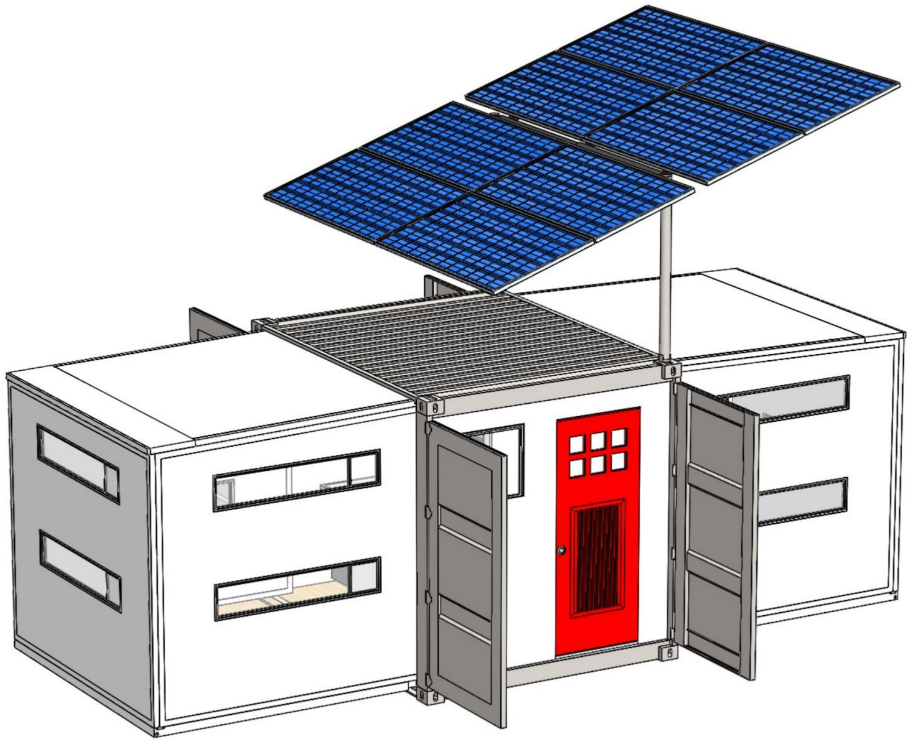

ASHRAE 2018 Applied Engineering Challenge:
Temporary Refugee Shelter
The Setty Family Foundation: 2018 Applied Engineering Challenge

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Executive Summary

December 2015, for the first time ever according the the UN Refugee Agency, the number of forcibly displaced families surpassed 60 million. 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.

The challenge consists of designing a structure that both shelters refugees as well as provides essential domestic systems. Constraints of the shelter included 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 standards that 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, also the shelter's sustainability, environmental impacts, and fiscal considerations.

The team's decision regarding a structure resulted in a retrofitted shipping container that has foldable walls to expand the occupiable space 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. Other provided systems deemed critical to day-to-day life were water management, waste management, and HVAC 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 completed major systems decisions through concept selection charts and analysis.

Following a 3rd place finish, we took our refugee shelter and designed a sustainable power generation system while maintaining most of the assumptions of the challenge. The primary assumptions that we are using are in line with the competition standards except for the height requirement. This began with calculating average power consumption demands over a broad range of weather conditions and places, and research in sustainable renewable energy power generation options.

Research of sustainable energy sources pushed for further investigation into solar and wind energy generation. Other alternative energy sources were found to be too location specific, expensive, or simply, impractical for implementation. Using eight Canadian Solar Polycrystalline panels mounted on a solar array frame on the roof, along with fifty rechargeable zinc-air batteries installed within the shelter, we are able to reliably power the shelter throughout Eastern Europe using solar power for ten months out of the year in the worst case scenario. This includes power storage for up to 3.6 days for heavy utility, but for countries in December and January throughout the northern half of Eastern Europe, such as Estonia and Sweden, there is not enough light to reliably sustain the heating loads of the shelter. In countries such as Switzerland, Ukraine, and latitudes further south, we can reliably power the shelter year-round.

Acknowledgements

Team Advisors:

Dr. Amanda Smith is an assistant professor of Mechanical Engineering at the University of Utah. Her research specializes in distributed energy resources, distributed energy generation, building science, building energy modeling, and environmental impacts.

Zahra Fallahi Arezoudar 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.

Dr. Thomas Tran received his doctorate in Mechanical Engineering from the University of Utah in spring of 2018. His research interests include renewable energy, energy systems, microgrid energy, energy efficiency, and building energy.

Team Consultants:

Dr. Divya Chandrasekhar is an assistant professor for The Department of City & Metropolitan Planning at the University of Utah. The meeting with her was informative for understanding the current conditions of refugee camps and understanding how our design could me improved to meet current refugee needs.

