Supplementary Materials

Worcester Polytechnic Institute IQP D23

Compiled by: Ian MacInerney, Valerie Childers, Michael Weideman, Zackary DiCelico

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Construction Manual

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Executive Summary

Best things to prioritize (High to low)

Insulation:

- **Closed cell foam** is the most effective but is expensive and requires professional installation.
- **Fiberglass Batts** are cheap and easy to install but not as effective and absorb moisture.
- **Foam boards** are cost-effective with easy installation. These boards are outside the studs and don't retain moisture or settle over time, making them highly compatible with other insulation solutions.
- Any insulation will do best if covered on both sides, preferably by plywood.

Sealing

- **Foam board** to cover gaps around the fridge due to its cheap and easy installation.
- **Garage seals** cover smaller gaps under the fridge. While this may make it harder to move the refrigerator, the extra seal provides more weatherizing overall.

Ventilation

- **Adjustable louver vents** are passive, cost-effective, and easy to install on any wall providing flexibility to the enclosures.

Roofing

- **Galvalume steel** is a weather-resistant and reflective corrugated sheet lasting up to 50 years per roof.
- **Cedar shingles** are an excellent choice for blending form and function, having a natural wood pattern, and being easily paintable.

Siding

- **Fiber cement** siding is costly however is damage-resistant, requires little maintenance, and is long-lasting.
- **Wood siding** is cheaper, ubiquitous, and less durable, needing more maintenance overall.

Foundation

- **Pier and beam** are durable, sturdy, and raised to prevent water from pooling. These are costly and need professional installation.
- **Paver bricks** were significantly cheaper while sacrificing some durability and accessibility.

Things to avoid

- When designing an enclosure, the insulation, seals, and vents should all be considered together. Changing one could impact the overall cooling of the fridge and weather resistance.
- One vapor barrier or no vapor barrier (a vapor barrier helps prevent moisture from getting into the rest of the enclosure, generally a plastic sheet) two vapor barriers can lead to moisture getting trapped between the two sheets and causing mold growth.

Things to consider

- Gasket seal maintenance is critical. All fridges contain a gasket around their doors, forming a seal when the door is closed, keeping the cold air in. A guide for maintenance is linked below: https://repair.geappliances.com/resources/faq/how-do-i-tell-if-a-refrigerator-door-seal-is-bad
- High emissivity paint is incredibly reflective against UV and can get rid of warming caused by the sun and even cool its surroundings in some situations.
- Ventilation is critical in an insulated enclosure. Without any ventilation, the condenser at the back of the fridge won't have anywhere to dump the excess heat from the fridge and heat up the enclosure.

Methods for Weatherization

The following are several methods that can be employed to protect a fridge and its enclosure from weather and extreme temperatures. The list is not exhaustive, but the methods listed are some of the more common solutions. For each method, diagrams will be provided.

Insulation

Insulation provides a barrier between the air inside and outside the enclosure, restricting heat transfer in a system and ensuring the internal temperatures are less dependent on the external air temperatures. By maintaining a more consistent internal temperature, refrigerators can keep food safe for long periods and will require less maintenance year-round.

Things to consider	
There is a lot to think about when choosing a type of insulation, like how it is installed, how well it works, and how durable it is in the long run. Here are a few important things to keep in mind when making a plan for an enclosure.	
Where to Insulate	
Insulation is only necessary for the fridge section of the enclosure. For the insulation to do best, it is a good idea to only insulate the external walls around the fridge, the wall between the fridge and the rest of the enclosure, and the floor and roof for the fridge section of the enclosure.	
Effectiveness	
Different kinds of insulation provide different levels of protection against extreme weather. An R-value is a measure of how insulative a material is, or how well a material resists heat passing through it. A higher R-value means the insulation is more effective. Every insulation type has an R-value which is dependent on the properties of the material, as well as how thick it is.	
Professional Installation	
Some kinds of insulation are readily available and relatively simple to install without a professional, which can significantly reduce prices. Other kinds of insulation require either expensive equipment or a professional to install them. Often, for smaller jobs such	

as a fridge enclosure, a professional will charge a “job minimum,” which helps them to cover the expenses of the time it takes to get to the enclosure and set up. Job minimums will significantly increase the cost of insulating an enclosure.
Superinsulation
Not all insulation is installed in the same location in the wall. While most insulations sit between the studs in the wall, some types are designed to be placed on the face of the wall. A material that is installed outside the studs could be used in addition to another kind of insulation. This technique is called superinsulation, and can significantly improve the effectiveness of insulation.
Hybrid Insulation
Hybrid insulation uses more than one type of insulation in order to get some of the benefits of both. A popular example of this is combining fiberglass with a thin layer of closed-cell spray foam, which is a less expensive way of getting the sealing qualities of closed-cell foam. Another method that can be employed is to install foam panels on the outside of the wall, essentially adding a second layer of insulation.
Water Resistance
Some kinds of insulation are known to absorb moisture. This often becomes a problem, as they can begin to lose their insulative properties or even begin to grow mold and degrade. If you have insulation that is known to absorb moisture, you may have to invest more in waterproofing the siding of your enclosure to help protect the insulation from rain and snow. However, a word of warning: you do not want to seal both sides of your insulation because if you do it will be unable to dry out over time.
Settling
Some kinds of insulation have been known to settle over time, slowly sinking in the wall and losing some effectiveness. If this becomes too severe, the insulation may lose effectiveness and wi.
Sheathing

Insulation needs to be protected from the elements, and it is also best to shield people from most types of insulation. Builders typically use 7/16” plywood sheathing on the external face of the wall to hold in and protect the material (there is also a material called zip plywood that is treated with a green coating that acts like a home wrap). A vapor barrier or home wrap is also used on the outside to protect the frame from moisture (More on this in siding!). Additionally, a thin material such as MDO or cement backer board should be used to protect both the insulation and the people interacting with the structure.

Sources -Here are a few sources for interior and exterior sheathing
Cement backer board:
https://www.homedepot.com/p/James-Hardie-HardieBacker-0-25-in-x-3-ft-x-5-ft-Cement-Backerboard-220022/100183556
Zip plywood:
https://www.homedepot.com/p/Huber-7-16-In-4-Ft-x-8-Ft-Zip-OSB-Wall-Sheathing-777198/202089190
Plywood:
https://www.homedepot.com/p/OSB-7-16-in-Sheathing-Panel-Application-as-4-ft-x-8-ft-386081/202106230

Stud sizing and wall thickness

Most walls are made out of 2x4 boards spaced 16” apart (known as studs), as that is the minimum standard for construction. The insulation lives between these studs, so if thicker boards such as 2x6 are used, more insulation can be put in the enclosure. The issue with this is that it makes the walls thicker, reducing internal space for the same footprint.

Insulation Options

Blow-in Cellulose

A fluffy material that can be used to fill the spaces inside completed walls. It is treated to protect from pests, but needs to be professionally installed and can lose effectiveness over time as it absorbs water and settles in the walls.

Source - This is often installed professionally, so a local insulation provider may be the best source. However, home improvement retailers will rent out the tools required. Here's a source for the cellulose itself.
https://www.homedepot.com/p/Greenfiber-25-lbs-Cellulose-Blown-In-Insulation-or-Spray-Applied-Insulation-INSSANC/311574454

Fiberglass batts

A fluffy material that is often backed with paper. It is usually placed in between studs before being closed in with plywood. It is inexpensive and relatively easy to install (with proper safety equipment like a good mask and gloves), but will also absorb water and settle over time.

Source - Readily available at home improvement stores
https://www.homedepot.com/p/Owens-Corning-R-13-Kraft-Faced-Fiberglass-Insulation-Continuous-Roll-15-in-x-32-ft-RF10/202585857

Rockwool

A fibrous material that is placed between the studs and closed in with plywood. It is very similar to fiberglass but has a higher R-value and is somewhat less prone to selling over time. It still does settle, and it also absorbs moisture.

Source - Readily available at home improvement retailers
https://www.homedepot.com/p/ROCKWOOL-R-15-Comfortbatt-3-1-2-in-x-15-in-x-47-in-Fire-Resistant-Stone-Wool-Insulation-Batt-59-7-sq-ft-RXCB351525/202090820

Spray foam

An expanding foam is sprayed into the walls. It is a phenomenal insulator but comes at the cost of being expensive and requiring a professional to install it.

Closed cell - The best in the business, closed cell foam is waterproof and sealed against air, and is the best insulator that is readily available. It is also the most expensive.

Open cell - A more porous material, it's great for filling small gaps and is cheaper than closed cell, but it is not water resistant, and it doesn't create a seal.

Source - This is one that is likely not a great idea to DIY. You're going to want a professional to install this stuff.

Foam board

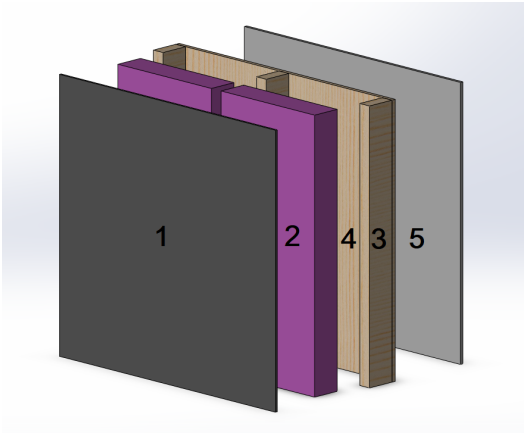
Foam panels are made of closed-cell foam but are sold in premade panels instead of being sprayed in. This comes with a number of advantages, namely the ability to install them outside of the studs and their resistance to moisture. If installed outside of the studs, it is a good idea to do 2 layers if possible and to have the seams of the boards offset from each other to prevent airflow.

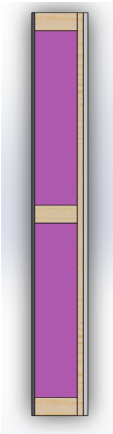
Source - Readily available at home improvement retailers
https://www.homedepot.com/p/Owens-Corning-FOAMULAR-NGX-F-250-2-in-x-4-ft-x-8-ft-SSE-R-10-XPS-Rigid-Foam-Board-Insulation-52DDNGX/315197962

Example wall sections

Here are a few diagrams of how walls can be constructed with different insulation layouts. These patterns would be repeated throughout the wall.

