Sani Secure

Team 10

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Abstract

The COVID-19 pandemic has increased the awareness of surface contamination risks as well as the demand for online-delivered packages and groceries. Packages and groceries are some of the surfaces interacted with on a daily basis - the United States Postal Service alone delivers 20.5 million packages a day. It is estimated that each year, America experiences 9.4 million foodborne illnesses due to inadequate refrigeration of foods such as dairy and meats. Furthermore, package security has also emerged as a big problem in America. An estimated $1.7bn worth of packages is stolen every year in the U.S, and theft increased by 7% from 2019 to 2020.

SaniSecure is a multi-purpose household device that provides sanitization for packages, refrigeration for delivered groceries, and increased package security. The device consists of an insulated steel box with inner dimensions of 26x20x20 inches to ensure compatibility for common package sizes. In under 15 minutes, the system achieves the same level of sanitization as common household disinfectants (99.9%). It is facilitated by UV germicidal lamps and reflective Aluminum films to ensure exposure to the entirety of the package. The refrigerated interior utilizes solid-state thermoelectric cooling units, maintaining a temperature range of 5℃ to 8℃. In order to ensure security, the box uses a secure keypad and solenoid lock that the owner and delivery operator can both access, and can withstand high degrees of stress as proven by our finite element analysis. The subsystems operate via solar powered SLA batteries as well as a backup power cord to ensure round the clock functionality.

Team SaniSecure is comprised of Dev Singhal, Harsh Meswani, Kohki Asai, Mohamed Elshabrawishy, Faisal Alsalloum, and Akshil Jhaveri and is advised by Professor Igor Bargatin.

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I. Introduction

The Covid-19 pandemic has changed the life of every person in the world in some way or the other, and has fundamentally altered the way that people think about health, safety and sanitation. Actions such as sanitization of day-to-day products, wearing masks and maintaining a more cautious attitude towards making physical contact with surfaces have become a "new normal" in many parts of the world. Studies[1] show that one of the ways that Covid-19 spreads is through surfaces. The virus can stay alive for up to 24 hours on cardboard and for upto 3 days on plastic and stainless steel. A study conducted by Australia's top biosecurity laboratory[2] states that Covid-19 can live for up to 3 weeks on surfaces such as paper currency and the glass touch-screens of electronic devices. Given this information and the results of our stakeholder outreach (described below in detail), we recognized that the delivery of mail packages of all kinds presents a real and perceived risk to people. The United States Postal Service (USPS) alone delivers about 472 million[3] mail packages every single day. Such a high volume of deliveries indicates that there is definitely a threat while the pandemic lasts, and potentially also in the long run (if peoples' attitudes towards sanitization are permanently affected). Currently, it is of course possible to disinfect packages, but there is no widely adopted system that does so. It is up to either the sender, receiver, or the delivery person to take initiative and do so. We therefore wanted to solve the problem by building a product that effectively and efficiently sanitizes packages.

After looking into the package delivery system in more depth, we realized that there are several existing problems other than sanitization that we can also try and solve. 1.7 million[4] packages are stolen every single day in the United States, and the total value of these packages is estimated at $25 million. Approximately 36% of the American population has had a package stolen[5] and the average amount spent on theft prevention amounts to $191 per household. Nearly 8 out of every 10 Americans are now online shoppers, and this market is only expected to grow in the future. Thus, package security is expected to remain a risk moving forward. Other from package theft, we noticed that the online grocery shopping market has been growing at an increasing pace[6] (22% growth last year) and is expected to get a boost given the Covid-19 situation. According to surveys, the freshness of perishable items is the most important factor for an online grocery shopper. One of the largest issues facing this market is that groceries are often delivered while the receiver is not at home, resulting in some perishable items spoiling. Hence, we realized that there is a need for a quick method of automatic refrigeration to preserve these groceries.

Our analysis so far led us to the idea that **we should build a consumer product that tackles all these three problems in the package delivery industry - sanitization/disinfection, package security, and refrigeration of groceries**. To confirm the legitimacy of these problems and evaluate a market opportunity before embarking on the engineering characteristics, we conducted 2 different kinds of stakeholder outreach - a multiple-choice survey and a set of detailed interviews with stakeholders at different parts of the supply chain.

Survey Results

Our customer survey sought to determine how seriously potential customers take each of the 3 requirements described above, and also to figure out how they currently approach these problems. We made sure that we get relevant demographic information (age, type of residence, marital status etc) so that we can later dissect the data better. We have a total of 158 responses - considering the breadth of responses that we received, we think this is a reasonable sample. Some of our key results are the following -

- Around 70% of respondents think that sanitization of incoming packages is an important consideration, and 75% of respondents conduct some form of sanitization currently.
- About 44% of respondents have either experienced theft or know someone who has, and 43% currently have packages left outside their front door in the open.
- 67% of respondents would find it extremely useful to have their delivered groceries instantly refrigerated.
- 72% of respondents are willing to pay for a device that solves all 3 of these problems, and based on our price range answers, a rough expected price for this product (not yet conclusive) came to $250.

Interview Takeaways

To get personal insights from all parts of the supply chain, we conducted interviews with the following people - a homeowner from Bryn Mawr PA, a UPS delivery driver, and a lawyer. These interviews reaffirm our stance that there is a need and market for our product. Here is a summary of relevant insights -

Bryn Mawr Homeowner -

- Spends at least 20 minutes each morning sanitizing packages that she receives.
- Had a food-processor stolen last year from her doorstep, and although the security cameras caught the thief, no action was taken and she re-ordered it.

- She would be interested in our solution as long as the price is justified and it fits the packages that she orders.

UPS Delivery Agent -

- He is on a very tight schedule, over 300 packages a day. Our product needs to be convenient and fast so that he can maintain his schedule
- They frequently get calls about stolen packages, especially during the holiday season.
- Even though UPS has a company-wide COVID-19 policy, he has seen customers receive packages while wearing wipes/gloves.

Lawyer -

- Orders groceries online for delivery as they are usually too busy to go shopping on a regular basis.
- They are often not at home for the pickup as the windows provided by the delivery services are always during working hours.
- Has experienced groceries perish on his front porch.

Target Segment

Based on the data we received through the surveys and personal interviews, we identified an ideal consumer segment to target for our device. This target segment was identified based on the attractiveness of different target segments on various metrics such as **size, profitability (willingness to pay), and fit with our competitive strength (providing a solution to** . The following are the features of our identified target segment:

- Working individuals living in suburban areas
- These individuals live in townhouses or isolated home units
- These individuals are busy during the day, and are usually not home to receive their deliveries

We determined the size of this target segment to be approximately ***35 million*** people across the United States. The calculation for this number has been shown in the Appendix. While this number highlights the potential number of people who would benefit from our product alongside having the willingness to pay for it, it doesn't reflect the true number of products we can expect to sell even in an ideal scenario where every person in this target segment finds this product useful. For instance, for a single family with multiple working members living in the same townhouse, only one unit of this product will be required. Identifying this target segment and its scope, however, validates the usability of this product for a large segment of the population. It will later enable us to price and position our product in a way that grabs the attention of the identified target segment.

I.I Social Impacts of the Solution

Our project's design choices have set up a solution space that aims to tackle several social problems and provide ways to ensure the safety of the product's users, a sustainable and environmentally conscious design, and a tool for society that provides convenience and safety. Our path to creating a device that effectively sanitizes incoming packages and mail provides users with an opportunity to minimise the risk of germ and virus transmission into households from outside sources. Through our research we learned that, mainly due to the emergence of the COVID-19 pandemic, individuals throughout society were becoming more conscious of the risks involved with surface transmission of bacteria and viruses, and were stressing the importance of desentization and hygiene in their daily habits. The SaniSecure box provides users with an efficient and effective method to sanitize all incoming packages and mail so that the user does not have to do it manually. The aim of the sanitation feature in the design is to eliminate the possibility of the spread of pathogens into households via delivered items, thus improving the safety and welfare of SaniSecure users.

As a team, through our research we identified the need of ensuring that our product is environmentally responsible and yields the minimum possible carbon footprint. Our decision was not only inspired by our research and knowledge on the current problems with power use and emissions, but was also a feature that was highly regarded among individuals who were surveyed throughout the project period. We performed calculations to assess the feasibility of incorporating renewable energy systems into our design and found that using two solar cells to charge a battery would be a feasible option for our primary source of power, if excess power was needed due to a high volume of packages or poor weather, we incorporated an outlet plug for secondary use. Although the system is not fully renewable, a hybrid power setup would ensure that the product is utilising as little power as possible from non-renewable sources, thus yielding a significantly smaller carbon footprint compared to a non-hybrid design.

