PEDC: Clean Room Environmental Chamber

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ENGR 01403

May 10, 2020

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Abstract

The Product Engineering and Development Clinic (PEDC) was tasked with designing and building an innovative and aesthetically-pleasing Environmental Chamber to store solder paste and FR-1 boards. This chamber would reside in the Clean Room, located in Engineering Hall. The purpose of this project was to explore the product design cycle, as well as practice human-centric and user-driven design principles in order to develop a product that is novel and aesthetically pleasing. Due to the unexpected circumstances resulting from COVID-19, the development of the Environmental Chamber has been halted. Though extensive work remains, a large majority of the project design has been completed. Testing, adjustments to the design, fabrication, and assembly still need to be completed before releasing the product to the client and end-user.

Introduction

The purpose of Rowan University's engineering clinic program is to provide students the opportunity to participate in unique projects. This allows students to utilize what they have learned in their respective engineering courses to solve real-world problems. The goal of this particular clinic was to utilize the design and creation of an environmental chamber to go through a human-centric design process.

Objectives

The objectives of this project, designing and fabricating the Environmental Chamber commissioned by the clients (Karl Dyer and Mario Leone), are:

- Challenge students to transcend expectations.
- Create a product that not only looks professional, but also elicits a strong emotional response from the user by implementing sensory aspects to the design.
- Provide temperature-controlled storage for FR-1 boards, solder paste tubs, and syringes.

Background and Relevant Theory

User-Driven

The design process of the Environmental Chamber was heavily influenced by two complementing schools of thought. The first, based on the book, “Start With Why”, by author and motivational speaker Simon Sinek, emphasizes the importance of determining *Why* a project is being done before product design can begin. Sinek introduces “The Golden Circle”, a visualization of three concentric circles each with a name - “What”, “How” and “Why” respectively - from the outside-in. The idea is to start with “Why” and move outwards, rather than starting with “What” and working towards “Why”. Sinek points to Apple as an example of a company that successfully “Starts with Why”; he states that “Apple’s “Why” is to challenge the status quo and empower the individual. Their challenging the status quo is a pattern repeating in all they say and do, which is the reason why people perceive Apple as authentic.”[2]. Their “Why”, their purpose as a company, defines their brand, rather than their “What” or “How”, what they make or how they make their products.

The *Why* drives the reasoning behind each design decision. In this design process, the *Why* is the purpose of the PEDC’s entire project. This project’s purpose is to learn how to successfully and efficiently design and build a project to completion that the users will enjoy. Another goal of this project was to create a product that looks like nothing else that has come out of Rowan’s College of Engineering; a professional and sleek product. The *How* is the process; specific actions taken to realize the *Why*. In this case, the students utilized structured continuous documentation and frequent client meetings to ensure a human-centric design was achieved. Finally, the *What*, an extension of the design process, is the result of the *Why* and works jointly with the *How*. The end result would be an Environmental Chamber that is functional, novel, and aesthetically pleasing.

The *Why*, *How*, and *What* can be equated to the requirements, specifications, and constraints of this project. The requirements allow the team to understand *why* the client wants their product a certain way. The specifications narrow down *how* the team will implement the client’s requirements. The constraints reveal *what* can realistically be achieved within the scope and the limitations of time, money, and resources, and standards.

Design Thinking

The second school of thought guiding the design process was “Design Thinking”, a process pioneered by David Kelley, founder of Stanford University’s Hasso Plattner Institute of Design, known as the “d.school”. Kelley is also the renowned founder of IDEO, a company that focuses on human-centered design. One of IDEO’s first iconic designs replaced an expensive mechanism with one that is more easily manufactured and readily available. This one design decision, made in 1980, shaped the physical design of computer mice to this day. IDEO’s focus on manufacturability, ease of use, and how humans would interact with their design from all angles, has made them one of the most innovative design companies in existence, with multiple news stories done about their creative approach to innovation, specifically in everyday objects [3].

Stanford University's "d.school" currently implements empathy in its design philosophy, which allows students and future designers to "Move beyond theory and dive into hands-on practice in the art of innovation. Master techniques for gaining customer empathy through a series of hands-on exercises that guide you from synthesis to prototyping and testing". Design thinking, according to the Interaction Design Foundation, "is a design methodology that provides a solution-based approach to solving problems." Design thinking "[is] extremely useful in tackling complex problems that are ill-defined or unknown, by understanding the human needs involved, by re-framing the problem in human-centric ways, by creating many ideas in brainstorming sessions, and by adopting a hands-on approach in prototyping and testing." [4]
This allows for customers and end-users to have a satisfying experience with the product or service being designed, as well as allowing the end product to be as efficient and effective as possible. Design thinking as an iterative process also allows for the efficient use of time and resources in engineering, by considering the practical use of the design being created, what aspects will be crucial, and what can be removed or replaced.

Design Thinking enables effective engineering designs to come to life and works conjointly with human-centric design. Both schools of thought, "Starting with Why" and Design Thinking, were recurring themes applied throughout each stage of this project.

Henry Rowan's Vision

Henry Rowan saw a need in the world when he saw young adults graduating from college with degrees and skill sets of how to manage a leveraged buyout, how to inflate stock prices, and how to take a company public, but a lack of college graduates who possessed the skills to design, create, or build. Regarding this problem, he is quoted to have said,

> "But at some point we have to make something...We have a generation of young people who have college degrees in Business Administration but know nothing about manufacturing or competing in world markets. We should be teaching people how to build things, how to create real wealth, real jobs. " [11]

Henry Rowan saw the benefit in supporting education that teaches young adults how to create products that benefit society; he wasn't one to support a solely theory-based education. He also saw value in deeply understanding how technology is designed and manufactured, and wanted to implement engineering theory practically with products that would change the world. Henry Rowan's purpose in donating $100 million to Glassboro State College was to build an outstanding technical college that would create "not more engineers, but more great engineers".

The PEDC clinic took this academic year as an opportunity to fulfill Henry Rowan's wishes. By refining product design and manufacturing skills to become better engineers, the clinic team strove to become more like the kind of engineer Henry Rowan was. "Make a difference. Make this world a little better because you lived in it."[11] He, no doubt, knew the importance of developing new technological theory, but knew that theory would be a waste without the knowledge of how to implement that scientific thought. Rowan believed the people best equipped to take that theory and create new products are engineers, and that's why the Henry Rowan College of Engineering exists today.

Engineering Standards

While aesthetics and quality user-experience were key objectives in this project, an important factor in the design and fabrication process was alignment with national and global engineering standards. Policies and guidelines posted by the American Society of Mechanical Engineers (ASME) and the Institute of Electrical and Electronics Engineers (IEEE) in particular were followed. Additional guidance was taken from the Federal Communications Commission (FCC), as well as the Occupational Safety and Health Administration (OSHA), and the Americans with Disabilities Act (ADA). It is important to be cognizant of the standards and regulations put forth by these institutions as well as others; they act as guidelines for safely and uniformly implementing engineering design. When engineering standards are not followed, the results can range from a product that is uncomfortable to use, to a product that is unsafe for consumers.

Proper Storage of Solder Paste and FR-1 Boards

The Electrical & Computer Engineering (ECE) Clean Room regularly utilizes solder paste when assembling printed circuit boards (PCBs). Solder paste must be stored between 2 and 10 °C, to maximize its shelf life.

FR-1 circuit board blanks are frequently used for milling circuit boards in the Clean Room. A common problem that occurs when reflowing FR-1 boards is if the board absorbs moisture from the air, bubbling occurs between the copper layers when the board is heated and they separate. This problem is mitigated currently by manually preheating the boards at a low temperature for 40 minutes in the reflow oven to remove the excess moisture. This tedious task can be eliminated by storing the FR-1 boards in a low-humidity compartment for .

Procedure

This section outlines the overall procedure of the project. This includes the scope of work for both the aesthetic and technical design processes, the high-level requirements, specifications, and constraints as well as the design and fabrication of each module of the Environmental Chamber. More details on requirements, specifications, and constraints can be found in Appendix C. The Environmental Chamber was divided into the following modules: Shell, User Interface, Chamber, Open/Close Mechanism, Lighting, and Main Control Board. These are explained in the following sections.

Scope of Work

This section outlines the scope of work pertaining to the aesthetic design and technical design process, respectively. These two design processes are distinguished from one another because they each focus on different aspects: form and function. These design aspects will be integrated together, with aesthetics being determined first and function fitting the physical constraints of the form. The order of design was an intentional challenge for engineering students, because typical engineering course projects focus very little, if at all, on how the end product looks and feels when performing the intended task.

Upon first glance, the user will see what looks like a marble sculpture with vines cascading down the sides. The exterior of the structure, referred to as the shell, is in the shape of a twisted rectangle that widens at the base. The lighting system controls lights that will undulate from within the shell to appear as though the sculpture is breathing.

The user's eyes are then led along the sweet potato vines towards leaves on the top of the shell with symbols on them. The user will then press the symbol on the leaf that indicates the chamber they would like to access, feel the tactile feedback from the click of the button, and as a result of user interface, the open/close system is activated to allow the chamber to rise from the shell.

The hot chamber is revealed first, which stores FR-1 boards, and then the cold chamber will be revealed, which stores solder paste and syringes for application of the paste. These temperature-controlled chambers are the fundamental function of the environmental chamber.

Once the user has retrieved the items needed, they will press the close button. The chamber will lower back into its shell, and will return to its sculpture-like state.

Aesthetic Design

Creating the requirements from an aesthetic standpoint required a deep understanding of the user and the client's wants. The design was determined through an iterative conceptualization process to determine the ideal shape and coloring, as well as frequent interviews with the client. The team had to be broken up to research different aesthetic themes and undergo multiple design reviews. In the end, it was decided that the environmental chamber must not be a rectangular prism, nor resemble a typical refrigerator on the market, as per the client's request.

From an economic perspective, allowing the function of the environmental chamber to fit the aesthetic of the shell contributes to increasing value of the product to customers. It was important to align with standards throughout this design process because standards provide reasonable structure and replicability to any design process. Sustainability, material selection, and usage were considered to reduce waste of time, effort, and resources during design, testing, and future fabrication of the external shell.

Technical Design

The technical development of this product involved high, mid, and low level design of the systems and components required to fabricate a functioning environmental chamber. The entire storage compartment must be able to hold leaded solder paste, syringes, and FR-1 boards in an organized manner in the appropriate temperatures that ensure the integrity of these materials. In order to produce the final product, the students had to calculate effective thermal energy flow values and create mechanical computer aided design (CAD) parts and assemblies, as well as electrical schematics and board layouts. In addition to designing to fit the objectives, the team had to consider a general user's abilities. The 2010 ADA Standards for Accessible Design sets the minimum requirements that must be met in order to make the product readily accessible and usable by individuals with disabilities [5]. This was something that was considered throughout the whole process especially when designing the components of the Environmental Chamber that would directly interface with the user.

A few other standards were followed when the team considered industry standards in designing schematics and models.The ASME B18, which provides standards for mechanical fasteners, was followed when choosing fastening components in the fabrication portion of design [6]. IEEE standards followed include 315-1975, the IEEE Standard for Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters) [7].

Requirements

Requirements aligning with clients' wants and needs were determined following frequent meetings with clients. The clients' needs, in this case, a product that stores solder paste and FR-1 boards, were combined with their wants: something stylish, and, in the client's words, "....something that doesn't look like it came out of Rowan University". This conglomeration produced a multitude of requirements, some of which have been highlighted below. For a full list of Requirements, see Appendix C, in the Overall System section.

1. Maintain solder paste at 2-10° C.
2. Provide storage for (2) solder paste tubs.
3. Provide storage for FR-1 boards and (2) solder paste syringes.
4. Built to withstand daily use up to 10 years.
5. Aesthetically-pleasing and human-centric design.

Building off of the above requirements allowed for a narrower list of specifications to be developed, this time taking into account the clients' needs and other considerations and constraints such as cost-effectiveness and design feasibility. In other words, once the *why* was defined, the *how* and *what* could also be recognized. The specifications (the *how*) are detailed below.

Specifications

Specifications for the Environmental Chamber were determined by the PEDC based on the Requirements section above, design constraints (detailed in the Constraints section below), in addition to the insight provided by frequent communication with the clients. This is a small sample of specifications compiled. For a full list of specifications, see Appendix C.

- The Environmental Chamber shall be able to operate using utilities offered on Rowan's campus; this included power outlets and the compressed air supply.
- The open-close mechanism shall ensure smooth movement when in use.
- The open-close mechanism shall take no longer than 4 seconds to move between states.
- The external structure shall be a twisted rectangle that widens towards the base.
- The Environmental Chamber's appearance shall give the illusion of polished marble.
- The Environmental Chamber shall include lighting to give a 'lit-from-within' glow.
- The Environmental Chamber shall include a realistic-looking artificial vine and flowers.

The specifications outlined above were developed based on the project's requirements, and altered as necessary due to the constraints described below.

Constraints

A number of design constraints were taken into consideration throughout the iterative design process. The constraints are outlined as follows:

- The chamber temperatures should never go below 2ºC in the cold chamber or above 60ºC in the hot chamber.
- The open/close system's pneumatics must be compatible with the Clean Room's existing compressed air system.
- The Environmental Chamber must be able to be manufactured via in-house methods.

Following the completion of the products overall requirements, specifications, and constraints, the actual design work was able to take place. Details regarding the resulting 3D models, schematics, and code are documented below in the Design and Fabrication section.

Design and Fabrication

Aesthetic Design

The PEDC team conducted a brainstorming process to evaluate different aesthetic concepts and ultimately finalize a design. The team was split into three groups, and each group explored a different visual style to explore possible shell structures. The three styles were inspired by interviews with the client. The client expressed wanting the product to make users “feel good”, as well as look visually appealing. Wondering what makes people “feel good”, one team thought about how fun and friendly cartoon characters can have the ability to make people smile, and decided to create a presentation showcasing “caricature” styles. Understanding that our client grew up in the second half of the 20th century and had a penchant for old products and technology that made him nostalgic about his youth, one group decided to explore a “retro” aesthetic for one of the vision boards. The third group pondered what style could evoke visual appeal in an objective sense and thus pursued creating a vision board showcasing a “modern” style. These brainstorming sketches and designs can be seen in Figures I-B1, I-B2, and I-B3, in Appendix B.

The team analyzed each of the designs and selected the most visually appealing mockup drawings. A list was generated to narrow the desired aesthetic: timeless and simplistic, novel, sophisticated and classy, and illuminated. Qualities of each design that were appreciated were pointed out and each design was evaluated (Figure I-B4). The team then assembled in three groups and returned with three seperate “frankenstein” designs that combined each style while focusing on the desired aesthetic qualities previously mentioned. After presenting each design, the team decided on the one that would best make the client “feel good” and align with the desired aesthetic qualities decided upon. Figures I-B5, I-B6, and I-B7 in show each “frankenstein” design presented and their descriptions.

1A 1B 1C

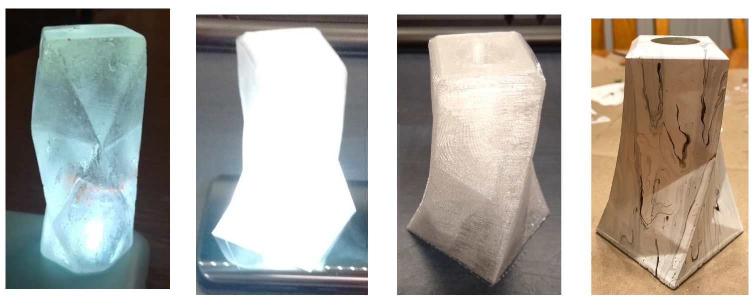
Figure 1A: Concept art for the chiseled marble design. 1B: Concept for the hot and cold chambers. 1C: Rendering concept of the chiseled marble design.

The idea of a twisted rectangular prism was expanded upon, and the structure was altered to widen at the base and have an exaggerated twist within its structure. The gradual slope of the prism towards the base was inspired by the draping effect of cloth. The illusion of a narrowed middle was created to give the viewer a subconscious thought of a waistline. The side panels of the structure were multifaceted to give the illusion of a chiseled surface, inspired by Susan Lordi’s Willow Tree, as seen in Figure I-B8, to make the structure appear as if it were a sculpture. To further the sculpture narrative, a material was used that gave the illusion of marble. The color scheme included a white-cream colored base and veins/swirls of oiled bronze and flecks of mica or comparable metallic flecks, based off of the client’s appreciation of oiled bronze appliances. To accomplish a ‘glow’, lights would be placed inside of the sculpture to shine through to the outer surface. Taking inspiration from James Cameron’s Avatar, it was decided to have the lights undulate, as if the structure were breathing. To further the narrative that the Environmental Chamber was a piece of art and not a refrigerator, realistic-artificial vines were added to the design. The vines selected were similar to that of a sweet potato vine, which draped like ivy on a sculpture and also featured purple flowers-to reflect the client's favorite color.

Shell

The shell consists of the outside facade and structure of the Environmental Chamber. It provides the professional aesthetic and encloses all the other subsystems.

