Worcester Community Fridges: Weatherizing and Protecting Fridge Enclosures

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Weatherization of Worcester Community Fridges

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Abstract

While collaborating with Worcester Community Fridges, we worked to understand and address weatherization issues the refrigerators face. Through collecting a variety of data and researching solutions, we synthesized design recommendations for future improvements to the enclosures and stock solutions that are ready to implement. Our team also provided a manual to break down the needs of a community fridge. We interviewed volunteers, Ph.D. students, and architects to inform our design process, ensuring the refrigerators can run with little maintenance regardless of the season. Working on weatherization design was an iterative process, requiring feedback from the community and cost-benefit analyses to deliver flexible and effective recommendations for current and future enclosures.

Executive Summary

In 2021, 33.8 million Americans lived in food-insecure households as a result of low and unstable incomes, lack of or unstable employment, disabilities, family challenges, and lacking family and community support (USDA key, 2021; Nord, 2003). The recent global pandemic and current inflation crisis have exacerbated many of these issues, putting many people's ability to access food at even greater risk. One can see this relationship in Figure S.1, where pre-pandemic levels of food insecurity were half of what they are now in Massachusetts (Project Bread, 2022).

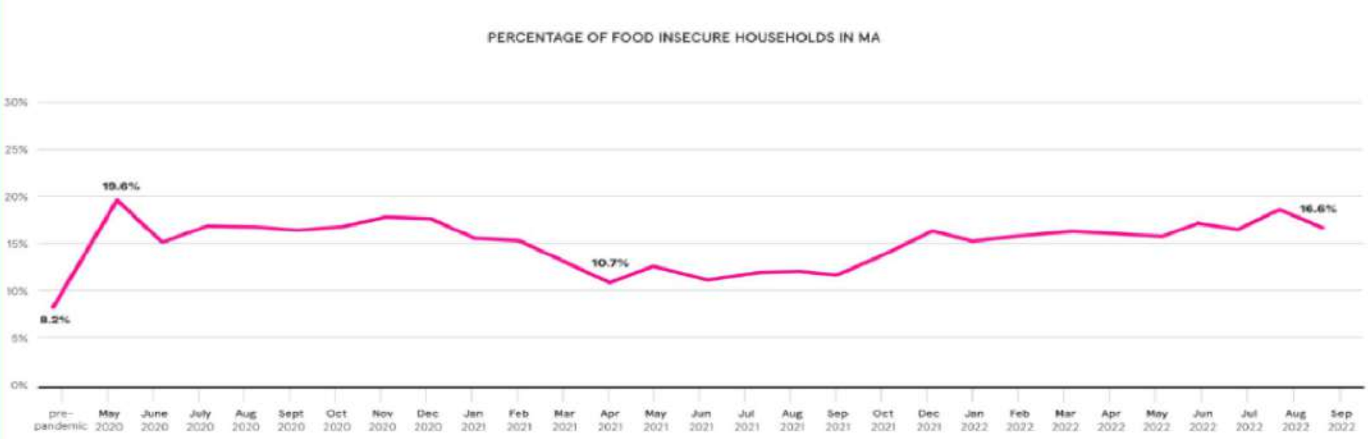

Figure S.1: Food insecurity in post-pandemic Massachusetts (Project Bread, 2022)

Worcester Community Fridges, or WooFridges, is a grassroots program centered on mutual aid that aims to eliminate food insecurity in our local community. Recently, our sponsor, WooFridges, has been experiencing issues with consistency of operations in refrigerators located in wide temperature ranges. The fridges respond adversely to heat and cold in the summer and winter, severely impacting efficiency and causing complete shutdowns. Our team has been working on delivering WooFridges with a weatherization strategy in order for their fridges to allow smoother operation during months with extreme temperatures (ranging from below 32 degrees F to above 90 degrees F).

We observed the effects of extreme temperatures on the fridges ourselves and through interviews with volunteers to assess the scope of the issue. Additionally, we collected data on the environmental challenges the fridges face, since any solution needed to exist within the same environment. To do this we conducted semi-structured interviews with volunteers from WooFridges along with field research around the enclosures to gauge the temperature variation and how much space was available around the enclosure. However, when interviewing volunteers it was shockingly evident to us how some of the biggest worries from volunteers were cleaning and accessibility. Consequently, this led to us having to bring these topics, which were initially more of an afterthought, to the front of our solutions. We had to ensure that any solution we created would not hinder or prevent cleaning or remove accessibility from the volunteers. While our interviews with volunteers did not clarify the degree to which weather was affecting the fridges and enclosures, our field research did. Using temperature probes on the internal and external of a fridge we were able to get a constant stream of quantitative data showing how the fridge's internal temperature was related to the external temperature. We had hypothesized that as the exterior temperature outside rose, the interior temperature of the fridge would follow. The hypothesis turned out to be correct. After discovering that the fridges were warming to an unsafe point, we discussed with our sponsor how to move forward with the information. Ultimately, we reached the conclusion that since the food in the fridges is generally being taken in under thirty minutes the fridges did not pose a health risk and would continue operating with careful observation of the internal temperatures.

Figure S.2 - Graph showing the temperature changes over the course of six days starting March 20th

After this, to better understand the fridges operation and how we can address the issues, we interviewed Ph.D students that all had an excellent grasp on heat transfer and systems. After learning that the vapor compression cycle is the main mechanism that keeps the fridge cold, it seemed that the vapor compression cycle in the fridge was heavily limited when operating outside of its desired temperature range. Several potential challenges were described all of which happen when in extreme low temperatures. In the opposite direction, overheating of a fridge is simply due to insufficient insulation of the enclosure, leading the heat seeping in through the walls and roof. Continuing to try and improve our knowledge we conducted case studies of other community fridge programs to better understand if they have similar problems and if they had addressed them in a way we could use. To accomplish this, we reached out to five different community fridge programs spanning across different climates to attempt to get data regarding extreme temperatures. For instance, we looked at fridge programs located in Regina, Saskatchewan, Canada for their notoriously cold winters, as well as Dallas, Texas for the other side of the spectrum. We discovered that most of these fridge programs did not have solutions for extreme conditions, rather opting to dissuade fridge users and donors to simply not use the fridge should it be out of the safe operating temperatures (around 40 degrees F). Leaving our project in a position to extend our recommendations and designs to other fridge organizations.

Next, we wanted to better understand the WooFridges organization as a whole as to learn their maintenance schedule, the time between cleanings, and any other considerations, to ensure our solutions wouldn't block or hinder their already existing structure. We spent several weeks observing their communications (they primarily use Discord for communication which is a set of online chat rooms) and helping them with maintenance where we could. However, we quickly discovered that this may not work since there were not as many maintenance calls made as we had thought there would be. In the end, we pivoted our observation from maintenance to the organization more broadly, using our interviews from objective one to gain a sense of how the organization operates and further observing through the discord and monthly meeting (occurring the first Saturday of every month, in this case, April 1st).

At that point we had several solutions along with a sense of their importance, drawbacks and effectiveness. We doubled down on this sense to perform a thorough cost-benefit analysis. To this end, we created a spreadsheet and analyzed our solutions on individual criteria broadly categorized as effectiveness in protecting from extreme temperatures, cost, difficulty of installation, resistance to adverse conditions, and importance to volunteers. Generally, we found many of our early ideas and theories about insulating the fridge were correct. The more thermal retention we could create for these enclosures the better. In the end, we shifted from our original thoughts of limiting solutions down to one answer and instead strove to give a thorough analysis of the options pertaining to each of our solutions (i.e. solar, insulation, ventilation, siding, etc). Ultimately this led to our spreadsheet of analysis and cost estimates for each individual solution as well as our recommendations for full designs of future and current enclosures. Following this we created three designs: a retrofit (made for currently existing enclosures), a budget-friendly new design, and a high-end design that would be most effective but also very costly.

Finally, we discussed our findings and recommendations with key community members and refrigerant experts that we had interviewed previously. We used this data to make any final revisions to our designs and analysis. These revisions were small with most of our design elements being approved by the interviewees. However, we did add a few elements like high emissivity paint and gasket maintenance.

Acknowledgements

To WooFridges, our team really enjoyed working with all of you. You made this project entertaining and engaging. We genuinely loved working with you all and hope to work with you again sometime.

To Julia, Maria, and Larry, you all have been a massive help to our team in accomplishing what we set out to do. You all were so supportive and always offered help and understanding when we needed it. Thank all of you so much for everything you helped us achieve.

To Laura and Mike, thank you to you two as well. The feedback on our work was seriously appreciated and helped guide our writing to where it is now. You two always gave helpful advice for not only writing but just general work environment things we hadn't experienced before. Thanks for all the help you gave us along the two terms.

Authorship

Our team did not take a divide and conquer approach to this report as we did in our planning class prior to this project. Instead we worked collaboratively to write the report. Generally, Valerie and Michael took the lead on gathering the data and drafting out the sections according to the guidelines given by our advisors. Taking care to ensure that the paper was easy to navigate and covered the necessary content all while being digestible to the reader. Then, Ian would ensure the information in the paper was accurate. Adding sections and making suggestions to information that should be included to further clarify the project and its results. Finally, Zack would go through editing the paper. Taking care of grammar mistakes and cutting down the wordiness of the paper ensures that long rambling is properly digestible. After getting comments back from our advisor, our team would go through them together and discuss strategies to address each concern as the process would start again. Valerie and Michael would take care of one comment at a time. Ian made sure everything is accurate and covered. Before Zack would read through ensuring there are no mistakes.

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Chapter 1: Introduction

The UN named a world free of hunger by 2030 as number two in its sustainable development goals (Martin, 2015). Food insecurity is growing globally and achieving the UN's goal will be impossible without addressing the issue on the local level. In 2021 alone 33.8 million Americans lived in food-insecure households (USDA key, 2021). According to Nord (2003), food insecurity is the result of many factors including low and unstable incomes, lack of or unstable employment, disabilities, family challenges, and lacking family and community support. The recent global pandemic and current inflation crisis have exacerbated many of these issues putting many people's ability to access food at even greater risk. One can see this relationship in Figure 1.1 where pre-pandemic levels of food insecurity were half of what they are now in Massachusetts (Project Bread, 2022).

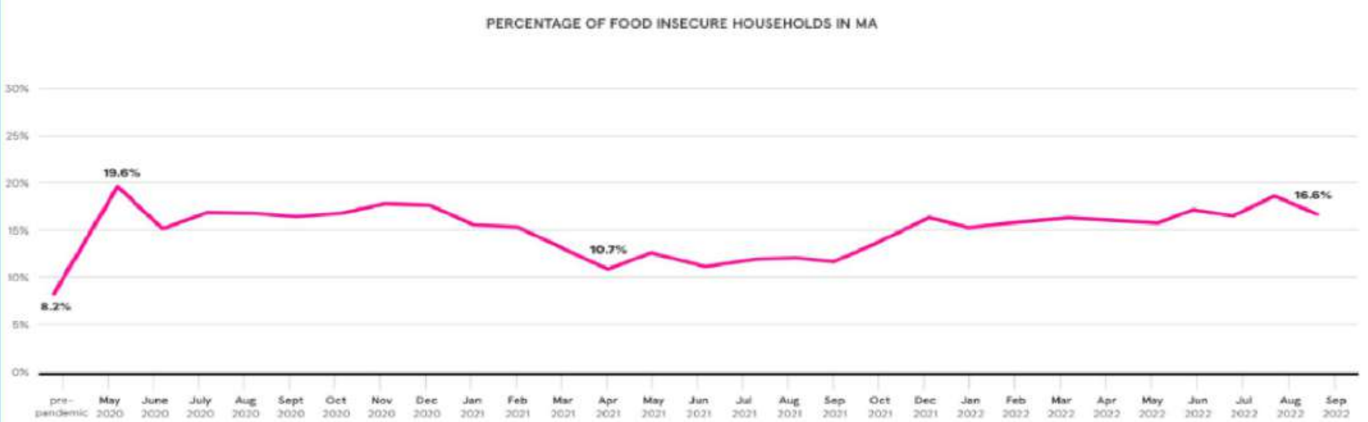


Figure 1.1: Food insecurity in post-pandemic Massachusetts (Project Bread, 2022)

In Worcester, 9.1% of households were insecure in 2020 and it has only risen since (Feeding America, 2022). Figure 1.2 illustrates how widespread the issue is in Worcester with one able to see that food insecurity ranges from 10% to over 30% in certain areas. As food insecurity grows, access to food aid is an important reliable method to help families.