SaniSecure's design also helps address another social issue that is of growing concern. As aforementioned, with the growing volume of delivered packages and groceries has also come with a corresponding spike in package theft across the US. The design of SaniSecure's box and security features helps tackle this trend by eliminating the presence of exposed packages sitting on the front porches of homes where they are easily accessible and therefore easy to be discreetly taken by a person walking by. This will allow users of SaniSecure to feel a greater sense of comfort knowing that the ordered items are safe even if no individual is present at the residence at the time of delivery. In addition, the refrigeration element in the box design ensures that perishable items are also safe against the climate conditions for long periods of time, thus ensuring that groceries are always kept fresh and users' health is not compromised by the risk of consuming badly stored food items.

II. Solution Characteristics and Constraints

Through a mix of stakeholders interaction and literature research, it was established that customers require three major features in a package receival system - sanitization of incoming packages, ensured security of packages to prevent theft or loss, and the ability to instantly refrigerate packages that require temperature controlled environments, primarily groceries. We identified specific considerations that stakeholders make while judging the effectiveness of the current methods (if applicable) they use to fulfil the purposes mentioned above.

For package cleaning, customers required a sanitization method that allowed the package to be cleaned thoroughly (on all surfaces), and that allowed minimal work on the part of the customer. Current sanitization methods (for example, clorox wipes, sanitizers etc.) lacked either one or both of these requirements. Our solution should enable customers to have their packages cleaned in a manner that is **less effort consuming** and **causes 360 degree cleaning**. Package safety was also identified as a defining need that customers had. Therefore, our system should ensure **thorough safety of delivered packages when the customer is not around to pick them up**. Refrigeration of certain packages such as delivered groceries was our third and final concern. As mentioned previously, consumers often get their orders delivered at times when they are not present in person to receive them. This proves to be critical for non-durable goods that may spoil after being in the sun for several hours. Our system should cater to the requirements of such deliveries that **need to be refrigerated or kept in a cool environment for sustained periods of time.**

To make this solution suitable for customers looking for an effective method of sanitizing packages, three additional considerations were made for system characteristics. The system should be **able to sanitize the package in the minimum time possible**, as consumers found it useful to have ordered items ready for use as soon as possible. The system should be **able to accommodate packages of all sizes, within reason**. We found an estimate for the most common package sizes that customers receive in their online orders. This data was sourced from a UPS delivery agent in one of our stakeholder reachout interviews.

The decisions on choosing the appropriate system characteristics were also made keeping in mind our target segment, which is working suburban adults living in townhouses or isolated units. We developed specific metrics to judge the performance of our system:

Table 1: System Level Metrics for Ideal Solution

Characteristics	Metrics
Sterilization Time	< 15 minutes
Sterilization Capability	All surfaces of the package (360 degrees)
Average Cost to User	< $300
Maximum Size of Delivery Accommodated by System	26" x 20" x 20"
Refrigeration Capability	Should be able to keep items refrigerated (<8℃) for a period of 4-6 hours
Safety Requirement	100% package theft resistant
System Level Expectations	Safety of user is given utmost importance (use of limit switches etc. in case electronics fails)
	Automation: 80-90% process automated
	Energy efficient and environmentally friendly

These quantitative metrics were selected based on a combination of the user's needs, and what was physically possible, as determined by our testing. To ensure both a 1-log reduction in the active disease molecules for packages of all sizes, while minimizing the time the user needs to wait for their package to be safe, a sanitization time of 15 minutes or less was chosen. Furthermore, based on our testing data for the "danger" zone of various perishable items (milk, ice-cream, chicken, etc.), we found that the temperature of the groceries must not exceed 8℃. This temperature must be sustained for 4-6 hours, as our consumer research showed us that this was the average time between when the groceries were delivered to people's residences and when they arrived to collect them. Building on this, the process must be nearly fully automated to minimize the extra time delivery agents need to spend placing the items into the device as well as allowing the busy users to control the device remotely when they are not home. Lastly, the product must be energy efficient and environmentally friendly to minimize cost and align with our own and our consumers' beliefs.

II.I Design Impacts of Standards

Standard Code	Title of Standard	Impact on the Project
ISO 15858:2016	UV-C Devices — Safety information — Permissible human exposure	This standard was of high importance when choosing the appropriate UVC germicidal lamps for our project. Since consumers will be in frequent use of the box, it was important to ensure that the power of the lamps were constrained to be in adherence to this code. As a result, we opted for 8 Watt UVC lamps which would ensure that the risk to users is low, and their safety is not compromised.
NIOSH 73-11009	Occupational Exposure to Ultraviolet Radiation	This standard indicated the safe wavelength regions that could be used for the UVC subsystem. In adherence with this code, lamps with a wavelength of 254nm were utilized in the final product which would ensure that in the event of accidental exposure, users would not be put in any significant danger. Our design ensures that the UVC subsystem is programmed to turn on only when the door is locked, thus in combination with this code, the product poses no threat to users under frequent use.
DS/ISO 15727	UV-C devices – Measurement of the output of a UV-C lamp	This code provided supplementary information to NIOSH 73-11009 concerning the time and intensity of exposure and safety to users. This code was used to assess the potential risks to users in the case that they are exposed. The team arrived at the conclusion that the chosen lamp's specifications would ensure that it still adheres to this code in the case of accidental user exposure.
ANSI/BHMA A156.25-2018	Electrified Locking Devices	This code impacted our design choices for the locking mechanism and construction. Ultimately, a solenoid lock that adheres to the code was chosen and the right mountain methods were used to place the mechanism and wiring in ways to ensure the safety of both the consumer and the items stored within.

CSA B52-2013	Mechanical Refrigeration	This code provided a higher level insight into the procedures involved when installing refrigeration systems in devices. This included the presence of a sufficient heat sink to minimise the strain on components and prevent failure. In adherence with this code, the appropriate size heat sink for the cooling unit was utilised in the product. In addition, the thermoelectric peltier plates that were purchased were also adherent with this standard, making it safe to use for the product.
ISO 5149	Refrigerating systems and heat pumps — Safety and environmental requirements	This code provided a framework for the safe and environmentally friendly procedures for refrigeration design. The team's choice to use a static thermoelectric cooler ensured that the materials used in the system were all in adherence with the ISO code.
ANSI/NEMA OS 1-2013	Sheet-Steel Outlet Boxes, Device Boxes, Covers and Box Supports	This standard guided design specifications for the electrical storage and wiring for the sheet metal design. In adherence with the code, special consideration went into ensuring that wires running through to the various subsystems were properly insulated with no exposed copper. Additionally, fuses were installed at several stages in the circuitry to make sure that in the case of an electrical failure, the user would not be put in any harm. Finally, a ground wire was incorporated into the circuit to ensure that there was no risk of electric shock.
IEEE 1188-2005	IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications	This standard guided the testing and early utilisation practices that were taken when testing and constructing the power subsystem. In adherence with the code, a specified battery case was used to store the battery when not in use. In addition, the code narrowed down the options for the battery placement in the product, thus aiding design choices for the team. In adherence with the code, the battery was placed in a closed case at the back of the box, minimising the chances of corrosion due to weather and ensuring the users safety by keeping it out of direct reach.
IEEE 1361-2014	IEEE Guide for Selecting, Charging, Testing, and Evaluating Lead-Acid Batteries	This code aided the selection of the appropriate battery for use with the solar cells. A 12V Lead-Acid battery was selected that adhered with the code, and it was ensured

	Used in Stand-Alone Photovoltaic (PV) Systems	that the battery was designed to be compatible with the selected solar cells.
ASTM C1696	Standard Guide for Industrial Thermal Insulation Systems	The code was used as a guideline when selecting insulation materials. The team selected XPS due to weather resistance capabilities making it appropriate for outdoor usage. This code helped narrow and constrain design choices when selecting insulation materials, and ensured that the binding and filler agents used were the correct ones for the product and its use.
ASTM F1416	Standard Guide for Selection of Time-Temperature Indicators	This code guided the selection of time-temperature indicators for use on perishable products. The team ensured that the selected thermistor was in adherence with this code.
ISO 4628-3:2016	Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 3: Assessment of degree of rusting	This was a very important standard in relation to the box design and finish. The team used the code to ensure that the outer layers had the appropriate finish material to withstand damp and rapidly changing climate conditions for extended periods of time. As a result, a rust-proof enamel coating was used to coat the entirety of the exposed surfaces in an effort to ensure that the structural integrity of the product is not impaired over long periods of exposure to unpredictable climate conditions.

III. Design, Engineering, and Realization

We envisioned our system to include three main subsystems based on the identified system characteristics: **security**, **refrigeration**, and **sterilization**. In addition to this, we analyzed our power requirements for the entire system.

Security

Our safety subsystem comprised a digital keypad operated locking system that used a 12V solenoid lock. This locking system was put in place to ensure that only the owner of the box could control who can access the box. While making considerations for the different types of locking mechanisms that could have been used, we found that a solenoid lock operated by a keypad was the most effective due to the robust strength of the lock itself and the ease of access through a keypad. A traditional lock and key system would have required the user to exert too much work, and a more advanced system of QR codes could have been costly for this purpose.