Using the fabrication methods available to students, three fabrication methods were tested to construct the shell: A clear cast resin, a Stereolithography (SLA) printed model, and a Fused Deposition Modeling (FDM) polycarbonate printed model. In the future, if this product reaches large-scale production, alternate fabrication methods such as plastic injection molding may be considered. Each prototype was a 15% scale of the full model and each prototype was assessed by how it looks when illuminated from the center, what painting methods would need to be used to achieve the desired aesthetic, and the viability, cost, and time it would take to manufacture a full-scale model.



2A 2B 2C 2D

Figure 2A: Resin material prototype, unpainted. 2B and 2C: FDM transparent polycarbonate prototype; lit and unlit. 2D: SLA prototype, painted.

The first prototype consisted of a clear resin, cast in a simple cardstock mold that utilized vaseline as a release agent. The result was a structure that was fairly transparent and dispersed light projected from the base. However, this method allowed for inconsistencies - such as air bubbles forming. The process to create a mold for the resin also posed a challenge. The unique geometric shape of the shell would require multiple seams to be made in the cardstock outline, and the desired size would largely increase the difficulty of forming the mold. The shell also has multiple vertices, so ensuring an even coating of release agent also added a layer of complexity. Each cardstock mold can only be used once, making this method time consuming and undesirable for scaled production.

The second prototype was an SLA printed shell structure. The cured material was clear with a smooth finish. Paint was applied to yield a marble look and light was then applied to the base of the structure; the material caused the light to give off a slight green tint, which while not a dealbreaker was undesired. The print process took a considerable amount of time and also placed a size limitation on the prints. The SLA printer available at Rowan has a build volume of 5.7 × 5.7 × 7.3 in; in order to produce a full-scale 8 x 8 x 10 in. model, the print would need to be split into sections. As the goal is for the Environmental Chamber to look like a solid piece of marble, printing in sections may have decreased from the aesthetic-any seams would have been timely to sand down and may have affected the lighting by changing the opacity layers. The resin required for the SLA printer was quite costly, and therefore not ideal for production.

The third prototype was an FDM print formed out of polycarbonate.This model gave off the whitest light, however, the surfaces were more rough than desired. Since this model gave off the best lighting, it was discussed that the surface could be altered by applying a layer of clear coating to fill in any bumps or ridges. Due to the mandated close of Rowan facilities, a clear coat was never applied. The largest FDM printers available to the team have a build volume of 12 x 12 x 15 in. therefore the shell could be printed as a solid piece or piecewise layers that can stack together. The FDM prints took the least amount of time to complete and the cost of the filament was much less than the resins.

Figure 3: Shell Material Inspiration, Marble Facade

Many methods were compiled to apply a marble facade: hydro-dipping, physical marbling of the shell's material, and painting. Hydro-dipping was deemed a non-viable option; Rowan University lacked the facilities to easily complete this process given the size and shape of the shell and the process cost more than desired. Physical marbling of the material was considered and ruled ineffective due to the fact that the structure would be 3-D printed. The painting method was cost effective and readily available to prototype with. Using this method on a thin sheet of plastic, a desirable outcome was achieved.

User Interface

Considering a user's ability was crucial in the design of this product in order to ensure that as many people working in the Clean Room would be able to use the environmental chamber. With this in mind, the user-interface was designed to consist of three buttons; Closed, Hot, and Cold. These buttons were graphically represented by a white 'X', a red sun, and a blue snowflake, respectively, as these are the types of symbols used on water dispensers and sinks in the United States, and would be easily recognizable to those using it.

4A 4B 4C

Figure 4A: Closed button render. 4B: Hot button render. 4C: Cold button render.

When pressed, the Hot button, as seen above in Figure 4B, triggers the inner chamber to rise halfway to expose the FR-1 storage containment area, or the hot compartment. The Cold button, seen in Figure 4C, has a similar function. When pressed, the inner chamber rises completely to expose the FR-1 boards in addition to the solder paste tubs and syringes, or the cold compartment. The Close button, denoted by ‘X’ as seen in Figure 4A above, triggers the inner chamber to fully retract to its original closed position. The button icons adhere to universal design, crossing global language barriers by the use of well-known graphics and colors to represent written words.

Tactile-dome buttons were chosen based on student feedback regarding satisfaction of tactility and ease-of-use. The tactile-dome buttons selected were the easiest to press and contained a hole in the center, which allowed LED illumination. Upon the selection of user-interface buttons and icons, the schematic design process began. Another aspect considered during user-interface, besides the buttons, was the spacing and positioning of other components that the user would need to physically interact with during use, such as the opening of the chamber where the user would reach in and remove the stored objects.

Electrical components for the user-interface board were modeled in Altium; minimal parts were included to streamline the board design. Refer to the User-Input schematic Figure I-D4 of Appendix D.

Lighting

The lighting system serves two purposes: to provide user feedback and aesthetic appeal. In terms of user feedback, varying lighting modes were used to indicate the status of the Environmental Chamber’s operation (these modes are highlighted in the Appendix).

The lighting aesthetics were inspired by Avatar and the undulation of plant life and objects in the film. To accomplish this, LEDs will brighten and dim sinusoidally at a frequency of 0.1 Hz. This visual is considered the Environmental Chamber’s steady state and is displayed during normal operation of the Chamber. If the temperature of the chamber passes its given threshold, the frequency of undulation will increase, much like a living creatures’ breathing pattern would to signal distress. Refer to Figure 5 below for the organization of normal operation logic flow.

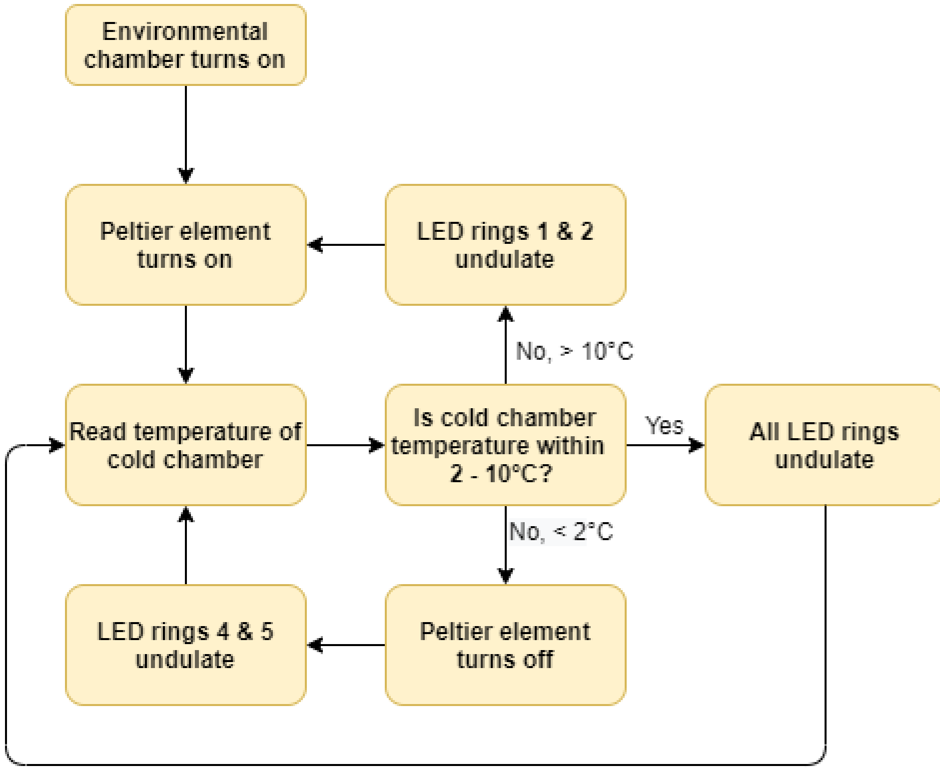


Figure 5: Normal Operation

As the temperature in the cold chamber reaches (+/-) 1.5°C of 10°C, the LED's undulate at a frequency of 0.267 Hz. Refer to the lighting system condition table in D5 of the appendix.

The above aesthetics are accomplished by implementing LED lights into the shell of the Environmental Chamber. The exterior shell features five individual LED rings, each on their own horizontal plane spaced evenly within the shell walls. The rings can be referenced in descending order where the top ring is Ring 1 and the bottom ring is Ring 5. The clearance of the LED rings from the outer shell wall was adjusted to provide optimal lighting intensity.

In addition to undulation, there are multiple modes that pertain to failure warnings and additional chamber operation. During the opening and closing of the chamber, each ring illuminates corresponding to its movement in increments of 20%. This acts to indicate the progress of the opening/closing mechanism.

Individual rings are also used to communicate errors within the Environmental Chamber. The first ring and second ring blink at a frequency of 1Hz to indicate if the chamber is unable to reach the desired position. When an error is detected from the temperature control system, the lighting system indicates that error by blinking the 3rd ring at 1Hz. Failure systems that will be indicated by the lighting system include failures to temperature control, temperature sensors, opening and the closing mechanism. Refer to the table in section D6 of the appendix for the full list of failure modes for the lighting system.

Main Control Board

The core of the Environmental Chamber's electrical system is controlled by the main control board. This board interfaces with the open-close system, the temperature control system, the lighting system, and the user input system. Themicrocontroller selected was the ATmega644PA, chosen due to its number of General Purpose Input/Output (GPIO) pins, and its dual UART peripherals.

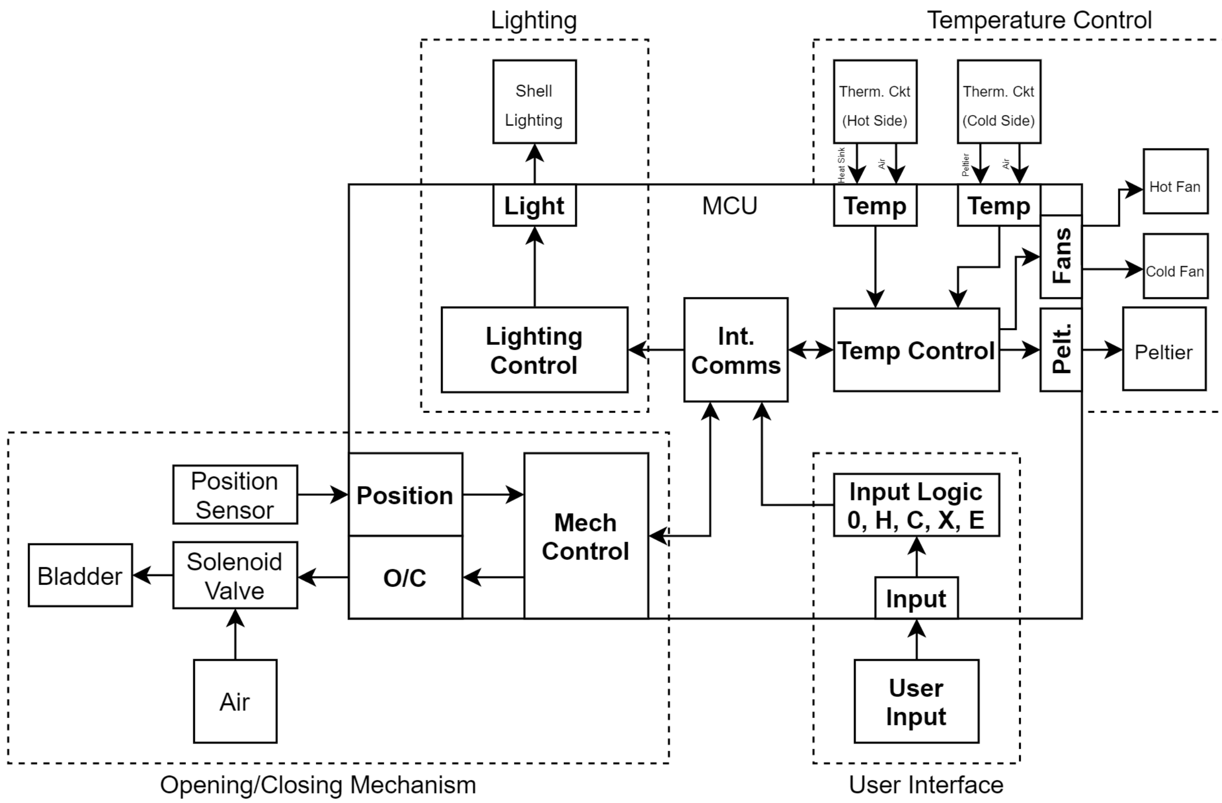


Figure 6: High Level Function Diagram

The first UART peripheral was used to communicate back and forth with the temperature control microcontroller, also an ATmega644PA. The second UART peripheral was reserved for debugging purposes. The remaining GPIO pins on the main board microcontroller were used to drive the MOSFETs which operate the solenoids in the Open-Close mechanism. In addition, the hall effect sensors (used for determining the current position, Position Sensor in Figure 4), the User-Interface buttons (used for choosing the desired position) and corresponding LEDs, and the Lighting system (used for displaying the error and temperature control status) also run off of the GPIO pins on the main board microcontroller. The communication between systems adheres to the FCC radio frequency (RF) electromagnetic fields safety standards [8]. The schematic of the main control board with microcontroller and its implementation can be seen in I-D1 of Appendix D.

Unit tests were written for each subsystem in the Environmental Chamber and truth tables were drafted to determine the necessary logic for each system. These truth tables describe the relationship between the various inputs and the outputs for each system communicating with the main board and how they interact, and can be seen in Appendix F.

Temperature Control Board

The communications and control between all temperature control elements (thermistors, fans, and peltier element) are located on the Temperature Control Board. On this board, there is a microcontroller, relay for the Peltier element, and connectors for the fans, thermistors, and SPI and UART communication. Additionally, there is a 12V input and voltage regulator to implement drops to 5V for certain components.

The PCB is located in the cold chamber and was designed to regulate the Peltier to ensure each chamber is in the desired temperature range. The temperature control board only needs power when the chamber is closed, therefore a set of electrical contacts were used for power and communications. These contacts, pogo pins, were mounted within the shell, underneath the chamber. The pins contact metal pads to a board mounted to the bottom of the chamber. Large pogo pins were chosen to handle the current required for the Peltier element, and large pads were chosen to allow for slight misalignment errors.

The schematic, Figure I-D3, can be found in Appendix D.

Chamber

The chamber contains three sections: the cold chamber where solder paste is stored; the hot chamber which houses FR-1 boards; and the thermal junction, which houses the Peltier element. Four thermistors were placed within the chambers; one in the cold chamber and one in the hot chamber to measure the temperature of the air in each, and one on each heatsink. Each thermistor is mounted via a thermal epoxy.

Thermal considerations

The temperature control board in the cold chamber controls the Peltier element to maintain a desired temperature. To do this, it reads the temperature from the four thermistors, then controls the fans and Peltier element accordingly. Other methods of refrigeration and temperature control, such as coolants and compressors, were looked into. Coolants would require additional chemical safety specifications, in addition to striking a balance between efficiency and environmentally friendly refrigerants. To implement a compressor for a modest sized refrigerator would be an inefficient use of materials. A Peltier element is, comparatively, an inefficient method of temperature control because most of its energy is turned into heat. Despite its inefficiency, it was selected for this environmental chamber because it is small, easily controlled, and performs exactly the task necessary to maintain the temperatures desired. As mentioned previously, this board also communicates with the main control board to know what state the system is in, and to report the temperature control state.

While the chamber is in motion, communication with the temperature is not required. Of the three possible states of chamber motion, temperature only needs to be maintained while in the closed state. Given the operation of the Environmental Chamber, it remains in open states for short intervals. A set of contacts pads - located on the bottom of the chamber - makes contact with a set of pogo pins located at the bottom of the cavity. When the chamber is closed, the contact supplies power to the temperature control and continues communication. When open, power is lost and temperature control is turned off.

Thermal calculations were completed to approximate how much heat would enter the Environmental Chamber during operation. Based on the calculations, design measures were taken to prevent ambient heat from leaking into the cold chamber. The assumptions used during the calculations were that: the chamber wall is flat (not curved), the ambient temperature surrounding the cold chamber wall is 298K (25°C), the wall thickness is ¼", the thermal insulation of the plastic in the wall is negligible, and there is no conduction through the ceiling of the cold chamber. See Appendix D for the thermal calculations of conduction into the chamber.

The cold chamber needed enough room to hold two tubs of solder paste and two syringes. During design, it was determined that the cold chamber would also need to house certain components that would aid in the removal of heat from that area. These components include a heat sink, a fan to circulate the air around the heat sink, and thermal mass. The purpose of the heat sink in the cold chamber is to increase convection from the Peltier element to the cold chamber air. The fan ensures there is always "new" air moving across the cold heat sink so it does not freeze over. If the air moisture freezes on the cold heat sink, the resulting ice will prevent the heat sink from removing heat from the ambient air, rendering it ineffective.

The floor of the cold chamber is designed with stones that are set in plaster to increase the thermal mass within the cold chamber. The addition of thermal mass reduces temperature fluctuation, decreases Peltier cycling, and shortens the time required to bring the cold compartment back to temperature after being opened. Figure II-B5 in the Appendix B shows a cross-sectional drawing of the layout of the chamber with the cold chamber being the lower half.

The top section of the chamber is referred to as the hot chamber because the temperature is ~25°C warmer than the cold chamber. The temperature of the cold side of the Peltier element is dependent on the temperature of the hot chamber, so heat needs to be removed constantly from the 'hot' side of the Peltier element. Another purpose of the hot chamber, besides temperature regulation, is to store FR-1 boards. The heat sink in the hot chamber conveniently doubles as a storage rack for FR-1 boards. A fan in the hot chamber will blow hot air out of the hot chamber through an open orifice by the chamber opening. Figure II-B4 in the Appendix B shows the implementation of the fan onto the top of the hot chamber and how the hot air will be directed away from the user for safety purposes.