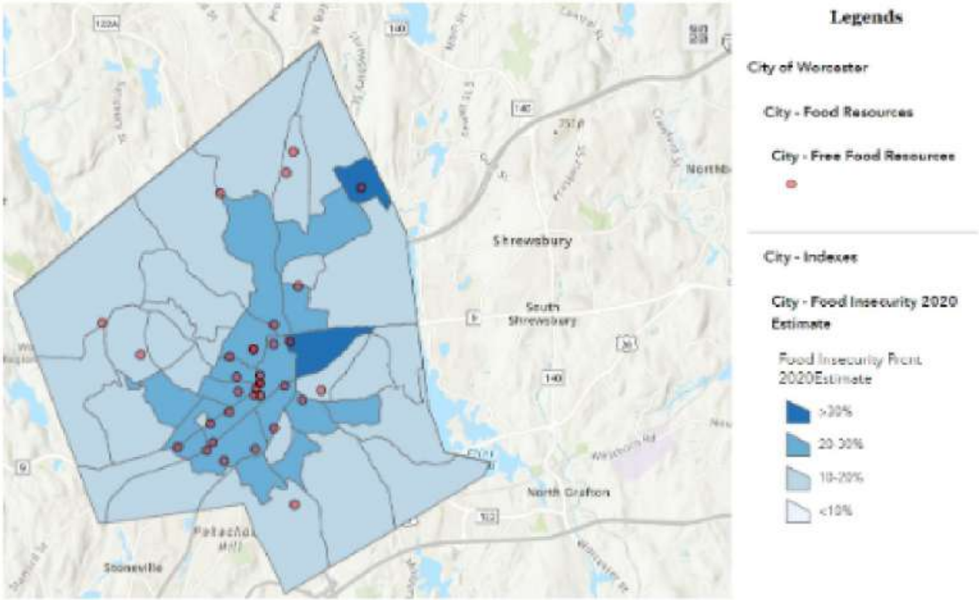


Figure 1.2: Food insecure areas in the city of Worcester (USDA, 2019)

Addressing this are grass root programs trying to close the current gap. Worcester Community Fridges, also known as WooFridges, is one such program. WooFridges is a community-run program that maintains the operation of multiple public-use refrigerators. Based on mutual aid, these fridges are used by members of the community who can drop off food or take food depending on their level of need. Recently, Woo Fridges has had issues regarding the consistency of service and maintenance of each refrigerator. The fridges respond adversely to heat in the summer and cold in the winter which harms efficiency and causes frequent shut-offs from the fridges. This leads to food in the fridges reaching dangerously warm temperatures inviting bacteria and mold.

Our team was tasked with delivering WooFridges with a weatherization strategy for their fridges to allow for smoother operation during months with extreme temperatures (temperatures ranging from below 32⊠ to above 90⊠). We observed the effects of extreme temperatures on the fridges ourselves and through interviews with volunteers. In the interest of finding a way to better insulate them we delivered a full manual, detailing all of the options for weatherizing a fridge as well as the advantages and disadvantages that comes with each individual aspect of the weatherization process.

In the following sections, we will go more in-depth on the background of the issue providing context for the existence and necessity of Woo Fridges. After this, we will provide more detail on our methods of data collection, and what we specifically did to gather data on the fridges. Before ending on our recommendations for the future of this project and conclusion.

Chapter 2: Background

After understanding the need for community food assistance in Worcester, one can better understand the need for the WooFridges program. In this section, we will go over institutionalized food aid and its gaps along with the history of WooFridges, their impact, and how the weather can impact their operations.

Section 1 - Institutionalized Food Aid

Food aid programs have proven to be an effective way to decrease accounts of food insecurity in households. Some examples of large food aid programs would be the Supplemental Nutrition Assistance Program (SNAP) and food pantries. SNAP is a government program designed to provide monthly funds to allow people to afford food. The program has strict qualification eligibility guidelines that dictate whether a family is eligible for aid or not. One study, shown in Figure 2.1 indicated a 19% decrease in food-insecure families in the first 6 months of their participation (Mabli & Ohls, 2015). This is based on a cross-sectional estimate in which the percentage of new entrant families is compared to the percent of existing 6-month enrolled families, and a longitudinal estimate, that compares the entrant households to the percentage of households 6 months later from the same original sample.

	Cross-Sectional Estimates			Longitudinal Estimates		
	New Entrant Households	6-mo Households	Difference	New Entrant Households	New Entrant Households (6-mo follow-up)	Difference
Food Secure	34.5	41.3	6.8	34.5	47.2	12.7
Food Insecure	65.5	58.7	-6.8	65.5	52.8	-12.7
Food insecure with low food security	26.1	26.7	0.6	26.1	22.4	-3.7
Food Insecure with very low food security	39.4	32.0	-7.4	39.4	30.4	-9.0

Figure 2.1: The change in food insecure households after joining the SNAP for 6 months. (Mabli & Ohls, 2015)

Furthermore, the more programs that are available, the more families are supported. This is supported in Figure 2.2 where in April 2021 rate of food insecurity reached an all-time low (10.7%) since the levels rose during the pandemic (8.2% to 19.6%) with four active programs. Looking at this one can see that having more programs directly coincides with declines in food insecurity. This data goes to prove that effective and ample food aid can help families who are food insecure.

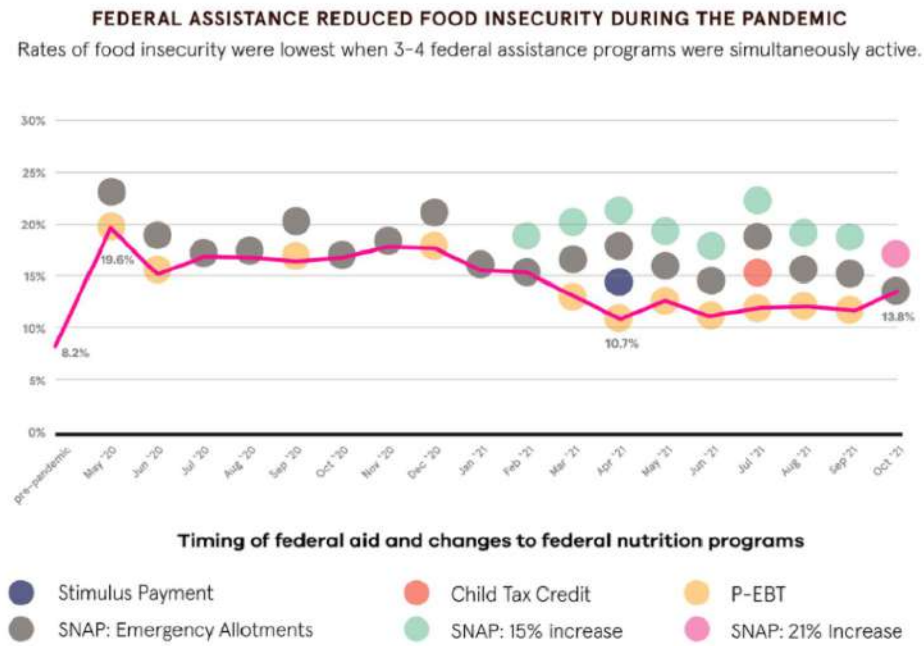


Figure 2.2: Shows the rate of food insecurity correlating with the number of national food aid programs from pre-pandemic to October 2021 (Project Bread 2022)

Section 1.1 - Common Issues with Institutionalized Food Aid

With food insecurity on the rise, going from 8.2% of households in Massachusetts before the pandemic, to 19.6% post-pandemic, people often find it hard to go and receive the aid they need (Project Bread, 2022). Worcester County Food Bank (WCFB) alone has had an increase of 26% in people seeking food aid (WCFB, 2022). It's estimated, only 1 and 12 people living in Worcester have access to consistent and nutritious food (Campbell, 2022). Food banks and pantries are struggling, with the Worcester County Food Bank trying to serve the estimated 68,460 individuals it gets (Feeding America, 2023). Additionally, the hours of operation for food pantries can be inaccessible for people who would take advantage of their services. According to a Massachusetts study done in early 2021, which tried to identify barriers to pantries and similar organizations, there is a communication gap as well (Marriott, 2022). This leads to many not knowing when these places are open; both cases are shown in Figure 2.3. While some of these places may have been inaccessible due to the pandemic, these statistics still illustrate a breakdown in communication that leads to confusion. This can be harmful when families are desperately searching for aid.

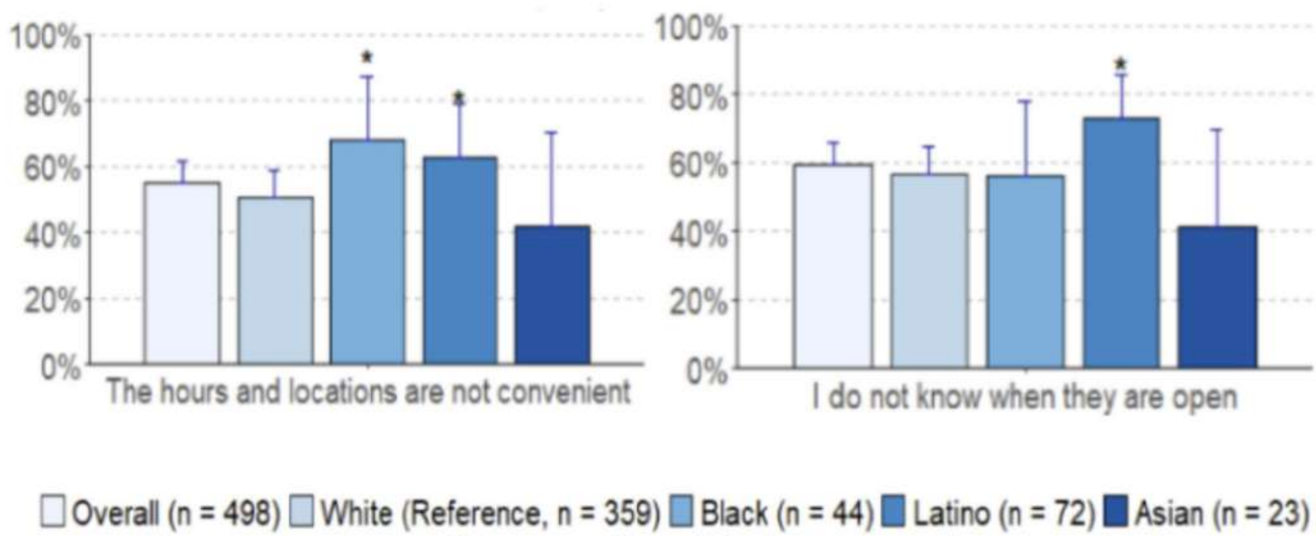


Figure 2.3: Commonly reported roadblocks to accessing pantries in Massachusetts (Marriott, 2022)

This leaves programs like WooFridges in a unique position to fill in some of the gaps that are left by other organizations in Worcester. Facilitating a space for people to take what they need whenever at any time ensures that everyone in the community will have a better chance at addressing their personal food insecurity struggles.