The security of this system also relied on the strength of the material used for creating the inner and outer shells of the box design. Two alloys of Aluminum were considered for this purpose - Aluminum 5052 and Aluminum 6061. Al. 5052 was preferred over Al. 6061 as it is easier to weld and is less expensive than Al. 6061. To check whether this material was useful for our purpose, we conducted three FEA tests on ANSYS. In these tests, the box structure was considered in its final form, and the relevant material properties were added to each component of the box (Al. 5052 was applied to the inner and outer shells, XPS foam properties were applied to the insulation). The information about the three tests can be found in the table below. Each of these tests were setup in a way that they emulated different ways in which the box structure could be damaged or harmed. The FEA considered both the total deformation that the box would undergo as well as the equivalent stress experienced by the box under these conditions.

Table 2: Finite Element Analysis Tests Setup

Test	Force (Magnitude and Location)	Other Setup Information
Test 1: Strong Pull Test	3000 N outwards on door front handle - emulates a strong pull	**Fixtures**: All faces of the box except front face (fixed geometry), door hinge (fixed hinge) **Component Contacts:** door solenoid lock +

		lock slot on the door
Test 2: Corner Strength Test	10,000 N inwards (top left corner at the intersection of front, top and side faces) - emulates a strong blow to the box corner	**Fixtures**: All faces of the box except front face (fixed geometry), door hinge (fixed hinge) **Component Contacts**: N/A
Test 3: Edge Strength Test	10,000 N inwards (top edge of side face) - emulates a strong blow to the box corner	**Fixtures**: All faces of the box except front face (fixed geometry), door hinge (fixed hinge) **Component Contacts:** N/A

Security Testing

Three Finite Element Analysis tests were conducted to verify the theoretical strength of the box structure. We saw that the maximum deformation is of the order of 10^{-4} m, which is a very small deformation. The box exterior is thus hardly affected by this sort of force. We also saw that the maximum stress applied is of the order of 10^{7} Pa, which is much below the yield strength of Aluminum 5052 sheets (of the order of 10^{8} Pa). Both these results confirm that our box will be able to endure such force conditions.

Similar results were found for tests 2 and 3 (all test results can be found in Appendix II). In all scenarios, these force conditions were found to be within the strength capacity of the box. Since these tests were modelled to emulate extreme versions of real life threats to our box, these theoretical test results help us draw the conclusion that this box structure is feasible.

Refrigeration

Theoretical Approach:

A thermal energy balance approach was done on the system (shown in Figure 1a in the Appendix).

$$E_{in} - E_{out} = \Delta E_{air,st} + \Delta E_{p,st}$$

Thus, the equation becomes a second order non-homogeneous differential equation (refer to appendix for a more detailed analysis):

$$(\rho V c)_{air} * \frac{dT_{air}}{dt} + (\rho V c)_{p} * \frac{dT_{p}}{dt} = \left(h_{air} A_{p2} + \frac{k_{p} A_{p1}}{L_{p}}\right)\left(T_{air} - T_{p}\right) + \frac{T_{surr} - T_{air}}{R_{ins}}$$

In order to simplify the computations, a first order differential equation for the temperature of the package can be found by approximating the final air temperature inside the box. The internal air temperature is affected by the heat of the package as well as the surrounding temperature. Since the initial air temperature is equal to the surrounding temperature, the rate of change of internal air temperature will be decreasing as colder groceries are placed inside the box. We can approximate a weighted average air temperature by using the rate at which the internal air temperature is affected by the package and the surrounding external air separately. This can be found by calculating the time constants that it takes for the package's heat to change the air's temperature by 63.2% compared to the heat from the surrounding:

$\tau_p = R_p * C_p$, where $C_p = (\rho V c)_p$ $\tau_{surr} = R_{ins} * C_{air}$, where $C_{air} = (\rho V c)_{air}$

Since the temperature in the beginning is equal to the surrounding temperature and larger than the weighted average temperature, the initial increase would be slightly steeper in an exact solution as shown in Figure 1b in the appendix.

The average air temperature would then be: $T_{airf} = \frac{\frac{T_{surr}}{\tau_{surr}} + \frac{T_{p,initial}}{\tau_p}}{\frac{1}{\tau_{surr}} + \frac{1}{\tau_p}}$

The solution to the differential equation after including frozen items was found to be:

$$T_p(t) = \begin{cases} (T_{p,initial} - T_{airf})\, e^{-\frac{t}{R_p C_{p,ice}}} + T_{airf} & 0 < t < t_{melt,i} \\ T_{melt} & t_{melt,i} < t < t_{melt,f} \\ (T_{melt} - T_{airf})\, e^{-\frac{t - t_{melt,f}}{R_p C_{p,water}}} + T_{airf} & t_{melt,f} < t < \infty \end{cases}$$

In this equation, we are assuming that the temperature of the box does not change with time. Instead of having that temperature be a function of time, for the purposes of our calculations, we found the weighted equilibrium temperature of the system and treated it as the ambient temperature that surrounds the product that is inside the box. The groceries are assumed to have the physical properties of water since most groceries such as milk, chicken, and ice cream contain a substantial amount of water.

Theoretical Results and Discussion:

According to USDA regulations, foods such as dairy and meats should not be placed at temperatures above 5°C for over 2 hours since bacteria thrives at these temperatures. As you can see from Figure 2a in the appendix, milk will go into the danger zone in less than 30 min and can be deemed to be dangerous after 2 hours and 30 minutes. Ice cream would “completely” melt within ~9 hours. Nevertheless, melting starts only after ~30 minutes. The same idea goes to frozen meats such as chicken. Therefore, an insulating only box can only hold perishable groceries such as ice cream and milk for no more than ~3 hours. Frozen meats will be partially melted, but still safe to consume, as seen in Figure 2b (appendix).

Calculations from the previous section indicate that the optimal solution is an active cooling and insulation hybrid. As we saw above, a purely insulation based system will pose a problem as the internal temperature of the box will reach an equilibrium temperature with the surrounding environments putting groceries in the danger zone. The refrigeration subsystem would need to cool down the internal area of the box to standard fridge temperatures (4°C) and allow the insulation component to do the rest of the work. With temperatures in this range, we can guarantee that perishable and frozen groceries will be safe for periods of around 4-6 hours (our expected use time). This conclusion is made due to the fact that 1. Frozen meats take at least 24 hours to thaw out in fridge-like environments (so negligible thawing is expected) and 2. With proper insulation we can maintain the internal temperature of the box to a close degree of accuracy for the time in question.

Refrigeration Design Choices

Upon arriving at the confirmation that an active refrigeration system was in fact needed, two system designs were considered for use: thermoelectric (TEC) units and the traditional compressor units found in the majority of household refrigerators. The comparison table used for the downselection process is available in the appendix as Figure 3.

After assessing the two refrigeration systems, it was concluded that TEC units were the more suitable option for the system design. Although the compressor system had a superior coefficient of performance and low temperature capability, the current input type and customizability of the TEC system made it the better choice for our system as it had the ability to seamlessly integrate with the rest of the subsystems and still had the capability to reach the target temperature identified by theoretical calculations.

Selecting the appropriate sized unit ws done by assessing data sheets for several options to ensure that they had the capability to effectively cool the internal volume of the box (each data sheet contained a range of recommended volumes that the unit should be used for).

Figure 4 in the appendix displays the chosen thermoelectric unit for the product. The module consists of two peltier plates with both a cooling sink and a heat sink. Additionally, there are fans on the end of both sinks to accelerate the rate of cool air transfer and heat expulsion. This was the ideal choice for the box as it offered the highest rate of cooling while ensuring that it was compatible with the power subsystem and operated on the same voltage specifications.

Insulation Design Choices

Several factors accounted for the choice of the insulation for the box. Firstly, the insulation needed to have a minimum R-value of 3 to be able to effectively support the TEC's active cooling. Additionally, the insulation needed to be weather and heat resistant in order to maintain performance over long periods of time in variable weather conditions. Finally, since the product was designed for consumers in mind, the insulation had to be economically priced to ensure that the cost of the unit is kept under $300 dollars as indicated by the system characteristics.

Using the engineering standards as an initial guideline, there were four viable options: Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), Polyisocyanurate (Poliso), and injectable foam insulation. Research into the comparative performances revealed that Poliso and injectable foam insulation had poor weather resistance and waterproofing capabilities, thus preventing them from being ideal materials for use in a product that will be consistently out in exposed conditions. When comparing EPS and XPS it was found that XPS has a superior R-value per inch (5) compared to EPS (3.2). Additionally, XPS's closed cell design gave it superior water and temperature resistance over extended periods of time. After reaching the conclusion that XPS was the ideal choice for the box design, the team decided that a thickness of 1-inch was the ideal choice due to it exceeding the identified minimum R-value threshold and it being commercially accessible from a number of vendors.