Ambient air would then be drawn in through orifices located on the walls near the floor of the hot chamber, perpendicular to the opening. The holes will be connected to ducts extending through the chamber to ensure the ambient air is able to flow completely across the heat sink fins. A flow simulation was completed in Solidworks to get a baseline understanding of what the flow inside the chamber would look like in action, which can be found in Figure II-B1 of Appendix B. An elliptical-like shape was chosen for the hot chamber to allow enough space surrounding the hot chamber for the ambient air to properly flow inside. A depiction of the shape of the Hot chamber can be found at the top of Figure II-B6 in Appendix B.

Calculations were conducted on the thermal resistance of the hot chamber's heat sink to ensure that the airflow across the heatsink was enough to keep the Peltier element at the desired temperature. See the heat sink calculations in Appendix D for more details.

Thermal Junction

The third section of the chamber is the thermal junction. It is where the Peltier element is located and the hot and cold chambers are connected. The chambers will be fastened using male-female connectors, which can be seen at the bottom of Figure II-B7 of Appendix B This is also where the heat sinks will be mounted to the chamber. Figure II-B3 in Appendix B depicts the design of the thermal junction.

Determining the Peltier element's mounting to the chambers and their corresponding heatsinks was an important consideration. To accommodate for this spacing, a copper block the same size as the hot face of the Peltier would be placed on top of the hot face. The total thickness of the thermal junction will be between ¼" and ½" depending on the thickness of the copper block, which also serves as an extension of the hot heatsink to help remove heat from the Peltier element. The heatsink for the hot chamber would be placed on top of the block.

A layer of thermal paste with silver will ensure better conduction and no gaps or movement between the hot components. The heatsinks will be physically mounted with screws, spacers, and washers as seen in Figure II-B3 in Appendix B. The nylon screws and washers will be used to prevent conduction from the hot to cold chambers. The attachment from both sides will ensure that the Peltier element would be securely held in the middle.

Open-Close Mechanism

Piston

Multiple options were explored for the open-close mechanism. Initially, a rack and pinion, lead screw, pneumatic linear actuator, and pulley system were considered. Thorough research of each option led to the eventual development of using an inflatable bladder and then the final design of a piston-like mechanism below the chamber.The ASME EA-4, Standards for Compressed Air Systems, was taken into consideration while designing the opening and closing mechanism for the Environmental Chamber [9]. (See Appendix C).

The Open-Close mechanism will allow the chamber to reach three different positions. It utilizes compressed air, which is controlled via the actuation of two 3-way solenoid valves; one on the inlet to raise the chamber and one on the exhaust to lower the chamber. The compressed air would flow into the air cavity of the chamber upon entering the system. The air cavity was sealed via a set of 2 O-rings to allow pressure to build. The set of O-rings helped to prevent racking and served as a double seal in the instance of an air leak. The location of the O-rings is drawn in Figure II-B2 in Appendix B.

Racking was negated by implementing the use of a key and keyshaft. An aluminum key was placed at the top of the shell with a corresponding shaft on the chamber's outer wall. This also kept the chamber aligned during movement and prevented twisting.

Manual Override

In the case that the centralized compressed air supply was compromised, a manual override was implemented. The override consisted of a handle located on the outside of the chamber, flush to the top surface, that can be easily grasped with one hand and pulled upward to reveal the chamber contents. OSHA provides regulations to keep workers safe from hazardous conditions, such as standard 1910.147, which "...covers the servicing and maintenance of machines and equipment in which the unexpected energization or start up of the machines or equipment, or release of stored energy, could harm employees." [10]. The manual override was designed with safety in mind when there is a potential need for maintenance of components inside the chambers.

Results and Discussion

Design Process

As previously stated in the background of this report, the team took inspiration from Simon Sinek and Stanford University's Hasso Plattner Institute of Design. Those two schools of thought helped the team approach the design process in a different light than any other college-level design project had been approached. Being able to pursue a project from a new perspective was a challenge, but the ideologies from these two sources helped the students discover how to go about designing a product for a customer while also thinking about a larger audience of consumers, especially when there was no previously defined process.

When starting product research, Simon Sinek inspired the team to "Start With Why." The team contemplated why a brand new environmental chamber was necessary when there were already many options on the market. After doing a lot of research and considering the academic timeline, the students came up with an answer that doubled as a purpose; the team needed to design a product that heavily considered how an ECE Clean Room employee could and would want to use it. The students then set to work utilizing continuous documentation and client interaction to focus on the client's needs. It was important that the group was able to come together with one purpose to ensure that everyone was motivated towards designing a new product that would require many hours of work. The unified efforts made coordinating between teams easier; the students learned that by holding multiple team meetings and taking notes during each allowed for division of labor but also the need for constant cross-communication as new ideas were discovered and researched.

When thinking about David Kelley's "d.class" process, the team was motivated to think about designing for the end-user. The students found it helpful to compile research on consumer markets and design and then share the information through group presentations. The students were split into different aesthetic groups and were tasked with researching different styles to appeal to the client and create a mockup design. After discussing the separate ideas with the client, the class broke out into its various teams again with the new goal of incorporating the various styles into one design. The teams referred to this as the 'frankenstein' approach because of the crude combination of different styles into one design. This process prompted discussion between the team members and allowed the students to see what the client wanted and what was missing from the initial ideas.The process would repeat itself and the team would go through multiple client review meetings and iterations of the Environmental Chamber design. The iterative process of brainstorming and talking to the client gave the team direction and new approaches to new product development like making the client's interests the top priority in design.

After learning about these two approaches and settling with an overall holistic approach to design, the team deeply understood and was able to execute the design method of creating a product where the function fit the form. As previously stated, the students first determined the look and feel of the environmental chamber so that it would be appealing to the user as that was the main learning objective; the next part of the process was to design systems that would fit within those parameters. For example, the overall shape of the shell was decided upon, a tall and curved vase-style shell, and the students needed to design the chambers for the solder paste and boards to fit inside the shell. This design constraint led the students to use a stacked chamber design for the cool and hot chambers. The team followed this thought process throughout the conception of each element in the environmental chamber. A product needs to accomplish basic functions, but in this case, considering ease of use was equally as important. Keeping the user's abilities and needs in mind during the design process allowed the team to learn that there were many more facets to product development.

Current State of Design

Mechanical

After the entire team collaborated on a list of aesthetic requirements, the mechanical team commenced designing the outer shell and chambers to fit the aesthetic specifications. Solidworks files were created for the outer shell and the hot and cold chambers. They were modeled to demonstrate size constraints in the environment and store items internally. The open/close system and connecting components were also modeled but need to be further modified and finalized after testing and prototyping has occurred. A bill of materials was created for the mechanical components that is filled out with all of the current items and have parts made in the Solidworks files.

Calculations and material testing were crucial components of the technical design of the environmental chamber. Thermal calculations were the basis of material selection and component placement for the cold chamber. Since the main functional purpose of the environmental chamber was to reduce moisture and refrigerate solder paste to maintain its structural and chemical integrity, these calculations were necessary to ensure the cold chamber materials could prevent excessive heat from conducting through the chamber walls..

Another part of the material selection process was creating test prints of a small-scale shell using SLA and FDM printers. Once the model was printed, paint was added on the outside to test the light's intensity through the print and the paint. There are images of the test prints and paint in Figures 3, 4, and 5 pictured above.

As for the integration of components between the electrical and mechanical teams, both groups communicated to confirm what was going to be installed internally. This pertains to the board placement inside the shell and chamber to make sure that each board has enough room and to ensure the wiring can integrate with the rest of the environmental chamber. The general placement of each of the boards has been confirmed; the temperature control board will sit in the syringe holder in the cold chamber, the main board will be located inside the shell, and the pogo pins will be placed in the bottom of the compartment. While there are places for the boards, there is no mechanism in place to hold the boards down except for the temperature control board.

Electrical

The temperature control and main board schematics went through a final peer review during the last day of in-person class. The schematics have their components specified and are shown in the appendix. Further work includes designing and fabricating PCB for each in accordance with the dimensions of the specified board placement locations inside the environment chamber. Currently, there are rough PCB designs (these include the outline of the board and placement of components), however there will have to be changes made to the PCB design and further consulting with the mechanical team to make sure the PCB will fit in the designated location. Once this is complete, the attachments of the boards to the lighting and open/close system must be discussed with the mechanical team and finalized with the specified wire and connector types.

Software

The high-level interface between each subsystem of the Environmental Chamber has been specified as seen in Appendix E. In addition, the high-level logic of each subsystem and their relationship to the other subsystems has also been specified as seen in Appendix E. The small amount of code written to implement the high-level and subsystem truth tables/diagrams are located in Figure II of Appendix C. These truth tables/diagrams need to be implemented into software code used by the microcontrollers on both boards. This implementation will require extensive testing and may require edits to the current truth tables/diagrams. If these edits happen, they should be reflected in the *HighLevelSystemDiagram.drawio* file in the specification folder.

Conclusions

Due to COVID-19, physical prototyping, other testing, and fabrication has been temporarily ceased. Fortunately, the majority of the electrical and mechanical work behind the Environmental Chamber has been completed. Aesthetic design has been completed entirely, and a high-level software framework exists in anticipation of the project proceeding in future semesters.

Future Work

Due to in-person classes transitioning to online for the remainder of the semester, leading to the team being unable to use the facilities at Rowan University, the environmental chamber clinic project was halted before the product life cycle could be completed. When this project resumes in future semesters, future work can be divided into four sections; mechanical, electrical, software, and overall aesthetic design. For each of these sections, final design reviews are required before prototypes can be created and testing can commence. Following this, the final version of the environmental chamber can be fabricated and assembled.

Mechanical

The main mechanical tasks that still need to be completed to complete the environmental chamber involve making Solidworks models of the entire system, prototyping and testing each subsystem, and ensuring each subsystem can be implemented together fluidly. Solidworks files of the cold chamber, hot chamber, and shell already exist. The Solidworks model for the cold and hot chambers requires modification to account for the implementation of the insulation, the air cavity for the opening mechanism, the pogo pins, the key-and-keyshaft system to connect to the thermal junction, and the keyshaft to prevent twisting.

The thermal junction must be rendered in Solidworks with the Peltier element and its wiring accounted for. The mounting for the heatsinks and the key-and-keyshaft system that connects to the hot and cold chambers also needs to be added to the Solidworks model. The hot chamber Solidworks model needs to be modified to finalize the overall shape of the chamber, account for the keyshaft, allow the key-and-keyshaft system to connect to the thermal junction, and implement the fan and the manual override system. The Solidworks model of the external shell needs to be modified to account for the implementation of the open/close pneumatic system underneath the chamber, as well as the final dimensions of the chamber. Underneath the shell, there is a bottom compartment that contains components such as the solenoid valves and main board. This layout needs to be integrated into the shell design.

A final assembly must be made to ensure all of the mechanical components can be successfully integrated. Once all the Solidworks files are complete, each subsystem must be prototyped and tested for functionality. Multiple iterations of the prototype may be required to ensure that all subsystems properly mesh. Other considerations involve ensuring that all electrical components are properly implemented into the Solidworks design. The insulation in the cold chamber must be tested, as well as the Peltier element, hot chamber ventilation system, the opening and closing mechanism, and the user input subsystem. The bill of materials also requires a final review and the parts need to be ordered.

Electrical

With the electrical schematics and bill of materials completed, the next steps will be to begin an iterative design process that includes the layout of each PCB. Each board has been primitively laid out to determine a rough estimate of the minimum required PCB area and the minimum clearances around each component, with the addition of 3D component libraries. These primitive PCB board shapes must be exported as STEP files to Solidworks so the mechanical team can make adjustments based on clearance and mounting requirements. Following mechanical layout and purchase of components, the PCB can be milled, populated, and tested using benchtop lab equipment.

Software

Using the Git version control system was successful at mitigating tasks to everyone on the software team and the GitLab repository CI/CD feature was successful in building and unit testing each push. The final software tasks will be to write low-level code that will bridge the high-level logic inputs and outputs to the microcontrollers' inputs and outputs. The embedded code will then need to be peer-reviewed and tested using the existing automated unit test deployment, uploaded and tested on the PCB hardware, and finally released to be used in production.

Final Product/Aesthetic

Overall, the environmental chamber must be prototyped and tested. The functionality of the chamber and opening closing mechanisms needs to be tested, as well as the software. The implementation of all mechanical and electrical systems require testing. Equally important is determining the optimum method of creating the marble appearance on the outer shell. If this product was to go to market, the environmental chamber would need to be further modified to ensure all its parts may be purchased and manufactured on a large scale. This might require slight modification of the design to incorporate parts that are cheaper and more readily available.

The manufacture of this product requires the purchase of parts from multiple companies, which assists the economy and keeps people employed, especially if this product were to be mass-produced in the future. The final cost of this product is intended to be as low as possible for consumers.

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Appendix A: Glossary

Chamber - Internal unit that contains the upper hot chamber, lower cold chamber, and the peltier element separating the hot and cold chambers.

Hot Chamber - Upper half of the chamber that is above the peltier element that is heated and stores the FR-1 boards.

Cold Chamber - Lower half of the chamber that is below the peltier element where heat is removed and stores the solder paste and syringes.

Storage Compartment - Insulated structure that holds and encompasses the chamber.

Outer Shell - The outermost layer of the climate chamber, does not include the storage compartment.

Shell Lights - The lighting that is located within the outer shell.

User Input - The mechanism(s) that the user will interact with in order to open and close the refrigerator.

User Feedback - The lighting patterns used to convey information about the system to the user.

User Interface - Encompases the User Input and User Feedback systems and how they create an interface for user interaction.

Marble Coating - a material that will convey the imagery of marble onto the outer shell.

Appendix B: Methodology

I. Aesthetic Design

Initial Designs

Figure I-B1: Example of Modern design drafts.

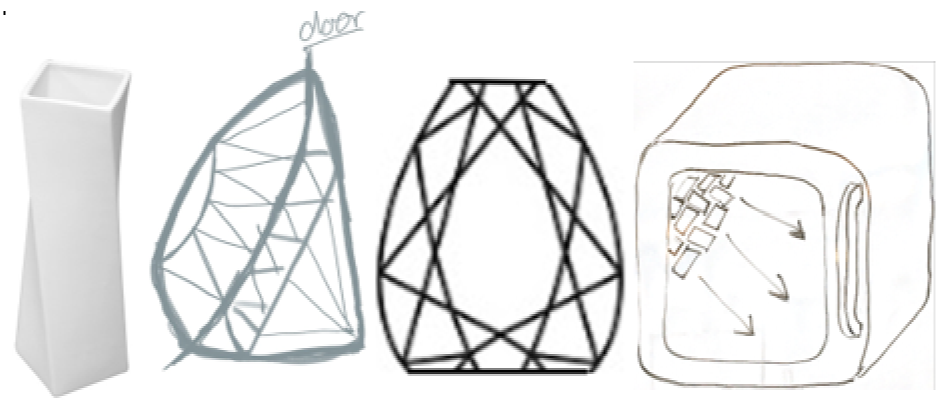


Figure I-B2: Example of Caricature design drafts.

Figure I-B3: Example of Retro design drafts.