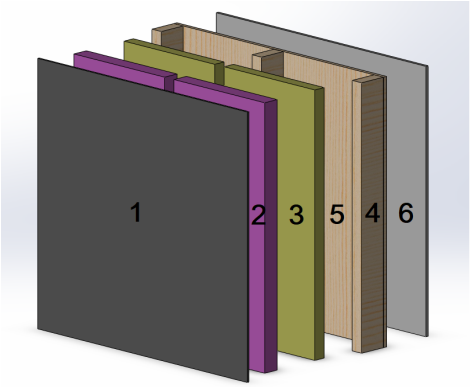
Typical Insulation

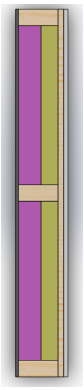




1. Interior sheathing
2. Insulation
3. Studs
4. Exterior sheathing
5. Siding/vapor barrier

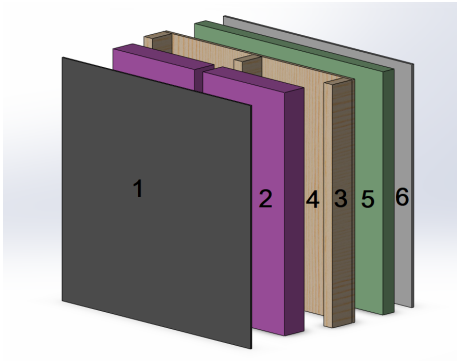
Hybrid closed cell/fiberglass insulation

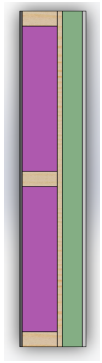




1. Interior sheathing
2. Fiberglass
3. Spray foam
4. Studs
5. Exterior sheathing
6. Siding/vapor barrier

Superinsulation





1. Interior sheathing
2. Insulation
3. Studs
4. Exterior sheathing
5. Foam panels with taped joints
6. Siding/vapor barrier

Comparison table

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

Siding

Siding's primary job is to protect the walls of the enclosure, but it is also the most important aesthetic component of the entire structure. The goal is to choose an aesthetically pleasing, weather-resistant, and durable enclosure, and balancing these factors while accounting for constraints and location can be challenging.

Things to consider	
Aesthetics	
Looking nice is a critical aspect of any fridge enclosure. A good-looking enclosure will help to make a space more pleasant and will strengthen the connection between the community and the fridges. As such, siding choice and color may be entirely dependent on complimenting the surrounding area.	
Expected Lifespan	
Depending on the material, siding can last any number of years. The lifespan of siding is often decades. This may be longer than an enclosure is expected to hold up for, but the lifespan can still be an indicator of the durability of any particular siding.	
Damage resistance	
Some siding varieties, namely wood, can be damaged somewhat easily. When damaged, they will begin to absorb water, furthering the damage, as well as their susceptibility to pests. These siding types need to be repaired relatively quickly or they will be ruined.	
Reflectivity	
How reflective a material is can have a notable effect on how it performs in the summer. Lighter colored siding will reflect more light, causing them to absorb less of it as heat. This can help keep enclosures exposed to direct sunlight cooler in the summer. There also exist paints that are high emissivity, meaning they can emit extra energy, causing additional cooling effects.	
Source - You can get normal paint at any home improvement retailer. Here is a source for high emissivity paint	

https://cpicoatings.com/products/stop-heat?variant=39713370439728&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gad=1&gclid=CjwKCAjwxr2iBhBJEiwAdXECww5AVPfNSRG_i0sZRwM_WgV-0lYkZeBkjN8lzKv-kq00gWKgaYSv7BoCFHEQAvD_BwE

Homewrap and vapor barrier

Unfortunately, no siding is perfectly waterproof. Moisture can trickle through small gaps in the siding, and over time can damage the wood frame of the enclosure. To stop this, you can use a home wrap or vapor barrier to help repel any water that gets through the siding.

Home wrap - A normal home wrap will be resistant to water but will allow water vapor to seep through, this can help to dry out an enclosure if it gets wet, but can also expose insulation to moisture that it can absorb

Vapor barrier - A vapor barrier repels water as well as water vapor. This is good for walls that have absorbent insulation in them. The challenge comes when moisture does get in, in which case it will have to dry towards the inside, meaning there needs to be a way for vapor to get out of the enclosure. Warning: putting two vapor barriers in a wall is a recipe for disaster, as water will eventually seep in, and then be unable to escape, rotting the wall.

Source - Readily available at home improvement retailers
Non-vapor barrier home wrap
https://www.homedepot.com/p/TYVEK-3-ft-x-165-ft-HomeWrap-Housewrap-D15540828/308793245
Vapor barrier
https://www.homedepot.com/p/HDX-10-ft-x-25-ft-Clear-6-mil-Plastic-Sheeting-RSHD610-25C/204711657

Siding Options

Vinyl siding	
Vinyl siding comes in dozens of different colors and styles. It can be made to look like just about any material while also being weather resistant. It requires little to no maintenance but can be limited in color and style selection. Unfortunately, it can degrade in sunlight, which will make it brittle and prone to cracking	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/Ply-Gem-Transformations-Double-4-in-x-150-in-White-Lap-Vinyl-Siding-PC4004H/301837334	
Wood Siding	
Wood siding is a common choice for fridge enclosures. It is readily available and can be painted in a near-infinite range of colors. However, it also requires high maintenance, needing to be repainted and repaired if damaged. It also has the advantage of coming in a wide variety of options, from beautiful cedar board siding to inexpensive T1-11 (a premade wood siding panel).	
Sources - There are several options for wood siding, here are a few T1-11: https://www.homedepot.com/p/Plytanium-Plywood-Siding-Panel-T1-11-8-IN-OC-Nominal-19-32-in-x-4-ft-x-8-ft-Actual-0-563-in-x-48-in-x-96-in-113699/100000016 Cedar shingles: https://www.homedepot.com/p/5-in-x-16-in-Eastern-White-Cedar-Kiln-Dried-Wall-Grade-Architectural-Shingles-63903747/324354723	
Fiber Cement Siding	
Fiber cement is a more expensive option for siding, but it comes with many of the same advantages as vinyl. It's durable, damage resistant, and requires no maintenance. The main draw, however, is that it's tougher and lasts longer than vinyl siding, and can be painted to be any color.	

Source - Readily available at home improvement retailers
https://www.homedepot.com/p/James-Hardie-HardiePlank-HZ5-5-16-in-x-8-25-in-x-144-in-Fiber-Cement-Primed-Cedarmill-Lap-Siding-6000265/202035444

Metal Siding

Metal siding is made from the same material as metal roofing. Its main advantage is that it is reflective, making it an excellent choice for enclosures that get a lot of sunlight. It is also waterproof and durable, making it excellent for protecting the wall underneath. The downside of metal siding is that it is not very attractive, and can dent and stain over time, eventually becoming unpleasant.

Source - Readily available at home improvement retailers
https://www.homedepot.com/p/8-ft-SM-Rib-Galvalume-Steel-29-Gauge-Roof-Siding-Panel-987601/314709085

Comparison Table

Siding	Price per square foot (Min and Max)		Expected lifespan (yrs)	Requires 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

Fridges

Best Practices to Keep Fridges Running Well

There is a lot to think about when choosing a type of insulation, like how it is installed, how well it works, and how durable it is in the long run. Here are a few important things to keep in mind when making a plan for an enclosure.

Gasket Maintenance

All fridges contain a gasket around their doors, which forms a seal when the door is closed that keeps the cold air in. These gaskets are made of rubber and will wear and harden over time, especially when exposed to the elements and frequent door openings. When they wear down, they will begin to leak air. To keep the gaskets functioning, there are several things that can be done.

1. Keep them clean - Mold and dirt will cause them to seal poorly
2. Oil them if they begin to get stiff - this can be done by coating them in a very thin layer of Vaseline
3. Check that the gasket is properly attached - Gaskets are not glued in and can be accidentally pulled out of place. Luckily they can be pushed back into place just as easily.
4. Replace damaged gaskets - If a gasket is damaged (cracked or split), you can order a replacement from the manufacturer. Here is an excellent guide on replacement/detecting damage https://repair.geappliances.com/resources/faq/how-do-i-tell-if-a-refrigerator-door-seal-is-bad

Leveling

Fridge doors close automatically using gravity. This means that if the fridge is not level, the door may not close properly. The best way to solve this is to make sure that the floor under the fridge is level, but this may not always be possible. Most fridges have adjustable legs that will allow you to level the fridge.

Fridge Options	
Garage-certified fridges These fridges are the most cost-effective option. They are specially designed to deal with the fluctuating temperatures of a garage, which can go a long way to help keep safe internal temperatures. They are also readily available and can be bought at most home improvement stores. Source - Readily available at home improvement retailers https://www.homedepot.com/p/GE-19-2-cu-ft-Top-Freezer-Refrigerator-in-White-GTS19KGNRWW/312429505	
Stainless garage-certified fridges These have the same design as a regular garage-certified fridge, but they are made of stainless steel. The steel makes the fridges more expensive, but it is more resistant to weather conditions. It is also reflective, which makes the fridge more resistant to direct sunlight. Source - Readily available at home improvement retailers https://www.homedepot.com/p/GE-19-2-Cu-Ft-Top-Freezer-Refrigerator-in-Fingerprint-Resistant-Stainless-Steel-GTS19KYNRFS/319881478	
Glass-door fridges These fridges are designed for restaurants and stores that want to display their products. The glass door allows users to see what's in the fridge without opening it, which can significantly reduce the frequency of door openings. This will drastically increase the effectiveness of the fridge, as it will not be leaking cold air as often. That said, glass doors can be broken, which can be a serious issue on the street, and they do not have freezers.	

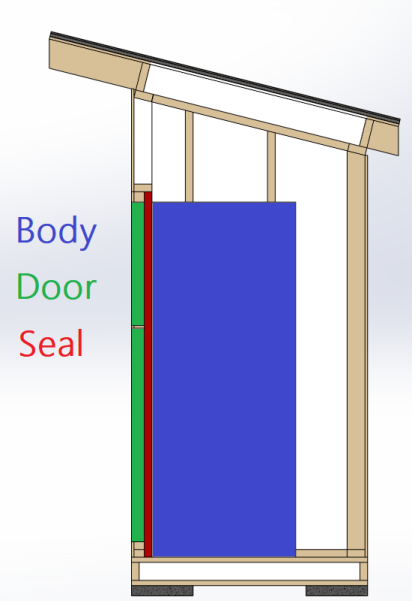
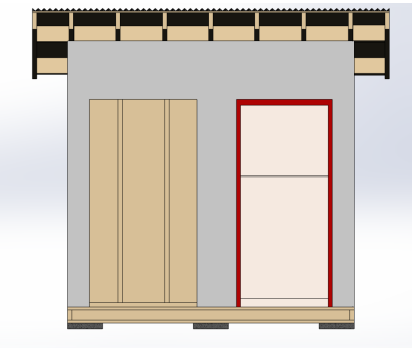
Source - Readily available at home improvement retailers https://www.lowes.com/pd/Premium-Levella-6-5-cu-ft-Commercial-Upright-Display-Refrigerator-Glass-Door-Beverage-Cooler-in-Silver/5013802245?user=shopping	
Commercial fridges	
These fridges are designed for restaurant use, and as such are larger and heavier duty than domestic fridges. They require more power, and make more noise, but are sturdier than domestic refrigerators.	
Source - There are a lot of places to get these fridges. Here is one of them https://www.kitchenall.com/coldline-u-12r-25-solid-door-commercial-reach-in-refrigerator-11-cu-ft.html?source=googleshopping&locale=en-US	

Comparison table

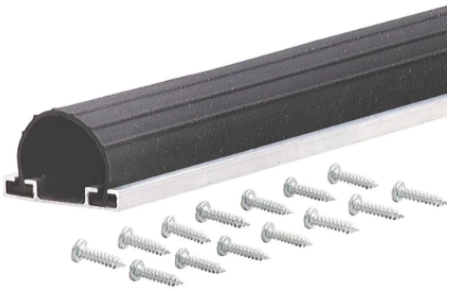
Fridges	Cost	Readily available	Freezer	Window
Garage Ready	$700	Yes	Yes	No
Stainless Garage Ready	$900.00	Yes	Yes	No
Glass Door Fridge	$1,000	Yes	No	Yes
Commercial Fridge	$1,350	No	No	No

Seals

A wide open fridge enclosure allows wind and debris to get in, which will both negate the effectiveness of the insulation, as well as cause garbage to build up around the fridge. Sealing around the fridge will significantly help this. The seal should be placed around the main body of the fridge, just behind the door, allowing the door to be opened while keeping the enclosure sealed. While this method is less effective than enclosing the entire fridge, it gives moderate protection while retaining full accessibility for users.

