ASHRAE 2018 Applied Engineering Challenge:
Temporary Refugee Shelter
The Setty Family Foundation: 2018 Applied Engineering Challenge

First Semester | Final Report

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1.0 Introduction

1.1 Executive Summary

December 2015, for the first time ever according the the UN Refugee Agency, 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 accessibility, and essential human amenities. The ASHRAE Applied Engineering Challenge for 2018 encourages students to explore potential solutions to this problem. ASHRAE is defined as the American Society of Heating, Refrigeration and Air-Conditioning Engineers.

The challenge consists of designing a structure that both shelters refugees as well as provides essential domestic systems. However, there are various design specifications that constrain the available design and living space. The most challenging design constraint, is to design a shelter with essential domestic systems without access to municipal water or sewage. Further constraints of the shelter include maximum square footage, height, electrical requirements, and must house a family of six to eight people. The shelter must also abide by ASHRAE Standards 55 and 62. The specified ASHRAE standards define specifications to comply with thermal environmental conditions for human occupancy, and ventilation and acceptable indoor air quality in residential buildings; respectively. The shelter must be designed to withstand the environmental conditions of Eastern Europe. The ASHRAE challenge not only desires a high level of creativity and sophistication of the shelter design, but is also interested in the shelters sustainability, environmental impacts, and fiscal considerations.

The team's decision regarding a structure resulted in a shipping container that had foldable walls to expand the usable size within. Using a ceiling that folded out, this would allow for great resistance to deformation under heavy loads while protecting refugees, while allowing for great logistical use.

Through careful research and analysis of multiple system options, the group 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, using PeePoo's company as a source for waste management, and a mini split with dehumidifiers for HVAC, the group has worked to complete major systems decisions though some still await before the June deadline.

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 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.[1]

ASHRAE identifies their challenge as a temporary shelter engineering challenge, although based off the challenge's constraint and requirements, it would be more appropriate to classify the challenge as an applied temporary housing engineering challenge. 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, bases off the design constraints set by ASHRAE, are the structural design, HVAC design, water management system, waste management system, and the overall sustainability of the shelter.

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[1] "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.

1.3 Conclusion

Currently the design team will be focusing on providing a single primary deliverable, with plans to provide additional deliverables for the future semester. The current primary deliverable is to provide ASHRAE with a temporary sheltering solution to compete in their hosted applied engineering challenge.

The design team will provide the 2018 ASHRAE Applied Engineering Challenge with a full technical report tailored to the specifications of ASHRAE's formatting requirements. The ASHRAE Applied Engineering Challenge has a list of explicit judging criteria, engineering constraints, and submission deadlines that the design team will fulfill with a complete computer-aided design of the shelter along with a full report. This report will include items specified by ASHRAE including but not limited to assumptions, justification of assumptions, selection of materials, equipment, energy consumption analysis, related engineering calculations, project cost estimates, and compliance confirmation with ASHRAE comfort standards.

Additional deliverables for the future semester may consist of providing a physical model of the shelter solution submitted to the ASHRAE Applied Engineering Challenge, or design a shelter that is more practical for real-world applications. The design team is currently working with their advisors to better define what is expected and what goals are desirable for the future semester.

2.0 Context

2.1 Problem Statement

In December 2015, the number of displaced people around the world topped 60 million for the first time. According to CARE, Cooperative for Assistance and Relief Everywhere, 24 more people around the world are displaced every minute. These displaced individuals leave everything behind in the hope of finding safety, a greater future, and relief from violence, famine, environmental factors, or the persecution that drove these individuals from their pre-displaced homes.[2] The number of refugees in need of a shelter is higher now than any historical refugee occurrence, and the issues of housing and caring for these displaced individuals will only continue to increase over the coming years. More than half of these refugees are children in need of a stable, protected environment that they can temporarily call home. These displaced children and their families would ideally be the primary end users for the designed shelter solution.

Refugees or similarly displaced individuals subjected to catastrophe, typically don't have enough resources to provide themselves with adequate shelter. Without adequate sheltering, clean water, and food resources, areas allocated for relief become unsafe, morbid, and ultimately lead to disaster relief neglect. Resulting in local governments, municipalities, and humanitarian organizations to provide the necessary resources to cultivate a safe, healthy, and properly organized relieve to these disaster victims.

2.2 Need Statement

ASHRAE requires a temporary shelter solution that is sustainable, scalable, and affordable to families who have been displaced. ASHRAE provides some details about what the temporary shelter must consist of and comply with. Defined by ASHRAE, the shelter should comply with standards 55 and 62, be tough enough to be portable, utilized resilient material, 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. ASHRAE also gives some specifics on the dimensions of the shelter, power demand, and municipal utility connections. The shelter is limited 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.

In order to compete in ASHRAE's Applied Engineering Challenge, the designed temporary shelter must be summarized in a 25 page technical report with the formatting restrictions of Times New Roman and size 11 font. ASHRAE, the organization hosting the challenge and the primary customer for this project, has set the constraints, and defined the specifics of the challenge. Even

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[2] "applied-engineering-challenge - ashrae." https://www.ashrae.org/communities/student-zone/competitions/applied-engineering-challenge. Accessed 25 Apr. 2018.

though ASHRAE is the primary customer for this project, the design team will also include the needs identified from governments, municipalities, and humanitarian organizations who would organizes and implement relief. Other need considerations that are not directly defined from ASHRAE will be derived from the individuals in direct need of disaster relief. Therefore, the final design will be tailored to the needs defined by ASHRAE but, will also attempt to include the needs of the direct purchaser and users.

2.3 Design Team

Team Members:

Daniel: Daniel has had experience in solidworks modeling, and CNC manufacturing at the Woods Hole Oceanographic Institution. He also has experience creating presentations and writing technical reports and documents. He is very interested in sustainable products and environmentally friendly engineering.

LeRoy: LeRoy has experience working with Residential New Home Construction. His experience with Residential New Homes Construction includes code compliance, energy audits, home energy consumption analysis modeling, minor experience with manual D, J, and S, as well as residential sustainability. LeRoy also has a great interest in net zero buildings, environmental and energy sustainability solutions, and unique building solutions.

Nicholas: Nicholas has had machine shop training. He has CAD software and EnergyPlus software experience which is used to generate building loads from an output based on information of the building type and weather files from a specific location. His course work of HVAC, and Intro to the Environment and Sustainability fits along the project guidelines. He has interests in building efficiency, enhancements in environmental sustainability, net zero buildings, and renewable energy generation.

Scott: Scott has experience in building various assemblies based on engineering prints. He is interested in creating a composite that can be used for walls for the structure that will be strong, and durable.

Andrew: Andrew has worked for Wasatch Construction for the past 3 summers and has grown up around construction. He has experience in building and planning and is comfortable with materials and cost management. Furthermore, he has experience with writing technical documents and memos.

Organization:

The team has adopted a laissez-faire style of organization. We do not have a set team lead, and work collaboratively to come to decisions. If a consensus cannot be reached, we have relied on democratic means to make decisions. This style allows for all group members to have a voice in the group, and for each member to feel free to express how they feel about any issue.

Responsibilities:

Responsibilities for each team member are assigned on an as needed basis. Team members are assigned a specific task and held responsible for completing their assigned in a timely manner. Other responsibilities include obliging by the Team Working Agreement, complying with team's mission and goals, and communicating effectively.

Team Advisors:

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Zahra received her Master of Science in Energy Management and Sustainability at ÉPFL, Switzerland. She is a Ph.D. candidate at the University of Utah in mechanical engineering. Her research interests include energy systems, optimization, thermodynamics, renewable energies, energy efficiency, sustainability, building energy, emission management, microclimates, microgrids, natural resources management.

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Thomas is a Ph.D. candidate at the University of Utah in Mechanical Engineering. He has received his Master of Science in Mechanical Engineering. His research interests include renewable energy, energy systems, microgrid energy, energy efficiency, and building energy.

3.0 Design Requirements

3.1. Overview of Customer Needs & Requirements

The primary customer for this project is ASHRAE. Our shelter must meet the requirements defined in the ASHRAE 2018 Applied Engineering Challenge. The secondary customers are governments and humanitarian organizations. As these governments and humanitarian organizations will ideally be purchasing these shelters and providing them to displaced families. The primary end users of these shelters are refugees and displaced families not legally identified as refugees. Primary end user needs were determined by reviewing the ASHRAE challenge requirements and constraints for this design challenge, and by researching the needs required for displaced families and identifying what is currently provided by refugee shelter providers; as well as what refugee shelter providers are lacking. We contacted Dr. Divya Chandraskhar, a University of Utah professor in the architecture department for urban planning specializing in disaster relief. She provided us with information and resources to define our secondary customers needs and end user's consumer needs.

3.2. Customer Needs Hierarchy

Primary	**Secondary**	**Tertiary**
Provide Shelter		
	Provide storage for perishable food within the shelter	
		Provide secure storage for personal belongings within the shelter
	Shelter needs to be fire resistant.	
	Able to accomodate 6-8 people within one shelter	
		Sleep 6-8 adults
	Shelter should be handicap accessible	
Essential domestic systems are contained in the shelter		

	HVAC system is compliant with ASHRAE standards 55 and 62	
	Contains 100 gallon potable water storage	
	The provided power connections are 220V/1ph with a maximum of 15 amps	
	Contains a sanitary waste management system	
Able to withstand inclement weather		
	Joints in shelter need to be watertight to prevent water leaks	
Low capital costs		
	Shelter to have low energy consumption	
		All components to be energy efficient
	Shelter to be made using cost effective materials	
		The materials should be locally available if possible
	Shelter to be low maintenance	
		Components used should be low maintenance
Able to perform in an Eastern European Country		
	Be able to provide thermal comfort year round	

		HVAC system for heating, cooling, and dehumidification
	Tough enough to be portable to multiple locations	
Sustainable and environmentally friendly		
	Shelter to be made of environmentally friendly materials	
Contained within a 24 m^2 (260 ft^2) footprint		
	Shelter should have a creative use of space	
A ceiling height limited to 2.6 meters (8.5 ft)		
Cost effective to construct		
	Easy to set up with minimal time/manpower	
	High reusability for long term usage	

Table 1. Customer Needs Hierarchy. Secondary needs are more specific goals that are encompassed within primary needs

3.3. Ranking of Primary Customer Needs

More stars indicate greater importance of customer need, five stars being the greatest level of importance.