Refrigeration & Insulation Testing

We conducted testing on our test rig and on the actual subsystem also. We placed perishable grocery items inside a bag and measured the temperature over time and recorded the data. The non-insulated test rig was made out of cardboard and aluminum foil, the insulated test rig contained foam-core insulation between inner and outer shells, and the final SaniSecure box had all features in it. The food items we used were chicken breast, milk, spinach and ice-cream. Figure 5 summarizes our data - we managed to get the temperature down to below 8 degrees Celsius. Room temperature was kept at 25 degrees Celsius.

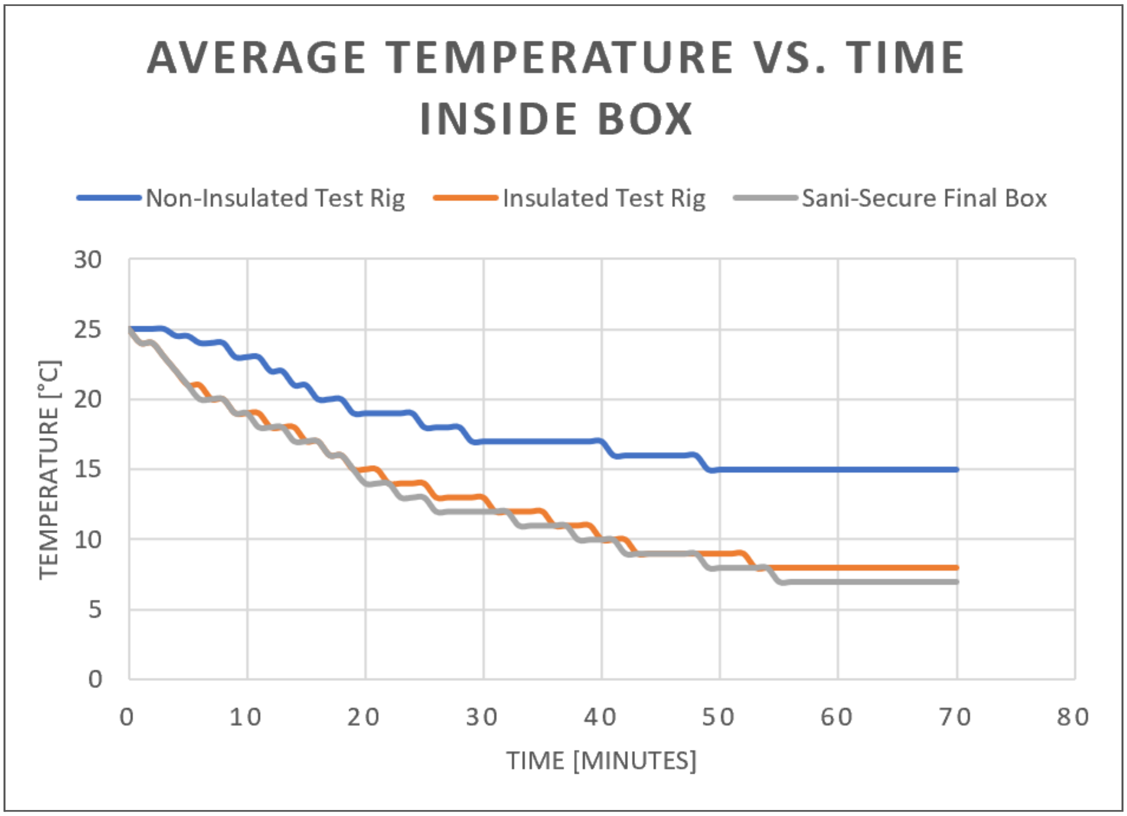


Figure 5: Average temperature vs. Time for multiple iterations of SaniSecure.

Sterilization

After considering several available alternatives, the method we chose to sanitize packages is UVC germicidal lamps. This is because it best fulfills our requirements for the system. Alcohol sprays would require frequent refills and easily damageable pressure nozzles, whereas mechanical solutions like Lysol wipes are not practical for use. UVC lamps sterilize surfaces by applying a frequency of 254 nm that prevents the bacteria's DNA or a viruse's RNA from being able to reproduce. Each bacteria and virus has a threshold for the amount of exposure needed to reduce their number to over 90% (> 1 log-reduction). The amount of exposure (Dose) is dependent on both the intensity of the lamp and the exposure time. Typical value of required doses for common types of organisms are shown in the table below. A safety factor of 3 is taken into account to ensure disinfection.

We can find the required exposure time in terms of the separation distance (r) given the dose of the organism and intensity of the lamp as following:

$Dose\ (J/cm^2)\ = Intensity \times time$

$Intensity\ (W/cm^2)\ = P_{output}/(4\pi r^2)$

$P_{output}\ (W)\ = P_{lamp}\ L_c\ \varepsilon$

$Dose\ \ = P_{output}\ t/4\pi r^2$

The maximum separation distance would be the distance between the edge of the box to the center (12”). The arc length of the lamp is half the length of the side of the box (12”). The power per cm is assumed to be 1W/cm with an efficiency of 30%. Thus, we can find an estimation of the exposure time shown in the plot in Figure 7 (appendix):

$$Time\ = (4\pi r^2 Dose)/(P_{lamp}\ L_c\ \varepsilon\ )$$

This exposure time is effective based on the assumption that the lamp is directly incident on the surface. The distribution of light on the surfaces of packages would not always be perfectly perpendicular, especially in the case when reflective walls are used. In order to make sure that our disinfection system would work under all circumstances, we conducted tests with regards to the configuration and number of UV lamps. These tests are described in the section below.

UVC Validation Results

In order to validate our results, we made use of the fact that photodiodes are electrical components that generate a small current (nA) when exposed to light. This current can be used to find the intensity of the incident light. Since UV-C sensors are expensive, an affordable GUVA-S12SD UV-A sensor with some electrical surgery was used. The bottom Op-Amp in Figure 8 (appendix) was deactivated to bring down the voltage gain from ~25V to ~5V with a transimpedance gain of 10^7. This will allow the photodiode to read the current induced by the light. From the specs of the sensor, the active area of the photodiode is 0.076 mm^2 and the responsivity at 254 nm (UVC range) is 0.04 A/W.

The calculations below show how the photodiode induced voltage read from an arduino can be translated to Intensity:

$Intensity = Power/Area$

$Power = Current/Responsivity$

$Current = \frac{V_{out}}{V_G * G_T}$

We tested different configurations of lamps and saw the intensity from different distances. We got the results shown in Figure 9 (appendix) that significantly validate our findings. These results were obtained when the lamp configuration was 2 lamps on diagonally opposite edges of the box standing vertically.

The exposure time of 15 minutes matches our system requirements for COVID-19 and Influenza, while it requires a little more time for Tuberculosis. Considering our budgetary constraints and cost requirements, we need to minimize the number of lamps. 2 lamps with additional reflective surfaces inside brings our cost sufficiently down. Therefore we decided on the diagonally opposite vertical configuration. This can be viewed in the pictures of our final system form.

Power Requirements

Refrigeration Power

The power needed to cool down our system would be the amount of work needed to bring the system down to the desired temperature. The input work can be found by applying the second law of efficiency for refrigeration and heat pumps (the ratio of the actual thermal efficiency (10%) to the maximum possible (reversible) thermal efficiency under the same conditions):

$$W_{in} = \frac{Q_L(T_H - T_L)}{\eta_{II} T_L} \qquad Q_L = \rho_{air} V_{air} c_{air}\left(T_{air,\,initial} - T_{air,\,final}\right)$$

$$W_{in} = \frac{\rho_{air} V_{air} c_{air}\left(T_{air,\,initial} - T_{air,\,final}\right)^2}{\eta_{II} T_{air,final}} = 87\ kJ$$

If this work is to be done in 70 minutes, the power consumption would be $P_{ref} = \frac{87000}{70*60} = 20.7\ Watts$. Since this value of power assumes perfect insulation of the box, a thermoelectric cooler of 120 Watts was used to ensure a suitable temperature environment for groceries.

Solar Cells as a Power Source

Thermoelectric coolers consume 120 Watts for a duration of ~70 min/day. Each UV lamp has a power of 8 Watts. Two lamps are used for a duration of 15 min/day. Solar cells are assumed to receive ~3h/day of sunlight on average. The surface area of the solar cells are limited by the system's (box) top surface area (0.34m^2). Assuming a typical solar cell efficiency of 15% and solar irradiance of 1000W/m^2 from the sun, the wattage that the 0.34m^2 surface area can produce would be $Potential\ Power\ Output = (0.15)(1000W/m^2)(0.34m^2) = 51\ W$. Two solar cells are being used with 25 Watts of power each. Since most of the circuit elements used operate under 12V of Direct Current, the inverter is only used on the UV lamps.

A suitable SLA battery with an estimated Depth of Discharge of 60% would require an AH capacity of $[(120W)(70min/60min) + (16W)(15min/60min)]/[(12V)(0.6)] = 20\ AH$. Charging the a 20 AH battery in 3 hours of sunlight would require a solar cell with an output current of $I_{solarCells} = 20AH/3H = 6.67\ Amperes$. This translates to a required power of $P_{req} = IV = (6.67)(12) = 80\ Watts$.The required power is 60% more than what the solar modules can deliver. So the need for a hybrid powering system is required. We would need 5-6 hours of sunlight per day to be able to power up the system with only solar panels. Thus, a wall power cord is introduced to the system. The introduction of the power cord also ensures that the system can operate in cloudy or obscured conditions.