Dr. John Horel is a professor of Atmospheric Sciences at the University of Utah. Helped the team to understand the possibilities and drawbacks of wind energy for our shelter based on wind.

Data Usage:

NOAA weather data was used to compute the shelter energy consumption and solar energy generation.

Table of Contents

1.0 Introduction

Our design project is split into two major phases. The first phase, was to design a shelter for the 2018 ASHRAE Applied Engineering Challenge. ASHRAE[1] specified design constraints for this shelter based on a variety of factors, see Table 1 for more details on constraints and judging criterion. Our final design featured an HVAC system that uses a heat pump mini-split system, and a structural folding system involving a folding mechanism to allow for easy transport of the shelter.

ASHRAE Design Competition Constraints and Relevant Judging Criterion	
Design Space	Shelters must have a height no greater than $2.6\ m\ (8.5\ ft)$ and a total square footage no greater than $24\ m^2\ (260\ ft^2)$ and should accommodate 6-8 people in an Eastern European location.
Design Systems	Shelters will have no access to municipal water or sewer, choice of essential domestic systems for the shelter is left to team discretion and justification. Provided power connections are assumed to be 220V single phase with a maximum current draw of 15 amps.
Judging Criterion	Relevant judging criterion is use and justification of ASHRAE Standard 55, Thermal environmental Conditions for Human Occupancy, and ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality.
Other Considerations	Report Presentation and Justification of Ideas, Reporting Methods, Shelter is Tough Enough to be Portable, Use of Resilient Materials, Creative Use of Space, Energy Efficiency, Cost, Ease of Setup, Sleeping Capacity, Integration of Essential Systems, Water Management, Waste Management, and required system maintenance.

Table 1: ASHRAE Applied Engineering Design Competition constraints and relevant judging criterion.

After competing in the ASHRAE competition, we began the second phase of our project. The second phase was to research and design a power generation system for the shelter using renewable energy technology. We had to understand both the energy demands of the shelter, and the renewable energy potential of the different areas the shelter was designed for. Once we had completed this preliminary research, we could begin to design a renewable power generation system which could provide reliable power to the shelter. For this new design, we chose to carry over the same constraints from the ASHRAE competition, with the exception of the 8.5 foot height restraint. This was omitted to allow for the placement of power generation devices on top of the shelter.

[1] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

2.0 Design Requirements

2.1 ASHRAE Applied Engineering Challenge Shelter Design

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 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.

ASHRAE Applied Engineering Challenge Needs			
Customer Needs Reference #	Customer Needs Hierarchy	Description	Importance
1	Primary	Structure Provides Shelter	5
2	Primary	Shelter provides essential domestic systems	4
3	Secondary	Shelter constructed from extensively available materials	
4	Secondary	Structure provides low manufacturing and development costs	

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

Table 2: ASHRAE Applied Engineering Challenge Shelter Design requirements by defined Customer needs, hierarchy of needs, and the importance of the customer need. Importance is on a scale of 5, with a 5 being the most important and a 0 being negligible. Primary needs are the only needs being scaled on the level of importance, as secondary and tertiary needs, from the primary needs are implied to have the same importance as the primary need; since these needs need to be satisfied to satisfy the primary needs.

2.2 ASHRAE Shelter Design with Sustainable Power Generation and Storage

For phase two of our project, our design has to be efficient, reliable, and able to generate enough power to meet the demands of the shelter. The power generation system needs to use the available space effectively, and cannot overcome inefficiencies with a greater size or area. It also needs to be reliable. As it will be the primary power source for the shelter, it cannot be prone to failure or susceptible to variations in weather from day to day. A robust storage system needs to be designed to store enough power for the shelter to sustain itself in the event of an outage. Finally, the power generation system needs to be able to meet the demands of the shelter to support the essential domestic systems within. This system will be the sole source of power for the shelter, so it must meet or exceed the yearly power demands to provide a reliable, effective source of clean power. Since the sustainable generation and storage system is being designed outside the ASHRAE challenge, we chose to do away with the height constraint on the design. All other constraints remained consistent across both phases of the project.

Additional Temporary Shelter Sustainable Power Generation Needs			
Customer Needs Reference #	Customer Needs Hierarchy	Description	Importance
25	Primary	Provide Sustainable Power to the Shelter	5
26	Primary	Provide Adequate Energy Storage	4
27	Primary	Ability to Reliably Generate Power	4
28	Primary	Power System must be able to package within the Shelter	4

Table 3: ASHRAE Applied Engineering Challenge Shelter Design with Sustainable Power Generation requirements by Customer needs. Importance is on a scale of 5, with a 5 being the most important and a 0 being negligible. Again Primary needs are only being scaled on a level of importance. This need are in addition to the ASHRAE Applied Engineering Challenge needs.