*****	Provide shelter/Withstand weather
****	Contained to a 24 m^2 or 260 ft^2 footprint
****	Able to perform in an Eastern European Country
****	A ceiling height limited to 2.6 meters (8.5 feet)
****	Essential domestic systems
****	Sustainable/Environmentally friendly
***	Made with available materials
***	Low capital costs
***	Power connections available are 220V/1ph with a maximum of 15 amps
***	Cost effective to construct
***	Contains potable water storage

4.0 Design Specifications

After identifying customer needs,the team created target design specifications for the shelter. Design specifications include metrics and standards that the group defined as critical to project success. For each specification the team identified marginal and target values as performance benchmarks for our design. Sections 4.0-4.7 provide detail, background, and justifications for all design specifications.

For reference, the main customer needs of our design are listed below:

1. Structure provides shelter
2. Shelter provides essential domestic systems
3. Shelter constructed from extensively available materials
4. Structure provides low manufacturing and development costs
5. Shelter is weather resistant (rain, snow, etc.)
6. Shelter consumes low energy
7. Shelter is of low maintenance construction
8. Structure appliances accommodates 6-8 people
9. Designed for Eastern European climates
10. The building is contained to a 24 m^2 or 260 ft^2 footprint
11. Shelters are portable
12. Shelter utilizes resilient construction materials
13. Uses sustainable and environmentally friendly materials
14. Shelter design utilizes creative use of space
15. Shelter height is less than 2.6 meters (8.5 feet) tall
16. The power connections available are 220V/1ph with a maximum of 15 amps
17. Shelter designed to be cost effective
18. Shelter is easy to set up
19. The shelter can be used and reused multiple times
20. The shelter sleeps 6-8 people
21. Shelter is equipped with a water management system
22. Wheelchair accessible
23. Shelter has personal storage capacity
24. Shelter is resistant to fire and floods

4.1. Overview of Specifications

Table 2 below illustrates the team-defined specifications and how they relate to the customer needs mentioned above.

Metric #	Customer Need #	Metric	Imp.	Units	Marginal Value/Range	Ideal Value
1	1, 2, 20, 21	Integrated Essential Systems	4	List	Waste management, Water management, Shelter heating and cooling, etc.	N/A
2	4, 7, 12, 24	Accident Prevention	3	Boolean	No / Yes	Yes
3	8, 13, 14	Sleep Capacity	4	People	6-8	8
4	1, 2, 8, 15, 20, 21, 22, 23	Amenities	2	List	Storage, cooking, sink, ect	N/A
5	3, 10	Shipping Weight	3	kg, lbs	< 35,000 kg ??	9,072 kg
6	13, 14, 16, 23	Assembly Size	3	m^2, ft^2	< 24 m^2	~ 23 m^2
7	18	Set-up and Assembly Time	4	minutes	120-240 min	45 min TBD
8	3,6,7,17,19	Sustainability	5	Boolean	No / Yes	Yes

9	2, 6, 11	Energy Consumption	5	W, kWh, BTU/hr	< 3300 W	< 2500 W
10	2, 11, 21	Water Management	4	Boolean	No / Yes	Yes
11	2, 11	Waste Management	4	Boolean	No / Yes	Yes
12	2, 9	Heating and Cooling Capacity	3	BTU	Heating: ~2143 BTU/hr Cooling: ~3996 BTU/hr	Heating: 2143 BTU/hr Cooling: 3996 BTU/hr
13	2, 5, 6, 7, 11, 17, 19,	Operational Cost	4	$, €	< $100.00/day Startup: < $12000	TBD ($50.00/day Startup: < $10000
14	16, 18, 23	Solution Creativity	2	range	1-5	5

Table 2. Metric Value Table. Table identifies the specific values to be used for the given metric. Reference customer needs are listed in section 4.0.

4.2. Description of Each Design Specification

Metric:	Customer Need #	Imp.:	Description:
Integrated Essential Systems	1, 2, 20, 21	4	Structure needs to be able to provide power (Electricity), be compatible with cleaning requirements, have the ability to store food, and heat, cool, and ventilate the space properly according to ASHRAE Standard 55 & 62. Essential Systems are critical to living standards and must be ranked accordingly. Ranked less than a perfect 5 because a the quantity of Integrated Essential Systems is not as important quality of life the Integrated Essential Systems provides. Directly related to 2, and 21; 1 and 20 are indirectly related.
Accident Prevention	4, 7, 12, 24	3	The shelter needs to be fire resistant, flood resistant, and withstand environmental conditions. It is ranked a 3 as it is important to longevity, but not more critical than the functionality of the shelter itself. 4, 7, and 12 indirectly provides a structure that is more resilient to accidents and 24 is a direct relation. Low maintenance inhibits accidents, and resilient construction limits the exposure to accidents.
Sleeping Capacity	8, 13, 14, 20	4	The shelter should be able to sleep 6-8 people. This is the ASHRAE requirement for the Applied Engineering Challenge. Therefore, the importance of this metric is high but, lenient and is in direct relation to customer need 20. As well as indirectly related to 8, 13, and 14. Since, the provided systems can accommodate 6-8 people but the shelter may not be able to sleep 6-8. Creative use of space must be utilized to sleep 6-8 people, and the construction of this space will utilize sustainable material.
Amenities	1, 2, 8, 15, 20, 21, 22, 23	2	Non-essential systems or spaces such as storage capacity, cooking appliances, etc. that exist to improve quality of life in the shelter. This metric is a list of amenities that improve the quality of life but are not essential systems. As a result, it is rated a 2 as they are non-essential and can only be included if all other

			design standards are met. Some needs subjected to this metric are more important than others.
Shipping Weight	3, 10	3	The shelter is easily shippable and is not climate restricted due to transportation issues. This metric is important so that the shelter can be transported to any area that requires assistance. Transportation limitations would be problematic for those in more rural or hard to access areas. A shelter less than 10,000 kg is optimal for shipping 4 shelters at a time on a conventional commercial trailer. This is rated as a 3, since the heavier the shipping weight, the more difficult the transportation process will be. However, the team's primary concern is the functionality of the shelter, and as such this has less overall importance to the main project goal.
Assembly Size	13, 14, 16, 23	3	The shelter, when completely assembled and unfolded, uses less than the full available space allocated for the design competition. Determined by shelter storage size and unfolding capacity. This is rated as a 3 as using the entirety of the provided space is not necessarily detrimental to project success, but the more efficient the team can allocate space, the more successful the project should be.
Set-up and Assembly Time	18	4	The shelter should not take significant time to set-up, as this detracts from usefulness in emergency situations where time is critical. Currently we have estimated 45 minutes for a complete initial set up; this only includes unfolding (15 min) the shelter and initial integrated system setup time (30 min). Additional time will be required to get the shelter to the specified location; this is dependent on geographic location and accessibility. This is rated as a 4, as especially during emergencies, time is of the essence when it comes to saving lives and providing adequate shelter. A short setup time for the shelter would be excellent towards overall shelter flexibility.
Sustainability	6, 7, 17, 19	5	The shelter should not have an adverse impact upon the health of the local environment. One of the main questions for the shelter judging for ASHRAE was the sustainability and long term impact of the shelter. Shelters that destroy the area that

			they are lived in could cause major issues over time and are unhealthy for local ecosystems.This is rated as a 5, as both the importance the group has placed on creating a long-term sustainable shelter, along with ASHRAE's emphasis on sustainability, make this a critical metric for our project.
Energy Consumption	2, 6, 11	5	The shelter must use less than 3300 rated Watts. This is a requirement from ASHRAE's design constraints of power connections of 220V/1ph and a max of 15 amps. With the current integrated systems we determined to utilize less than 2500 W at peak operation loads. Needs 2 and 11 are included in this metric because the essential systems use energy and require transportation; which also consumes energy. This is very important to the longevity and practicality of the shelter, and as such is ranked as a 5.
Water Management	2, 11, 21	4	The shelter must have a system that allows for potable water storage and use. This is important as humans are required at minimum to have 7.5 liters per day of water at their disposal for drinking, food, and basic hygiene. Needs to be able to withstand external forces when transported and stored. Since water is critical to human survival, a well designed water system is important, and as such is ranked as a 4.
Waste Management	2, 11	4	The shelter must have a system that allows for management of waste without it becoming a safety hazard. Ideally we want to provide a system that manages waste and avoids health hazards. Needs to be able to withstand external forces when transported and stored. This is ranked as a 4 as this is an important problem to resolve, and if left alone could become a biohazard and could have dangerous health consequences.
Heating and Cooling Capacity	2, 9	3	The shelter must be able to provide systems that are compliant with ASHRAE Standards 55 and 62. Which handles occupant comfort and thermal loading. 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, it is ranked as a 3.
Operational Cost	2, 5, 6, 7, 11, 17, 19,	4	The shelter should cost under $100 a day to operate, and less than $12000 for startup cost. These values are determined from preliminary energy consumption and construction cost analysis. The operational and start up costs are important, as expensive shelters limit the number that can be built and utilized. As a result, the team would like to keep cost down to increase the practicality of shelter use, even in economically tougher situations and ranked this metric a 4.
Solution Creativity	16, 18, 23	5	The solution should be creative in use of time, materials, energy, and space allocation. This is ranked as important, as the team knows that creativity is necessary for successfully handling complex projects. As a result, this is ranked as a 5.