Circuitry and Control

The developed circuitry is shown in the appendix (Figure 9).. The two power sources are shown on the left side of the diagram. The loads and control subsystems are on the right side of the diagram. The solar panels charge the battery through a solar charge controller. The current then goes through a safety fuse rated at 20A and into the Arduino, the UVC lamps, the cooling system, and the lock. The Arduino triggers a relay switch to control the current flow into the subsystems. For radiation safety precautions, a limit switch is used to turn off the UVC lamps when the door is opened. An inverter is used to convert the DC current to AC for UVC lamp compatibility.

Subsystem	Rating
UVC Lamps (16 Watts)	110V/0.1A AC
Refrigeration (120 Watts)	12V/10A DC
Lock (9.6 Watts)	12V/0.8A DC
Arduino Mega 2560	12V/0.2A DC

All programming was done with an Arduino Mega 2560. A keypad is used for input/output control. A password is inputted to lock and unlock the door. The letter C initiates cooling for expected groceries. A thermistor is utilized to automatically turn off the cooling units when the internal air temperature goes lower than desired. The letter B commences the UV sterilization for a duration of 15 minutes.

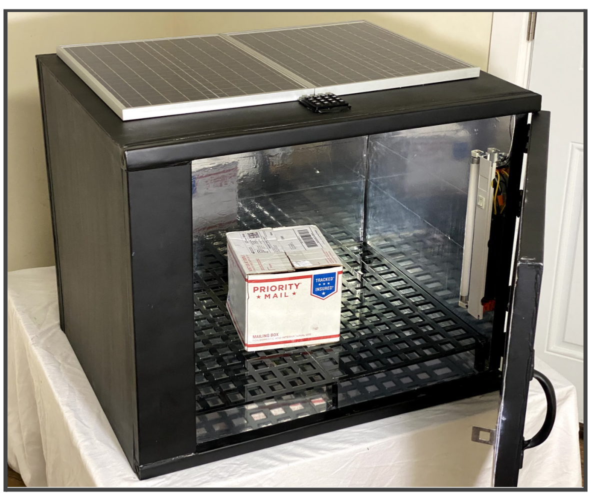
When the power cord is plugged into the wall, the 110V AC current is converted to 12V DC through a full bridge rectifier. It then triggers a SPDT relay to switch the current path from the battery to the wall source. A capacitor is used to prevent the ground from drawing all the current. The system continues to power the loads just like the battery.

IV. Final System Form

Based on a comprehensive analysis of the stakeholder requirements and system characteristics, our final system design is the SaniSecure package receival box. This system provides a 3-in-1 utility by facilitating package sanitization, refrigeration of delivered groceries, and security of delivered packages.

The package receival box utilizes two 8W Germicidal UV-C lamps for the sanitization process. These UV-C lamps are optimally placed inside the box for maximum UV-C incidence on the packages placed. The inner surface of the box is reflective to UV-C light, which aids in the sanitization process. The system also uses a two-piece thermoelectric unit to facilitate the refrigeration process. Experimental data has shown temperatures below 8 degree Celsius can be achieved comfortably.

Our product utilizes two 25W solar panels to power the entire system - these panels are aided by a battery that can store excess energy. A solenoid lock is operated to ensure that the box is locked and secured when not in operation. The box structure is attached to a housing unit at the back - this helps store all the electronics of the system. The figures 11 & 12 below show a prototype of the final system form.




Figures 11 & 12: Images of the Final SaniSecure Product.

User Interaction

Users are able to operate their SaniSecure box with an app - the app has various features to control the different functions that the box performs. For instance, the user can monitor how much time is left for their package's UV disinfection. In a typical scenario, a customer would place an order for a delivery. The delivery agent would set out to deliver the product. The delivery agent will place the package in the box after receiving an OTP from the owner. This OTP will enable the delivery agent to operate the system by entering the password on the keypad. The box will perform its functions - this could include both sanitization and refrigeration simultaneously, in case there are groceries involved. The box will then ensure the security of packages in case the user is not home. Finally, the user can retrieve their package from the box by entering their code once they are home. .

V. System Performance

Our final system was able to:

- Sanitize packages within the required exposure time of 15 minutes. This is in line with our system characteristics.

- Bring the temperature of groceries (chicken breast and milk) down to 7 degrees Celsius. This is lower than our requirement of 8 degrees Celsius

- Withstand extreme forces of greater than 10^7 Pa and have a maximum deformation of less than 0.1mm, with an entire order of magnitude as a safety factor.

The tests and validation for these results can be found in the design & engineering section of our report. In addition, the final cost of our system (in Appendix III) is $202.15, which is significantly below our cost requirement of $250.

VI. Conclusions and Future Work

At the end of this project, we were able to construct a product that was able to sanitize packages, refrigerate groceries, and safely secure both within the unit. The final product was able to reduce the concentration of pathogens and germs by 1-log, maintain a maximum temperature of 8℃ for 4-6 hours, and safely secure all reasonably sized packages. This was achieved while keeping our cost of production below the target $300, and while being energy efficient with a hybrid power system.

Over the course of this project, a number of learning opportunities presented themselves. These ranged from theoretical knowledge and quantitative analysis methods to manufacturing abilities and construction techniques. One of the most important lessons that our team took away from this project was the design and manufacturing differences between a regular product and a consumer product. Having selected to manufacture the latter, the importance of not only functionality but aesthetics and ergonomics were also key factors in our decision making at every point during the design process. Other outcomes that resulted from the project effort were an increased understanding and appreciation of the difficulties associated with integrating subsystems, project management, and the importance of rapid prototyping and testing.

Our understanding of the effects of various external factors on refrigeration cycles and the safety concerns associated with the use of UV-C light were also tested and improved over the course of this project. The modelling and testing involved with the UV and refrigeration subsystems enhanced team members' fluency in these engineering topics. Moreover, the difficulty associated with manufacturing the product predominantly from sheet metal was severely underestimated by our team, due to our lack of experience working with this material. Throughout the manufacturing period, we were able to adapt our manufacturing methods to accurately cut and bend structural components and gain a deeper understanding into the tolerances and limitations of the material.

In the future, this project could be improved by using a battery with a larger capacity, as this was the limiting factor in our energy delivery system. Even though the solar panels were able to supply sufficient power for day-to-day use, the battery was incapable of storing sufficient charge for the refrigeration system to run for extended periods of time. Another improvement that could be made in the future would be in the refrigeration system as a whole. Even though the thermoelectric unit was capable of maintaining a sufficiently low temperature, in extreme environments where ambient temperatures may rise to 40℃, the groceries would not survive for the 4-6 hours we targeted. Thus, with the use of a compact condenser unit instead of a thermoelectric unit, we could accommodate consumers living in regions of the world where the aforementioned issue prevents them from purchasing our product. The insulation of our product is already sufficient to accommodate the re-designed cooling unit, however in an effort to prioritize aesthetics, a matte-black rust-proof enamel coating was applied. Although it succeeded in improving the attractiveness of the product, there was a negative impact on the product's ability to reflect sunlight, increasing the temperature of the structure as a whole. If a more reflective finish was applied, this issue could be prevented. Finally, by using a high density polymer rather than sheet metal to create the structure of the product, the manufacturing process could be simplified and optimized as it is much easier to work with. Overall, the future work required on this product would not influence the cost of the product to a great extent, meaning the price point of $269.99 selected would still remain feasible.

VII. Statement of Roles

Team member	Components	Details of efforts
Akshil Jhaveri	CAD, Manufacturing	Designed the overall CAD, Cut and bent all sheet metal components. Laser cut electrical housing unit. Managed manufacturing, assembly efforts and subsystem integration.
Dev Shaurya Singhal	FEA Analysis, Financial Manager, Manufacturing	Managed team budget and finances, set and followed up on weekly goals and deadlines for the team, conducted FEA tests for security subsystem, provided assistance in CAD design and manufacturing efforts.
Faisal Alsalloum	Electronic Components, Subsystems Integration	Integrated electronic systems, designed PCB layout, designed power unit and solar panel systems.
Harsh Meswani	UV-C Subsystem, Business Opportunities	Conducted cost and price analysis, UVC testing and lamp configurations, assisted manufacturing efforts and assembly of the final system.
Kohki Asai	Security Subsystem, Business Opportunities, Manufacturing	Conducted cost and modularity options, designed security subsystem.
Mohamed Elshabrawishy	Refrigeration Subsystem, Manufacturing	Lead the design and integration of the refrigeration subsystem, performed down selection of components and testing validation of the thermoelectric coolers. Assisted in the manufacturing of the box structure, surface finishes, and final subsystem integration.