3.0 Design Specifications

The design tables in this section are to illustrate the details and specifications of the project design, and their relation to customer needs. Metrics were employed to ensure customer needs are properly satisfied. Justification of the metrics utilized are defined in this section as well.

3.1 Overview of Metric Specifications

Temporary Shelter Design Metric Summary						
Metric #	Customer Need #	Metric	Imp.	Metric Units	Marginal Value/Range	Ideal Value
1	1, 2, 20, 21, 25, 26	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	Yess
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, 26, 28	Shipping Weight	3	kg, lbs	< 6800 kg, 15,000 lbs	5000 kg, 11,000 lbs
6	13, 14, 16, 23 ,25	Assembly Size	3	m^2, ft^2	< 24 m^2	~ 20 m^2
7	18, 25, 26	Set-up and Assembly Time	4	minutes	120-240 min	<45 min
8	3, 6, 7, 17, 19, 25, 26	Sustainability	5	Boolean	No / Yes	Yes

9	2, 6, 11, 26, 27	Power Consumption	5	W, kWh, BTU/hr	< 13 kWh/day	Location Dependent
10	2, 11, 21	Water Management	4	Boolean	No / Yes	Yes 100 Gal. fresh water, 50 Gal grey
11	2, 11	Waste Management	4	Boolean	No / Yes	Yes
12	2, 9, 26, 27	Heating and Cooling Capacity	3	BTU	Heating: ~2143 BTU/hr Cooling: ~3996 BTU/hr	Heating: 8400 BTU/hr Cooling: 6000 BTU/hr
13	2, 5, 6, 7, 11, 17, 19, 25, 26, 27	Operational Cost	4	$, €	< $100.00/day Startup: < $25000	$95.00/day Startup: < $25000
14	16, 18, 23, 25, 26	Solution Creativity	2	Range	1-5	5
15	25, 27	Sustainable Power Generation	5	kWh	>200 kWh per month	>200 kWh
16	26, 27, 28	Power Storage	4	kWh	93.5 kWh	67.2kWh

Table 4: Design Metric Value Table. Table identifies the specific values to be used for the given metric. Reference customer needs are listed in Table 2 (ASHRAE Applied Engineering Challenge) and Table 3 (Sustainable Power Generation).

3.2 Description of Each Design Specification

Temporary Shelter Design Metrics Description			
Metric	Customer Need #	Imp.	Description
Integrated Essential Systems	1, 2, 20, 21, 25, 26	4	Structure needs to be able to provide sustainable power (Electricity) reliably day or night, 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, 26, 28	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. The power storage will need to be limited due to the excessive weight of some batteries. The power generation will also need to be light and modular to allow for ease of shipping. 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, 25	3	The shelter, when completely assembled and unfolded, uses less than the full available space allocated for the design competition. A solar array was added to the top of the structure which increases the height but not the footprint of the shelter. 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, 25, 26	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 60 minutes for a complete initial set up; this only includes unfolding (15 min) the shelter and initial integrated system setup time (45 min). The solar panel assembly will be bolt together with color coded plugs for quick easy assembly. 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, 25, 26	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. The shelter should have self sustaining power, depending on location, for at least 80% of the year. 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, 26, 27	4	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 4.
Water Management	2, 11, 21	5	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 5.
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, 26, 27	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. In order to provide the heating and cooling we need to be able to generate the power to run the heat pump and have power stored for heating and cooling during off peak times. We designed for thermal loading in climate zone Dfb. This was chosen as the majority of Eastern Europe is zoned Dfb. It is a colder, humid climate making cooling not as necessary as heating. As a result, while it is important to have good heating, since cooling is not required, it is ranked as a 3.
Operational Cost	2, 5, 6, 7, 11, 17, 19, 25, 26, 27	4	The shelter should cost under $100 a day to operate, and less than $27,700 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. To keep operating costs down the team implemented power generation and power storage into the design. 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, 25, 26	5	The solution should be creative in use of time, materials, energy generation, energy storage, 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.
Sustainable Power Generation	25, 27	5	The shelter will be required to utilize sustainable power generation sources, with the intention of not diminish the quality of life and affecting the health of local ecosystems. Sustainability is critical to the project and therefore, this metric is ranked as a 5.
Power Storage	26, 27, 28	4	The shelter will be required to store unutilized sustainable power generation for later consumption when sustainable

			power generation is not available. Keeping the cost within reason will be difficult with a large reliable power storage system and will increase the weight of the shelter solution. Therefor, the power storage metric is ranked as not being absolutely critical to the shelter but, still important; reflecting a rank of 4.

Table 5: 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 Tables 2 (ASHRAE Applied Engineering Challenge) and Table 3 (Sustainable Power Generation).