Section 2 - About Worcester Community Fridges

Worcester Community Fridges, or WooFridges for short, is a grassroots program based on a neighbor-help-neighbor approach that formed in response to the food insecurity spike due to the pandemic. Its goal is to connect people with resources and food aid to combat hunger. WooFridges, like many community fridge programs all over the world, is based on an idea originally developed in Germany by the organization “foodsharing.de”(Foodsharing) which is founded on the idea of eliminating food waste and redistributing excess to those in need. Additionally, the Woo Fridges organization has partnered with the Open Collective Foundation (OCF) providing them with money management software and non-profit status to grassroots programs to allow them to apply for grants and take donations without sacrificing the flexibility of not being a fully nonprofit organization (Julia Rose Karpicz, personal communication, April 1). OCF’s money management software also is integrated with the Woo Fridges discord server (a platform of online chat rooms), allowing fast and convenient recurring and custom donations from any device (Open Collective, 2023). WooFridges started when Maria Ravelli observed systemic problems in Worcester such as limited accessibility for pantries in the community and understood that many in the community weren’t able to effectively address food aid. After hearing about community fridge programs worldwide, she reached out to the “Worcester Mutual Aid” Facebook group and found those in the community willing to volunteer to help with her idea to bring community fridges to Worcester (Maria Ravelli, personal communication, March 24). The idea of these fridges is based on mutual aid and accessibility: a designated space for people with a little extra to drop off food and for people who need it to take whatever they might need (woofridge.org). She aimed to allow any member of the Worcester community to receive aid whenever they’re in need. This culminated in their first fridge opening on January 31st, 2021 at Fantastic Pizza on Main St serving all of the people of Worcester. The shop owner heard about the idea through Facebook and loved it, letting the donated fridge and built enclosure be put outside his restaurant.

After the first fridge opening, Maria invested more time connecting with people, including Julia Karpicz, who helped get WPI involved with WooFridges, and resources to help spread the word about the fridge's purpose. Maria and Julia spent a lot of time organizing regular donations from different restaurants and farms to help keep the fridge filled throughout the day (Maria Ravelli, personal communication, March 24). Since Main St, there have been three more fridges put up each with donated fridges and materials for the enclosures with a fifth fridge on the way. WooFridges' responsibilities consist of cleaning each fridge enclosure as well as repairs for the current fridges and enclosures that currently exist across Worcester.

The building cost for enclosures, fridge sourcing, electricity bills, and general maintenance are covered by the owners of the property they reside on with WooFridges helping these owners get in contact with resources that could help them accomplish these tasks. Thus organizers of WooFridges only organize the building of new fridges at the request of property owners like in the case of the Pizzeria (Julia Rose Karpicz, personal communication, March 24).

However, the fridges do not require constant upkeep or supervision for operation and are simply set outside for other people to use. Mechanical maintenance for the fridges mostly comes about from extreme temperature conditions that subject the fridges to sub-par operating conditions that cause breakdowns and food rot. All of these issues require a volunteer to travel to the fridge and manually address the issue. As mentioned before, volunteers are asked to clear out spoiled food and sanitize the fridges regularly, about once a month. Both stocking and maintenance of the fridges are coordinated by volunteers through a Discord server.

WooFridges is a unique program with 24/7 operation and an active volunteer base, committed to providing for families in our community addressing the gaps left by systemic food aid, such as limited hours and accessibility for those in need (woofridge.org). The program is flexible and allows any property owner to ask for a fridge to be built. Furthermore, these fridges provide access to a variety of foods intended to keep everyone in the community healthy. The take-and-leave philosophy is a straightforward approach that helps subsidize other food aid programs to give Worcester a holistic approach to food insecurity. There are also other sources of food for the community fridges. The fridges currently are regularly stocked by local chefs, farms, stores, and restaurants in addition to community members (Julia Rose Karpicz, personal communication, March 24). Woo Fridges recognizes that anyone at any time could need help and aims to help provide a space to facilitate flexible and immediate community drive aid. Consequently, due to the nature of the anonymous donations the fridge receives, food moves quickly from donors to those who need it. The speed at which food comes in and out has made data collection difficult without interfering with the anonymity of all parties. (Julia Rose Karpicz, personal communication, March 24)

Section 3 - The Challenges of Worcester Weather

With WooFridges representing a useful source of food assistance in Worcester, it's important to consider how the fridges' effectiveness is affected by the extreme temperatures of Massachusetts. The refrigerators used by Worcester Community Fridges are protected by enclosures, as shown in Figure 2.4. These enclosures protect from damage due to weather, but they do not protect the fridges from extreme temperatures. The exposure of the fridges is a necessary situation, as it makes the fridges accessible to the users, but it also makes the fridges far more susceptible to the harmful effects of extreme temperatures.

Figure 2.4 - One of the fridge enclosures for WooFridges

The domestic fridges that WooFridge uses are designed for household temperatures (60-80 degrees F according to GE appliances), but Worcester weather is routinely outside of this range. Temperatures can reach above 90 degrees Fahrenheit in summer and below 10 degrees Fahrenheit in winter. Figures 2.5 and 2.6 show the hottest and coldest months in Worcester in 2022. The fridges are directly exposed to these temperatures, yet need to both stay operational and maintain a safe internal temperature to preserve the donations inside.

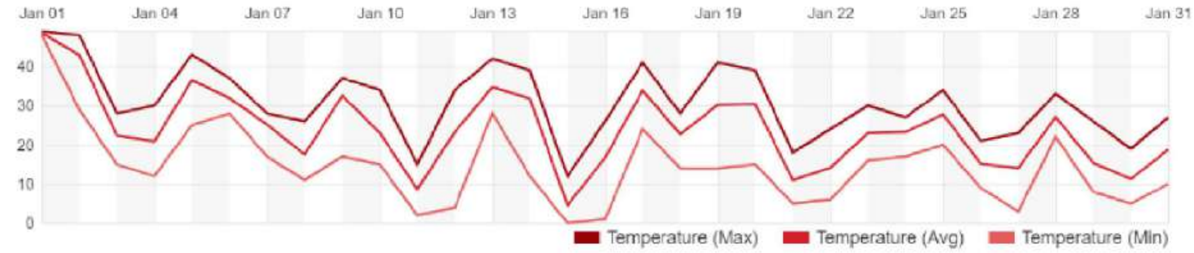


Figure 2.5- Highs, lows, and average temperatures in Worcester for January 2022 (Weather Underground)

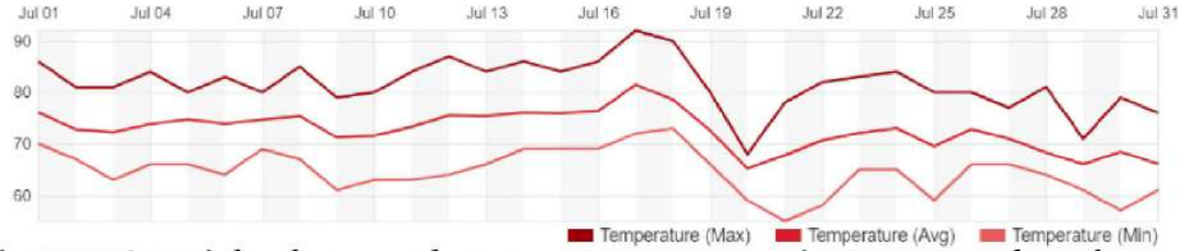


Figure 2.6 – Highs, lows, and average temperatures in Worcester for July 20/22 (Weather Underground)

Section 3.1 – How Weather Affects Fridges

These adverse climate conditions are detrimental to the operation of the fridges. Extreme temperatures, both high and low, cause fridges to have difficulty maintaining their internal temperature, as well as increase wear on the system.

Hot weather negatively impacts the efficiency of refrigerators. According to Saidur and Masjuki (2002), high temperatures increase the rate at which fridges warm as shown in APPENDIX D. This forces them to use additional energy to keep their contents safe. Therefore, as temperatures increase, power requirements and system wear also increase, as shown in Figure 2.7. If the temperature gets hot enough, the refrigerator will not be able to keep its internals at a safe temperature, risking spoiling the donations inside. This issue has in the past, forced WooFridge to put up signs limiting donations of perishable goods during the hottest days of the summer.

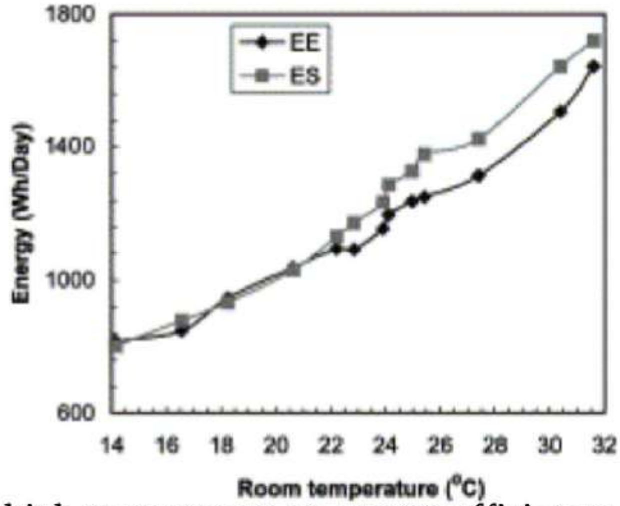


Figure 2.7 - Effect of high temperature on energy efficiency. EE and ES refer to two different models of household fridges. (Saidur R. & Masjuki H, 2002)

The low temperatures experienced during the winter months also pose a threat to the operation of the fridges. According to Björk and Palm (2006), cold weather causes refrigerant, the internal fluid that is used to transfer heat from inside the fridge to the outside air, to build up in the evaporator (The part where the refrigerant is boiled to release energy into the outside environment). This can cause the system to "flood" when enough liquid has built up to reach the compressor. Flooding can cause damage to the refrigerator, as well as reduce the ability of the fridge to control its temperature.

Another major challenge in cold weather is maintaining the internal temperature of the food inside. According to General Electric's support page (https://www.geappliances.com), several issues contribute to an inability to maintain its temperature. First, the low temperatures can trick the fridge's thermostat into thinking the fridge is at the correct temperature, resulting in the fridge not running. Second, the refrigerant does not evaporate as effectively, which reduces the efficiency of the refrigeration mechanism. Even if this doesn't cause damage, it can reduce the effectiveness of the unit. These two factors can lead to a refrigerator not being able to control its internal temperature in cold weather, which can damage the food stored inside.

Considering how much the weather can affect refrigerators, protecting them from extreme conditions is important to the Worcester Community fridge project as a whole. Weatherizing the fridges would help to protect donations, reduce maintenance, as well as save on operating costs going forward.

Chapter 3: Methodology

The goal of this project was to present WooFridges with a cost-effective and viable weatherization plan for their fridges. In the interest of achieving this goal, we came up with the following objectives:

1 - Investigate the impact of the weather on the fridges

2 - Obtain insights on weatherization from experts in the field and other similar operations

3 - Observe the maintenance and upkeep of the fridges

4 - Explore the effectiveness of potential solutions

5 - Propose an optimal weatherization solution

In this chapter we will describe the methods we've chosen to obtain and analyze data from the community and environment. Furthermore, we will discuss how the results of that analysis will develop our proposal for an optimal solution.