Figure I-B4:Brainstorm Design Evaluation

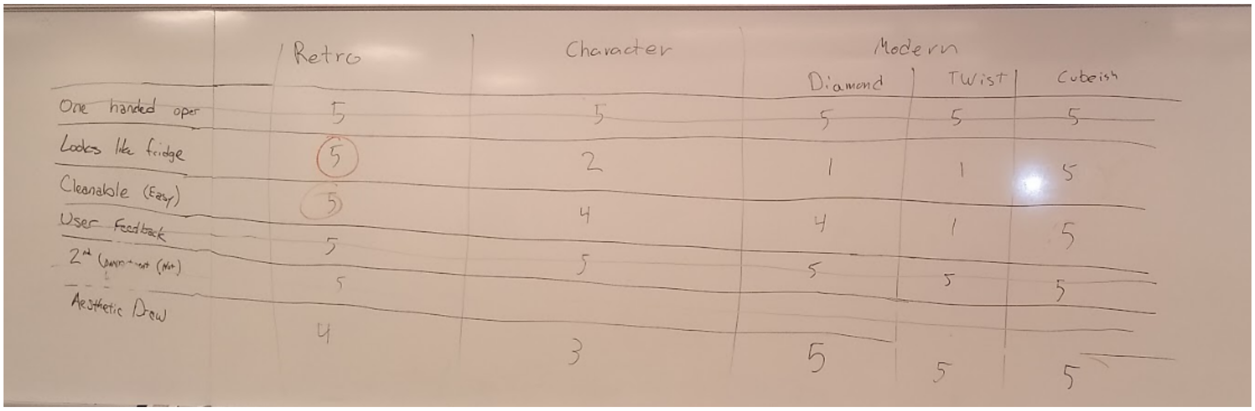
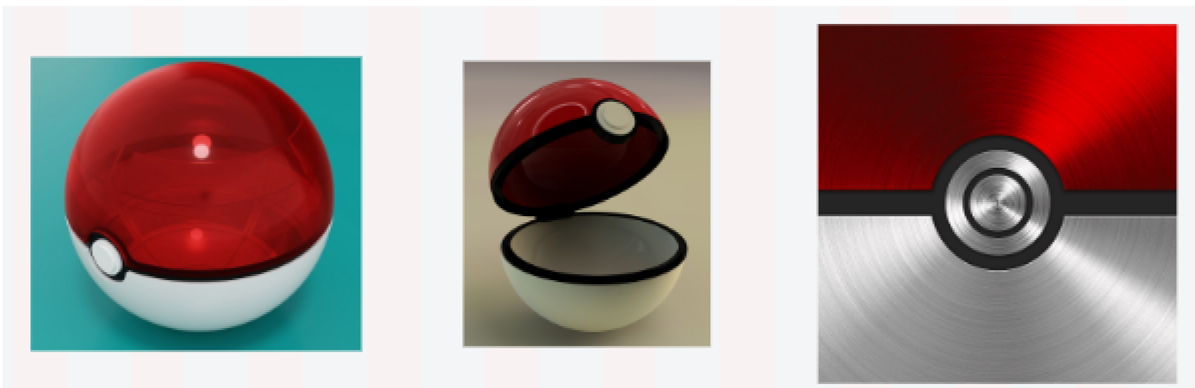
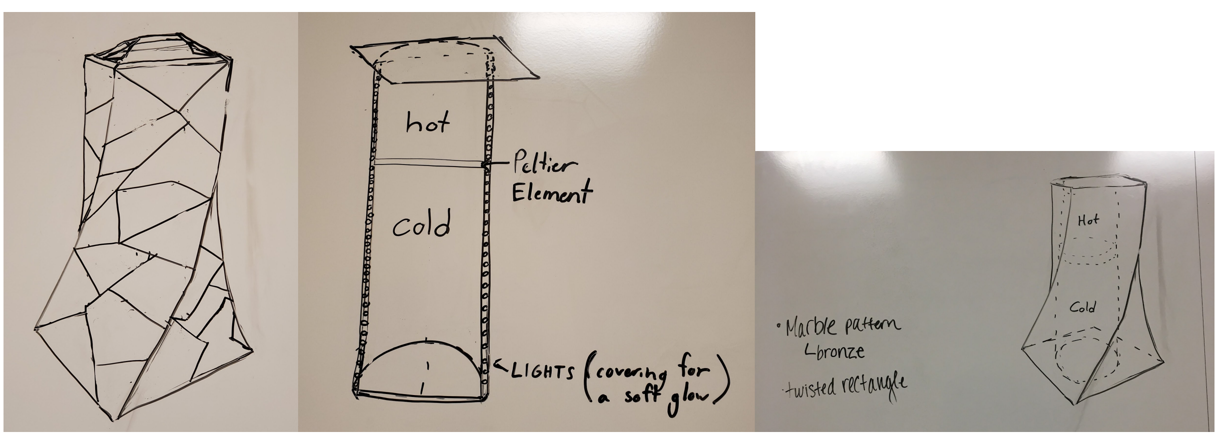


Figure I-B5: Frankenstein “Poke-Ball” Design.



i. Poke-Ball Shape
   1. Outside will have a metal finish
   2. Hot and cold compartments will be the top and bottom halves of the sphere
   3. Button on front will open the fridge

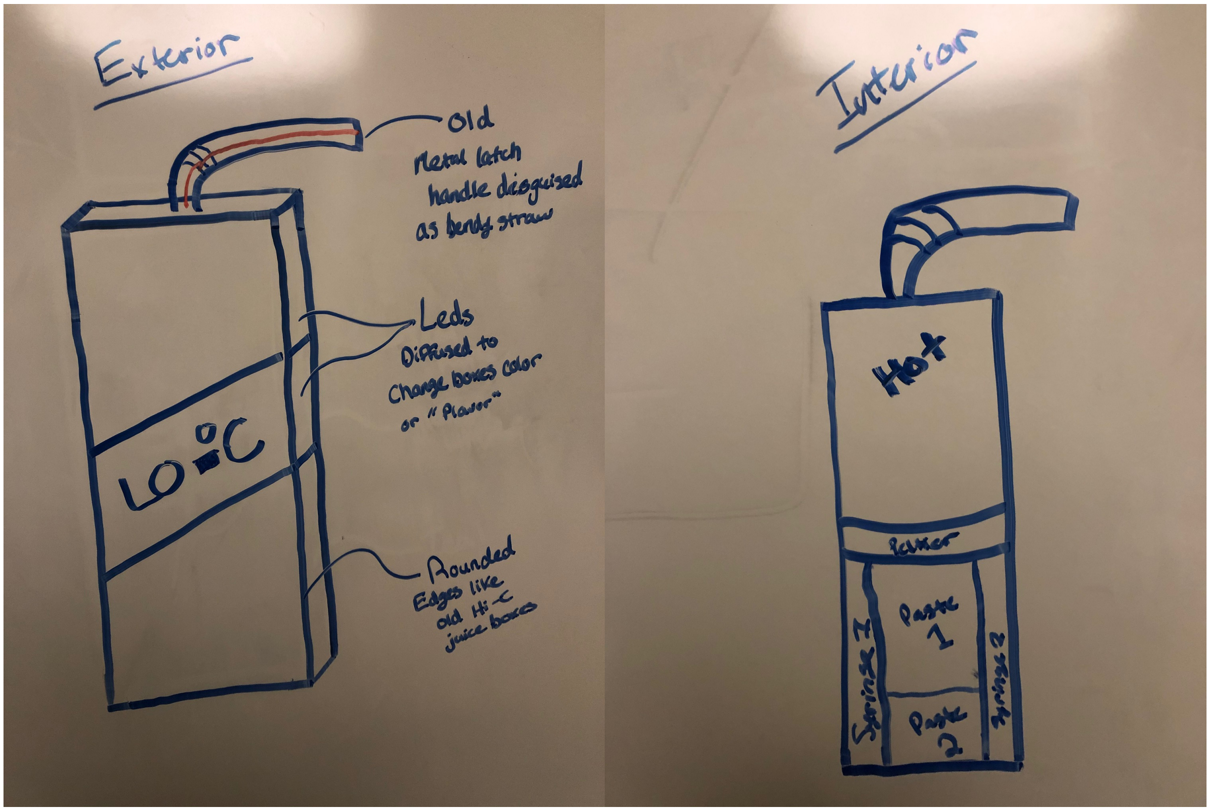
Figure I-B6: Frankenstein “Marble Finish” Design.



1. Twisted rectangle with marble finish
2. Automatic push to raise door
3. Lights shining through marble or indicate refrigerator is working

4. Top heating chamber and lower refrigerator
5. Use peltier element

Figure I-B7: Frankenstein “Emerald Cut” Design.



1. Emerald-cut shape
2. Jewel-cut w/ internal glow
3. Hi-c juice box w/ straw handle at top
4. “Frosted glass” sphere with either swivel-out or lift-up opening
5. Two spheres (or other 3D shape) connected at the top
6. Retro-esque rounded trapezoidal shape with a door

Figure I-B8: Example of “chiseled” multi-faceted texture.

Figure I-B9: Example of the Willow Tree in Avatar.

II. Technical Design

Figure II-B1: Flow Simulation of Hot Chamber

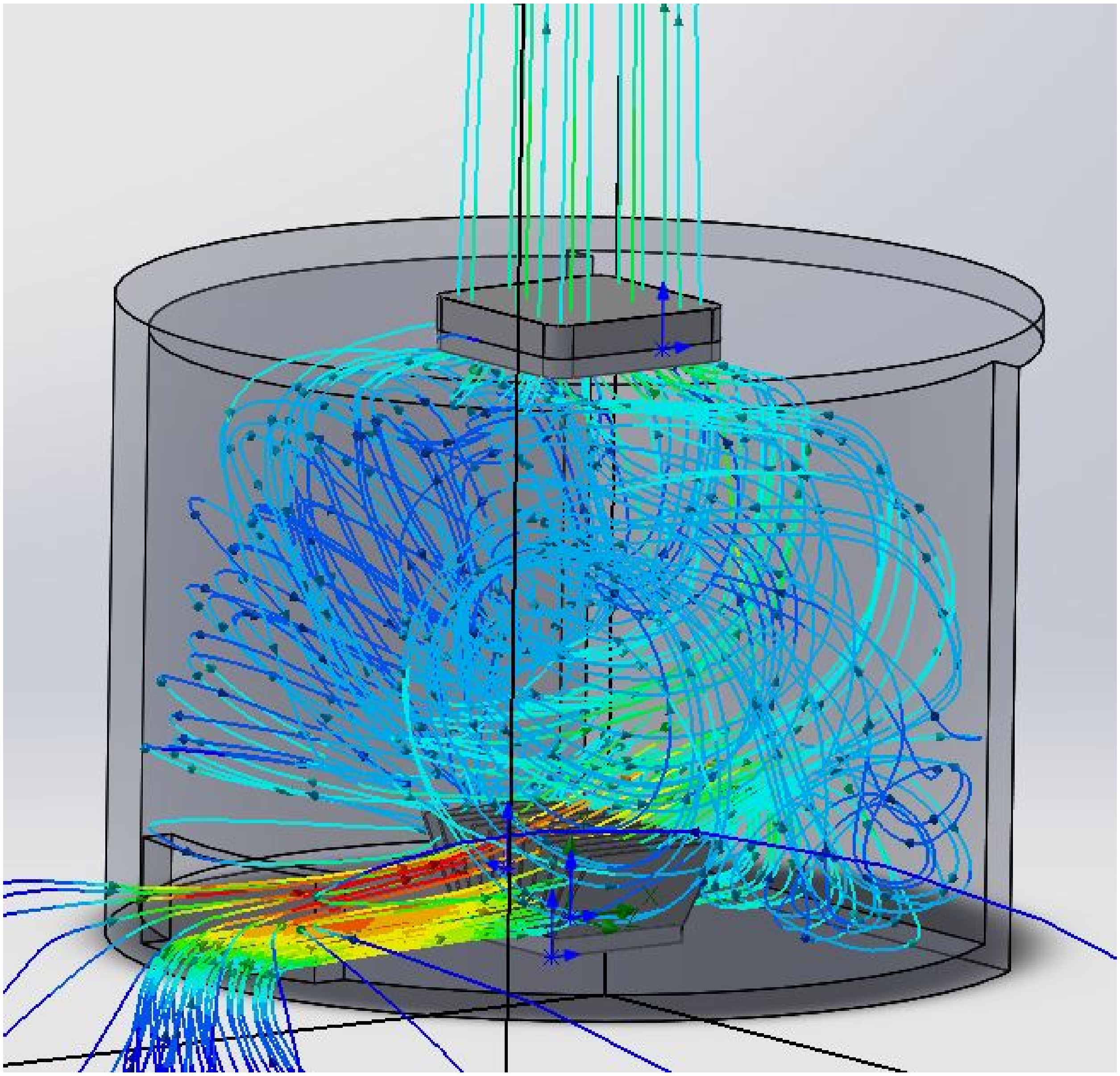


Figure II-B2: Open/Close System Skeleton Sketch

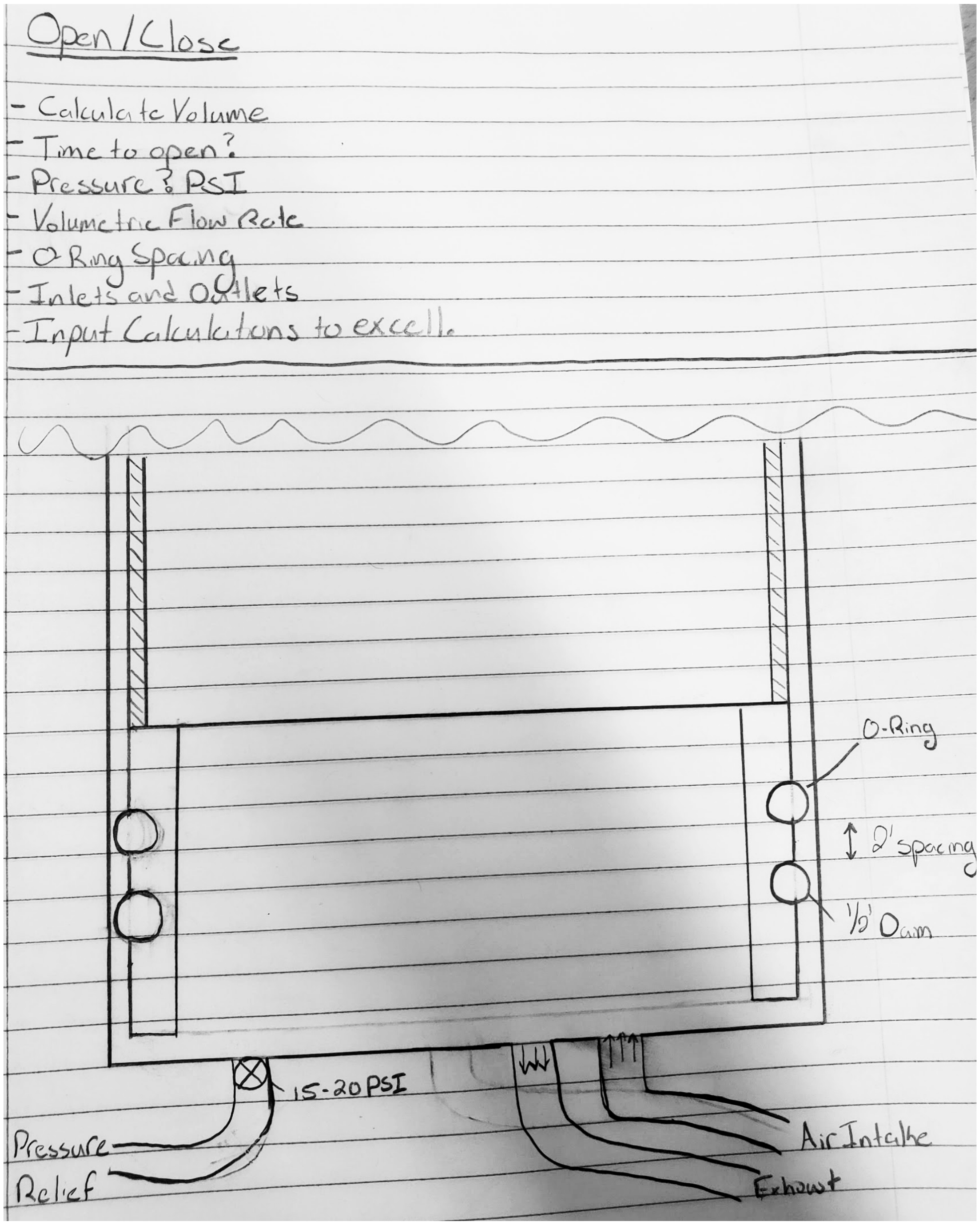


Figure II-B3: Thermal Junction (detailed view)

