The Setty Family Foundation:
2018 ASHRAE Applied Engineering Challenge

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1.0 Introduction

1.1 Executive Summary

December 2015, for the first time ever according the the UN Refugee Agency[1], the number of forcibly displaced families surpassed 60 million. This has been a growing trend over the last two decades, with diverse causes of inter-regional conflict, disease, and catastrophic environmental conditions. As the number of refugees continues to climb, it is critical to provide these displaced families with adequate sheltering, access to clean water, food, and other essential human needs.

Analyzing established refugee camps left our team desiring a stronger structural foundation that would resist difficult weather conditions and provide subsequent protection to refugees. We wanted to build a sturdy structure, but knew that we could not sacrifice transportability and living space to simply achieve resiliency. This led our team to choose a shipping container that has foldable walls to expand the usable size within. Using a ceiling that folded out allowed for great resistance to deformation under heavy loads while still sheltering refugees. This special fold out design also dramatically increased our living space and transportability. Our team desired a high level of creativity and sophistication for out structural design, and accomplished this through our folding shipping container.

Through careful research and analysis of multiple system options, our team decided upon three unprovided essential systems that needed to be included. These systems were water management, waste management, and HVAC systems. These three systems were deemed critical to day-to-day life for refugees and an important part of our shelter. Concept selection charts were created in order to allow the group to compare and contrast the benefits of multiple systems. By deciding upon a polyethylene potable water storage tank with a foot pump and sink for water management the issues of potable water storage and usage were dealt with. For waste management, using the company PeePoo's biodegradable would help to keep the refugee camp clean while creating nutrient rich fertilizer for future crop growth. Finally, a mini split with dehumidifiers solved our HVAC issues of not only cooling, but the most substantial problem of heating in a colder, wetter climate. Our team successfully addressed the pressing issues of system management while still allowing 17.93 m^2 (193.0 ft^2) of livable space inside the shelter..

As the problem and number of forcibly displaced families continues to increase, it will take a large effort in order to provide adequate shelter for the resilient individuals subjected to refugee circumstances. Our design team hopes to provide a stepping stone into future affordable, sustainable housing for disaster relief solutions.

1.2 Project Focal Purpose

Before discussing structural and operational aspects of the shelter, the four different classification terms for disaster sheltering and housing should be clarified; Emergency Sheltering, Temporary Sheltering, Temporary Housing, and Permanent Housing. Emergency Sheltering permits the least planning and has the shortest time duration. Emergency Sheltering is when potential disaster victims are threatened by situational factors that influences them to seek and occupy shelter in a public, or quasi public, structures that may be unacceptable under other circumstances. Due to the short time duration of Emergency Sheltering, there usually is no need for supervisory personnel, meal arrangements, or

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[1] "UNHCR - Figures at a Glance." http://www.unhcr.org/figures-at-a-glance.html. Accessed 29 May. 2018.

emergency medical considerations. Temporary Sheltering encompases the temporary occupation of living quarters outside of the victim's pre-disaster housing arrangement after the emergency period. Temporary Sheltering often requires communal planning, physical shelter arrangements, meal arrangement, and are typically operated on a communal scale. Temporary Housing involves the reestablishment of household routines with the understanding that a more permanent dwelling will be obtained. Temporary Housing is operated on a household basis and is an arrangement similar to pre-disaster housing with temporary occupational characteristics. Permanent Housing is the most similar classification and greatest attempt to reestablish the pre-disaster housing arrangement. The original pre-disaster dwelling may not be obtainable, but Permanent Housing attempts to re-establish the same characteristics and circumstances of the pre-disaster housing.[2]

The design team decided to create a sheltering solution that is a hybrid between Temporary Shelter and Temporary Housing. The shelter is to be designed for rapid deployment and scalable, similar to a Temporary Shelter, and also functional for daily domestics tasks, similar to Temporary Housing. This document will still reference the shelter solution as a temporary shelter design and not a temporary housing design.

Designing disaster relief solutions involve many considerations and circumstances that may require pre-established infrastructure in order for a single design to be employed effectively. Some considerations and circumstances may not be explicitly defined and may be influenced by local municipalities, political views, religious perspectives, and allocated fiscal budgets for disaster relief. Therefore, our design team will focus our efforts to be limited to the physical shelter design and operations, neglecting preliminary infrastructure and implementation. The primary project components that were identified to be the most critical are the structural design, HVAC design, water management system, waste management system, and the overall sustainability of the shelter.

1.3 Conclusion

This report will detail the design process and final product of a temporary refugee shelter. This shelter will provide for the needs of a family of refugees in an Eastern European Location. We will define the needs of a refugee family, and discuss the underlying assumptions and constraints of the design. We will identify the key design choices and provide details into the design process that brought us to our final decisions. Finally we will detail the finished design for the shelter, and report the results of numerical prototype testing. This report will provide all necessary background and quantitative analysis to understand not only the capabilities of the final design, but also the underlying decisions and assumptions that led the team to the finished product.

[2] "University of Delaware Disaster Research Center PRELIMINARY ...." http://dspace.udel.edu/bitstream/handle/19716/542/PP170.pdf?sequence=3&isAllowed=y. Accessed 25 Apr. 2018.

2.0 Context

2.1 Problem Statement

Families who have been displaced require a temporary shelter solution that is sustainable, scalable, and affordable. The shelter should comply with ASHRAE standards 55 and 62, be tough enough to be portable, utilize resilient materials, have a creative use of space, and have sustainable aspects. The shelter design should be accommodating, as well as provide the necessary domestic systems for a family of 6-8 people who have been displaced in Eastern Europe. In this report, we will define essential domestic systems as waste management and disposal, security, potable water, and reliable power. The footprint of the shelter needs to be less than or equal to $24\ m^2\ (260\ ft^2)$ with a maximum height of $2.6\ m\ (8.5\ ft)$. Power connections are limited to 220V/1ph 15 amps, and the shelter will have no access to municipal water or sewage. Other indirect needs are estimates for deployment feasibility, ease of set up, capital cost, manufacturing cost, maintenance cost, and energy consumption.[3]

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[3] "Applied-Engineering-Challenge - ASHRAE." https://www.ashrae.org/communities/student-zone/competitions/applied-engineering-challenge. Accessed 1 June. 2018.

3.0 Design Specifications

3.1. Overview of Specifications

To begin our analysis process, our team defined a list of specifications that we desired to achieve for our shelter. Some of them were broader specifications that included integrated essential systems, sustainable systems, and even solution creativity. These were countered with concrete goals in energy consumption, sleeping capacity, and heating/cooling loads. This mix of broad, big picture goals contrasted nicely with finely tuned specifications, and helped our team to keep flexibility throughout the design process. Our team broke down the specifications into five different systems: structural, HVAC design, water management, and waste management.

3.2. Shelter Structural Specifications

The structure of the shelter is to be comprised of a recycled shipping container retrofitted to provide the portability, durability, and fundamental foundation for all the encompassed amenities and domestic systems. The designed shelter will utilize a specialized 10 foot shipping container that is typically used for domestic logistics. Shipping containers are manufactured with Corten steel, which has similar material properties to that of AISI 1020 steel only with weathering properties. Maximizing the available occupiable space within the container will be accomplished by allowing the longer two sides of the container to unfold. With the two sides unfolded, the exterior walls and ceiling can then be erected from the main foundation of the container. This configuration allows for minimal space to be used when the shelter is stored, while maximizing living space when occupied. Figure 1 demonstrates the necessary steps to unfold the additional occupiable spaces. When completely unfolded, the shelter has an estimated $17.93\ m^2$ ($193.0\ ft^2$) of occupiable space and $19.32\ m^2$ ($208.0\ ft^2$) of total area used; well within our sizing constraints.

