exposed to different weather conditions
- Custom PCB should be able to connect to microcontroller and control light adjustment for the glass

Component(s)	**Parameter**	**Specification**
Battery	Discharge Time	4 Hours
PDLC Film	Power Consumption	≤ 10 Watts
PDLC Film	Time to Activate	≤ 5 Seconds
PDLC Film	Transparency	≥ 80%
PDLC Film	Opaqueness	10 - 90 %
Sensor	Accuracy	≥ 95%
Cooler	Weight w/o Food/Drinks	≤ 30 Pounds
PV Panel	Power Output	≥ 10 Watts

Table 1: Requirement Specifications (Blue Highlight has been Tested for Final Demonstration)

II.iii House of Quality Diagram

This section contains our House of Quality (Figure 1) which is used to show how customer requirements relate directly to engineering requirements. This tool is helpful in showing us the advantages and disadvantages of adding specific functionality in a marketing and an engineering perspective.

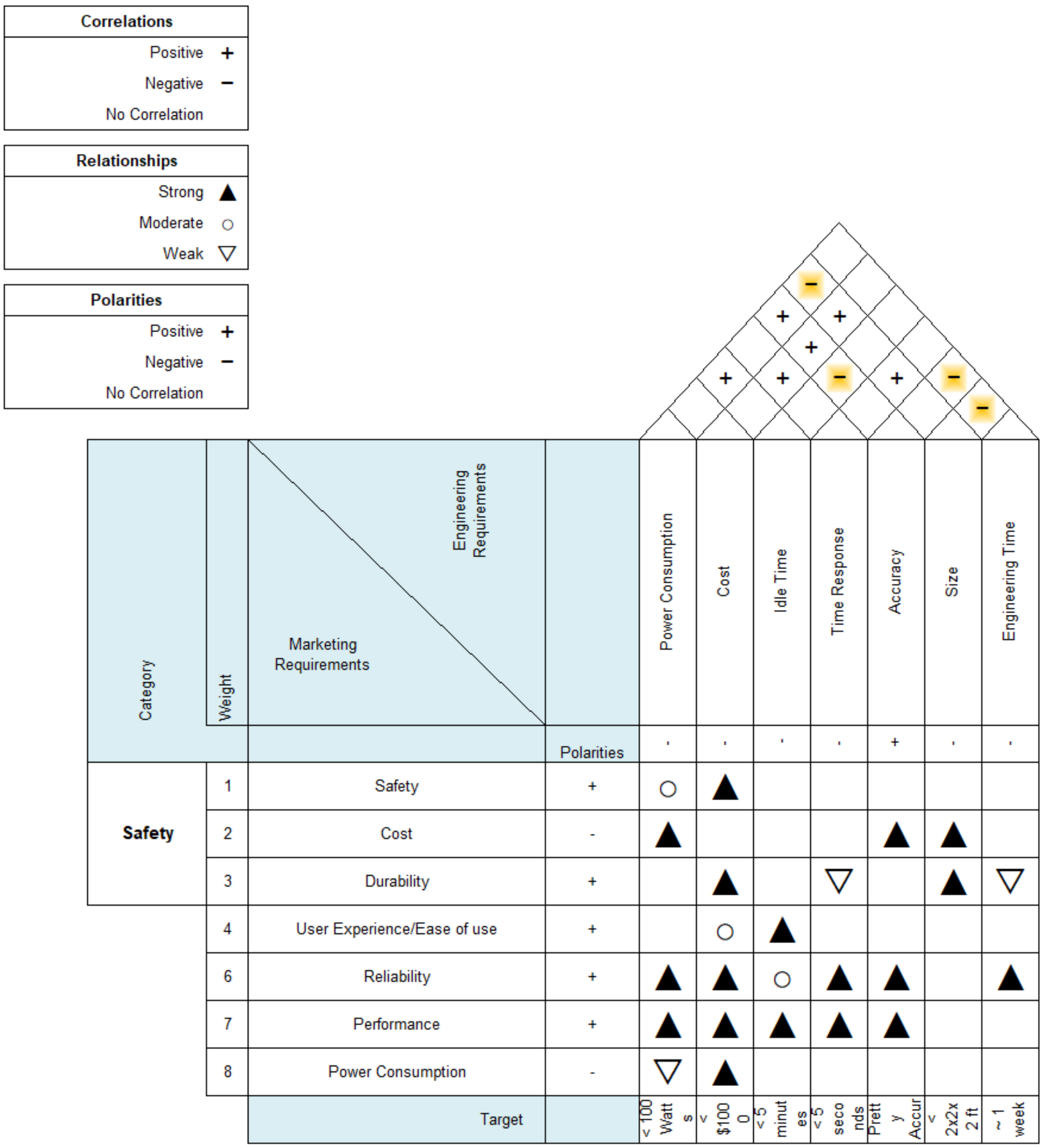

Figure 1: House of Quality

II.iv Block Diagram

This section goes over a general block diagram that outlines which group member was generally responsible for. This diagram does not completely depict everything that each group member worked on. Each member worked in different sections when they would like to or if another group member needed assistance in a section.

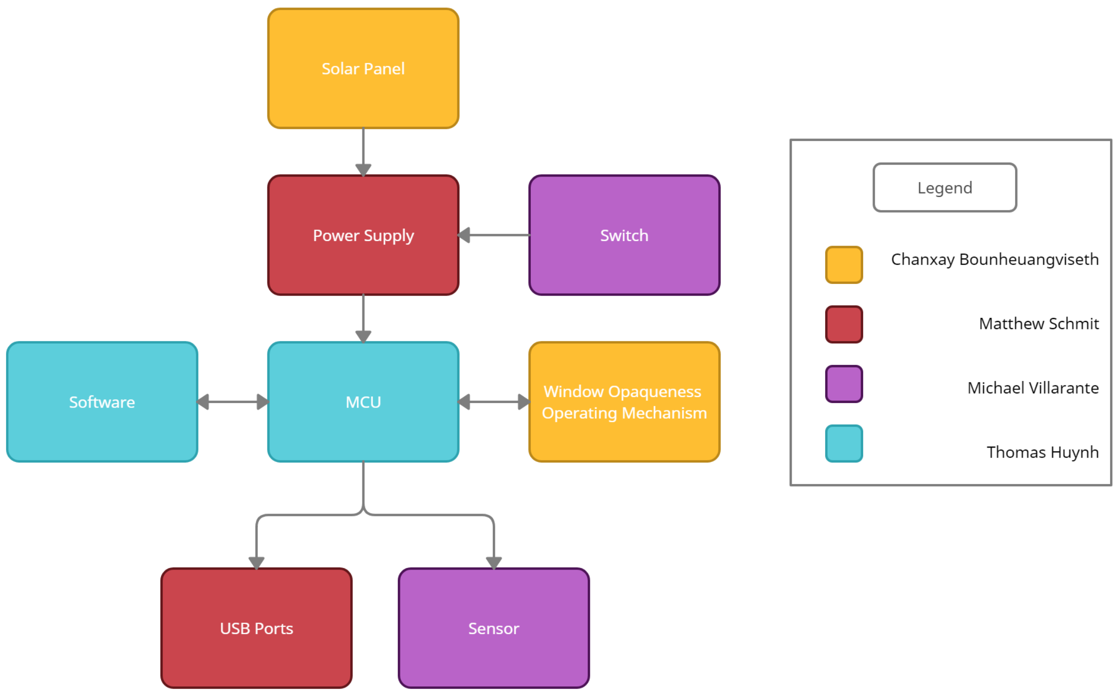

Figure 2: Block Diagram

III Research

This section explains the different technologies being used within the project and further breakdown each individual component into the different types available. It also highlights key advantages and disadvantages to using either one as a result of tradeoffs in attributes such as material or size. Taking a look at products that already exist and produce similar traits seems fitting to get a better understanding of the expectations from this project.

III.i Related Technology

Here we can take a look at similar products that have been done throughout the years which helped to see how our project developed. Not everything is exactly the same but they show some similarities in the products that were used. Taking a look to see parts that can be improved on as well as adding new things for our project to make it different compared to other similar products. And with the research of the different parts and previous projects we worked to develop a product that has the best possible solution for the product of this project.

III.i.i Smart Cooler

With the smart cooler, this helps to show how a normal cooler can be improved into something better. It adds features of showing temperature, lights, and being able to charge. This is something that can help improve the basic functions of a normal cooler for the user to be more productive and efficient than before. With the use of sensors, switches, and solar panels, this makes it possible for the features to have the best solution for the user's cooler needs in different situations.

Figure 3: Smart Cooler Project Design

III.i.ii Smart Windows

When looking at other projects that work with smart windows, they usually don't have sensors or displays on them. The displays that are used on them are transparent which gives better accessibility as well as a good price for the user. But with that, it doesn’t mean that there are displays that are not transparent. Depending on the display is based on what the user would like for their use. The smart glass itself is made up of a PDLC film, which is a mixture that has liquid crystals in it. From there, these types of smart glasses can have features like blocking UV light and IR from the user which can be harmful.

Figure 4: Smart Windows Project Design

III.ii Smart Film/Glass

Smart film, smart glass, switchable film, privacy glass, all of these names and more describe the unique characteristic of this technology that allows users to control the amount of light that passes through a visible window or any other see-through material. They can be distinguished into two main categories which are passive and active. The passive technologies include thermochromic and photochromic. The distinguishing features of those that fall in the passive category include the use of natural, non-electrical stimuli to activate the light transparency feature of smart glass. This includes such stimuli like heat or light. As the names might suggest, thermochromic makes use of the heat generated from direct sunlight and darkens as the intensity increases, which lends its usefulness to an outdoor setting. Photochromic on the other hand does change its transparency in response to the intensity of light on the glass or film. Active glass is the opposite, and that it is stimulated through the use of electricity to activate its mechanisms. Active glass or film seemed to be more suitable to our project goals, so understanding each one lent itself to the appropriate choice as we have shown.

III.ii.i SPD Glass

SPD or Suspended Particle Devices are small microscopic particles that have the properties of light absorption that respond to an AC power source. These suspended particles are aligned once the voltage is applied and it allows light to travel through the material. It can change from clear to dark, as the power source is turned on.

III.ii.ii EC Glass

EC or Electrochromic is able to switch colors through the use of an external DC voltage or current and applying it to the system. This type of glass switches from clear to dark, and even at its darkest visible light can still be transmitted through, a little less than three percent.

III.ii.iii PDLC Film

PDLC is an abbreviation for Polymer Dispersed Liquid Crystals, where the film is a plastic polymer full of these micron-sized holes that are filled with liquid crystal microdrops. Since these microdrops are dispersed throughout the film in random orientations and thus scatter light in different directions, the film appears opaque normally. The crystals are sandwiched between two conductive layers so when we run an AC current through the film, all of the crystals will align their orientations in the same direction, allowing light to pass through in one direction and the film will appear transparent.

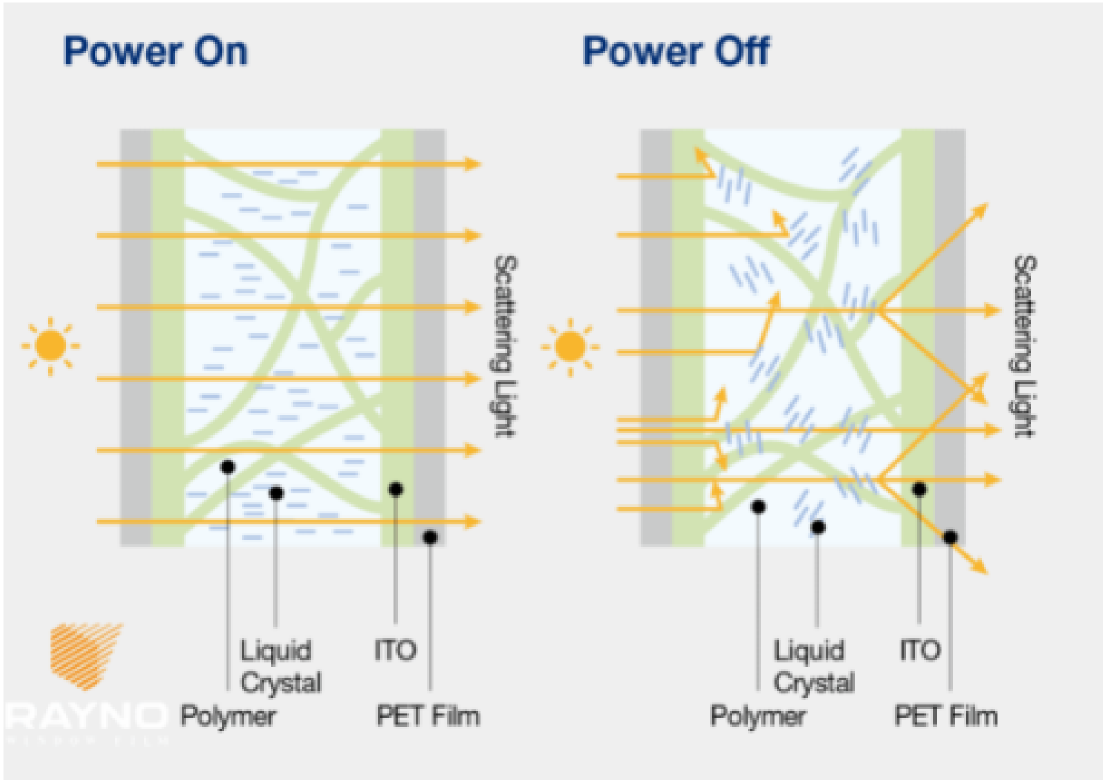

Figure 5: Picture of PDLC Film technology from Rayno Window Film

III.ii.iv Suitability and Purpose

As per the project description, one of our smart cooler's attractions would be the privacy we want it to have when we design it. Looking over the three different types of active smart films and glass, it appears that the polymer dispersed liquid crystal (PDLC) provides the largest amount of privacy over the other two. This lends itself to the fact that some visible light is still able to pass through the electrochromic and the suspended particle devices, so the privacy it offers is weak to moderate. The PDLC film in its opaque state cannot be seen through and offers the best privacy. The other two may serve better purposes for other projects, maybe one involving the tinting of windows or creating shade.

Now looking over the costs between the three, PDLC tends to be the most expensive option. This may be negated though due to the size of the film we would need. Carving out a sizable see-through window into one of the cooler's lids allows us to not spend too much on it, even with it being pricier of the three. SPD is a little cheaper and electrochromic is the cheapest, but once again their functionalities do not meet our purpose and goals.

Smart Glass	Type	State Change	State Trigger
Thermochromic	Passive	Clear to Dark	Heat/solar infrared
Photochromic	Passive	Clear to Dark	Light
SPD	Active	Clear to Dark	Electricity
EC	Active	Clear to Dark	Electricity
PDLC	Active	Opaque to Clear	Electricity

Table 2: Smart Glass Attributes

III.ii.v Companies Using Smart Film/Glass

There have been many different producers in the marketplace that have already made use of smart glass and its unique properties. Taking a closer look at some of their products and its uses did evidently help shape its placement in our project. Inspiration from a fellow project or product that also makes use of this smart technology with a container would be most beneficial if we were to find one.

III.ii.v.i Cheoy Lee Shipyards

Cheoy Lee is a producer of many different aquatic vehicles from ferries to yachts. They are a company that values performance, innovation, reliability, quality, and service at their core. Due to this, they have chosen to work with smart glass technology in tandem with their ship models. During 2011, they revealed the Alpha Express 76 that debuted during the Fort Lauderdale International Boat Show. The yacht is fitted with SPD smart light-control on the windows and other areas of the ship. This implementation is quite fitting since the reflective qualities of the water and being exposed to light for most of the day warrant such practices. It helps all people on board to reduce exposure to the harsh rays and helps give some shade to passengers.

Figure 6: Cheoy Lee Alpha 76 Express Yacht equipped with SPD technology

III.ii.v.ii Rayno Window Film

Rayno Window Film is a company that takes pride in its products through window technology innovation. Besides some of the many other technologies they offer like automotive window tinting, they deal with smart film and more specifically PDLC technology. They seem to sell specific lengths of PDLC film in rolls to the general consumer as their own specific brand, which glorifies some of their unique characteristics such as color film and low voltage drive. Their uses for the smart film is more open-ended since they deal with the selling of the film, but highlight some uses such as on the windows of a private plane, or on the windows of an office meeting room.

III.ii.v.iii Fisker

Fisker is another company that has innovation on the forefront of their mission. Henry Fisker is quite imaginative as a widely-acclaimed car designer, which fuels the connection between such technologies. Back in 2018, Fisker debuted their model car Fisker E-Motion that boasts a four-segment SPD smart glass roof. This is a fitting use for smart glass, specifically suspended particle devices as we know that SPD glass can change from dark to clear. In this case, you have the option of switching between sunlight contrasts and visibility within the automobile.

III.ii.v.iv Mercedes-Benz

Prior to some electric cars that have popped up more recently like the Fisker E-Motion that make use of SPD, Mercedes-Benz has one of the earliest dates of implementing such an idea. They adopted this new technology around 2011 with their Mercedes-Benz SLK, and further improved upon it in the coming years. In 2014, they introduced their new S-Class Coupe which featured their magic sky control roof. This name was essentially the company making use of SPD smart glass, at an early adoption where not many other people were using it.

III.ii.v.v CERN

CERN or Conseil Européen pour la Recherche Nucléaire which translates to “European Council for Nuclear Research”, also makes use of smart glass technology. As one of the world’s largest and most renowned scientific research facilities, CERN delves into the latest and greatest technologies while trying to research humanity's future projects. One of CERN’s key landmarks is the Globe of Science and Innovation, an interactive exhibition which is used to present CERN’s work from their particle physics lab and from the world’s largest and most powerful particle accelerator, the Large Hadron Collider. The skylight located at the top of the globe was fitted with SPD smart glass in order to solve the problem of reflecting sunlight on the screen throughout the day.

Figure 7: The SPD Smart Glass skylight inside the Globe of Science and Innovation

III.ii.vi Rising Demand for Smart Glass

According to an article from Fortune Business Insights from 2020, the smart glass market is increasing in demand and expected to reach USD 15.02 billion by 2026. Its prevalence is starting to become more apparent as more and more commercial structures begin to see its benefits. As many companies have already seen, the benefits extend to many aspects of what consumers are looking for in this day and age.

From the previous highlighted examples, we know that smart glass excels with their implementation in windows. Airplane window seats have been seen as a luxury with their front-row view of the outside sky as one flies across the world. Sometimes the sunlight provides glare and direct heat to passengers through these windows, as most of them are not tinted and have a dropdown cover for when you want to block it. The inclusion of smart glass windows have been shown to reduce temperature in the cabin by roughly 18 degrees Fahrenheit, which would further bring down costs for air conditioning. Smart glass has grown quite popular with the aviation industry, such that Boeing’s 787 Dreamliner has also installed smart glass.

Economically and environmentally, the smart glass industry seems to be improving the world on both fronts. Windows that use smart glass are very adaptable to the surrounding environment, namely the temperature conditions. As heat levels change, so can the tint on the windows which results in better heat absorption capabilities and decreases the resulting inside temperature. Energy savings from smart windows are at a high, the electrical energy used to power approximately 100 smart glass windows would still be less than the energy needed for a 75-watt bulb.

III.ii.vii Overview of Real-Life Uses

Based on the findings from the example use-cases, it appears that a common theme for some of these companies is the use of smart glass, more specifically SPD smart glass as a means for lighting control. SPD smart glass is quite fitting for such ideas like the sunroof of an automobile that may benefit one’s quality of life while in a high-light exposure area like the outdoors. It also introduces the question of how much light you would want to allow into whatever system one is implementing it in, and based on that could give way to maybe other smart glass options. If someone wanted more privacy, we can see that something like the PDLC glass may be a much better fit, as SPD still allows light to travel through but with minimized visibility.

III.iii Cooler

As the vessel and frame for which all other parts are attached to, understanding what a cooler entails is crucial before deciding which is the perfect fit for this project. A cooler goes by many names: portable ice chest, ice box, cool box, etc. but it essentially is an insulated container that is used to keep food and drinks cold, sometimes even hot. Many are under the impression that every cooler performs the same task so they do not put too much thought behind their decision when buying one other than price and size, but there happens to be a variety of different coolers that can be categorized into multiple types. They can be broken down even further by properties such as material and purpose, but the main categories of coolers are passive, thermoelectric, absorption, and compressor. Looking at the differences between the types did help distinguish pros and cons of each, and whether our project would benefit through its implementation.

Figure 8: The Coleman 62-Quart Xtreme Hard Cooler - an example of a passive cooler

III.iii.i Passive Coolers

These are probably the most common and most recognizable type of coolers, as they are commonplace throughout the world for its simplicity and value. Passive coolers do not self-cool, or cool automatically through the use of other devices or machines. Many are kept cold purely on ice or ice packs and the insulation of the cooler to keep it cold throughout its use.

III.iii.ii Thermoelectric Coolers

Thermoelectric coolers can be used in places such as inside of a car or truck since they typically run on 12 or 24 volts. The coolers inside temperature is based off of the outside temperature, cooled to 20 degrees Celsius in relation to the external temperature. This means that the items should be colder prior to being placed inside of the cooler, especially in warmer climates such as tropical areas.

Figure 9: An example thermoelectric cooler - Koolatron P-27WH - 12V DC 1.0

III.iii.iii Absorption Coolers

Absorption coolers are less restricted when it comes to where they can be used. They can be powered by different energy sources from 12 volts, 24 volts, even 230 volts, or by using gas. Items' temperature when going into the cooler does not matter much as the cooler can cool itself without other sources. These coolers can come down to roughly 25 degrees in relation to the ambient temperature. Just make sure there is no blockage of airflow so that the cooler can circulate warm air out of it.

III.iii.iv Compressor Coolers

Much like the absorption coolers, compressor coolers are not influenced or affected by outside temperature. They self-cool at a constant temperature and their unique characteristic is that they can even freeze items as well. They typically are powered by the same voltage levels as absorption coolers, allowing them to be used in cars, trucks, or caravans.

III.iii.v Cooler Overview and Considerations

As stated previously, these are not all classifications of coolers. Coolers can be broken down even further by material, portability, size, etc. Our project did require one such cooler that can meet design requirements on a variety of fronts. Whether that be a cooler large enough to accommodate other components, or a cooler priced within our budget range, knowing how to differentiate the numerous cooler types did help in our decision and provide further insight into how far we can go with our project.

Cooler Types	Voltage Levels	Self-Cooling Capabilities	Price Range
Passive	0	None	$20 and up
Thermoelectric	12 or 24	20 degrees Celsius relative to outside temperature	$50 and up
Absorption	12, 24, 230	25 degrees Celsius relative to ambient temperature	~$200
Compressor	12, 24, 240	Can freeze	$269 and up

Table 3: Comparisons of the different cooler types

III.iv Solar Panel

Solar panels are a technology that is relatively new and not well-explained to the average consumer. Many are being offered a livelihood based off of solar energy from solar panels, but they do not exactly know what or how solar panels exactly perform this task. Our plan in this project is to implement solar panels in order to use solar energy for our rechargeable battery, making portability still relevant and the potential uses for our project that much more broad in locations it can be used. Most solar panels fall into one of four categories:

- Monocrystalline
- Polycrystalline
- Amorphous
- Passivated Emitter and Rear Cell

As we look further into the different types of solar panels, seeing the qualities and features that distinguish them helps better our understanding of the technology so that we can choose the best option for our project later on.

III.iv.i Monocrystalline

As the name might suggest, monocrystalline solar panels are created from a single pure silicon crystal that is cut into multiple wafers. Due to them being made from pure silicon, they are the longest-lasting and have the best space-efficiency among the solar panel types. They are also quite expensive due to the waste produced while creating a single monocrystalline cell.

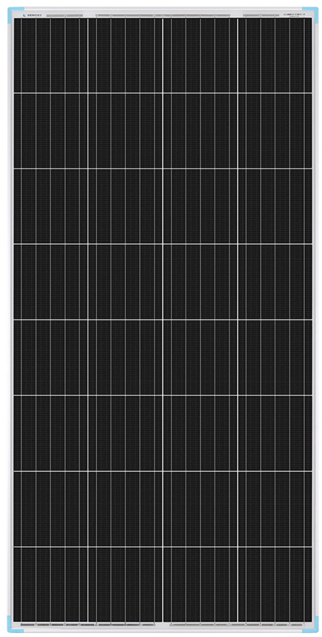

Figure 10: 175 Watt Monocrystalline Solar Panel from Renogy

III.iv.ii Polycrystalline

Polycrystalline is a bit different in its production, as it comes from many different silicon crystals rather than one. The crystals are melted and formed in a mold to produce the different panels. This method makes polycrystalline more affordable than monocrystalline due to less waste during production of silicon. However, this means its space efficiency and energy conversion is not as efficient due to the lesser purity of silicon. They also have a lower heat tolerance, so stay clear of heat-intense areas or prolonged exposure to it.

III.iv.iii Amorphous (Thin Film)

Unlike the other two, amorphous or thin film solar panels are made of a plethora of different materials. The most abundant amorphous-type solar panels tend to be made from cadmium telluride. To be produced, a layer of the cadmium telluride would be placed between some sunlight-capturing layers with a layer of glass for added protection. Another option is to use amorphous silicon which is similar to monocrystalline and polycrystalline, but is created with non-crystalline silicon between materials like glass, plastic, or metal. Otherwise someone may choose to use copper indium gallium selenide (CIGS) solar panels composed of these four elements between multiple conductive layers. Then, electrodes are placed on either side of the material to capture electric currents.

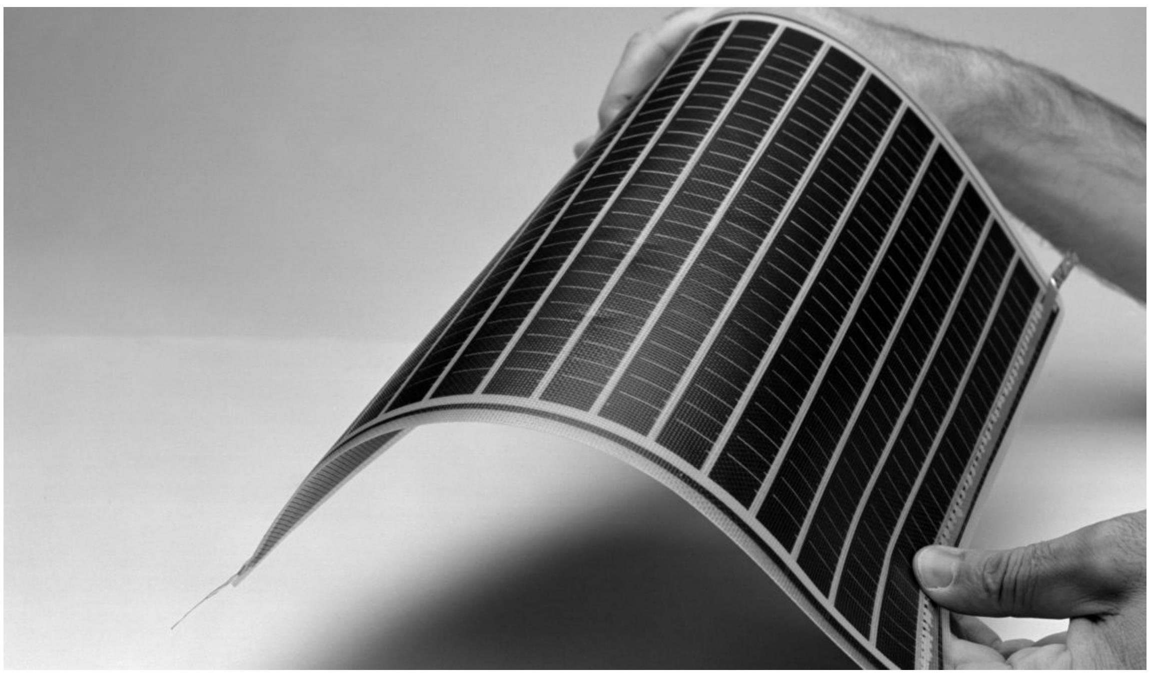

Figure 11: Example of Amorphous Silicon PV Panel

III.iv.iv Passivated Emitter and Rear Cell (PERC)

Not entirely a separate entity, but it is an improvement of the monocrystalline cell type. Its premise is based on enhancing efficiency through a newly added passivation layer at the surface of the cell. A problem with silicon tooling lies in the inability to absorb certain wavelengths of light, greater than a certain threshold which means it passes through the cells and heats up the back sheet of the panel. This makes it less efficient so the passivation layer will reflect the higher wavelength light to reduce the back sheet heating.