3.3 Metric Value Justification

Temporary Shelter Design Metric Values and 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	5000 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	~ 20 m^2	The shelter, when completely assembled and unfolded, uses less than the full available footprint space allocated for the design competition. Determined by shelter storage size and unfolding capacity. Height of the shelter will exceed the 8.5ft (2.6 m) limit to satisfy the need of sustainable power generation requirements.
Set-up and Assembly Time	45 min - 2 hours (with solar generation)	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. Including the solar power generation system, it is expected to take a couple of hours to set up the solar array; there are more parts that need to be assembled together that will take more time.
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; this metric is location and occupant dependent.
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: 8400 BTU/hr Cooling: 6000 BTU/hr	The shelter must be able to provide about 1500 BTU/hr for heating and, if found necessary, 475 BTU/hr for cooling. Designed thermal loading and capacities were determined by the climate conditions of climate zone Dfb..
Operational Cost	TBD ($95.00/da y Startup: < $25000)	The shelter should cost under $100 a day to operate, and less than $25000 for startup cost without sustainable power generation; less than $35000 with sustainable power generation. 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.
Sustainable Power Generation	>200 kWh/mon	This value is location, occupant thermal preference, and seasonally dependent. The shelter was found to be most effective when the sustainable power generation system is able to output an average of at least 200 kWh/month; more temperate ambient conditions of summer, the power demand is lower, the colder months of winter, the power demands are higher, and occupant initialized demands are assumed to be constant. Power generation will need to be wired for 24V to meet the AC power demands and DC power demands.
Power Storage	67.2 kWh (~3.6 Days)	The power storage is limited to 67.2 kWh (~3.6 Days heavy utility) due to the limited space within the selter and the batteries utilized; batteries being utilized have a capacity of 1.344 kWh per battery. Batteries to be used are rechargeable Zinc-Air; estimated to fit 50 batteries within the shelter. Power storage will need to be wired for 24V to meet the AC power demands and DC power demands.

Table 6: Metric justification Table. Table lists the metrics utilized for the project, their values, and justification of the values.

4.0 Conceptual Design

Design concepts considered included shelter structure, HVAC, water management, waste management, and power generation. The structural design for the shelter was decided using a concept selection chart shown in Appendix C attachment 4. Options included a shipping container, integrated folding shipping container, fabric scaffolded shelter, and collapsible material home. The integrated folding shipping container was chosen based on structure, sustainability, comfort, installation, cost, and manufacturing. The 10 foot folding shipping container choice allows for a small packaged unit for shipping, but a large interior area when unfolded for occupancy.

A heating ventilation and air conditioning (HVAC) system was selected using a concept selection chart shown in Appendix C attachment 1. Options included a ductless air source heat pump (mini-split), packaged terminal heat pump, hydronic heated floor system, baseboard heaters, passive solar heating, and a wood burning stove. The minisplit was selected based on the criteria of heating and cooling load capacity, size, complexity of installation, cost, occupant health impact, life expectancy, and quietness. The system provides both heating and cooling into one unit and allows for renewable energy integration because of the electrical energy source. It is also paired with the Eva Dry 500 for dehumidification.

The water management system was picked using a concept selection chart shown in Appendix C attachment 2. The options included tanks between 50 and 100 gallons with criterion of ease of use followed by maintenance, storage capacity, as ease of setup, lightweight, and climate proof. A 100 gallon potable water storage tank was chosen that can be filled by the communal water tap.

The waste system was chosen using a concept selection chart shown in Appendix C attachment 3. The options included Peepoo bags, a classic household toilet, a compostable toilet, or zero waste solution. The selection was based on structure, sustainability, comfort, installation, cost, and the users point of view. The Peepoo bag option was chosen for covering the entire waste management process, from the toilet to treatment. Peepoo bags are made to be used as fully self-contained, individual, compostable toilets.

The electricity generation of the shelter was selected through process of elimination. The options included photovoltaic solar panels, wind turbine, gasoline generator, diesel generator, biofuel generator, hydroelectric turbine, hydrogen fuel cell, and geothermal steam turbine. The selection was based on sustainability, energy capacity, transportability, fuel availability, cost, and setup. Emphasizing on a sustainable shelter we chose the photovoltaic solar panels coupled with a zinc air battery storage system. We considered a small wind turbine for the shelter along with solar panels, but determined it would not be worth the extra cost and space of a turbine due to the unreliability of wind for various locations. Eight Canadian Solar Polycrystalline panels were chosen to make the shelters solar system. The solar panels and battery bank offer to meet most power demands of the electrical appliances throughout the year.