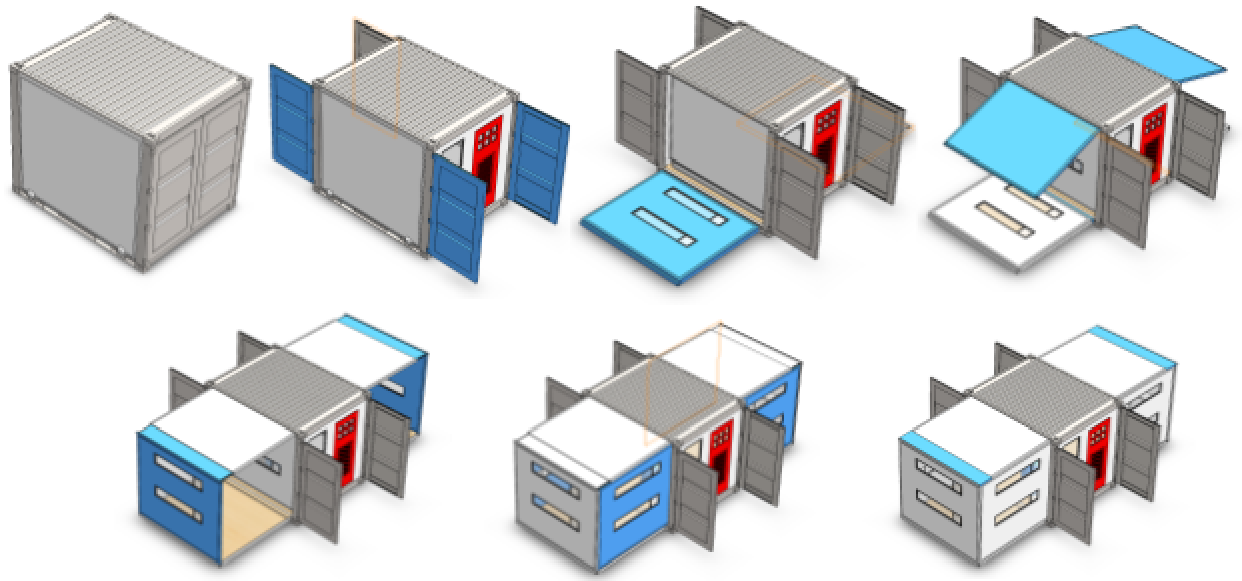

Figure 1. Unfolding shelter steps. This figure shows, in order, the steps necessary to properly unfold the shelter from the container foundation. Open container doors, lower cantilever floors by hand crank, ajar ceiling panel and insert floor gap panels, unfold far-wall panels while simultaneously connecting to ceiling panel, pull-out four side wall panel, and lastly install ceiling clip-ons. Additionally ensure that all panels are properly connected integrated frame locks.

The folding panels that comprise of the cantilever floor, extended walls, and ceiling are to have solid structural supports. The structural supports of the panels will ideally be constructed of 6000 series T6 aluminium extruded tubing with 4000-5000 series aluminum as structural filler where needed. The floor cantilever is to be constructed of 3”X1.5” perimeter rectangular tubing with 1” square tubing for cross supports. All other panels are to be constructed of 2” perimeter square tubing with 1” square cross supports. The floor cantilever panel is to have a 5/16 inch stainless steel cable that connects the far end corners of the panel to the steel shipping container foundational structure. The stainless steel cable is the primary support for the floor cantilever and is to have a crank for ease of lowering and folding the floor panel by a mechanical crank. The ceiling panel will have an assisted gas support for ease of mobility. All panels are to have a shaft and pin based hinges. To avoid premature corrosion between Corten steel and aluminum parts, stainless steel bushing a pins will be utilized.

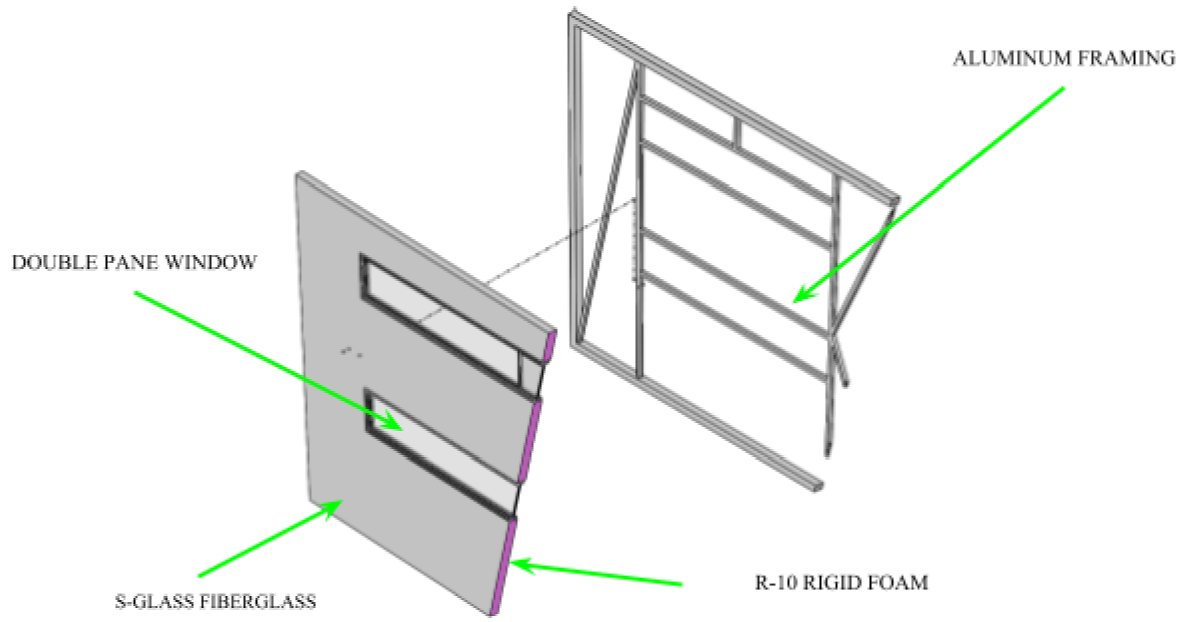

Figure 2. Example of side wall panel composition; other panels have similar composition. This image is of an exploded and sectional cut through components comprised of the panel.

The panels are then to be insulated with rigid foam board that has an effective R-value of R-10.0. The exterior of the panels is made of S-Glass fiberglass with Fibre Glast's 2000 epoxy resin. These materials were selected for strength, and durability. Other materials that were considered were aluminum siding, and carbon fiber. The aluminum siding was not chosen as it damages easily. Carbon fiber was almost twice the price of S-glass. The panel skins are to be approximately 1/8 inch thick. By having the panels 1/8 inch thick the walls will be very strong and be able to withstand environmental conditions. The thickness was also chosen to help keep the weight of the structure to a minimum.

3.3. Heating and Cooling Design Specifications

The heating and cooling for the shelter was calculated considering many factors. The climate where the shelter will be located was specified to be an eastern european location. With this information, Warsaw, Poland weather data was chosen for calculations due to the similarity of climate conditions to other eastern european locations. The climate data showed conditions of extreme dry bulb temperature conditions between -16C with a 86% relative humidity, and in the summer 27C with a relative humidity of 68%.[4] The 240 ft^2 housing will have six to eight occupants. The shelter was assumed to have 1 inch of spray foam insulation along the walls. The worst case scenario for the maximum heating and cooling load for the shelter were calculated. The factors that contributed to these calculation was the human metabolic heat rate, the heat conduction through the walls, roof, two windows, and skylight of the shelter. The heating load did not account for any human metabolic heating, but the summer cooling load does include metabolic rates in the calculation. After analysis, the winter heating and summer cooling loads

[4] "Design conditions for WARSAW/OKECIE, Poland - Ashrae." http://cms.ashrae.biz/weatherdata/STATIONS/123750_s.pdf. Accessed 28 Apr. 2018.

were found to be 2,143 Btu/hour, and 3996 Btu/hour respectively. The HVAC system must be able to produce the heating and cooling power requirements calculated for the shelter.