Table 3. Metric Description and Importance Table. This table defines the metrics used, associated customer needs, the metrics importance, and finally the description of the metric. Reference customer needs are listed in section 4.0.

4.3. Metric Value Justification

Metric:	**Value:**	**Justification:**
Integrated Essential Systems	N/A	Structure needs to be able to provide power (Electricity), be compatible with cleaning requirements, have the ability to store food, and heat, cool, and ventilate the space properly according to ASHRAE Standard 55 & 62. Therefore, we can not provide a single value to this metric but, rather a list of Essential Systems the shelter provides; for now we'll identify this metric's value an N/A.
Accident Prevention	Yes	The shelter needs to be fire resistant, flood resistant, and withstand environmental conditions. Accidents will always happen, but shelters that are more resistant to accidents such as fire and flooding will be longer lasting and better equipped to safely house people.
Sleeping Capacity	8 People	The shelter should be able to sleep 6-8 people. This is the ASHRAE requirement for the Applied Engineering Challenge. We've determined from the spatial analysis of the shelter design, it will sleep at least 8 people.

Amenities	N/A	Non-essential systems or spaces such as storage capacity, cooking appliances, etc. that exist to improve quality of life in the shelter. This metric will be useful in determining quality of life for those living in the shelter. This metric is a list of amenities that improve the quality of life but, are not essential systems.
Shipping Weight	9,072 kg	The shelter is easily shippable and is not climate restricted due to transportation issues. This metric is important so that the shelter can be transported to any area that requires assistance. Transportation limitations would be problematic for those in more rural or hard to access areas. A shelter less than 10,000 kg is optimal for shipping 4 shelters at a time on a conventional commercial trailer.
Assembly Size	~ 23 m^2	The shelter, when completely assembled and unfolded, uses less than the full available space allocated for the design competition. Determined by shelter storage size and unfolding capacity.
Set-up and Assembly Time	45 min TBD	The shelter should not take significant time to set-up, as this detracts from usefulness in emergency situations where time is critical. Currently we have estimated 45 minutes for a complete initial set up; this only includes unfolding (15 min) the shelter and initial integrated system setup time (30 min). Additional time will be required to get the shelter to the specified location; this is dependent on geographic location and accessibility.
Sustainability	Yes	The shelter should not have an adverse impact upon the health of the local environment. One of the main questions for the shelter judging for ASHRAE was the sustainability and long term impact of the shelter. Shelters that destroy the area that they are lived in could cause major issues over time and are unhealthy for local ecosystems.
Energy Consumption	< 2500 W	The shelter must use less than 3300 rated Watts. This is a requirement from ASHRAE's design constraints of power connections of 220V/1ph and a max of 15 amps. With the current integrated systems we determined to utilize less than 2500 W at peak operation loads.
Water Management	Yes	The shelter must have a system that allows for potable water storage and use. This is important as humans are required at minimum to have 7.5 liters per day of water at their disposal for drinking, food, and basic hygiene.

Waste Management	Yes	The shelter must have a system that allows for management of waste without it becoming a safety hazard. Ideally we want to provide a system that manages waste and avoids health hazards.
Heating and Cooling Capacity	Heating: 2143 BTU/hr Cooling: 3996 BTU/hr	The shelter must be able to provide 2143 BTU/hr for heating and, if found necessary, 3996 BTU/hr for cooling. Designed thermal loading and capacities were determined by the climate conditions of climate zone Dfb; neglecting the shelter constructed thermal loads. This value will need to be recalculated after structural materials are selected.
Operational Cost	TBD ($50.00/day Startup: < $10000)	The shelter should cost under $100 a day to operate, and less than $12000 for startup cost. These values are determined from preliminary energy consumption and construction cost analysis.
Solution Creativity	5	The solution should be creative in use of time, materials, and space allocation. The value of 5 indicates a shelter design that is very creative but, also practical.

Table 4. Metric Value Justification Table. This table defines the metrics used, their specified values, and the justification for the specified values.

4.4. 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 19.32 m^2 (208.0 ft^2) of occupiable space and 20.19 m^2 (217.3 ft^2) of total area used; well within ASHRAE's sizing constraints.

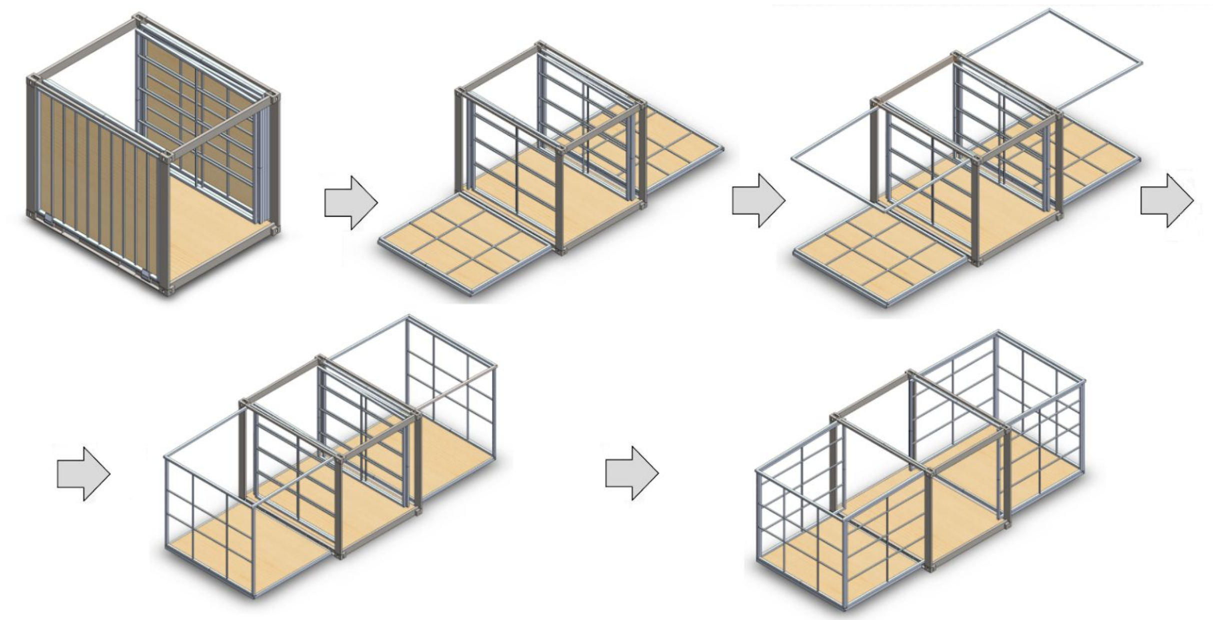

Figure 1. Unfolding shelter steps. This figure shows, in order, the steps necessary to properly unfold the shelter from the container foundation. Lower the two floor panels, lift the ceiling panels, lift the far wall panels, and finally pull-out the four side wall panels. Refolding the shelter is obtainable by reserving the order illustrated.

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. The ceiling panel will most likely 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.

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. For the selection chart of the see attachment 6. The wall panels will be approximately 1/4 inch thick. The fenestration of the temporary shelter has yet to be defined and will be further discussed in the design recommendation for ASHRAE.

4.5. 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%.[3] 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. 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.

4.6. Water Management Specifications

After completing research into different refugee organizations, the assumptions for our water management system were made based on UNHCR camp planning standards[4]. 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. 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.

4.7. 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

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

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

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. 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. With no way to predict the cultural group that would be using the shelter, we had to plan for all possibilities. 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[5]. These specifications were used in the concept selection process to generate metrics against which the different waste management options were compared.

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

5.0 Design Development

5.1. Design Assumptions

Designing a temporary shelter for refugee situations requires a lot of planning and considerations. Therefore, the design team has made the following assumptions to stay within the focal purpose of the project and avoid exhausting resources on unnecessary design details.

Assumption:	**Justification:**
Necessary Infrastructure Established	Necessary infrastructure will need to be establishing in order for any temporary shelter design to be implemented. This also includes the assumption that municipalities and humanitarian organizations are able to allocate the correct resources to implement a temporary shelter design. This includes adequate food, a nearby, reliable water tap, 220V 15 Amp/1ph electrical power and trash disposal services.
Dfb Köppen Climate Classification	Climate condition Dfb covers the largest area of Eastern Europe; see Figure 2. Therefore , the probability of the shelter residing in this climate classification is fairly high. Defining a particular climate condition allows the design team to focus on designing a solution for that climate. Different climate conditions require alterations to the insulation, re-evaluation of the heating and cooling loads, as well as the fenestration and ventilation of the structure. Dfb is classified to be cold, without a dry season, have a warm- summer, and be a humid continental climate condition.
Preliminary Manufacturing	The design team is assuming preliminary manufacturing of the shelters is obtainable and desirable.
Established Logistics	The team is under the assumption that typical modes of transportation are still operational and accessible by disaster relief organizations.

Table 5. Assumptions Table. This table list the assumptions the design team has identified and their justifications.