Considerations	
Sealing the gaps around a fridge is a tricky balance between closing the enclosure and keeping the fridge available. A potential balance between these is to seal around the body of the fridge and leave the door exposed. The rest of this section operates under the assumption that this method is used. The diagrams on the right show the positioning of the seals. The seals attach to the body immediately behind where the door starts.	 
Attachment method	
How a seal is attached can affect its long-term viability. Seals either are adhered in place or screwed on the enclosure. Screws add to installation difficulty, while adhesives may fall off over time and need replacement.	
Gap Size	

Depending on the construction of the enclosure, the gap between the fridge and the sides may vary. Different seals are going to work better for different gap sizes. Larger gaps will likely need something more durable, as they will likely be more exposed, while small gaps may require something that fits better.	
Pest Resistance	
Seals keep more than airflow out of an enclosure. Pests may find the protective environment to be an excellent home or at least a meal. The seals around the fridge can help to keep them out, so long as they are strong enough.	
Long-term durability	
Different seal designs will deteriorate in different ways. Depending on the seal design, they may need to be replaced more often to continue doing their job.	
Accessibility	
The backs of the fridges still need to be accessed in case of a breakdown. As such, a fridge needs to be able to be removed without damage in order to fix or replace it.	
Vents	
If an enclosure is completely sealed, some problems can arise. First, if moisture gets in, it won't be able to get out. Second, the fridge still needs airflow to function properly, or it may overheat the enclosure in the summer.	
Sealing larger gaps	
For abnormally large gaps, it may be necessary to modify the frame, or to install a piece of rigid foam board insulation to fill the space	

Options	
Foam Weather Stripping	
An excellent solution for tight spaces, this foam comes with an adhesive side that can be placed on the edges of gaps around the fridge. They are easy to install, and seal the gap effectively, but will likely make removing the fridge more difficult	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/M-D-Building-Products-1-1-2-in-Black-Platinum-Expandable-Foam-Weatherseal-for-Uneven-Gaps-03115/314012150	
Garage Door Seals	
These seals are designed to go on the bottom of garage doors. They can be bolted in place, and are highly durable. They will likely make the fridges somewhat more difficult to remove, but provide a good seal and can prevent pests.	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/Xcluder-X2-Rodent-Proof-Garage-Door-Seal-Kit-8ft-x-1-75in-x-1-75in-Individual-Pest-Control-Retainer-162971/313936107	
Door Sweeps	
These seals are made of stiff bristles or rubber flaps. They would likely be the best option for fridge accessibility. They will not provide the best air seal, but they will reduce airflow. They are also somewhat resistant to pests.	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/Frost-King-36-in-x-25-in-Heavy-Duty-Aluminum-and-Brush-Door-Sweep-Weatherstrip-SB36/202525375	

Comparison table

Seals	Cost estimate	Mounting method	Gap size (inches)	Pest Resistant	Long term durability	Easy to remove fridge
Garage door seal	$200	Screws	2	Yes	Yes	Yes
Adhesive foam tape	$30	Adhesive	1.5	No	No	No
Brushed Door Sweeps	$50	Screws	1.75	No	Yes	Yes

Vents

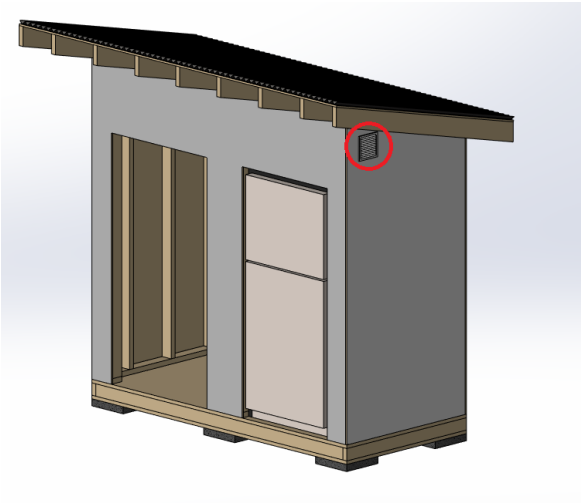
If an enclosure is sealed and moisture gets in, it will have nowhere to go. Having ventilation allows the moist air to escape, preventing mold and bacteria buildup. It can also help with the heat in the summer by allowing hotter air to leave the enclosure. Additionally, when a fridge cools its internals, all of the heat that it is removing needs to go somewhere. If it is all trapped in the enclosure the fridge will be at serious risk of overheating.

Considerations	
Sizing	
The sizing of a vent is largely dependent on the amount of airflow that is desired. Most fridge enclosures are relatively small, so less ventilation is needed. It is important to not over ventilate the structure, as that will defeat the purpose of sealing and insulating the enclosure. Due to the small size of the enclosure, smaller vents will likely be sufficient.	
Water/Pest resistance	
Adding vents to an enclosure provides another avenue for water and pests to get in. There are many ways this can be counteracted. Vents can be placed under overhangs or be shielded from water, and screens can be added to keep insects and other pests out.	
Powered Airflow	
Vents can be considered either passive or active. Passive vents have no mechanism for creating airflow, they only permit air to pass through them. As a result, they are usually cheaper and simpler solutions to implement. Active vents contain a mechanism to push air, which significantly increases the throughput of air. Active solutions are very effective for ventilation but can be expensive and delicate, as well as running the risk of moving too much air, which would negate the insulation.	
Placement	
The placement of vents is important to their function. Ideally, a vent should be placed high up in the enclosure, preferably under the overhang of the roof to keep water out. Placing the vent high up also allows for the hotter air to escape, which will also contain most of the moisture.	

Modern fridges have an internal fan that pulls air in from vents in the back, and pushes it out the vents at the bottom front of the fridge (there is a handy diagram included). Older fridges have large coils on the back that passively release heat.
For a modern fridge, it may be a good idea to put a vent near the air intake on the back. In a normal house, modern fridges need approximately 1 to 2 inches of space behind them. This is likely a good practice to follow if there is only a vent at the top, but if there is a vent directly next to the air intake of the fridge this may not be entirely necessary. For an older model, 3 to 4 inches is needed, and more than that may be necessary due to the reduced airflow of an enclosure.

Air intakes on the back of a modern fridge

Vent placement to remove moisture



Options

Louvered Wall Vent

Louvered wall vents are on the smaller side of vents. They are passive vents, which mount onto a hole cut in the wall. The louvers are designed to keep water out without blocking airflow. They are inexpensive and can be mounted on almost any wall. They are often screened to prevent pests from getting in, and if not a screen can be added to them.

Source - Readily available at home improvement retailers
https://www.homedepot.com/p/Master-Flow-6-in-x-6-in-Galvanized-26-Gauge-Louver-with-Screen-26L6X6GS/205430389

Turbine vent (whirligig)	
A turbine vent is a clever way to make an active vent without requiring power. It uses wind power to force air out. It mounts onto the roof of the enclosure. It is expensive and can be off putting, but if active ventilation is needed it can be an effective solution. They are also often adjustable, so they can be closed or opened depending on the season.	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/LOMANCO-12-in-Galvanized-Steel-Internally-Braced-Whirlybird-Wind-Turbine-GT12/100572638	
Soffit Vents	
Soffit vents go on the underside of the roof overhang. They are the lowest-profile vent on this list and are relatively inexpensive and durable. The main disadvantage they possess is that for them to work there must be a path for air to take through the ceiling beams. This will require a path to be made through the insulation and will result in reduced airflow.	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/Master-Flow-3-in-Resin-Circular-Mini-Wall-Louver-Soffit-Vent-in-White-4-Pack-RLSC3/100038053	

Comparison Table

Vents	Cost estimate	Size	Water-resistant	Pest-resistant	Durability	Forces airflow
Louvered vent	$20	Small	Yes	Yes	High	No
Turbine Vent	$60	Large	Yes	Yes	Medium	Yes
Soffit vents	$20	Medium	Yes	Yes	Medium	No

Foundations

A good foundation has several benefits for an enclosure. Most importantly they provide a base for the structure, keeping it level and stable. Furthermore, they keep the frame off of the ground, preventing moisture from absorbing into the building.

Considerations	
Location	
Where an enclosure is built determines what it is going to need for a foundation. If the area is already paved, an enclosure can likely get away with being put up on blocks just to protect it from water damage. If it is being built on an unpaved area, a more substantial foundation is likely needed to keep the structure safe from moisture as well as level.	
Stability	
Fridge enclosures tend to be rather tall with a narrow base, making them liable to tip if conditions are right. As such, a foundation may be extra necessary to ensure a fridge doesn't fall over or shift.	
Accessibility	
Lifting a structure off of the ground, while excellent for protecting it from moisture, can become an issue for some users. For the best accessibility, it is good to raise the structure off the ground as little as possible (just an inch or two).	
Freeze/thaw line	
In colder climates, the ground will often freeze in the winter. This can cause excess stress on a concrete foundation, which will eventually cause it to get damaged. A way to prevent this is to have your foundation go down below the line where the ground freezes, but this can get expensive and difficult for some types of foundations. It is important to note, however, that a foundation of a smaller size is less susceptible to these issues	

Options

Pier and Beam A pier and beam foundation is a way to build an enclosure in an unpaved area. It is made of a series of concrete piers, which are poured into the ground. Wood beams are placed between the piers to make a solid base that is raised off the ground to protect the wood from rotting. This solution is relatively simple and is an excellent way of working around particularly uneven terrain. It is also a good way to reach below the freeze/thaw line. The biggest downside is that it is more expensive, and it will likely raise the fridge higher off the ground than other solutions.	
Slab A slab foundation is another way to build an enclosure on an unpaved area. Concrete is poured directly into the ground in the shape of the floor, and the structure is built on top of it. Unfortunately, slabs require relatively flat ground to work best and may run into freeze-thaw issues.	
Bricks Bricks are an easy way to put a structure up on blocks if you have a paved surface. They are cheap and readily available, but they rely on the underlying surface to be level and are small, which may cause uneven distribution of weight.	
Pavers Putting an enclosure up on pavers has the same advantages as bricks, but pavers are larger, thus distributing loads more evenly. They are also large enough to be a potential solution for non-paved surfaces, but a concrete foundation will be far more stable.	

Comparison Table

Foundation	Materials	Labor	Total cost	Stability	Good on unpaved surfaces
Pier and beam	$800.00	$1,000	$1,800	Excellent	Yes
Slab	$180.00	$500	$680	Excellent	Yes
Bricks	$10.00	$0.00	$10.00	Questionable	No
Pavers	$30.00	$0.00	$30.00	Good	Sometimes

Roofing

The roof of a fridge enclosure is important for several reasons. First and foremost, it protects the enclosure from snow and rain making it run off someplace else. Second, it protects the enclosure from the sun. Lastly, it provides a barrier against heat transfer between the inside and outside of the enclosure.