Objective 1 - Investigate the Impact of Weather on the Fridges

Our first objective for data collection was to precisely define the issues the fridges were experiencing due to weather conditions. The fridges were said to be having trouble maintaining a food-safe internal temperature during the summer and winter months; however, without data we didn't understand the scope or details of the problem. To better gauge the fridges' responses, we collected data from volunteers and temperatures from the fridges to record how adverse weather caused issues.

Semi-Structured Interviews:

To leverage the experiences of Woo Fridges volunteers and gain valuable anecdotal data, we conducted semi-structured interviews as described in Beebe (2001). Allowing the interviewees to speak freely about their time working in Woo Fridges was more valuable than just having them answer a list of rigidly structured questions.

Our data collection focused on the fridge's behavior in extreme temperatures and volunteers' needs for maintenance. To collect the qualitative data necessary, we asked the volunteers to share their experiences with the fridges throughout the year. Our questions, referenced in Appendix B, covered subjects like potential sources of environmental damage, daily use, and previous maintenance requests. Key points and follow-up questions are all included in Appendix B. After our data collection, we coded all the gathered qualitative data with labels based on what issues the volunteers experienced and analyzed our results to prioritize concerns and observations.

The active volunteer population of WooFridges is estimated to be around 30 people, we were able to reach a purposeful sample of just over five volunteers from the WooFridges Discord server. At this sample size our team was able to manage the data gathered from responses and ensure that we would be able to follow up with them for our later objectives. We used a purposeful sample since most of the population is accessible, allowing us to optimize our interviewing process by selecting volunteers who are most active and experienced. The risk of purposeful sampling was that it "May be challenging to locate information-rich participants." (Gill, 2020); which we did find to be a notable challenge, as we were not able to get as much interest from volunteers as we had hoped. However, due to how active the members we interviewed were, we collected some excellent data about the fridges and the organization.

Field Data Collection:

In order to benchmark how the fridges were operating in their existing enclosures, we recorded data on the internal and external temperatures of the fridges throughout the project. Quantitative data on the performance of the fridges helped us understand the severity of the problem so that we could develop solutions that address the issue. To collect this data, we first observed the internal and external temperatures of the fridges twice a day for about a week with a handheld infrared thermometer, recording internal and external temperatures of the fridges. However, we found this method to be cumbersome and time consuming, as we had to travel to the fridge whenever we wanted to take a data point, and we weren't able to record data at night when temperatures were the lowest.

Our solution was to install a pair of sensors in the main street fridge that updated automatically every 5 minutes (Figure 3.1). These devices were concealed in inaccessible positions in the fridges and their enclosures to protect them from being removed. Data collected by these sensors was stored in the cloud, where it could be extracted in the form of a CSV file (Comma Separated Value file). In order to read and plot this data, we developed a tool in Java to read the CSV file and output a graph of the temperatures as a function of time. This tool was also provided to WooFridges so that they could continue to monitor internal temperatures after this project concluded.

Figure 3.1 - The third party sensor system that was employed in the fridges (MOCREO)

Objective 2 - Obtain Insights from Experts

Our second objective was to reach out to people with experience and knowledge relevant to fridges for their insights and opinions. By this point, we had a broad understanding of the problems but still needed help with specific pain points. To address this, we found experts on refrigeration and spoke with them about the issues the fridges were dealing with. We also had a series of interviews with Larry Haley, the architect who designed some of the current enclosures, looking to collaboratively assess the challenges involved in weatherizing the fridges to identify potential solutions. Finally, we looked at other community fridge programs and purpose-built outdoor fridges to see how they have dealt with inclement weather.

Semi-Structured Interviews:

Our first order of business in interviewing experts was to obtain a more technical understanding of the issues the fridges were facing, as well as some insights into potential solutions. We determined that the best source of this information was academics working in the field of refrigeration, so we contacted a few professors at WPI who specialized in thermodynamics. Unfortunately, they were unable to fit us in their schedules, but they were able to redirect us to their Ph.D. students.

From the list of Ph.D. students, we took a purposeful sample of two who both specialized in refrigeration and were able to meet with us. The students had limited information about fridges, so we varied from Beebe's (2001) semi-structured interview format. Before we started to ask questions, we provided them with images of the enclosures, and the data we collected in objective 1. After providing them with context about the fridges, we proceeded with the typical semi-structured interview. We asked them if they had an explanation for the issues the fridges were facing, and if they knew of existing solutions to the issues. A complete list of our questions can be found in Appendix A.

After obtaining a technical explanation for the issues, we needed to understand what other considerations went into the design of enclosures. To do this, we did a series of two semi-structured interviews with the architect responsible for the design and construction of the enclosures, Larry Haley. We opted to use the semi-structured interview format because we had limited knowledge of the architectural side of the project, so we would get better data if we allowed the conversation to be somewhat free-form.

In our first interview with Larry, we asked about what design principles were central to the construction of the enclosures. We discussed how the enclosures interact with their users, how the structure of the enclosures needs to withstand the wear and tear of Worcester streets, and how aesthetics are affected by the surrounding environment. We also used this interview to inquire about solutions that were available in the architectural field.

In our second interview with Larry, we explored the implementation of solutions in the enclosures. For this interview, we asked him to bring some of his architectural drawings of the enclosures. We went over his drawings and discussed how various solutions would fit into the enclosure. We also discussed who was expected to build the enclosures, and how to make drawings such that they could be easily interpreted by the volunteers building the enclosures.

Case Study:

We looked at five other fridge programs in locations around the world with extreme climates. These included Regina Community Fridge in Saskatchewan Canada, or Providence Community Fridge in Rhode Island or Dallas, Texas' fridge program. We were looking for any kind of techniques or solutions that these groups had applied to their enclosure that improved the weather or temperature resistance of the fridge and its food. For example, if the fridge had a slanted roof or if the fridge is up on blocks to keep the enclosure away from the snow we kept track of it to add to our own considerations.

Objective 3 - Observe the Maintenance of the Fridges

Our third objective was to closely observe the community that supports and maintains the fridges. WooFridges are kept running by a team of volunteers, whose needs and workflow needed to be accounted for in any potential solution we proposed. If we didn't intimately understand the organization, the solutions we proposed could have ended up directly conflicting with the volunteers and be unsustainable. To that end, we observed the volunteers working with the fridges by participating in their meetings, observing their operations through discord, and participating where we could in the upkeep of the fridges.

Observation:

Understanding the needs and ideas of the volunteers maintaining the fridges was essential to ensure that potential solutions would work well within the community. Our team planned on taking time listening to stories and logging relevant qualitative data to better understand the needs of volunteers and opportunities with the fridges. The logs are formatted and detailed in Appendix C. Our team has also kept a contact tree including volunteers and members of the community we've spoken to and who introduced them. We also set aside time to attend meetings and contribute in discussions with the WooFridges organizational body. After the four weeks of participation observation, all the notes and observations from our time with the organization have been collected and formatted for future reference.

Objective 4 - Design Solutions

Our next objective was to take all of our data and use it to inform a few suggested designs along with a catalog of individual solution options. At that point in the project, we had many ideas for solutions, data on how effective each solution would be, and the community's opinions. From here, we used this data to narrow our pool of solutions down to three suggested designs based on longevity, effectiveness, durability, cost and maintenance. Our solutions had to be built to last to minimize maintenance, effective at maintaining operable temperature in the fridge, be durable enough to withstand being left outside in a public space, and priced at a point that WooFridges can afford them, all while requiring minimal maintenance to operate at its best. We decided on a retrofit design to update existing enclosures, a budget design for future enclosures, and a high-end solution representing what was possible without constraints.

Cost-benefit Analysis:

In order to properly compare our options, we did a cost-benefit analysis for each solution as well as each of our full design recommendations. Our analysis was based on our initial interviews with volunteers along with all the other data we collected. Initially, to narrow down our options for the full designs, we compiled all of our individual solutions (insulation, ventilation, solar, gray water, etc) into a singular spreadsheet. Comparing not just each solution side by side but also different implementations (brands, methods, versions, etc) to see which ideas were most viable. Below is an example of the spreadsheet.

Type	R value per inch (Min and Max)		Price per sq. Foot (min and max)		Amatuer installation	Perfectly retains shape	Water resistant	Outside of studs
Blow-In Cellulose	3.1	3.8	$1	$2.80	No	No	No	No
Fiberglass Batts	2.9	3.8	$0.80	$2.60	Yes	No	No	No
Closed Cell Spray Foam	6	7	$2.50	$5.80	No	Yes	Yes	No
Open Cell Spray Foam	3.6	3.9	$0.88	$3.00	No	Yes	No	No
Foam Board	4.5	5	$1.20	$1.50	Yes	Yes	Yes	Yes
RockWool	3.3	4.3	$1.10	$3.10	Yes	Yes	No	No

Figure 3.2 - Comparison sheet for methods of insulation

Our criteria for each solution were based on the following: longevity, effectiveness, durability, cost, and maintenance . While we considered all these criteria, we believed that cost, longevity, and effectiveness were the most important. From our analysis, we created three concepts: a retrofit, a budget design, and a high-end design. Our criteria for these designs revolved around cost and effectiveness. Each solution's main difference was the cost of each solution versus its effectiveness in terms of weatherization and thermal retention. This was because we wanted to provide designs representing both what was possible and what was reasonable too WooFridges. These designs were also planned with a degree of interchangeability, such that WooFridges could mix and match different aspects of solutions on a case-by-case basis.

Objective 5 - Finalize Recommendations

Our final objective was to take the designs and solutions we created in the previous objective, get feedback from volunteers, and make any final revisions to our recommendations. We collected data on each design to see how they would affect the fridges, the people who use them, and the volunteers that work on them along with any other suggestions they might have. Using quantitative and qualitative data to get a sense of how the different solutions were compared.

Semi-Structured Interviews:

Volunteer opinions were critical for the viability of potential solutions. To help mitigate the risk of suggesting potentially harmful solutions to the organization, we re-interviewed many of the same people from objective one. The reasoning behind this sample remains the same. The volunteers we selected were some of the more active members, and as such they knew the enclosures and the maintenance procedures the best.

These interviews were semi-structured, as described in Beebe (2001), seeking to record opinions, concerns, and potential opportunities about various solutions. The semi-structured approach allowed us to obtain more detailed responses and was more likely to give us unexpected insights. We have also presented volunteers with our solutions and recommendations, asking for their opinions, concerns, and suggestions. All of our questions are detailed in Appendix A.

After our interviews, we compiled our logs and established codes for all the feedback gathered. These codes allowed us to find patterns in responses, which helped us quantify how volunteers view our recommendations, as well as to identify and potentially be able to address issues.

Ethical Considerations:

Most interviews were conducted anonymously thus not needing written consent, instead opting for oral consent. Any other interviews that gathered the interviewee's personal information was provided with a written consent form (Appendix E). This was only the case for the two sponsors, Julia Karpicz and Maria Ravelli, and the architect for WooFridges Larry Haley. This paper has been approved by the IRB guidelines.

Chapter 4: Findings and Results

Through our methodology, we discussed the strategies we used to gather data and determine our final recommendations. In this section, we will discuss our findings from each objective: the responses from the people we interviewed, the temperature and dimensional data from our field research, and the spreadsheets we used to analyze our solutions.