III.iv.v Overview of Solar Panels

Much like many other produced goods, you sometimes have to trade quality and efficiency for price and size, and solar panels are no different. The solar panel would need to be able to charge up a 12V rechargeable battery over x amount of hours to be considered for our project, so it is one of the many considerations we deal with while looking through our options. Taking a deeper look into the efficiency difference between the many types may sway us in one direction or the other. Efficiency in terms of cost, size, light absorption and conversion speed.

Solar Panel Type	Cell Composition	Efficiency	Average Cost per Watt
Monocrystalline	Single Silicon Crystal	20% and up	$1-$1.50
Polycrystalline	Multiple Silicon Crystals	15-17%	$0.70-$1
Amorphous	Variety - Cadmium Telluride (CdTe), Non-Crystalline Silicon (a-Si), Copper Indium Gallium Selenide (CIGS)	CIGS: 13-15% CdTe: 9-11% a-Si: 6-8%	CIGS: $0.60-$0.70 CdTe: $0.50-$0.60 a-Si: $0.43-$0.50
PERC	Single Silicon Crystal + Passivation Layer	25% and up	$0.32-$0.65

Table 4: Solar Panel Overall Comparisons

III.v Microcontroller Unit (MCU)

To choose the satisfactory microcontroller, there are multiple features and specifications to consider. One feature would be to consider the number of inputs and outputs. In this project, there are currently not a large number of inputs and outputs required. However, the project should also consider possible expansions and other features that would be added in the future. Having an excess number of inputs and outputs would be ideal in order to not run into issues later on in the future.

One of the main features to cover is the amount of memory the microcontroller unit, specifically, the flash and random-access memory (RAM). Running out of program space or variable space would not be ideal. Like with the number of inputs and outputs, it would be more ideal to have an excess amount of memory rather than running out when trying to work out the code. Of course, cost and power constraints need to be considered as well.

Even if there is a microcontroller with a large amount of memory and inputs and outputs, costs and power consumption are an issue. The microcontroller needs to fit within the budget and the amount of power consumed should not exceed the project specifications. It should also be noted that part availability needs to be accounted for. During this time, the pandemic has affected the production of multiple parts and it has become harder to find parts fit the project and would ship in time for testing. Consider the features mentioned above and then some, the 3 microcontrollers in consideration are the ATmega4809, MSP430, and ESP32.

III.v.i ATmega4809

The ATmega4809 has features that include 3 sleep modes: idle, standby, and powerdown. The modes are useful for lessening power consumption overall when the product is not being used. Since the smart cooler does not rely on having the product being on at all times the microcontroller can make use of these modes. Some of the specifications for the microcontroller can be found below:

- Program Memory Size: 48 kB
- I2C: 1
- Program Memory Type: Flash
- Number of ADCs: 1
- ADC Channels: 16
- Operating Voltage 1.8 - 5.5
- Pin Count: 48
- USART: 4

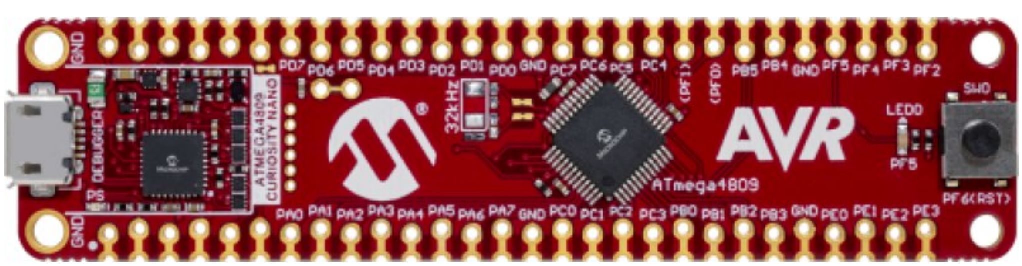

Figure 12: ATmega4809 Curiosity Nano

III.v.ii MSP430

The microcontroller considered is the MSP430FR6989 from Texas Instruments. The MSP430FR6989 has many capabilities with the downside of higher power consumption and higher cost. It is important to look for possible future expansions but the microcontroller should not be too expensive. Some of the specifications for the microcontroller are listed below:

- Non-Volatile Memory: 128 kB
- RAM: 2 kB
- ADC: 12-bit SAR
- GPIO pins: 83
- UART: 2
- I2C: 2
- SPI: 4
- Comparator Channels: 16

The MSPFR6989 is a good board with many possibilities tied to it. However, the MSPFR6989 does not have any bluetooth/wifi capabilities so this would mean there would be no features that would require bluetooth/wifi. This might be considered a downfall since most technologies now have some sort of bluetooth/wifi features.

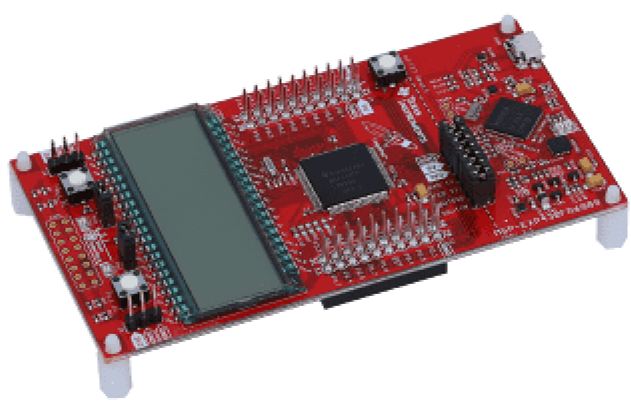

Figure 13: MSP-EXP430FR6989 Development Kit

III.v.iii ESP32

The ESP32-WROOM-32E is unique since the MCU has bluetooth/wifi capabilities. This microcontroller allows for future expansions and additional feature upgrades as the technology evolves. By having the extra space for expansions, the project has a longer life cycle compared to other products. This microcontroller can be one of the cheapest for home projects. This would help bring down the cost of the product and make it more marketable to future customers. The microcontroller also has the benefit of having dual core processors, making processing information a lot quicker. This helps if there is a programmed interface for the user to interact with on the cooler. Some of the specifications are listed below:

- 240 MHz dual core Tensilica LX6 Microcontroller with 600 DMIPS
- Integrated 520 KB SRAM
- 4 MB flash
- Integrated 802.11 b/g/n HT40 Wi-Fi Transceiver
- Integrated dual mode Bluetooth (Classic and BLE)
- 32 kHz crystal oscillator
- 3 x UARTs
- 3 x SPI
- 2 x I2C
- 12 x ADC Input Channels
- 2 x I2S Audio
- 2 x DAC

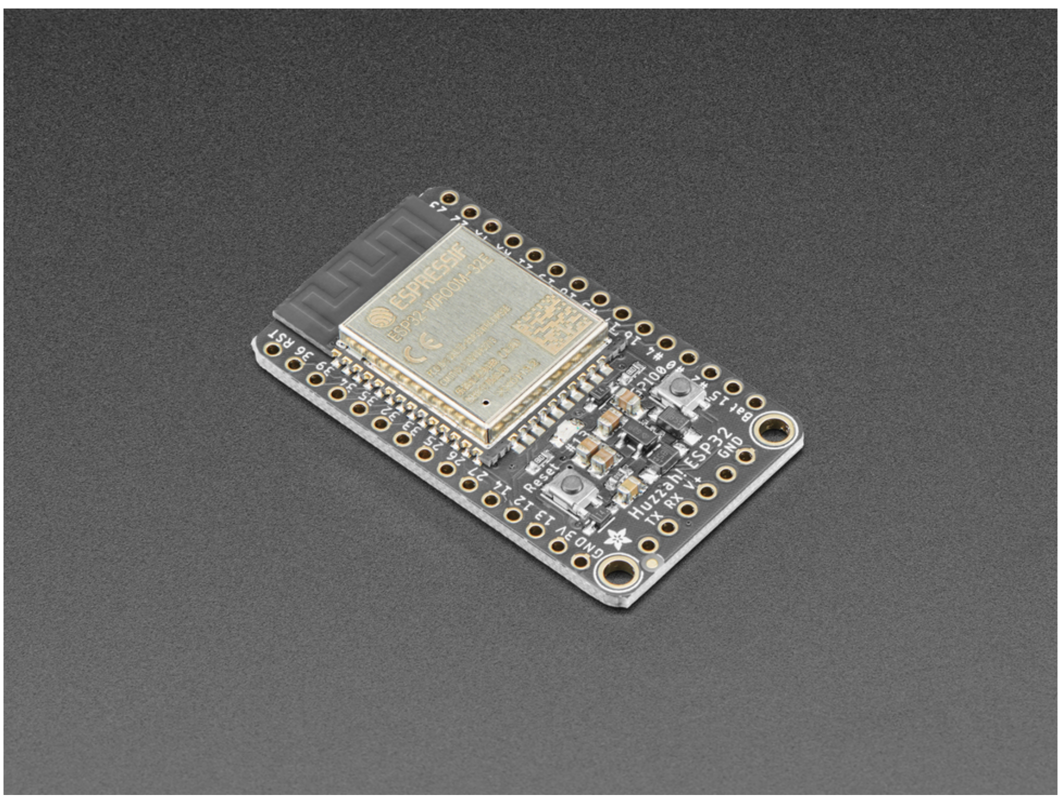

Figure 14: ESP32 Breakout Board

III.v.iv Comparison of MCUs

Each microcontroller has their own advantages and disadvantages and this section covers the comparison between the microcontrollers discussed above. The table below shows the comparison between the microcontrollers and the selected microcontroller is highlighted in blue. The features and price point are too valuable to pass up compared to the other microcontrollers.

Description	ESP32	MSP430FR6989	ATmega4809
Architecture	32-bit	16-bit	8-bit
Integrated Development Environment	Arduino		AVR Studio
Bluetooth	Dual Mode Bluetooth (Classic and BLE)	n/a	n/a
Wi-Fi	802.11 b/g/n ~2.4 MHz	n/a	n/a
Microprocessor Speed	240 MHz	16 MHz	20 MHz
Voltage Supply	3 V ~ 3.6 V	1.8 V ~ 3.6 V	1.8 V ~ 5.5V
Operating Temperature	-40°C ~ 105°C	-40°C ~ 85°C	-40°C ~ 125°C
Memory Type	4 MB, Flash	128 kB, FRAM	48 kB, Flash
ROM	448 kB	n/a	256 kB

SRAM	536 kB	2 kB	6 kB
I/O	48	63	41
Costs	$13.50	$20.00	$20.89

Table 5: Comparison Between Three Microcontrollers

III.vi Sensors

This project wouldn't be considered smart without the use of sensors. There are many sensors that come into play to allow the smart cooler to function the way it needs to with the help of ones like temperature, humidity, and uv sensors to give the data it needs. Sensors help to give information to the system so that the features added function correctly for the user. There are many sensors out there that come in all different shapes and sizes, as well as different price ranges. Each of the different sensors used help to contribute to how they function correctly throughout our system.

III.vi.i Temperature Sensor

Temperature sensors are used almost everywhere as temperature is a very useful quantity to know. The measurement can dictate whether or not a chemical reaction occurs, give insight to the condition of machinery, and even warn a user before they plan on touching something hot. There is a lot of value placed in knowing the temperature of something so choosing the right sensor for the intended application is worth spending some time on. Some specifications for the sensor are listed below:

- Power Supply: 3.3V-6V DC
- Operating Range: Temperature: -40~80 Celsius
- Accuracy: Temperature: <+-0.5 Celsius
- Resolution/Sensitivity: Temperature: 0.1 Celsius
- Repeatability: Temperature: +-0.2 Celsius
- Humidity Hysteresis: +-0.3% RH
- Long-term Stability: +-0.5% RH/year
- Sensing Period: Average of 2 seconds
- Dimensions: Small size: 14 x 18 x 5.5mm; Big size: 22 x 28 x 5mm

III.vi.ii Humidity Sensor

Humidity plays a large part in how comfortable a certain temperature feels. The more humidity in the air the stickier the air feels. This is an important measurement to consider for the Smart Cooler since the user would want to know how the air inside is in comparison to outside. The same humidity at different temperatures can make the air feel different depending on dew point. Dew point is the temperature at which water droplets begin to condense resulting in dew forming. Some specifications for the sensor are listed below:

- Power Supply: 3.3V-6V DC
- Operating Range: Humidity: 0-100% RH;
- Accuracy: Humidity: 0-100% RH;
- Resolution/Sensitivity: Humidity: 0.1% RH;
- Repeatability: Humidity: +-1% RH;
- Humidity Hysteresis: +-0.3% RH
- Long-term Stability: +-0.5% RH/year
- Sensing Period: Average of 2 seconds
- Dimensions: Small size: 14 x 18 x 5.5mm; Big size: 22 x 28 x 5mm

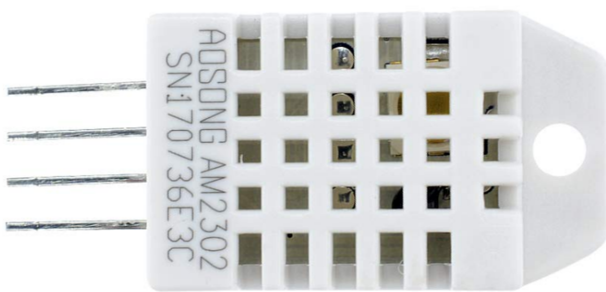

Figure 15: DHT22 Digital Temperature & Humidity Sensor Module

III.vi.ii.i Comparison of other Temperature/Humidity Sensors

Here is a comparison table of the temperature/humidity sensors researched and what they have to offer. This helps to show them side by side in certain areas and be able to show which of the parts we have selected to use throughout our project.

Type	DHT22	SHT31-D	AM2320
Voltage	3.3V-6V	2.4V-5.5V	3.3V-5V
Dimensions	Small size: 14 x 18 x 5.5mm; Big size: 22 x 28 x 5mm	12.7 x 18 x 2.6mm	22.5 x 12 x 4.7mm
Price	$10-$11	$13-$14	$4-$5

Table 6: Temperature/Humidity Sensor Comparison

III.vi.iii UV Sensor

With the UV sensor this allowed for the system to detect how much light is coming through the glass and determine the state of the glass. This helped to either block out light from coming in/going out of the cooler through the glass. With that, depending on the situation, if there is not enough light to see, this triggers the sensors to turn on inside the cooler to allow the user to view through the glass. Some specifications for the sensor are listed below:

- Measurement Range: ALS: 500nm-600nm; UVA: 300nm-350nm
- Supply Voltage:3V-5V DC
- Communication Interface: I2C
- Interface Address: 0x53

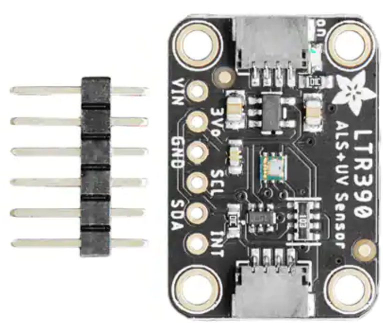

Figure 16: STEMMA QT LTR390 UV LIGHT SENSOR

III.vi.iii.i Comparison of other UV Sensors

Here is a comparison table of the temperature/humidity sensors researched and what they have to offer. This helps to show them side by side in certain areas and is able to show which of the parts we have selected to use throughout our project.

Type	Stemma QT LTR390	SI1145	TCS34725
Voltage	3.3V-5V	3V-5V	3.3V-5V
Dimensions	28 x 17 x 3mm	20 x 18 x 2mm	20.44 x 20.28 x 2mm
Measured	Ambient Light and UVA	Visible Light and IR Light	RGB and CLear Light
Price	$4-$5	$9-$10	$7-$8

Table 7: UV Sensor Comparison

III.vi.iv Motion Sensor

With this sensor, it allows for the detection of motion that is closest to the smart cooler. With that, it allows you to turn on/off lights and such depending on how close or how far the user is from the system. From there, this allows certain features to turn on and off and be of use. This helps to detect when the system needs to use certain features and helps to turn them off when they are not in use. Some specifications for the sensor are listed below:

- Supply Voltage Range: 2.7V-12V
- Operating Temperature Range: -40-60 Celsius
- Sensing Range: 100 degree cone angle
- Delay Time: 2 seconds
- Trigger mode: repeatable

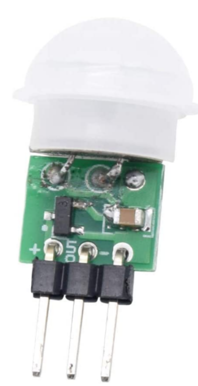

Figure 17: AM312

III.vi.iv.i Comparison of other Motion Sensors

Here is a comparison table of the motion sensors researched and what they have to offer. This helps to show them side by side in certain areas and is able to show which of the parts we have selected to use throughout our project.

Type	AM312	Tilt Ball	Breaker Beam
Voltage	2.7V-12V	Up to 20V	3.3V-5V
Dimensions	12 x 25mm	23 x 5 x 5mm	20 x 10 x 8mm
Price	$8-$9 (3ct)	$2-$3	$5-$6

Table 8: Motion Sensor Comparison

III.vi.v Tilt Sensor

With this sensor, this allows us to get specific measurements on the orientation of the product. It can tell whether it is leaning too much on a specific side or show the level of the surface is at 0. This sensor is beneficial because it helps the user know where to put the product and make sure that it is in a safe place so the contents within it won't spill and such. Some specifications are listed below:

- Electrical Rating: < 6mA; 24V DC
- Electrical Life: > 50,000 Cycles
- Contact Resistance: 1 Ohm
- Ambient Temperature: 0 Celsius ~ 100 Celsius

Figure 18: Tilt Sensor - AT407

III.vi.vi Pressure Sensor

With the pressure sensor, this allows us to measure the force or pressure being applied around the product and then turn it into a signal. With this signal, it can then help to inform the user on certain things like if it is too heavy in a certain place or if there is something much heavier on itself in which it cannot handle the weight. And this way, in the future, there could be some kind of warning implementation that notifies the user of such circumstances that helps keep the product and the user safe. Some specifications are listed below:

- Trigger Force: 20g, triggered
- Pressure Measuring Range: ~20g-6kg
- Activation Time: < 0.01sec
- Operating Temperature: -40 Celsius~80 Celsius
- Lifespan: >1 million times
- Response Time: < 10ms

Figure 19: RP-C18.3-ST THIN FILM PRESSURE S

III.vi.vii Sound Sensor

The sound sensor helps to detect sound waves within the area and then change into an electrical signal which can be configured to turn on/off different features. This sensor picks up the sound vibrations throughout the air depending on where it is located, it helps to amplify certain sounds, or it can detect how loud something is. There are many uses that a sound sensor can be used for. Understanding what it can do and how it is implemented into a project helps determine if it is useful or not because it all depends on the situation of the device and what it is used for. Some specifications are listed below:

- Power Supply: 3.3V-5.3V
- Mic Sensitivity: 52dB
- Frequency Range: 50Hz~20KHz

- Mounting Holes: 2.0mm
- Dimensions: 18.67mm x 34.42mm

Figure 20: Sound Sensor

III.vi.viii Comparison of the Sensors

Here is a comparison table of the sensors researched and what they have to offer. This helps to show them side by side in certain areas and shows which of the parts we have selected to use throughout our project.

Type of Sensor	Voltage	Dimensions	Price Range
Temperature	3.3V-6V	Small: 14mm x 18mm x 5.5mm; Big: 22mm x 28mm x 5mm	~$10.00-$11.00
Humidity	3.3V-6V	Small: 14mm x 18mm x 5.5mm; Big: 22mm x 28mm x 5mm	~$10.00-$11.00
UV	3V-5V	3cm x 2cm x 1cm	~$5.00
Motion	2.7V-12V	9.2mm x 9.2mm x 18.2mm	~$3.00
Tilt	24V	4mm x 22mm	~$2.00
Pressure	N/A	18.3mm x 32mm x 0.4mm	~$5.00

Sound	3.3V-5.3V	18.67mm x 34.42mm	~$3.00-$4.00

Table 9: Sensor Comparisons

III.vii Switch

With switches this helps to turn on certain features of the project based off of the sensors that are triggered whether be with the led switches to turn on lights within the cooler or just turning on specific sensors with a sensor switch. These allow for easier use once the system gets powered on and is functioning correctly.

III.vii.i LED Switch

With the LED switches, this allows for lights to be either turned on and off depending on the state of the cover when it is either open or closed. It is a basic push button switch to either turn on/off the LED. This obviously makes viewing inside the cooler much easier for the user and adds an aesthetic effect for lights. These lights are controlled through the sensors on when to turn on and off. It allows for being able to change to different colors depending on the user's preference.

Figure 21: Battery Snap pre-connected to a Micro Push-button Switch

III.vii.ii Limit Switch

When using the limit switch, this allows to turn on/off certain features on the product that are used by the user. Rather than having the switch be pressed physically by the user, it can be triggered by either the presence/absence of an object that is in contact with the limit switch. Some specifications are listed below:

- Voltage Rating: 125V AC
- Contact Rating: Gold 0.4VA max @ 20 VDC/VAC Max; 0.1Amps @ 125VAC; 1.5Amps @ 250VAC; 3 Amps @ 125V AC
- Mechanical Life: 1 million
- Insulation Resistance: 100Mohms min. @ 500V DC
- Dielectric Strength: 500VDC
- Operating Temperature: -25 Celsius ~ 75 Celsius

Figure 22: SWITCH SNAP ACTION SPDT 3A 125V

III.vii.iii Comparison of the Switches

For the switches that were researched for this project, this is a table that shows a comparison between them and what they offer for the project. In some areas, one switch might be more effective than the other depending on what it has to offer. But overall, this table shows which of the parts we have selected that are applied into our project.

Type of Switch	Voltage	Size	Operation	Price Range
LED	N/A	Small	Physically push button	~$2.00-$3.00
Limit	125V AC	Small	Presence/absence of object	~$1.00-$2.00

Table 10: Switch Comparisons

III.viii Power Delivery Technology

In this section we discuss the various ways power is utilized to the components of our smart cooler system. Researching the various ways benefits the team with the knowledge needed to be able to effectively choose the right parts needed for the task at hand as well as adequately power the system. A cooler's main reason for use is its ability to store the items placed inside cool while keeping them cool. For our cooler to uphold this responsibility our cooler must also be portable and not rely on staying in one place for power. We explored two different methods for powering our smart cooler, namely direct power as well as power storage and depletion from batteries.

III.viii.i Mains Electricity

A main form of power for this project would be mains electricity, also referred to as "utility power" or "wall power". Main's electricity is an alternating current (AC) electric power supply that is used in homes to power devices like microwaves, televisions, or other devices that can be plugged into a wall outlet. This power supply has two main properties which are voltage and frequency which vary between regions but in North America the common combination is 120 V and 60 Hz [1]. Alongside the power generation of the solar panel in the cooler, there is a way to charge the battery from an AC power plug that can be used in electrical outlets found in everyday homes.

Research for a voltage regulator as well as a rectifier is also required alongside the research of the main power source.

III.viii.ii Rectifier

Since the smart cooler is designed to be able to charge the battery using the wall plug in a normal household, a rectifier is needed to convert alternating current to direct current. Most electronics run off of direct current so this part is essential to the smart cooler. There are usually two types of rectifiers, half-wave and full-wave.

The half-wave rectifier is a different type of rectifier that allows AC voltage to be transformed into DC voltage. However, this conversion is not the most efficient. The transformation when using a half-wave rectifier does not allow the program to be as efficient as possible.

The most efficient form for a rectifier is to have a full-wave rectifier. This ensures that essentially all of the alternating current would become direct current. A diagram of an exam circuit can be seen in the figure below.

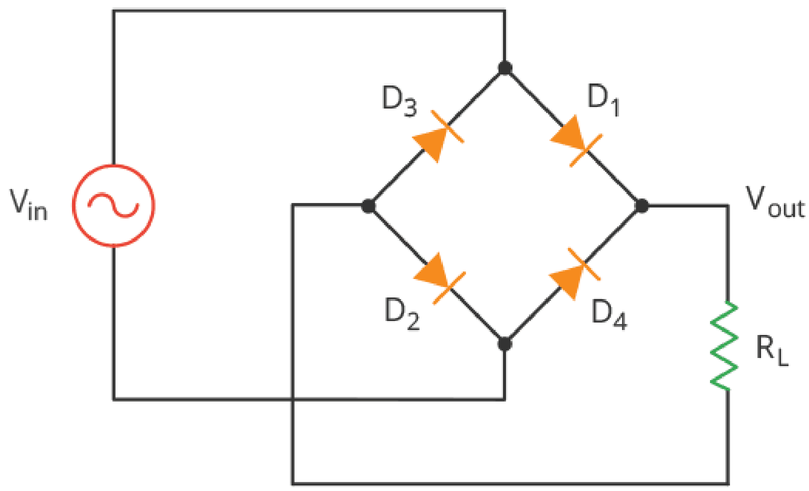

Figure 23: Full-Wave Rectifier Example

There are also other designs for the rectifier that include a capacitive filter. The capacitor is there to reduce the small ripples that the load causes. The capacitor essentially creates a better power quality when converting alternating current to direct current.

III.viii.iii Voltage Regulator

The voltage regulator is a key device to making sure that the voltage stays at the desired value. There are a few types of regulators but the main two are a fixed voltage regulator and an adjustable voltage regulator. The fixed regulator maintains the set voltage while the adjustable voltage regulator has a potentiometer that allows for voltage value to change.

Both of these regulators are important to building the circuit design for the smart cooler since different parts need different voltages. The fixed voltage regulator can be used to make sure that one specific voltage can stay at a specific value. However, the switching regulator is more flexible and can be used to become a buck-boost converter. The buck-boost converter allows for voltage to be stepped up or stepped down. Making this a valuable tradeoff for certain parts of the product.