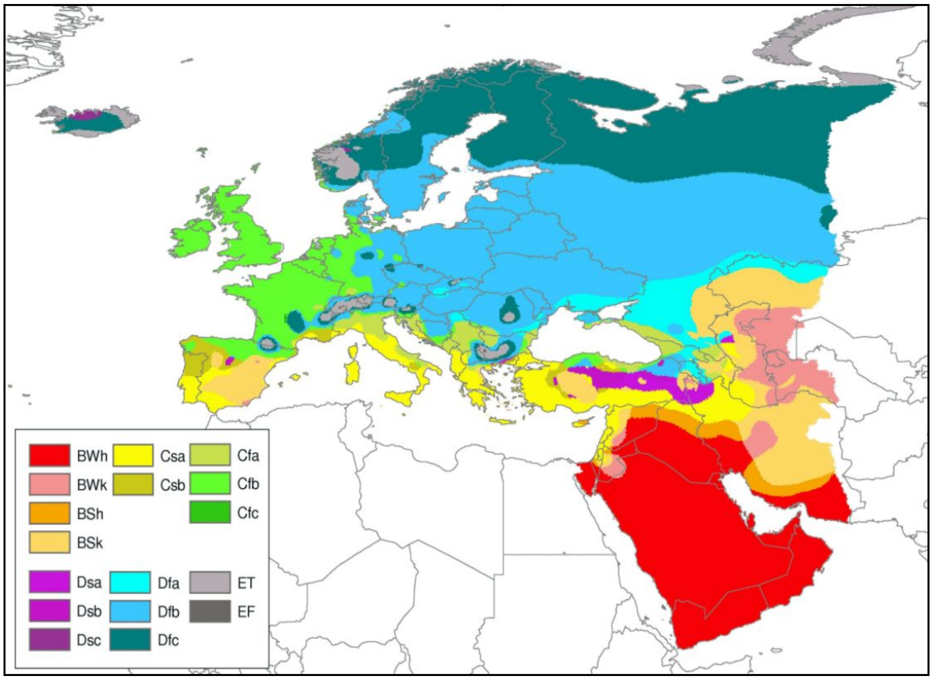


Figure 2. Geographic Köppen Climate Classification in Europe and part of the Middle East.[6] This figure shows that the climate classification of Dfb (light blue) covers the majority of Eastern Europe.

Additional design considerations are the shelters sustainability and local environmental impacts; minimizing environmental detrimental solutions. The shelter must be within ASHRAE design specifications of height and square footage, while also abiding by ASHRAE standards 55 and 62 for ventilation as well as comfort. Essential systems such as potable water storage, waste management, and power must also be handled in an appropriate manner.

5.2. Design Development Overview

The most critical design requirement is to provide a temporary shelter with essential domestic systems to be used by governments and humanitarian organizations. The shelter must be capable to accommodate a family of 6-8 people in Eastern Europe. Essential domestic systems are defined as, waste management, water management, and comfort amenities.

Critical Function Prototypes (CFP) are critical to design development to ensure that ideas are employable. The critical function prototypes the design team decided to analyze are the HVAC system and the structural design. We want to analyze the HVAC system to ensure that its configuration is adequate enough to provide the calculated heating and cooling conditions that are acceptable for human occupation. Creating an HVAC system CFP will also allow us to analyze heat loss and gain from the HVAC system internal components, as well as from infiltration leaks of the structure from fenestration design. The HVAC design must be able to withstand weather conditions that are

[6] "Updated Köppen-Geiger climate map of the world." https://people.eng.unimelb.edu.au/mpeel/koppen.html. Accessed 30 Apr. 2018.

common for Eastern Europe, as well as be environmentally conscious to local ecosystems. Structural design is important to our temporary shelter because it encompasses all essential systems and is the foundation of the shelter. The structure is required to maximize the amount of interior occupiable space, while minimizing shelter storage space. Accommodating both requirements is solved by allowing two exterior walls of the shelter to fold out from the main construction of the shelter. Encompassing occupiable space from these fold out walls is achieved by unfolding an additional four surfaces; three exterior walls, and a ceiling. A CFP for the structural design is important to analyze to ensure all folding mechanisms are achievable and will operate at minimal effort by the operator. The CFP of the structure will also ensure the folded out sections are strong enough to support the applied load of both the occupants and environmental conditions.

There are many interdependent parts in this project that requires additional time and research to determine an optimal solution. The product solution that may derive from this project may not be the solution for sheltering refugees, or those not legally identified as refugees but, it will be designed for sustainability, energy conservation, ASHRAE constraints, and the well being of its occupants in mind.

5.3. Brainstorming

Appendix A provides the concept selection charts utilized for finalizing design decisions. Each design process followed the same procedure: generate as many ideas as possible, define a baseline solution, define metrics that reflects the customer needs, define metric weights based on design importance, and score each idea appropriately for each metric. The solution that ranked the highest was chosen as the best solution for that particular design concept selection. Designs that ranked lower than the baseline were neglected. The concept selection charts in Appendix A show the top two concepts derived from the team's brainstorming meetings. These brainstorming concepts were mostly derived from preliminary research and from concepts that are already implemented around the world.

General ideas about how the shelter would be constructed were recorded, later refined to construction specifics, and ultimately developed into structural design concepts. The design team conceived five general temporary shelter structural concept design solutions. Two solutions involving shipping containers, two involving module panels with a central modular hub, and the last was a fabric solution with a modular hub. The design team then defined generalized metrics that best defined customers need and some user considerations. These metrics were then weighted based on their importance to the shelter design. The design concepts were then compared to a baseline shelter that is view to be the best designed refugee shelter to date; the Ikea refugee shelter. Following the design concept selection procedure described previously, ultimately lead to the design team's current shelter solution; a retrofitted shipping container with folding panels.

The nature of the retrofitted shipping container with folding panels lead to another concept selection process about how to fold the panels within the structure. The design team researched structural folding solutions and were able to identify some folding solutions. The best folding solution that was found, and to score the highest on the concept selection chart, comes from a company in the

United Kingdom called Ten-Fold Engineering. This company develops and patents elegant linkages for folding housing solutions. The design team contacted Ten-Fold Engineering to get additional information on using the companies' folding solutions and were told to purchase licensing to use Ten-Fold's solutions. The team is still considering purchasing Ten-Fold licensing but, for the meantime, has decided to continue with the second best folding design concept. Please see section 4.4, the Shelter Structural Specification section, for the best description of the current structural design.

Brainstorming for the water management system consisted mainly of research into types of water storage tanks and pumping systems that would fit within a small space. The pump system was quickly decided, as the group agreed that a foot pump would be most effective for any hazardous situations. Upon further research into the tanks, a concept selection chart was created in order to compare the options the group had for water storage. This chart was created specifically for tanks between 50 and 100 gallons, as group research determined that any larger than 100 gallons would be an inefficient use of space and unreasonable to fill. The most important metrics in this chart were ease of use followed by maintenance and storage capacity, with other metrics such as ease of setup, lightweight, and climate proof.

For the waste management system, brainstorming consisted of breaking down the system into three main subsystems, and coming up with as many idea as possible for each subsystem. The three subsystems consisted of the toilet, the storage, and the treatment systems. Preliminary research was done into each of these subsystems to determine the possibilities for each. For the toilet system, there were options for a waterless toilet, a water based toilet, and a bag toilet. For the storage system, a permanent tank, a temporary tank, individual bags, and no storage were considered. For treatment, compost, electrolysis, burning, and no treatment options were considered. After these options were created, extensive research was done into each, and possible combinations were created. These combinations were put into the concept selection chart, and ranked against one another. The most important metrics in this chart were sanitation, environmental friendliness, cost, and refugee point of view.

The HVAC system brainstorming was started by listing and researching different devices and systems that could provide heating, cooling, or dehumidification to the shelter space. The ideas which were generated included a heat pump mini-split, packaged terminal heat pump, hydronic heated floor system, direct expansion unit, utilizing passive solar heating, or wood burning stove. The important factors influenced the selection of the HVAC components included energy of fuel type, energy or resource availability, pollution generated, feasibility, complexity, and energy consumption.

5.4. Benchmarking

To properly justify that the team has selected the shelter design that is the most viable option to implement, the design team defined generalized metrics the shelter must comply with. The shelter must be structurally sturdy, be with the ASHRAE size constraints, be sustainable, provide the appropriate comfort, ease of setup, cost considerations, manufacturing considerations, and consider refugee point of view. The benchmarking design concept metrics are included in the Appendix A, Attachment 4. With the shelter design metrics defined, it was found that the integrated shipping container concept was the most viable out of all the concepts generated for this particular concept selection. The nature of this project is subject to only theoretical benchmarking, as physical benchmarks are more difficult to define and obtain consistent data for; especially in a country that is not directly subjected to a current refugee crisis. Therefore, the majority of the design teams benchmarking will be carried out on theoretical analytical basis.

The water system concept generation chart pushed the group to go with a short, cylindrical tank with a capacity of 100 gallons. Using a short tank, with a height of only 42 inches, should make it significantly easier to access for filling and much easier to maintain. Furthermore, with a full 100 gallons available, it can store enough water to last a family a few days. These three most important metrics were all fulfilled in this design, but other factors helped to contribute to this choice. The tank analyzed by the group in the concept selection chart wasa short tank made of a dark colored polyethylene, which was important to climate proofing and long-term use as shown in Appendix A, Attachment 2. The choice to go with a shorter container would help make it easier to refill after use instead of having to elevate containers of water which could be dangerous. The dark color will prevent algae growth in the tank due to sunlight, which would contaminate the drinking water, and since the material is polyethylene, the long-term usage is better than for regular plastic which has a greater potential to crack and fail.

The waste management system concept selection chart ranked the bag option as the most viable option, as seen in Appendix A, Attachment 3. This bag option consisted of using Peepoo bags for the entire waste management process, from the toilet to treatment. Peepoo bags are made to be used as fully self contained, individual, compostable toilets. They are made to be used once, sealed, and disposed of in the ground. After disposal, enzymes within the bag break down to waste material into usable fertilizer after 4 weeks. This design met every benchmark we had for the waste management system. The bags are biodegradable, and create usable fertilizer, enriching the soil around them. They are single use, and thus can handle any volume of waste created over a period of time. They are also extremely flexible, and can be used in a variety of locations and styles to fit each individual.