Considerations	
Overhang	
Since the front of the fridge is exposed to the elements, it is important to try and keep it protected. A large overhang (1'-2') over the fridge will help to shade the fridge in the summer, as well as keep water off of users. For the other sides, a smaller overhang (at least 6") is all that is needed, as its main role is to keep the rain off the siding.	
Reflectivity and Insulation	
A lot of heat in the summer comes from direct sunlight. As such, a reflective or lightly colored roof material will go a long way in keeping the structure cool. Additionally, it is important to insulate the roof of the enclosure to keep any heat that does get transferred to the roof out of the enclosure.	
Lifespan	
The durability of roofing is particularly important, as it is responsible for keeping most of the rain and snow out. A roof that is beginning to leak can cause serious damage to an enclosure if not	

repaired quickly. A more durable roof provides extra peace of mind as to the safety of the enclosure.

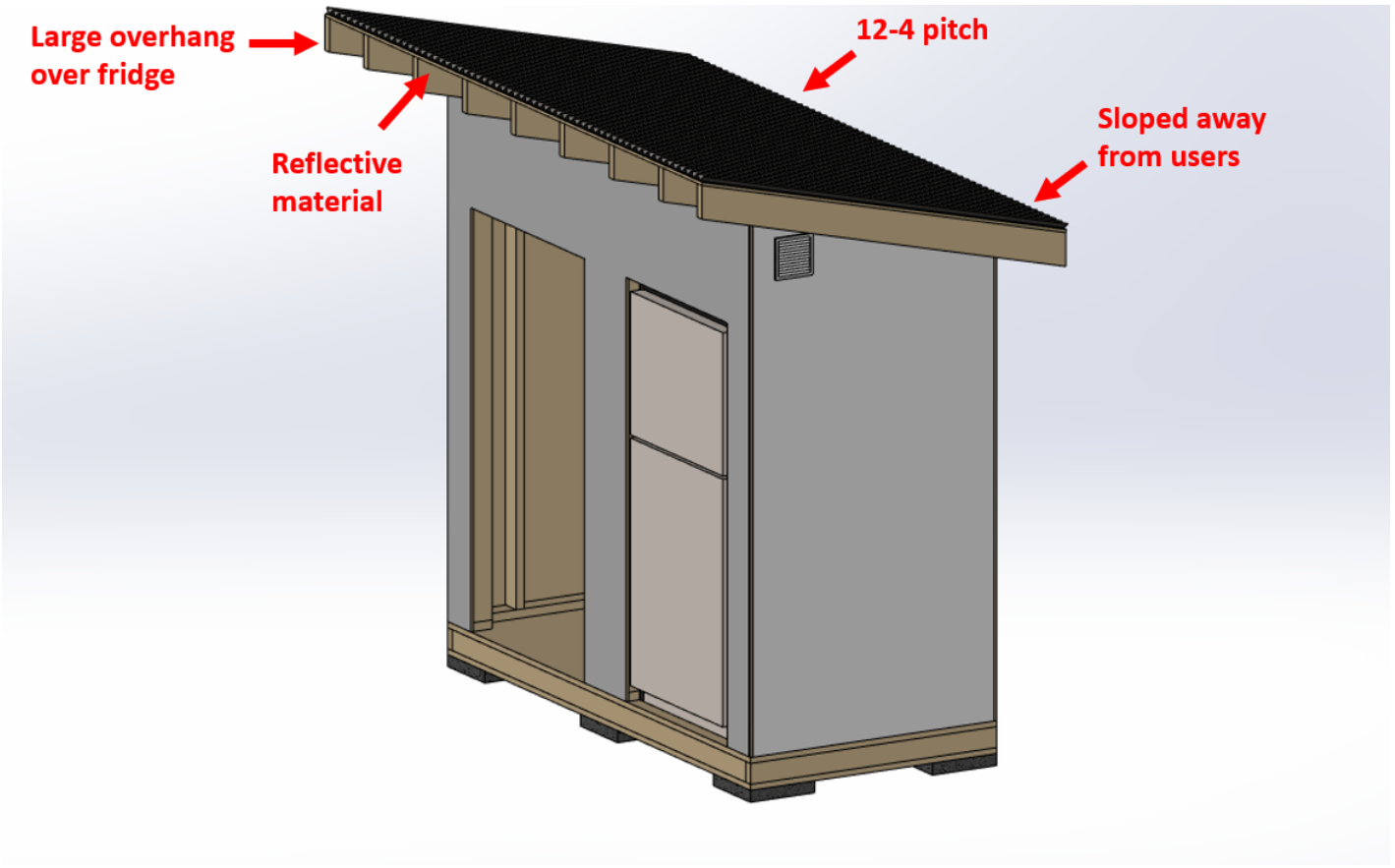
Slope Direction	

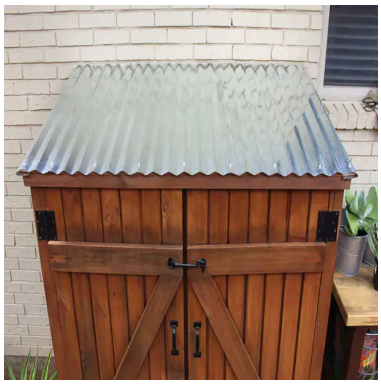
The slope of the roof depends heavily on the fridge's surroundings. The most important thing is to keep runoff from falling on users, but the runoff must also be kept away from any nearby buildings, as it can damage them over time. The optimal slope direction has its high side where people access the fridge. If there is a building behind it's best to either have the high side on one of the side walls or to leave a space between the enclosure and the building. Single-slope roofs are usually better, as they take less complexity to build.

Slope Pitch	

Pitch defines how steep the slope of the roof is. Steeper slopes are better for shedding rain and snow, but they make the enclosure taller and reduce the effectiveness of the overhang. The recommended pitch for the roof is at least 4-12 (for every 12 inches sideways, the roof rises 4 inches up). This is the standard slope for most houses.

Drawing of an optimal roof	



Options	
Galvanized Steel	
This option has been a mainstay of roofing for decades. It is made of steel with a zinc coating that prevents rust and corrosion. Being steel, it's on the tougher side, but it will corrode over time as the coating fails. This is why it is being switched out over time for Galvalume.	
Source - Readily available at home improvement retailers https://www.homedepot.com/p/8-ft-Corrugated-Galvanized-Steel-31-Gauge-Roof-Panel-13513/202092961	
Aluminum	
The main advantage of aluminum is its corrosion resistance. It is excellent at resisting corrosion, even when exposed to a lot of salt. The downside is that it is more expensive, and is a softer material and thus prone to denting.	
Source - Not as common as the steel varieties, if you decide on aluminum you will want to look at local providers	
Galvalume Steel	 Image credit
Galvalume is similar to galvanized steel, but its coating includes aluminum. This gives it some extra corrosion resistance, while not sacrificing the strength of the steel inside. It is likely a better option than galvanized steel, and as a result, is more readily available	
Source - Readily available at home improvement retailers	

https://www.homedepot.com/p/10-ft-SM-Rib-Galvalume-Steel-29-Gauge-Roof-Siding-Panel-987602/314709088

Asphalt Shingles

Asphalt shingles are the cheapest option on the market. They are easy to find and easy to put up. Unfortunately, they do suffer from a number of drawbacks. The main issue is that they don't last very long. Roofs usually need to be re-shingled every 20 years. They are also not reflective and are a dark color that absorbs even more heat.

Source - Readily available at home improvement retailers
https://www.homedepot.com/p/GAF-Royal-Sovereign-Charcoal-Algae-Resistant-3-Tab-Roofing-Shingles-33-33-sq-ft-per-Bundle-26-Pieces-0201180/100040028

Cedar Shingles

Cedar shingles are the nicest-looking option. They have the same lifespan as asphalt shingles but are slightly more reflective due to their light color. They come in at roughly the same price as metal roofing but look much nicer. The other major disadvantage of cedar shingles is that they are labor intensive to install.

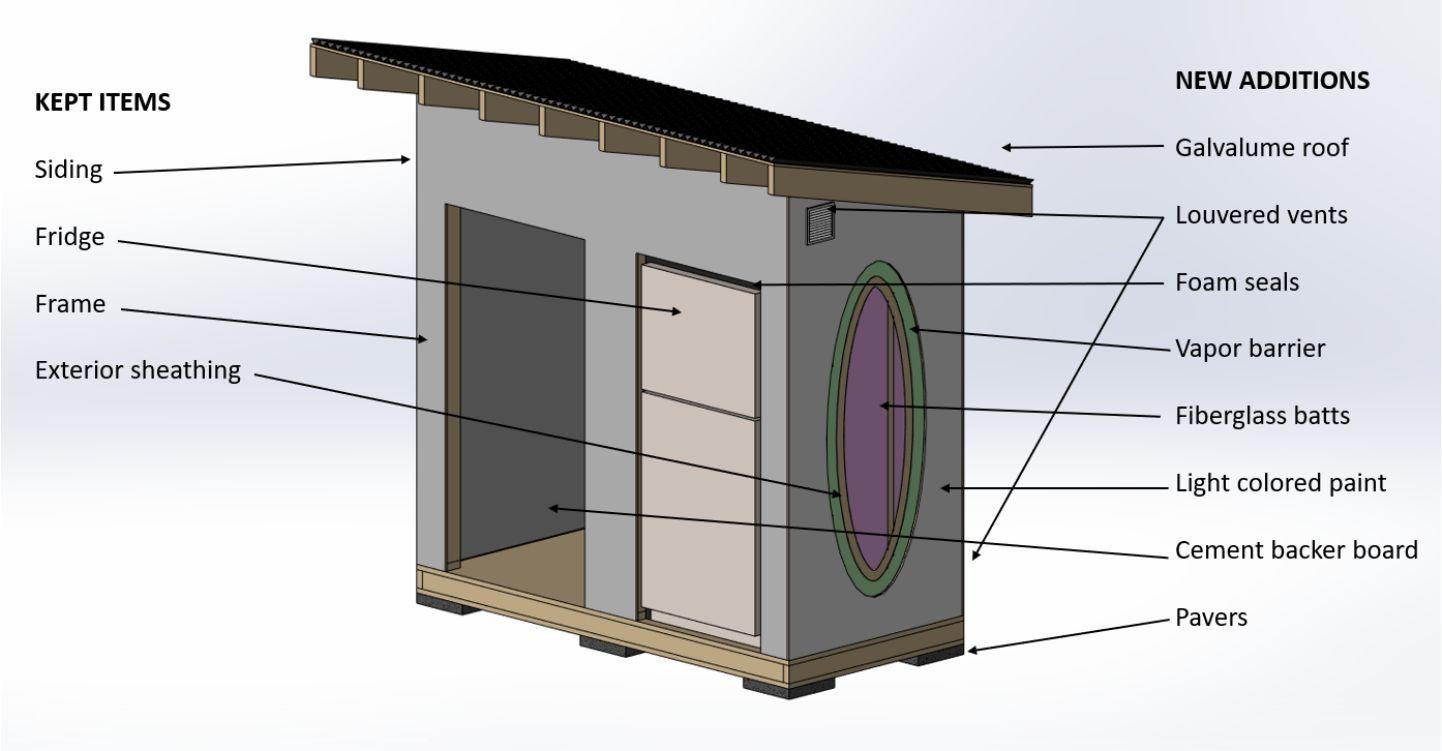
Source - Readily available at home improvement retailers
https://www.homedepot.com/p/2-in-to-12-in-W-x-18-in-Wood-Cedar-Shingle-Siding-234159/307421043