3.4. Water Management Specifications

After completing research into different refugee organizations, the assumptions for our water management system were made based on United Nations High Commissioner of Refugees (UNHCR) camp planning standards[5]. These standards included a water tap located within walking distance of every shelter, with a maximum distance of 250 m, with clean water being provided at each tap. This led the group to assume that water would have to be transported individually by buckets or similar containers, which would then need to be stored. Through some water consumption analysis, the concept selection chart would focus on tanks that were between 100 and 400 gallons. This would be enough water for a couple of days for six to eight people according to the UNHCR emergency camp standard of four gallons per person per day[6]. While we acknowledge that keeping this container filled would not necessarily be feasible on a day to day basis, this would allow water to be stored at a reasonable rate at a minimum space cost.

The other main assumption that was made consisted of access to water via pump to allow for water usage after using the bathroom or other similar situations. This would help prevent contamination of drinking water along with increasing ease of access compared to gravity-based flow out of the tank. These two specifications helped the group narrow down their options, and create an effective concept selection chart.

3.5. Waste Management Specifications

The waste management system had many factors that needed to be considered in the design. With the potential for thousands of shelters in one area for an extended period of time, the shelter's waste management system needed to be sustainable, long lasting, efficient, and above all, sanitary. We made assumptions that there would be no communal bathroom facility, or communal waste disposal site. Under these assumptions, the waste management system would need to be completely self contained throughout the entire disposal process. In addition, the system would have to be robust enough to handle the waste generated by up to 8 adults. The average human excretes 100 to 250 grams of fecal waste per day.[7] With 8 people, our system needed to be able to handle 800 to 2000 grams of waste per day. Finally, the system would need to be flexible enough to be used by people from a variety of cultures as there is no way to plan for everything, In summation, the waste management system needed to be sanitary, self contained, be able to handle up to 2000 grams of waste per day, and be flexible to handle different customs and practices[8]. These specifications were used in the concept selection process to generate metrics against which the different waste management options were compared.

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[5] *UNHCR|Emergency Handbook*, emergency.unhcr.org/entry/45582/camp-planning-standards-planned-settlements. Accessed 28 Apr. 2018.

[6] "Emergency water standard - UNHCR|Emergency Handbook." https://emergency.unhcr.org/entry/115974/emergency-water-standard. Accessed 1 June. 2018.

[7] Britannica, The Editors of Encyclopaedia. "Feces." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., 8 Jan. 2015, www.britannica.com/science/feces.

[8] The Editors of Encyclopædia Britannica. "Feces." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., 8 Jan. 2015, www.britannica.com/science/feces. Accessed 28 Apr. 2018.

4.0 Design Development

4.1. Design Assumptions

Before starting the design process, we made multiple assumptions about infrastructure, climate, and logistics. Firstly, we considered the infrastructure required for a successful refugee camp. Using the UNHCR Emergency Handbook[9] as a guide, we created a set of infrastructure assumptions that we would design our shelter under. These assumptions are as follows:

- Water Supply: We assume that no less than 20 liters of potable water per person per day should be supplied to any planned refugee camp. There should be one water tap stand per 80 persons, and no tap should be more than 200 meters from the households it serves.

- Trash disposal: We assume that here is one 100-liter rubbish container per 50 persons, and one 2mx5mx2m refuse pit per 500 persons. Garbage is collected at least twice a week from rubbish containers.

- Power Supply: We assume that a 220V 15 amp/1ph electrical power supply is available for use at every household. This assumption is vital for our shelter to perform its critical functions. In order to run the lighting and HVAC system, each shelter will need to be connected to a reliable power supply. While many early stage refugee camps could not be expected to have power supplied to every household, late stage, permanent housing units can be expected to have power readily available. This infrastructure would need to be installed and operating before the camp is fully set up.

- Food Assistance: We assume that emergency food assistance is provided via a distribution center that is no less than 10 kilometers from the households it serves. The food provided meets regular nutritional requirements to sustain a healthy diet.

The UNHCR Emergency Handbook sets the global standard for humanitarian emergency response procedures. It is used the world over to effectively coordinate long-term solutions to humanitarian crises. It is currently in use in 20 active situations around the world, including Syria and Southern Europe. We felt that these standards, which represent years of real world data, research and on-the-ground experience by the UNHCR were more than sufficient to begin designing our shelter under.

Secondly, we made assumptions about the climate in which the shelter would be used. Eastern Europe comprises a vast area of the world, and the climate can vary greatly depending on location. Before we started designing anything, we wanted to have rough estimates of temperature ranges and precipitation amounts. To accomplish this, we used the Köppen Climate Classification System.[10] The Köppen Climate Classification System is the most widely used system for classifying and quantifying the world's climates.

[9] "Camp Planning Standards." *UNHC Emergency Handbook*, UNHCR, https://emergency.unhcr.org/entry/115940/camp-planning-standards-planned-settlements.

[10] "The Köppen Climate Classification System | Resources." *ISC-Audubon*, www.thesustainabilitycouncil.org/resources/the-koppen-climate-classification-system/.

Using this system, we decided to design our structure under the climate classification Dfb as shown in Figure 3 below. Dfb is classified to be cold, without a dry season, have a warm- summer, and be a humid continental climate condition. This means that the area's warmest month must have a mean temperature that is above 50 degrees Fahrenheit, and its coldest month must have a mean temperature of below 27 degrees Fahrenheit. In addition, a Dfb climate receives regular precipitation throughout the year. This climate classification was used because it covered the largest area of Eastern Europe, and so allowed us to design a shelter that could be used in the highest possible number of eastern European locations.

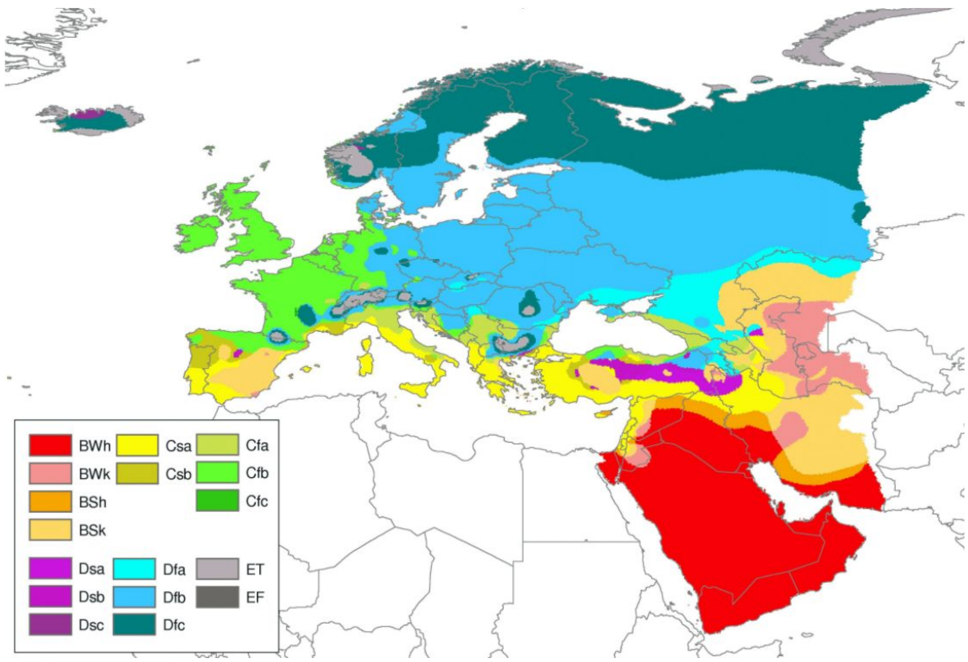


Figure 3. Köppen Climate Classification System Map for Eastern Europe

Lastly, we assumed that the infrastructure, logistics and necessary vehicles were all intact and available to transport our shelter to the refugee camp location. We assume that if the refugee situation is to the stage that it requires long term, sustainable housing, then it is also to the stage that large vehicles can access the camp location to drop off our shelters. We also assume that the human power and expertise exists in the camp to construct the shelters before the refugees arrive.