The HVAC selection chart scoring was based on many factors including capable heating and cooling capacities, energy efficiency, size, complexity of installation, cost, maintenance, life expectancy, and noise generation as show in Appendix A, Attachment 1. The mini-split unit was selected because if its ability to provide heating, cooling, and occasionally dehumidification during the air conditioning cycle into one unit. It also uses electrical power and has the capability to be used with renewable or nonrenewable electrical energy sources. An array of four Eva-dry E-500 dehumidification units were chosen to aid in additional dehumidification for the shelter located in a humid climate. The devices are small, reusable, and only need to be plugged into an outlet to be dried after 48 hours of use. The two systems together will allow for a simplified system for heating and cooling for the thermal comfort of the shelter.

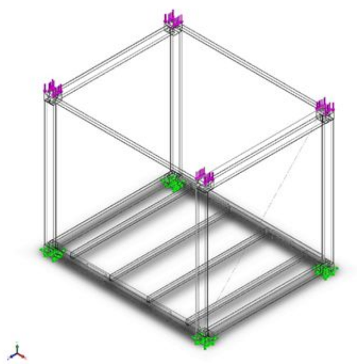
5.5. CFP Motivation

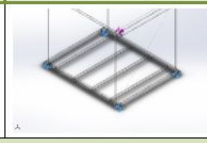
Structural motivations were derived from the importance of the durability and portability of the temporary shelter. The design team is aware that shipping containers are built to be resilient and tough, however it is very difficult to quantify how tough they really are. Therefore, we want to conduct an analytical load analysis onto a modeled shipping container structure, without the corrugated sheet metal, until we start to observe yielding. Analytical loading analysis of the shipping container structure will ensure the structures durability and help the team determine extreme logistics stacking conditions the shelter could withstand. The team also wanted to conduct another analytical loading analysis on the cantilever floor panel. As the floor panel will need to hold the greatest load. The floor panel will need to withstand the weight of the occupants and any snow, or debris, loading. Climate conditions identified in the assumption table, Table 5, it is reasonable to assume that the shelter will be subjected to significant snow loads. The folding panels created another unexpected CFP, which was to determine how the panels would fold relative to one another to avoid binding, and any unexpected interference connections. The folding panel CFP will not be discussed in proceeding sections.

The motivations for our HVAC CFP stem from the importance of following ASHRAE standards 55 and 62 in both the ASHRAE competition, as well as ensuring comfort for those using our shelter, ASHRAE Standard 55 is Thermal Environmental Conditions for Human Occupancy, which is especially critical in a cold climate such as Eastern Europe, while ASHRAE Standard 62 is Ventilation and Acceptable Indoor Air Quality in Residential Buildings. The group decided that focusing our efforts to construct a shelter and HVAC system that can pass these two standards would be a critical step towards completing a functioning and livable shelter.

5.6. 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 5.7. 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.



Fixture name	Fixture Image	Fixture Details
Fixed Points		Entities: 4 face(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	6.83078	2.21606e+006	-2.06688	2.21606e+006
Reaction Moment(N.m)	0	0	0	0

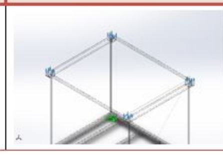
Load name	Load Image	Load Details
Static Force		Entities: 4 face(s) Type: Apply normal force Value: 498200 lbf

Figure 3. Boundary conditions of the shipping container. Purple arrows are the applied loading force locations defined in the red table. Green arrow indicate surfaces that are fixed and is defined in the green table.

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

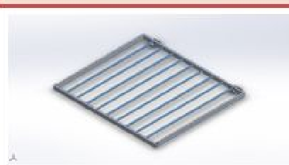
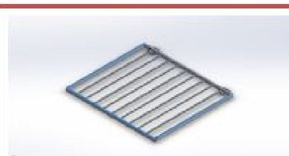
Load name	Load Image	Load Details
Force-Occupants		Entities: 9 face(s) Type: Apply normal force Value: 2400 lbf
Force-Snow		Entities: 3 face(s) Type: Apply normal force Value: 1000 lbf

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.

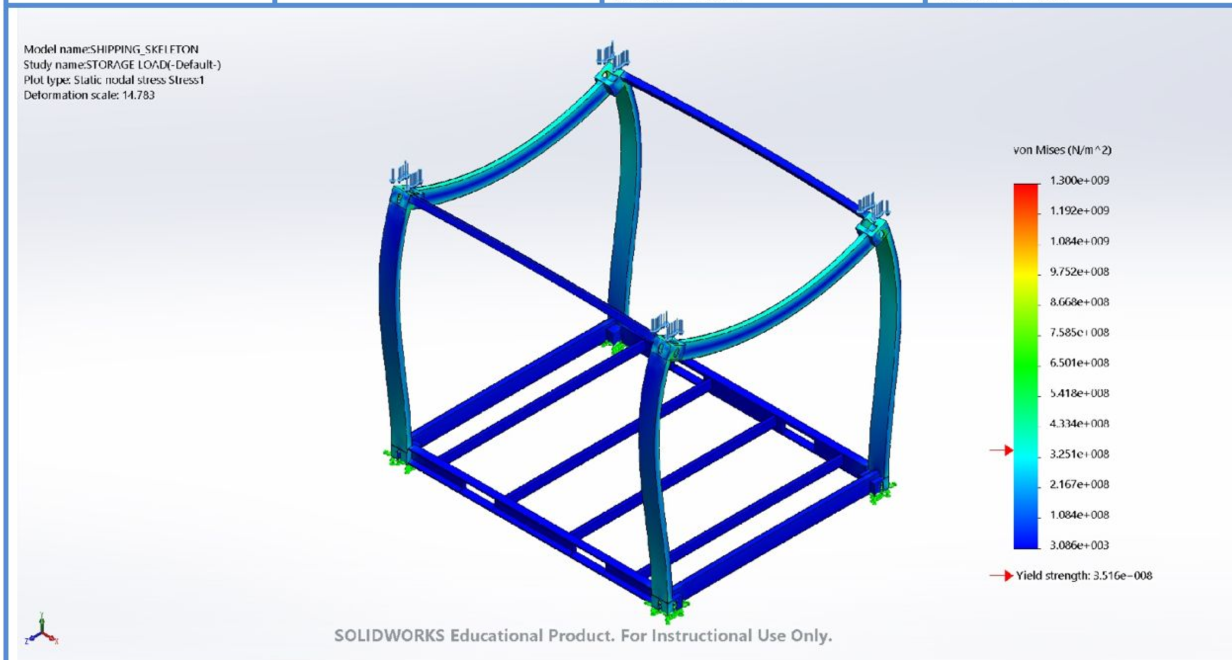
ASHRAE standard 55 is used to specify combinations of indoor thermal comfort environmental factors and personal factors which will allow for most occupants in a space to feel comfortable. The factors that influence thermal comfort in a space include temperature, thermal radiation, humidity, air speed, 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 67.2 CFM. To figure 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 square feet of natural ventilation from air leaks. This gives us a value of 4.8 CFM. So the total CFM that is required for a ventilation fan is 62.4 CFM.