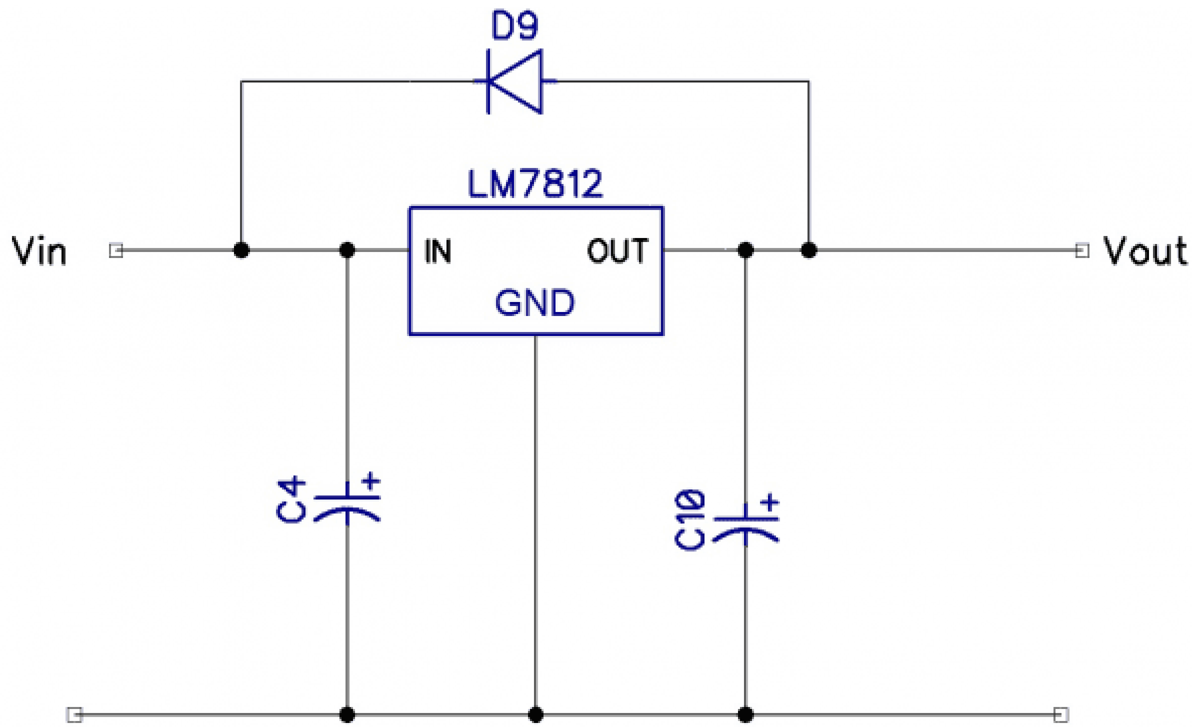

Figure 24: Schematic of Linear Regulator

The linear voltage regulator can be used as a step-down converter but they are often considered to be inefficient. The transistor is essentially acting as a resistor and it is wasting electrical energy by converting it into heat. Hence why they usually have a heat sink. Linear regulators are cheap and can generally be used for light loads or when the desired output voltage is around the input voltage.

Zener voltage regulator is when the zener diode is used and is connected in parallel with the load. The advantage of a zener diode is the special properties when the diode is in the breakdown region. The diode has a steep drop at a specific point in the zener diode. The graph of the breakdown region for the zener diode can be seen below. Zener diodes are used in applications such as power strips.

The main usage of the voltage regulator would be regulating the 12V coming from the battery. The battery is labeled as 12V but this does not mean that the battery itself is producing a constant 12V. This is when the voltage regulator would come in to make sure that there is a constant 12V being generated instead of having a fluctuating voltage generation. This helps with making sure that the components do not need to consume more or less power.

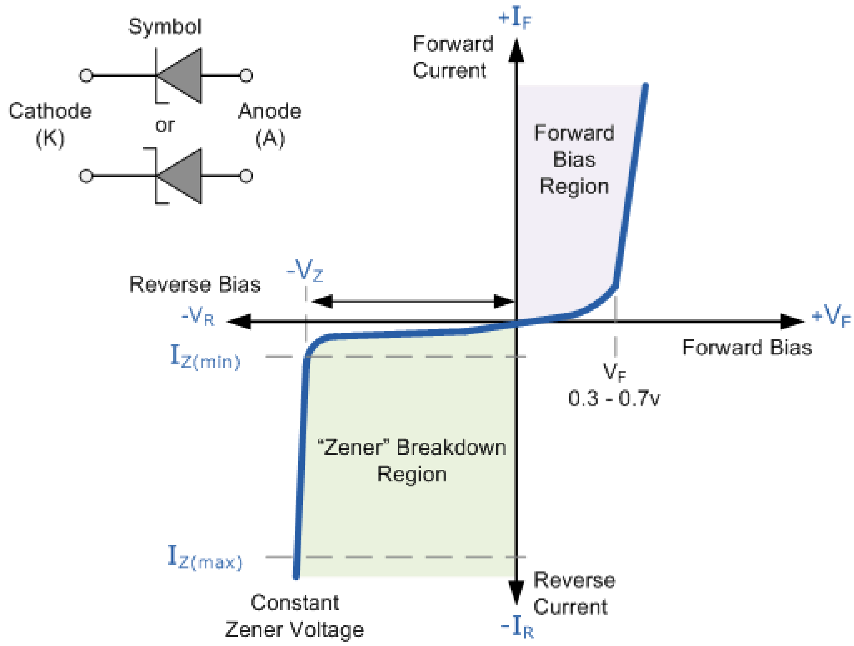

Figure 25: Zener Diode I-V Characteristics

A switching regulator is a voltage regulator that uses a switching element to turn the incoming power supply into a pulsed voltage. The disadvantage of this is that there is a lot of noise that is produced when the switching element is constantly turning on and off to reach the proper value. This can be solved by using a filter, like a capacitor, to smooth out the noise. The switching voltage regulator is generally highly efficient and causes little heat generation compared to the previous two regulators. The figure below shows the general concept of a switching regulator.

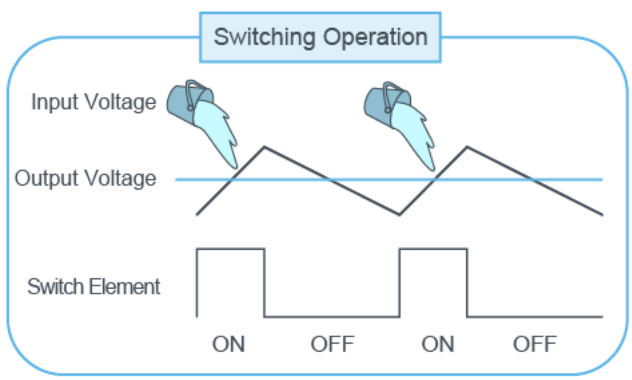

Figure 26: Concept of Switching Regulator

The converters can also be categorized as buck, boost, and buck/boost converters. A buck converter is a DC/DC switch mode power supply that is intended to lower the input voltage of an unregulated DC supply to a stabilized lower output voltage. The boost converter is another DC/DC switch power supply that is meant to increase the input voltage. This is possible by increasing the voltage but then decreasing the current flowing. The idea can be seen through Ohm's Law with V = IR. The buck-boost converter can increase or decrease the voltage output. The problem with these types of converters is that they are larger but they are extremely versatile. Buck-boost converters can be used for powering the LED lights. The lead-acid battery supplies a voltage around 12V.

Description	Linear Voltage Regulator	Switching Voltage Regulator
Efficiency	Low	High
Size	Small - Medium	Smaller than Linear Voltage Regulator
Design Flexibility	Buck	Buck, Boost, Buck-Boost

Table 11: Comparison Between Regulators

III.ix Batteries

Primary Battery is a cylindrical shaped cell most known as AAA or AA batteries. These types of batteries are small, inexpensive, and portable which allow use in various applications that would need power quickly and not weigh much. The advantage of a primary battery is in the capacity of energy it can hold compared to secondary batteries. Although they have a higher capacity of energy, they are unable to be recharged and once depleted must be replaced. Secondary Batteries are similar to primary batteries but have the advantage of being recharged. In this section we discuss secondary batteries with different compositional makeup.

III.ix.i Lead-Acid

A secondary battery that has a relatively low energy density. Although it has a low energy density it can supply high surge currents which gives it a high power-to-weight ratio. The types of applications this type of battery is used for is in motor vehicles which need a high current to start motors. This battery is relatively inexpensive

III.ix.ii Nickel-cadmium

A secondary battery that has a terminal voltage during discharge of around 1.2 volts continuously throughout discharge. A battery of this type has a good life cycle and can perform at low temperatures with a fair capacity. The main advantage of this type is compared to other secondary batteries, a nickel-cadmium can deliver its full rated capacity during high discharge. The materials used for construction are more costly than others and deplete at a faster rate. The applications for this type are more accustomed to emergency lighting, standby power, and uninterruptible power supplies.

III.ix.iii Nickel–metal hydride

A secondary battery that has a voltage of 1.2 volts with a higher energy density, a high-power capability, and a good cycle life than that of the nickel-cadmium battery. The chemical reaction that happens at the positive end of the battery is similar to a nickel-cadmium battery however what happens at the negative end is different in that it uses a hydrogen absorbing alloy. These types of batteries are used as replacements for similarly shaped non-rechargeable batteries even though they have a lower but compatible cell voltage. They are also less prone to leaking and explosions as other types.

III.ix.iv Lithium-ion

A secondary battery that has a high energy density, has no problem with storing less charge than advertised, and a low discharge rate when not attached to anything. These types of batteries are the most commonly used batteries in portable electronics nowadays. The battery has a nominal cell voltage of 3.6 volts. They have a low-cost, high-energy density and do not use toxic materials in their construction.

III.ix.v Lithium-ion polymer

A secondary battery that is like a lithium-ion battery but instead of a liquid electrolyte it has a polymer electrolyte which gives it a higher specific energy and is used in applications where weight is critical to what it is being used in.

When selecting a battery, it has to provide power for all the sensors, lights, and any charging being done. The parameters we set to help us choose a battery include power output, size, weight, and cost. We want to find a battery that could power the components along with having enough storage to also provide charging for any external devices that would need it. Power output is of high priority since it is powering all the electrical components and needs to have the capability to charge devices plugged in. Size is a moderately high priority since if the battery takes up too much space, then there is less space for items to be placed inside. Weight is also moderately high priority since the cooler contains food, drinks, and ice and any extra weight makes the cooler not be portable. The price of the battery is a low priority since the price can vary depending on all the other parameters.

The table below summarizes the different aspect of the batteries discussed above:

Type	Lead Acid	Nickel-cadmium	Nickel–metal hydride	Lithium-ion	Lithium-ion polymer
Specific Energy Density (Wh/kg)	30-50	45-80	60-120	100-265	90-190
Life Cycle (80% discharge)	200-300	1000	300-500	2000	500-2000
Fast Charge	8-16 hours	~1 hour	2-4 hours	Less than 1 hour	Less than 4 hours
Cell Voltage	2 V	1.2 V	1.2 V	3.7 V	3.3 - 3.6 V

Table 12: Comparison of different battery types

III.x Charging Connections

In this section we discuss the possible connector types that can potentially be present on our smart cooler to be used for charging various devices. Universal Serial Bus also known as USB is an industry standard connection type for cables for connection, communication, and power supply. There are multiple types of USB connectors along with multiple standards for each connector.

III.x.i USB Type A

Is the most common type of USB connection. These are found predominantly in computers, consoles, television's, peripherals, and plenty of other devices. The Type A connector can supply 5 volts DC with load current levels of less than about 2 amps.

III.x.ii USB Type B

Is very similar to the Type A connector except for the shape of the plug. The reason for development of this connector type was to allow the connection of devices without worrying about connecting two host computers together. The connector can supply the same as Type A which is 5 volts DC with load current levels of less than about 2 amps.

III.x.iii USB Type C

This is an industry-standard connector for transmitting both data and power on a single cable. This connector is more powerful than the previous by being able to supply up to 20 volts for up to 5 amps at 100 watts.

Along with the different connector types, there are some connector standards that change the rate at which each connector can transmit data across. The table in the section on standards has the different connector standards along with other useful information such as the max data speed that can be transferred.

III.xi Lights

For our users to be able to use the smart window effectively there must be a way to have the inside of the cooler be lit enough to see inside. To light the inside of our cooler when a user changes the opaqueness of the window. The options for lighting are very limited and the best option for the use case we are intending are Light Emitting Diodes. The formfactor of the LEDs and the types that were under consideration are Surface Mounted Diodes, Chip on Board LEDs, and Tube LEDs.

III.xi.i Surface Mounted Diodes

These lights are a type of LED that emit light and are mounted and soldered flat against a circuit board. This reduces their size, gives them an improved beam angle and a lower cost. A use case for the SMD are for LED strip lights which are able to be applicable for our need of lights.

III.xi.ii Chip on Board

Or COB refers to the mounting of an LED directly in contact with a substrate to produce LED arrays. COB LEDs can provide much higher lumen density because of the use of several diodes together. The use of more diodes allows for a more uniform light intensity. For a COB LED there are only two contacts regardless of how many diodes are on the chip making the circuit design much simpler.

III.xi.iii LED Tubes

These lights are a type of LED lamp that are used as a replacement for traditional fluorescent tubes. The LED tubes are energy efficient and have a long service life. The typical use case for tube lighting is in office spaces because they can replace fluorescent lights in both parabolic and indirect light fixtures.

III.xii Screen

For the screen, this helps to display the information given off by the sensors to tell the user what is happening on the product. There are many different kinds of screens to use and the screen chosen depends on the information that it displays and how compatible it is to the rest of the product. In all, it is to help display messages based on what the product is measuring.

III.xii.i Liquid Crystal Display

The screens for a liquid crystal display module are created by light-modulating properties of liquid crystals combined with either a backlight or reflector to create images in color or monochrome. The use for LCD screens can be seen in televisions, computer monitors, and instrument panels.

Figure 27: LCD1602 module

III.xii.ii Light Emitting Diode

The screen for a light emitting diode module is created by a collection of multiple LEDs. There is a circuit with a conductor track that connects the LEDs together. The integrated circuits are assembled in the back and control the different properties of the LED. Though LEDs are generally better than LCD displays, it is difficult to find a module that has LEDs in a small form. Generally, the modules are too big. The table below shows the comparison of the types of screens and some features of the two.

Type	LCD	LED
Response Time	Slow	Fast
Power consumption	Low	High
Picture Quality	Low	High
Cost	Low	Moderate
Viewing Angle	Low	High

Table 13: Comparison of two types of screen

III.xiii Speaker/Buzzer

This section discusses the topic of speakers and buzzers for the smart cooler. Having a bluetooth connected speaker is a long term goal for the smart cooler. However, it is necessary to research the idea beforehand to see if the goal is viable even as a long term idea. The goal of having a speaker is to be able to continue the idea of having a convenient smart cooler that has multiple purposes beside being able to see through the PDLC glass. Speakers are marketable and especially if the speaker has bluetooth capabilities. The section discusses the research of active and passive buzzers to micro speakers.

III.xiii.i Active and Passive Buzzer

The buzzer is a component that is made from an oscillating transistor circuit on the inside to create the buzzing noise when voltage is applied to it. An active buzzer will constantly play a tone when voltage is applied to it. The active buzzer is simply an on and off type of buzzer so it is not ideal when it comes to playing other sounds. The passive buzzer does not buzz right away when applying voltage to the component. The passive buzzer only produces a sound when the component is coded properly. The code and specify a frequency to produce and then the buzzer will produce a buzzing tone in the coded frequency.

Typical buzzers are either piezo or electro-mechanical devices. Piezo buzzers contain a piezo ceramic element which moves up and down when a voltage is applied. The movement of the piezo disc creates sounds. Electromechanical buzzers contain a magnet, diaphragm, and coil. When a voltage is applied, the diaphragm is pulled towards the magnet. As current flows through the coil, a fluctuating magnetic field is produced which causes the diaphragm to vibrate and emit sound.

III.xiii.ii Speaker

Speakers use AC voltage to generate sound and generally require additional parts like an audio amplifier. The speaker contains a magnet, voice coil, and diaphragm. AC voltage moves through the coil of wire creating a magnetic field. The newly created magnetic field interacts with the magnetic field generated by the permanent magnet inside the speaker. The voice coil moves up and down as it is attracted and repelled by the magnet and this turns the speaker diaphragm. The movement is what creates different sounds.

III.xiii.iv Speaker Specifications

When it comes to selecting the correct speaker there are a few factors to consider such as sound pressure level, resonant frequency, and power. Sound pressure level is measured in decibels and this is the level of sound pressure in front of the speaker at a given power at a given distance. Essentially, this determines how loud the device is and how much power is needed to achieve this. The resonant frequency is the natural frequency that the speaker resonates at. The component needs to be driven at that frequency to generate the optimal sound output. Power determines how much input power is required for the speakers to perform at different ranges. The more power consumed, the louder the sounds produced.

III.xiii.iii Buzzer and Speaker Comparison

Buzzers are smaller than speakers and they are compact devices that are able to produce an audible alert or alarm for a variety of applications. Piezo buzzers use minimal current so draw less power. Their current consumption is typically less than 10mA. Buzzers also contain their own drive circuit which makes them a simple and effective solution. Speakers have a wide range of frequency which makes them more versatile and flexible than a buzzer. Speakers also have better acoustic quality and are more suitable for voice and music reproduction. Generally, when it comes to choosing a buzzer or a speaker it depends on what qualities are needed for the case. In the case of having music being played from the smart cooler, the speaker would be more suitable.

III.xiv 555 Timer

This section discusses the 555 timer and how it works. The 555 timer is a unique component that would be needed to create a LED light dimmer on the PCB. Creating a light dimmer may be an added goal but it provides the user with some freedom when choosing how bright the LEDs to be. This can also cause the battery to last longer if the system is not drawing a lot of power to power the LEDs.

III.xiv.i 555 Timer IC

The 555 timer IC is an integrated circuit used in a variety of timer, delay, pulse generation, and oscillator applications. The internal design usually consists of a few resistors, a flip-flop, and some operational amplifiers. Some timers work differently but all the pins for 555 timers are the same and are labeled as shown in the table below.

555 Pin	**Pin Name**	**Pin Direction**	**Pin Description**
1	GND	Power	This pin is the ground reference voltage
2	TRIGGER	Input	When the voltage at this pin falls below ½ of the voltage of CONTROL, the OUTPUT goes to the high state and a time interval starts
3	OUTPUT	Output	This is a push-pull output that is driven to either a low state or a high

			state
4	RESET	Input	A timing interval may be reset by driving this pin to GND, but the timing does not begin again until this pin rises above ~0.7V
5	CONTROL	Input	This pin provides access to the internal voltage divider. Applying voltage to the pin changes the timing characteristics
6	THRESHOLD	Input	When voltage at this pin is greater than voltage at CONTROL, then the OUTPUT high state ends
7	DISCHARGE	Output	For bipolar timers, this pin is an open-collector output, CMOS timers are open-drain
8	V_{cc}	Power	For bipolar timers, the voltage range is from 4.5 to 16V. However, most of them will be operating around 3V

Table 14: Description and Purpose of 555 Timer Pins

III.xv Software

With the implementation of various technologies, there is bound to be an assortment of software that may be used in conjunction or sometimes even as a prerequisite before getting the devices to work. Working with newer technology or technology that one is unfamiliar with can be daunting, so understanding the software behind them is the first step in furthering your knowledge in hopes of making your design plans flow more smoothly.

III.xv.i Eagle

Eagle is an essential PCB layout software that allows engineers to create and modify PCBs. Eagle features a schematic editor that includes SPICE simulator, modular design blocks, and electronic rule checking. The software also features their PCB layout editor with real-time design synchronization, push and shove routing, and automatic routing tools. Eagle was used to create schematics and PCB designs since the group has prior experience with the program. The online support shown by the various libraries means that parts can be easily found and implemented into the program with little to no issues. The software also features the 3D PCB modeling to ensure that all the components are able to fit onto the PCB.

III.xv.ii C

The C programming language is a general-purpose programming language that has a variety of uses from system applications to calculations within games. It is oftentimes used for low-level programming as it combines qualities from both the low and high ends. When it comes to the C programming language, it is highly prevalent in many embedded systems. Through the use of microcontrollers within our project, C was used in the background to program different functionalities from the microcontrollers such as LED light customization for the inside of our smart cooler.

The language itself is very versatile, as its simplicity lends itself to a plethora of different solutions depending on what you are looking for. Simplistic in design, but can quickly become more and more complex as it works with items such as code for operating systems. There are many other variations of the C language as it branches off into others such as C++, which is an extension of C with object-oriented capabilities.

III.xv.iii C++

Speaking of C++, the programming language itself can be dated back to 1979 which is roughly a little less than 40 years after the first electrical powered computers were created. We can thank Bjarne Stroustrup for its creation whilst he was preparing work for his Ph.D thesis. Back then he was familiar with a language called Simula, which had its primary functionality embedded in simulations. More specifically, he worked with the Simula 67 language which was a variant of the language that was the first to support object-oriented programming.

Although Simula 67 was quite helpful in his research, it was quite slow for his intended uses. So he migrated to try to create a C derivative called “C with Classes.” This essentially was an implementation of a lesser C++ that is C with object-oriented programming capabilities but more general with support for basic inheritance and such. As with a new language, you need a supporting compiler which in this case was called Cfront: the first C with Classes compiler. Its general purpose was the translation of the C classes to normal C until it eventually was abandoned in 1993 for its inability to integrate new features. Eventually in 1983, C with Classes was renamed to C++ and the rest is history as it advances to what we know it as now as a largely powerful language with countless capabilities.

III.xv.iv Arduino IDE

Arduino itself is an open-source hardware and software company that provides different microcontrollers through their own design and manufacturing. They officially began in 2005 after branching off from the Wiring development platform project and being named Arduino. The IDE originated back from the Wiring and Processing IDE used back for those languages. This one was written in Java, but supports the C and C++ programming languages.

With all of the different sensors and the use of the ESP32 Breakout board in our project, it comes as no surprise that the Arduino IDE would come into play as a key software tool. Arduino IDE is an open-source software that allows you to write and upload code to different electronic boards such as the ESP32.

The programming language used while creating code in the Arduino IDE is C and C++, which is why these specific languages were mentioned previously. The IDE itself is widely compatible with different boards throughout the world, making it very versatile and reliable should our project need some extra flexibility. It is also relatively straight-forward to use with writing the code, uploading it, and debugging when needed. Even if one was to not have used Arduino IDE before and is new to using it, it has thorough documentation for help.

III.xv.v AutoCAD

AutoCAD is a computer-aided design (CAD) software used for the drafting of 2D and 3D modeling, as well tools to automate different tasks to improve an engineer's quality of life. It provides a wide array of features from drawing comparisons to 3D mapping, and much more. Implementing it into our workflow may be ideal to improve our productivity.

Many projects are complex and require proper planning in order to deliver a working and accurate product. Beginning to work on one without a proper design laid out proves quite difficult, so software such as AutoCAD aims to help with such challenges. Hardware components need to be mapped to specific areas based on their interaction with other components, so one may use AutoCAD to help design the overall schematic of how the project would come together.

A few benefits to using AutoCAD lies in its ability to provide easier edits, faster production, and better accuracy to designs being drafted. Manipulating and changing designs has changed a lot from earlier years where they would have to do it manually, but a lot of it is automated and straightforward now. Reusability has lent itself to faster production, as it has increased efficiency with the ability to easily replicate design parts from libraries. Manual hand-drawn designs have struggled with scalability, especially when it comes to very small or large designs, so AutoCAD provides better accuracy by allowing designers to scale down or up to extremities that are quite difficult to do by hand and still be as accurate.

III.xv.vi Discord

With the Spring semester being mainly remote due to the pandemic, our group members needed a reliable platform to host our communication methods such as meetings that we could not do in person. Discord is a free voice, video, and text app that allows people all over the internet to communicate from any phone, computer, or device that supports it.

It has become a huge platform used by everyone both recreationally and professionally. With new updates being rolled out consistently, they have provided many new features that support a wide range of goals. They added events that allow servers hosted on Discord to schedule different events, which our team has used to schedule meeting dates and pin important deadlines for the project.

Discord also allows the transfer of files which helps tremendously with collaboration efforts. Design documents to API documentation, it supports communication through different valves and pipelines it across for the whole team to see.

As many messenger applications, Discord also keeps a log of messages to refer to later. This can act as a pseudo database for our group to store different files and meaningful messages that may serve a purpose later.

III.xv.vii GitHub

Our workflow may be based around GitHub and the introduction of commits. This includes branching off from a main branch when developing code, and only merging it in after the pull requests get approved. It allows for version control, which is key in keeping our project working without bugs and errors. This also allows group members to easily collaborate when working on the same code, as they can pull in each other's changes.

IV Components and Part Selection

This section explains the various components chosen for the parts as done so by the research that was made in section III. This section gives the possible components and parts selected for completion of the smart cooler. The final subsection provides a table summarizing the selected components and parts by the team.

IV.i Smart Film/Glass

While all of the different smart glass and smart film types are great pieces of technology, some types are naturally suited better for our project than others. Suspended-Particle Devices (SPD Glass) act almost like window blinds, being able to customize the amount of light you would like to pass through. It is not suitable for our project because naturally we do not think having a range of visibility fields for our look-through window of the smart cooler would provide any added benefit. SPD also is not fully light preventable even at its darkest state, which would be detrimental to our privacy attribute of the smart cooler.

For many of the same reasons, Electrochromic shares some properties as SPD so it also does not seem very suitable. While it does boast a lower energy output due to it maintaining its state once the electricity is applied, you are still able to see clearly out of an Electrochromic window whilst fully tinted, so once again privacy concerns are something to take into account. It is also a bit slow compared to the others at switching states, sometimes taking a bit less than three minutes.

Ruling out the other types, we are left with Polymer-Dispersed Liquid Crystal (PDLC) smart glass. The greatest benefit PDLC glass has over the others is that while in its opaque state, no light can pass through due to the nature of the dispersed liquid crystals within the polymer. It rests in this opaque state without any electricity being applied, then immediately allows light to pass through once it does, and can become completely clear based on the voltage level. This is great for our privacy implementation as well as power output, since we do not have to maintain our power source through the film, only when we would want to be able to see through the cooler itself.

PDLC seems like the correct option to go for this project. We found a viable option with the PDLC Switchable Smart Film on Amazon that is not too expensive considering PDLC usually boasts a higher cost than the others. Our project does not need a large amount of the smart film, so this size is perfect rather than buying an entire roll from a producer. It already comes hooked up to a button for activating, but we plan on soldering it to our design implementation.

For the final design of the smart cooler, our PDLC film was sandwiched in between two panels of acrylic. This was in order to provide protection for the film, and also combat condensation that would naturally build up inside due to the differences in temperature. Then we used a 3D-printed frame to secure the film inside the cutout portion of the cooler. This gave rigidity to the cooler lid and kept the frame securely in place.

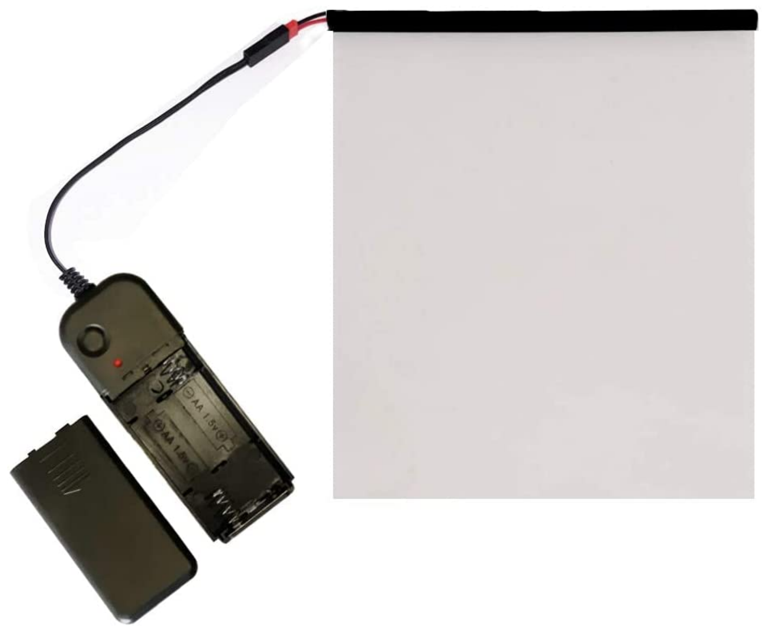

Figure 28: PDLC Switchable Smart Film/Electronic Adhesive Smart Glass Film from Amazon

IV.ii Cooler

For this project, we selected the cooler that allows for ample storage space along with a lid that provides enough space to house the solar panel and smart glass. Since a portion of the lid is cut off to fit our smart glass, it was beneficial to choose a cooler with a lid that is still durable while providing a soft enough material that can be cut with standard tooling.