Comparison table

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

Retrofit for Existing Enclosures

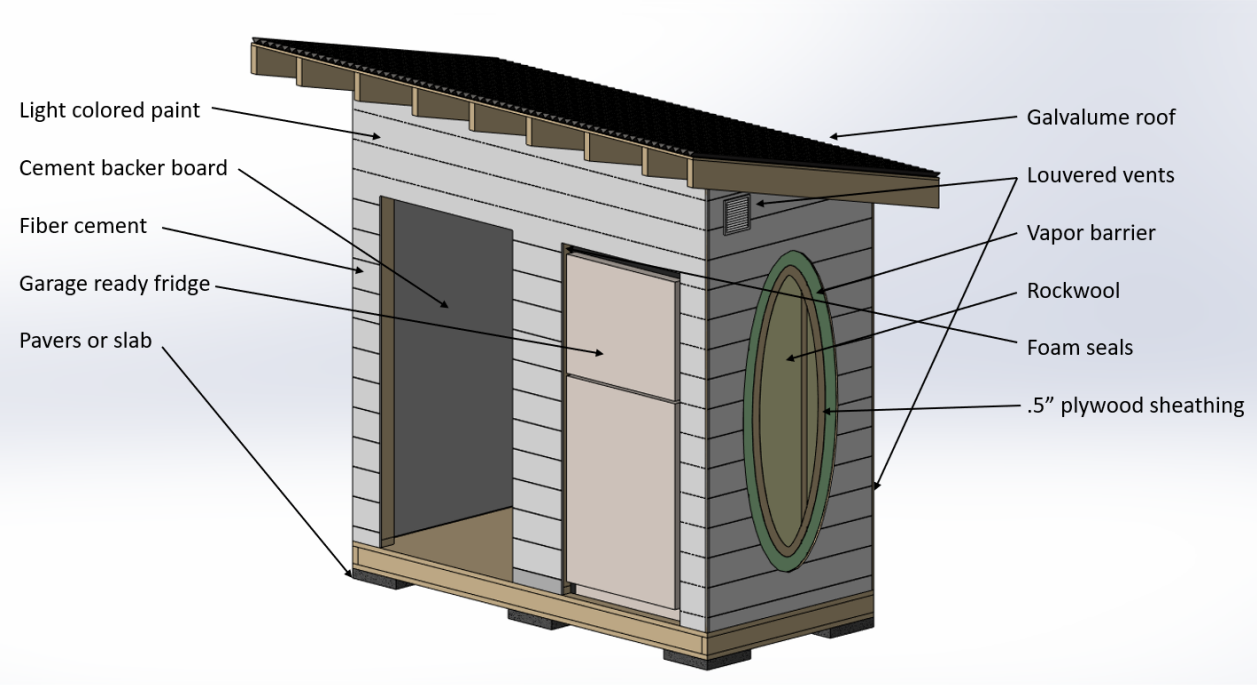
Diagram



Cost estimate

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

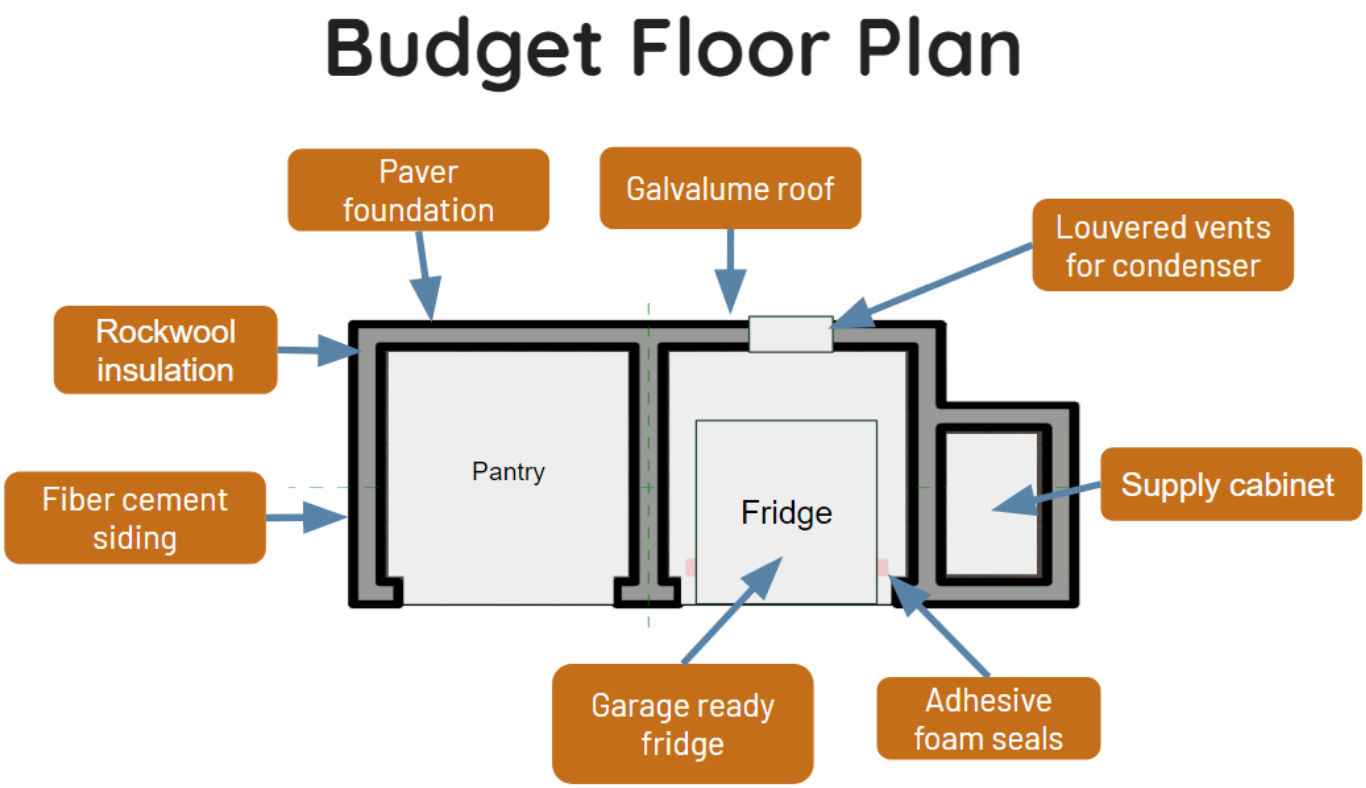


Cost estimate

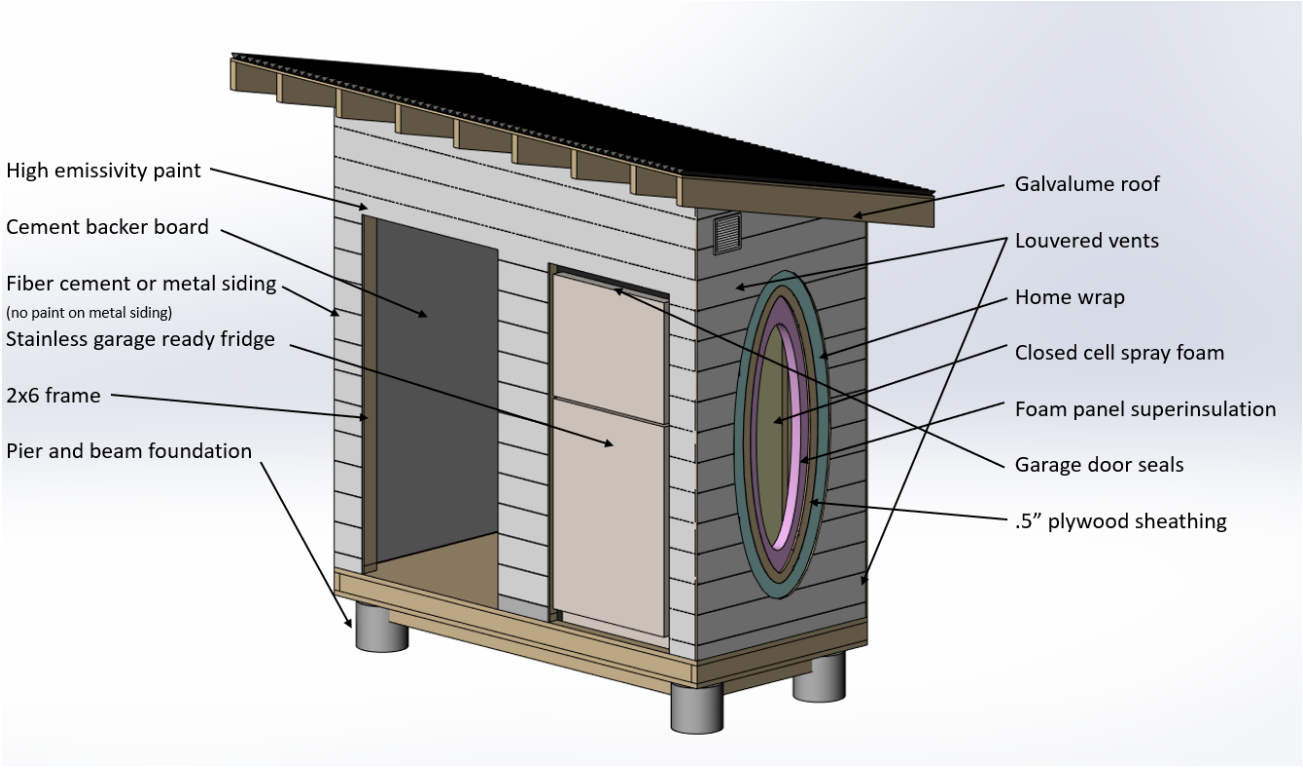
Item	Material	Professional labor	Total
Rockwool	$225.00	$500.00	$725.00
Slab foundation	$200.00	$500.00	$700.00
Plywood sheathing	$320.00		$320.00
Vapor barrier	$75.00		$75.00
Fiber cement siding	$250.00		$250.00
Light color paint	$50.00		$50.00
Louvered vents	$40.00		$40.00
Galvalume roof	$120.00		$120.00
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

Proposed Second Iteration Floor Plan For Budget Enclosure

Below is the second iteration of the budget design's floor plan. Not illustrated 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, we suggest using the same construction methods shown in the above diagram.