4.2. Theoretical Analysis and Calculations

The shipping container model was subjected to typical loading conditions present in logistic transportation methods. These typical loading conditions occur on the corner stacks of the shipping container, where each container connects to another. The bottom of the container was defined to be fixed as if attached to another container, or simply placed on a flat surface. The top of the container was then defined to have a static force that would represent additional containers stacked on top of the modeled container. The static force was then increase incrementally until yielding became present in critical structural elements; discussed in the next section 4.3. The material for this structural selection is to be modeled using AISI 1020 steel, which has the closest material properties to that of the physical Corten steel typically used to construct shipping containers.

The cantilever floor model was subjected to the worst case loading scenario. With an applied force of $10,676\ N$ $(2,400\ lbf)$ applied to the cross-supports. This load represents the maximum occupant weight who would occupy the interior space at a single time. On top of the occupant load, another load was applied to the parameter of the cantilever to model the transferred snow load. The snow load modeled is $4,448\ N$ $(1,000\ lbf)$, which is equivalent to about $1\ m$ thick of freshly fallen wet snow onto the shelter. The hinge was treated as a fixed hinge and the cable supports were treated as fixed; ideally the cables would be fixed to the shipping container structure and the far end corners of the cantilevered panel. The cantilever floor frame will be modeled using 6063-T6 aluminum. This aluminum is typically used for extruded tube applications.

Fixture name	Fixture Image	Fixture Details
Fixed Hinge		Entities: 2 face(s) Type: Fixed Hinge

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	4.62381	8238.45	15640.6	17677.7
Reaction Moment(N.m)	0	0	0	0

Fixture name	Fixture Image	Fixture Details
Fixed		Entities: 2 face(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-3.36619	16665.3	-15640.9	22855.4
Reaction Moment(N.m)	0	0	0	0

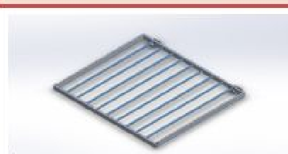
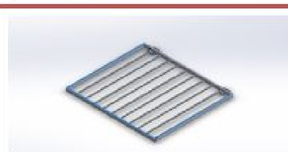
Load name	Load Image	Load Details
Force-Occupants		Entities: 9 face(s) Type: Apply normal force Value: 2400 lbf
Force-Snow		Entities: 3 face(s) Type: Apply normal force Value: 1000 lbf

Figure 4. Floor Cantilever Boundary Conditions. Fixed elements are defined in the green table and applied loads are defined in the red table. The y-axis is perpendicular to the cross supports, z-axis is orthogonal to the panel hinges, and the x-axis is parallel to the panel hinges.

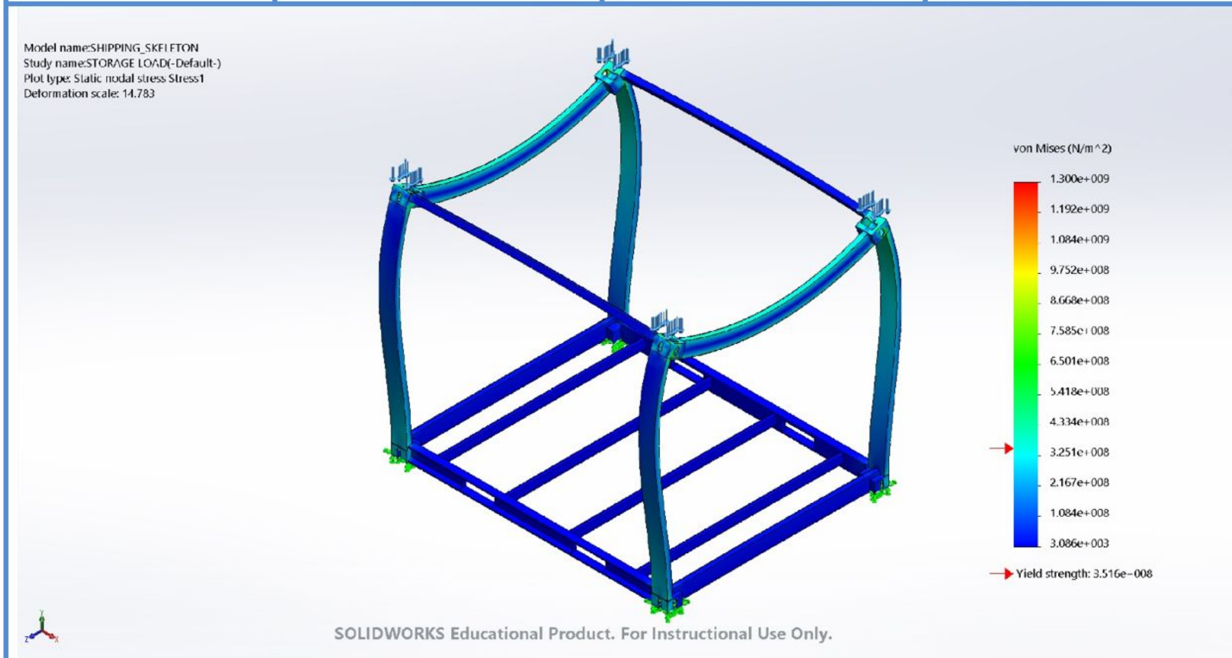
ASHRAE standard 55 is used to specify combinations of indoor thermal comfort environmental factors and personal factors which will allow for most occupants in a space to feel comfortable. The factors that influence thermal comfort in a space include temperature, thermal radiation, humidity, air speed, human activity, and clothing. The inputs we used for standard 55 included a dry bulb temperature of 20 C, relative humidity of 40%, airspeed traveling at .54 m/s, metabolic rate for walking around at 1.7 met, and clothing level similar to wearing sweatpants and a long sleeve shirt at .74 clo. All of these factors were used to calculate a solution which can be located on the psychrometric chart shown in Figure 9. The allowable area for human thermal comfort is shaded on the chart and the location for our indoor environmental conditions, the red dot, is positioned in the middle of the acceptable comfort area. These indoor environmental conditions and human assumptions successfully passes the ASHRAE standard 55.

ASHRAE standard 62 is used to specify acceptable indoor ventilation and air quality for residential buildings. It requires that for a space smaller than 500 square feet that there be a minimum of 50 CFM(cubic feet per minute) of airflow. For a total CFM calculation ASHRAE uses the equation $CFM\ Total\ =\ 0.03(Floor\ Area)\ +\ 7.5\ (Number\ of\ Occupants)$. Using this formula we would need $66\ CFM$. To determine out how much mechanical air flow we need to provide using a fan, we take this number and subtract the amount of air that naturally leaks. To calculate the amount of air that leaks ASHRAE recommends performing a blower door test on the actual structure. Since we don't have a physical structure to perform this test, the other method is to estimate that you have $2\ CFM$ per $100\,ft^2$ of natural ventilation from air leaks. This gives us a value of $62.4\ CFM$ .. So the total CFM that is required for a ventilation fan is $62\ CFM$.