IV.ii.i Cooler

Being that coolers can vary in prices quite drastically depending on the type dissuades us a bit from choosing a more complex one such as a compressor or absorption cooler. Not only do they tend to be more expensive, but their functionalities just do not seem beneficial for our project, even though they provide a bit of support. Self-cooling could be a nice feature or even freezing, but they lend themselves to design changes that may complicate our other components such as the smart glass.

Weighing our remaining options between a passive cooler and a thermoelectric cooler seemed ideal as both are relatively cheaper and could provide great enough support either way. A drawback that has been noticed with thermoelectric coolers are the lids that are quite unique to that specific cooler, with hardtops that do not seem ideal for cutting. Thus, thermoelectric coolers seemed less feasible to functionally modify than passive coolers.

Due to the commonality of passive coolers, there happens to be so much variety to choose from. Most of them provide the support we are looking for, so we decided on a standard forty-eight quart Coleman cooler that you might find at get-togethers or outdoor functions. It appears large enough to mount some of our components such as the solar panel and the lid is soft enough to cut through. It provides adequate insulation and is cheap enough to be replaced in case of any troubles we face with the design.

The forty-eight quart Coleman cooler provided ample space as the main vessel of our project. Even with sectioning off a compartment inside for the battery, there was a generous amount of space for drinks and other items. In hindsight, a larger cooler would produce better results as far space distribution and temperature control goes, but this cooler was sufficient for our final implementation and provided a well-balanced final product.

Figure 29: Coleman 48 Quart Cooler from Amazon

Type	Coleman 24-Can	Coleman 48 Quart	Coleman 60 Quart Wheeled
Dimensions (inches)	13.41 x 22.95 x 8.35	25.59 x 14.96 x 13.39	34.7 x 22.9 x 17.5
Weight (kilogram)	0.04	0.8	11.9
Capacity (quarts)	12	48	60
Cost	$34.99	$34.99	$54.99

Table 15: Comparison of Different Coolers

The table above lists other types of passive coolers that were looked into. The Coleman 24-can is generally cheaper than the Coleman 48 quart but due to circumstance the prices are the same. The comparison comes down to the 60 quart wheeled cooler vs the 48 quart cooler. The wheeled cooler provides another interesting layer for features in the future. The wheels could be modified so that there would be a motor that can wheel the cooler for the user. However, this may be unrealistic in a sense that a powerful motor would be required to move a cooler full of items. The wheeled cooler was too expensive compared to the regular 48 cooler and then the extra space would not be used in this current design.

IV.iii Solar Panel

With so many different solar panel choices to choose from, it can be quite daunting to begin looking for one and once chosen, deciding to buy this technology without having used one before. Based on our prior research, each type offers their own advantages and disadvantages, so starting to weigh them against each other should point us in the right direction.

Amorphous solar panels are comparatively cheaper than the other panels since they are created using multiple different materials. They tend to also be more flexible due to their composition and thin layers that allows them to mount to areas that stiff panels would not be able to, and also more portable based on their weight. However, since we plan on mounting the solar panel to the top of our lid on the cooler, the flexibility is not really a selling point for us. Amorphous solar panels are also not as solar-efficient since they have other materials that are not conducive to light absorption. As such, finding a solar panel with larger power capacities would be more beneficial for our project.

Polycrystalline solar panels are cheaper than monocrystalline panels since they are formed from multiple different silicon crystals rather than a single one. This also means that they are not as efficient since their silicon purity and space efficiency is lower than monocrystalline. Polycrystalline panels tend to have lower wattages since their power generation is not as strong. When placed at the same size, monocrystalline will usually generate more electricity than other types.

We know that the most efficient types are the monocrystalline panels due to their single-source silicon crystal composition. We also know that they are typically the most expensive also because of the silicon crystal purity it has due to this. Luckily we do not need such a large panel so the price point was not too expensive and within our budget. Since the panel is mounted to the lid of our cooler, we also need dimensions small enough to fit it on top while also leaving enough room for the Polymer-Dispersed Liquid Crystal smart film. After some searching, we found a ten watt and twelve volt monocrystalline solar panel battery charger kit that comes with a ten amp charge controller and extension cable. It aligns with our design plans and a matching twelve voltage rechargeable battery that the PV panel charges. It is roughly half the dimensions of the cooler lid's length and width which is ideal for mounting.

Figure 30: 10W 12V Monocrystalline Solar Panel Battery Charger Kit from Amazon

The table below shows three different solar panels to consider. Two of the solar panels are from the same company but one has an increase in output power. The size of the solar panel is bigger, allowing it to produce more power. However, after careful consideration, it was decided that this solar panel would be too large. The size of the solar panel was compared to the size of the cooler and the solar panel was much bigger than the cooler. This causes issues since the solar panel needs to fit on top of the cooler. Even if the solar panel could fit, it takes up too much room to fit other components on top.

The Amplesol solar panel was much smaller in size compared to the 30W solar panel from LuceSolar. This made it much easier to find space on top of the cooler so that the panel could properly fit. This solar panel also comes with an adjustable axis so the solar panel could move around instead of staying in a stationary position. Movement for the solar panel could allow for some software implementation of solar tracking. If the solar panel could track the sun's movement, it would efficiently gather more energy. However, this solar panel does not provide enough power output to charge a 12V battery effectively.

The chosen solar panel is LuceSolar 10W solar panel. This solar panel takes up an efficient amount of space compared to the other two solar panels. This panel also produces enough power to charge a 12V battery. This solar panel does not come with an axis so that the solar panel could move around. However, a solar panel does not need to track the sun to still be effective. The smartcooler is a product that does not consume a large amount of energy so tracking the sun for more solar energy would not be necessary.

The solar panel was integrated into the cooler lid after precise cuts were made to create space for it. It is a snug fit, meant to keep the solar panel from moving and not falling out when the lid was opened. The solar panel hangs about half an inch above the lid due to its thickness, but this did not create any foreseeable problems.

Type	Amplesol Solar Panel	LuceSolar Solar Panel	LuceSolar Solar Panel
Operating Voltage	5V	12V	12V
Operating Temperature	-20° ~ 50° C	-20° ~ 50° C	-20° ~ 50° C

Output Wattage	3W	10W	30W
Dimensions	33 x 18 x 3 cm	34.29 x 23.37 x 1.524 cm	59.944 x 34.29 x 2.54 cm
Costs	$27.99	$32.99	$57.99

Table 16: Comparison of Different Solar Panel Options

IV.iv Microcontroller Unit (MCU)

Selecting a microcontroller unit is not an easy task since it requires planning ahead carefully and thinking about the future. Selecting a microcontroller that meets the minimum requirements for the current product is not enough since a product can always evolve. There also needs to be room for some mistakes to happen as well. Since the group is not well versed in design projects, there can be mistakes for things such as programming or voltage usage. There can be a miscalculation and somewhere later in the design process it can be detrimental to have a microcontroller that meets minimum requirements.

This is why the ESP32 microcontroller is selected. There is a high evolution ceiling for the product to improve on. As mentioned earlier, the ESP32-WROOM-32E is unique since the MCU has bluetooth/wifi capabilities. There are some stretch goals for this product, such as bluetooth speakers and mobile phone applications so this microcontroller is ideal for the job. The specifications mentioned also work well since they seem to meet all the requirements necessary. It should also be noted that this may not be the best microcontroller choice. As of the time of the writing, the global pandemic has made an impact on supply chains. This means impacting the production of certain microcontrollers. This microcontroller is in stock and there are more than enough to order in case some of them fail during the prototyping stage of the product. The downside of the ESP32 is that the microcontroller does not have a low operating voltage rating. The lowest that the ESP32 goes to is 3 volts compared to the 1.8 volts that the MSP430 and the ATmega4809 can go to. The upside of the ESP is the impressive memory size compared to the other competitors.

Type	ESP32 Thing	Adafruit Huzzah ESP32	MakerFocus ESP32

Operating Voltage	3.0 - 3.6	3.3 - 3.6	3.3 - 7
Operating Temperature	-40ºC ~ 90ºC	-40ºC ~ 105ºC	-40ºC ~ 90ºC
Flash Size	4MB	4MB	8MB
GPIO	28	36	29
Costs	$23.02	$13.5	$20.99

Table 17: Comparison of Different ESP32 Options

The table above shows 3 different types of ESP32 breakout boards, each one had a different style and unique build but were generally the same. The major difference between these 3 is the flash size and the number of gpio pins. The huzzah has the most gpio pins and cost the least compared to the other boards. This makes the huzzah board more viable compared to the others.

IV.v Sensors

In this project, sensors helped show how this product functions as a whole for the user. With multiple different sensors, there are many features that are added to the product. For our project, these sensors that are mentioned are what we chose to work with and to accomplish the features that we set out at the beginning of the project.

IV.v.i Temperature and Humidity Sensor

For this project, for the temperature and humidity sensor, we selected the DHT22 Digital Temperature & Humidity Sensor Module to do the work of collecting what the temperature and humidity of the inside of the cooler would be. WIth this part, it had the feature of both temperature and humidity all in one. Rather than having them be separate parts, with a 2-in-1 part, this made it easier for the design and cost effectiveness of the project. Its small design was effective in gathering the information needed to tell the user what is happening inside the cooler without having to actually open it.

IV.v.ii UV Sensor

With the UV sensor, the part that we selected for this project was the STEMMA QT LTR390 UV LIGHT SENSOR to check for UV lights coming into the system. With this sensor, it can help to collect information on how much light is coming into the cooler and relay that information to the system to help turn on/off the smart glass to either allow the user to see into it or not. Being able to reduce how much light is coming in as well as knowing how much light there isn't helps the user to know depending on the status of the smart glass on the cooler.

IV.v.iii Motion Sensor

For the motion sensor, the part that we chose to use for our project was the IRA-S210ST01. With this part, this was used on the cooler to detect motion around the cooler, which then triggered different parts on the cooler. These features could either be turning on/off the lights connected to the cooler or could be allowing the glass to be able to see through or not depending on what the setup is like. With this part, it is a small component on the cooler, but can have a big impact depending what exactly it is turning on/off.

IV.vi Switch

In any project, a switch can have many jobs. As for this project, it helps in the feature of the LED lights being able to be turned on/off by the user depending on the situation. It has a simple and easy design that isn't hard to use. This switch that was chosen has everything that we need for our project and helps to accomplish its intended use.

IV.vi.i LED Switch

For the LED switch, the part that we selected for our project was the Battery Snap pre-connected to a Micro Push-button Switch to help with the function of turning on/off the lights for the cooler. With this part, it has a battery component on it but modified it so that it works connected directly with the system, without having to use the extra battery part that is connected to it.

IV.vii Power Technology

With a project that so heavily revolves around power usage, we must make sure our design aids us in being as efficient and sustainable as we can. In a society that has evolved quite far in science and technology from where we were before, our options are quite vast and are inherently designed more efficiently in general. Using the parts that we need for our design is key, rather than using parts we think we need but are not actually necessary.

IV.vii.i Main Electricity

For our main source of power for our project take advantage of the power supplied from outlets able to be found widely around the world. A cooler is meant to be a portable piece of equipment for storing food or drinks and keeping them cool. In order for our smart cooler to keep its main functionality of being portable it must be able to be disconnected from the wall power and still function. That is why the wall power is only a form of charging the system and will be able to be done anywhere there is an outlet such as in a home.

In senior design 2, the main power part of the system was not built in time and needed to be reworked. However, users of the smart cooler can choose to buy an available product that charges their 12V lead-acid battery.

IV.vii.ii Rectifier

The rectifier was built on the PCB board and was used there to convert alternating current into direct current. The specific design for the rectifier has not been decided yet since the size of the PCB has not been decided on. The goal is to use a full-wave rectifier but the design for these rectifiers can take up a lot of area due to having four diodes in the schematic.

In senior design 2, the rectifier was not created since the using 120VAC was not designed in time to incorporate the results. However, users can still charge the 12V battery by using the solar panel.

IV.vii.iii Voltage Regulator

The voltage regulator is an essential part to the smart cooler since there are multiple electronics working at different voltages. The ideal choice would be to have the switching voltage regulator since it allows for a better voltage regulation. The pricing between the different regulators seem to be around the same price but the switching regulator offers the highest efficiency compared to the other two regulators.

Type	Linear Voltage Regulator	Zener Voltage Regulator	Switching Voltage Regulator
Price	$0.75	$0.75	$0.79

Efficiency	40%	40%	90%
Power Loss	7 Watts	7 Watts	0.7 Watts
Can Step Up Voltage	No	No	No
Needs Heat Sink	Yes	Yes	No

Table 18: Comparison of different voltage regulator types

Looking at some of the DC/DC regulators, there are multiple options to consider. Below shows the table of switching regulators that are ideal for the project. Using the TI WEBENCH tool, there are multiple voltage regulators to consider. The regulators being evaluated are the buck converters since the voltage needs to be dropped down to around 3.3V for the microcontroller to be properly powered.

Type	LMR51420X	TPS56339	LM27341
$V_{in(max)}$	36	24	20
$V_{out(min)}$	0.6	0.8	1
$V_{out(max)}$	28	16	18
$I_{out(max)}$	2	3	1.5
Efficiency	90.8%	91%	75%
Area (mm^2)	280	161	118
Cost	1.56	1.4	2.99

Table 19: Comparison of Buck Voltage Regulators

The voltage regulator chosen is the LM27341 because of the stocking issue compared to the others. The other voltage regulators provide better performance compared to the LM27341, but they are out of stock. The issue resides for many of the highly efficient buck voltage regulators. The one upside the LM27341 is the area of the schematic that would take up the least amount of space. The LM2731 would take up 162 mm^2 less space than the LMR5120X design and 43 mm^2 less than the TPS56339. Even though the other voltage regulators are cheaper, the space saved on the PCB can make the overall design cheaper when considering all of the components. The less space taken on the PCB, the cheaper the board is to produce.

The highest efficiency is the TPS56339 and the closest in efficiency would be the LMR51420X, however the downside to this one would be the amount of space it takes up. The LMR5120X takes up 280 mm^2 which is a large amount of area compared to the other voltage regulators. The LMR51420Y takes up less space than the LMR51420X and the TPS56339 but it has a lower efficiency. The reason the V_{in} requirements are so high is because the solar panel has a $V_{out,max}$ of around 22V. The disadvantage of the TPS is the low voltage output compared to the other competitors. This may not be too bad of a trade off though, the only reason a high voltage would be needed in the smart cooler would be for the PDLC glass. The PDLC glass requires a relatively large amount of voltage (~50V DC). However, this can be compensated by using a boost voltage regulator.

In senior design 2, the LMR51420 voltage regulator was also used to create the 5V voltage regulator section of the PCB. This allowed the USB port to function properly and the LCB to have sufficient power.

IV.vii.iv Batteries

For our main source of power storage we decided on a lead-acid battery. Size played a large role in the decision making process for which battery to choose. We wanted to make sure that the functionality of every component of the smart cooler would be able to function for a long enough period of time without needing to be charged. The battery needed to be large enough to power all the components along with being able to provide charge to external devices that would be plugged in such as a smartphone. Newer smartphones are getting to have larger batteries with each iteration and can get up to the size of around 5000 mAh, so to be able to provide power to external devices along with the system itself the size of the battery must be large to provide the needs. Along with size came cost.

A common occurrence between each battery was that for a larger battery, the cost of the battery would increase. With lead-acid the price was already cheaper than all other options available at its exact size. The battery that was close to being selected was a lithium ion battery. It was relatively inexpensive, and had a good enough size. The reason for not making the selection process was ultimately it was far more expensive to purchase more lithium ion batteries to make up the difference in size compared to the lead acid. The lead acid battery is also more plug and play whereas having to purchase multiple lithium ion batteries would require wiring in parallel to get the desired capacitance from them.

Type	Mighty Max 12V Battery	ExpertPower 12V	ELK 1280
Voltage	12	12	12
Weight (lb)	4.93	11.68	5.21
Amp Hour	7.2	18	8
Dimensions (Inches)	5.56 x 2.56 x 3.74	7.13 x 3.03 x 6.57	7.48 x 4.41 x 2.76
Cost	$23.32	$40.00	$41.99

Table 20: Comparison of Lead-Acid Batteries

The table above shows the lead acid battery choices to choose from. Most batteries have the same features beside the difference of weight, amp hour, and their dimension size. The battery chosen is the Mighty Max 12V battery because of the weight, amp hour, and dimension size. The ExpertPower 12V could also be a contender to choose from since it is so economical. It has a large battery capacity with 18 amp hours and the price point for $ per amp hour is better than the Mighty Max 12V. The issue with the ExpertPower 12V is the heavyweight and large dimension size that it has. One of the goals of the smart cooler is to have the cooler be under a specific weight. The ExpertPower 12V would make this goal harder to achieve. The dimension size would also take up a large amount of space and fitting the battery would prove to be difficult. The Mighty Max battery is the best when it comes to the weight and dimension size.

IV.viii Charging Connections

A large part of our project is deciding what peripheries are going to be receiving power from the power supply. It is a factor that is taken into account during the part selection time so the voltage level is sufficient enough to supply electricity for all components. The decision to choose these items were largely based on functionality and feasibility.

IV.viii.i USB Type A

Since our project is designed to be portable and taken to a place like a beach where food and drinks are wanted to be cold, people tend to carry devices such as smartphones with them. One of the most common plug types on a smartphone charging cord is the USB Type A. With this being the most common plug type on smartphones as well as being one of the most common plug types, we chose the USB Type A port to be supported on the smart cooler for charging devices that are plugged in.

Along with being USB Type A we also had to decide on a type standard for the connector. With charging smartphones in mind, we wanted to provide something that would be able to be fast enough for use when on the go, but also not drain the entire system too fast. For this we decided on providing the USB 2.0 High speed standard port on our smart cooler for charging.

IV.ix Lights

To see inside the cooler there must be some light inside. For this application we have chosen Surface Mounted Diode lights to fit our needs of lighting up the inside of the cooler. The SMD lights provide ample light needed to illuminate the inside of the cooler when the smart glass is being used to see inside. Since they are mounted straight to the board they can be easily applied to the inside rim of the cooler without obstructing either the glass or causing problems with the contents inside.

Type	Foxdam Flexible LED Strip Lights	Tenmiro Smart LED Strips	String LED Lights
Length (Feet)	16.4	50	10
Color	White	RGB	White
Bluetooth	No	Yes	No
Cost	$12.88	$16.99	$7.99

Table 21: Comparison of Different Types of LED Lights

The table above compares the different LED options that are accessible and the features that they provide can be compared to each other. On paper, the string LED lights seem to be the best option out of the three because of the cost. However, this is not the cast since the string LED lights take up too much room. The lights would be hanging on the inside of the smart cooler and would not be aesthetically pleasing. This would mean that the smart cooler would be harder to advertise. This leaves 2 options to decide on, the normal white LED lights or the

RGB LED lights. The white LED lights are much cheaper than the RGB LEDs and so this option is chosen. It should be noted that the RGB lights are a good option as well but the cooler is not utilizing LED strips that long. The RGB light strips are a good choice for future adaptations of the smart cooler. The RGB lights would give a nice aesthetic and more options for the user to use besides a white light.

IV.x Screen

The screen chosen is the LCD screen due to the flexibility and cheap cost that it has over the LED screen. The LED screen may be better overall, but the cost of choosing the LED screen is too much considering what is being implemented for the smart cooler. The main purpose of the screen is to show the user what the temperature and humidity is inside of the cooler. This does not require an LED screen for this function. However, there is a possibility in the future to upgrade into an LED screen for this design. Future design could incorporate an LED touch screen that allows the user to interact more with the smart cooler, such as changing light levels, etc. The more features that are incorporated the more likely an LED has more benefits than the general LCD screen in the current design.

Type	Sunfounder LCD	TFT Touch Screen	OLED Display Module
Display Size (Inches)	2.56	2.8	0.91
Color	White on Blue	RGB	Blue
Bluetooth	No	No	Yes
Costs	$7.99	$15.99	$9.99

Table 22: Comparison of Different Screen Types

The table above shows the different options for the screens that are able to be connected. There is the LCD screen, the touch screen, and the OLED to consider. The LCD is the cheapest of the screens and it does the basic necessities. As noted before, the other types of screens are add-ons that would improve the future quality of the product. The touch screen display could be for a future implementation. The OLED display however, could be a reasonable upgrade since it is fundamentally the same thing as the LCD display. The unique thing about the OLED screen selected is the bluetooth capability. This could mean multiple new features.

IV.xi Part Selection Summary

Below list the table showing the components that were decided upon and are included into the initial smart cooler design. These parts were chosen based on the characteristics talked about in previous sections. Though these are the parts chosen for the initial design, this does not mean that the final design has the exact same parts. For example, more components may be included in the future to promote sustainability and longevity for the product.

In senior design 2, there were no changes in our part selection and we built the final product using the selected parts as shown below.

Name	**Specific Part**	**Links**	**Cost**
Cooler	Coleman 48-Quart Cooler	Here	$34.99
Smart Glass	PDLC Smart Film	Here	$35.99
Solar Panel	10W 12V Solar Panel Battery Charger Kit	Here	$32.99
MCU	Adafruit Huzzah32 - ESP32 Breakout Board	Here	$13.50
Sensor	DHT22 Digital Temperature & Humidity Sensor Module STEMMA QT LTR390 UV LIGHT SENSOR AM312 Motion Sensor	Here Here Here	$10.35 $4.95 $8.49

USB Connector	USB-A	USB A	$0.70 each
Battery	12V 7Ah Sealed Lead Acid (SLA) Rechargeable Battery	Battery	$23.32
Light	String LED	Light	$15.00
Switches	Battery Snap pre-connected to a Micro Push-button Switch	Here	$2.75
Screen	LCD 1602	LCD	$7.99

Table 23: Part Selection

V Standards and Design Constraints

This section discusses the different standards and design constraints that are related to our project and other general topics. These help other users understand the guidelines for certain products, how they are used throughout the project, different constraints that can affect the project, and much more. These helped to smoothly execute the project to be successful and completed in a timely manner with little issues.

V.i Standards

Standards are documentations that have been published to the public to give information. This information can be stuff about the product being made, the services that are given, how reliable are certain materials compared to others, and much more. All these different kinds of standards help to shape the project in its final form in areas of how it was designed, the specific requirements needed, and how to characterize specific parts in certain areas. These standards are not limited to just engineers but all other fields which is really incredible.

V.i.i Wi-Fi Standards

802.11 is the first WLAN standard created but it only supports a maximum network bandwidth of 2 Mbps. This generally means that this technology is not used for most applications. However, there are newer standards of 802.11 that branches off into different categories such as 802.11b, 802.11g, etc. The ESP32 breakout board has a wifi compatibility of 802.11 b/g/n. 802.11b is the expansion of the original 802.11 standard that supports speeds up to 11 Mbps. 802.11g emerged around 2002/2003 and supports up to 54 Mbps using a 2.4 GHz frequency for greater range. The 802.11n is the improvement of the 802.11g and now supports up to 600 Mbps of network bandwidth with a slightly better range. Some other Wi-Fi standards can be seen in the table below, but the ones to be concerned about are 802.11 b/g/n. This project may have a feature that uses Wi-Fi so it is important to note all of the standards.

Wi-Fi Standard	Maximum Network Bandwidth	Radio Frequency	Pros	Cons
802.11b (Wi-Fi 1)	11 Mbps	2.4 GHz	Lowest cost and good signal range	Slowest maximum speed
802.11a	54 Mbps	5 GHz	Fast	Higher cost

(Wi-Fi 2)			maximum speed	and shorter signal range
802.11g (Wi-Fi 3)	54 Mbps	2.4 GHz	More consistent maximum speed than 802.11a	Higher cost than 802.11g
802.11n (Wi-Fi 4)	100 Mbps	2.4 GHz and 5 GHz	Fastest maximum speed and best signal range	Highest cost and using both 2.4 GHz and 5 GHz may interfere with other products using the frequency

Table 24: Comparison of Wi-Fi Standards

V.i.ii Bluetooth Standards

The IEEE 802.15.1 is the standard for Bluetooth and it is in the same family for wireless standards, 802. Bluetooth is a wireless communication for a shorter range compared to Wi-Fi but it provides the ability to be used by lower cost devices with lower power consumption. Even though the range is much shorter compared to Wi-Fi, it is more flexible and more applicable in this project.

Bluetooth Class	**Maximum Power**	**Operating Range**
Class 1	100 mW (20 dBm)	100 meters
Class 2	2.5 mW (4dBm)	10 meters
Class 3	1 mW (0dBm)	1 meter

Table 25: Comparison of Bluetooth Classes

V.i.iii Universal Serial Bus (USB)

The universal serial bus standard is divided by different types of usb ports. The split is from USB 1.0 to USB 4.0. The different versions of the USB standards depict the data transfer speed but also show the different USB connector types. For this project, USB A connector is used since it is the most commonly available everywhere. The USB A connector is used as a way to connect a phone charger to the cooler. The USB was designed by multiple designers such as Microsoft, Intel, etc. By having a proper standard that everyone can use, it becomes easier to transfer data without having any issues from device to device. Below list a table of the USB standards:

USB Version	**Maximum Transfer Rate**	**USB Connector Types**
USB 1.0	12 Mbps	Type A, Type B
USB 1.1	12 Mbps	Type A, Type B, Mini-A, Mini-B
USB 2.0	480 Mbps	Type A, Type B, Type C Mini-A, Mini-B, Mini-AB, Micro-A, Micro-B, Micro-AB
USB 3.0	5 Gbps	Type A (SuperSpeed), Type B (SuperSpeed), Type C, Micro-A (SuperSpeed), Micro-B (SuperSpeed), Micro-AB (SuperSpeed)
USB 3.1	10 Gbps	Type A (SuperSpeed), Type B (SuperSpeed), Type C, Micro-A (SuperSpeed), Micro-B (SuperSpeed), Micro-AB (SuperSpeed)
USB 3.2	20 Gbps	Type C
USB 4.0	40 Gbps	Type C

Table 26: Comparison of USB Types

V.i.iv Power Plug and Outlet Standards

Power plugs and sockets are an important standard to go over since the cooler has a rechargeable battery that can connect to standard wall sockets in the United States. There are 2 main types of plugs and sockets used in the United States and they are Type A and Type B. The difference between the 2 is that Type A is not ground while Type B is. Both of these types can use 120 V at 60 Hz frequency so they are compatible with the standard ratings in the United States.

The standards for plugs and socket-outlets are standardized by the International Electrotechnical Commission (IEC). Specifically, the IEC TR 60083 which states that "...limited to systems for a.c. with a rated voltage above 50 V but not exceeding 440 V, intended for household and similar purposes,...".

In senior design 2, the 120VAC electricity is not used due to some time constraints for the proper design.

V.i.v Energy Efficiency Standards

Since the product is being created in the United States, the Code of Federal Regulations. 10 CFR 430.2 is the Energy Conservation Program for Consumer Products. Specifically, the regulation that should be followed is for battery chargers since the product has a rechargeable battery component. To test to see if the product meets requirements, the CFR states to "Measure the maintenance mode power, standby power, off mode power, battery discharge energy, 24-hour energy consumption and measured duration of the charge and maintenance mode test for a battery charger other than uninterruptible power supplies…", "Calculate the unit energy consumption of a battery charger other than uninterruptible power supplies…", and "Calculate the average load adjusted efficiency of an uninterruptible power supply…".