5.7. 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

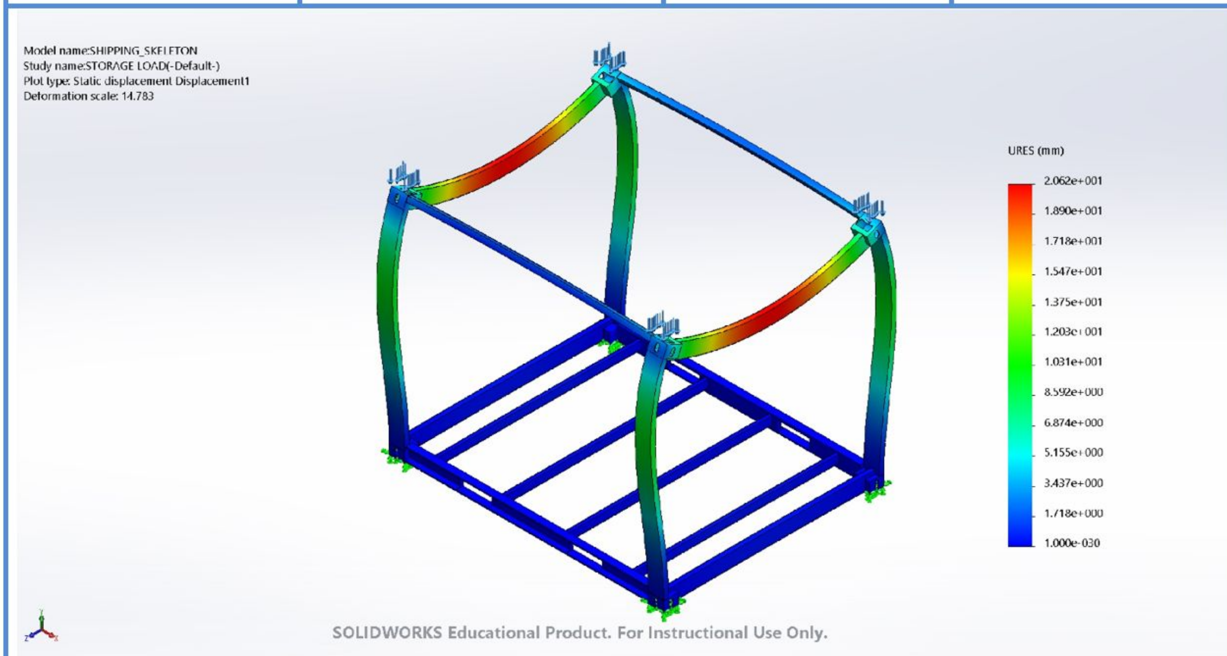


SHIPPING_SKELETON-STORAGE LOAD-Stress-Stress

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

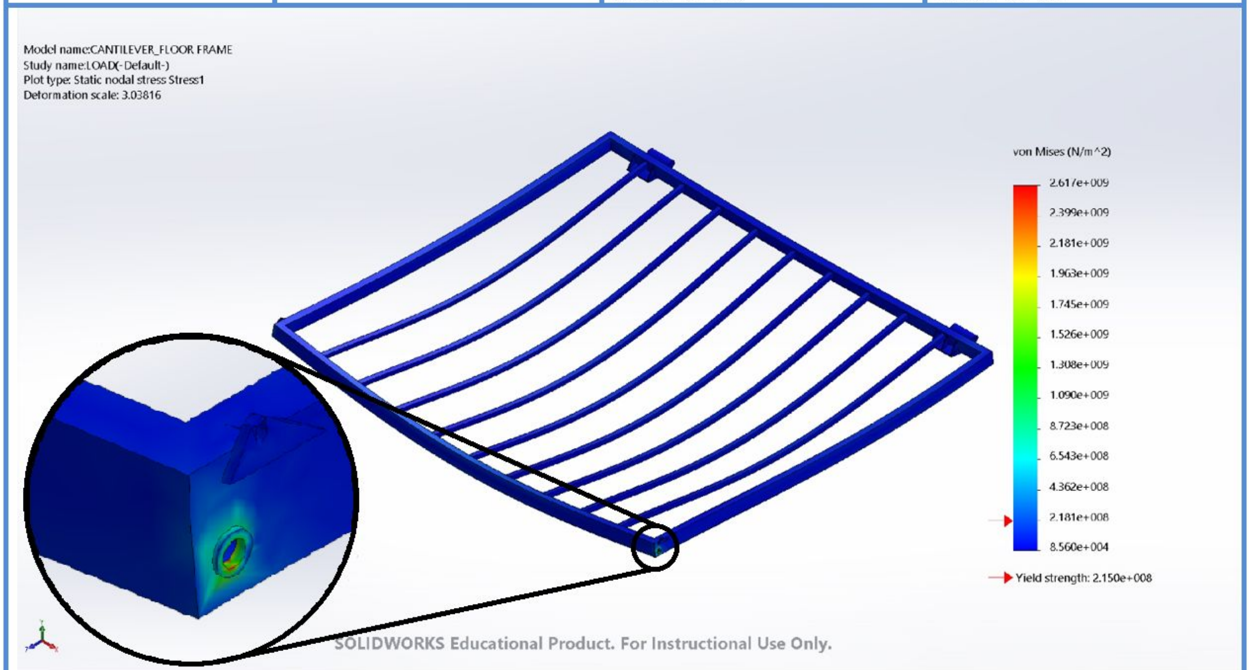


SHIPPING_SKELETON-STORAGE LOAD-Displacement-Displacement

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.

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

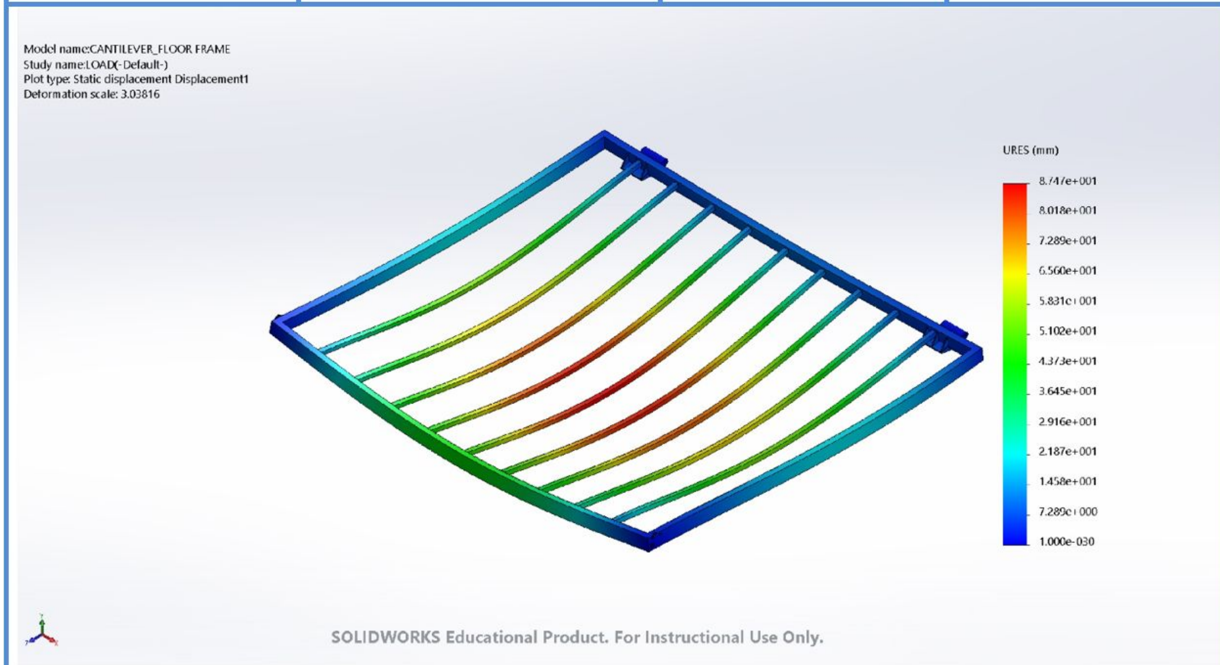


Figure 8. Cantilever Floor Displacement Analysis. Image show that the maximum displacement with the defined loading conditions in section 5.6 is about 90 mm (3.54 in).

In order to test ASHRAE standard 55, a tool[7] developed by the University of California Berkeley was used. The inputs for the program for the parameters previously defined in the section 5.6 were used. All of these factors combined to calculate a solution which can be located on a psychrometric chart shown in Figure 9, which was developed by this tool. The allowable area for human thermal comfort can be shaded on the chart and the location for the indoor environmental conditions is positioned in the middle of the acceptable comfort area. So these indoor environmental conditions and human assumptions successfully passes the ASHRAE standard 55. For ASHRAE standard 62 the ventilation system calculation is 62.4 CFM, which is below our current projection of 65 CFM, and passes the standard.

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

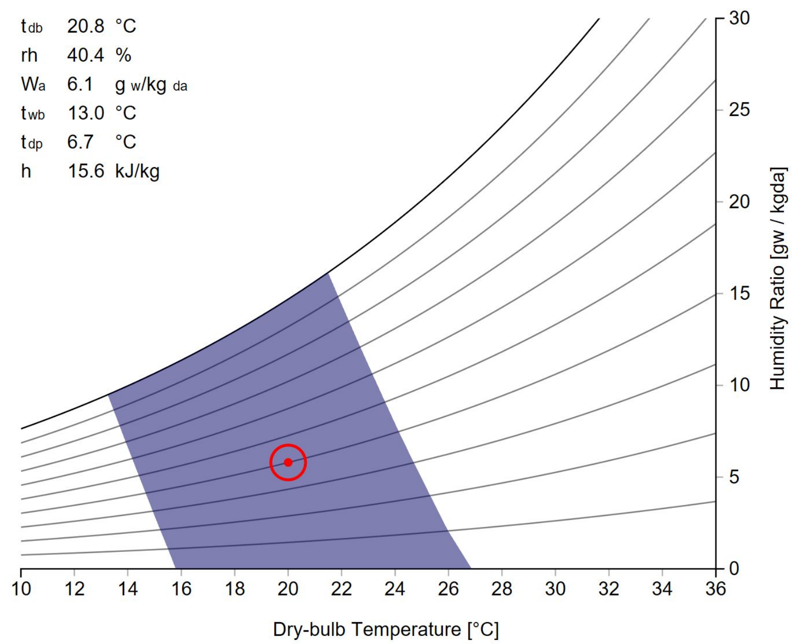


Figure 9. Psychrometric Chart for ASHRAE Standard 55. The red dot is the group's current placement on the psychrometric chart based on current metrics, which is within the the purple confines of ASHRAE comfort standards.

5.8. Performance and Compliance

The shipping container foundation is capable to withstand any typical logistic conditions without causing any damage to the encompassed shelter elements. This result was expected and reassuring that shelter won't structurally fail under logistic conditions and complies with the desired loading performance demand. The cantilever floor panel proved to fail in the cable supports under extreme conditions, failing the desired loading performance demand. The cantilever floor panel cable supports should be redesigned such that they don't fail under extreme loading conditions. All other aspects of the cantilever floor provided the desired loading performance.

For the HVAC CFP, our analysis has determined that our shelter passes both ASHRAE Standards 55 and 62. Our metrics for ASHRAE Standard 55 determined that we were in compliance with comfort standards as shown in Attachment 6. 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. With these two results, the group can move forward with our current metrics in designing the shelter to comply with ASHRAE standards.

Sustainability aspect of the shelter's structure was based on using environmentally friendly materials, product life span, and reusability. Using a recycled foldable shipping container was chosen to use a repurposed out of service shipping containers 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.

5.9. Design Refinement

There weren't many changes that needed to be made to the design after testing. The HVAC system was compliant with all ASHRAE standards, and thus did not need any further refinement. The structural system needs slight modification to decrease loading stress on the cable support of the cantilever floor. This will be accomplished by utilising a bracket that will distribute the load more consistently along the corner of the floor panel framing.