5.0 Final Design

The final design of the shelter begins with a modified shipping container that folds out as shown in Figure 1 above. This cantilever folding system lowers the aluminum walls of the container and expands the space into one large conjoined space that is approximately 192 square feet of livable space. After the main container is complete, two bars and couplers would be installed on top for the solar array to hold the 8 solar panels. Inside of this container contains water, waste, and HVAC management systems to meet living conditions and ASHRAE Standards.

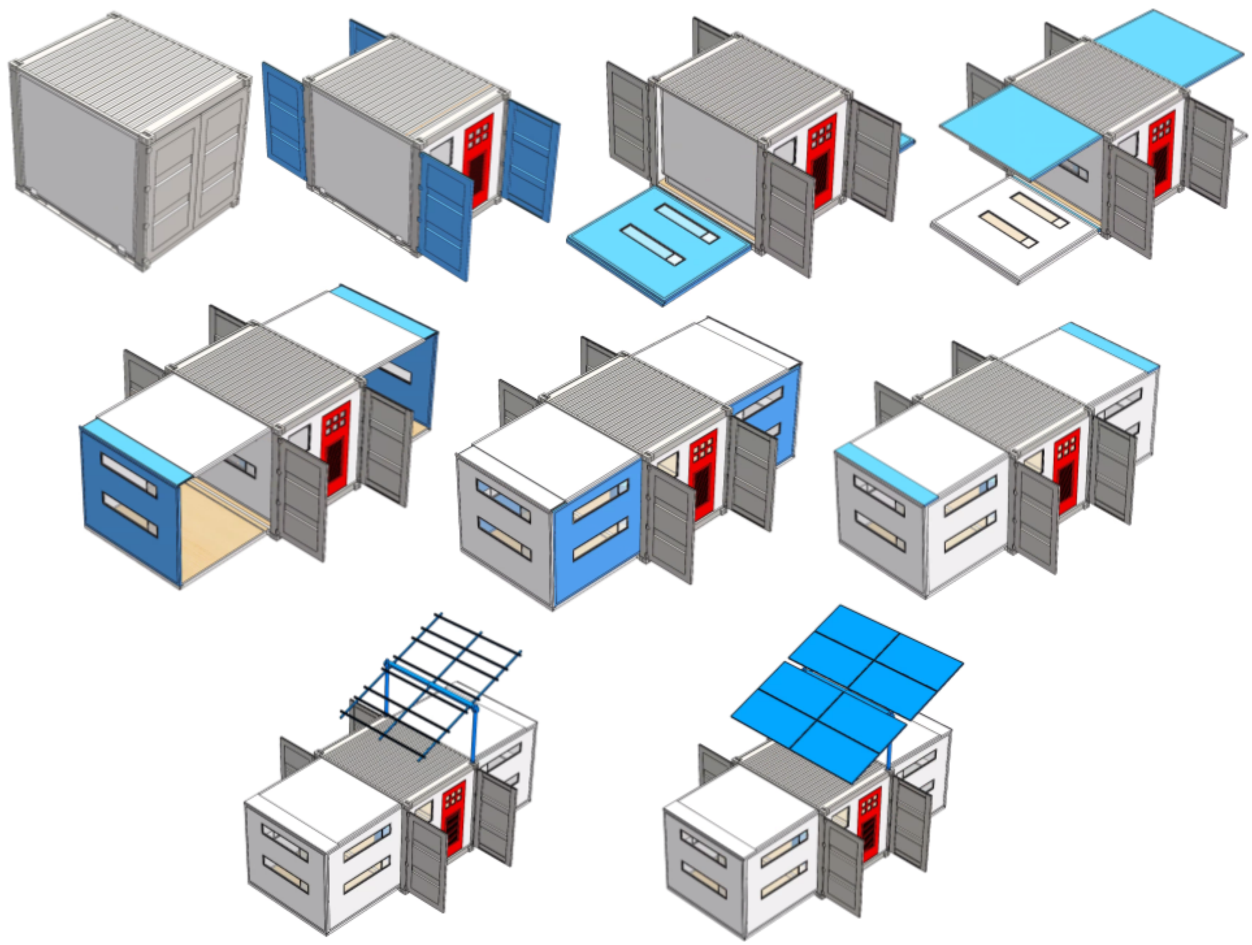

Figure 1: Final shelter design depicting the required steps for complete assembly of the shelter once on site.

Water management was handled by installing a 100 gallon polyethylene potable water storage tank with a foot pump and sink. The tank will be a dark color so as to prevent algae growth due to sun exposure, and the foot pump and sink will help with easy water access for any cooking, cleaning, or drinking needs. The sink will drain to a smaller gray water tank for disposal and with the 100 gallon tank being only 42" in height, it should be easier to refill than a larger tank.

For waste management, we used PeePoo's biodegradable bags for ease of use and transportability. These bags post-use will biodegrade in approximately two weeks and create a fertilizer that can be used in soil. They are exceptionally convenient in that they can be used anywhere and help to prevent the biohazards that can be caused with no municipal sewer system.