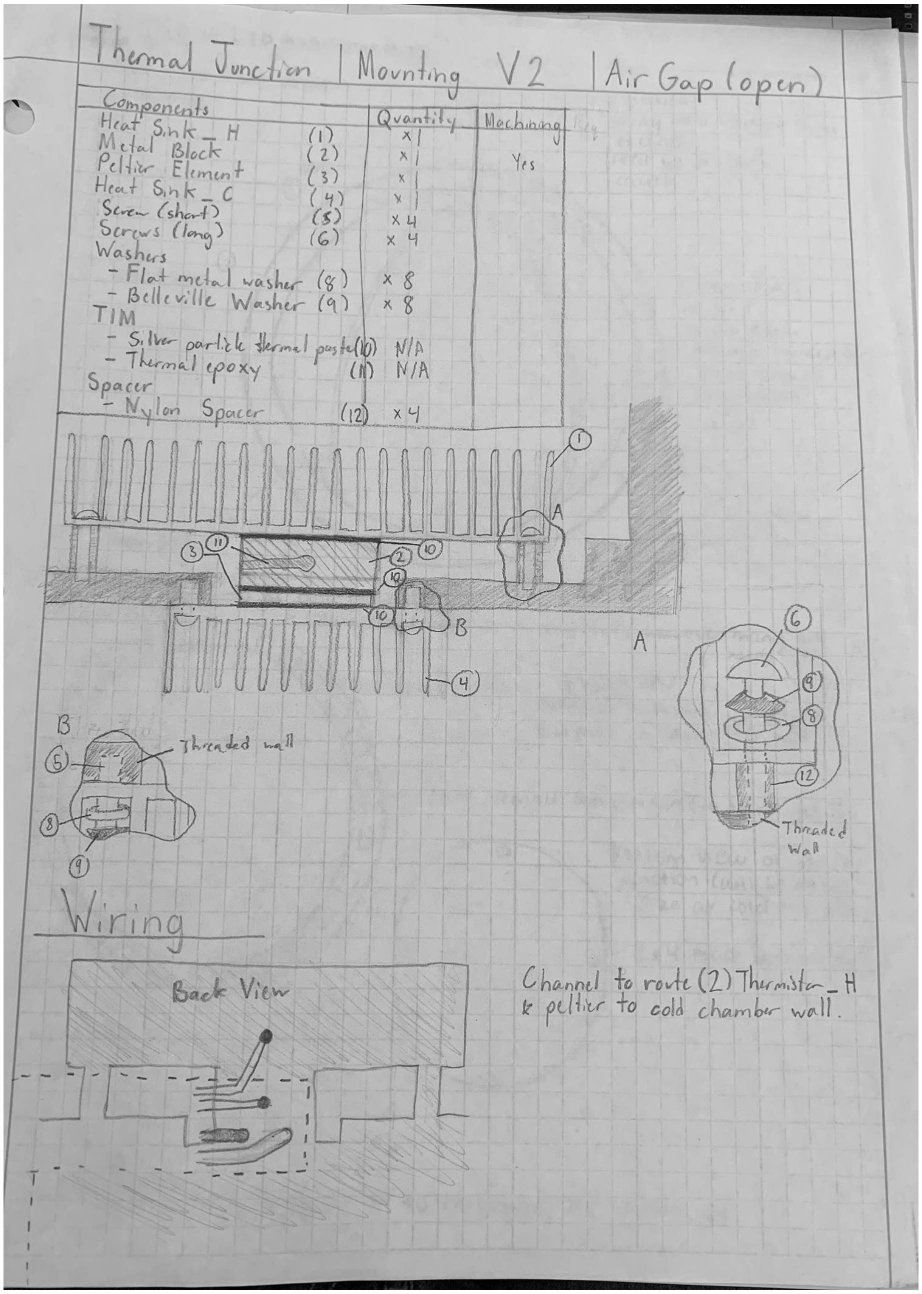


Figure II-B4: Ventilation for the hot chamber

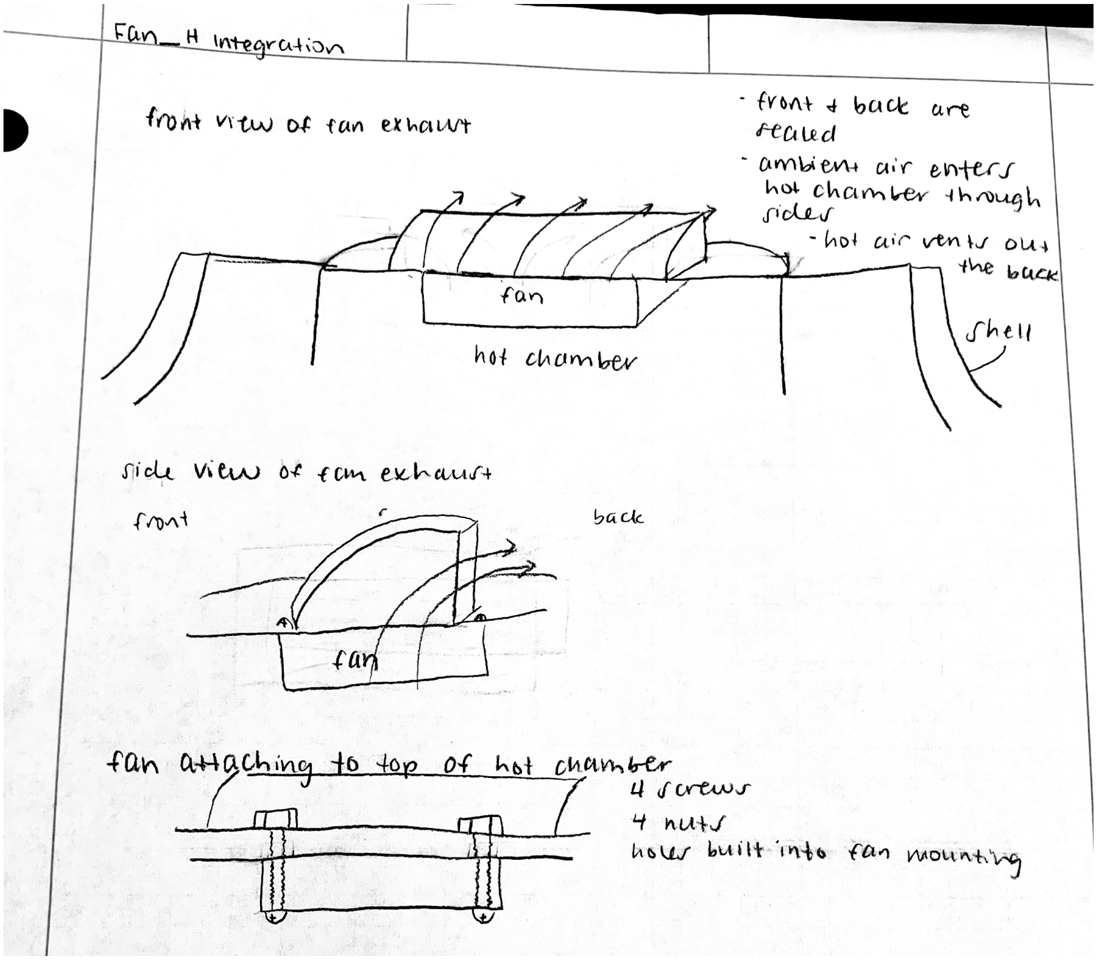


Figure II-B5: Overall chamber design with insulation

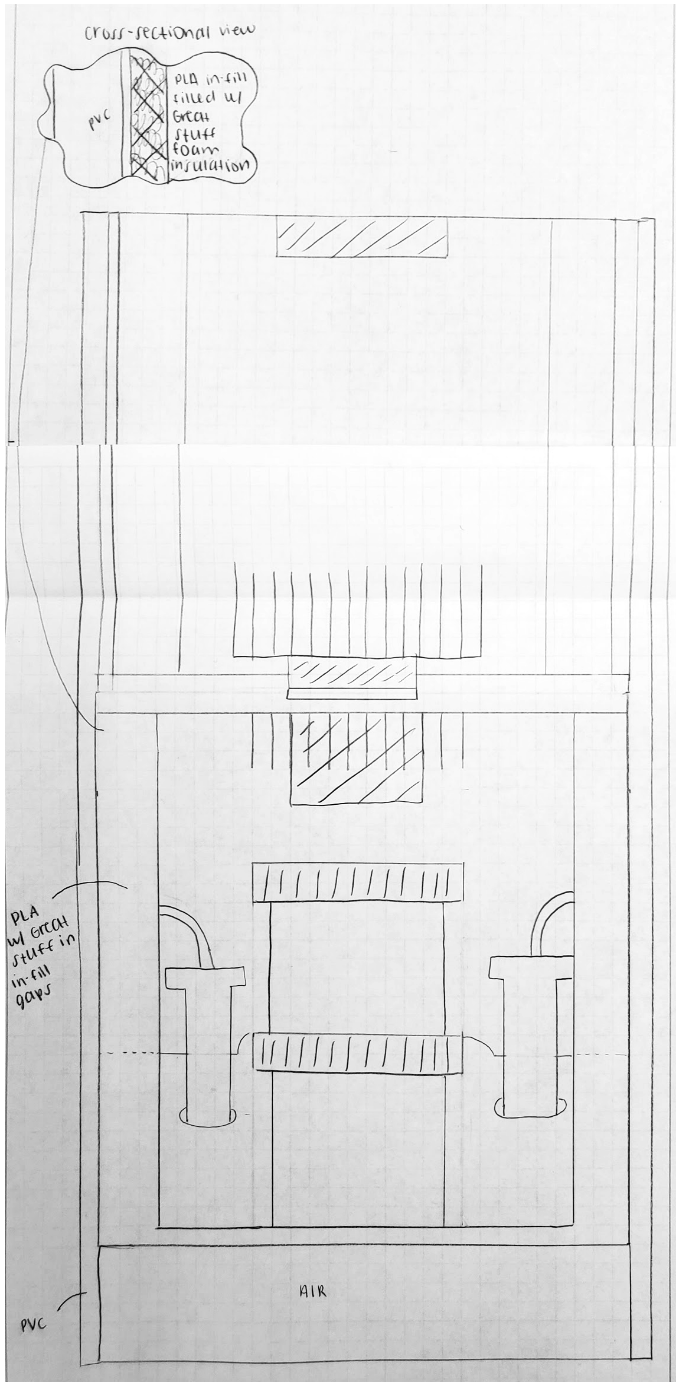
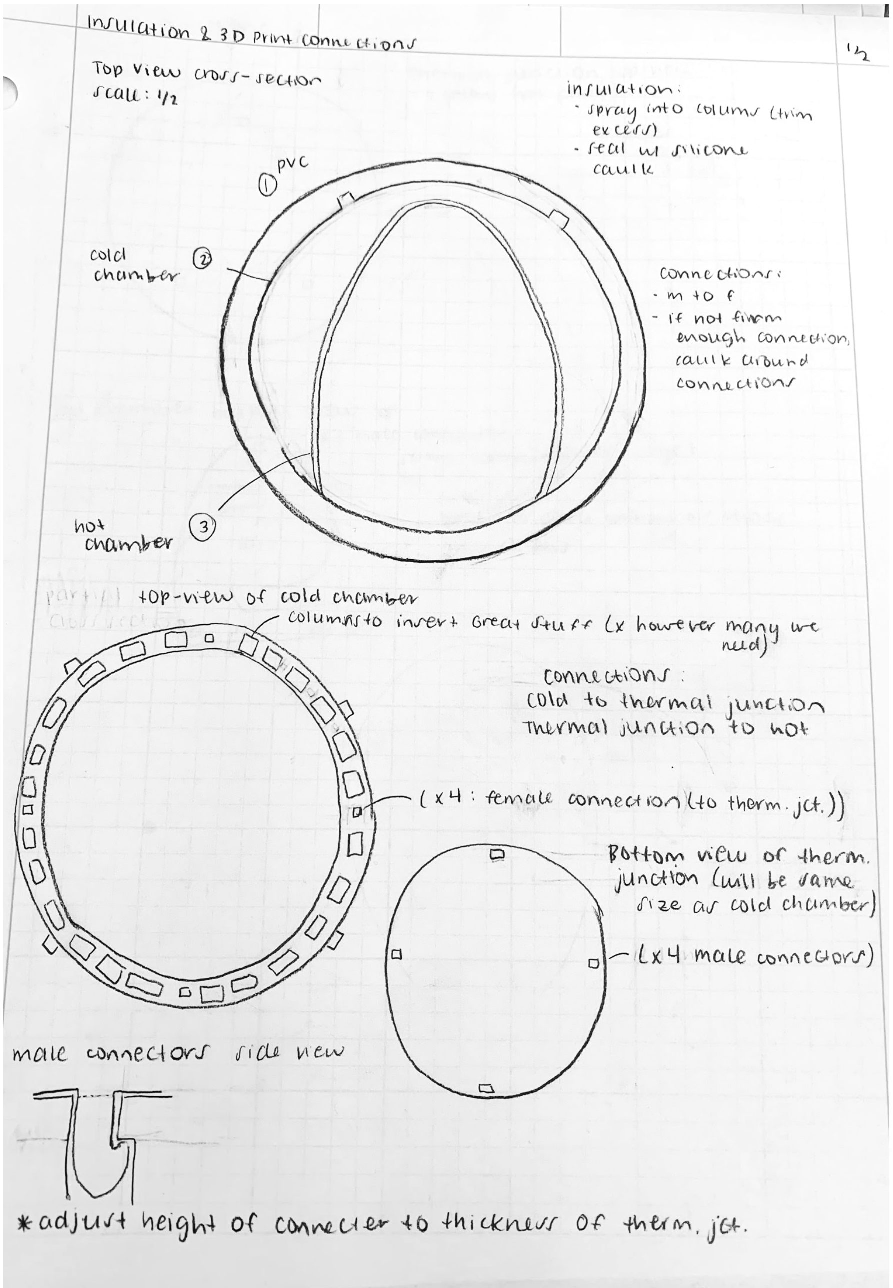


Figure II-B6: Hot chamber integration (connectors, insulation gaps, etc.)



Appendix C: Requirements, Constraints, and Specifications

I. Aesthetic Design

Requirements

Per the Aesthetic Design Scope, the clients require a “stylish, compact refrigerator to hold solder paste and syringes inside of the ECE clean room”. The fridge must be able to hold at least two tubs of solder paste, weighing 250 grams each and about the size of a large pill bottle, and two solder syringes. The fridge will contain both leaded and unleaded solder. The design shall contain the following aesthetics:

1. Timeless + Simplistic
2. User feedback
3. Novelty
4. Luster
5. Sophisticated / Classy
6. Illumination

Constraints

1. The outer shell shall incorporate fabrication methods that are outside of ones available in the Engineering Building facilities.
2. The outer shell shall not resemble a refrigerator, but instead resemble an art piece to a layperson.

Aesthetic Specifications

1. The marble coating shall contain swirls of oiled bronze with mica flakes as well as colors from a grayscale.
2. The marble coating shall be translucent.
3. The light shining through the outer shell shall be clearly visible to users through the marble coating, much like the illumination of a himalayan salt lamp.
4. There shall be realistic leaves, vines and flowers (similar to that of a sweet potato vine) on the Outer Shell.

Technical Specifications

Overall System

Specifications

1. Shall comply with the aesthetics specified in the Aesthetic Scope of Work.
2. Shall not exceed noise levels above 50dBa.

3. Shall comply with industry standards and regulations.

Test Specifications

1. Use decibel meter to make sure the system doesn't exceed noise levels above 50 dBa.

Implementations

This system will integrate a Temperature Control System, User Interface System, Opening/Closing System, Lighting System, and Power Distribution System including both the inside of the fridge that illuminates the internal chamber and a soft glow that is visible from the outside of the fridge.

Affects

1. The User Interface - the aesthetics shall tie together with the overall aesthetic of the system.
2. Opening/Closing Mechanism - the aesthetics of the shell tie together with the overall aesthetic of the system, shall not exceed sound limit, shall fit in .
3. Power Distribution - Shall comply with the FCC EMC standard.
4. Chamber and Storage Compartment are all involved with working together to satisfy the specifications in the overall system.
5. Temperature Controller - Shall comply with the FCC EMC Standard

Affected By

1. Users - universal design
2. Utilities - 120VAC/20A and compressed air
3. Environmental conditions - temperature, humidity, lighting

Failure Modes

Failure of any of the aforementioned systems, whether in the mechanical or electrical components, will prevent the fridge from optimal performance and from providing a pleasant experience for the end users.

Outer Shell

Specifications

1. The outer shell shall enclose the chamber, lighting, opening mechanism, temperature control, and storage compartment systems.
2. The outer shell shall hide the internal electronics and mechanisms from the user's sight.
3. The outer shell's *inner material* shall be translucent to allow the internal lighting to shine through.

4. The outer shell’s *outer coating* shall be opaque and have a chiseled physical appearance, where the cracks in the outer coating show reveal the inner material.
5. The outer shell shall include mounts on the top surface for the buttons the user interface system.
6. The outer shell shall not topple or rock during normal operation.

Test Specifications

1. The refrigerator is put in the fully open position and (x N) force is applied radially to the top of the chamber parallel to the base. The base should not wobble or tip.

Implementations

1. The outer shell is designed to look like marble, which will be accomplished by using a veining pattern and a polished finish.
2. The outer shell shall integrate a realistic looking sweet potato plant (vines, leaves and flowers) to blend together the user interface and overall aesthetic.

Affects

1. The aesthetics of the outer shell affect the layout and physical design of each of the mechanical/electrical systems in the environmental chamber.
2. The opacity of the material which the lights are shining through will determine the luminosity required for the LEDs.

Affected By

1. The size of the outer shell will be directly impacted by the size and shape of the rest of the mechanical and electrical systems

User-Interface

Technical Specifications

1. The user-input shall require only a single press to operate.
2. The refrigerator must give visible user feedback in less than 200 milliseconds.
3. The interface shall convert the 3-button input into 5 output states: Hot, Cold, Close, None (no buttons pressed), or Multiple buttons pressed.
4. The button (Snaptron BL12340) requires a pressure force of 340g to activate the button press within a tolerance of +/- 30 g or 10% of the trip force.
5. The PCB shall be horizontally oriented and approximately 8.89 cm by 2.5 cm, and shall have a space of 1.27 cm between buttons and from each horizontal end of the PCB with a space of 0.635 cm from each vertical edge.

6. The buttons corresponding to opening the cold and hot chamber shall have a blue and red LED under the tactile dome, respectively. The button corresponding to closing the chamber shall have a white LED under the dome. This will guide the user to complete the desired action.
7. Each button will have a leaf placed on top with a symbol on the leaf for hot, cold, and close respectively.
8. attachment method
    a. domes to PCB pads
        i. The pads & tactile dome should be covered by a transparent plastic sheet.
    b. PCB to shell
        i. Board shall lay in a recess (approximately 8.89 cm by 2.5 cm by ***insert board thickness***) and the wires should be accessible but not seen externally
        ii. PCB shall be mounted so that the buttons are exposed through the outer shell
    c. Leaf to dome:
        i. There shall be one leaf attached on top of each button.

Test Specifications

1. While the button is pushed, an output signal should be sent to the lighting system to indicate to the user that the signal from the button push has been received.

Implementations

Final: 3 tactile domes under tinted leaves; the vine with these leaves will only be on the right side of the chamber to make it intuitive. Press leaves to translate motion to buttons.