5.10. Final Design

The final design of the HVAC and structural systems has been completed for the ASHRAE Applied Engineering Challenge. The HVAC system uses the heat pump mini-split detailed in the previous sections, and the structural system uses the folding mechanism as seen in Section 4.4, Figure 1. With these two systems completed, the team will need to focus their efforts to other aspects of the design to ensure an adequate and complete report is provided to the ASHRAE Applied Engineering Challenge by the June 1st submission deadline.

6.0 Preliminary Recommendations

6.1. Design Recommendations for ASHRAE Competition

While the group has design recommendations for many systems, a full recommendation for the completed shelter has not been obtained. Because of the nature of our project, with many interconnected systems and subsystems, we have had to take extra time to do research and to fully understand our design needs before making final decisions. Our deadline with ASHRAE in June will allow the group more time to arrive at practical conclusions beyond just the two CFPs mentioned in Section 5. For decisions that cannot be made this semester, such as the unfinished CAD design as shown in Figure 1, the extra month after the semester will be critical to completing a full recommendation. We will need to finish the CAD design in entirety along with a final selection of some indoor materials and system integrations to complete our project.

For now, our recommendation for the structure consists of a shipping container that has been modified to fold outwards. The main systems contained within include a water storage tank along with a sink and foot pump for water management, PeePoo bags for the waste management, and a mini split along with dehumidifiers for our HVAC system. Our team has plans to continue our analysis and refinement of choices throughout the month of May ahead of ASHRAE's submission deadline, and look forward to making a full recommendation to ASHRAE.

6.2. Future Design Considerations for Real World Application

Our group met with Dr. Divya Chandraskhar in order to discuss some assumptions we had decided upon and to have her examine our approach to constructing a shelter. This meeting helped the design team reveal some of the unrealistic aspects of the temporary shelter design. The largest design flaw that was revealed during this meeting with Dr. Chandraskhar was the retrofit of a shipping container as the foundation of the design. Although shipping containers are optimized for all forms of transportation and logistics, they are not a solution that can be rapidly deployable on a practical scale. Especially when the only available form of transporting the designed shelter is by air, which is not uncommon for relief situations. Other issues with our design mainly involve the cost to include all of these systems which is unavoidable for the competition, but is a greater factor in reality. Governments and humanitarian organizations may not have adequate funds in order to build and transport these shelters, so lower cost housing options are more appealing. This allows for greater funds to be allocated to food and water resources, along with stipends for families to get back on their feet. This is all costly, and many of the amenities in our shelter would have to be reconsidered in order to make it a reality. This will be something that our group will explore in the coming semester in terms of adjusting our shelter for it to be more realistic, and reconsidering our choices that were forced on our group by the ASHRAE competition constraints.

7.0 Project Planning

7.1. Schedule

The table below organizes the design team's scheduled milestones for the project. A Gantt chart of specific goals and tasks would have been provide but, has proved to be difficult to scale and readability is limited.

April 6, 2018	Material Selection
April 27, 2018	HVAC Calculations
April 27, 2018	Total Energy Usage Calculation
April 27, 2018	Cost Analysis
April 27, 2018	CFP CAD design - Frame
April 27, 2018	CFP CAD design - HVAC System
April 27, 2018	CFP CAD design - Water Management
April 27, 2018	CFP CAD design - Electrical
April 27, 2018	CFP CAD design - Waste Management
June 1, 2018	Final Paper - Sustainability Assessment
June 1, 2018	Final Paper - Quantitative Analysis
June 1, 2018	Final Paper - Explanations of each quantitative item
June 1, 2018	Final Paper - Materials List
June 1, 2018	Final Paper - Cost Analysis
December 6, 2018	Built Shelter Model

Table 6. Projected Project Schedule.

7.2. Second Design Semester: Fall Semester 2018

What is expected for the future semester is currently vague and ill-defined. Future expectation ideas are still being discussed with project advisors and will hopefully be resolved over the 2018 summer semester. Currently, the design team's primary goal is to compete in the 2018 ASHRAE Applied Engineering Challenge. Ideally for the future semester, the design team will identify their own design constraints that are more applicable to real-world circumstances.

7.3. Budget

The nature of this project persuades the design team to develop two types of budgets. One being of the academic variety, and the other being of the real-world application variety. These two budgets are explained in sections 7.3.1 for the academic budget, and section 7.3.2 for the real-world application.

7.3.1 Academia

Academia Budget		
	Allotted	Used
Shelter Model	$250	$0
ASHRAE Standards (55 & 62)	$250	$0

Table 7. Academic Budget. Resources utilized for design processes.

The ASHRAE standards 55, and 62 were donated to us by Survey and Testing Services; Standard 55 valued at $105.00 per copy and Standard 62 valued at $99.00 per copy. Computer models were generated from the already accessible Solidworks software available to engineering students at the University of Utah.

Currently, the design team is only planning on building a scale model of the designed shelter solution; the model scale should not exceed $250 to construct. Building a full scale model would be ideal but, organizing sponsorship for this project will be extremely difficult. Difficulty derives from foreign policies and political complication about disaster relief across country borders.

7.3.2 Design Implementation

Shelter Materials Projected Cost	
Shipping Container	$2000
Raw Building Materials	$5000
Heat Pump Mini-Split	$2000
Ventilation	$800
Water Storage	$200
Total	$10,000

Table 8. Implementation Budget. Real-world temporary shelter material costs.

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 is unrealistic as government need to allocate funds for other relief dividends. On the extreme end of shelter costs, if we assume the shelter costs $100,000 to construct and implement, then it would take between 2-24 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.

Currently the designed temporary shelter material costs sum to $10,000, 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.

7.4. 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 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.

The sustainability scoring for the water management system was based upon the disposal after use. The 100 gallon tall 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.

8.0 Reference Material

Appendix A | Concept Selection

For readability, the concept selection charts have been abridged to show only the selected design, or top options considered.

HVAC Concept Selection Chart

HVAC Concept Selection Scoring								
METRICS & WEIGHTS			Mini Split			Packaged Terminal Heat Pump		
Metrics:	Sub Metrics:	Weight:	Rating	Weighted Rating	Rational	Rating	Weighted Rating	Rational
Heating Loads	0.3							
2,143 Btu/hr	Heating Capacity	15.00%	5	100%	18000 Btu's/hr	5	100%	7000 Btu's
	Efficiency	15.00%	5	100%	13 eer=btu/watts eer =energy effciency rating	4	100%	11.5 eer
Cooling Loads	0.1							
3,996 Btu/hr	Cooling Capacity	15.00%	5	100%	15000 Btu's/hr	5	100%	7000 Btu's
	Efficiency	15.00%	5	100%	21 seer=btu rejected/watts	4	100%	11.6 eer=btu/watts
Size	0.05							
	Dimensions	5.00%	4	100%	11.635"x31.4375"x9.125" inside 3338in^3	3	100%	42"w x16"t x 7.25"d inside 4872in^3
Complexity of Installation	0.075	0.075	3	100%	Essentially, you need to attach both the indoor and outdoor units, connect refrigerant lines, and make some electrical connections.	4	100%	Essentially cut a hole, install the sleeve, and slide it in, and make electrical connections.
Cost	0.1	10.00%	2	100%	$1000-$3000 depending on BTU's needed, from Home depot website	3	100%	$700-$1100 from home depot website will need to purchase a sleeve if not included.
Maintaince	0.05							
	Interval Between Service	2.50%	3	100%	service every 6 months by spraying off the compressor. And every few months changing the filter	3	100%	Recommended to check or replace filters monthly.
	Availability of parts	2.50%	5	100%	Depends on the manufactor, but lots of websites that sell parts for mini splits	4	100%	There are some websites that sell replacement parts, but all depends on manufactor.
Life Expectancy	0.1	10.00%	3	100%	12-15 years (shelter life is 20 years)	2.5	100%	10 years (shelter life is 20 years)
Noise	0.025	2.50%	4	100%	indoor unit 19-49 dB, outdoor 58-65 dB, depending on load	3	100%	indoor 43-49 dB outdoor 58-61dB
	Weight Total	100.00%						
Total Score			4.225			3.95		
Rank			1			2		

Attachment 1. HVAC Concept Selection Chart with selection metrics and rating justifications. A heat pump Mini-split is the primary concept to satisfy HVAC requirements.

Water Management Concept Selection Chart

METRICS & WEIGHTS			100 Gallon Cylindirical Tank - Tall			100 Gallon Cylindrical Tank - Short		
Metrics:	Sub Metrics:	Weight:	Rating	Weighted Rating	Rational	Rating	Weighted Rating	Rational
Ease of Use		20.00%	3	100%	Height is a concern for refilling	4	100%	Smaller tank, and easy to work with cylinder
Maintenance		15.00%	4	100%	Regular checkups for leakages is fine	4	100%	Regular maintenance should be fine
Storage Capacity		15.00%	5	100%	Can store 2 days water	5	100%	Can store 2 days water
Ease of Setup		10.00%	4	100%	Ease of cylinder, but height could be an issue	5	100%	Ease of cylinder and no height concerns
Lightweight		10.00%	4	100%	Tied for lightest	4	100%	Tied for lightest
Climate Proof		10.00%	3	100%	Concerns over algae growth	4	100%	Will be fine inside, dark color should stop algae growth
Environmentally Friendly		10.00%	4	100%	Environmentally friendly until no longer used, concerns over long term degradability	4	100%	Environmentally friendly until no longer used, concerns over long term degradability
Long Term Use		10.00%	4	100%	Plastic should hold up, concerns over abuse due to height (78 inches)	5	100%	Made of polyethylene, no major long term concerns
	Weight Total	100.00%						
Total Score			3.85			4.35		
Rank			2			1		

Attachment 2. Water Management Concept Selection Chart with selection metrics and rating justifications.