1 – The environmental impacts on community fridges

In our first objective our focus was to gain a better understanding of the impacts adverse conditions have on the fridges and how volunteers handled these issues. However, when interviewing volunteers especially it was surprising to us how some of the biggest worries from volunteers were cleaning and accessibility. This led to us having to bring these topics, which were initially more of an afterthought, to the front of our solutions ensuring that any solutions we gave would not negatively impact these areas. While our interviews with volunteers did not clarify the degree to which weather was affecting the fridges and enclosures, our field research did. Using temperature probes on the internal and external temperatures of a fridge we were able to get a constant stream of quantitative data showing how the fridge's internal temperature was related to the external temperature. Similar to what we hypothesized, the fridges were getting very warm when the outdoor temperature was higher; however, we were surprised by the degree to which the two temperatures are correlated with the internal temperature following the external trends closely as shown in Figure 4.1.

Figure 4.1 - Graph showing the temperature changes over the course of six days starting March 20th

After discovering that the fridges were warming to an unsafe point, we discussed with our sponsor how to move forward with the information. Ultimately, we reached the conclusion that since the food in the fridges is generally being taken in under thirty minutes the fridges did not pose a health risk and would continue operating with careful observation of the internal temperatures.

In addition to the issues with temperature, with how the probes recorded data. The probes only gave a live temperature reading and any previous data would be in a CSV generated by the company on request. To aid in this our team developed an application to parse these CSV's and produce a readable graph of the temperature data. Attempting to make the app as intuitive as possible (simple buttons and UI, using file explorer to browse for files, confirmation messages, a go button that highlights when both files are submitted) so it will be easily usable even if the people using it are not tech-savvy as seen in Figure 4.2.

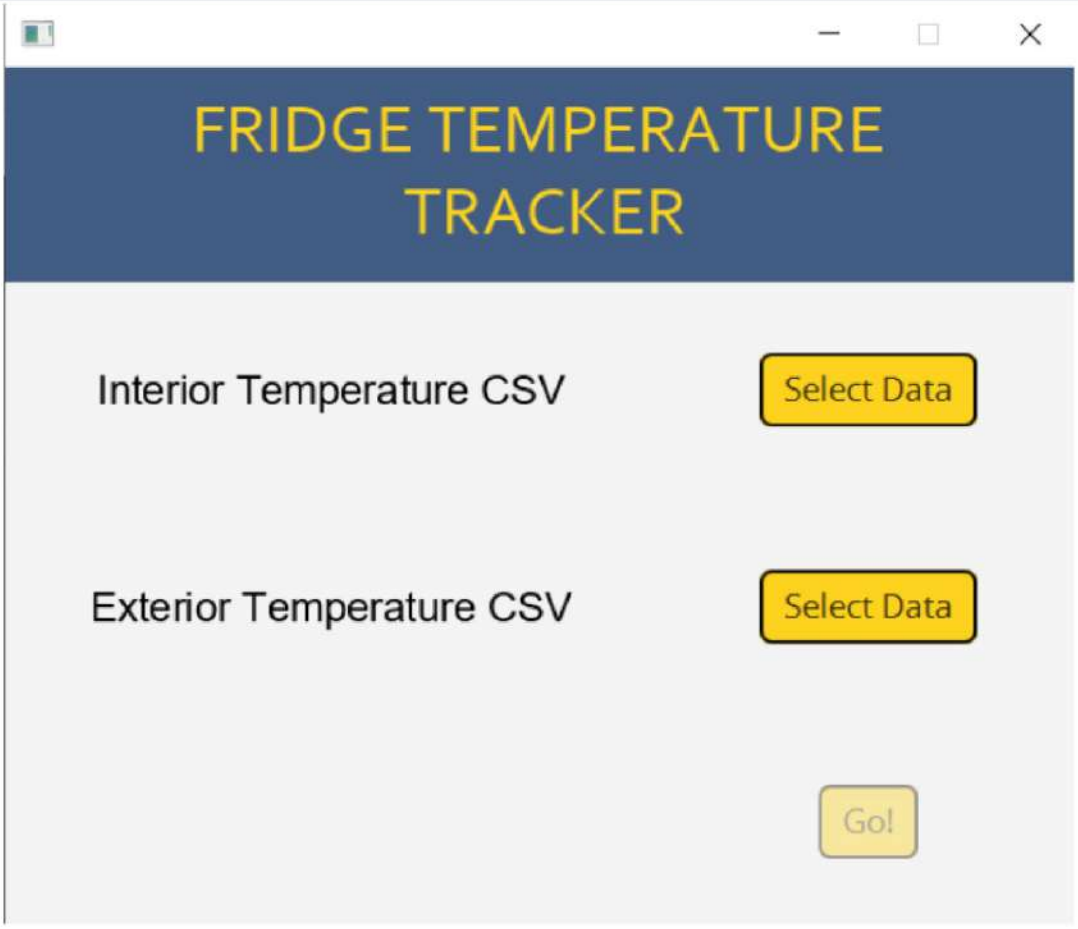
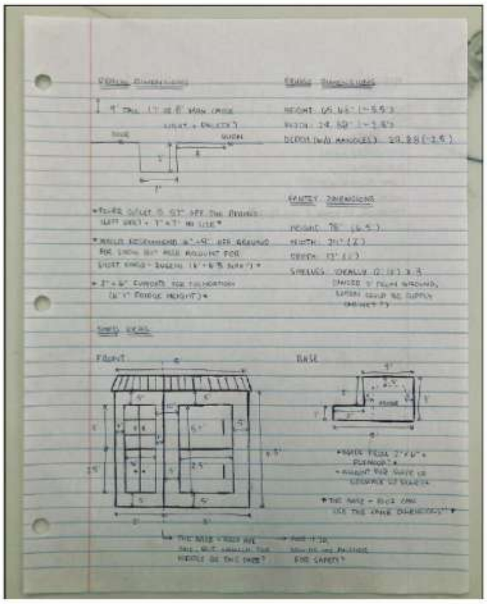


Figure 4.2 - The opening screen of the CSV parsing application

2 – Expertise from other organizations and advisors

In the second objective we wanted to gain better insight into the main causes of fridge interior warming and freezing and how other organizations may have handled them. To do so we reached out to five different community fridge programs spanning across different climates to attempt to get data regarding extreme cold as well as extreme heat. A few fridge programs we looked at were Regina in Saskatchewan Canada for their notoriously cold winters, as well as Dallas, Texas for the other side of the spectrum. We discovered that most of these fridge programs had not come up with a solution for extreme conditions, rather opting to dissuade fridge users and donors to simply not come up with a solution for extreme conditions, rather opting to dissuade fridge users and donors to simply not use the fridge should it be out of the safe operating temperatures of around 40 degrees Fahrenheit or lower.

For a significant amount of the fridge programs, they had a similar design as shown here.



Figures 4.3, 4.4 - Basic guides for fridge building enclosures from programs in Regina and Calgary, Canada

This leaves our project in a position to extend our recommendations and designs to other fridge organizations who could use them to optimize and create better-weatherized fridges for their own programs.

When interviewing PHD students, we found that the vapor compression cycle, the main mechanism that keeps the fridge cold, is heavily limited when operating outside of its desired temperature range. Several potential challenges were described, such as ice buildup on the evaporator, flooding of the evaporator, as well as a general loss of cooling efficiency at extreme temperatures. Any or all of these issues happen when in extreme low temperatures, causing the fridge to stop functioning. In the opposite direction, overheating a fridge is simply due to insufficient insulation of the enclosure, leading the heat seeping in through the walls and roof, heating the fridge and therefore the interior of the fridge.

3 - Observations of volunteers and the community

For our third objective, our goal was to observe the WooFridges organization to gain a better understanding of how they operate and how our solutions could impact their work. Originally we had asked to be taken to the maintenance of the fridges by following alerts in the community discord; however, we quickly discovered that this may not work since there were not as many maintenance calls made as we had thought there would be. Furthermore, in many cases, there were community members who would regularly clean, stock and fix the fridge without alerting anyone. In the end, we pivoted our observation from maintenance to the organization more broadly. Using our interviews from objective one to gain a sense of how the organization operates and further observing through the discord and monthly meeting (occurring the first Saturday of every month, in this case, April 1st). In the meeting on April 1st, we discussed with everyone there, the possibilities for expansion of the program through interactions with other organizations or volunteer cooks who would be willing to help WooFridges with their growing problem of mass, unportioned food (which needs to be separated into individual portions before being placed in the fridge).

4 - Analyzing solutions and effectiveness

The fourth objective in this project was to evaluate our proposed solutions based on the criteria outlined by experts and volunteers as well as our own research. Since each solution was vastly different we applied the broad criteria stated in our methodology as well as specific requirements for each individual solution. Generally, we found that the more thermal protection we could engineer for these enclosures the better off they would be in the long run. We found that many ideas complemented each other, so we shifted from our original plan that would have limited solutions and instead strove to give a thorough analysis of the solutions presented for each individual plan. After extensive research and deliberation, we settled on six different concepts to take into account when engineering a design for an enclosure: insulation, seals and vents, siding, fridges, roofing, and foundation.

Insulation

For insulation, we found six different types that would work in a fridge enclosure: blow-in cellulose, fiberglass batts, rockwool, closed cell spray foam, open cell spray foam, and foam panels. We then evaluated these different types based on cost, effectiveness, and ease of installation in order to fit our more overarching design objectives. Based on our research into these various types of insulation we found an additional two factors that were essential to long-term sustainability: water resistance and whether it would lose effectiveness over time due to settling. All of this information is compiled into the following table. From this table, we determined that the best option was a combination of closed-cell spray foam and foam board which was the most effective, simple, and resistant for a reasonable cost. The runner-up, RockWool, is also a viable cheaper option.

Insulation	R value per inch (Min and Max)		Price per sq. Foot (min and max)		Estimated job minimum	Easy installation	Retains shape	Water resistant
Blow-In Cellulose	3.1	3.8	$1	$2.80	$800.00	No	No	No
Fiberglass Batts	2.9	3.8	$0.80	$2.60	$600.00	Yes	No	No
Closed Cell Spray Foam	6	7	$2.50	$5.80	$1,500.00	No	Yes	Yes
Open Cell Spray Foam	3.6	3.9	$0.88	$3.00	$1,500.00	No	Yes	No
Foam Board	4.5	5	$1.20	$1.50	$600.00	Yes	Yes	Yes
RockWool	3.3	4.3	$1.10	$3.10	$600.00	Yes	Yes	No

Figure 4.5: Our cost benefit table of possible insulation solutions

For insulation to work best, our research and interviewee's told us that it was critical that the enclosure be as sealed as possible. However, fully sealing an enclosure would cause three problems- the fridge would be inaccessible to users, any moisture that got in would be trapped inside, and the fridge would not get proper ventilation for function. The solution that we found was to seal around the body of the fridge such that the door was still accessible, and to provide two small vents: one for the vents on the fridge and one at the highest point in the enclosure to let moisture out.

Seals

In terms of sealing around the fridge, we were able to find three potential options: garage door seals, adhesive foam tape, and brushed door sweeps. We chose these solutions because they were relatively available in the market and easy to install. We then evaluated them on cost, durability, and how easily the fridge could be removed to be maintained or replaced. For the ease of access, we mainly considered what steps would be required to do mechanical maintenance, as none of the seals would get in the way of the routine cleanings, given the full accessibility of the door. We organized our results and criteria into the following table, from which we determined that the garage door seal was the best option in terms of durability, but due to its expense and difficulty of installation, a foam tape seal would likely suffice for most applications.