To meet ASHRAE Standards, a 6000 BTU Mitsubishi mini split with dehumidifiers was used to keep the shelter comfortable for refugees. With heating in a cold dfb climate being our main temperature concern, R-10 foam insulation inside of the walls along with this 6000 BTU mini split provided enough heat generation to keep the shelter warm in the colder months of the year. The dehumidifiers were added to help deal with the humid climate and keep the shelter within ASHRAE Standard 55. The E^2 heat recovery ventilation system was installed to keep the shelter in compliance with ASHRAE Standard 62 at around 60 cubic feet per minute.

The 8 panels on top are 300W Canadian Solar polycrystalline panels which harness our solar energy and divert it to the 50 NantEnergy rechargeable zinc-air batteries; 46 batteries installed in the ceiling of the shelter and 4 accessible from the maintenance panel, along with the inverter. The batteries store about 3.6 days of power storage in the event of a storm that blocks most of the solar power that could be obtained. The inverter is an Aims Power 1500W continuous 3000W surge inverter which should handle our electrical load, simplified schematic shown in Figure 2 below.

The shelter interior contains about 192 square feet of interior space with some LED light bulbs, double pane glass windows, and an outlet for phone chargers included. Finally, there is a hot plate meant for boiling water and other cooking purposes as necessary. While the shelter is being transported, everything will be placed inside the container to make each shelter independent. The base shelter can be built on site without the use of large power tools or significant manpower to its own benefit. We reasoned that two people with a hand drill could reasonably setup the base shelter, while more manpower and tools would be required for the solar panel installation.

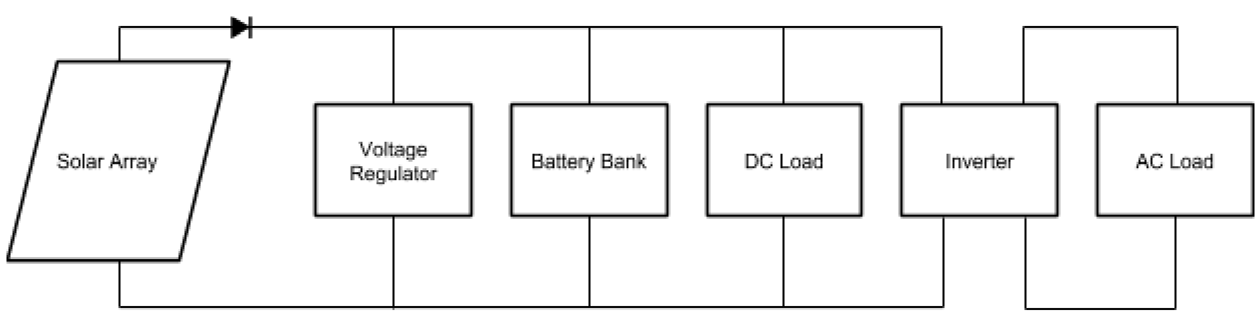

Figure 2: Solar Power Generation System simplistic schematic.

6.0 Performance Verification

Verification of performance was validated by utilizing computer model simulations and sample calculations to estimate necessary components of the shelter's power characteristics. As a physical model of the shelter design is outside our budget, time frame, and availability of necessary work space. Utilizing computer models and sample calculations to estimate power characteristics seemed to be the most appropriate and practical verification method. Performance verification requires the analysis of two power characteristics of the shelter, the shelter's power consumption demands and shelter's power generation reserves; with these we can estimate for how much demand is met by reserves.

The amount of power consumption utilization and power generation availability is dependent on the geographic location and orientation of the shelter. Performing an analysis on 40 cities across Eastern Europe and the United States is sought to adequately justify the power demands for the shelter; assuming that the solar array faces south and is at an angle equivalent to the cities latitude.

Country	**Location**	**Köppen Classification**[2]	**Surveyed Cities**
Estonia	Eastern Europe	Dfb	Tallinn | Pärnu | Tartu | Valga
Germany	Central Europe	Dfb & Cfb	Hamburg | Cologne | Berlin | Munich
Greece	Eastern Europe	Csa	Larissa | Thessaloniki | Athens | Aegina
Poland	Eastern Europe	Dfb	Gdynia | Warsaw | Wrocław | Kraków
Sweden	Northern Europe	Dfb & Dfc	Stockholm | Gothenburg | Malmö | Kalmar
Switzerland	Central Europe	Dfb	Zürich | Bern | Lucerne | Grindelwald
Ukraine	Eastern Europe	Dfb	Kyiv | Lviv | Poltava | Odessa
United Kingdom	Western Europe	Cfb	Edinburgh | Leeds | Liverpool | London
United States	North America	BSk, Dsb, Dfa, Csb, & Cfa	Seattle, WA | Minneapolis, MN | Dallas, TX | Atlanta, GA | Salt Lake City, UT | Saint George, UT | Park City, UT | Wendover,

[2] The Köppen Climate Classification is one of the most widely used climate classification systems that subdivides terrestrial climates into five major types; A (Tropical), B (Arid), C (Temperate), D (Cold), and E (Polar). The Köppen Climate Classification specified when designing the shelter is Classification Dfb (Warm-Summer, humid, coldest month average below −0 °C (32 °F), at least four months average above 10 °C (50 °F), and all months average below 22 °C (71.6 °F), with no significant difference in precipitation between seasons).