4.3. Theoretical and Experimental Test Results

The structure of the Shipping Container began to experience yielding when a massive load of $2.16\ MN\ (498,190\ lbf)$ was applied to the corner stacks of the shipping container. To put the load into perspective, $2.16\ MN$ is equivalent to about 20 fully cargoed 10 foot shipping containers stacked onto a single 10 foot shipping container. The yielding locations of the shipping container structure are displayed in Figure 5. Typically shipping containers are not stacked any higher than 9 containers to avoid tipping of the container stack.

Name	Type	Min	Max
Stress Analysis	VON: von Mises Stress	3.086e+003N/m^2 Node: 41081	1.300e+009N/m^2 Node: 71179

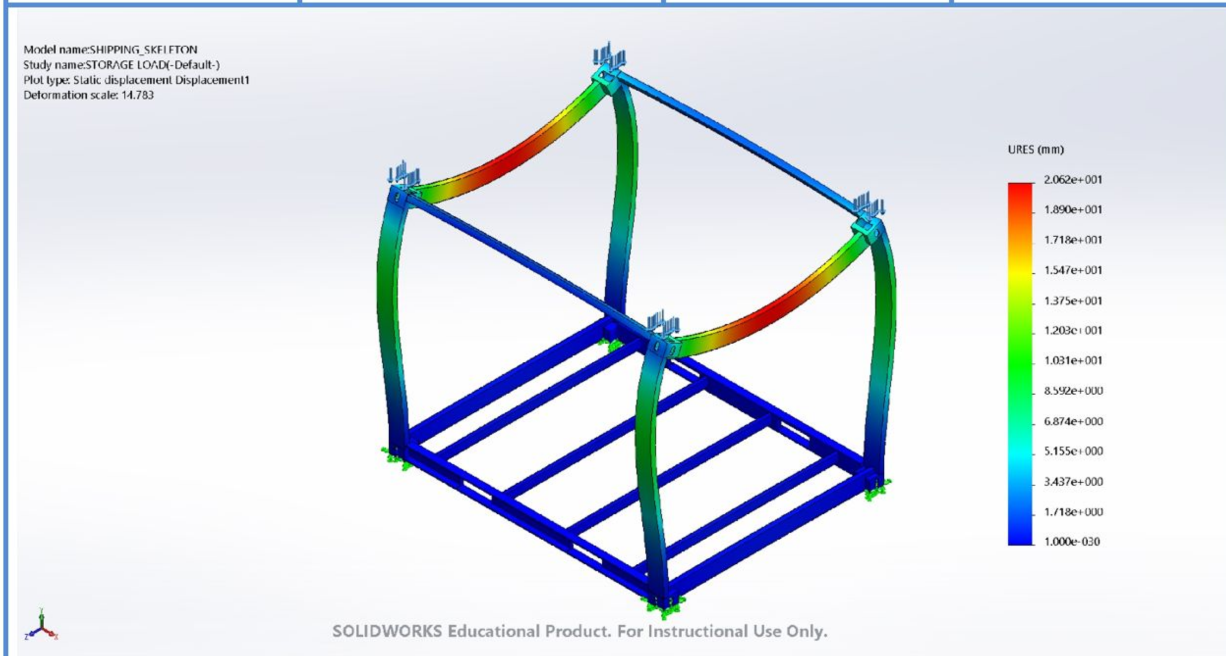


SHIPPING_SKELETON-STORAGE LOAD-Stress-Stress

Figure 5. Shipping Container structural Stress Analysis. Notice yielding only occurs in the corner stacks and the header on the containers structure.

Other considerations when loading the shipping container structure under extreme conditions, is to ensure that the enclosed folding panels won't be damaged under extreme loading. Figure 6 illustrates that the maximum displacement is 21 mm (0.83 in) and only occurs in the header support of the shipping container. With these results, it can be derived that the enclosed folding panels won't be damaged under extreme loading conditions. As maximum displacement occurs on the front and rear faces of the container and not on the two side faces, where the folding panels are.

Name	Type	Min	Max
Displacement Analysis	URES: Resultant Displacement	0.000e+000mm Node: 1158	2.062e+001mm Node: 28779

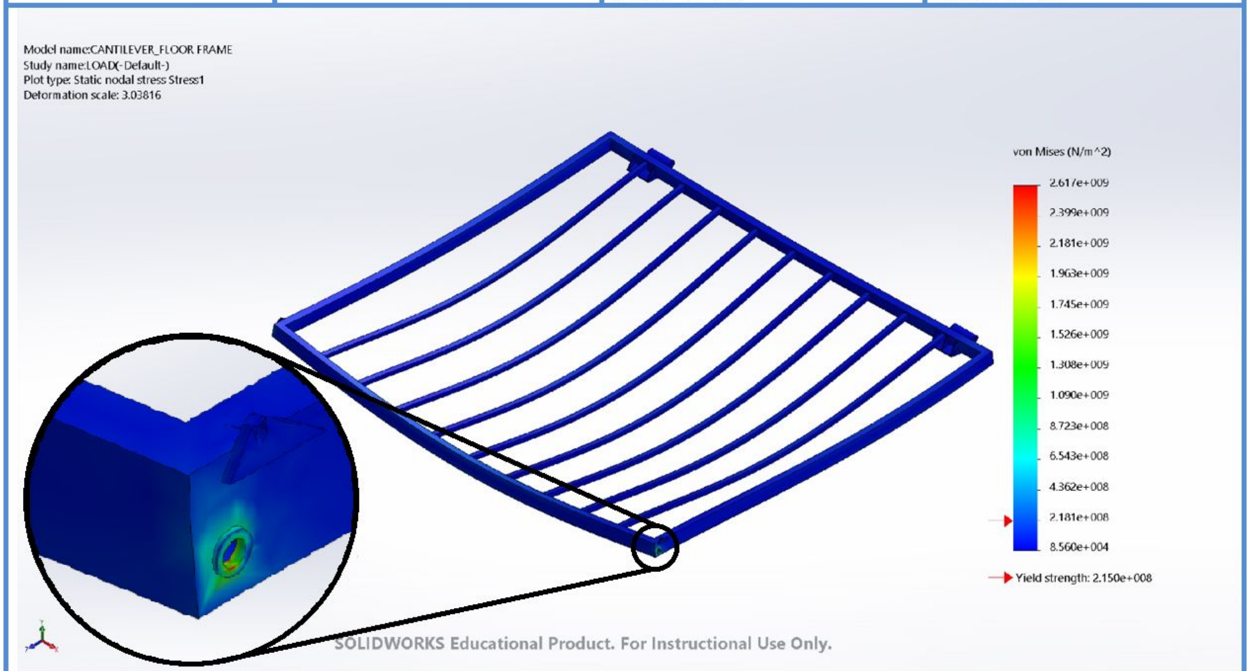


SHIPPING_SKELETON-STORAGE LOAD-Displacement-Displacement

Figure 6. Displacement Analysis of Shipping Container structure. The maximum displacement occurs in the header of the container, about 21 mm (0.83 in) of displacement; $2.16\ MN$ ($498,190\ lbf$) applied load.

The cantilever floor analytical loading analysis gave the team insight on where the most yielding occurs in the current design. In Figure 7, it is observed that the weakest area in the floor panel frame occurs around the corner support for the cantilever cables. The analytical model actually suggest that the cable supports on the floor panel will fail under the extreme loading conditions. This analysis proves that the design of the floor panels corner support framing should be reconsidered. Everywhere else on the floor framing proved to provide the desired framing performance.