Seals	Cost estimate	Mounting method	Long term durability	Easy to remove fridge
Garage door seal	$200	Screws	Excellent	Yes
Adhesive foam tape	$30	Adhesive	Will need replacements	No
Brushed Door Sweeps	$100	Screws	Good	Yes

Figure 4.6: Our cost benefit table of possible sealing solutions

Ventilation

For ventilation, we found three different solutions, each with its own application. Our criteria for comparing vent options was durability, aesthetics, and airflow. The first type of ventilation was louvered vents, which over all were the cheapest and most useful option. However, if more airflow is required, a turbine vent can be added which, while more expensive, could be necessary. Finally, if a lower profile solution was desired a soffit vent could be added, which is barely noticeable, but would have a trade off of reducing the effectiveness of the roof insulation. From our research, we found that louvered vents are likely the best option, but the other designs could be easily swapped or added in if needed for their specific advantages. An analysis of the vents is shown in the table below.

Vents	Cost estimate	Noticeability	Water-resistant	Pest-resistant	Durability	Active airflow
Louvered vent	$20	Medium profile	Yes	Yes	High	No
Turbine Vent	$60	High profile	Yes	Yes	Medium	Yes
Soffit vents	$20	Low profile	Yes	Yes	Medium	No

Figure 4.7: Our cost benefit table of possible ventilation solutions

Siding

As for siding, we found four options to consider: vinyl, wood, fiber-cement, and metal. We evaluated these solutions based on how much they cost and how durable and long lasting they would be. The durability of siding was especially important in our analysis as these enclosures exist in a highly damaging environment and any damage could compromise the effectiveness of the insulation inside. We compiled all of our options into the following table, and used it to determine that fiber-cement and metal siding were the best options due to their high levels of durability. Additionally, we found that if any of our siding options were to be painted in a light color or were reflective it would reduce the heat load in the summer, therefore lessening the wear and tear on the fridges themselves.

Siding	Price per square foot (Min and Max)		Expected lifespan (yrs)	Requires routine maintenance	Damage and pest resistance
Vinyl	$2.00	$13.00	30	No	Yes
Wood	$6.90	$13.90	30	Yes	No
Fiber cement	$4.70	$8.50	50	No	Yes
Metal	$4.50	$21.00	50	No	Yes

Figure 4.8: Our cost benefit table of possible siding solutions

Fridges

In terms of fridges, we looked at four different options: garage-ready fridges, stainless steel garage-ready fridges, commercial fridges, and glass door fridges. These options were difficult to qualitatively compare as manufacturers did not provide detailed specifications about operating ranges and insulative properties, nevertheless, an analysis of the pros and cons of each system was possible. For the two garage ready fridge types, we found that they were specially designed to function in a wider range of temperatures (from around 32 to 110 degrees fahrenheit). We also found from our interviews with Ph.D students that a stainless steel fridge would have a significantly reduced thermal load from direct sunlight, making it an excellent option for a community fridge. For the glass door fridges, we found that they likely had a similar, if not slightly larger, operating range to a normal domestic fridge, but the glass door could help to prevent users opening the door as much as they would be able to browse from the outside of the fridge which lowers energy cost. Finally, we found that the industrial fridges had a more powerful cooling system, which would likely be up to the challenge of extreme weather. In addition to this qualitative information, we were able to put together the following table comparing the cost and relative market availability of each design, as well as if they had a freezer and/or glass door.

Fridges	Cost	Readily available	Freezer	Window
Garage Ready	$700	Yes	Yes	No
Stainless Garage Ready	$900.00	Yes	Yes	No
Glass Door Fridge	$1,000	Yes	No	Yes
Commercial Fridge	$1,350	No	No	No

Figure 4.9: Our cost benefit table of possible fridges

Roofing

Our roofing options included galvanized steel, aluminum, galvalume steel, asphalt shingles, and cedar shingles. Our criteria for what made an ideal roofing solution was cost, lifespan and reflectivity. We chose to focus on lifespan, as it was the most readily available metric for durability among the roofing market. Reflectivity was chosen as an essential variable because reflection can significantly reduce the heat load from the sun during hotter months. And, of course, cost was taken into account as well. This criteria was used to create the following table, from which we determined that the most optimal solution for a roof was galvalume, as it is inexpensive, reflective, and highly durable.

Roof	Cost per square foot	(Min and Max)	Reflective?	Lifespan
Galvanized Steel	4.5	17	Yes	50
Aluminum	6.5	21	Yes	50
Galvalume Steel	4	9	Yes	50
Asphalt Shingles	1.75	5.5	No	20
Cedar Shingles	4.1	7.5	No	20

Figure 4.10: Our cost benefit table of possible roofing solutions

Foundation

Finally, we considered four methods of construction towards a foundation for the enclosure in order to help keep the frame of the structure safe from wet ground and to provide some extra structure. The methods we considered were pier and beam, slab, pavers and bricks. We evaluated these solutions based on their cost, stability, and how well they would work if not given a pre-existing paved surface. This data was compiled into the following table. Since the success of a foundation is highly dependent on the surroundings, we came up with the following general guidelines: slab foundation is best for a flat unpaved area, pier and beam is best for uneven ground, and pavers for a paved surface.

Foundation	Materials	Labor	Total cost	Stability	Good for unpaved surfaces
Pier and beam	$200.00	$1,000	$1,200	Excellent	Yes
Slab	$200.00	$500	$700	Excellent	Yes
Bricks	$10.00	$0.00	$10.00	Questionable	No
Pavers	$30.00	$0.00	$30.00	Good	Sometimes

Figure 4.11: Our cost benefit table of possible foundation solutions

Ultimately this led to a rough manual containing the costs, benefits, and drawbacks of each individual aspect of contracting enclosures, as well as our recommendations for full designs of future and current enclosures. From this, we created three full designs: a retrofit (made for currently existing enclosures), a budget-friendly new design, and a high-end design that would be most effective but also very costly. For these designs, our criteria revolved around cost because WooFridges is a community run organization. Because of this, they are unable to get regular funding. So our designs needed to be able to cater to them at an achievable price point as well as showing what's possible. To this end, we took the best options from each category as listed above to make each design as effective as possible for its goal price point (1000$ for the retrofit, 3000$ for the budget design, and 6000$ for our high-end design).

5 - Making final revisions using feedback

In our fifth objective we aimed to get feedback from those we had previously interviewed in objectives one and two. From the interviews, we found that all of our solutions were getting positive feedback from our interviewees. However, there were some things that we had to be sure to account for that were previously not fully calculated. Namely sun exposure seemed to be an important note from our follow ups with volunteers. While sun exposure heating the fridge could be considered a positive in the winter, during the summer this added heat load would only add to the issues the fridges face in trying to keep the internal temperatures down.

Our interview with the PhD students further corroborated this as they stated this heat load would be adding hundreds of watts to the fridge. However, they suggested that a quick solution could be the use of high emissivity paint. This paint is incredibly effective at reflecting the UV rays the sun emits and in proper conditions can have a net cooling effect. This could be done in conjunction with some of the volunteers' suggestions of having white fridges, as white is more reflective, and larger roof overhangs to provide shade. All of which we added to our design to ensure the heat load was reduced as much as possible. Apart from this, in some of our volunteer interviews we learned about the importance of the fridge gasket in maintaining the seal of the fridge to ensure the fridge cools properly. This was another item not previously considered and while we were hesitant to suggest making significant modifications to the fridge we wanted to ensure the gaskets were maintained. Thus, in our manual we added a section for maintaining the gasket of a fridge and replacing them if necessary. Finally, in our interviews with the PhD students they warned us of insulating the enclosure of the fridge to a point where the condenser would not have anywhere to dump the heat. Since the condenser takes out heat from the internals of the fridge and drops it into the air outside this could lead to a significant heat load if that hot air had nowhere to go. While this could be helpful in warming the fridge in the winter, it would cause a problem in the summer. Without a doubt we understood this and had previously accounted for methods of ventilation but these conversations in particular made us feel that adding extra ventilation that could be opened and closed depending on the season was very important. Ultimately, from all our interviews we added a few features to our solutions (high emissivity paint on the siding, a reflective fridge, and extra ventilation that could be opened and closed).

Recommendations and Conclusion

In our time working on this project, we discovered many possible solutions to the issue of weatherization. Using the tables for solutions described in section four of our findings, we created a design manual that would detail the more in-depth pros and cons of each individual solution as well as their effects and how they work. We also included installation guides for all of these in the manual. We researched the effects of temperature on fridges and talked to experts to create a criteria for what solutions are viable, then used volunteer and community feedback to narrow them down to solutions that are low price, effective, accessible, sustainable and easily accepted by WooFridges and the community around the fridges. With this feedback we finalized our weatherization options. As mentioned in sections four and five of our findings, we used these solutions to create three potential designs to choose from based mostly on cost (1000$ for the retrofit, 3000$ for the budget design, and 6000$ for our high-end design). These premade recommendations being a retrofit solution, a ground-up budget build, and a high-end unlimited budget version as detailed below.

Retrofit for Existing Enclosures

For the retrofit it was important to us that we maximize our effectiveness while prioritizing very low cost and minimal installation. These were our priorities since the existing enclosures have a lot of variation from one to another and are all in use frequently. So creating a design that could be easily and quickly installed in any of the existing enclosures was the most important thing when making this design. To this end, for insulation we included fiberglass batts which are cheap and do not need a professional install; along with, paver stones for our foundation as they would be very easy to place and would decrease wear on the wood of the enclosure. These choices along with others listed in our design show the philosophy we described for this design.

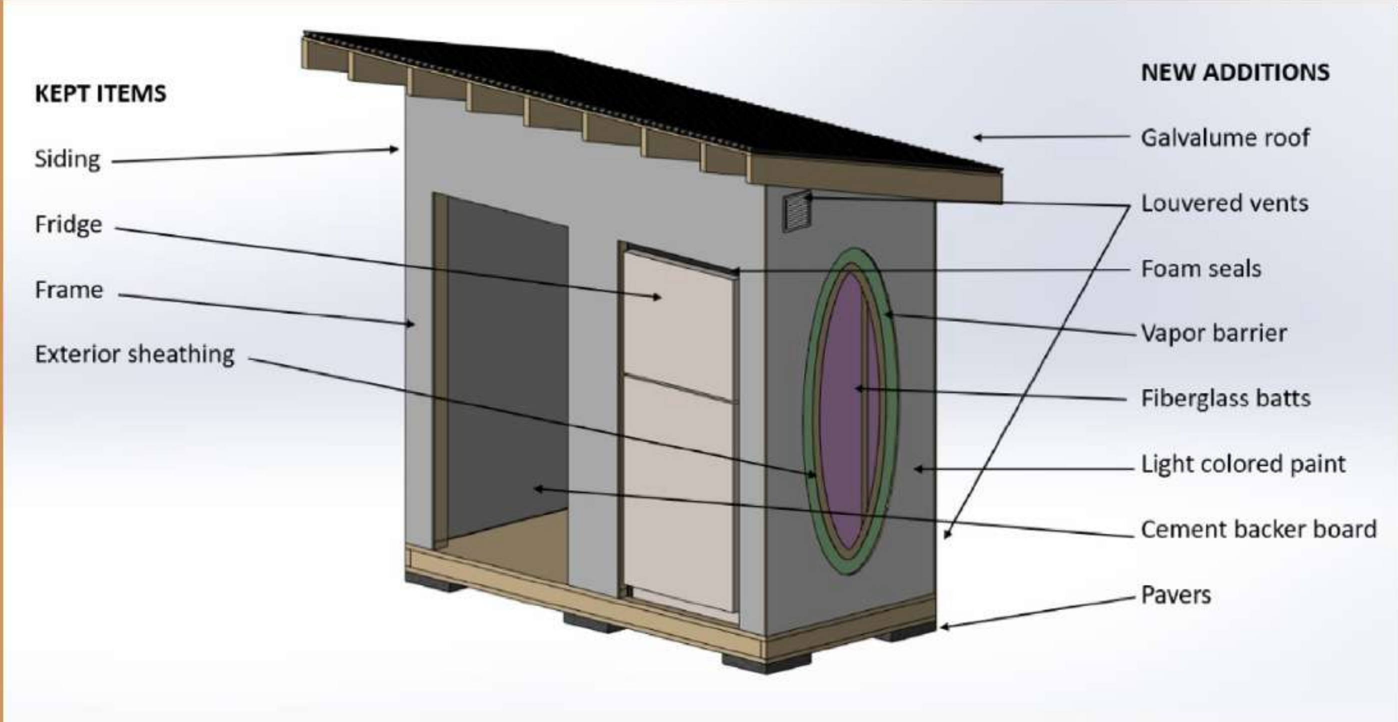


Figure 5.1 - Shows a 3D model representing the weatherization techniques of the retrofit design, the included weatherization solutions, and the wall composition for insulation as well as the cost breakdown.