VIII. Acknowledgements

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Appendix

Figure 1a: Theoretical Thermal Energy Balance on the Box.

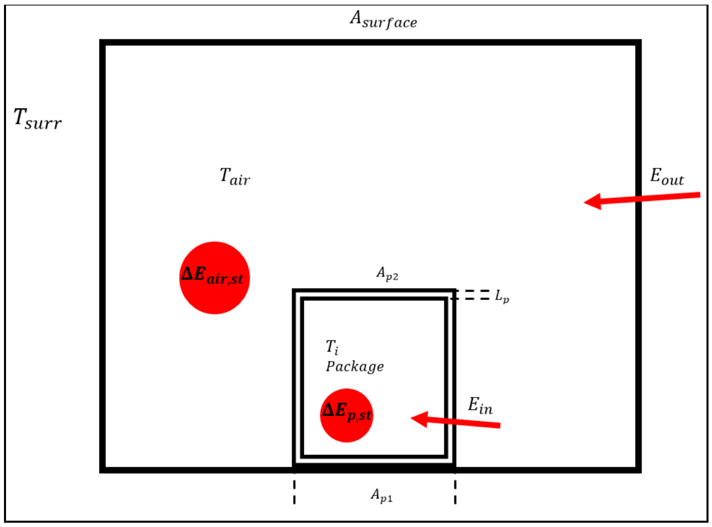


Figure 1b: Exact and Approximate Temperature vs. Time graph.

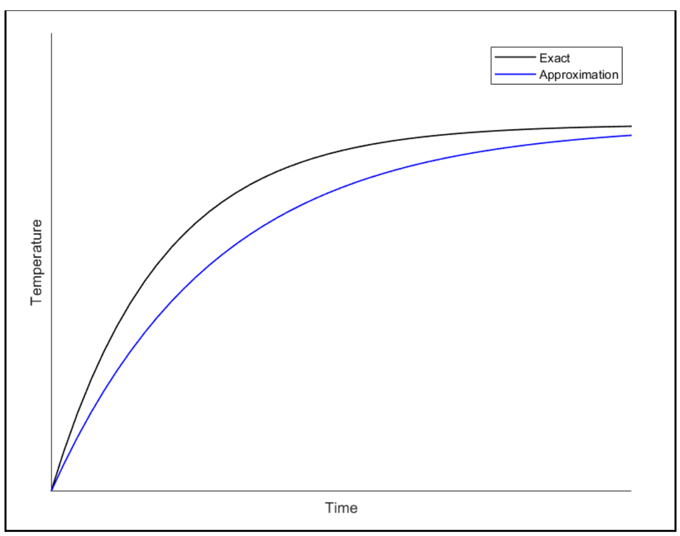


Figure 2a: Temperature of various groceries over time, with only insulation.

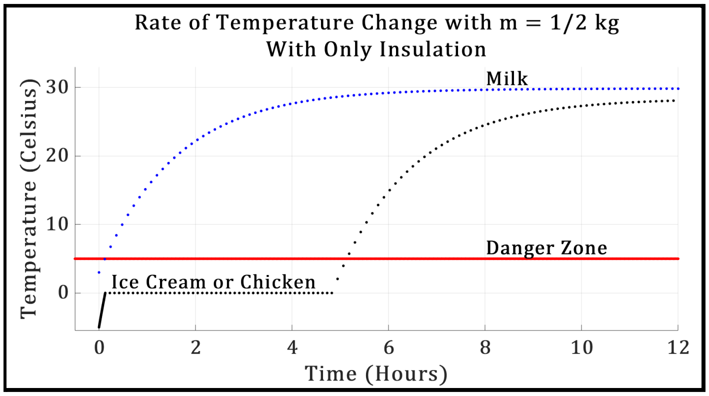


Figure 2b: Temperature of various groceries over time, with insulation and refrigeration.

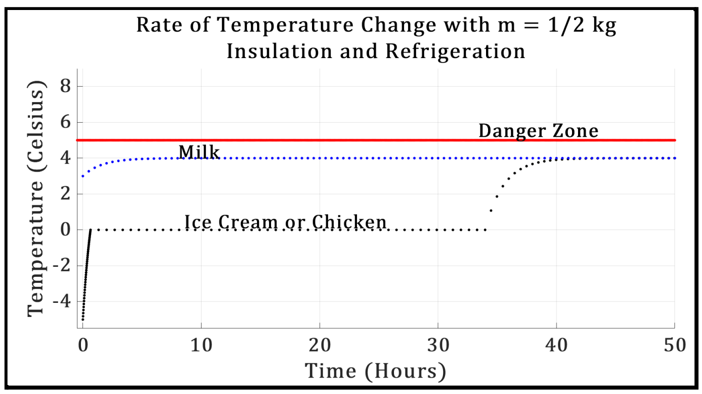


Figure 3: Downselection table for refrigeration subsystem.

Metric	TEC	Compressor
Noise Level	15-23 dB	32-47 dB
COP	0.4-1.2	2-3
Current input type	DC	AC
Max. Power Output	100 W	250 W
Low temperature capability	≅ 4°C	1.7°C
Customizability	High	Medium

Figure 4: Thermoelectric unit image.

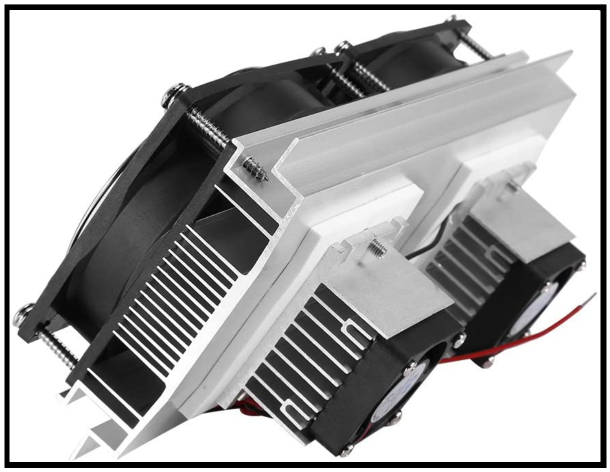


Figure 6: Refrigeration subsystem integration.

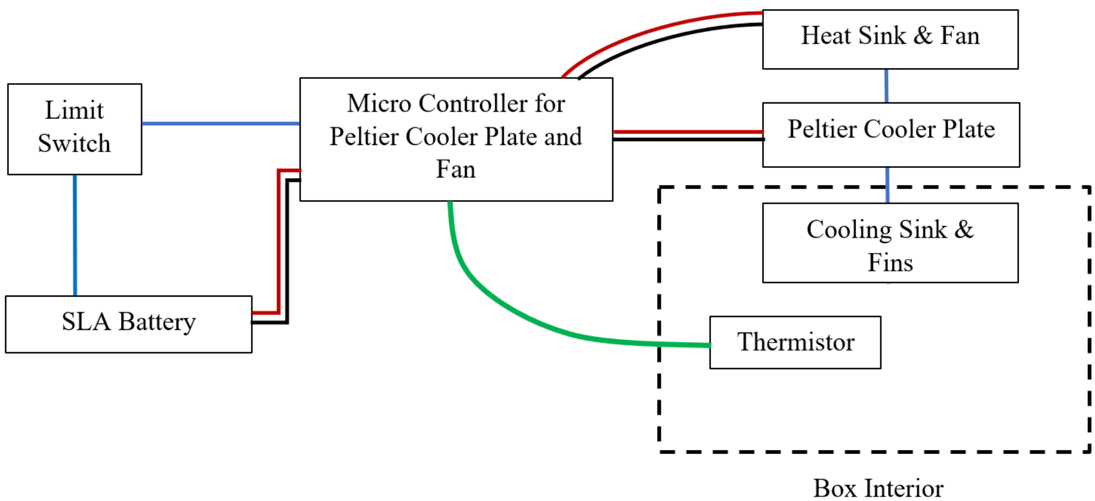


Figure 7: Theoretical UV-C Exposure time vs. Separation Distance for various diseases.

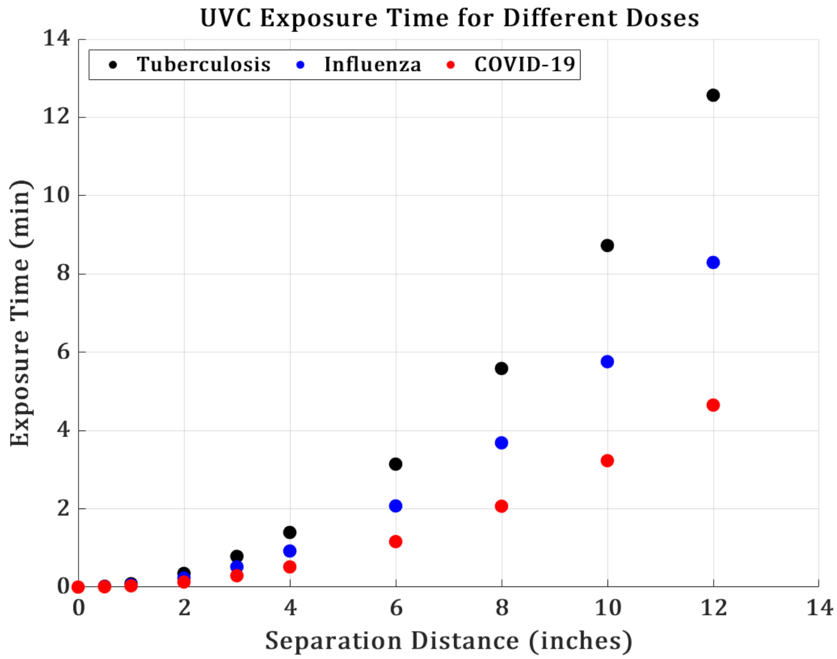


Figure 8: Experimental UV-C Exposure time vs. Separation Distance for various diseases.