V.i.vi Light Emitting Diodes (LEDs)

The standard for LEDs requires a specific brightness from LEDs to mitigate health risks to the viewers. The standard is created by IEEE PAR1789 and has been asked to view the concern about flickering in LED lighting. At specific frequencies, LEDs will flicker and potentially cause a health concern to the public. To prevent this from happening, IEEE recommends that the LED should be properly modulated in order to stay within the recommended operating area. The figure below from IEEE PAR1789 shows the recommended frequencies in green.

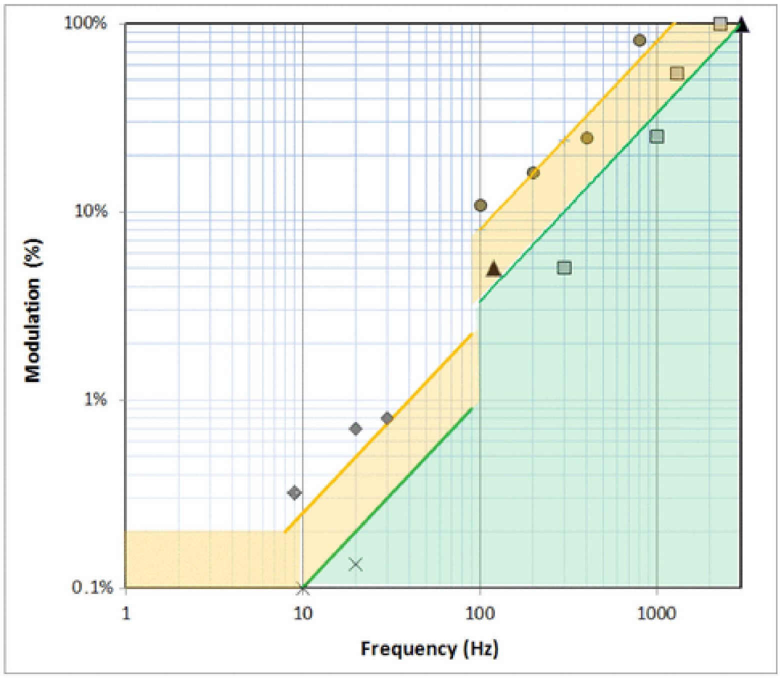

Figure 31: Low-Risk Level and No Observable Effect Level

V.i.vii Photovoltaic System Standards

When it comes to photovoltaic systems, there are few standards set by different groups such as IEC, IEEE, UL, and ASTM.

Standards	**Definition**
IEC 62093: Balance-of-System Components for Photovoltaic Systems - Design Qualifications Natural Environments	The standard covers electronic power conversion equipment (PCE) such as DC-to-AC, DC-to-DC converters, battery charger converters, and battery charge controllers. The standard states that PCEs that are connected to photovoltaic systems do not nominally exceed a maximum circuit voltage of 1500 V DC.
IEC 62109-1: Safety of Power Converters for Use in Photovoltaic Power Systems Part 1 - General Requirements	Defines minimum requirements for the design and manufacture of power conversion equipment for protection against electric shock, energy, fire, mechanical and other hazards.

IEC 62109-2: Safety of Power Converters for Use in Photovoltaic Power Systems Part 2 - Particular Requirements for Inverters	Safety requirements relevant to DC-to-AC inverter products. Where the inverter is intended for use in photovoltaic systems. General testing includes testing in single fault condition, electrical ratings test, and additional tests for grid-interactive inverters
IEC 60269-6 ed1.0: Low-Voltage Fuses	Information on fuse-link protecting photovoltaic strings and photovoltaic arrays in equipment for circuits.
IEC 62124: Photovoltaic Stand Alone Systems - Design Verification	Performance test to check functionality, the autonomy, and ability to recover after periods of low state-of-charge of the battery to make sure the system will not fail prematurely.
IEC 62509: Battery Charge Controllers for Photovoltaic Systems - Performance and Functioning	Establishes the minimum requirements for the functioning and performance of battery charge controllers used with lead acid batteries in terrestrial photovoltaic systems. These tests ensure maximum battery life.
IEEE 1526: IEEE Recommended Practice for Testing the Performance of Stand Alone Photovoltaic Systems	Tests determine the performance of stand-alone PV systems. Only applies to complete systems with defined load.
IEEE 1562: IEEE Recommended Practice for Sizing Stand-Alone Photovoltaic Systems	Sizing the array and battery of a stand-alone PV system. Protecting the battery from being under or over charged.

Table 27: Photovoltaic System Standards

V.i.viii Standard for Sensor Parameters

The IEEE 2700 standard ensures that the sensor being used in this project continues functioning as intended with the standard parameters given. Within the document, there is a common framework for sensor performance specification.

The document covers a number of sensors, some of which include humidity and temperature sensors which are used in this project. This standard helps later to make sure that every part is working before beginning to build the main product.

V.i.ix Glass Standards

Below list a table of glass standards that can be used to insure that the PDLC glass is safe to use.

Standards	Definition
ASTM C-162: Standard Terminology of Glass and Glass Products	Documentation giving standard terminology relating to glass products. The standard also mentions that there are certain companies that have their own definitions and terminologies.
ASTM C-1036: Flat Glass	This document covers the requirements for flat, transparent, clear, and tinted glass. This document ensures that the PDLC glass received is of proper quality before implemented in the main product.
ASTM C-1172: Laminated Architectural Flat Glass	Quality requirements for cut sizes of flat laminated glass of 2 or more lites of glass bonded with an interlayer material. Test method performed: impact test safety, test for missile impact, detention glazing, etc.
ASTM C-1464: Bent Glass	Standards for bent glass and involves impact testing for safety glazing.
ASTM D1003: Haze and Luminous Transmittance of Transparent Plastics	Testing method covers the evaluation of specific light-transmitting and wide-angle-light-scattering properties of planar sections of materials.

Table 28: Glass Safety Standards

V.i.x Programming Languages

The ESP32 can be programmed using Arduino which is essentially a “framework built on top of C++”. Using Arduino to program the microcontroller is convenient since the hardware and the software is open-source. Arduino has also been known to be used in multiple projects and has a number of supports for the system. The microcontroller can be programmed using C or C++ using a standard applicable programming interface. Arduino provides an integrated development environment to code everything on and has an array of libraries to choose from. Both C and C++ are used but the key difference between the two can be found in the table below.

Description	C	C++
Programming Style	Procedural language	Object-oriented language
Approach	Top to bottom programming approach that focuses on the steps rather than the data	Bottom to top approach that focuses on data rather than overall procedure
Program Division	Divided into separate blocks known as functions	Object-oriented programming language, the code is is divided into objects and classes
Data Type	Supports primitive, fixed data types	Same as C but also supports generic data types
Application Development	More suitable for assemblers, text editors, network drivers, and low-level implementations	Suitable for high-end programming including game development, and embedded systems

Table 29: Difference Between C and C++

V.i.xi Speaker Standards

When it comes to speakers, there are few standards set by different groups such as CEA, IEC, and IEEE.

Standards	Definition
CEA-2031 Testing and Measurement Methods for Mobile Loudspeaker Systems	CEA-2031 defines test procedures for rating the performance and physical size of mobile loudspeakers, and requirements for reporting these characteristics.
IEC 60268-1 Sound system equipment - Part 1: General	Applies to sound systems of any kind, and to the parts of which they are composed of which are used as auxiliaries to such systems
IEC 60268-5 Sound system equipment - Part 5: Loudspeakers	This standard applies to sound system loudspeakers, treated entirely as passive elements. Loudspeakers with built-in amplifiers are excluded.
IEC 60268-13 Sound system equipment - Part 13: Listening tests on loudspeakers	Gives recommendations for establishing, conducting and evaluating listening tests on loudspeakers, as well as general guidelines.
IEC WD 63034 Microspeakers	IEC 63034:2020 specifies the characteristics of micro speakers as well as the relevant test methods on microspeakers using steady-state sinusoidal signals, sinusoidal chirp, multi-tone or noise.

Table 30: Speaker Safety Standards

V.i.xii Camera Standards

When it comes to cameras, there are few standards set by ISO/TC 42/WG 18 for the last three decades that are being applied to a wide range of imaging applications.

Standards	**Definition**
ISO 12233:2017 Resolution Measurements	Resolution and spatial frequency responses specify methods for measuring the resolution and the spatial frequency response (SFR) of digital cameras.
ISO 15739:2017 Noise Measurements	Noise measurements specify methods for measuring and reporting the noise versus signal level and the dynamic range of digital cameras. It includes methods for measuring the fixed pattern noise, temporal noise, and the visual noise.
ISO 12232:2019 Sensitivity Measurements	Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index specifies methods for assigning and reporting these metrics.
ISO 17957: 2015 Shading Measurements	Shading measurements define methods for measuring the systematic intensity variation across an image, known as luminance shading, as well as the color variations within the image.
ISO 17850:2015 Geometric Distortion Measurements	Geometric distortion (GD) measurements specify a protocol to measure departures from the ideal image geometry. Geometric distortion is mainly caused by the variation of magnification in the image field of the camera lens, and can cause straight lines to appear to be curved.
ISO 19093:2018	Measuring low light performance

Low Light Measurements	specifies a test chart, measurement conditions, and a table format for reporting the low light capabilities of a camera.
ISO 20954-1:2019 Image Stabilization Measurements	The measurement method of optical image stabilization performance for still images compensating for handheld blur consisting of two rotational components, yaw and pitch.
ISO 17321-1:2012 Color Characterization Test Procedures	Specifies color stimuli, metrology, and test procedures for the color characterization of a digital still camera (DSC) to be used for photography and graphic technology.
ISO/TR 19247:2016 Camera Testing Guidelines	Guidelines for reliable testing of digital still cameras describes best practices for performing tests of digital cameras, including test criteria, conditions, protocols and documentation, as well as the training of personnel for reliable testing.

Table 31: Camera Safety Standards

V.i.xiii Battery Standards

When it comes to batteries, there are few standards set by different groups such as IEC, and IEEE.

Standards	**Definition**
IEC 60896-11 Stationary Lead-Acid Batteries	
IEEE 937-2019	Design considerations and procedures for storage, location, mounting, ventilation, assembly, and maintenance of lead-acid storage batteries for photovoltaic power systems
IEEE 1361-2014	Applicable to all stand-alone

	photovoltaic (PV) systems where PV The only charging source. Stand-alone PV system parameters and operating conditions are discussed in relation to battery characteristics and expected system performance.
IEEE 1013-2019	The energy-capacity requirements (sizing) of both vented and valve-regulated lead-acid batteries used in terrestrial stand-alone photovoltaic (PV) systems
IEEE 485-2020	Methods for defining the dc load and for sizing a lead-acid battery to supply that load for stationary battery applications in float service
IEEE 1375-1998	Guidance in the protection of stationary battery systems

Table 32: Battery Standards

V.ii Design Constraints

When thinking about a project or product, in theory, it is easy to make many assumptions that allow that product to turn out well. However, there needs to be a realistic expectation for the overall product as well. Without these realistic views, the product falls short during its life cycle. A constraint can be defined as "a design decision imposed by the environment or a stakeholder that impacts or limits the design". There are multiple constraints to consider such as economic, environmental, time, social, political, health, safety, manufacturability, and sustainability. These may not be all the constraints possible but they give a good general outline of what should be considered.

V.ii.i Economic, Environmental, and Time Constraints

Economic requirements include the costs associated with the development and sale of a system. The economic constraint for this project is the budget from the members of the project. It is ideal to keep the budget as low as possible since investing too much into the product can lead to issues later in development. An example situation would be having to order more parts since the ones tested during prototyping broke or had a malfunction. It would be much better to order parts that are cheaper than having to spend more than expected due to unexpected errors. There could also be the possibility of expanding the project and the excess budget can go towards improving the product. The lower the overall budget spent, the more feasible the project becomes. The current projected budget is around $705. However, after doing some more research on the specific parts of the project. The budget is now under $300 due to the overestimation before beginning the project research.

Efforts can be made to make things cheaper, such as looking at multiple online retailers and comparing which prices are the cheapest, and ordering from there. There are certain parts that were chosen in the part selection because some project members have those parts already and this would make the budget even lower. The customizable PCB can be ordered at specific manufacturers to make sure that the price becomes as low as possible.

Environmentally, the project should use as few resources as possible. This would mean making sure that every part has a specific design or has multiple design features. By using fewer parts, the smart cooler has less of an impact on the environment. For this, it is important to check on specific standards to make sure the product is following specific codes that need to be regulated. An example would be checking the energy consumption of the smart cooler and comparing it to the code set by the United States Department of Energy. The idea of recyclability should be considered as well. The issue with the smart cooler is that the cooler itself is not recyclable. The plastic that coolers are made from is made using multiple layers and this makes the recycling process too difficult. However, even though the cooler can not be recycled. The cooler can be repurposed for something else or even donated if the user decides not to use the product anymore.

The battery portion can be recycled since it is a lead-acid battery. They can be recycled easily by being crushed into tiny pieces and being repurposed. However, if the battery is not properly disposed of it can cause health issues. Batteries tossed away in the trash can end up in landfills where they start to decay and leak. The chemicals can then soak into the soil and contaminate water. There is also the issue of having a lead-acid battery since some lead compounds are extremely toxic. Long-term exposure to the compounds can lead to brain damage, kidney damage, hearing impairment, and learning problems in children.

It is important to have a product that does not produce a lot of electronic waste when the consumer no longer has a use for the product. The electronics can still be of good use when the product is no longer being used by the consumer. A large pile of electronic waste can lead to unsafe handling of all of the waste, such as burning and acid baths for electronic components. This method of destroying reusable electronics is a hazard for the environment and to the people disposing of the materials in this fashion. It is important to notify the consumer to not have the electronics go to waste and be able to reuse some parts. This helps use less materials to create electronic parts in the world.

There are multiple time constraints for this project and they are broken up into 2 groups, Senior Design 1 and Senior Design 2. For Senior Design 1, there are time constraints for writing the papers and preparing the final documentation. This is also the time when the design process is put into place and the ordering of parts should be established. Designing the product is more of Senior Design 1 and testing the product can be established in both Senior Design 1 and Senior Design 2 depending on how quickly everything is completed during Senior Design 1. The time for Senior Design 1 is limited from the beginning of January 2022 and the final paper is due at the end of April 2022.

For Senior Design 2, roughly the same amount of time is given as Senior Design 1. The main goals for Senior Design 2 are to create the final product and create the final presentation. The product as well as the documentation have been finely tuned to meet the requirements needed. Ideally, everything is ready to be presentable to the advisors. Ideally, the product should begin to be created in Senior Design 1 to work out all of the errors during the first few builds. This allows for more time to troubleshoot and optimize certain aspects for the final product.

V.ii.ii Social and Political Constraints

Social constraints exist and they can determine if a product is successful or not. From a basic viewpoint, this is essentially a cooler with some extra features attached to it to improve overall usability and convenience. If the consumer deems the smart cooler to be too costly compared to the competitors, then the product fails. There are also consumers who are concerned about having so much technology being implemented in basic items that did not have them before. They can be concerned about the safety and risks associated with having electronics constantly surrounding them. This is why codes and standards are followed to ensure that the safety of the consumer is guaranteed and they would not have to worry. Though it is difficult to reach out to every concerned group about a product. Each group has a different culture, educational background, and willingness for innovations. There are some who will accept new technologies right away and those who will refuse the product outright.

Political constraints address the relationship to political, government, or union organizations. The political constraint for this project is from the United States Department of Energy. The product must meet certain energy requirements to be able to be put out in the market. The smart cooler can potentially be transformed into a potential emergency survival kit in the future. The cooler can provide a good form of insulated storage and the smart glass can be turned on or off to see what is inside. The photovoltaic panels on the cooler also provide a way to generate power in a clean way. The world is moving towards a cleaning environment and photovoltaic products can help government motives to push for cleaner products.

V.ii.iii Health and Safety Constraints

The health and safety of a product are constraints that must be considered when looking at the final product as well. It is the job of engineers to be able to create a product that is properly functioning and does no harm to people. As mentioned before, this is why there are codes and standards in place. It is to make sure that the people are safe or at least knowledgeable of the risks when using a product.

The first safety issue that could come up in this product is the location of all the electronics. The electronics need to be in an area where they would not interfere with any items that are stored inside the cooler. This is to make sure that the electronics do not become damaged and to make sure that the electronics do not cause a health hazard for the items inside the cooler. To overcome this issue, there are a few ideas to combat the safety issue. One is to create a barrier within the cooler that completely isolates the electronics from the stored items in the cooler. Two is to create something on the outside of the cooler that allows for the electronics to be away from items inside. The issue of having the electronics outside of the cooler is that there are weather concerns to take into account for. If the electronics are stored on the outside of the cooler, there is a chance rain is an issue. That being said, the PDLC glass had to be exposed outside in some way. In this case, the PDLC glass needs to be safe to have water exposure or would need to be isolated from the outside when not being used. Storing the electronics inside the cooler would need some sort of barrier that blocks the electronics from interacting with stored items. This idea can work well and there does not need to be some complex design on the outside to store the electronics on. An idea would be to have a separator between the stored items and the electronics. However, the separator uses some space within the cooler.

Another safety issue that was briefly mentioned before was about the battery for the product. Since batteries have a chance of exploding when not properly taken care of, it becomes a safety issue for consumers. Consumers should be knowledgeable that the battery can be a health and safety issue if they do not dispose of the product properly afterward. Consumers should also be wary of the glass product that is used in the smart cooler. The glass can become another safety concern if the product is misused or dropped. The shattered glass becomes a safety hazard and it is possible to become seriously injured. It should also be noted that any modifications done to the cooler should not ruin the initial design of the cooler. The cooler should still be properly isolated and maintain temperatures for a long period of time. This is to make sure that any food items that are meant to be cold can still maintain their proper requirements and not become a biohazard.

V.ii.iv Manufacturability and Sustainability Constraints

Manufacturability is an important step in the design process that some engineers do not consider when making the product. It could be properly designed and have all the ideal parts together but the overall design could never be properly produced. Without proper instructions addressing how to produce the design without some sort of major redesign, the product will fail. The parts chosen for the smart cooler are abundant and they do not cost very much. Manufacturing the PCB can be a big time commitment since custom PCBs usually take some time to be made and then shipped. The PCB should be ordered as early as possible and tested to make sure everything works. This is to make sure that redesigns for the PCB can be done in case there are some parts of the PCB that do not work properly. The design of the PCB should also make sure to make putting everything together easy as well.

There are a few parts in the overall product but they still need to be properly wired and connected. This part makes manufacturing more difficult since the costs of designing around manufacturing needs to be lower than the potential profit gain for the product. It is easier said than done when it comes to designing the manufacturing process. The initial design for the product is not complete yet and there are multiple factors to consider when selecting the parts as well. It becomes harder and harder to discuss manufacturability when the product is still in the beginning stages.

Sustainability needs to be considered if the product is meant to stay in the market for a long time. Being sustainable means the system can continue being developed and worked on even when the final product is finished. The current design for the smart cooler allows for multiple expansions in the future. That is the reason for having a powerful microcontroller. The microcontroller allows for the product to evolve and expand later on in the future. As mentioned in the stretch goals, there are extra features that can be added on. These features can be bluetooth speakers, phone/mobile applications, etc. The smart cooler is an adaptable system that allows the product to be reused for future applications. There are parts chosen that can be upgraded as well in order to increase the lifespan of the product. The chosen parts are relatively cheap to purchase but these parts can be changed and more sustainable parts can be chosen. This product lays out a foundation that can be continued upon instead of having a non reusable product after the final design is created.

VI Hardware and Software Design Detail

This section contains in detail the specifics on how each portion of the project is implemented, designed, or built. This section contains both the Hardware designs as well as the Software designs of the project.

VI.i Hardware Block Diagram

The hardware block diagram goes over the general block diagram for the power systems and the main power supply for the smart cooler.

VI.i.i Power Supply System

The power of the smart cooler is using the 12V lead acid battery selected earlier. The general block diagram can be seen in the figure below. The solar panel is charged and is then going into the pulse width modulator. The pulse width modulator is there to manage the power going into the battery bank. Since solar power production varies depending on the time of day.

Managing the power going to the lead-acid battery is very important since the battery requires a specific amperage to charge properly. If this amperage is not maintained, the battery could be permanently damaged and the whole system could be ruined. The modulator ensures that the battery is not overcharged during the day and that the power does not run backwards into the solar panels.

The battery is then connected to the 3.3V buck regulator and the regulator then powers the multiple components. The microcontroller is connected to the sensors, the LCD screen, and the LEDs. The microcontroller controls the LEDs when the UV sensor detects that the area is too dark and turns on the LEDs. Data from the UV sensor and the temperature sensor is then displayed on the LCD screen to show the user how the cooler is doing. The switch is directly connected to the PDLC screen to give the user freedom of use of when to turn on/off the PDLC screen.

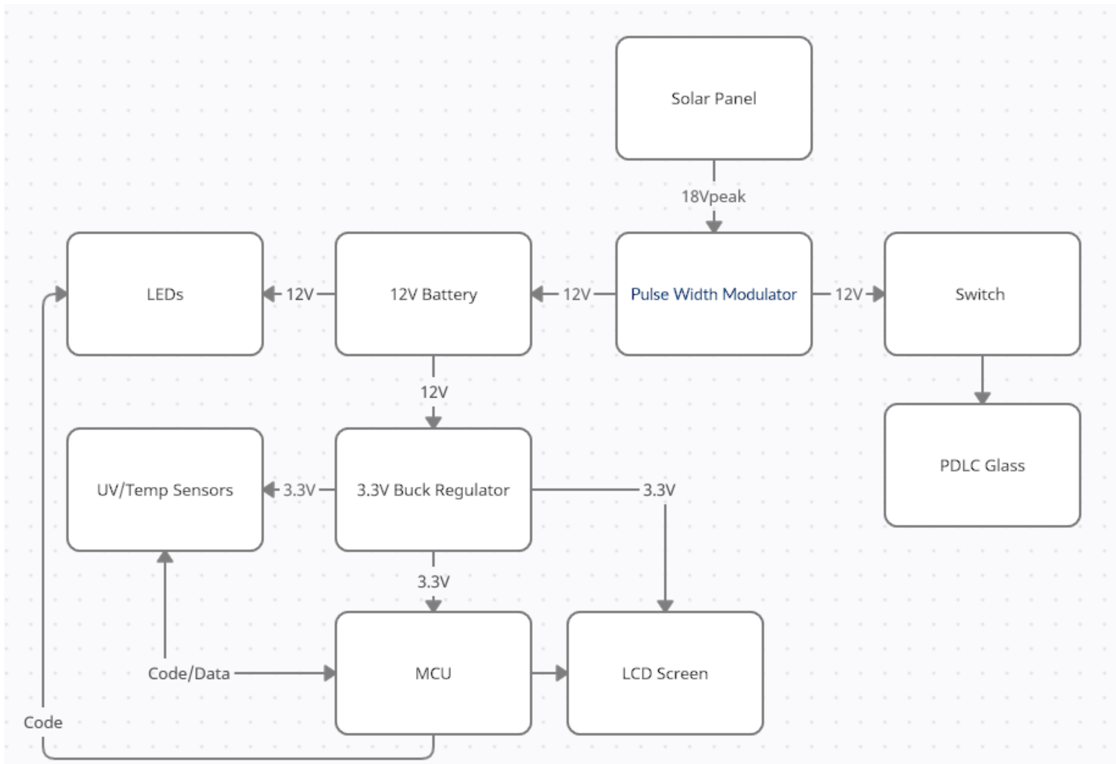

Figure 32: General Block Diagram of Hardware

In senior design 2, the general block diagram was updated to include the 5V regulator and some other peripherals to it as well. Overall, it became more organized and easier to understand how the power flows throughout the system. The figure below shows the updated general block diagram.

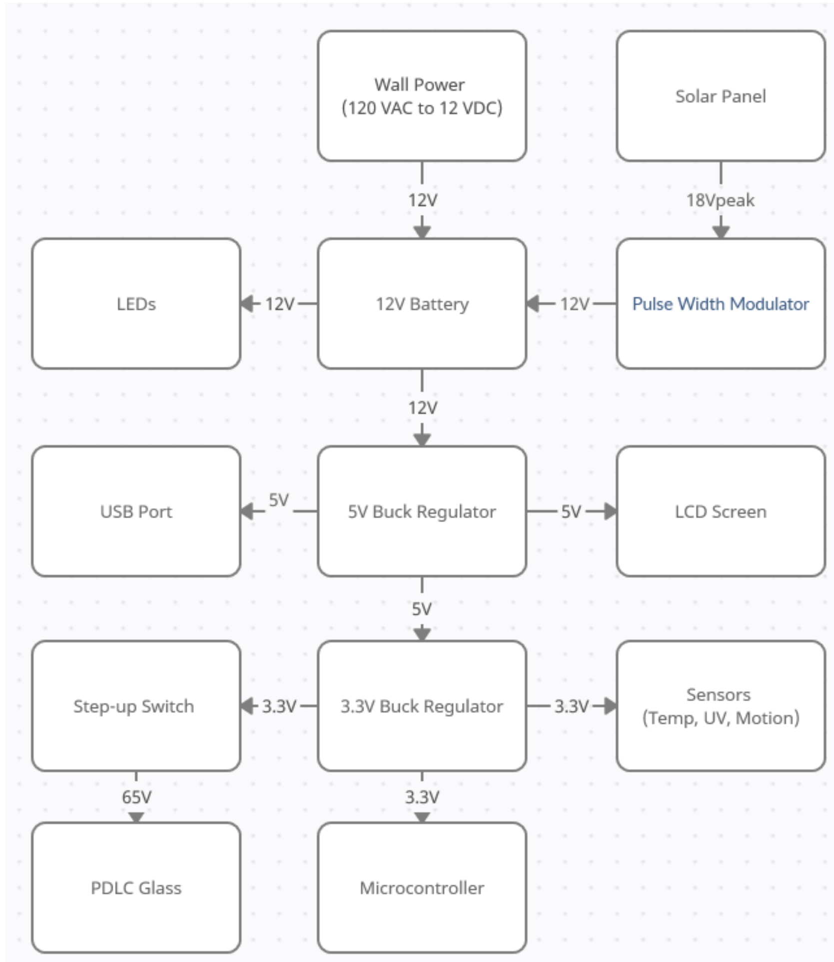

Figure 33: Final General Block Diagram of Hardware

VI.i.ii LCD

For the sensors to be beneficial to the project we are incorporating the LCD to display the information provided to it directly from the sensors.The LCD being used provides sixteen characters by two lines for display. To be able to display all the needed information, the data cycles between all the needed information. The LCD requires 5 V of power for operation, a ground, and seven data lines. The LCD to Arduino pin connections are shown below

LCD Pin	**Description**	**Arduino Board Pin**
VSS	Ground	GND

VDD	5V DC Supply	5 V
V0	Potentiometer	GND
RS	Register Select	12
RW	Read / Write	GND
E	Clock Enabled	11
D0 - D3	Bits	-
D4	Bit 4	5
D5	Bit 5	4
D6	Bit 6	3
D7	Bit 7	2
A	LED Anode +	5 V
K	LED Cathode -	GND

Table 33: LCD to Arduino Board

VI.i.iii Lid Design

The lid design needs to be custom made to have the wiring of the cooler not be intrusive. With the current setup for the cooler, there are no easy access points for the wires to connect to the electronic components on the inside and the outside of the smart cooler. As things stand, there are electronic components inside the cooler, such as the LED lights. Also, there are electronic components on the outside, such as the solar panel. The current cooler has no access points for the inside to the outside without damaging the wires by closing the lid on them. Therefore, a custom lid needs to be created to have the wires easily access the outside and inside components.