Item	Material	Professional labor	Total
Fiberglass batts	$100.00	$500.00	$600.00
Homewrap tape	$15.00		$15.00
Foam seals	$50.00		$50.00
Light colored paint	$50.00		$50.00
Louvered vents	$40.00		$40.00
Pavers	$20.00		$20.00
Galvalume roof	$120.00		$120.00
Vapor barrier	$75.00		$75.00
Cement backer board	$120.00		$120.00
		Total	$1,090.00
		Cost of materials	$590.00

New Enclosure for a Reasonable Budget

Similarly to the retrofit design it was important to us that we maximize our effectiveness while prioritizing low cost for the budget enclosure. However, since this design was intended to be for any enclosures being built from the ground up there was more wiggle room in terms of how much depth we could include in the design. To this end, for insulation we included rockwool which was a bit more expensive than fiberglass but had more insulative power; along with, plywood sheathing that would be placed between the foam boards to further insulate. Along with this, we chose a garage ready fridge which has a higher temperature operating range meaning a higher likelihood of operation year round. These choices among others listed below demonstrated the depth of solution versus cost philosophy that embodied this design.

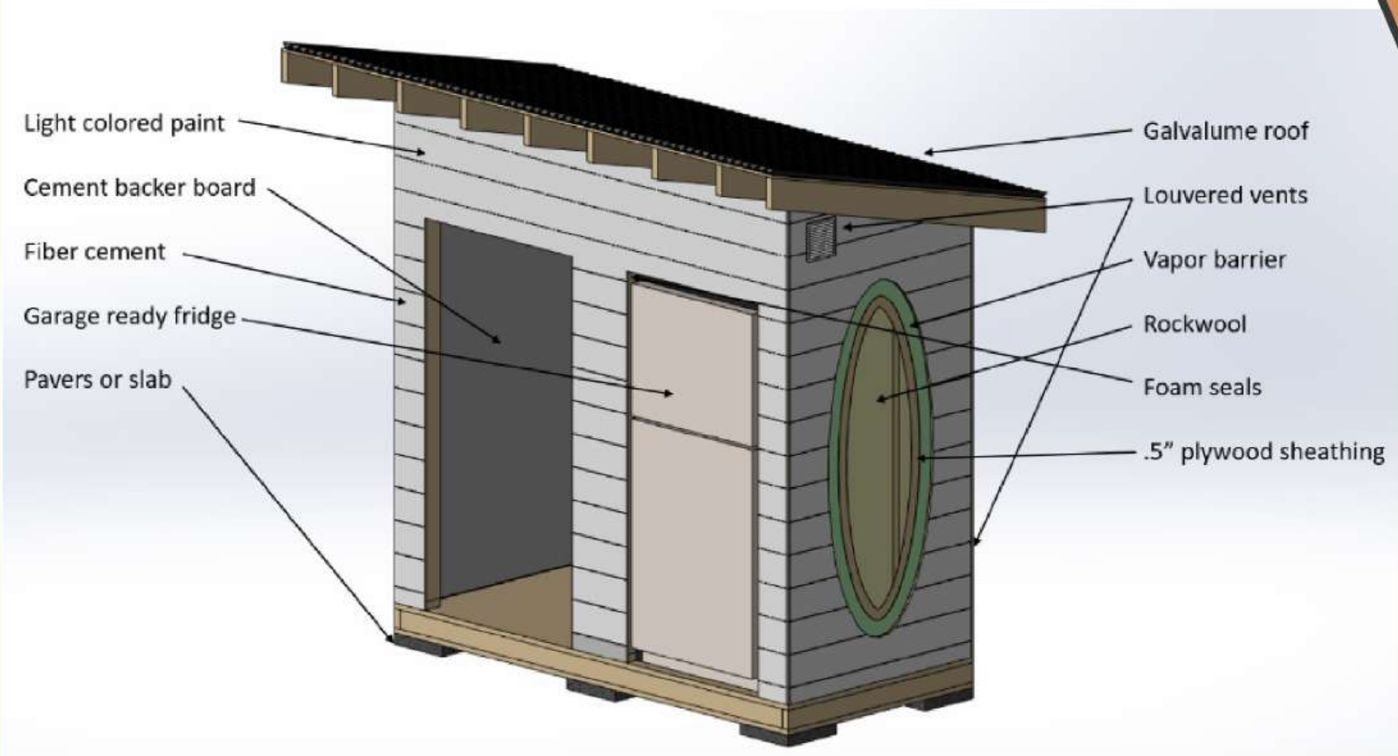


Figure 5.2 - Shows a 3D model representing the weatherization techniques of the budget design, the included weatherization solutions, and the wall composition for insulation as well as the cost breakdown.

Item	Material	Professional labor	Total
Rockwool	$225.00	$500.00	$725.00
Slab foundation	$200.00	$500.00	$700.00
Plywood sheathing	$320.00		$320.00
Vapor barrier	$75.00		$75.00
Fiber cement siding	$250.00		$250.00
Light color paint	$50.00		$50.00
Louvered vents	$40.00		$40.00
Galvalume roof	$120.00		$120.00
Garage ready fridge	$700.00		$700.00
Timber (2x4 frame)	$500.00		$500.00
Cement backer board	$120.00		$120.00
Foam seals	$50.00		$50.00
		Total	$3,650.00
		Cost of materials	$2,650.00

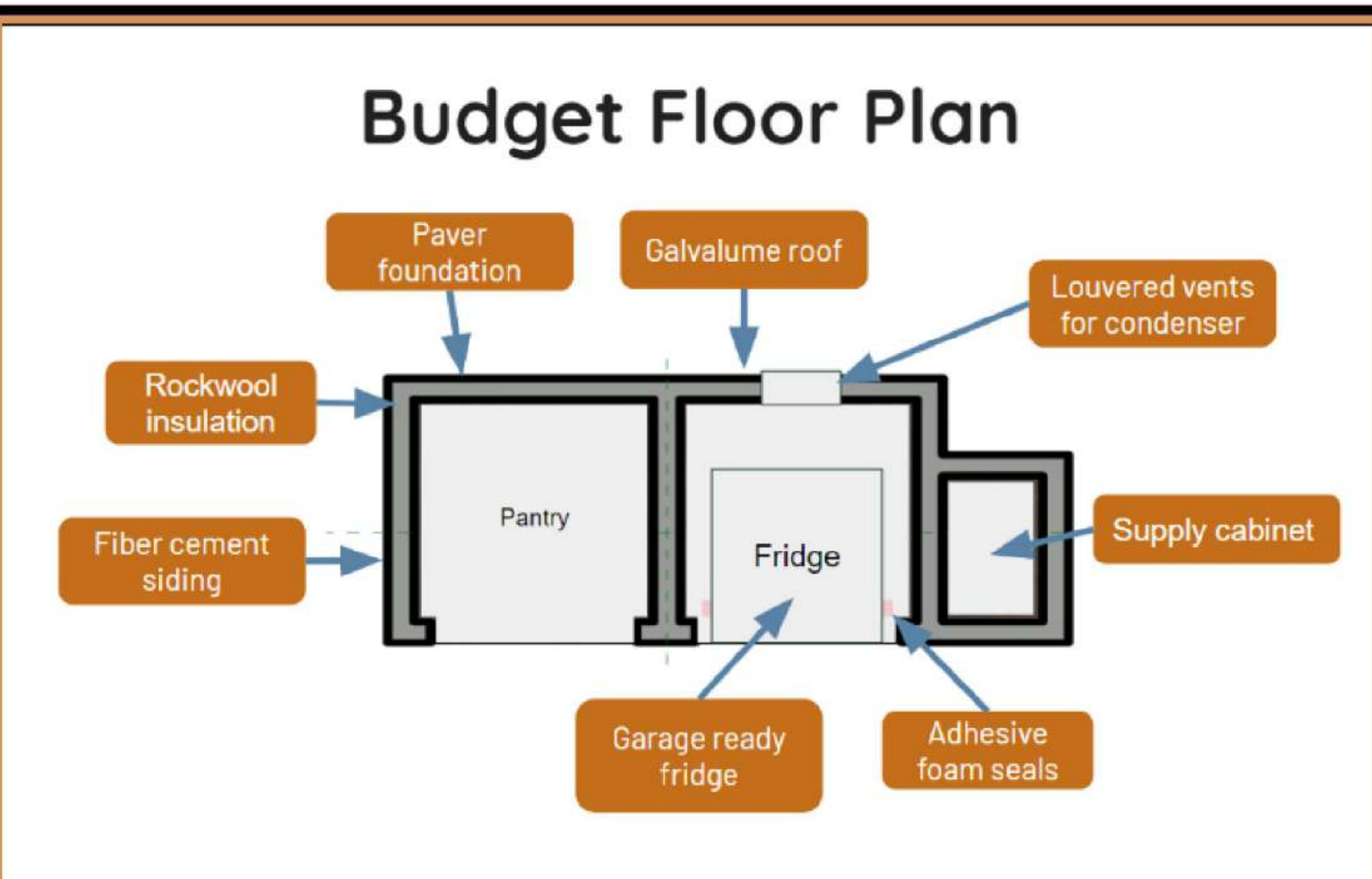


Figure 5.3 - Shows the potential floor plan for the budget enclosure including labels for the different sections of the fridge and some weatherization solutions

High-End Enclosure for Larger Budgets

In contrast to the other designs for the high-end design our focus was effectiveness and what the best possible solution could be regardless of cost or constraint. Due to this, there was no limit to how much depth we could include in the design. To this end, for insulation we prioritized using known successful combinations of insulation to create a super insulated structure to almost negate heat transfer in and out altogether. This was achieved by layering homewrap, closed cell foam, plywood, and foam panels on the walls and roof. To further reduce the heat load on the enclosure we used high emissivity paint to negate UV rays from the sun which add a significant heat load over the course of the day. Along with this, we chose a stainless steel garage ready fridge which has a higher temperature operating range meaning a higher likelihood of operation year round and the steel surface will reflect UV further reducing the heat load introduced by the sun. These choices among others embodied the philosophy of thoroughness in this design.