High-End Enclosure for Larger Budgets

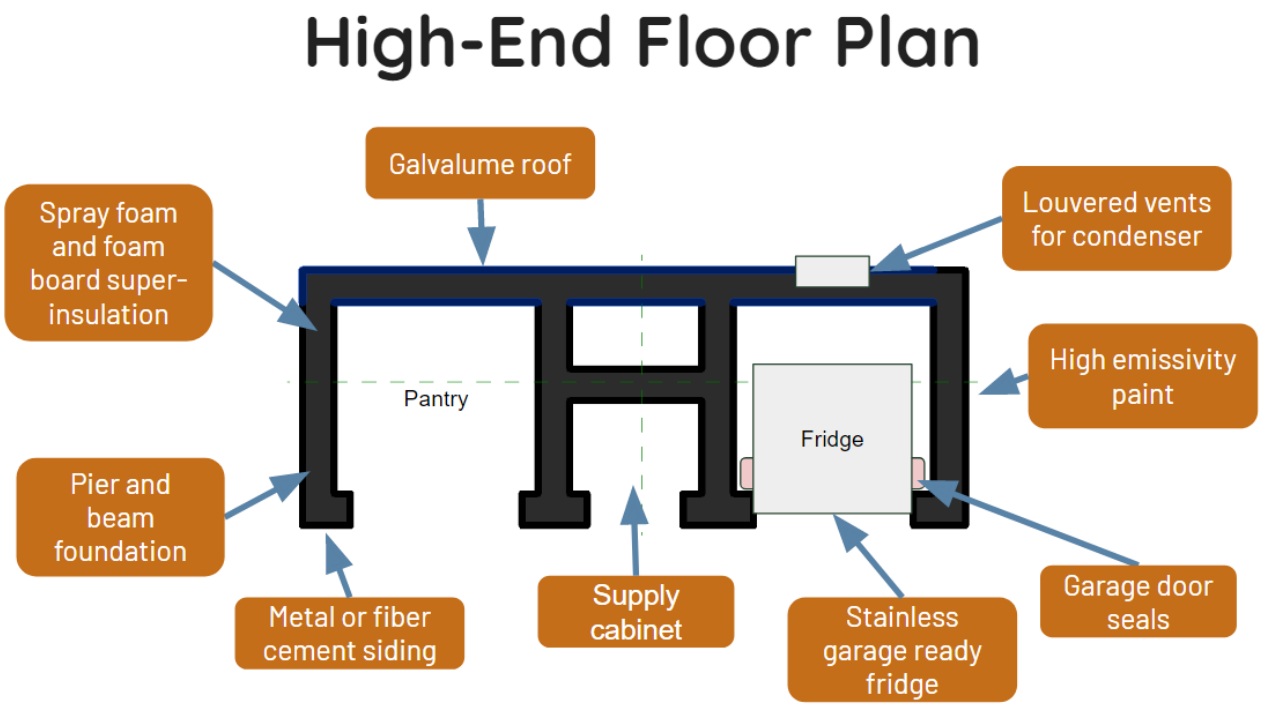


Cost estimate

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

Proposed Second Iteration Floor Plan for High-End Enclosure

Similar to the previous design, barn doors are also present in this iteration. This particular floor plan is proposed to be larger than previous designs, at 8' 5" by 4' 5". The extra room grants 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.



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Weatherization of Worcester Community Fridges

Worcester Polytechnic Institute

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Introduction

Food insecurity has doubled across Massachusetts since the 2020 pandemic (Project Bread, 2020). Worcester alone in the past few years has had an increase in food-insecure families, jumping from 8.6% to 9.1% from 2017 to 2020 (Feeding America, 2023).

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 causes frequent shut-offs from the fridges. This means a volunteer from the group is required to provide maintenance for the fridge resulting in unpredictable downtime over the course of each refrigerator's lifespan.

Our team is tasked with delivering WooFridges with a weatherization strategy for their fridges to allow for smoother operation during months with extreme temperatures. We plan to observe the effects of extreme temperatures on the fridges, to find a way to better insulate them or a simple workaround. We plan to deliver a weatherized fridge to Woo Fridges, an installation guide, and a maintenance manual.

In the following section, 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 plan to do to gather data on the fridges.

Background

Section 1 - Food Insecurity

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 attacking 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).

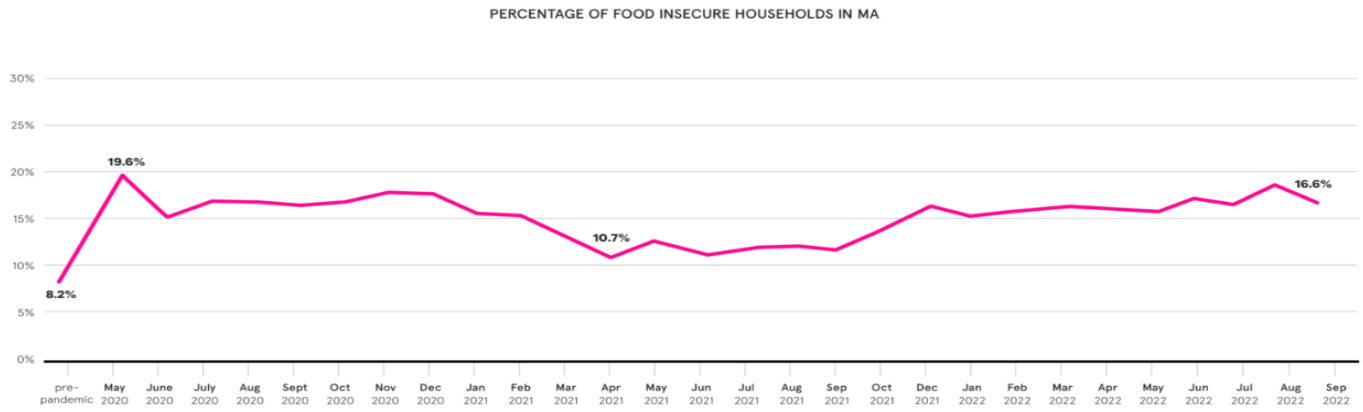


Figure 1.1: Food insecurity in post-pandemic Massachusetts (Project Bread, 2022)

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.

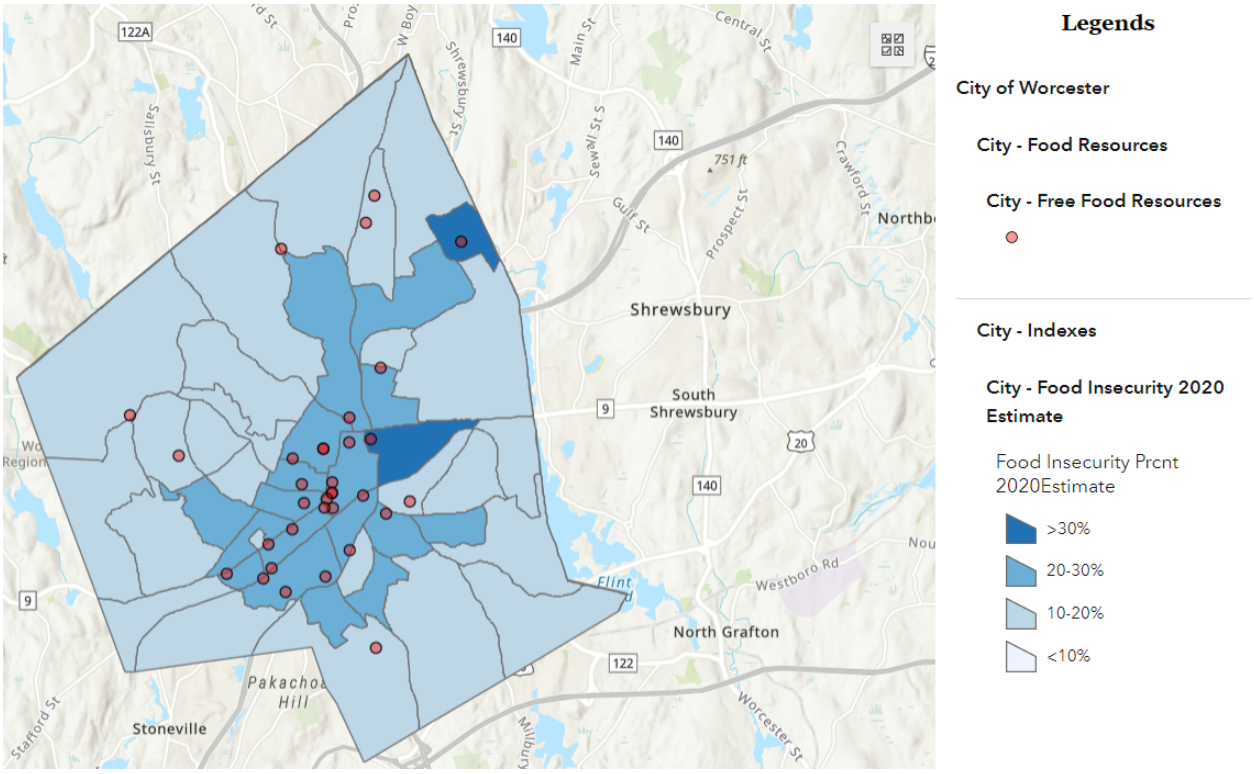


Figure 1.2: Food insecure areas in the city of Worcester (USDA, 2019)

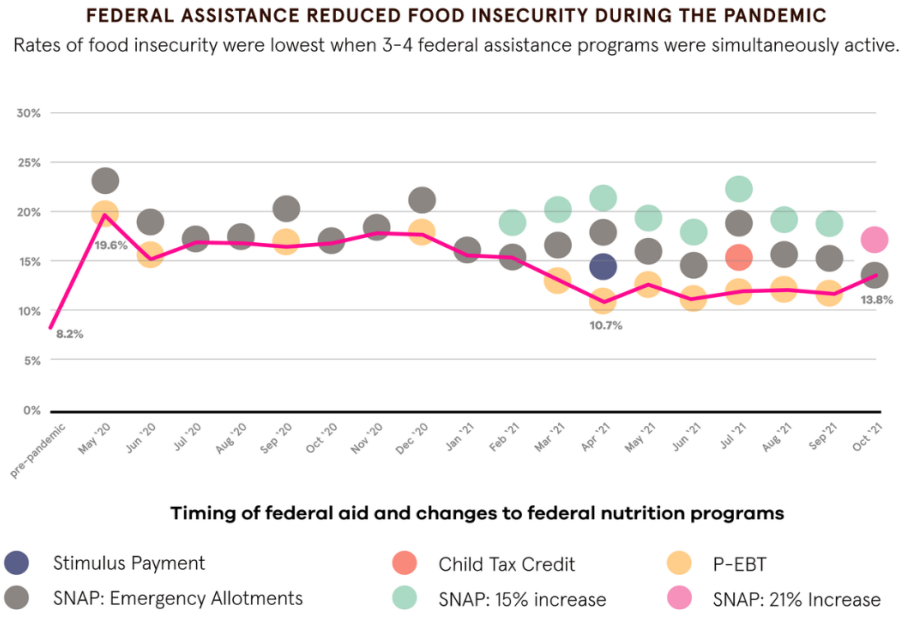
Section 2.1 - Institutionalized Food Aid

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.

	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)

One study indicated a 19% decrease in food-insecure families in the first 6 months of their participation (Mabli & Ohls, 2015). Furthermore, the more programs that are available, the more



families are supported. This is supported in Figure 2.2 where one can see that having more programs lead to large decreases 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 2.2 - 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 alone trying to serve the estimated 68,460 individuals it gets (Feeding America, 2023). Additionally, the hours of operation for food banks and pantries can be inaccessible for people who would take advantage of their services. There is a communication gap as well, leading to many not knowing when these places are open, both shown in Figure 2.3.