			UT

Table 7: List of cities across Europe and the United States utilized for power demand analysis with major Köppen Classification of the cities surveyed.

6.1 Power Consumption Analysis

Power consumption were estimated by utilizing monthly averaged ambient low and high temperature weather data provided by NOAA[3] for 40 cities across Eastern Europe and the United States; averaged between all surveyed are shown in Figure 3. Estimating the power consumption across the United States allows for a relative climate comparison, as the shelter is designed for an Eastern European location but, could be implemented anywhere in the world

Power consumption demands are estimated by calculating the required latent heat, sensible heat, solar heat gain, occupant heating loads, and projected occupant circuit loads. Projected occupant circuit loads are assumed to be constant by assuming the occupants have a daily power demand based off daily activities; estimated daily consumption about 3.0 kWh. Occupant metabolic heating loads are also assumed to be constant with a heating output of 175 W per occupant. Other heat sources, latent heat, sensible heat, and solar heat gain, are dependent on ambient conditions including the ambient temperature, relative humidity, and solar irradiance; these are all location and seasonal specific heating sources. Required heating, or cooling, from these sources are subjected to Standard 55 Thermal Environmental Conditions for Human Occupancy.

[3] National Oceanic and Atmospheric Administration (NOAA)

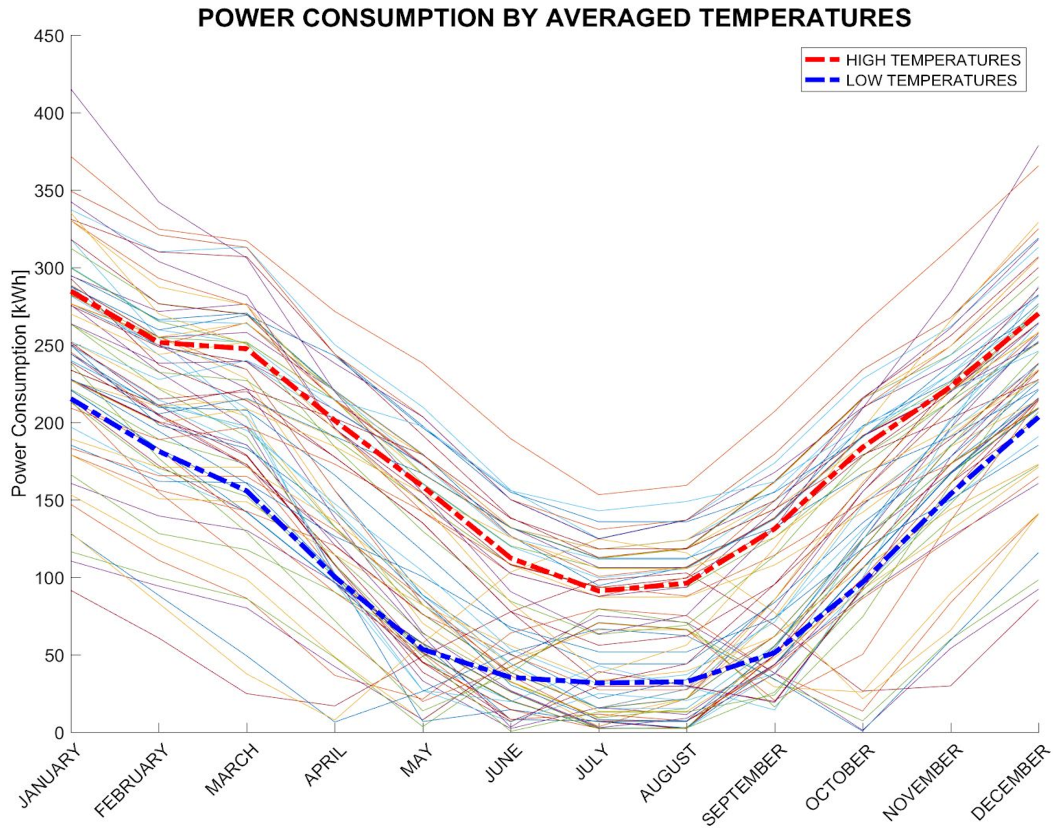

Figure 3: Estimated Annual Power Consumption per month utilizing ambient temperature from NOAA for the 40 examined cities. The dotted red line indicates the estimated average energy consumption for ambient high temperatures. The dotted blue line indications the estimated average energy consumption for ambient low temperature.