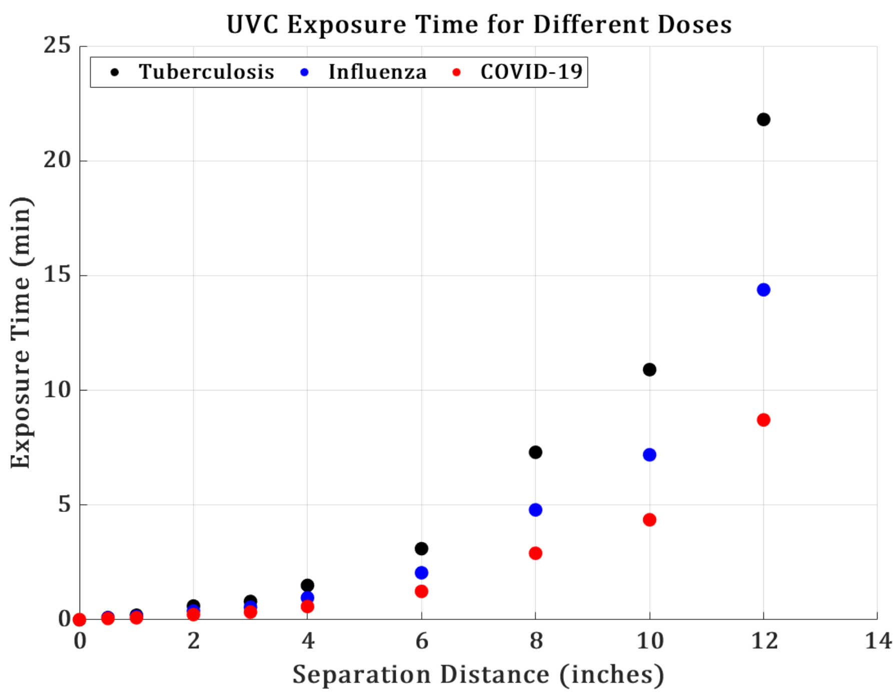


Figure 9: PCB Layout.

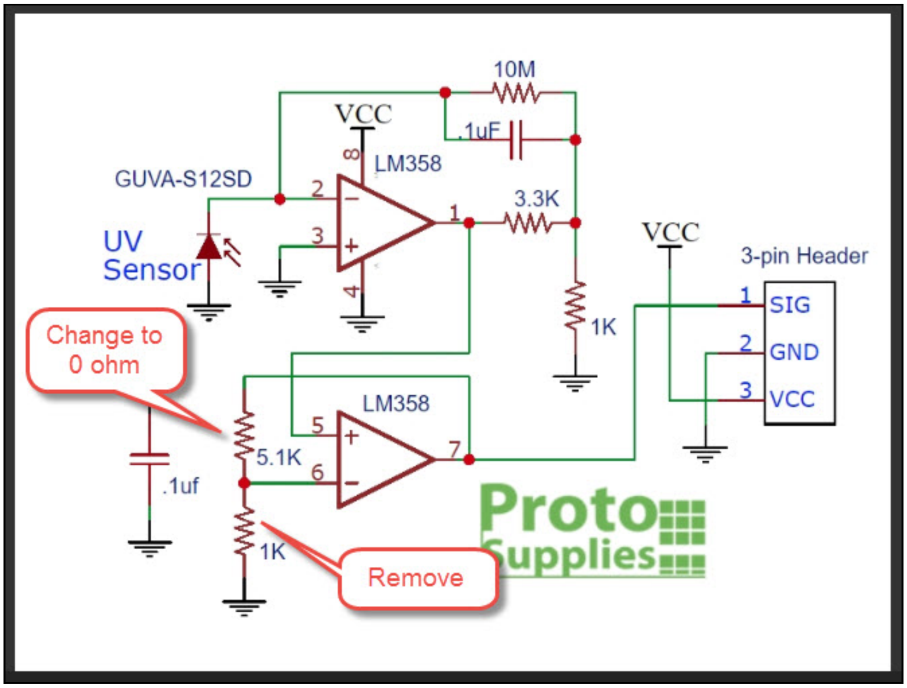
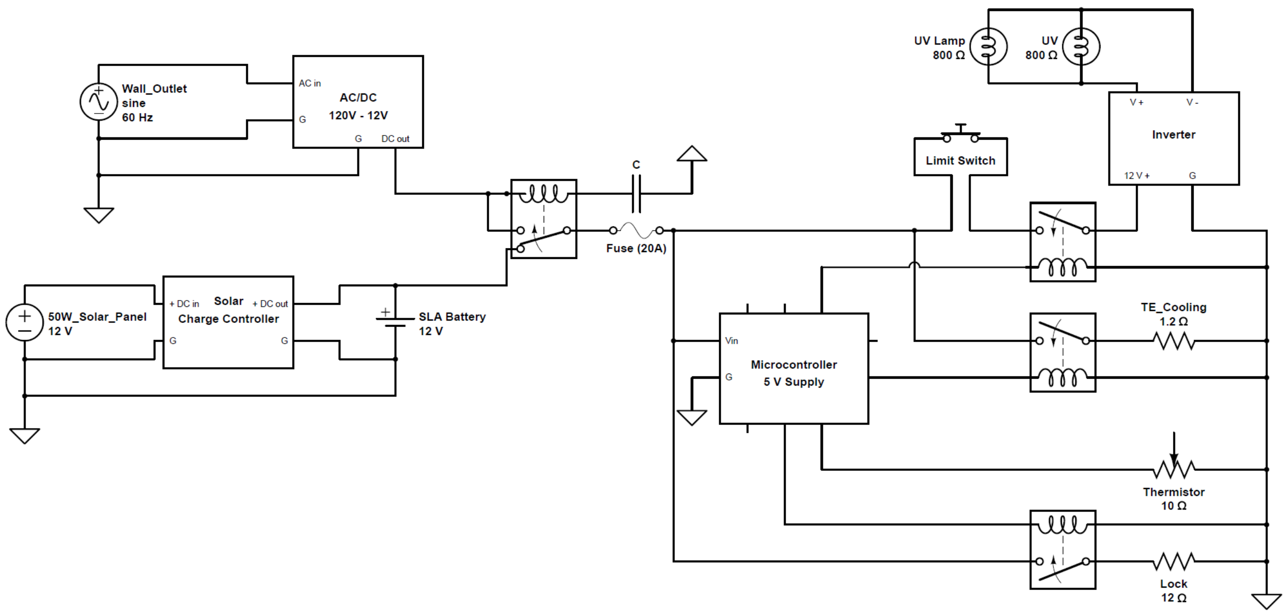


Figure 10: PCB Layout.



Appendix II: FEA Analysis Results

Figure IIa: Test 1 Data (Total Deformation).

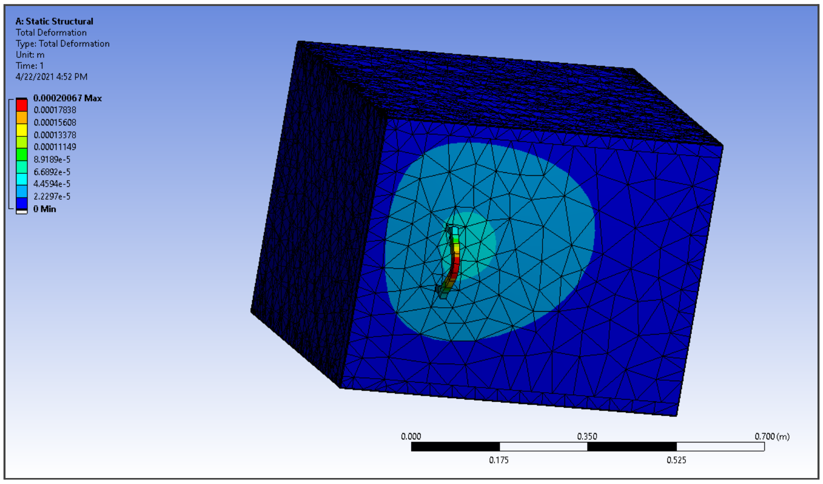


Figure IIb: Test 1 Data (Equivalent Stress).