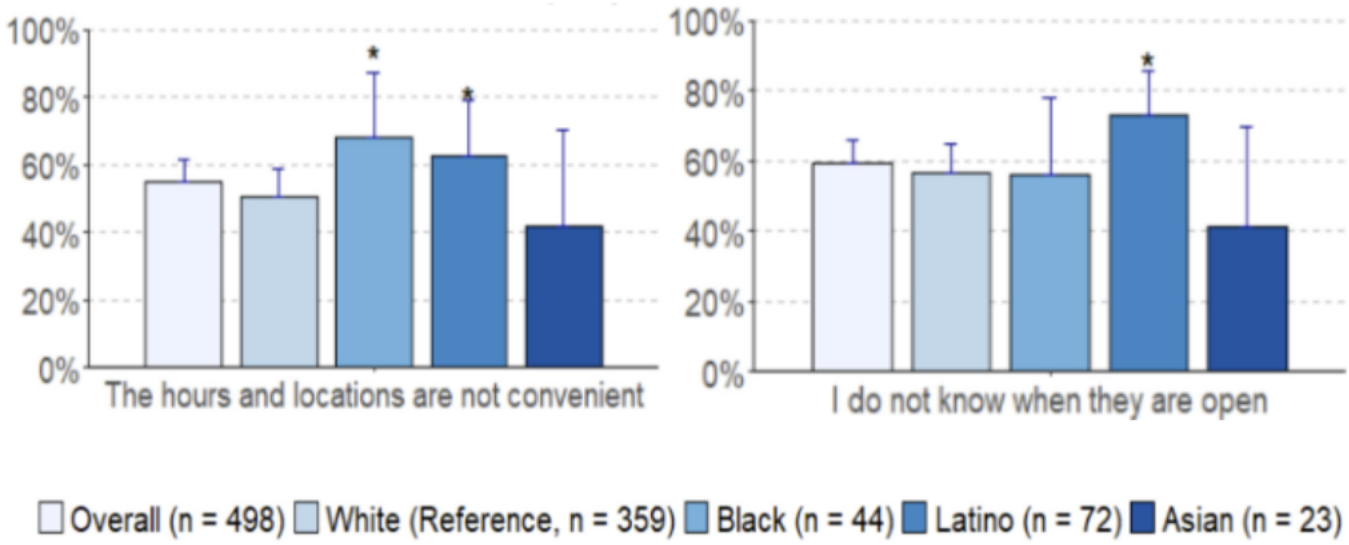


Figure 2.3: Commonly reported roadblocks to access pantries in Massachusetts (Marriott, 2022)

SNAP is effective, but the requirements for enrollment into the program are strict. The criteria say that to be eligible, the family must be under the federal poverty line and also have less than a certain value of assets. These qualifications change yearly based on SNAP's Cost of Living Adjustments (COLA).

SNAP Eligibility Chart

Household Size	Maximum Monthly Income (before taxes)	Maximum Monthly SNAP Amount*
1	$2,265	$281
2	$3,052	$516
3	$3,838	$740
4	$4,625	$939
5	$5,415	$1,116
6	$6,198	$1,339
7	$6,985	$1,480
8	$7,772	$1,691
Each additional person	+ $787	+ $211

Figure 2.4: A chart that shows eligibility requirements for the SNAP program for 2023. (Mass.gov, 2023)

People also use financial aid programs like P-EBT(Pandemic Electronics Benefits Transfer) to help fill in the gaps, however, the P-EBT is only temporary as it was created to soften the blow of the pandemic ending on March 2, 2023 (Mass.gov, 2023).

Section 3 - About WooFridges

Worcester Community Fridges, WooFridges for short, is a grass root program based on a neighbor-help-neighbor approach that many use. Their first fridge opened on January 31st, 2021 at a Pizzeria. When the idea was being discussed by some Worcester community members on Facebook after hearing about similar programs, in Massachusetts and worldwide, the owner of the shop loved the idea and let the fridge be put outside his restaurant. Since then there have been three more fridges put up each with donated fridges and materials for the enclosures with a fifth fridge on the way. Since the fridges' electricity bills and general maintenance are covered by the owners of the property they reside on, the organizers of WooFridges only build the fridges at the request of property owners like in the case of the Pizzeria. The idea of these fridges is based on mutual aid. 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. The maintenance of the fridges is divided between the property owners and the volunteers. Taking care of stocking and maintenance of the fridges, which volunteers coordinate through a Discord server (a set of online chat rooms).

WooFridges is a unique program with 24/7 operation and an active volunteer base, committed to providing for families and filling in any gaps in our community's diet. The program is incredibly flexible and just about any property owner could ask for a fridge to be built. Furthermore, these fridges provide access to a variety of foods with the goal of keeping everyone in the community healthy. The take-and-leave approach is a humble and straightforward approach that helps subsidize other food aid programs to give Worcester a holistic approach to food insecurity.

Section 4.1 - Fridges and Worcester Weather

With WooFridges representing a useful source of aid in Worcester, it's important to consider how the fridge's efficiency is affected by the major temperature changes in Massachusetts. The refrigerators used by Worcester Community Fridges are partially exposed to the elements, as shown in Figure 3.1. This is a necessary situation, as it makes the fridges accessible to the users, but it also makes the fridges far more susceptible to weather conditions.

Figure 3.1 - One of the fridges for WooFridges

Worcester weather is routinely outside of the expected operational temperature range of domestic refrigerators. Temperatures can reach above 90 Fahrenheit in summer and below 10 degrees Fahrenheit in winter. Figures 3.2 and 3.3 show the hottest and coldest months in Worcester in 2022. The fridges have to endure these temperatures while still maintaining a safe internal temperature to preserve the donations inside.

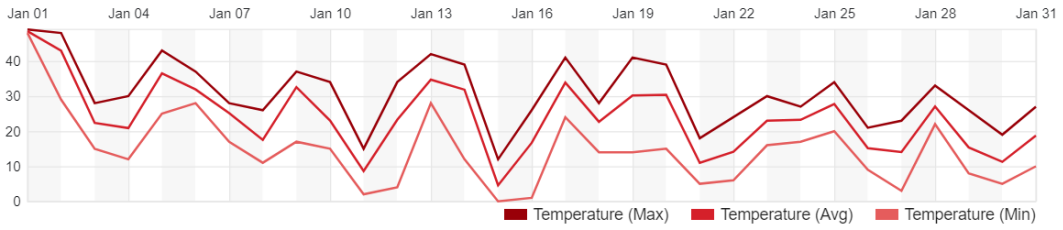


Figure 3.2 - Highs, lows, and average temperatures in Worcester for January 2022

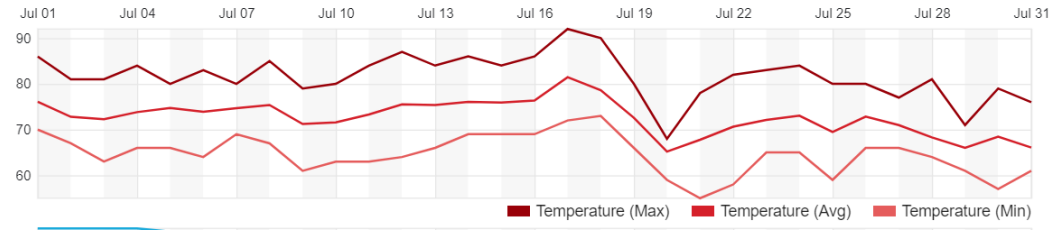


Figure 3.3 - Highs, lows, and average temperatures in Worcester for July 2022

Section 4.2 - How Weather Affects Fridges

These adverse climate conditions are detrimental to the operation and efficiency of fridges. Extreme temperatures can increase the maintenance required to keep the domestic refrigerators employed by WooFridges running.

Hot weather negatively impacts the efficiency of refrigerators. According to Saidur and Masjuki (2002), high temperatures force refrigerators to use extra energy to keep their contents cold. Therefore, as temperatures increase, power requirements also increase. This correlation is shown in Figure 3.4. Additionally, the need for the refrigerator to be running constantly in hot environments can significantly increase wear on the internal components over time, and can even cause the compressor, the device that powers the cooling system, to burn out. Exposing refrigerators to summer temperatures will drastically increase the energy costs of running them and decrease the life spans of the units.

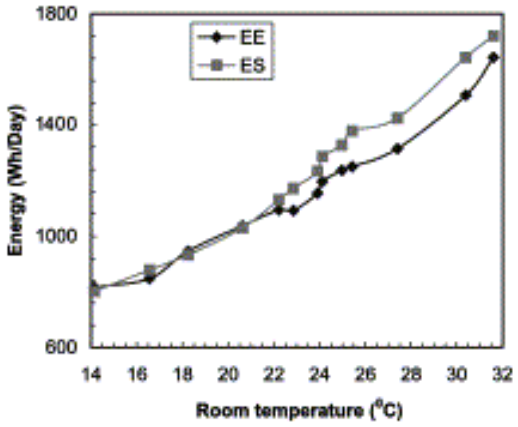


Figure 3.4 - Effect of high temperature on energy efficiency. Saidur R. Masjuki H (2002)

The low temperatures experienced during the winter months have a less direct relationship with energy requirements, but can still cause issues with refrigerator operation. According to Björk and Palm (2006), cold weather causes some refrigerant, the internal fluid that is used to transfer heat from inside the fridge to the outside air, to dissolve into the oil that protects the compressor. This results in less refrigerant than expected being available, which reduces the efficiency of the refrigerator. Furthermore, if the device gets too cold the refrigerant will stop evaporating fast enough, and the compressor will “flood” becoming filled with liquid refrigerant. Flooding can cause severe damage to the internal mechanism of the refrigerator

An additional 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), two issues are contributing to an inability to keep the insides cold. First, the low temperatures can trick the fridge's thermostat into thinking the fridge is colder than it is, 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 any food stored inside. As such, G.E. recommends avoiding installing a refrigerator in a location that can be below 60 degrees Fahrenheit.

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 donated food, reduce maintenance, as well as save on operating costs.

Section 5 - Takeaway

Addressing food insecurity in Worcester is a multifaceted issue. As mentioned above, the more programs the more benefits families will see. The WooFridges program is unique and simple in that it provides struggling people with 24/7 access to donated food products, something many other aid programs can't. Unfortunately, the accessibility of these fridges leads them to many problems related to weather exposure, which hinders their effectiveness. We will be providing a solution to WooFridges as outlined by the methodology below.

Methodology

The goal of this project is 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.

Terminology:

- **Anecdotal**: An account based on personal accounts rather than facts or research
- **Extreme temperatures**: temperatures ranging from below 0℃(32℉) to above 32℃ (90℉)
- **Discord Server**: An online platform for messaging that WooFridges uses to coordinate their volunteer work
- **Weatherization**: The process of making a structure weatherproof
- **Refrigeration**: the process of subjecting food or drink to low temperatures to chill or preserve it
- **WooFridges**: A shortening for Worcester Community Fridges

Objective 1 - Investigate the Impact of Weather on the Fridges

Our first objective is to precisely describe the issues that the fridges are experiencing due to weather conditions. We know they are having trouble maintaining internal temperature, but we don't have the data to assess the scope of the issue. We will collect data both from volunteers and the fridges, specifically looking to record exactly how adverse weather causes issues. Additionally, we will use this time to collect data on the environmental challenges the fridges face, since our solution will exist in the same environment.

Data to collect

- Data on internal vs external temperatures (℉ and ℃)
- Average runtime for fridges as a function of temperature (seconds)
- Additional environmental challenges (vandalism, salt damage, etc)

Semi-structured Interview:

To leverage the experiences of Woo Fridges volunteers and gain valuable anecdotal data, we plan to conduct semi-structured interviews described in Beebe (2001). Allowing the interviewees to speak freely about their time working in Woo Fridges is more valuable and efficient than just having them answer a list of rigidly structured questions. The qualitative data gained should provide a high level of detail and insight into areas we may have overlooked while also allowing us to establish stronger bonds than traditionally structured interviews.