The first version of the lid design is shown in the figure below. This version includes the spacing for the PDLC glass in the middle for the cooler. This version proved to be ineffective since there is no room for the solar panel to comfortably fit anywhere. The goal of this version is to visually show how much area the PDLC glass takens up and to improve from this point onwards.

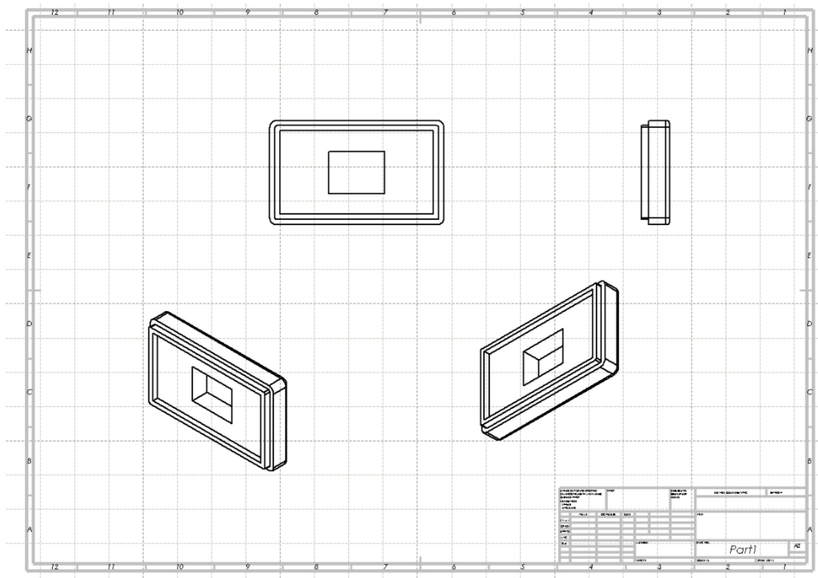

Figure 34: Schematic of Version 1 Lid Design

Version 2 of the lid design moves the PDLC glass to the left side of the cooler and oritents the PDLC glass vertically instead of horizontally. This makes sure that the PDLC does not take up too much space horizontally. Though there is some room to spare on the cooler, the vertical alignment also lines up with the photovoltaic panel. There was also another missing component to fitting the PDLC glass on the lid. The first version of the lid shows the area that the PDLC glass takes up. However, this would just mean that the PDLC would fall right through the hole made instead of being held there as intended. The improvement made to the next version creates a small ledge for the PDLC glass to rest on. This allows the PDLC to have an area to comfortably rest on and not require some other material to keep the glass stable there. This version also includes the addition of the photovoltaic panel, the LCD display, and the wiring channels. The photovoltaic panel is placed on the right side of the cooler and is aligned vertically. The area of the photovoltaic panel takes up a large amount of space, but the panel should be able to fit on the cooler lid. The wiring channeling shown may not be to scale yet since the amount of space required for all of the wires are undetermined yet. However, the wiring channel gives a visual representation of how the wiring has been done. The wiring channel makes organizing the wires much easier and cleaner. This ensures that there are no loose wires around in the design and it allows the design to look visually appealing. The figures below show version 2 that includes these new adjustments.

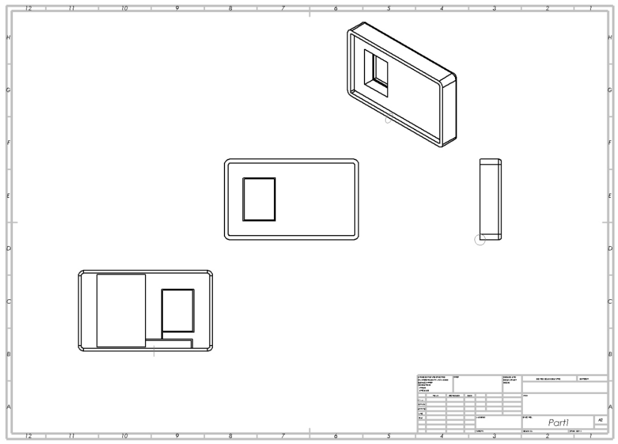

Figure 35: Schematic of Version 2 Lid Design

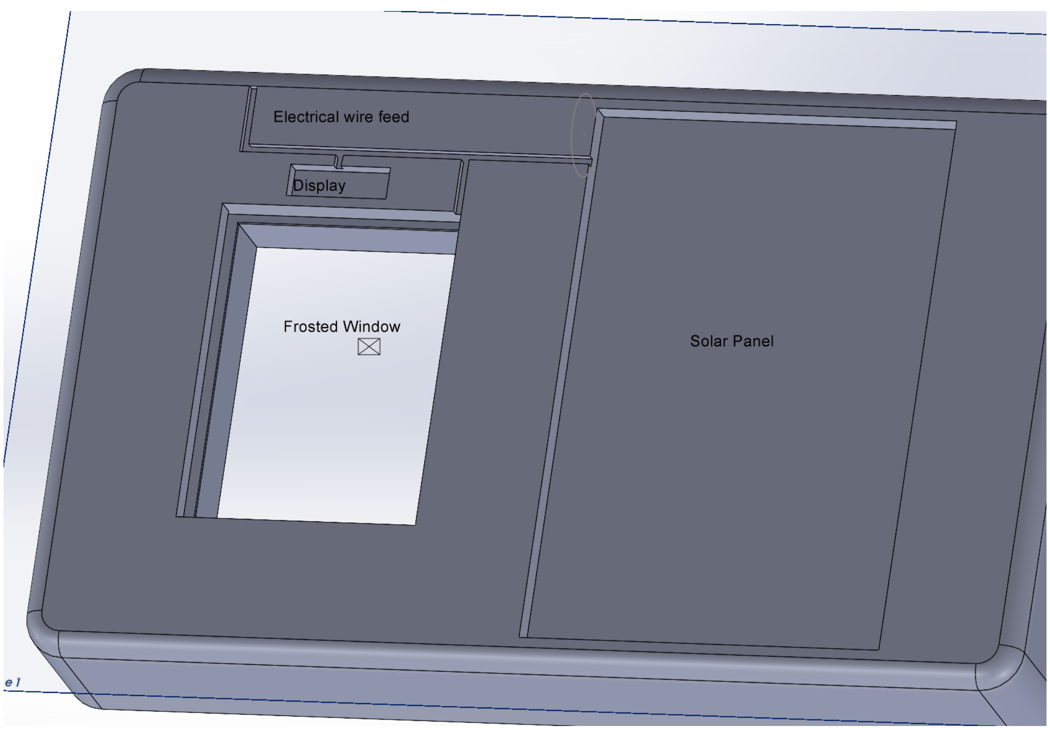

Figure 36: 3D CAD Model of Version 2 Lid Design

Version 3 of the lid design properly models the interior of the lid since the lid is not a complete rectangle. There is a lip on the interior for the lid that allows the lid to be able to tightly fit on top of the cooler. This version also revises the position of the photovoltaic panel. In version 2, the photovoltaic panel is aligned vertically but in version 3 the panel is aligned horizontally. This is to account for any potential errors in measurements. Now that the lid is closer to fitting onto the lid, this allows for the creation of a new 3D printed lid. The figures below show the schematics for the lid and the AUTOCAD models from above and below.

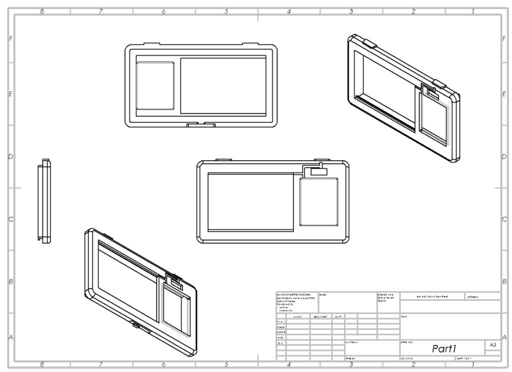

Figure 37: Schematic of Version 3 Lid Design

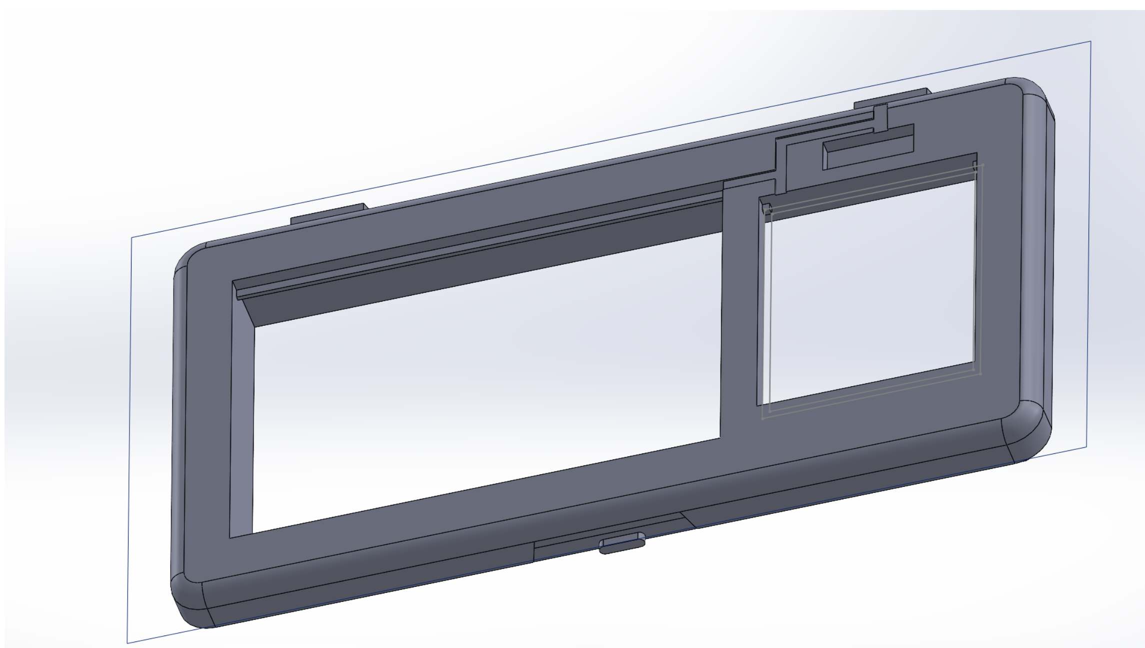

Figure 38: 3D CAD Model of Version 3 Lid Design Above

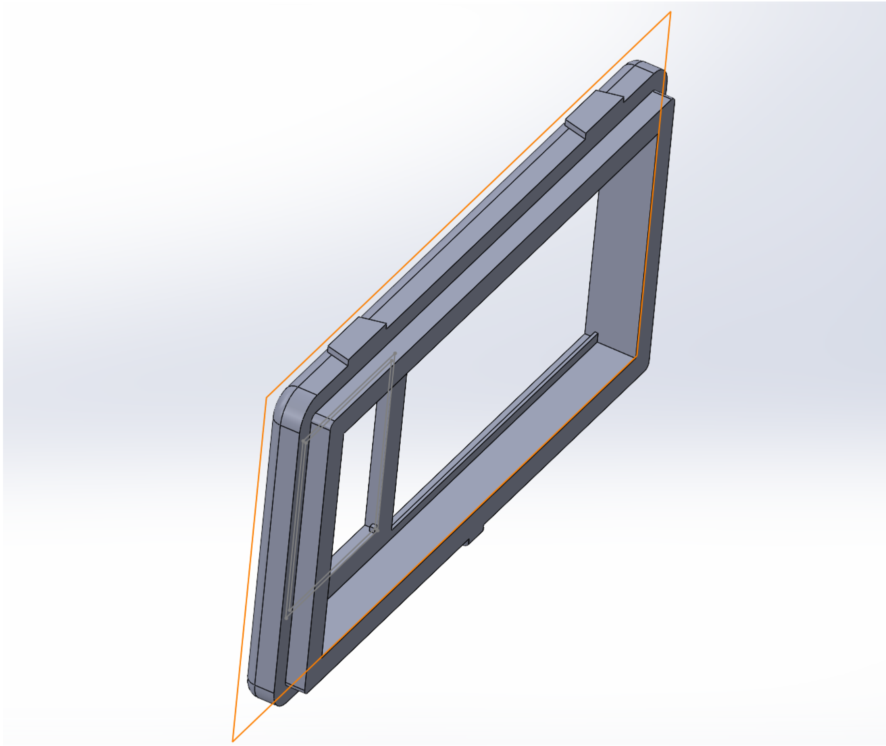

Figure 39: 3D CAD Model of Version 3 Lid Design Below

In senior design 2, the final design for the lid was created. The final design for the cooler lid included some new changes to the original. The new lid design now compensates for the hollowed out area in the cooler lid itself. Originally, the cooler lid was assumed to be solid. After some research, it was discovered that the lid was hollowed out. Starting from the left from the figure included below, the solar panel area now has a sitting place to fit in. In the previous design, the solar panel area was completely cleared out and it was realized that the solar panel needed somewhere to sit neatly. The hollowed out sections in this area are from the ribs of the original cooler. The ribs were there originally and the CAD design is built around it. The top right area of the cooler lid includes the cut out sections for all of the sensors and the button that activates the PDLC film. The bottom right cutout is for the PDLC frame and PDLC film. The modeling of the frame is described in the next section.

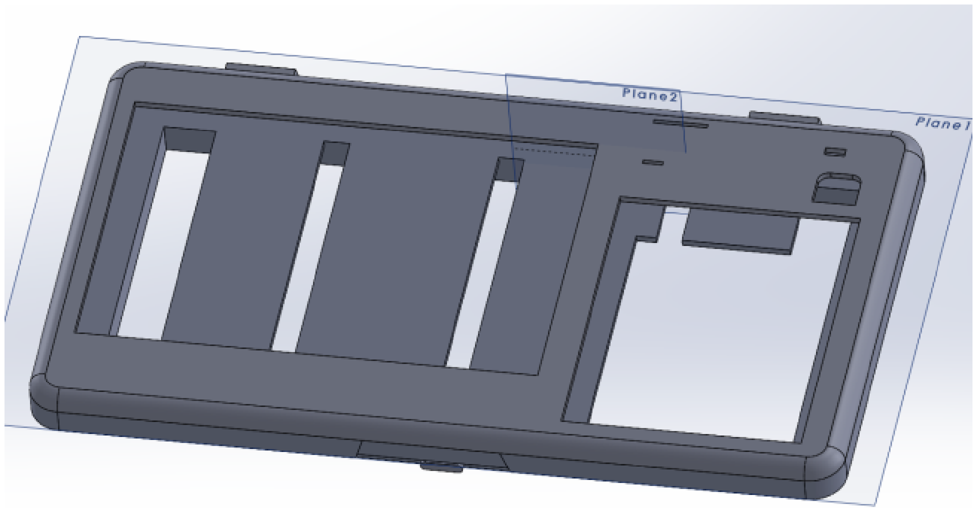

Figure 40: 3D CAD Model of Final Version Lid Design

In senior design 2, the cooler lid model was designed to hold a frame for the PDLC film. The frame's purpose is to hold the PDLC film in a stable state and have it protected by using 2 sheets of acrylic. The model for the frame design is shown in the figure below.

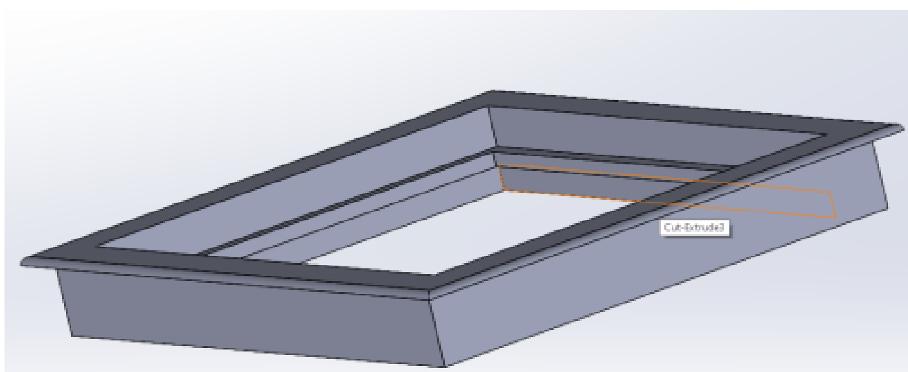

Figure 41: 3D CAD Model of Frame Design

VI.ii Software Inputs

With so many different technological components, they need to be programmed with functionality and be able to communicate with one another via whatever software we decide to use. Since there are a variety of options to choose from, it makes deciding the best one for us more challenging. Intuitively, with newer technologies and ones you have not worked on before, the route may be to go for the software that is the easiest to use. Oftentimes though there is a tradeoff of easy to use with less features or more difficult to navigate and more customizability. Ideally we would like a mix of both so we can use software that is not too difficult to pick up, but still lends itself to a large range of programmability.

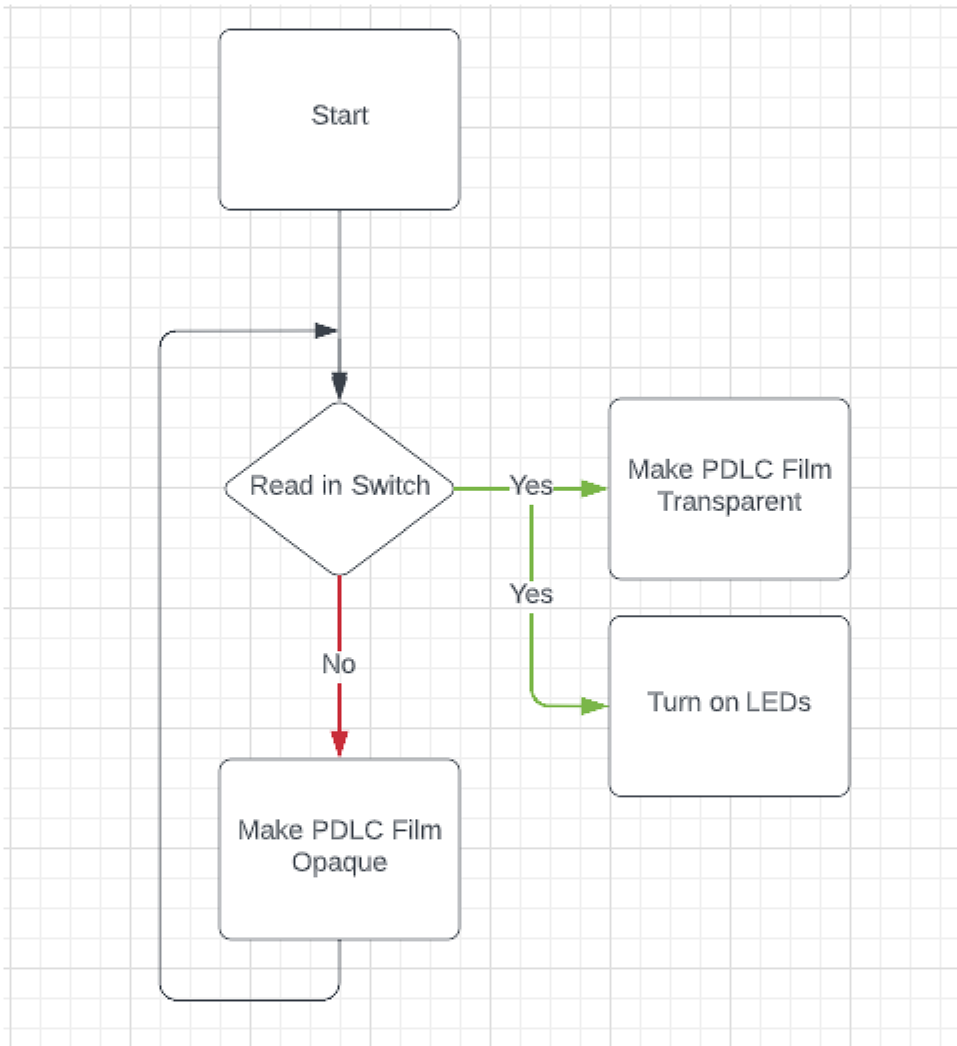

Figure 42: General Block Diagram of Software

VI.ii.i Sensors

We have multiple sensors we used for our project such as a temperature sensor, humidity sensor, and a UV sensor. From the information gathered while planning and testing each one, it seems like using the Arduino IDE is the path forward with our implementation. The main reason is that they are all supported on the software and many others have provided support to use as reference while programming the components' functionality. Many of the producers for these components have libraries with helper functions and code to reference when needed. Arduino IDE serves as the foundation for these items.

VI.ii.ii PDLC Control

A primary function of the software is to maintain the opaqueness of the glass and to be able to change from opaque to transparent when the user specifies it to be done. This means that the current flowing through the PDLC is controlled and alternated to allow current to flow or block it all together. For this to be done in software is pretty simple. All that has to be done is to set one pin to on and allow the current to go through and make the window transparent. To make the film opaque, all that has to be done is set the output to be off and cut the current off.

VI.ii.iii LCD

The LCD must display to the user all the information about the system. To do that we programmed the screen to display the information from the sensors provided by the MCU.VI.ii.iv Code Quality Control

As many other teams working on the same project, oftentimes we need to look at how our code is being developed and keep that same standard of quality across each item in the codebase. If it is not up to par, we must make sure we are reviewing and not cutting corners when it comes to functionality. Many people across the world use Github or Gitlab so it comes as no surprise that we also made use of this public database to store our repositories.

It is quite convenient, especially when working with others due to the nature of the site. It allowed us to stay organized through the different users and respective branches. The code always had a working copy pushed to main as a means of quality control, and no code was merged into the main branch without reviewing their pull request first. If something were to break, the list of commits and previous versions allow for easier cleanup and debugging if we were to need it.

VII Integrations, PCB Design, Component Testing

This section covers the component testing and the PCB designs for the smart cooler. The PCB designs are broken up into some individual smaller pieces and then the overall combined schematic is shown at the end. Methods of testing and the results from the test are shown in the component testing section. The component testing section also explains the thought process for the tests.

VII.i PCB

To design our board we used the software Autodesk Eagle which allows for the development of a schematic which can then be transitioned into the board layout. One issue with Eagle is that in order to create a schematic, all the proper libraries have to be downloaded and imported manually. For this to not be a big issue the build of materials (BOM) for the PCB should be finalized resulting in less time needed to search for the desired libraries. Using Multisim, our designed schematic is tested to ensure the results are what we want and validate our design. After careful validation of the schematic we move to board layout which consists of routing all of the connections for the board. Autodesk Eagle software makes transitioning from schematic to board layout very easy and simple.

VII.ii Cooler Design

For this part we provide details in our plan for construction of the cooler and how the components are laid out for the smart cooler. We attempted to make the design simple while still incorporating all the aspects talked about above. This allows for any potential problems that may occur while constructing and wiring the final product.

The plan for the cooler design is as follows. We took the cooler mentioned above and cut holes for the solar panel as well as the PDLC film window into the lid. This allows for the film and solar panel to be flush to the rest of the lid and allow for the top of the lid to be used as usual. The tools required to cut through the plastic lid will be provided by a group member, but on the off chance that they are not suitable for the task we would rent the tools from Home Depot. Since the PDLC is a film, we purchased a piece of acrylic to attach the film to that acts as a transparent material. We chose acrylic because of its durability, cost, and readily available. The purchase of this was on Amazon because of its ease of access and a wide catalog for selection that met the requirements.

In senior design 2, our group made use of the machine shop available at UCF and was able to discuss more professional methods of cutting our cooler lid.

To find out the exact measurement of the hole that should be cut into the cooler, the measurements of the PDLC glass is measured. The surface area of the PDLC glass is 15.24cm x 20.32cm = 309.68 cm^2. The surface area of the photovoltaic panel is 34.29cm x 23.368cm = 801.29 cm^2. The total surface area of the cooler lid is around 62.23cm x 38cm = 2364.74 cm^2. So the total surface area used by the PDLC glass and the photovoltaic panel would be around 1110.97 cm^2. This would leave the total surface area of the cooler lid to be 1253.78 cm^2. This means that another photovoltaic panel could be added right next to the other photovoltaic panel. However, this design is not doing this but it could be a consideration for future updates for the smart cooler.

With so many different functionalities and features we could have applied to our cooler, we had a variety of stretch goals. One for example is the inclusion of a video camera. This seemed like a great addition if we had time to implement it due to the extra layer of protection it would provide and recreationally it would act as a makeshift tripod for videos and photos.

Another one of our stretch goals was a mobile application that would control some of the other features on the smart cooler. This would involve some bluetooth connectivity or a way to transmit the data over wifi, which we have not yet looked too in-depth at yet. One of the complications with this idea is that implementing it could be considered a project in of itself due to the complexity and design it would need to work with our project. It is still potentially a component, but its precedence is a bit lower right now with the knowledge we currently have.

In senior design 2, this stretch goal was not reached due to time constraints. There are possible iterations of this project in the future that can make use of the mobile application should another group decide to build on this project.

Continuing with the wireless capability ideas, a bluetooth speaker seems much more manageable and less complex of an implementation than the previous mobile application. Its compatibility with a project like ours is quite high, as we have seen example products already produced with similar standards. It supplements the goal of being able to be mobile with this smart cooler, but having a provided comfort that you may also have lacked with a normal cooler already on the market.

The last addition for the cooler is the addition of a barrier that blocks the electronics from the items inside of the cooler. The barrier is in the form of an isolated foam. The size of the barrier is based on the size of the PCB. The size of the PCB determined how much space should be allocated for the barrier.

VII.iii Component Testing

This section will be covering the component testing for all of the electronic parts. Testing ensures that the parts that were ordered work properly before putting them all together in the PCB board. The most important component to test is the microcontroller and the PDLC glass. Without the microcontroller most of the software could not be started and the design would not work. The main design of the smart cooler uses the PDLC glass and the test is essential to make sure that the glass works properly.

VII.iii.i PDLC

As per our design constraints, the PDLC film should be activated within five seconds of executing the technology through a button or switch. The PDLC film we have chosen to integrate into the project is already wired to a button to allow the activation of the liquid crystal alignment. This provides ease of testing to ensure we meet the requirements of our design constraints. From the moment the button is pressed, a timer is run to measure the amount of time it takes for the PDLC film to go from opaque (inactive state) to clear (active state).

When the PDLC film was shipped to us, it came in two parts. One part was the PDLC film itself with an open-ended wire connection, and the other part was the controller with a button and the other half of the wiring connection. Without double-a batteries, we could not use the controller and button to test the film. We instead made use of the DC power supply located in the Senior Design Lab, and touched both ends of two male wires to the open-wired connection points on the PDLC film. As we did this, the film went from opaque to see through and we knew the film was working as it should. Using different voltage levels on the DC power supply would allow one to showcase different levels of clarity in the film.

Another constraint to test for the smart film is the power consumption. The film itself is assumed to use less than 0.005 kilowatt hour of electricity while on, so making sure this holds true is key to a working product. This can be done with a multimeter or power meter once we disconnect and strip the wiring for the PDLC film cables from the button.

Figure 43: PDLC Inactive State

Figure 44: PDLC Active State

VII.iii.ii Solar Panel

Much like with the PDLC film, the monocrystalline solar panel is tested with a multimeter in order to see that the voltage output matches what was described by the product. The solar panel is affected by outdoor weather conditions so adjusting for cloudy days is necessary in order to obtain an accurate measurement. Ideally, a bright and sunny day would work best in order to make full use of the solar panel's capabilities. The voltage output should match or be very close to that voltage written on the back of the solar panel on a sunny day. On a cloudy day, the measurements may read slightly lower which is fine.