Name	Type	Min	Max
Stress Analysis	VON: von Mises Stress	8.560e+004N/m^2 Node: 20468	2.617e+009N/m^2 Node: 37431



CANTILEVER_FLOOR FRAME-LOAD-Stress-Stress

Figure 7. Cantilever Floor Stress Analysis with close-up of corner cable supports. The corner cable supports are the only elements of the cantilever floor to display large von Mises stress. All other elements are well below the yielding point of the 6000 series T6 aluminum extruded framing.

The largest displacement observed from the analytical loading conditions of the cantilever floor is about 90 *mm* (3.54 *in*) . This displacement may be large but, to reiterate this occurs under the most extreme loading condition. Even under this loading condition the occupants will only notice a slight slope in the floor and possibly less retention in the floor; assuming the cable supports don’t completely fail before. The maximum displacement also allows the design team to extrapolate that the center of the cantilever may just rest on the ground under extreme loading conditions.

Name	Type	Min	Max
Displacement Analysis	URES: Resultant Displacement	0.000e+000mm Node: 15	8.747e+001mm Node: 20061

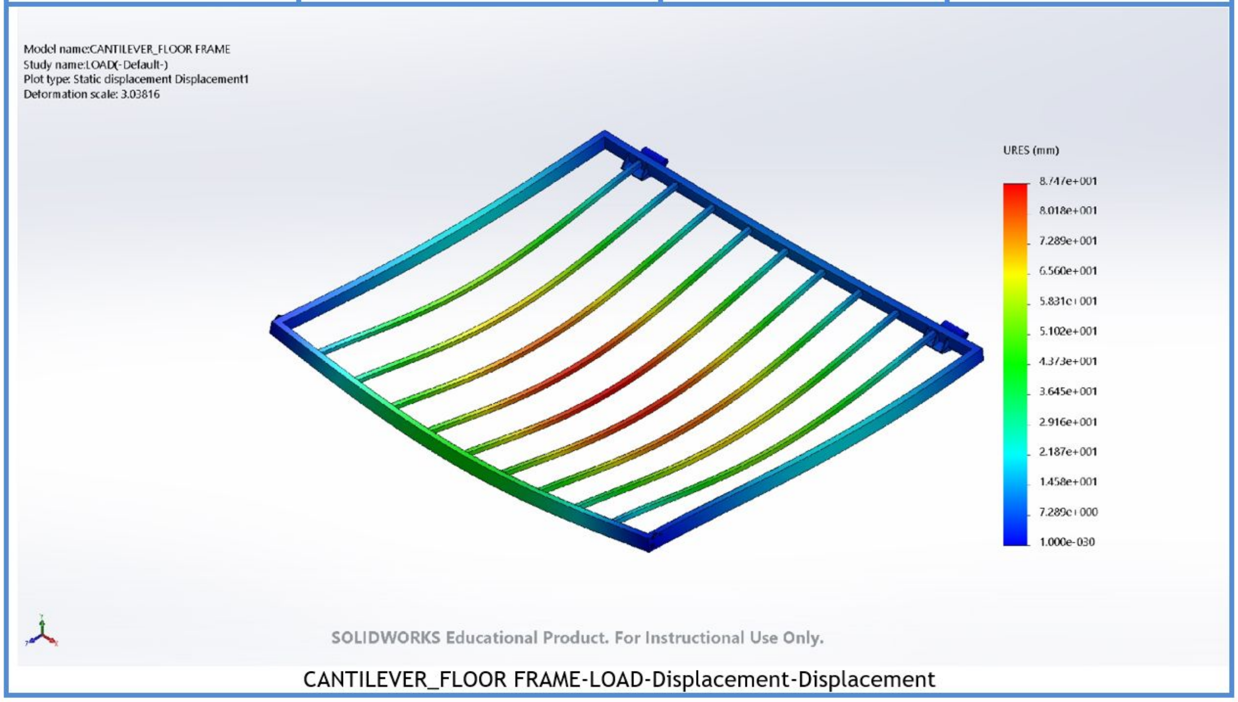


Figure 8. Cantilever Floor Displacement Analysis. Image show that the maximum displacement with the defined loading conditions in section 5.6 is about 90 mm (3.54 in).

The shelter must be able to provide systems that are compliant with ASHRAE Standards 55 and 62. We are designing for thermal loading in climate zone Dfb. Since Dfb is a colder, dry climate, cooling is not a necessary as heating, and truly only in the wintertime. As a result, while it is important to have good heating, since cooling is not required, and even heat may not be required for most of the year.

The heating and cooling for the shelter was calculated considering many factors. The climate where the shelter will be located was specified to be an eastern european location. With this information, Warsaw, Poland weather data was chosen for calculations due to the similarity of climate conditions to other eastern european locations. The climate data showed conditions of extreme dry bulb temperature conditions between -16C with a 86% relative humidity, and in the summer 27C with a relative humidity of 68%.[11] The shelter was assumed to have 1 inch of spray foam insulation along the walls. The worst case scenario for the maximum heating and cooling load for the shelter were calculated. The factors that contributed to these calculation was the human metabolic heat rate, the heat conduction through the walls, roof, two windows, and skylight of the shelter. The heating load did not account for any human metabolic heating, but the summer cooling load does include metabolic rates in the calculation. The results show the winter heating and summer cooling loads are 2,143 Btu/hour, and 3996 Btu/hour respectively. The HVAC system must be able to produce the heating and cooling power requirements calculated for the shelter.

[11] "Design conditions for WARSAW/OKECIE, Poland - Ashrae." http://cms.ashrae.biz/weatherdata/STATIONS/123750_s.pdf. Accessed 28 Apr. 2018.

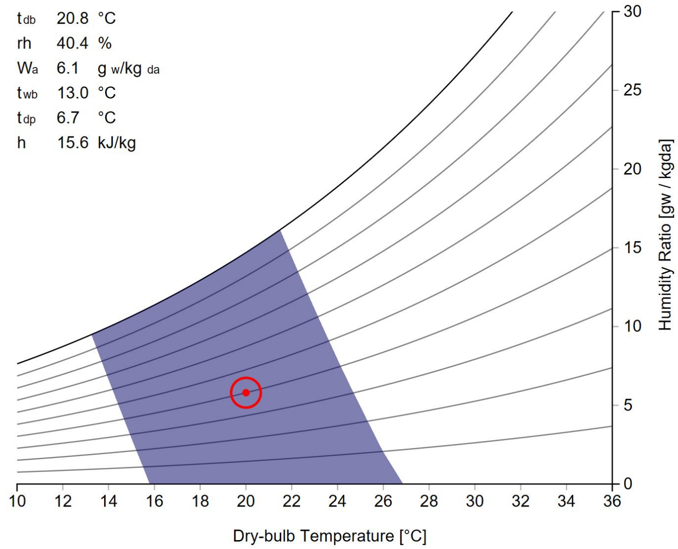


Figure 9. Psychrometric Chart for ASHRAE Standard 55. The red dot is the shelter conditions on the psychrometric chart based on current metrics and assumptions, which is within the the purple confines of ASHRAE comfort standards.

4.4. Performance and Compliance

The shipping container foundation is capable of withstanding any typical logistic conditions without causing any damage to the encompassed shelter elements. Considering that we are using multiple folding parts, this was a critical result that ensures our shelter complies with the desired loading performance demand. The cantilever floor panel proved to fail in the cable supports under extreme conditions, and these should be redesigned such that the high concentration of stress is not squarely on the joint. All other aspects of the cantilever floor provided the desired loading performance.