The user input system will allow for three separate inputs, each corresponding to one of the three states: hot (the hot chamber accessible to the user), cold (the cold chamber is accessible to the user) and closed. There will be three different buttons in order to trigger each action. One button will correspond to the cold chamber, the other to the hot chamber and the third to close. When the mechanism is in its closed state, pressing the hot button will signal to the user and then open to the hot chamber, and the cold button will signal the user and then open to the cold chamber. When the mechanism is open to any chamber, pressing the close button will bring the chamber back to its original closed state.

Affects

1. The user input directly impacts the aesthetic design and its external appearance based on the state of the user interface system. (specification #1)
2. The user input system will have to work with the lighting system to indicate the input received. (specification #5)
3. The user input affects the opening and closing mechanism, as it will trigger the

actions of the open/close mechanism. (specification #6)

Affected By

1. The type of lighting chosen will affect what the user sees to indicate the refrigerator is working.

Failure Mode

1. Button fails open, the lighting will not display the designed visual input feedback and the open/close mechanism will not be triggered.
2. Button fails closed, the lighting will continually display the visual input feedback and the open/close mechanism will run to the position related to the failure and requires manual override to exit that position.

Lighting System

Specifications

The climate chamber shall provide user feedback and diagnostics with the use of a lighting system.

1. The lights shall be used internally to provide a glowing effect on the outside.
2. The cold chamber shall have enough light to read the content labels.
3. The External shell lights have 5 rows of rings and will be used to relay status. Each ring will have 8 lights. The 5 rows will be positioned equally along the external shell.
4. The rings will be mounted behind an opaque material.
5. The lights that are located inside the chamber will light up as the refrigerator opens.
6. The lighting system shall interface with temperature sensors to indicate the temperature of the cold chamber.
7. Depending on the internal temperature of the cold chamber, all the external lights shall display a breathing effect to indicate if the refrigerator is cooling down and slow down as the temperature stabilizes.
8. If the temperature of the internal chamber is greater than +/-1.5 C of the set point, the external shell lights will flash the corresponding ring to indicate the chamber temperature.
9. External Shell Lights will indicate how far the climate chamber mechanism is opened. Each ring of light will illuminate when the position of the mechanism moves in increments of 20%.

Test Specifications

1. Using software flag a sensor reading error. This should trigger the 3rd ring to flash at 1 Hz.
2. Using software causes failure to reach a set temperature. This should trigger the 3rd ring to flash 3 times at 1 Hz and rest for 2 sec.

3. Using software flag error to reach a desired position. This should trigger the 4th and 5th to flash 4 times at 1 Hz and rest for 2 sec.

Implementations

In order to accomplish a glow, there will be backlighting within the refrigerator shell to accomplish a ‘lit-from-within’ look. This lighting will be visible through the base color of the faux-marble. The quotient of the total luminous flux emitted by the total lamp power input. It is expressed in lumens per watt (lm/W). The opacity of the material which the lights are shining through will determine the luminosity required for the LEDs.

Microcontroller-driven LEDs will be mounted behind a translucent material to provide a backlighting effect. The LEDs will change patterns to indicate temperature, normalized operation and failure mode in the refrigerator. There will be 10 control lines coming from the microcontroller which will control the output of the 5 external shell rings and the 5 internal chamber rings.

Affects

1. The lighting system does not affect other systems

Affected by

1. The lighting system shall be powered by the power distribution system.
2. The lighting system shall take the temperature reading from the temperature sensor and shall indicate the user whether the system is stable or cooling until it reaches the desired temperature.
3. The lighting system shall receive positional status from the open/closing system, this will turn on and off the interior lighting and convey the position with the exterior lighting.
4. The failure modes of the opening/closing, position sensor, user interface, and temperature systems affect the lighting system, the lighting system shall light up in different patterns and different locations that correspond to the systems that are indicating failure.

Failure Mode

1. The lights are disconnected, they will all be off.
2. If an individual LED burns up it will be off.
3. If the diagnostic boot pattern is incorrect, then the lights are failing.
4. Visual user feedback is not displayed in resting state or when the button is pressed but the open/close mechanism operates normally, check for lighting system failure.

State	Steady State	Temperature Transition	Motion Transition

Condition	If **Cold Chamber** Temp is within +/- 1.5C of 10 C	Internal **Cold Chamber** Temperature Exceeds 1.5C of upper or lower limits **1st ring**: Temp >= 15C **2nd Ring**: Temp >= 11.5C and <15 **All Rings**: Temp at within Setpoint 1.5C **4th Ring**:Temp <8.5C and >=7C **5th Ring**: Temp <7C	Opening Mechanism begins to open
Effect	Shell Lights Slow frequency (0.267 Hz)	Corresponding Single Ring Blinks Quickly (1 Hz)	Shell and internal chamber Light rings turn on to indicate position. All Rings light up when fully opened.

Error Indications

	Errors	Lighting Rings	Pattern
Position			
	Limit Switch, Open close error	Rings 1 and 2	blink at 1 HZ
Temp Control			
	Peltier Element, thermistor, insulation	Ring 3	blink at 1 HZ
Power Distribution			
	Electrical Failure	Rings 1 and 5	blink at 1 HZ

Temperature Control and Sensors

Specifications

1. At steady state, the control system shall keep the cool chamber air between the minimum of 2 °C and a maximum of 10 °C.
2. The user, peltier, and other materials shall be protected from temperatures exceeding 50 °C by opening the chamber to the hot side if it is too hot, and

notifying the lighting system of an error
3. The cold side of the peltier shall not get below the dew point
4. The cold chamber fan shall be turned off when the peltier is turned off
5. The hot chamber fan shall always be on
6. Cooling/heating system shall have an automatic safety turn-off mechanism in case of a faulty temperature sensor, open circuit, short circuit.

Test Specifications

1. While the temperature control system is running, one of the thermistors should be removed to simulate a sensor electrical failure. This should trigger the system's automatic safety turn-off mechanism.

Implementations

Controlling Algorithm: Bang Bang with Hysteresis

Monitors the hot and cold side temperatures and controls the pelter driver. If the cold side ambient is too hot, it will turn the output on. If the cold ambient side gets too cold, it will turn the output back off. The hot side shall not exceed 50 °C while the cold side shall not go below 2 °C. If the cold side peltier is below the dew point, it will turn the output off to avoid condensation.

Temperature Sensors: Thermistor

Three thermistors will be used to monitor the temperatures of the hot side of the peltier, the cold side of the peltier, and the cold compartment ambient temperature, so that the controlling algorithm can control the peltier driver accordingly.

Peltier Driver: Relay

A relay will be used to drive the peltier element.

Affects

1. Lighting System - the control system will send temperature information for the two compartments, as well as error state information to the lighting system.
2. Power system - the power system shall supply the appropriate voltage and current to the control system and the Peltier element.
3. Wiring and internal mounting of the components inside the compartments.

Affected By

1. Opening/closing - must turn off output when open, on when closed.

Failure Modes

1. Sensor mounting failure

2. Sensor electrical failure

3. Sensor out of calibration failure
4. Driver failure
5. Peltier failure

Opening and Closing Mechanisms

Specifications

1. The chamber shall move fluidly from fully closed to fully open in 4 seconds.
2. The hot and cold chambers must be fully accessible, vertically, in the open position.
3. The chamber must engage an environmental seal when not in the cold open position.
4. The chamber must be able to stop in two different open positions: Hot & Cold.
5. The mechanism shall allow a manual override.
6. All mechanism components must have a minimum life cycle of 11,000 cycles.
7. The mechanism shall use the same orifice for opening and closing so the closing profile matches the opening profile, to prevent user harm.
8. The air bellow must be contained within the compartment.

Test Specifications

1. Use a timer to make sure the chamber moves from fully closed to fully open in 4 seconds.

Implementations

In order for the refrigerator to open and close, a raising/lowering mechanism is needed. There will be **limit switches** to sense the position of the chambers.

Air Bellow

Inflating and deflating a round bellow allows the cylinder to have vertical motion. Controlled by compressed air, which is already supplied to the clean room.

- Uniform force
- Closes with gravity therefore serves as a safety feature

Solenoid Valve

Possible valve systems:

- 3 way normally closed, 2 position valve could allow 3 positions to be reached; closed(all valves closed), hot (valve A open), and cold (valve A and B open and mixing).
- 4 way, 3 position valve can stop an actuator or allow it to float in addition to its reachable positions

Affects

1. The opening/closing mechanism will influence how the fridge seals and, in turn, how the temperature is regulated/maintained.
2. The opening/closing mechanism will affect the user interface in terms of aesthetics. It must raise smoothly as to not distract from the overall design.
3. The position of the mechanism will determine the lighting on the chamber.
4. Failure modes of the opening/closing mechanism will affect the lighting of the refrigerator shell.

Affected By

1. The user input will determine the position of the opening mechanism.
2. The dimensions of the shell and storage compartment will affect the size of the mechanism.
3. The intuitive user input will trigger the open/close mechanism.

Failure Mode (Pneumatic Inflatable Bellow)

1. In case of a power failure, the climate chamber can be opened by using force to manually raise the chamber.
2. If the system loses air pressure, the chamber will not move.

Power Distribution

Specifications

1. Must supply regulated voltage and current to the Temperature Control System, the Lighting system, and the Opening/Closing Mechanism (tentative).
2. Must have safety mechanisms for breaking circuit in failure cases where current draw exceeds current limits.
3. Power Distribution system must be powered with utilities in clean room, 120VAC/ 20A a wall outlet, (compressed air if needed).

Test Specifications

1. Use voltmeter to show the Temperature Control System has the correct regulated supply voltage.

Implementations

The Power Distribution system will be powered from a standard 120VAC/20A wall outlet, will use an off the shelf AC/DC power plug, a power distribution PCB with connector headers that will distribute DC power to the Temperature Control, Lighting, and User Interface systems via wires with corresponding header connectors.

Affects

1. The Power Distribution system provides power for the peltier element.
2. The Power Distribution system provides power to the shell lighting.
3. The Power Distribution system provides power to the compartment lighting of the refrigerator.
4. The Power Distribution system supplies power to the Opening/Closing Mechanism.
5. The Power Distribution system provides power to the Temperature Control system.
6. The Power Distribution system provides power to the User Interface system.

Affected By

N/A

Failure Mode

1. An internal wire is disconnected.
2. External power plug is unplugged.

Chamber

Specifications

1. When the storage container is opened, the user must be able to access the compartments by reaching in and grabbing the desired materials.
2. There shall be two separate chambers within the main chamber; one for the hot area and one for the cold area.
3. Cold chamber must be illuminated to allow the user to read labels.
4. The cold chamber space must be able to hold two pots of solder as well as two solder syringes.
5. The overall chamber shall be a complete cylinder, while each compartment has a circular sector open for access.
6. The cold chamber shall contain one LED on either side of the opening.
7. The chamber shall engage in an environmental seal when in the closed position.
8. The chamber shall require no more than 33 lbf to be manually raised. (OSHA std)

Test Specifications

1. Measure the dimensions of the hot and cold chambers to ensure the soldier pots and soldier syringes have 1.5” of clearance from the chamber edge.

Implementations

The main chamber is made up of two separate chambers, a hot chamber and cold chamber. The hot chamber is the upper half of the chamber and the cold chamber is the lower half. Both of these chambers will be separated with the peltier element in between. The cold side of the peltier element will be against the ceiling of the cold chamber, and the hot side of the peltier element will be against the floor of the hot chamber.

Ballpark dimensions of the chamber (NOT final):

- the total height of the chamber will be 12”
- the diameter of the chamber will be 12”
- cold compartment height will be 7”
- hot compartment height will be 4”
- chamber will allow 1” of space between compartments for the peltier element
- the chamber opening shall be about 10.5” wide (120 degree angle)
- Chamber compartment should allow for 1.5” minimum clearance in addition to solder paste jar dimensions

Affects

1. Overall system - the space needed by the solder pots are will drive the inside dimensions of the chamber which will affect the dimensions of the storage compartment and how large we will make the fridge.
2. Lighting system - There will need to be a light setup along the compartment opening which is separate from the pulsing light setup being used within the shell.

Affected By

1. Temperature Control System - The two separate compartments for hot/cold are regulated via this system.
2. The amount of solder paste and syringes being stored in the chamber.

Failure Mode

1. The chamber opening is blocked and the user cannot reach into it.
2. The lights do not illuminate the inside of the chamber and the user cannot see all the items it holds.

Storage Compartment

Specifications

1. The storage compartment shall insulate the hot chamber and cold chamber when in the closed position.
2. The storage compartment shall allow the open/close mechanism to raise/lower the chamber.
3. The storage compartment shall not impede the peltier element receiving power.

Test Specifications

1. Measure the temperature immediately outside the storage compartment to ensure the temperature does not deviate from the room temperature (+/- 3 °C)

Implementations

Polyurethane foam is the most commonly used material for refrigerator insulation. It has a very high R value ranging from 5.0 to 7.0 per inch based on they type of Polyurethane (Board, Spray on, Poured, and Sheets or “Styrofoam”) and is moisture resistant. Rigid polyurethane foam is the typical form of polyurethane used for refrigerator applications. Polyurethane foam also has high rigidity and adhesion of external skins such as plastics and metals.

Affects

1. The storage compartment dimensions will affect the dimensions of the shell.

2. The storage compartment fully insulates the chamber.

Affected By

1. The chamber dimensions will determine the dimensions of the storage compartment.
2. The shape of the chamber may affect how the polyurethane is applied.
3. The storage compartment size will be affected by peltier cooler efficiency.

Failure Modes

1. Any gaps or breaks on the polyurethane will compromise the insulation.
2. The peltier element may damage the polyurethane foam from high temperatures.

II. Technical Design

Overall System

Specifications

1. Shall comply with the aesthetics specified in the Aesthetic Scope of Work.
2. Shall not exceed noise levels above 50dBa.
3. Shall comply with industry standards and regulations.

Test Specifications

1. Use a decibel meter to make sure the system doesn't exceed noise levels above 50 dBa.

Implementations

This system will integrate a Temperature Control System, User Interface System, Opening/Closing System, Lighting System, and Power Distribution System including both the inside of the fridge that illuminates the internal chamber and a soft glow that is visible from the outside of the fridge.

Affects

1. The User Interface - the aesthetics shall tie together with the overall aesthetic of the system.
2. Opening/Closing Mechanism - the aesthetics of the shell tie together with the overall aesthetic of the system, shall not exceed sound limit, shall fit in .
3. Power Distribution - Shall comply with the FCC EMC standard.

4. Chamber and Storage Compartment are all involved with working together to satisfy the specifications in the overall system.
5. Temperature Controller - Shall comply with the FCC EMC Standard

Affected By

1. Users - universal design
2. Utilities - 120VAC/20A and compressed air
3. Environmental conditions - temperature, humidity, lighting

Failure Modes

Failure of any of the aforementioned systems, whether in the mechanical or electrical components, will prevent the fridge from optimal performance and from providing a pleasant experience for the end users.

Opening/Closing Mechanism

Specifications

1. The chamber shall move fluidly from fully closed to fully open in 4 seconds.
2. The hot and cold chambers must be fully accessible, vertically, in the open position.
3. The chamber must engage an environmental seal when not in the cold open position.
4. The chamber must be able to stop in two different open positions: Hot & Cold.
5. The mechanism shall allow a manual override.
6. All mechanism components must have a minimum life cycle of 11,000 cycles.
7. The mechanism shall use the same orifice for opening and closing so the closing profile matches the opening profile, to prevent user harm.
8. The air bellow must be contained within the compartment.

Test Specifications

1. Use a timer to make sure the chamber moves from fully closed to fully open in 4 seconds.

Affects

1. The opening/closing mechanism will influence how the fridge seals and, in turn, how the temperature is regulated/maintained.
2. The opening/closing mechanism will affect the user interface in terms of aesthetics. It must rise smoothly as to not distract from the overall design.
3. The position of the mechanism will determine the lighting on the chamber.
4. Failure modes of the opening/closing mechanism will affect the lighting of the refrigerator shell.

Affected By

1. The user input will determine the position of the opening mechanism.

2. The dimensions of the shell and storage compartment will affect the size of the mechanism.
3. The intuitive user input will trigger the open/close mechanism.

Failure Mode (Pneumatic Inflatable Bellow)

1. In case of a power failure, the climate chamber can be opened by using force to manually raise the chamber.
2. If the system loses air pressure, the chamber will not move.

Implementation Analysis

Table B1: Rack and Pinion Pros and Cons.

Pros	Cons
• Inexpensive • Easy way to convert rotation to linear motion • Low sound • Easy to install or design • Easy to maintain or replace • Can be produced “in house” (cnc/3d printed)	• Possibility of binding • Could stress/overheat motor • Could not align itself • Not 1 unit, 2 seperate parts • Bulkiness of 1-2 motors

Table B2: Lead Screw Pros and Cons.

Pros	Cons
• Can lift heavy loads • Can stop when needed (no safety risk) • Low cost • Compact • Easy to manufacture	• Low efficiency (Slow) • High friction leads to wear and tear on threads

Table B3: Pneumatic Linear Actuator Pros and Cons.

Pros	Cons

- Fluid smooth motion - Relatively quiet - High speed and load capabilities	- May have trouble switching between compartment levels - May not be able to stop if safety becomes an issue - May require maintenance

Table B4: The Pulley System Pros and Cons.