Waste Management Concept Selection Chart

METRICS & WEIGHTS			PeePoo Bags			Compostable Toilet		
Metrics:	Sub Metrics:	Weight:	Rating (X/5)	Weighted Rating	Rational	Rating (X/5)	Weighted Rating	Rational
Strucuture	0.15							
	Sturdiness	6.00%	4	100%	Flexible, but could rip	4	100%	Strong plastic
	Weight	3.00%	5	100%	Very lightweight	4	100%	<200 lbs
	Size	6.00%	4	100%	Would need to store 96 packages for 1 years supply	2	100%	very large tank
Sustainability	0.3							
	ECO-Friendy	15.00%	5	100%	Biodegradable, enriches soil	5	100%	creates usable compost
	Long-Lasting	9.00%	5	100%	Shelf life of 10 years	5	100%	Lasts years
	Scalable	6.00%	4	100%	With extreamly high density of usage, might run out of places to bury	4	100%	might have issues with high density smell
Comfort	0.3							
	Sanitary	18.00%	5	100%	Extreamly sanitary	5	100%	Extreamly sanitary
	Low mainance	6.00%	5	100%	Zero maintance	4	100%	would require some mainance
	Easy to Use	6.00%	4	100%	Some symbolic directions	3	100%	removal of treated waste would take instruction
Installation / SETUP	0.05	5.00%	5	100%	Include bags with every shelter, no plumbing or set up needed	4	100%	Would come preinstalled with every shelter
Cost	0.1	10.00%	5	100%	2 cents per bag	2	100%	~$5000
Refugee POV	0.1	10.00%	5	100%	Very versitile to support any cultural need	3	100%	Only suitable for sitting style
	Weight Total	100.00%						
Total Score			4.76			3.94		
Rank			1			2		

Attachment 3. Waste Management Concept Selection Chart with selection. Collaboration with the Peepoo organization is the primary consideration for waste management solutions.

Temporary Shelter Design Concept Selection Chart

METRICS & WEIGHTS			Integrated Shipping Container Solution		
Metrics:	**Sub Metrics:**	**Weight:**	Rating	Weighted Rating	Rational
Strucuture	0.25				
	Sturdiness	12.50%	5	100%	STRUCTURE WILL BE CONSTRUCTED WITH STEEL, FOLD OUT FLOORS MAYBE "BOUNCY"; THERE IS A POSSIBILITY TO MAKE THE FLOORS MORE RIGID.
	Size	12.50%	4.6	100%	THE SIZE OF THE STRUCTURE IS AROUND 240 FT^2 (240/260*5 = ~4.6)
Sustainability	0.15				
	ECO-Friendy	5.10%	4	100%	RECYCLED SHIPPING CONTAINERS, SINCE THE STRUCTURE IS OF A RECLAIMED MATERIAL.
	Long-Lasting	7.50%	5	100%	CONTAINER CAN LAST 20 YEARS BEFORE RUST BEGINS TO DEVELOP.
	Reusability	2.40%	5	100%	SHELTERS ARE INTENDED TO BE REUSED, STACKED, AND STORED; UNTIL NEW SHELTERS ARE AVALIBLE OR SHELTERS COMPLETELY FAIL.
Comfort	0.2				
	HVAC Ventilation	15.00%	5	100%	STRUCTURE WOULD HAVE BALANCED AIR, NATURAL VENTILATION, AND HVAC. WOULD COMPLY WITH ASHRAE STANDARDS.
	Security	5.00%	5	100%	VERY SECURE, RIGID, ONLY WEAK PIONT WOULD BE WINDOWS, AND POSSIBLY FOLDED WALLS. IF WALLS PIN LOCK INTO PLACE, ISSUE IS AVOIDED.
Installation / SETUP		10.00%	5	100%	FLOOR, WALL, AND CEILING UNFOLD IN MINUTES. EVERYTHING WOULD "SNAP" INTO PLACE.
Cost		10.00%	2	100%	THE COST WILL BE HIGHER FOR A 10' SHIPPING CONTAINER, DOUBLE FOLD OUT. (240 FT^2; ASSUME ~$42.00-$100.00 A FT^2)
Manufacturing	0.15				
	Construction	7.50%	2	100%	FOLDING PARTS MAY BE DIFFICULT TO MANUFACTURE
	Material Type (Working With)	2.50%	4	100%	STEEL/ALLOY FRAME, POSSIBLY WOOD, MOSTLY STEEL STRUCTURE AND SUPPORT. METAL JUST REQUIRES THE CORRECT TOOLS.
	Accesibility of Material	5.00%	5	100%	STEEL AND ALLOYS ARE COMMON BUILDING MATERIALS. EASY OBTAINABILITY.
Refugee POV	0.05	5.00%	5	100%	BETTER THAN A TENT, AND WOULD BE AN ACTUAL STRUCTURE.
	Weight Total	100.00%			
Total Score			4.349		
Rank			1		
Development					

Attachment 4. Temporary Shelter Concept Selection Chart with team identified metrics and rating justifications.

Structural Concept Selection Chart

	METRICS & WEIGHTS			TEN FOLD ENGINEERING	
Metrics:	Sub Metrics:	Weight:	Rating	Weighted Rating	Rational
					USE ONE OF TEN FOLD ENGINEERING LINKAGES
*PANNEL WEIGHT					
PANNEL STRENGTH	0.2				
	AMBIENT STRUCTURAL LOADING	10.00%	5	100%	ENGINEERED TO BE EXPOSED TO AMBIENT LOADING, MAY NEED TO BE ADJUSTED FOR SNOW LOADS
	CANTILEVER LOADING (HANGING ITEMS ON WALL)	5.00%	2	100%	WALLS ARE NOT DESIGNED TO HAVE WALL CANTILEVER LOADING; DESIGN WHOULD NEED TO BE ADJUSTED
	STRUCTURAL INTEGRITY	5.00%	4	100%	LINKAGES AND PANNELS ARE ENGINEERED AND DESIGNED TO BE STRUCTUALLY SOUND ; WILL STILL NEED TO BE MODIFIED TO SUPORT WALL LOADING
EASE OF SET UP	0.4				
	UNFOLD DIFFICULTLY	20.00%	4	100%	ALL LINKAGES ARE COUNTER BANANCED; VERY EASY TO UNFOLD AND TO INSTRUCT HOW TO
	INTERCONNECTION LINKAGES (ABILITY TO CONNECT PARTS)	12.00%	5	100%	PANNELS ARE FAIRLY EASY TO UNFOLD AND CONNECT; TEN FOLD ALLOWS ESSENTIALLY ALL AUTOMATIC UNFOLDING PARTS
	MANUAL UNFOLD (MANNED LABOR)	4.00%	0	100%	VERY MINIMUM MANUAL UNFOLDING
	TOOL UNFOLD (HAND CRANK)	4.00%	3	100%	TEN FOLD IS A TOOL CRANK UNFOLD; THIS MAY REQUIRE MORE TIME IN ORDER TO COMPLETELY UNFOLD.
MANUFACTURING DIFFICULTY	0.2				
	DESIGN	10.00%	1	100%	VERY COMPLEX LINKAGES AND UNFOLDING DESIGN; WOULD NEED TO REQUEST TEN FOLD'S LICENSING
	COST	2.00%	2	100%	WILL NEED TO GET TEN FOLD ENGINEERING TO BE APART OF DESIGN AND PROVIDE THEIR DESIGNED LINKAGES AS WELL AS THEIR MANUFACTURING SPECIFICATIONS
	CONSTRUCTION	4.00%	3	100%	COMPLEX CONSTRUCTION; MAY NOT BE EASY TO ASSEMBLE; ALTHOUGH ALL LINKAGES ARE PIN-BASED, UNFOLDING MECHANISM MAY BE THE DIFFICULT BIT
	MAINTENANCE EASE	4.00%	2	100%	MAINTENANCE COULD BECOME DIFFICULT WITH MORE MOVING PARTS; MORE ITEMS THAT COULD GO WRONG FASTER
SPACE CAPACITY		10.00%	4	100%	UNFOLD CAPABILITYS ARE ENDLESS; CAN VIRTUALLY UNFOLD TO ANY DIMENTIONS DESIRED
FOLDED EMPTY SPACE		10.00%	3	100%	WILL BE SHIPING SOME EMPTY SPACE BUT, COULD LIMIT THE AMMOUNT OF WASTED SPACE
	Weight Total	100.00%			
Total Score			3.36		
Rank			1		
Development					

Attachment 5. Structural Concept Selection Chart with selection metrics and rating justifications. Ten Fold Engineering concept is the primary design for the shelter structure.

Exterior Wall Material Selection Chart

Material Concept Selection Scoring					
METRICS & WEIGHTS			**S Glass**		
Metrics:	**Sub Metrics:**	**Weight:**	Rating	Weighted Rating	Rational
Cost	0.25				
	Cost	25.00%	3	100%	$464 per layer for 8.9 oz weave + epoxy
Weight	0.2				
	Pounds	20.00%	4	100%	0.09 lb/in³ 48.3 lbs per layer + epoxy
Durability	0.2				
		20.00%	4	100%	Will not damage with minor impacts
Weather Effects	0.3				
	Thermal expansion	0.15	4	100.00%	.025" from 0 to 90 degree F (in fiber direction)
	Water Absorption	0.15	4	100.00%	With proper epoxy water absorption should be minimized
Life Expectancy	0.05	5.00%	3	100%	Will deteriorate over time, unsure of how long
	Weight Total	100.00%			
Total Score			3.7		
Rank			1		

Attachment 6. Wall Material Selection Chart with selection metrics and rating justifications. Chart used aluminum siding as a baseline and compared carbon fiber and S-Glass fiberglass.The use of S-Glass and epoxy is the best option.