The HVAC system's sustainability was based on energy efficiency, type of energy source, maintenance, and life expectancy. The HVAC heat pump mini-split was chosen for its high energy efficiency, electrical energy input, relatively low maintenance, and 12-15 year life expectancy. The heat pump mini-split combines heating and cooling for the shelter into one unit. The Eva-dry E-500 unit was selected for dehumidification of the shelter due to the continuously humid climate. This option was sustainable because it is environmentally safe, refills are not required, only occasionally uses electrical power for drying, and has a 10 year life span. The dehumidifier will work in conjunction with the mini split to ensure that comfortable humidity level is achieved.

For our HVAC calculations, our analysis has determined that our shelter passes both ASHRAE Standards 55 and 62. For the indoor environmental conditions and human assumptions listed in Section 4.2, the shelter successfully passes the ASHRAE standard 55. In order to fully test ASHRAE standard 55, a tool[12] developed by the University of California Berkeley was used with the inputs for the program being the parameters previously defined in the Section 4.2. This is illustrated in Figure 9, as the allowable area for human thermal comfort is shaded on the chart and the location for our indoor environmental

[12] "CBE Thermal Comfort Tool." http://comfort.cbe.berkeley.edu/. Accessed 28 Apr. 2018.

conditions, the red dot, is positioned in the middle of the acceptable comfort area. Furthermore, our calculations for the ventilation required for ASHRAE Standard 62 show that 62.4 CFM will be required to properly ventilate the space. Our ventilation systems can operate at 65 CFM, which complies with the projected necessary CFM and ensures that both ASHRAE Standards are met for our shelter.

5.0 Ancillary Analysis

5.1. Budget

The budget for our temporary shelter can be broken down into five groups, Structural, HVAC, Electrical, Water storage, and Waste Management. Each group is composed of the items needed to construct that part of the shelter. The bill of materials is listed in Table 1 with the quantity needed as well as the price.

Material	Qty.	Cost per	Total
Structural			
Shipping Container	1	$1500-$200	$1500-$2000
6061 T6 square aluminum tubing 2”x2”x8’ 3/16” thick	28	$62.33	$1745.24
Insulation 2”x4’x8’ R10 foam board	864 sq ft 27 sheets	$29.00	$783.00
Windows dual pane	12	$69.50	$834.00
Fiberglass S-glass/2000	512 sq ft 1/8” thick 4435 lb	$3 per lb including labor	$13,305.00
Interior Paneling plastic panel 4x8	664 sq ft 21 sheets	$23.88	$501.48
7/16”x4’x8’ OSB for subfloor	200 sq ft 7 sheets	$17.56	$122.92
Vinyl Flooring	200 sq ft	$1.30 sq ft	$260
Exterior Door 36”x80” prehung steel	1	$134.00	$134.00
Interior Door 24”x80”	1	$59.98	$59.98
Winch assembly	Round Stock, Sprockets, Roller Chain, Cable, Crank Handle, Bearing Blocks		$250.00

HVAC			
LG 12,000 BTU 17 SEER Ductless Heat Pump Air Conditioner Condenser	1	$577.00	$577.00
LG - 7k BTU - Ceiling Cassette with Grille	1	$472.15	$472.15
Misc. installation parts	Thermostat Mini split lines Filter Drain tubing Electrical		$350.00
Lunos e^2 HRV Set of 4	1	$2059.00	$2059.00
Dual rocker Switch	1	$14.75	$14.75
Water and Waste Management			
100 Gallon water tank	1	$152.99	$152.99
Foot pump	2	$20.99	$41.98
Kitchen sink	1	$272.99	$272.99
Bathroom sink	1	$51.72	$51.72
Grey Water Storage tank	1	$30.00	$30.00
PeePoo bags	1600	$0.50/person/month for 8 people	$48.00 per year
Pipe	10 ft	$1.18/ft	$11.80
Electrical			
Wire	50 ft	$0.85/ft	$42.50
Electrical panel with circuit breakers	1	$118.88	$118.88
Outlets	2	$1.50	$3.00

Light Switch	1	$1.10	$1.10
LED Can Lights	2	$23.99	$47.98
			Total $23,638.47

Table 1. Bill of Materials with quantity needed as well as cost.

Currently the designed temporary shelter material costs sum to $23,638.47, the design team has projected that the end cost of the temporary shelter will be roughly $27,000; depending on the location of manufacturing and necessary shelter logistics. This projection also neglect the cost of labor to manufacture and probable economic inflation of the utilized materials, and needs further considerations.

Utilizing available fiscal considerations, it was found that countries will spend between $1,054-$12,800 on single refugee per year; depending on which country the refugee originates from. We are assuming that 50% of the cost will be contributed to sheltering a single individual, multiplied by 8 people we have a shelter budget between $4,216-$51,200 a year. This projection would mean it would take between 6 months-2.5 years for the shelter to become cost effective for a family of 8 people. Our specific shelter design would last approximately 20 years with minimal maintenance reoccurring approximately every 2 years.

5.2 Sustainability Analysis

The design of the shelter's sustainability is an integral part of the project. For multiple systems sustainability is incorporated into the concept selection chart to quantitatively choose the best system. The systems include the shelter structure, HVAC, waste management, water management, and electrical. The sustainability of the shelter structure was based on environmentally friendly materials, longevity, and reusability. Using these criteria, a recycled foldable shipping container was selected. Repurposing out of service shipping containers are the target to avoid the shipping containers going into the waste stream and the trash. This method allows the material and energy used to manufacture the container to be reutilized. The steel frame allows for a long lifetime and capability for reuseal.

The HVAC system's sustainability was based on energy efficiency, type of energy source, maintenance, and life expectancy. The HVAC heat pump mini-split was chosen for its high energy efficiency, electrical energy input, relatively low maintenance, and 12-15 year life expectancy. The heat pump mini-split combines heating and cooling for the shelter into one unit. The Eva-dry E-500 unit was selected for dehumidification of the shelter due to the continuously humid climate. This option was sustainable because it is environmentally safe, refills are not required, only occasionally uses electrical power for drying, and has a 10 year life span.

The waste management was scored based on environmental friendliness, longevity of system, and scalability. The PeePoo[13] bags scored the highest for all of these categories. The doubled bag system allows for the bags inner enzyme layer allows for the break down of the waste inside and dispose of the bag in the ground. Another option is to collect bags in a centralized location then they can be properly relocated and disposed of.

[13] "Peepoople." *PeePoople*, www.peepoople.com/.

The sustainability scoring for the water management system was based upon the disposal after use. The 100 gallon short cylindrical tank was chosen, and it is recyclable after its product lifetime. The electrical system incorporates the usage of electrical based appliances which allows for capability to be run on clean renewable energy sources. Overall the shelter is designed with sustainability as a forethought, and not an afterthought.

6.0 Recommendation

6.1 Design Recommendations

In designing the shelter we wanted it to be strong, portable, sustainable, as well as cost effective. The same criteria was used in the selection of materials. The design uses a shipping container as the main structure with the shelter being able to unfold by lowering the two sides of the container. This has many advantages such as set up time of under 20 minutes, requiring no special tools, it's all self contained, and no lost boxes of parts. The shipping container was selected because of its durability and the infrastructure to ship containers is already in place. For the heating and cooling loads a mini split heat pump was the most sustainable and cost effective option. For ventilation we wanted to use a heat recovery ventilation (HRV) system for energy savings. The mini split and the HRV system also help us to be compliant with ASHRAE standards 55 and 62.

The layout of the shelter was designed to be as open as possible. The center back section has a area the is walled off to form a private area for a bathroom. The outside of the wall will have a small countertop, and sink. It will also be where the freshwater, and grey water tanks are stored; see Figure 10. A feature that sets this shelter apart is the maintenance access panel on the exterior of the shelter. This provides access to the electrical system, heat pump, and grey water drainage without entering the shelter; see Figure 11.