We intend to ask the volunteers to share their experiences working with fridges and explore how extreme weather has negatively impacted the operation and maintenance along with other potential sources of environmental damage. Our interview structure and questions are in Appendix A, including key points for follow-up questions. After our data collection, we will code all the gathered qualitative data with labels based on what issues the volunteers are experiencing and analyze our results to see what issues are critical.

The active volunteer population of WooFridges is estimated to be around 30 people, leading us to expect a purposeful sample of 10 to 15 from the WooFridges Discord server. This sample will help our team manage the many interviews and corresponding data. We are using 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 is that it “May be challenging to locate information-rich participants.” (Gill, 2020); however, we plan on choosing more active volunteers to mitigate this. With volunteers active on Discord likely being more willing to participate in an interview.

Field Data Collection:

By collecting data on each fridge in the field, we can effectively benchmark how each refrigerator operates. Quantitative data on the performance of the fridges will help us understand the severity of the problem so that we can develop solutions that address the issue. Furthermore, this preliminary data is a resource, enabling us to compare the results of our future solutions. With this in mind, we will first observe the operation of the fridges and the problems they face. Then we

will take measurements of the internal and external temperatures of the fridges, as well as a record of when the refrigeration system is running. This data will help us understand why the fridges have difficulty maintaining their internal temperature and influence our interview questions for later in the project.Unfortunately, we expect low temperatures early in the project, so we will have fewer opportunities to get the best quantitative data. To counter this, we will corroborate our measurements with our data from interviewing volunteers.

Objective 2 - Obtain Insights from Experts

Our second objective is to reach out to people who have experience relevant to fridges for their insights and opinions. By this point, we will know what the issues are, but can still benefit from a better understanding of the reasons behind them. We also won't know much about existing solutions. We plan to find experts on refrigeration and weatherization. Then speaking with them about the issues we are dealing with, as well as reach out to the architect who designed the current enclosures. We will also look at other community fridge programs to see how they have dealt with inclement weather.

Data to collect

- Technical explanation of issues
- What kind of solutions exist

Semi-structured Interview:

We plan to interview two separate populations of professionals: academics who work with thermal systems and the designer of the current enclosures. For both of these groups, we will again use the semi-structured interview format from Beebe (2001). This method will be particularly useful to us, as it emphasizes inciting dialogue as opposed to subjects simply answering questions. This helps us obtain more comprehensive explanations than we would have gotten otherwise.

We will use purposeful sampling for both of these groups. For academic opinions, we will find professors from WPI (Worcester Polytechnic Institute) who teach about thermal systems. This is because we already have contact with them, and they are more likely to be familiar with the conditions. In terms of the architect, we have chosen to interview him because out of all of the volunteers, he has the most experience with the design of the enclosures.

In the interviews with the WPI professors, we plan to show the professors the data collected in objective 1 and ask them what they know about the precise cause of these issues. We will also ask

them if they have suggestions as to how we could weatherize the fridges, as they will likely have dealt with similar challenges in the past. A complete list of our questions can be found in Appendix A. The notes from these interviews will be used as a reference when developing and comparing solutions.

In our interview with the architect, we will be asking about the design and construction process for the fridge enclosures. Our goal in this is to understand what challenges exist in planning enclosures, and what has or hasn't worked in the past. Also inquiring if any measures have already been taken to weatherize the enclosures.

Case Study:

The issue of running a refrigerator outdoors is not new. Other community fridge programs around the world have addressed similar problems. Similarly, commercial solutions exist such as in vending machines and refrigerated lockers for food delivery. We will research the systems that these organizations employ to see what solutions are proven to be reliable and effective. Even if these designs are out of reach for this particular program, we may still be able to learn important lessons about what ideas work and what ideas do not.

Objective 3 - Observe the Maintenance of the Fridges

Our third objective is to closely observe the community around the fridges. WooFridges are kept running by a team of volunteers, whose needs and workflow must be accounted for in any potential solution we propose. If we don't intimately understand the organization, our solution could end up directly conflicting with the volunteers and be unsustainable. To that effect, we will talk with volunteers and participate as volunteers ourselves.

Data to collect

- Maintenance procedures
- Accessibility requirements for components
- Maintenance time (Minutes)
- Downtime due to maintenance (Minutes)

Participant Observation:

Understanding the needs and ideas of the volunteers maintaining the fridges is essential to ensure our solutions have longevity. According to Munck (1998), "[Participant Observation] is the

single best way to gain access to the backstage life of a society or group that you are interested in studying.”. Knowing the inner workings of the volunteer organization will unearth how the volunteers see the issues in the fridge's operation and how our solutions impact them. Munck (1998) also states that participant observation requires a significant time commitment to get good data, as it takes time to form relationships with the group. As such, we will allocate half of our team to this for the first four weeks of our project. Ian MacInerney and Zackary DiCelico will participate in the discord to find out when fridges are maintained, cleaned, or stocked and will show up to participate as often as possible. Alongside maintenance, they will develop a rapport with the volunteers at the heart of WooFridges and record logs of their interactions with volunteers. These logs will be formatted as described in Appendix B. They will also keep a contact tree of which volunteers they have met, and who introduced them so that we can better understand how the group is interconnected.

Upon completion of the four weeks, we will compile all of the notes from our time with the organization, and code our qualitative data. Looking into the challenges Woo Fridge volunteers face, building rapport is key to gathering the best qualitative data for thematic analysis, since it is well suited for pattern finding and is highly flexible in generating new insights.

Objective 4 - Test potential solutions

Our fourth objective is to test methods of weatherizing fridges. By this point, we will have many potential options. The next step will be to collect data on our ideas to see how they will affect the fridges, the people who use them, and the volunteers that work on them. We will find both quantitative and qualitative data to get a sense of how our different solutions compare.

Qualitative Data

- Volunteers’ thoughts on potential solutions
    - Concerns
    - Suggestions
    - Opinions

Quantitative Data

- Challenges to implementation
    - Cost
    - Installation difficulty
- Effectiveness

    - Insulative properties
    - Effect on the internal temperature
- Long-term sustainability

Semi-Structured Interviews:

Volunteer opinions are critical for the viability of potential solutions. To help mitigate the risk of the organization rejecting our solution, we will re-interviewing the same purposeful sample from objective 1. We assume the more active volunteers are also the ones who will implement and work with any solution.

These interviews will be semi-structured, as described in Beebe (2001), with recorded opinions and concerns. The semi-structured approach allows us to obtain more detailed responses and is more likely to give us unexpected insights. We plan to present each volunteer with two to three potential solutions and ask for their opinions and concerns. Our questions are detailed in Appendix A and are subject to change as the project progresses.

After our interviews, we will compile our logs and establish codes for positive opinions as well as concerns. These codes will allow us to find patterns in responses, which will tell us both how positively volunteers see solutions, as well as to find and potentially be able to address issues.

Field Research:

Our potential options will have prototypes to analyze their effectiveness via testing. Recording each solution's effectiveness through a series of tests ensures the proper response from the fridges to extreme temperature scenarios with our log template in Appendix C. These tests will seek to replicate conditions from our first objective, allowing us to compare how effective each solution is under the influence of the weather. We will also be exploring the methods of constructing each solution to optimize price and complexity, as well as to compare the installation difficulty of the different options.

Objective 5 - Propose a Solution to WooFridges

Our final objective is to take all of our data and use it to decide on and propose a singular solution. At this point, we will have a few potential solutions, data on how well they work, and the community's opinions on them. From here, we will use our data to narrow our pool of solutions down until we have an effective option for weatherizing the fridges. We expect to be able to come up

with a cost-effective weatherization plan that protects the fridges, does not significantly interfere with the operation of the fridges, and is achievable by the volunteer organization.

Cost-benefit Analysis:

As a final step to our project, we will do a cost-benefit analysis to determine the best solution for WooFridges based on our solutions and the data we have collected. To narrow down our options, we will compile all of our data into a singular document comparing each solution side by side to see which ideas are more viable than the others. The data will include the following: effectiveness, cost, the difficulty of installation, opinions of volunteers, and volunteers' concerns. While all the data will be important to consider, we believe that cost, opinions of volunteers, and effectiveness will be the most important. WooFridges has limited funding so any solution we propose needs to be able to be implemented with whatever money they have. This goes for the opinions of the volunteers as well. The solution we propose must be deemed favorable by the volunteers or it won't be used. Finally, we want to maximize the effectiveness of the designs within the other constraints. While we are analyzing the options and narrowing them down to our choice for the best option, we will share our compiled data and thoughts with our sponsor and collaboratively come to a final decision.

Potential Obstacles

The following is a list of potential obstacles that we may run into with regard to implementing solutions.

Budget constraints - WooFridges does not have an extensive budget, and no money is allocated to our project. We will need to design our tests in a way that is as inexpensive as possible

Size constraints - The enclosures for the fridges can be space limited, especially on Main Street. We will need to find solutions that can effectively operate and be maintained in small spaces

Time constraints - We may not have enough time to implement our solution, so we will need to find a way to make our solution easy to put in place with set instructions.

Maintenance - The fridges will need to be maintained. Any solution we come up with will need to not interfere with or greatly increase maintenance.

Project Deliverables

The following list details our expected deliverables for the end of the project.

- Implementation of weatherization solution on a fridge
- Guide to weatherization of future fridges
    - A step-by-step guide
- Maintenance manual
    - Covering regular maintenance as well as do’s and don’ts

Timeline

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Objective 1- Weather	Valerie Michael						
Objective 2- Expert insight	Team	Team	Team				
Objective 3- Maintenance	Ian and Zack	Ian and Zack	Ian and Zack				
Objective 4- Solutions			Team	Team	Team	Team	
Objective 5- Proposal					Team	Team	Team

Conclusion

At the end of our time with WooFridges, we intend to have presented a cost-effective and viable weatherization solution for the fridges. We will leave them with a detailed methodology to follow and conceivably will have carried out this methodology on an existing fridge. If we are successful, WooFridges will be a step further along in its mission to provide community-run aid to food-insecure people for years to come.

Appendices

Appendix A - Interview Questions

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

Interview with Woo Fridges' volunteers (Objective 1)

- Can you describe how the fridges are dealing with the weather?
  - Common issues
  - Common solutions

- Could you tell us about any issues you've had working with the fridges during extreme cold or heat?

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 refrigeration 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?

Interview with volunteers part 2 (Objective 4)

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

- Would our proposed solution cause any issues with the maintenance or usability of the fridges?

- Are there any changes you would make to our solution?
  - Concerns
  - Challenges

Appendix B - Participant Observation

We plan on logging and taking notes on each maintenance call for the fridges. Additionally, we will participate in maintenance as volunteers. The goal is to experience the organization and challenges associated with WooFridges. Accurately tracking data for objective 4 is essential making this template essential to our efforts.

Date	Name of Maintainer	Observations

Appendix C - Field Research

The following is the current data collection template required for objectives 1 and 4. Recording temperature and general notes on the fridges are essential to tracking the impact of weather and our solution on the fridges.

Date	External Temperature	Internal Temperature	Condition of Fridge

Appendix D -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 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 it's 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 an 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

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