Pros	Cons

• Relatively Quiet (only sound from motor)
• Can reduce the amount of force needed via motor to raise/lower compartments by adding wheels
• Can stop when needed (no safety risk)
• Low cost
	• Requires ropes
	  ○ Could become tangled or cause unnecessary friction
	• Requires space so it can co-exist with chambers
	  ○ Will not have room with the shell design selected
	    ■ Conflicts with slender shape

Lighting System

Specifications

The climate chamber shall provide user feedback and diagnostics with the use of a lighting system.

1. The lights shall be used internally to provide a glowing effect on the outside.
2. The cold chamber shall have enough light to read the content labels.
3. The External shell lights have 5 rows of rings and will be used to relay status. Each ring will have 8 lights. The 5 rows will be positioned equally along the external shell.
4. The rings will be mounted behind an opaque material.
5. The lights that are located inside the chamber will light up as the refrigerator opens.
6. The lighting system shall interface with temperature sensors to indicate the temperature of the cold chamber.
7. Depending on the internal temperature of the cold chamber, all the external lights shall display a breathing effect to indicate if the refrigerator is cooling down and slow down as the temperature stabilizes.
8. If the temperature of the internal chamber is greater than +/-1.5 C of the set point, the external shell lights will flash the corresponding ring to indicate the chamber temperature.
9. External Shell Lights will indicate how far the climate chamber mechanism is opened. Each ring of light will illuminate when the position of the mechanism moves in increments of 20%.

Test Specifications

1. Using software flag a sensor reading error. This should trigger the 3rd ring to flash at 1 Hz.
2. Using software causes failure to reach a set temperature. This should trigger the 3rd ring to flash 3 times at 1 Hz and rest for 2 sec.

3. Using software flag error to reach a desired position. This should trigger the 4th and 5th to flash 4 times at 1 Hz and rest for 2 sec.

Affects

1. The lighting system does not affect other systems

Affected by

1. The lighting system shall be powered by the power distribution system.
2. The lighting system shall take the temperature reading from the temperature sensor and shall indicate to the user whether the system is stable or cooling until it reaches the desired temperature.
3. The lighting system shall receive positional status from the open/closing system, this will turn on and off the interior lighting and convey the position with the exterior lighting.
4. The failure modes of the opening/closing, position sensor, user interface, and temperature systems affect the lighting system, the lighting system shall light up in different patterns and different locations that correspond to the systems that are indicating failure.

Failure Mode

1. The lights are disconnected, they will all be off.
2. If an individual LED burns up it will be off.
3. If the diagnostic boot pattern is incorrect, then the lights are failing.
4. Visual user feedback is not displayed in resting state or when the button is pressed but the open/close mechanism operates normally, check for lighting system failure.

User Interface

1. Button fails open:
    a. Lighting will not display the designed visual input feedback
    b. Open/close mechanism will not be triggered.
2. Button fails closed:
    a. Lighting will continually display the visual input feedback
    b. Open/close mechanism will run to the position related to the failure and requires manual override to exit that position.
3. If the diagnostic boot pattern is incorrect, then the lights are failing.
4. Visual user feedback is not displayed in resting state or when the button is pressed but the open/close mechanism operates normally, check for lighting system failure.

Temperature Control System

Specifications

1. At steady state, the control system shall keep the cool chamber air between the minimum of 2 °C and a maximum of 10 °C.

2. The user, peltier, and other materials shall be protected from temperatures exceeding 50 °C by opening the chamber to the hot side if it is too hot, and notifying the lighting system of an error
3. The cold side of the peltier shall not get below the dew point
4. The cold chamber fan shall be turned off when the peltier is turned off
5. The hot chamber fan shall always be on
6. Cooling/heating system shall have an automatic safety turn-off mechanism in case of a faulty temperature sensor, open circuit, short circuit.

Test Specifications

1. While the temperature control system is running, one of the thermistors should be removed to simulate a sensor electrical failure. This should trigger the system's automatic safety turn-off mechanism.

Implementation Analysis

Controlling Algorithm: Bang Bang with Hysteresis

Monitors the hot and cold side temperatures and controls the pelter driver. If the cold side ambient is too hot, it will turn the output on. If the cold ambient side gets too cold, it will turn the output back off. The hot side shall not exceed 50 °C while the cold side shall not go below 2 °C. If the cold side peltier is below the dew point, it will turn the output off to avoid condensation.

Temperature Sensors: Thermistor

Three thermistors will be used to monitor the temperatures of the hot side of the peltier, the cold side of the peltier, and the cold compartment ambient temperature, so that the controlling algorithm can control the peltier driver accordingly.

Peltier Driver: Relay

A relay will be used to drive the peltier element.

Affects

1. Lighting System - the control system will send temperature information for the two compartments, as well as error state information to the lighting system.
2. Power system - the power system shall supply the appropriate voltage and current to the control system and the Peltier element.
3. Wiring and internal mounting of the components inside the compartments.

Affected By

1. Opening/closing - must turn off output when open, on when closed.

Failure Modes

1. Sensor mounting failure
2. Sensor electrical failure

3. Sensor out of calibration failure
4. Driver failure
5. Peltier failure

Microcontroller Selection

Table B5: Main Board Microcontroller GPIO and Communication Needs.

	A	B	C	D	E	F
1	**Main Board**	**Ins**	**Outs**	**InOuts**	**PWMs**	**Serial**
2	*LED Rings*	0	0	0	5	0
3	*User Interface*	0	0	3	0	0
4	*Solenoids*	0	2	0	0	0
5	*Position Sensors*	3	0	0	0	0
6	*Comms*	0	0	0	0	1
7	*Debug*	0	2	0	0	1
8	**Total =**	3	4	3	5	2

Table B6: Temperature Microcontroller GPIO and Communication Needs.

A	B	C	D	E	F	G
Temperature Control Board	**Ins**	**Outs**	**Analog Ins**	**InOuts**	**PWMs**	**Serial**
Peltier	0	1	0	0	0	0
Thermistors (4)	0	0	4	0	0	0
Fans (2)	2	0	0	0	2	0
Cold Chamber Lights	0	1	0	0	0	0
LEDs	0	1	0	0	0	0
Comms	0	0	0	0	0	1
Debug	0	1	0	0	0	1
Totals =	2	4	4	0	2	2

Table B7: Condensed GPIO and Communication Need and Possible Microcontrollers.

	A	B	C	D	E	F	G	H	I	J	K	L
1					**Module**	**Ins**	**Outs**	**Analog Ins**	**InOuts**	**PWMs**	**UART**	**GPIO**
2					Main	3	4	0	3	5	2	10
3					TemperatureControl	2	4	4	0	2	2	6
4					**Minimum Spec**	**3**	**4**	**4**	**3**	**5**	**2**	**10**
5												
6												
7												
8	**Processor**	**Manufacturer**	**Datasheet**	**Price**	**Packages**			**Analog Ins**		**PWMs**	**UART**	**GPIO**
9	ATmega324PA	Microchip	http://www.microchip	$2.77	40/PDIP, 44/TQFP, 44/VQFN, 49/VFBGA			4		6	2	32
10	ATmega164PA	Microchip	http://www.microchip	$3.54	40/PDIP, 44/TQFP, 44/VQFN, 49/VFBGA7			4		6	2	32
11	**ATmega644PA**	**Microchip**	**http://www.microch**	**$3.54**	**40/PDIP, 44/TQFP, 44/VQFN**			**4**		**6**	**2**	**32**
12	ATmega64A	Microchip	http://www.microchip	$3.54	64/TQFP, 64/VQFN			8		8	2	53

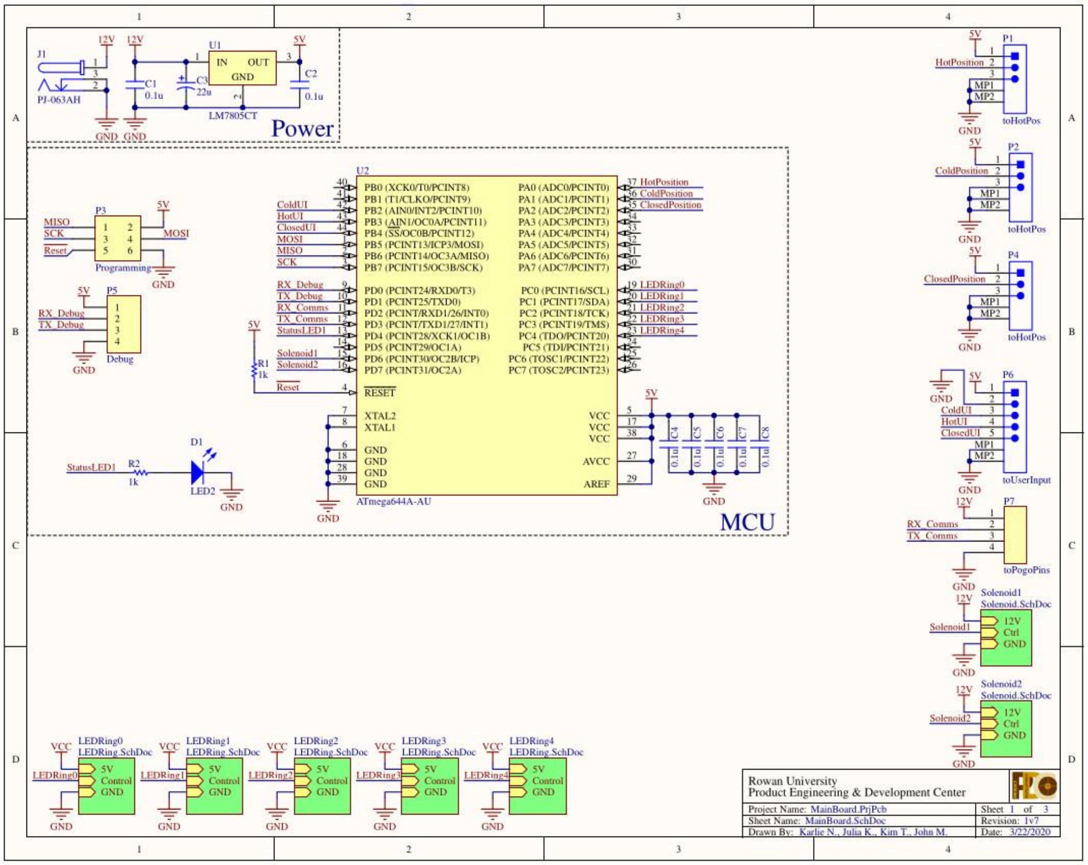
The microcontroller was selected based on the required specifications of the two PCBs. The team decided that in order to speed up both software and electrical development, it would be most effective to use the same microcontroller for the Main Board and the Temperature Control Board. A matrix of requirements was made for both PCBs and a microcontroller that will satisfy both board requirements. PIC, Microchip, Texas Instruments, and ST processors were parametrically searched. Ultimately, the processor choice was narrowed by a mean time to failure and development time costs. Mean time to failure increases with complexity of the system so the processor meets all of the requirements and has the least complex architecture is more favorable than one with additional functionality that is unneeded for this application. The development time cost metric was based on what materials need to be purchased to program and debug the processor and how long the software development time would take compared to another processor. ATmega644PA was ultimately chosen because it was one of the only processors with an 8-bit architecture that also had the least excess features. Additionally, all of the program and debugging hardware for the processor had already been purchased and members of the software team had past programming experience with similar Microchip processors so the development time would be faster and ultimately cost less than the other options. The 644PA was chosen over the 164PA and 324PA because it had more memory at an insignificantly higher price, so the software team would have more programming headroom to make memory space less of a constraint.

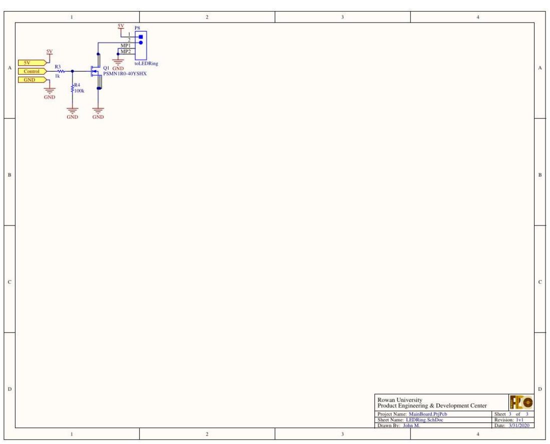
Appendix D: Electrical & Software Development

Electrical Development

The team used Altium Designer as the ECAD software for the PCB design. The team used git version control and a GitLab repository to manage merging multiple students working on the same project. Each design requirement was converted to a GitLab issue where one student checked out the issue's branch, implemented the change, and pushed to start a peer review. If the change was accepted, it was merged into the master branch.

The GitLab repository can be found here:
https://gitlab.com/A-Team-Rowan-University/pedc/cleanroomfridge/cleanroomfridge-ecad





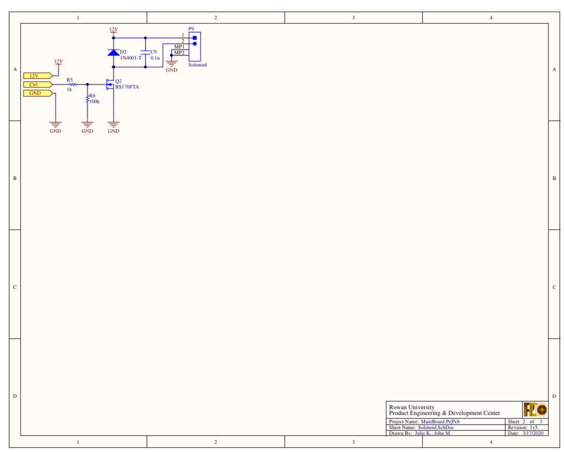


Figure I-D1: Main Board Schematic

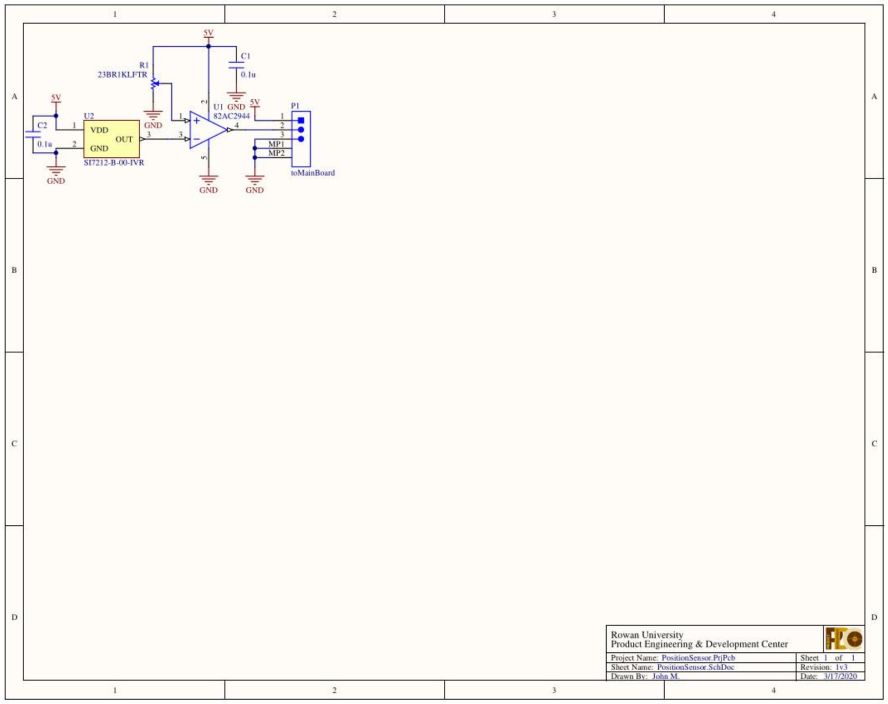
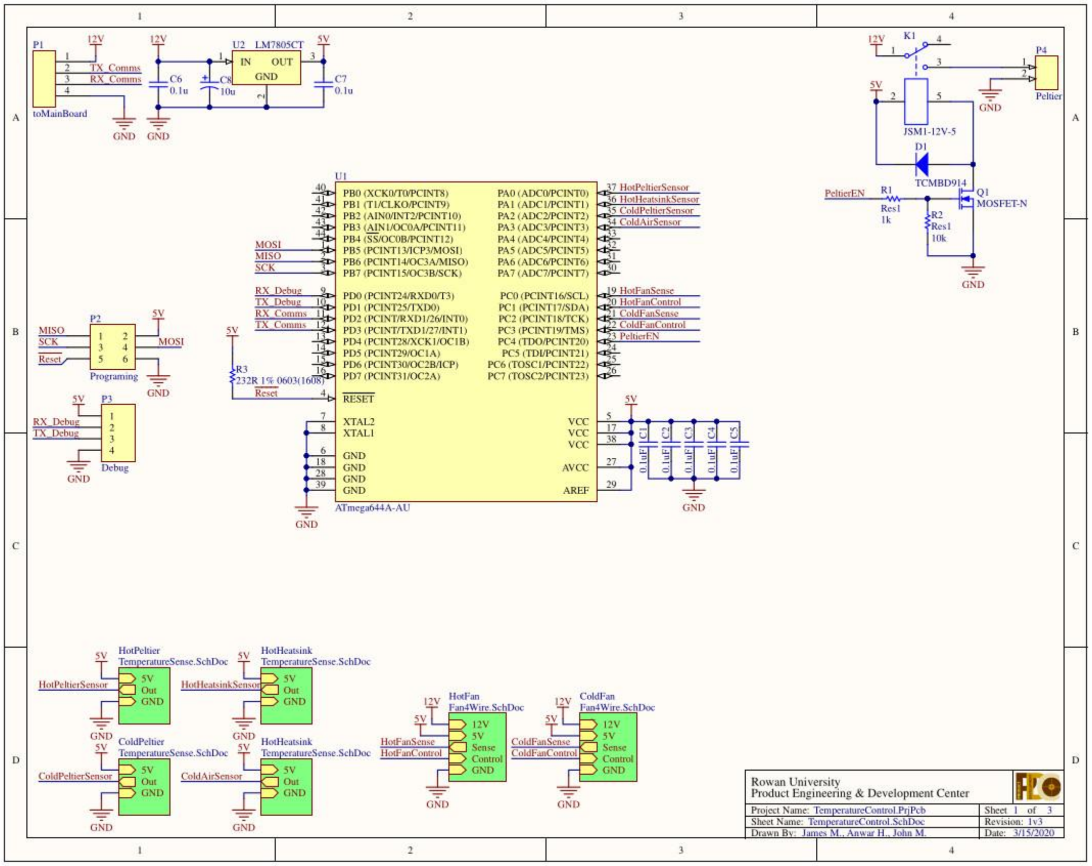
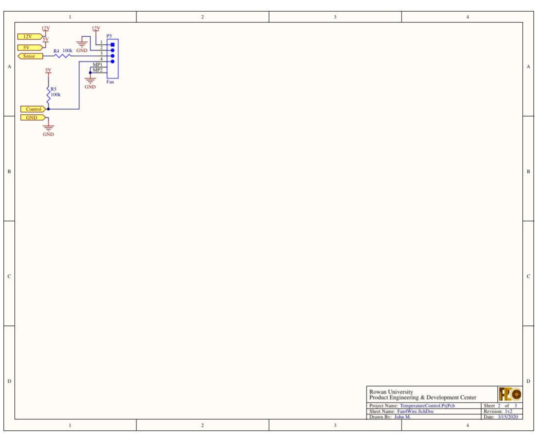