The water management system includes a short 100-gallon potable water storage tank that will be filled by transporting water from the communal water tap to the tank. This tank will have a foot pump that will pump water to the sink, which will help prevent water contamination and biohazards for refugees that have recently used the bathroom or simply have dirty hands. The sink will be multipurpose for washing clothes, preparing food, and bathing/cleaning. There will be a gray water tank underneath the sink in order to collect the used water for storage until it can be properly disposed of.

The waste management will use PeePoo bags to handle human waste. These biodegradable bags will help keep communities clean and free of human waste. After two weeks, the bags break down and provide the option of being used as fertilizer for gardens. If they are not used in gardens, they will provide a safe, clean way to dispose of human waste, with no adverse effects to the community. In addition to being sanitary and environmentally friendly, the bags provide at risk refugees with a safe, private toilet that they can use anywhere. This allows refugees who may be threatened in a communal bathroom setting their own way to use the toilet without fear of attack or harassment. Lastly, Peepoo bags are very cheap to use and provide, as detailed in section 5.1.

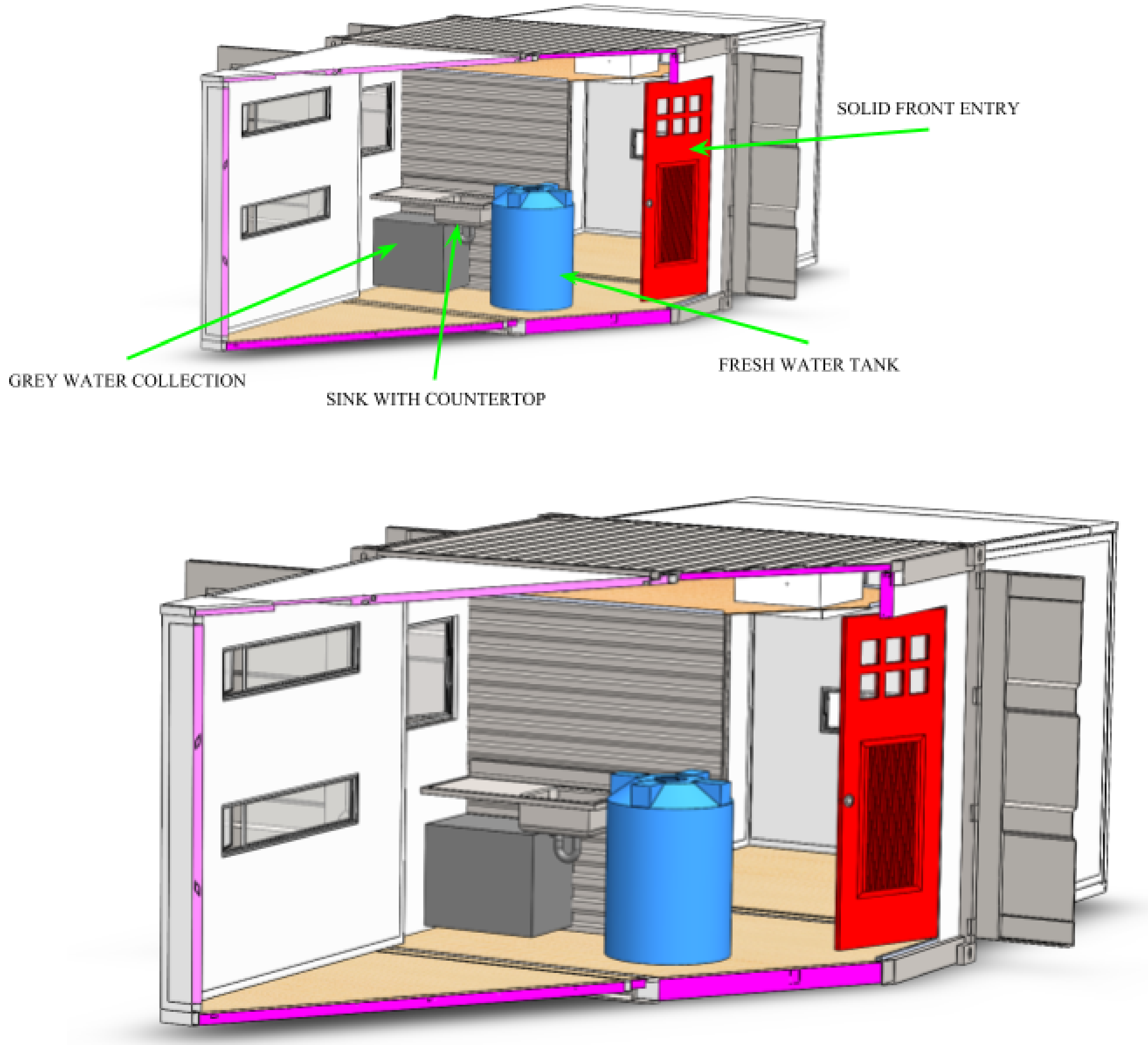


Figure 10. CAD Isometric cut inside view of the shelter. Image depicts some internal integrated systems; fresh water tank, grey water collection, and sink with counter space.

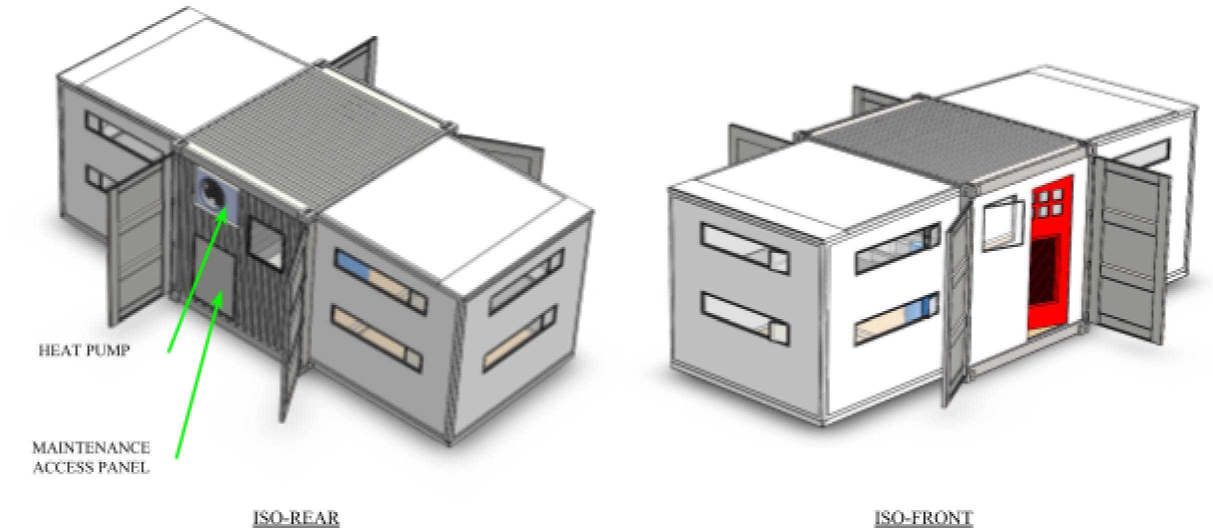


Figure 11. CAD Isometric view of the shelter. Images indicates the location of the air-source heat pump and access panel for operational maintenance.

6.2 Future Design Recommendations

A future design recommendations that our team has discussed and would like to incorporate in future designs would be solar panels, windmills, and other energy generation systems. As well as integrate a communal shelter design, as such design is more appealing to disaster relief organizations, and may provide a more cost effective solution. Energy generation systems would help the shelter become more self sustaining and would be a plus for the shelter's local environment. Another recommendation would be to research composite plastic materials for the exterior to see if they would be less expensive, but still keep the same strength and durability.