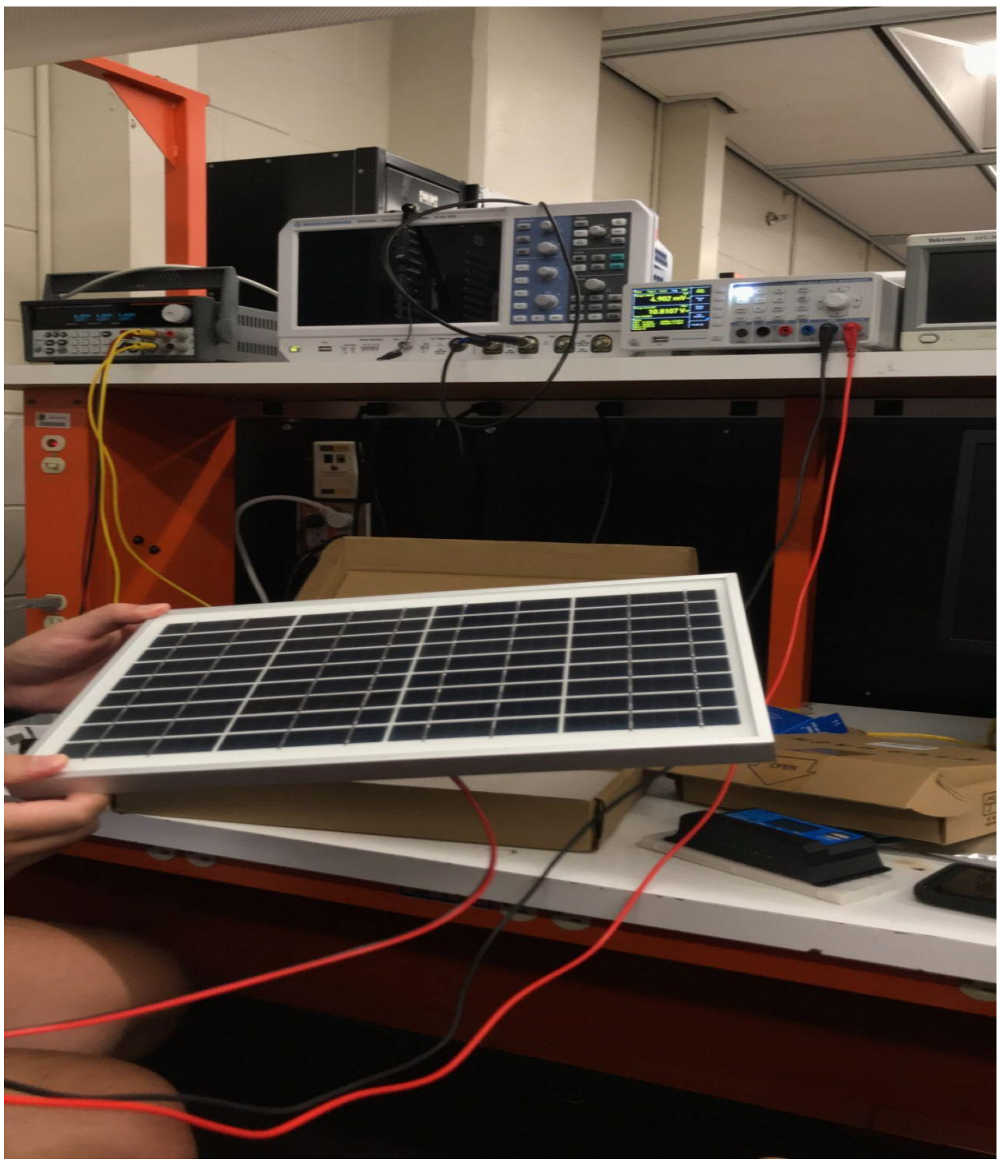

Figure 45: Our monocrystalline solar panel hooked up to the multimeter for testing

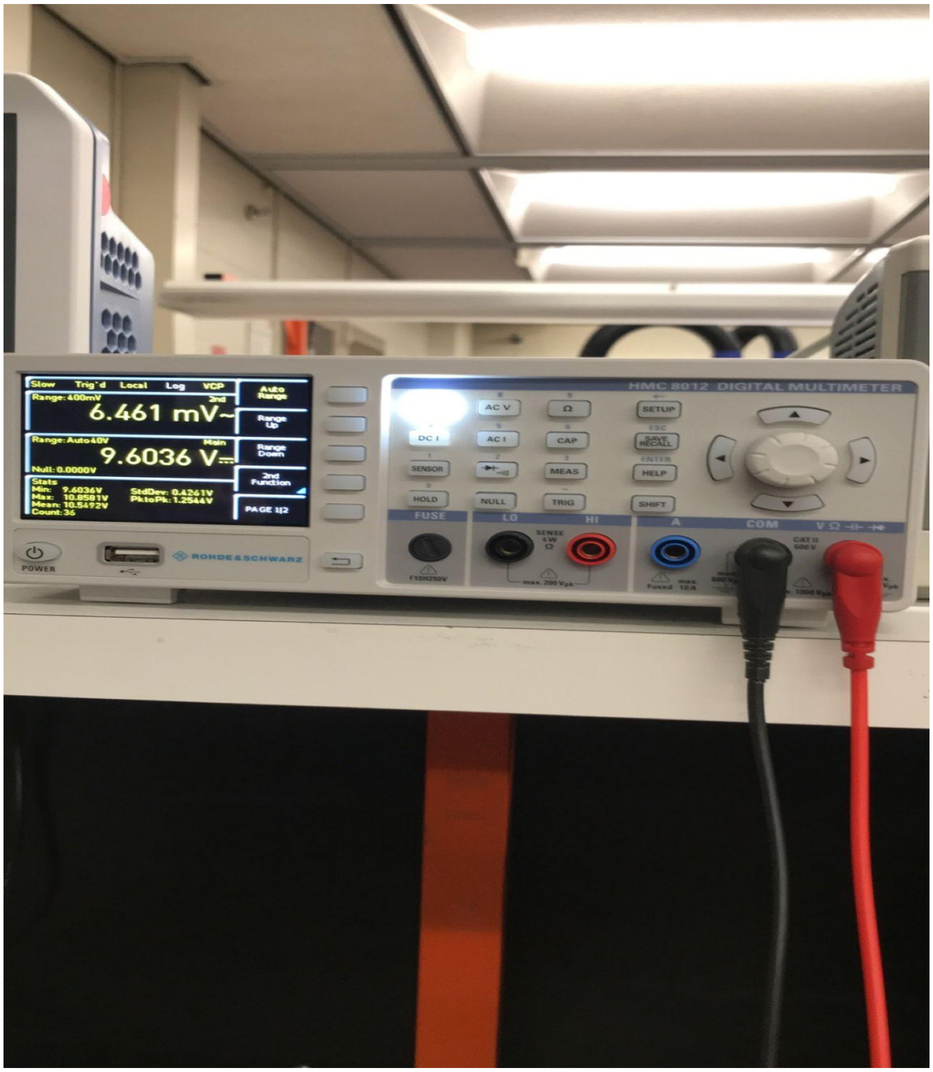

Figure 46: Voltage output of the solar panel while indoors through the multimeter

Using the Senior Design Lab was really beneficial to our testing methods, as it provided so much utility through technologies such as a digital multimeter. As stationary as it was, this meant we would not be able to go test the solar panel outdoors yet, so we had to adjust and understand outside factors were coming into play with our outputs.

In the figure above, we can see that we are getting a 9.6036 minimum voltage which is a bit low compared to the 12 volts we are expecting in ideal conditions. Taking into account that we are indoors with no outdoor sunlight, it appears accurate and thus the component works as intended.

VII.iii.iii Sensor

With sensors, you cannot test them as they are since they do not work standalone and are just components to the project. First we began with testing the Adafruit LTR390 UV Sensor and we had to connect it to our breadboard in order to begin the wiring and use Arduino IDE to upload the sketches or functionality. Then we connected the Arduino 5 voltage pin from our MCU to the voltage input of the sensor, the ground of the sensor to the ground of the MCU, the SCL pin of the sensor to the the SCL pin of the MCU, and the SDA pin of the sensor to the SDA pin of the MCU. As you can see from the green light on our figure below, the sensor was working and just needed additional programming to become fully functional.

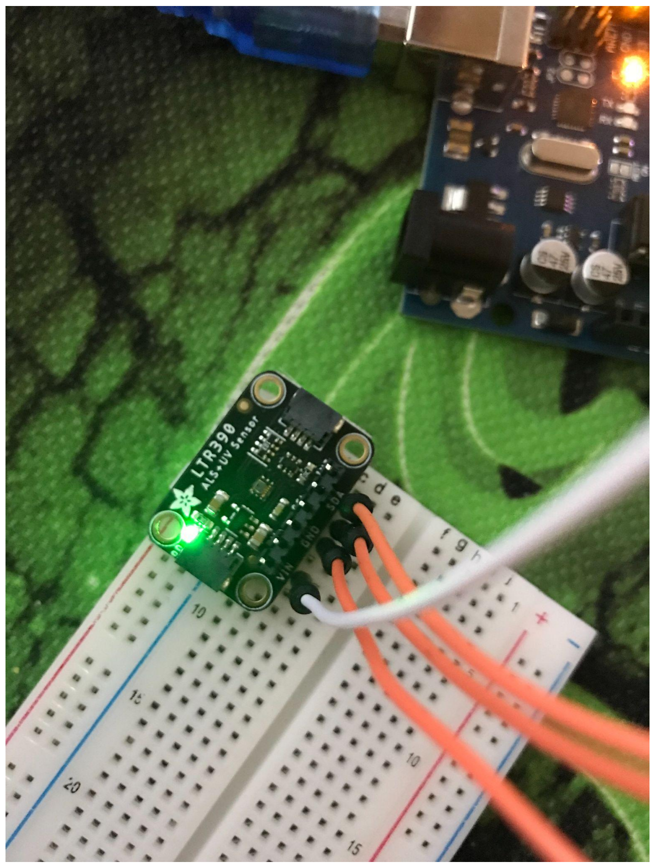

Figure 47: The LTR390 UV Sensor connected to the MCU

Our next sensor is the DHT 11 Temperature and Humidity Sensor that was also being tested on the breadboard with Arduino IDE. In order to set it up, we had to connect the voltage input of the sensor to the 5 voltage pin of the Arduino, ground to ground on both systems, and the data output of the sensor to pin 2 in our case but you can define any other digital pin you would like. Between the voltage input and the data pin we would put a 10 Kilo-ohm resistor to pull up on the data line.

On the software side, we use the Arduino IDE to upload a working sketch onto the MCU. First we grab the correct library, which in this case we need the DHT sensor library provided by Adafruit. Once it finished installing, we also needed the Adafruit Unified Sensor library due to version 1.3.0 of the DHT library. After that, the library provided working examples for specifically our DHT sensor so we uploaded that onto our board after changing the defining DHTTYPE from 22 to 11. As we can see from the below figure, it was correctly outputting the necessary values and also after breathing on the sensor, we can see how the temperature and humidity jump accordingly.

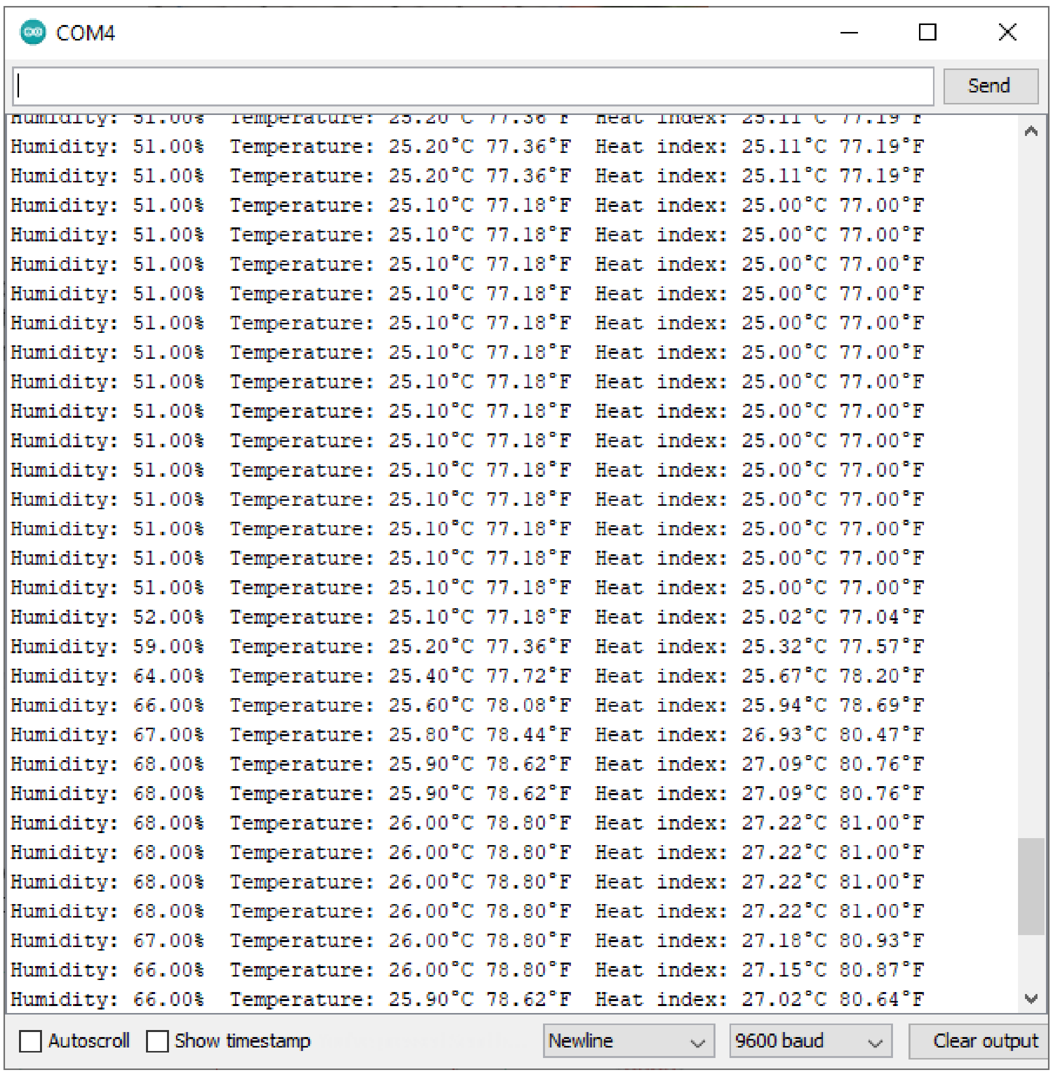

Figure 48: Output of the temperature and humidity sensor showing the results after breathing on it

VII.iii.iv Voltage Regulator

The schematic below shows the voltage regulator using the LM27341 regulator. Even though this regulator is not the most efficient, it is one of the better ones that are already in stock. All of the components have not been ordered yet but the bill of materials listed on the next page may change due to stocks changing on a daily basis. The bill of materials gives a general idea of how much the components may cost but this is not the final cost.

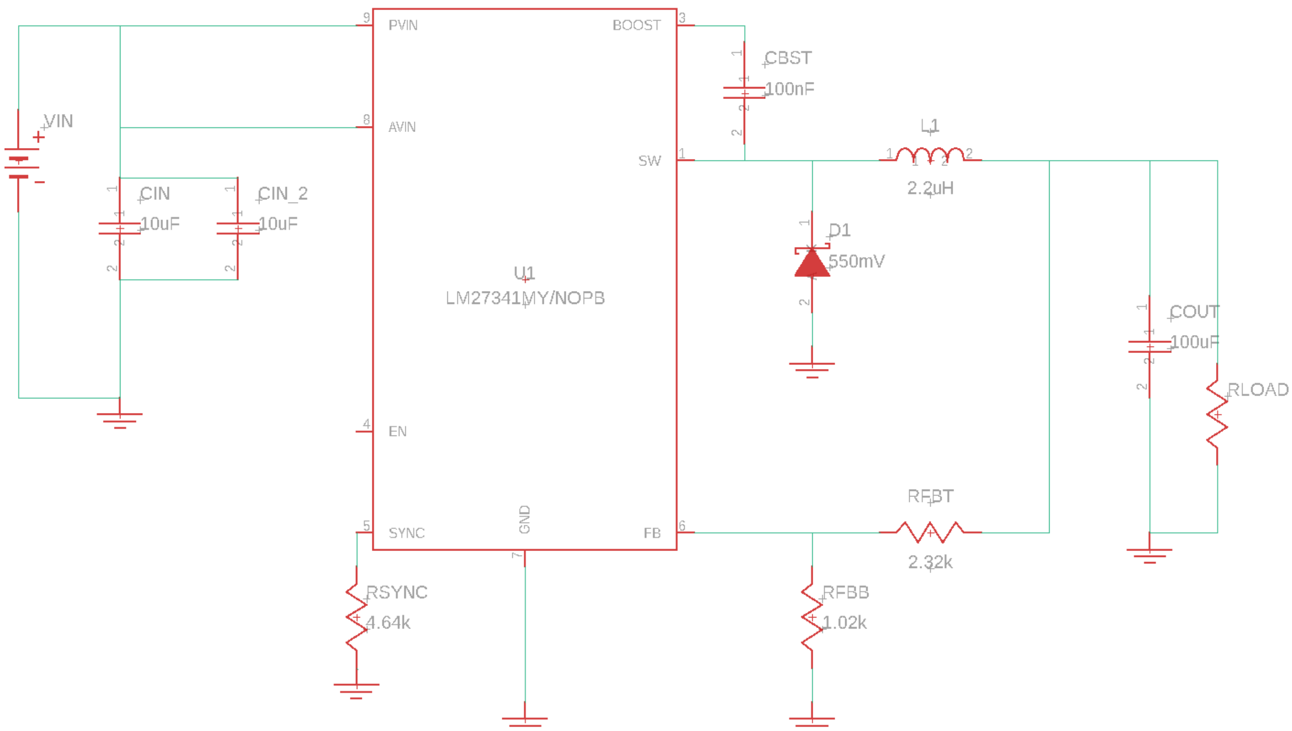

Figure 49: Schematic of a Buck Voltage Regulator Design

Part	Manufacturer	Part Number	Price ($)	Footprint (mm²)	Description
Cbst	Taiyo Yuden	EMK107B7104KA-T	0.01	4.68	Cap: 100 nF Total Derated Cap: 100 nF VDC: 16 V ESR: 1 mΩ Package: 0603
Cin	TDK	C3225X7R1H106M250AC	0.28	14.7	Cap: 10 μF Total Derated Cap: 13 μF VDC: 50 V ESR: 1 mΩ Package: 1210
Cout	MuRata	GRM31CR60J107ME39L	0.34	10.92	Cap: 100 μF Total Derated Cap: 38 μF VDC: 6.3 V ESR: 4.88 mΩ Package: 1206
D1	Fairchild Semiconductor	SS24FL	0.05	11.7	Type: Schottky VRRM: 40 V Io: 2 A
L1	Pulse Engineering	PA4332.222NLT	0.22	27.04	L: 2.2 μH DCR: 48 mΩ IDC: 4.3 A
Rfbb	Vishay-Dale	CRCW06031K02FKEA	0.01	4.68	Resistance: 1.02 kΩ Tolerance: 1.0% Power: 100 mW
Rfbt	Vishay-Dale	CRCW04022K32FKED	0.01	3	Resistance: 2.32 kΩ Tolerance: 1.0% Power: 63 mW
U1	Texas Instruments	LM27341MY/NOPB	1.065	23.6	
Rsync	Vishay-Dale	CRCW04024K64FKED	0.01	3	Resistance: 4.64 kΩ Tolerance: 1.0% Power: 63 mW

Table 34: Bill of Material for 3.3V Voltage Regulator

VII.iii.v Microcontroller

For testing, the microcontroller needs to be programmed to perform the intended features for the smart cooler. As of right now, we can test the microcontroller to make sure it is functional and works through the Arduino IDE. The microcontroller we plan on using is the Adafruit Huzzah ESP32 Breakout Board, which has a supported library in the program. The board is connected to the computer via FTDI USB cable as you can see in the image below (6 wires). The other two connections are negligible and were for another component.

Once in the Arduino IDE, we had to install the Adafruit ESP32 Library in order to pull in all of the supported files. The board selected for the dropdown menu was the Adafruit ESP32 Feather which provided similar support. Had to make sure the correct port was chosen, and finally we could begin our program. The ESP 32 Library and even Arduino itself has built-in examples like the blink test to help test your board, which we used as shown in the picture below.

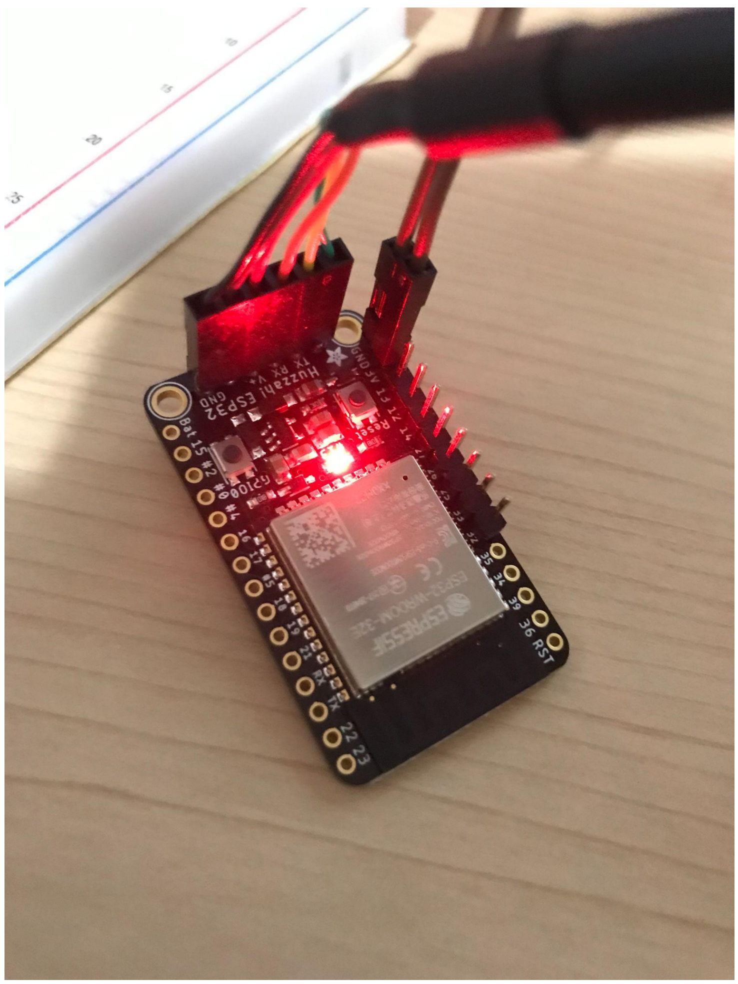

Figure 50: Microcontroller flashing red LED

VII.iii.vi USB-A

As discussed in the parts selection, the USB-A port was selected because of its versatility and frequency to be found on device cables around the world. The port has 4 pins, one for Power, one for Ground, and two for Data, one being positive and one being negative.

For the purpose of the smart cooler, the USB-A connections only need to supply power to the devices that are connected to it. To test that there can be power delivered to the devices connected we set up a simple circuit of an LED connected to the power of the USB-A. The USB was supplied with 5 V of power from a Digital Power Supply. When supplied with power, the LED was able to be lit up shown in the figures below:

Figure 51: Powering a USB-A port connected to LED

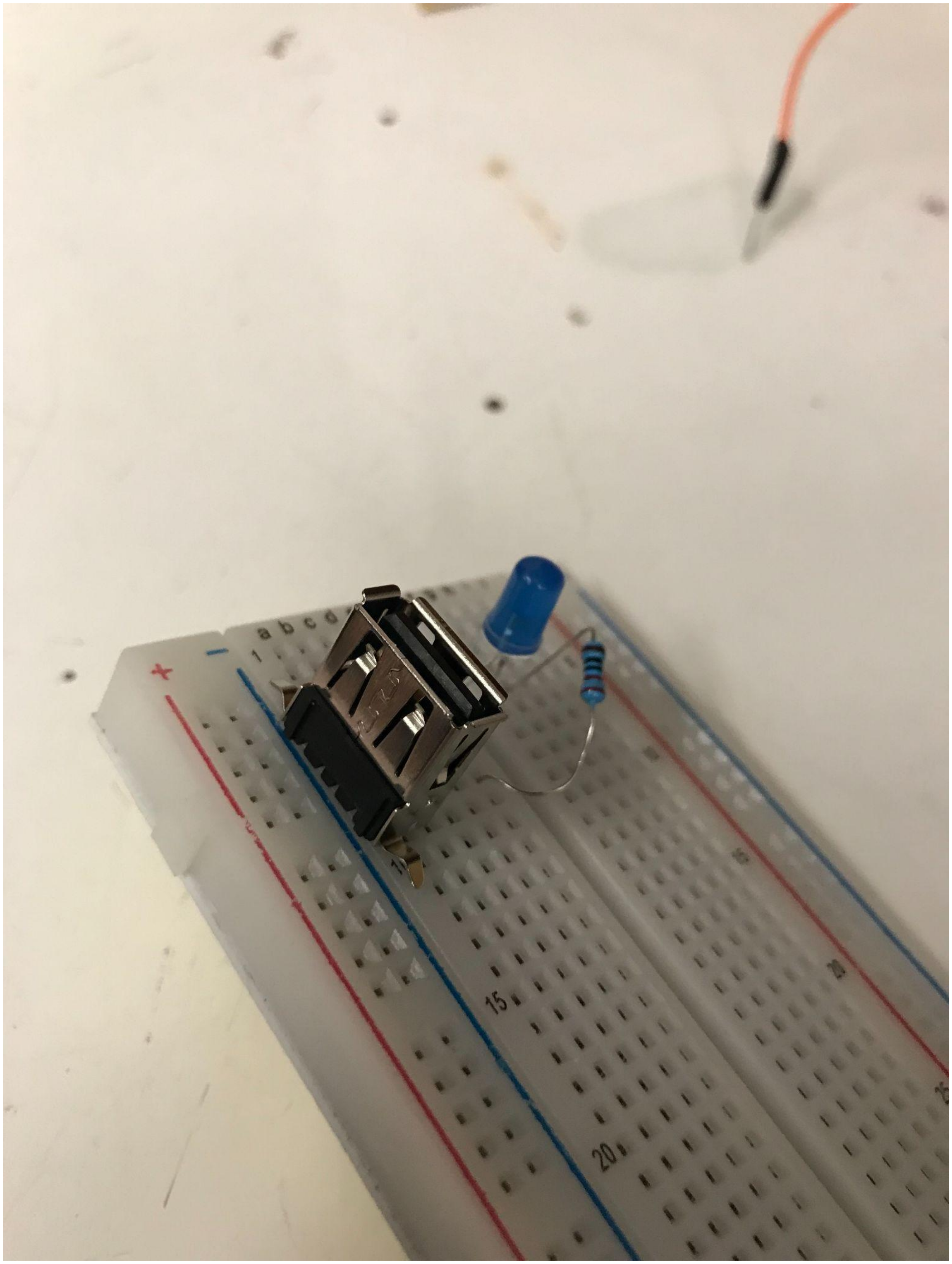

Figure 52: USB-A connected to LED

VII.iv Overall Schematic and PCB

This section covers the overall schematic design and the PCB design of what the board would look like before moving onto printing the board itself.