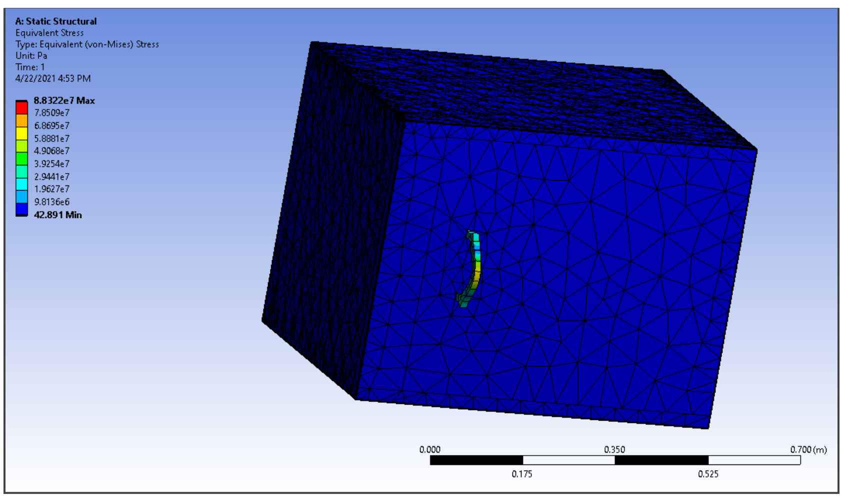


Figure IIc: Test 2 Data (Total Deformation)

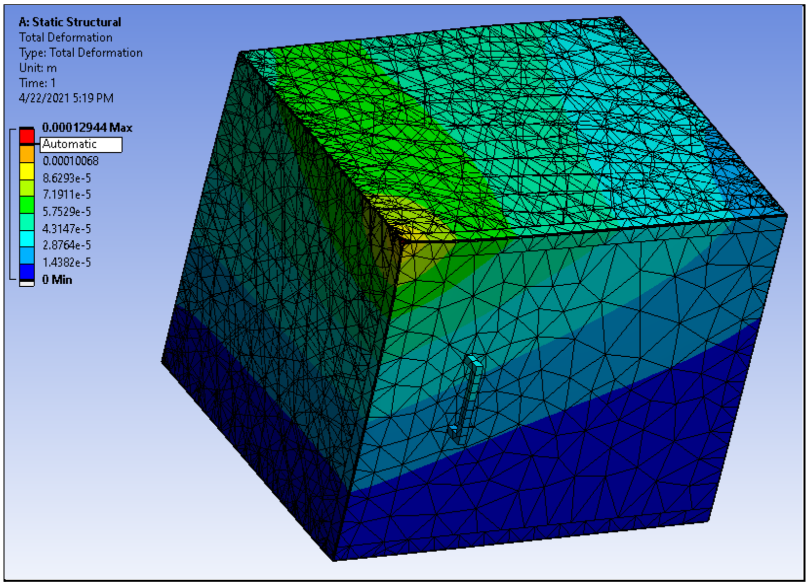


Figure IId: Test 2 Data (Equivalent Stress)

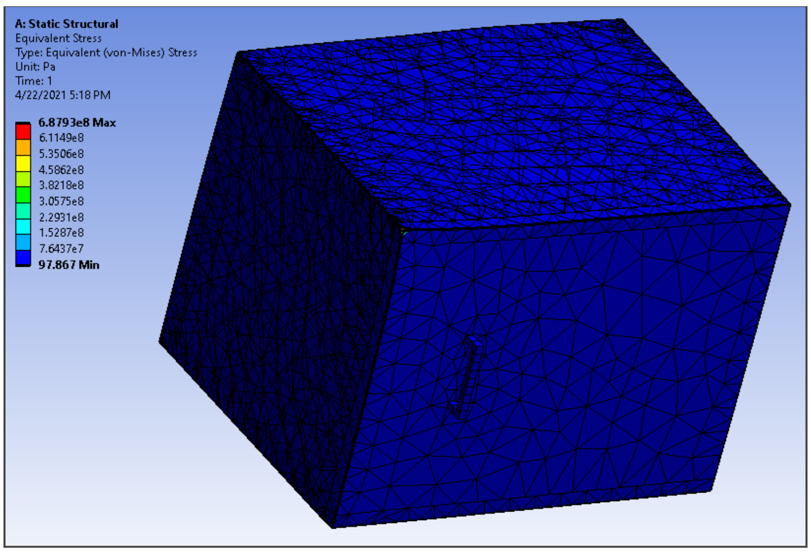


Figure IIe: Test 3 Data (Total Deformation).

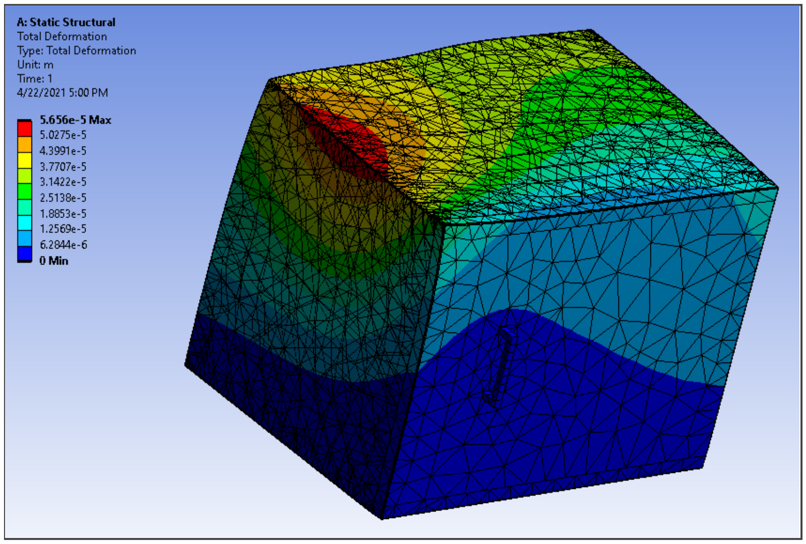
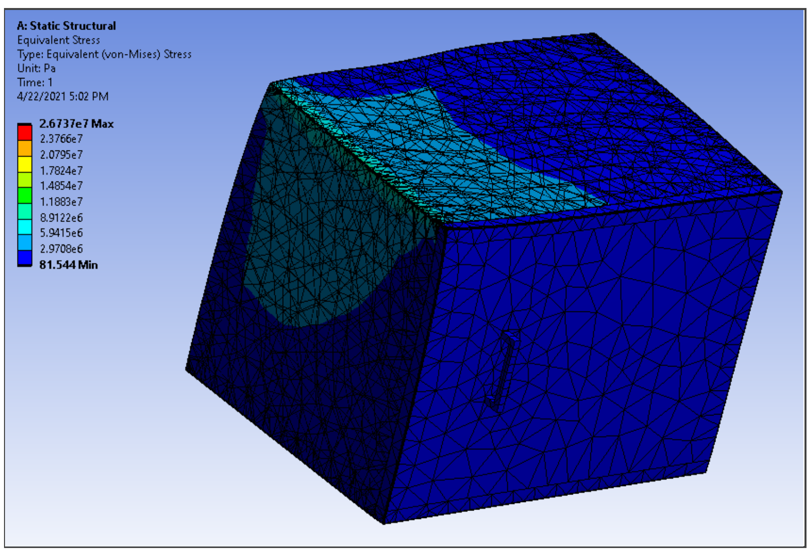


Figure IIf: Test 3 Data (Equivalent Stress).



Appendix III: Business Analysis

Item	# Ordered	Total ($)	Note
Easy-to-Weld 5052 Aluminum Sheets	4	182.80	*24" x 48" - 0.032" thickness*
Easy-to-Weld 5052 Aluminum Sheets	2	46.56	*24" x 24" - 0.032" thickness*
Easy-to-Weld 5052 Aluminum Sheets	7	479.92	*24" x 48" - 0.05" thickness*
Easy-to-Weld 5052 Aluminum Sheets	2	69.84	*24" x 48" - 0.05" thickness*
Germicidal Lamps	3	33.57	
Solar Cells	2	73.98	
Battery	1	37.99	
Solar Charge Regulator Controller	1	15.99	
TEC	1	55.58	
Photodiode	3	35.97	
Microcontroller Arduino	1	23.00	

Item	# Ordered	Total ($)	Note
UVC Protection Gear	1	129.99	
Keypad for Lock	1	8.99	
Boost Converter	1	17.99	
Battery Bag	1	14.99	
Solenoid Lock	1	12.99	*12V 0.8A 10mm*

Sonar Sensors	1	7.08	*400cm*
Cable	1	9.08	*15A*
AC/DC Converter	1	23.99	*12V 30A*
Fuse	1	10.99	*40 A*
Cabinet Light Fixture	2	64.42	8W
Total	**$ 1355.71**		