Figure I-D2: Position Sensor Schematic





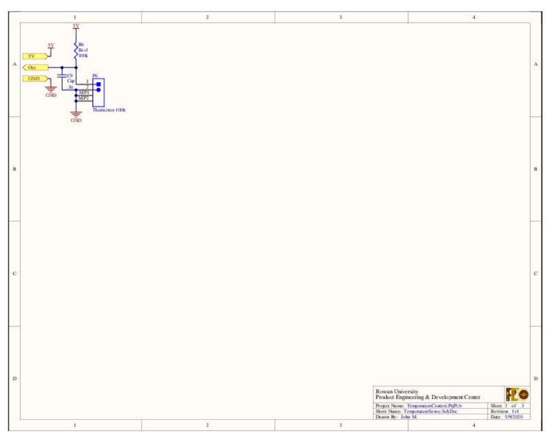
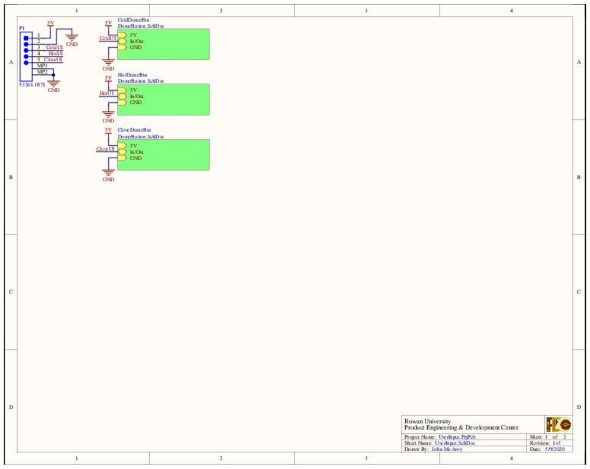


Figure I-D3: Temperature Control Board Schematic



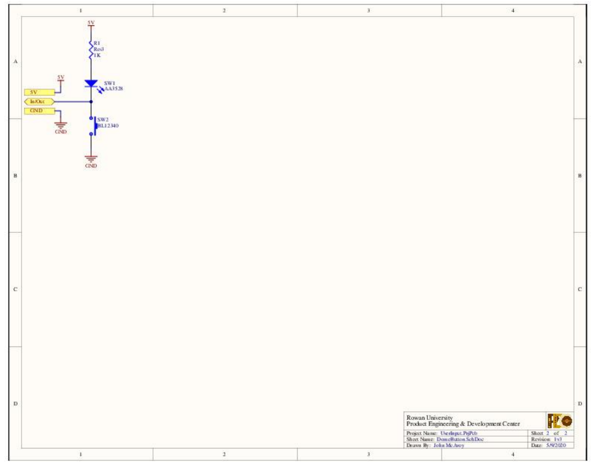


Figure I-D4: User Input Schematic

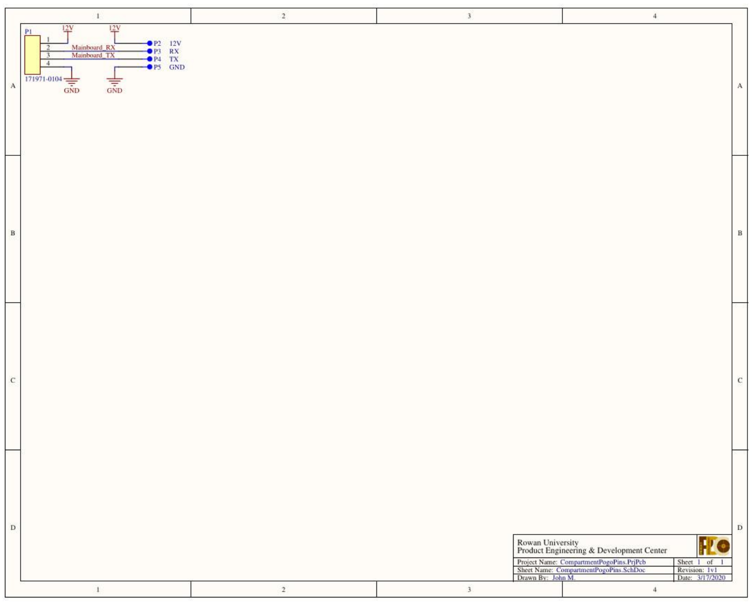


Figure I-D5: Compartment Pogo Pins Schematic

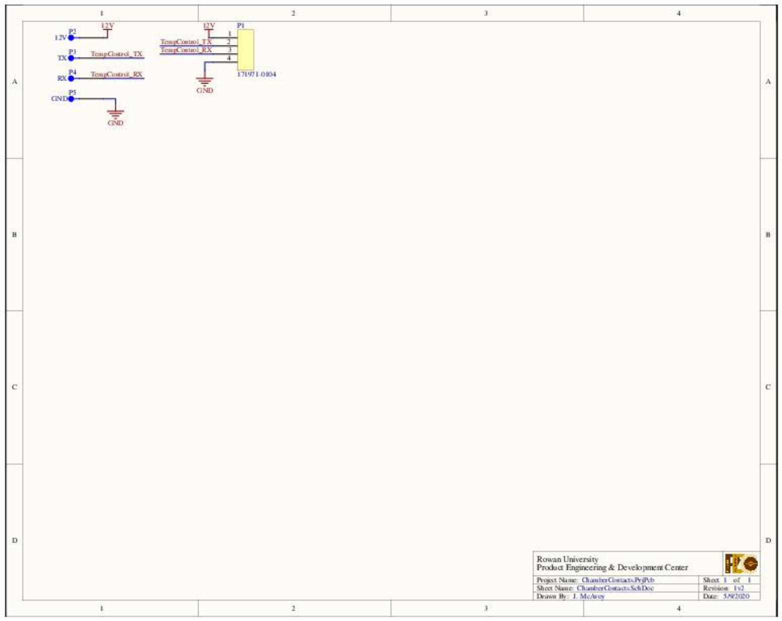


Figure I-D6 : Chamber Contacts Schematic

Software Development

The embedded software development approach used was to start developing a unit testable high-level logic library. This library consists of modules that correspond to the high-level logic specifications for the Lighting, Open/Close, Temperature Control, and User Input systems. Next, these modules are unit tested to ensure their logic corresponds to the specifications. Finally, the low-level, processor-specific code that will interface with the high-level library.

The git version control system allows code changes to be tracked, and for team members to work independently. Individual changes can then be easily merged together later. The GitLab repository was configured to use continuous integration that compiles the code, runs each unit test, and generates the documentation web-page every push to a merge request.. This can make sure that if anything breaks, it is easy to find where, why, and who broke it and if the test passes, the incoming code can be peer reviewed and eventually merged into the master branch.

The GitLab repository can be found here:
https://gitlab.com/A-Team-Rowan-University/pedc/cleanroomfridge/cleanroomfridge

Appendix E: Calculations

I. Thermal Calculations

The assumptions used during the thermal calculations were that the chamber wall is flat (not curved), the ambient temperature surrounding the cold chamber wall is 298K (25°C), the wall thickness is ¼", the thermal insulation of the plastic in the wall is negligible, and there is no conduction through the ceiling of the cold chamber. These assumptions were made to get a realistic 'ballpark' number of Watts entering the cold chamber. We used the equation for conduction through a plane wall from Fourier's Law:

$$Q_{total} = Q_{Wall} + Q_{Floor} = \frac{k \cdot A_{Wall} \cdot \Delta T}{L} + \frac{k \cdot A_{Floor} \cdot \Delta T}{L} \qquad \textbf{[C1]}$$

Where Q_{Wall} is the conduction through the wall, Q_{Floor} is the conduction through the floor, k is the thermal conductivity of Great Stuff insulating foam, A_{wall} is the area of the inside cold chamber wall, A_{Floor} is the area of the floor, ΔT is the difference between the ambient temperature and the temperature inside the cold chamber, and L is the thickness of the wall. The results of the thermal calculations can be found in the table below.

Table D1: Cold Chamber Thermal Calculations

Cold Chamber Thermal Calculations			
Wall Area	Aw	0.07536	m^2
Floor Area	Af	0.020096	m^2
Inner Diameter	da	0.16	m
Outer Diameter	db	0.16635	m
Height	h	0.15	m
Chamber temp	Ti	275	K
Ambient Temp	To	298	K
Thermal Conductivity (Great Stuff)	k	0.037	W/m*K
Wall Thickness	L	0.00635	m
Wall Conduction	Qw	10.09942(	W
Floor Conduction	Qf	2.693180	W
Total Conduction	Q	12.79260	W

II. Heat Sink Calculations

Ballpark calculations were done on the thermal resistance of the hot chamber heat sink to ensure that the airflow across the heatsink was enough to keep the Peltier element cooled to the desired temperature. The calculations were formatted in an excel sheet to allow values to be quickly plugged in from various heatsinks and fans for the different surface areas and velocities.

The calculations can be found in the table below. The equation used to find the thermal resistance of the hot heat sink was:

$$R = F / P \quad \textbf{[C2]}$$

Where R is the thermal resistance of the heat sink, F is the performance factor, and P is the profile perimeter of the heat sink. These calculations were used to pick out a heatsink and fan that would remove heat from the hot chamber.

Table D2: Thermal Resistance Calculations.

Peltier Temp	80	Tc							
Ambient Temp	25	Ta			Fans:				
Peltier Power	45	P			https://www	7.4 CFM	859.35 LFM		
Fan Air Velocity	400	V			https://www	13.4 CFM	1113.91 LFM		
Heat Sink Length	4.6	L			https://www	9.7 CFM	1135.61 LFM		
Performance Factor	21.3543601	F							
Profile Perimeter	50.8	PP							
Thermal Resistance	0.42036141								
					Heat Sink:	length	fins	fin height	PP=base wi
Goal Thermal Res.:	<1.22				https://www	3.54	40	0.28	25.94
					https://www	4.6	8	0.9	19
					https://www	4.6	24	0.449	50.86272

Figure D3: Heat Sink Calculations

Heat Sink _ H Calculations | Notes / Method

$Q_{in} = 45\,W$

* Data Sheet on Peltier

How a Heat Sink works...

* Thermal Interface Material (TIM) applied @ base of heat sink to provide more conduction paths

• Thermal Resistance - heatsink performance rating

* θ_j [°C/W]

* Performance of heat sink defined by θ_{CA} [case temp to ambient]

$\frac{(T_c - T_A)}{P_D}$ $T_c \equiv$ external case [°C] $T_A \equiv$ ambient [°C]

$P_D \equiv$ power dissipation of oscillator [W]

* $\theta_{CS} \equiv$ Thermal resistance of TIM

$$\theta_{SA} = \frac{(T_c - T_A)}{P_D} - (\theta_j + \theta_{CS})$$

Assume so thin that both θ_j & θ_{CS} is negligible

$$= \frac{(80°C - 25°C)}{45\,W} - \left(0\ \frac{°C}{W}\right)$$

* θ_j = unsure (negligible)

min ≡ 3.6 typ ≡ 4 max = 4.4 Ω

$4\left[\frac{V}{A}\right] = \underline{\text{'4' typ}}$ [°C/W]

• giangrandi.che site ? Check w/ ECEs

* $\theta_{CS} = .0803$ °C/W

$$= \frac{(\rho)(t)}{A_p} = \frac{(56)[°C \times in/W](.002)[in]}{[W](1.395)[in^2]} = .0802867\ °C/W$$

○ Peltier area $(A_p) = 900\,mm^2 = 1.395\,in^2$

$\theta_{SA} = 1.22$ °C/W

Ballpark Volume via online calculator

Using: $Q = 45\,W$ $T_{max} = 80°C$ $T_{amb} = 25°C$ $R_V =$

Estimate:

Forced Convection

$$\theta_{SA} = \frac{\text{Performance Factor}}{\text{Profile Perimeter [in]}}$$

$= \underline{\qquad\qquad}$

★ Add on ★ $(-\theta_{CS})$

* V = air velocity [LFM]

* L = Heat sink length [in]

• Performance Factor $= \frac{916}{(V \times L)^{.5}}$

Figure D4: Heat Sink Calculations Continued.

$$\dot{Q} = \frac{k A_H \Delta T}{L_p}$$

$L_p = .15'' = .00381\ m$ $\quad k = .13\ W/mK$

$A_H = 28.27\ in^2 = .018238673\ m^2$

∘Ball park D~6''

$k = .13\ W/m{\cdot}K$ (PLA)

$$205\ W = \frac{(.13)[W](.0183)[m^2](328.15)[K]}{[mK](.00381)[m]}$$

∴ needs to be thicker

$$30.7W = \frac{(.13)(.0183)(328.15)}{(.0254)[m]}$$

(1'' thickness no insulation)

$$37\ W = \frac{(.04)(.0183)(328.15)}{(.00635)}$$

(.25'' thickness insulation)
Great Stuff ≡ .04 W/mK

$$9.46W = \frac{(.04)(.0183)(328.15)}{(.0254)}$$

(1'' thickness insulation)
Great Stuff ≡ .04 W/mK

↳ For worst case scenario

(2'' thickness insulation)
Great Stuff = .04 W/mK

$$4.72W = \frac{(.04)(.0183)(328.15)}{(.0508)}$$

↳ For worst case scenario

$1'' \leq t$

Fan & Sink θ_{SA} req. - GABE!!!!!

Sora - Screws, milling heat sink, milling Cu block

III. Opening Mechanism Calculations

These calculations were done to find the correct choke size of the intake so we meet the desired cold state open in 4 seconds. In this excel function several variables can be changed and the choke size will change accordingly to these changes in variables.

Table D5: Chamber Lift Calculations.

Chamber Weight (Lbs)	Cylinder Radius (in)	**PSI Required for Equilibrium (PSI)**
8	3.4	7.087412407
Cylinder Radius (in)	Cylinder Height (in)	**Cylinder Volume (in^3)**
3.4	4	145.2671216
Volume of Tank (in^3)	Time (s)	**Volumetric Flow Rate (in^3/s)**
145.2671216	4	36.3167804
Diameter of Tube In (in)	Area of Tube In (in^2)	Cd or the Clunk Factor
0.25	0.049087344	0.61
Temp Air (K)	Pressure In (atm)	Universal Gas Constant R (J/mol*K)
298	97732.01514	287

Pressure In (lb/in^2)	Pressure Tank (lb/in^2)	Density of Air (lb/in^3)	**Diameter of Orifice (in)**
14.17482481	7.087412407	4.12833E-05	0.233926908
Density of Air (kg/m^3)	**Density of Air (lb/in^3)**		
1.142717012	4.12833E-05		

Appendix F: Truth Tables

Our team used a Google Sheet to create the truth tables for the high-level main system (shown in Figure 6) and each of the systems. Each of these tables were discussed through peer review sessions in class to accurately define the function of the Environmental Chamber subsystems.

The Google Sheet link can be found here:
https://docs.google.com/spreadsheets/d/1nBbF5GMWpfs_RGPP5kn15QzdPHiXfmzV4Z1hg-QYFnk/edit?usp=sharing