VII.iv.i Overall Schematic

The overall schematic design lists the connections for the microcontroller. The temperature and UV sensors are connected to the microcontroller so that they can be properly programmed. The same idea follows with the LCD screen that allows the screen to be properly printed. The top section of the schematic includes the usb-a port that would be available for charging devices such as phones. The right side of the schematic is the buck converter from the 12V battery source to 3.3V. Pin headers are used in the schematic since they are connected to the actual component and then the components are in an area different from the PCB. For example, the LCD screen needs to be available to be seen for the user. This is why the LCD screen is placed on top of the cooler for visibility and then wired down to the PCB. This would be considered the first version for the schematic before other suggestions are made. The schematic also needs to be tested in smaller sections beforehand to make sure each part works before asking a PCB manufacturer to print a PCB board. This is to make sure that the budget is not wasted on anything that might not work properly. Proper testing is key to making sure that everything goes smoothly when producing the final product.

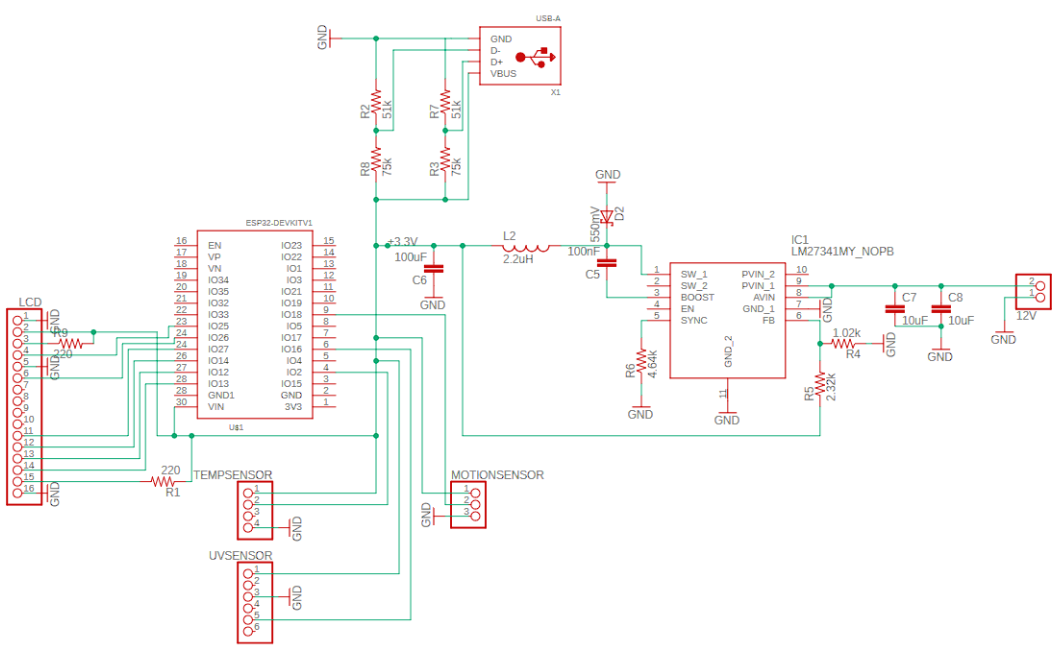

Figure 53: Overall Schematic

In senior design 2, the overall schematic was changed to include a 5V regulator as well. So now the power system has the 12V step down to 5V and then further down to 3.3V using the 3.3V regulator. The 5V regulator was included to power the USB charging port since 3.3V is not sufficient enough. The schematic for the ESP32 also changed since the original schematic used the ESP32 development kit in the schematic. The final build for the product should not include any development boards so it was removed and replaced with the actual ESP32 microcontroller. The figure for the final schematic can be seen below.

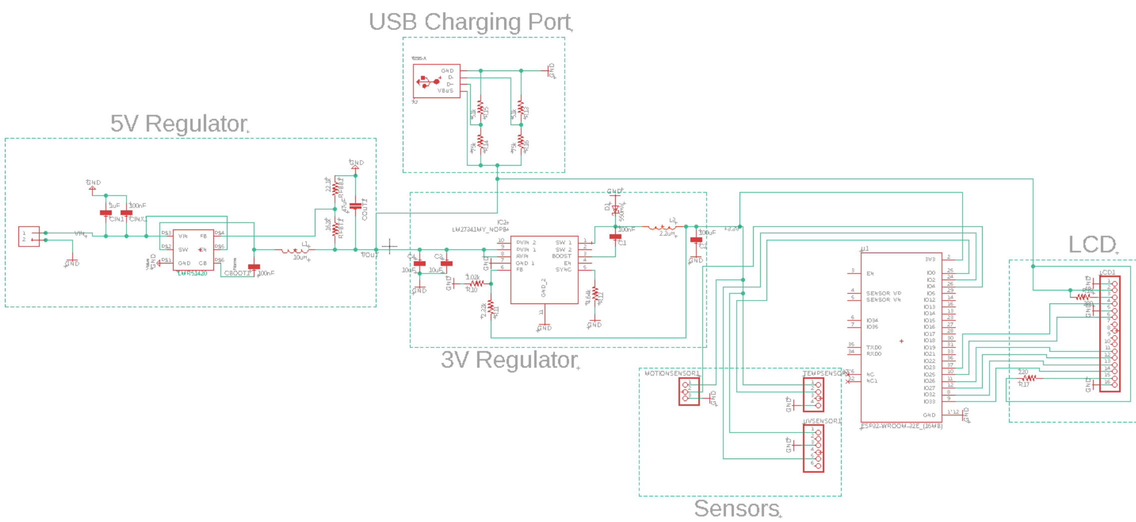

Figure 54: Final Overall Schematic

VII.iv.ii Overall PCB

The image below shows the overall PCB design using EAGLE. Routing and vias were all done by EAGLE's automatic software and the software makes the most optimal choices when it comes to selecting the right routing.

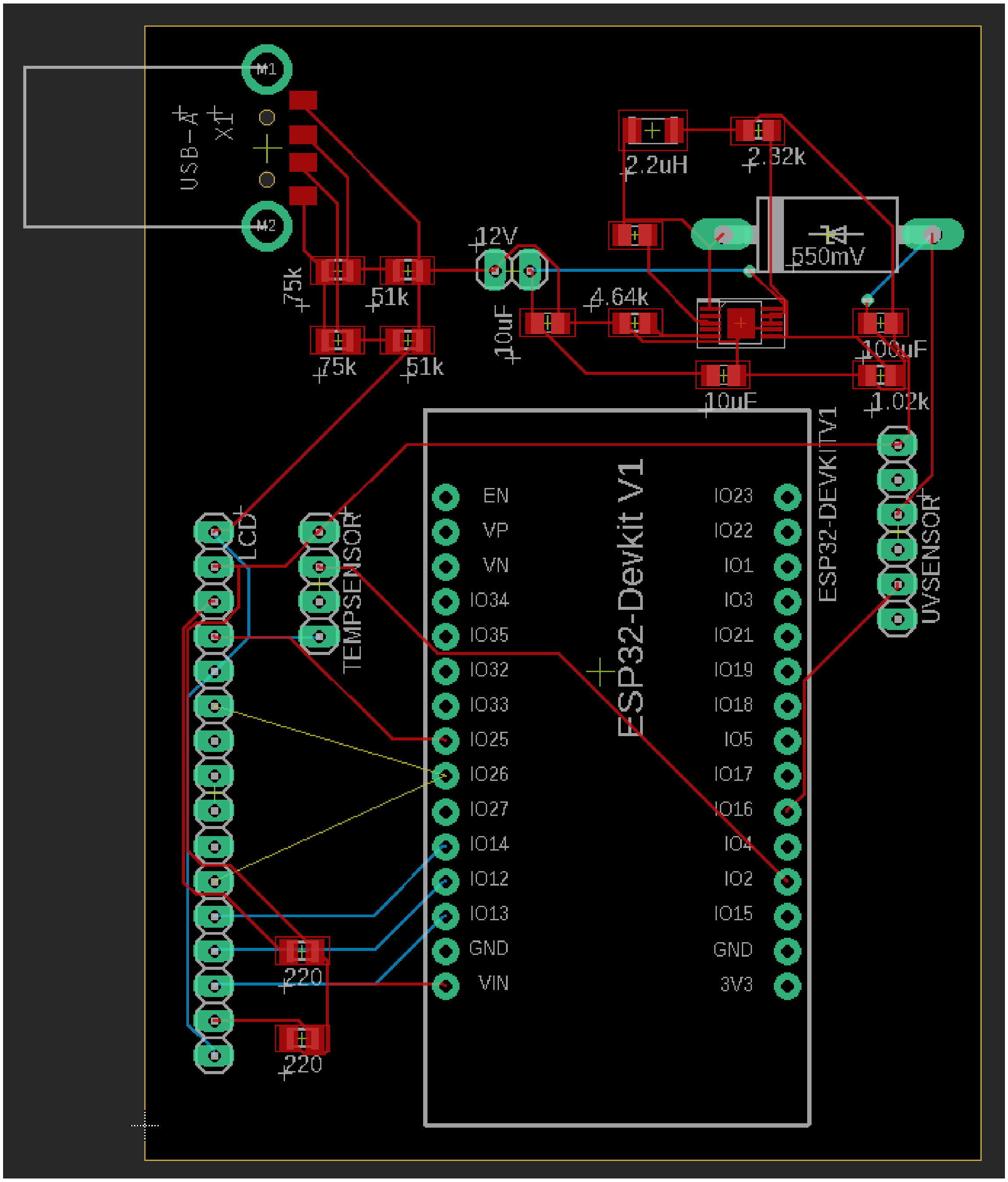

Figure 55: Overall PCB

In senior design 2, the final PCB was modified from the original PCB. The final PCB was based off of the final schematic. The placement of the components on the board became more efficient as well to save space and production cost. The figure for the final PCB can be seen below.

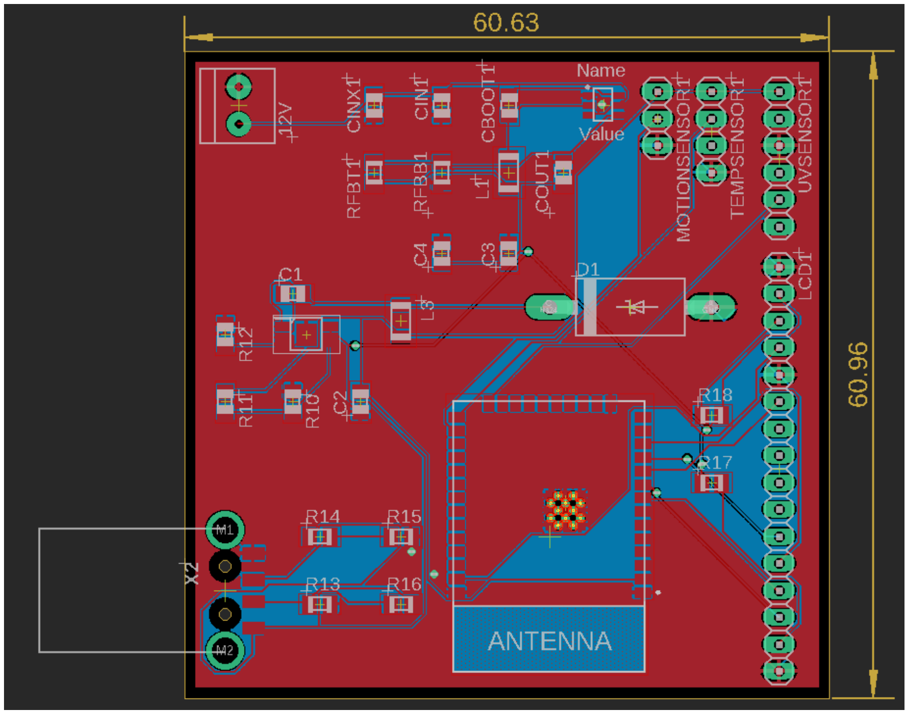

Figure 56: Final Overall PCB

VIII PCB Manufacturing and Suppliers

In this section, this goes over the different manufacturing and suppliers for the PCB selection. The in-depth information about each one helps determine which to choose when producing our PCB for our project.

VIII.i Manufacturing Companies

There are an endless amount of companies out there that can manufacture and produce PCBs, but companies vary distinctly per circuit board. Looking at their build qualities and component selection is essential to proper supplier selection.

VIII.i.i ALLPCB

ALLPCB is committed to building up a super Electronic Collaborative Manufacturing Service system with business covering PCB, SMT, Electronic Components, CNC, Injection molding, and other fields.

Features	Capabilities
Layer Count	1-14 Layers
Material	CEM-1 / FR-4 / Aluminum
TG Value	Shengyi TG 170 Kingboard TG 170
Max PCB Size	506 * 580mm
Min PCB Size	80 * 80mm
Board Size Tolerance	±0.15mm
CTI	Class 3
Board Thickness	0.4 - 3.2mm
Board Thickness Tolerance	Thickness > 1mm: ±10% Thickness < 1mm: ±0.1mm
Outer Layer Copper Thickness	1 oz / 2 oz (35 um / 75 um)
Inner Layer Copper Thickness	0.5 oz / 2 oz (18 um / 70um)

Table 35: ALLPCB Capabilities

VIII.i.ii PCBGOGO

PCBGOGO is a company operating since 2017 and has delivered to over 100 thousand customers around the world. They advertise "Even if the price is not the lowest, quality and service will be the best". Some of the company's capabilities are listed below.

Features	Capabilities
Layer Count	1, 2, 4, 6, 8, 10 Layers
Material	FR-4
TG Grade	TG130~140, TG150~160, TG170~180
Max PCB Size	1 Layer & 2 Layers: 1200mm * 300mm or 600mm * 500mm Multi-layers: 600 * 500mm

Min PCB Size	5mm * 5mm
Board Size Tolerance	±0.2mm (CNC Routing) ±0.5mm (V-Scoring)
Surface Finish	HASL with lead, HASL lead free, Immersion Gold (ENIG), OSP, Hard gold, ENEPIG, Immersion Silver (Ag), None
Board Thickness	1 Layer / 2 Layers: 0.2~2.4mm 4 Layers: 0.4~2.4mm 6 Layers: 0.8~2.4mm 8 Layers: 1.0~2.4mm 10 Layers: 1.2~2.4mm
Board Thickness Tolerance	Thickness > 1mm: ±10% Thickness < 1mm: ±0.1mm
Outer Layer Copper Thickness	1 oz / 2 oz / 3 oz (35 um / 70 um / 105um)
Inner Layer Copper Thickness	1 oz / 1.5 oz (35 um / 50 um)

Table 36: PCBGOGO Capabilities

VIII.i.iii JCLPCB

JLCPCB was founded in 2006 and has been running since then. The company has over 20,000 orders daily and around 1 million customers. The company has a good standard and a strong foundation to be trusted for building a PCB in a timely manner. Below list some of the capabilities of the company.

Features	**Capabilities**
Layer Count	1,2,4,6 Layers
Controlled Impedance	4/6 Layer, Default Layer Stack-up
Material	FR-4
Dielectric Constant	4.5 (Double-Sided PCB)

Max Dimension	400x500mm
Dimension Tolerance	±0.2mm
Board Thickness	0.4 / 0.6 / 0.8 / 1.0 / 1.2 / 1.6 / 2.0 mm
Thickness Tolerance (Thickness > 1mm)	±10%
Thickness Tolerance (Thickness < 1mm)	±0.1mm
Finished Outer Layer Copper	1 oz / 2 oz (35um / 70um)
Finished Inner Layer Copper	0.5 oz (17.5um)

Table 37: JCLPCB Capabilities

VIII.i.iv Comparison of PCB Manufacturers

Below shows the table that compares the PCB manufacturers with each other with all their features and capabilities.

	JCLPCB	**PCBGOGO**	**ALLPCB**
Features	**Capabilities**		
Layer Count	1,2,4,6 Layers	1, 2, 4, 6, 8, 10 Layers	1-14 Layers
Material	FR-4	FR-4	CEM-1 / FR-4 / Aluminum
Max Dimension	400*500mm	1 Layer & 2 Layers: 1200mm * 300mm or 600mm * 500mm Multi-layers: 600 * 500mm	506 * 580mm
Min Dimension	N/A	5mm * 5mm	80 * 80mm
Dimension Tolerance	±0.2mm	±0.2mm (CNC Routing)	±0.15mm

		±0.5mm (V-Scoring)	
Board Thickness	0.4 / 0.6 / 0.8 / 1.0 / 1.2 / 1.6 / 2.0 mm	1 Layer / 2 Layers: 0.2~2.4mm 4 Layers: 0.4~2.4mm 6 Layers: 0.8~2.4mm 8 Layers: 1.0~2.4mm 10 Layers: 1.2~2.4mm	0.4 - 3.2mm
Thickness Tolerance (Thickness > 1mm)	±10%	±10%	±10%
Thickness Tolerance (Thickness < 1mm)	±0.1mm	Thickness > 1mm: ±10% Thickness < 1mm: ±0.1mm	Thickness > 1mm: ±10% Thickness < 1mm: ±0.1mm
Finished Outer Layer Copper	1 oz / 2 oz (35um / 70um)	1 oz / 2 oz / 3 oz (35 um / 70 um / 105um)	1 oz / 2 oz (35 um / 75 um)
Finished Inner Layer Copper	0.5 oz (17.5um)	1 oz / 1.5 oz (35 um / 50 um)	0.5 oz / 2 oz (18 um / 70um)
Drill Hole Size	0.20mm - 6.3mm	0.20mm - 6.3mm	0.20mm - 6.5mm
Drill Hole Size Tolerance	+0.13/-0.08mm	±0.08mm	±0.075

Table 38: Comparison of PCB Capabilities

In senior design 2, our team went with OSH Park to have our PCBs built and delivered to us. This decision was made since the company is based in the United States of America and did not need to be shipped internationally.

IX Administrative Content

This section shows the budgeting done for the project of the smart cooler, milestones that were created and followed, and the division of labor. In this section, it gives more in-depth information on each part, giving detailed information to understand the process that the project took to be completed throughout the whole semester.

IX.i Budget and Finance

This section discusses the overall cost for completing the project. Section VII.i.i shows the initial estimation for the smart cooler created when the project was originally chosen. After our immense research, section VII.i.ii shows the budget of the final project used to complete the smart cooler.

IX.i.i Initial Project Budget (Estimate)

For budgeting, the whole project's estimated cost is gonna be around $700-$800 for both Senior Design 1 and Senior Design 2. Overall, the team is flexible in the budget, but we look to be cost effective in the resources that we acquire for the project. With that, this is not the final total, as things can either go up/down in prices, looking for replacements, damaged items, etc. As for certain items, some might be free and already hanging around, so that helped how much of the budget we are using. We believe that parts like the PDLC film can be found at a lower cost than planned, as well as the solar panel and PCB. Since this is our first time designing and producing our own PCB and we are not sure of the exact components that are needed we decided to have a higher cost for fabrication along with the parts for fabrication. At the end of the chart is an additional feature total. This was added to give us an idea of what it would end up costing after incorporating the components from our stretch goal. We plan to split the cost of all the parts equally four ways with each member agreeing on what part we purchase. We split the parts up for each group member to purchase a portion of the components then repay the required split amount to each group member.

Item	**Cost**
Smart glass	$150
Solar panel	$150
Switches	$30
Cooler	$30
Battery	$40
PCB	$150
Sensor	$15
Controller	$60
Miscellaneous	$80
Total	$705
Camera	*$100*
Speakers	*$150*
Bluetooth	*$50*
Additional Features Total	*$1005*

Table 39: Estimated Budget/Funding Information

IX.i.ii Final Project Budget and Finance/Bill of Materials

After immense research over the different products used for the project, this section provides the actual cost and budget for the completion of the smart cooler.

Item	Supplier	Price/Unit	# Units	Total Cost
Coleman 48 Quart Cooler	Amazon	$34.99	1	$34.99
LED Strip Lights	Amazon	$12.66	1	$12.66
10 Watt 12 Volt Monocrystalline Solar Panel	Amazon	$32.99	1	$32.99
PDLC Switchable Smart Film	Amazon	$35.99	1	$35.99
Adafruit HUZZAH32 – ESP32 Breakout Board	Adafruit	$13.50	1	$13.50
12-Volt 7 Ah Sealed Lead Acid (SLA) Rechargeable Battery	Home Depot	$23.32	1	$23.32
DHT22 Digital Temperature and Humidity Sensor	Amazon	$10.35	4	$41.40
LTR390 UV Sensor	Adafruit	$4.95	4	$19.80
USB-A UJ2-AV-1-TH	Digikey	$0.70	4	$2.80
PIR Human Sensor Module	Amazon	$9.04	1	$9.04
Step-Up Voltage Regulator	Amazon	$10.64	1	$10.64
Battery Snap pre-connected to a Micro Push-button Switch	Amazon	$2.75	4	$11.00
LCD1602 Module	Amazon	$7.99	1	$7.99
3.3 and 5 Volt Regulators	Amazon	$2.06	10	$20.64
Push-button Switch	Digikey	$3.06	3	$12.25
PCB	OSH Park	$39.55	3	$39.55
PCB Electronics	OSH Park	$39.55	3	$39.55
Pink Insulation Foam	Amazon	$3.19	4	$12.77
Step-down Voltage Regulator	Amazon	$1.95	6	$11.70
Total				**$392.58**

Table 40: Final Project Budget and Finance/Bill of Materials

IX.ii Project Milestones

This section goes over the project milestones split into two categories: Senior Design 1 and Senior Design 2 that allowed for the completion of the smart cooler project. Senior Design 1 category focuses on the beginning steps of the project which includes selection of the project, research, hardware and software for the project, and design and prototyping. Senior Design 2 category focuses on the actual designing and testing of the smart cooler.

IX.ii.i Senior Design 1

The Senior Design 1 milestones focused on the selection of the project for the team members. This process involved communicating the team goals and working towards completing said goals. The initial project identification involved brainstorming project ideas and deciding as a group which project was doable, met all group members expectations, and was something not done exactly the same before. Senior Design 1 milestones shows the timeline of project selection, research done for the project, hardware and software design details. If all the Senior Design 1 milestones are successfully met, then the group expects to build a prototype completed by the end of Senior Design 1.

Milestone	**Description**	**Duration**	**Dates**
Group Formed		1 week	Jan. 13
Project Selection	Divide & Conquer V.1 & Divide & Conquer V.2	5 weeks	Feb. 18
Document Submission: Divide & Conquer V.1			Feb. 4
Document Submission: Divide & Conquer V.2			Feb. 18
Technology Investigation	Hardware Software	2 weeks	Feb. 19 - Mar. 5

60 Page Draft	Divide and Conquer V.2 Revision	3 weeks	Mar. 6 - Ma. 25
Document Submission: 60 Page Draft			Mar. 25
100 Page Report	60 Page Draft Revision	2 weeks	Mar. 25 - Apr. 8
Document Submission: 100 Page Report			Apr. 8
Final Document	100 Page Draft Revision	2 weeks	Apr. 8 - Apr 26
Document Submission: Final Document			Apr. 26

Table 41: Senior Design 1 Milestones

IX.ii.ii Senior Design 2

Senior Design 2 milestones focus on the designing and implementation of the design details from the Senior Design 1 final documentation. If the milestones are followed, by the end of Senior Design 2, the project should be fully tested, and a final product will be available to present.

Milestone	**Description**	**Duration**	**Dates**
Build Prototype		1 week	May 27 - June 3
Test & Redesign		2 weeks	June 3 - June 17
Finalize Prototype		1 month	June 24 - July 24
Peer Presentation		3 weeks	June 3 - June 24

Final Report	1 week	July 25 - August 2
Final Presentation	1 day	July 27

Table 42: Senior Design 2 Milestones

IX.iii Important Deadlines

This section covers the deadlines that occurred through Senior Design 1&2 that helped keep all team members on track with the main goal of providing a completed prototype for the smart cooler.

- February 4th - Initial Group and Project Identification (Divide and Conquer)
- February 18th - Updated Divide and Conquer Document
- March 25th - 60 Page Draft Senior Design 1 Documentation
- April 8th - 100 Page Senior Design 1 Report
- April 26th - 120 Page Senior Design 1 Final Report
- June 23th - CDR File Submission
- July 5th - Middle Term Demo
- July 15th - 8 Page Conference Paper
- July 24th - Final Presentation
- August 2th - Final Documentation

IX.iv Division of Labor

With the Smart Cooler project, the workload was divided equally into the respective areas of study. Though certain areas were tasked to specific team members, each member collaborated together in those areas of the project, whether it was in the research, design, testing, and building aspects. Team meetings were held on a weekly basis throughout the semester with any extra days needed. Through these meetings, team members would discuss the progress of the whole project, any new updates or ideas for the project, as well as any issues that arose throughout the process of the project. The group stayed with the discussed milestones listed above to stay on track for the completion of the project throughout the spring and summer semesters. Members are usually tasked with specific topics to do. However, this does not mean the members need to stay within their topic. If another member needed help on a topic, then other members would come to help.

IX.v Final Comments

For the documentation for this project, the team members of the Smart Cooler product finished the final report and organized everything in a timely manner. The whole process of the documentation, the research, the design, and all features implemented can be continued in future iterations of this project. For the most part, the team feels proud and confident in the Smart Cooler project, and all of its features and benefits that it brings to the users. The project reached its goal of completion and the team continued to work together smoothly. There were some times when the team needed to come together to put some more time into finishing the project but everything was eventually finished in a timely manner.

This project could not have been possible if the machine shop and TI lab at UCF did not help the team. We would like to especially thank Jim and Luke because they helped guide our group to something greater than we initially thought. They helped us understand the design process of a product overall and gave us things to think about and parameters that were never considered to the team beforehand. This project turned out to be a huge learning experience that the whole team will never forget and take this to future experiences.

X Conclusion

In conclusion, after completion of our design paper, our group is ready to start the implementation and building of the smart cooler. After numerous design considerations, thorough research capabilities, and many stages of testing, the implementation should be smoother to transition into the actual building in Senior Design 2.

After totaling all the purchased component prices, we came in well under our estimated budget for the project. The budget was a high overestimation of the components because we overestimated the price on certain parts but were all willing to make the project happen with the estimated price. The totaling under the estimate was a great achievement for our team such that it gives more freedom to work with the components we acquired and add more than initially anticipated.

In regards to the stretch goals mentioned earlier on, each of those implementations were heavily decided on the progress of this project in the upcoming semester with just the main features. Currently, there is an expectation to hopefully add in at least one of those items to give some additional functionality and uniqueness to our overall project. In the case that the stretch goals seem out of reach due to deadlines, the project is still delivered as a working product.

Whilst documentation is being finalized for this semester, it is important to be thinking about our upcoming prototype and what we hope to showcase as part of our early development model. It gives some real-life insight into what components may provide trouble to the overall infrastructure and how we can improve upon it. With Senior Design 2 being in the Summer, our time to spend on the project is a bit less than a typical Spring or Fall Semester, so understanding our design thoroughly early on is key to a successful project.

Senior Design projects should encompass an idea that allows group members to showcase and highlight the depth of their knowledge gained throughout their undergraduate career, and we think this project is perfect for that. It introduces familiar concepts from microcontrollers and PCB design, to software programming in languages like C and C++. The project should also challenge the group by bringing in skills that they have probably never been subjected to, which for us include using solar panels and new technology like smart glass or smart film. Working on the project in a group builds soft skills like teamwork and better communication to develop for use in the professional industry.

As this project is nearing a developed product our team has worked hard to get to this point in the development stages as well as delivering the necessary deliverables and completing our tasks with ease. From all the work done this semester we all believe in the work that we have put forward and that we have delivered a finished product we were all happy with in the summer semester even with the shortened length.

Table Index

Figure Index

References/Appendix

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