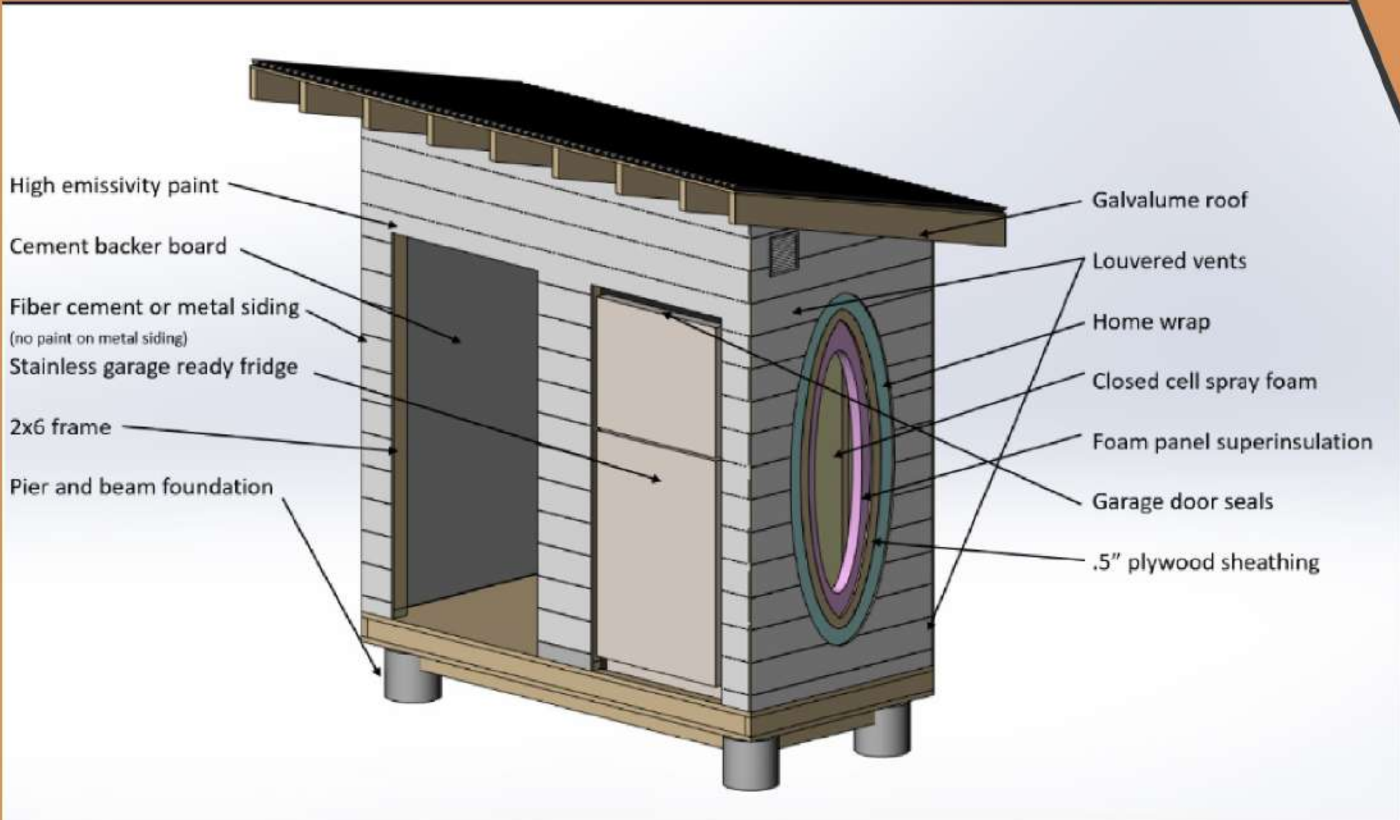


Figure 5.4 - Shows a 3D model representing the weatherization techniques of the high-end design, the included weatherization solutions, and the wall composition for insulation as well as the cost breakdown for it.

Item	Material	Professional labor	Total
Closed Cell foam	$800.00	$700.00	$1,500.00
2 layers foam board	500		$500.00
Pier and beam foundation	$200.00	$1,000.00	$1,200.00
Plywood sheathing	$320.00		$320.00
Homewrap	$75.00		$75.00
Fiber cement siding	$250.00		$250.00
High emissivity paint	$90.00		$90.00
Louvered vents	$20.00		$20.00
Galvalume roof	$120.00		$120.00
Stainless garage ready fridge	$900.00		$900.00
Cement backer board	$120.00		$120.00
Timber (2x6 frame)	$700.00		$700.00
Garage door seals	$240.00		$240.00
		Total	$6,035.00
		Cost of materials	$4,335.00

Figure 5.5 - Shows the potential floor plan for the high-end enclosure including labels for the different sections of the fridge and some weatherization solutions

Other Potential Design Details for the Future

Below are some other design ideas that could be included in future designs that we unfortunately, due to the short nature of our project, could not analyze. First is the inclusion of the barn-style door, similar to the one currently used on the Portland St Fridge. Our team recommends sealing the door and including a wooden stop positioned parallel to the door keeping the door from coming off the rails and preventing potential harm from the door falling on someone. Additionally, any extra room could be more space to accommodate more than one person using the enclosure at a time and can be paired with railings, ramps, and other accessibility options. Finally, the option of having a separate chest-style freezer in the enclosure could benefit accessibility and be more sturdy against heat load.

Limitations and Conclusion

However, these solutions are somewhat limited. These recommendations that we created are not necessarily universally applicable and were made with WooFridges and Worcester in mind only taking into account temperature ranges from -10 to 95 degrees Fahrenheit. This project also is limited in its scope as the options created were tailored towards WooFridges which has little to no funding. The solutions presented are also theoretical and have not been tested in the field. On top of this, free-use public fridges are a newer concept, being only a few years old (The WooFridge program only started in 2021). Sadly this means that not as many programs exist and many have not been around for very long, meaning case study work and external references were limited during the time of this project. That being said, we hope that our recommended designs and analyzed solutions will go on to help community fridge programs like WooFridges in the future. This project represents an excellent opportunity for future engineers to test these designs and further push the boundaries of what community fridges can do.

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Appendices

Appendix A – Timeline

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Objective 1- Weather							
Objective 2- Expert insight							
Objective 3- Maintenance							
Objective 4- Solutions							
Objective 5- Revise							

Appendix B – Interview Questions

The following interview questions are organized based on the questions we had answered during each Semi-structured interview. Alongside our interviews, we also listed the relevant objectives. Additional notes and key ideas that were covered are under each question in case of reiteration or clarification.

Interview with Woo Fridges' volunteers (Objective 1)

- Can you tell us about how you got involved in the WooFridges community?
- Can you describe how the fridges are dealing with the weather?
- Could you tell us about any issues you've had working with the fridges during extreme cold or heat?
    - Common issues
    - Common solutions
- How often do you respond to maintenance calls?

Interview with the architect (Objective 2)

- Can you describe the design and construction processes for new fridge enclosures?
    - Design philosophy
    - Working with Volunteers
    - Limitations
    - Concerns moving forwards
- What do you feel are critical design elements of an enclosure?
    - How would you define critical design elements?
- How do weather conditions factor into your designs?
- Have you done any work on weatherizing the enclosures further? If so, could you tell us what you did?
    - Any challenges you have dealt with or foresee for the organization?
- Do you have any concerns in regards to the enclosures?

Interview with refridgeration experts (Objective 2)

- Can you tell us what issues you expect a domestic refrigerator to experience in extreme temperatures?
- How would you explain the fridge shutting off in response to extreme temperatures?
- Have you worked with these issues before, and if so, what did you do?
- Is there a known solution to this problem that would be possible to implement?

Follow up interviews (Objective 5)

- How do you think this proposed solution would affect your volunteer work?
    - Maintenance
    - Implementation

- Describe how this proposed solution might cause issues with the maintenance or usability of the fridges?

- What changes would you make to this proposed solution?
    - Concerns
    - Challenges

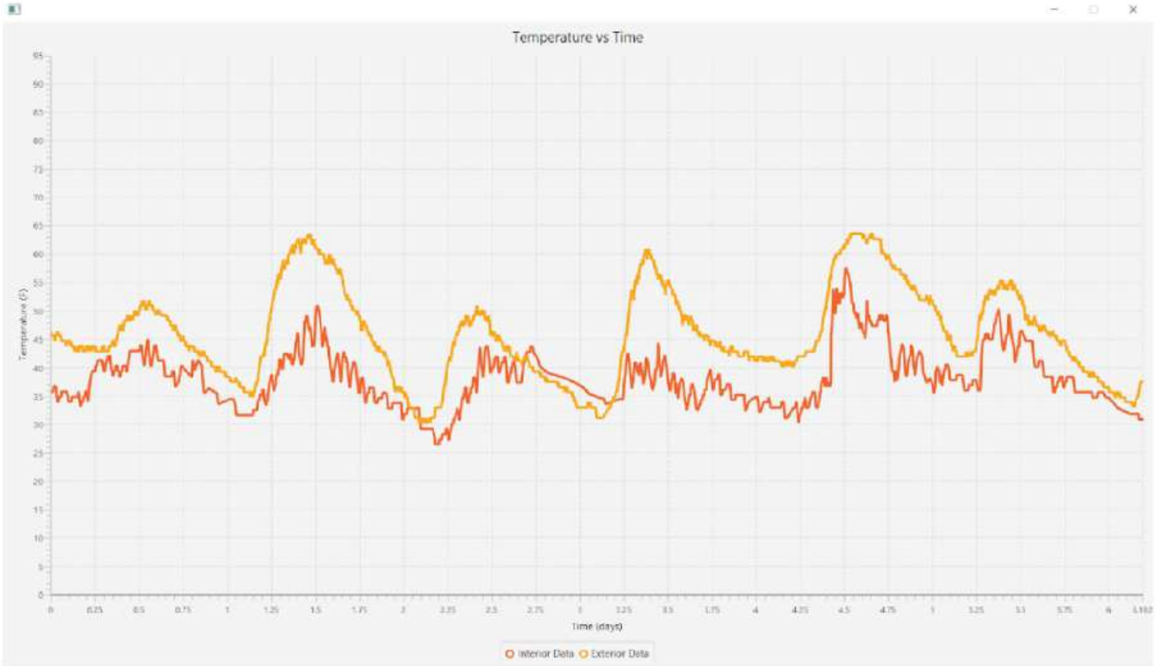
Appendix C – Observation

We planned on logging and taking notes on the WooFridges organization in their in person meetings and over their discord. Additionally, we participated in their meetings. The goal was to experience the organization and challenges associated with WooFridges.

Date	General things talked about	Important issues/problems

Appendix D - Field Research

The following is the data representation for objective 1. Recording temperature and general notes on the fridges was essential to tracking the impact of weather and potential solutions on the fridges.



Width of Fridge	Height of Fridge	Depth of Fridge	Width of Enclosure	Height of Enclosure	Depth of Enclosure	Width of Pantry	Height of Pantry	Depth of Pantry

Appendix E – Informed Consent

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:

This study focuses on the effects of extreme weather on the community run refrigerators maintained and operated by Worcester Community Fridges. This study aims to create a weatherproofing method to allow for continued and unhindered use of the fridges through the hotter and colder months.

Procedures to be followed:

Participation in the study will last the length of a short semi-structured interview, with an average runtime of 15-20 minutes. Any further participation in the study is not expected.

Risk to study participants:

There is no risk to the participant in this study.

Benefits to research participants and others:

There is no benefit to the participant for participation in this study.

Record keeping and confidentiality:

Records of answers to the interview questions will be held in a document only accessible to the investigators. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:
You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:
gr-wocfridgesiqpd23@wpi.edu for contact with the investigators.
Laura Roberts, Email: lroberts@wpi.edu for the IRB Manager.

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

____________________________ Date: ____________________
Study Participant Signature

____
Study Participant Name (Please print)

____________________________________ Date: ____________________
Signature of Person who explained this study