6.2 Power Generation Analysis

Power generation were estimated by utilizing the amount of available solar hours and seasonal irradiance of the surveyed location; data provide by NOAA. The amount of power generation is also seasonal and geographic location dependent. Climate conditions that experience more precipitation and are farther from the equator, will experience less solar power generation. Figure 4 depicts the average solar generation across the 40 cities across Eastern Europe and the United States surveyed.

Estimating the amount of solar power compatible with adequate utilization, included not only the data provide by NOAA but, also the latitudinal position of the surveyed city, its climate classification, and the assumption that only 80% of the accessible solar power generation is utilized. Assuming 80% of the accessible solar power generation is utilized allows for a worse case situation to be analysed; as we can only predict the weather conditions and efficiency of the system without an actual implemented model. Accessible solar power generation includes the availability of direct solar power to the occupant and the ability to store excess solar power generation into a power storage system for later consumption.

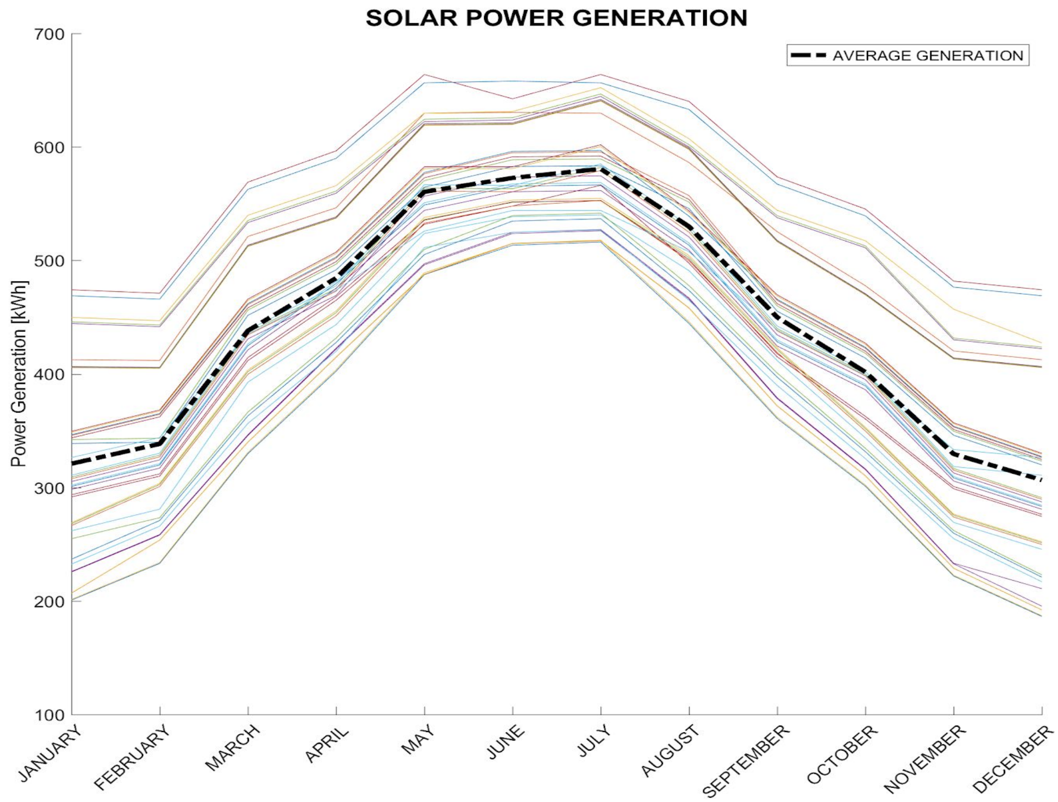

Figure 4: Estimated Annual Power Generation per month utilizing Solar Availability from NOAA[4] for the 40 examined cities. The average power generation across the analysis is indicated with the dotted black line. Cities with high solar generation reside in Greece, and cities with low solar generation reside in Sweden and Estonia.

6.3 Power Demand Results

The reliability of the shelter's power generation reserve is dependent on the geographic and climate location of the shelter. Most locations surveyed are estimated to meet, or exceed, the power consumption demand using the prescribed solar power generation design. In the summer months, the solar power generation reserves will exceed the power consumption demands and provide sustainable power reliably throughout the summer months. In the winter months, the power consumption demand will most likely exceed the solar power generation reserves and will require an alternative source of power to satisfy the shelter's power consumption demands.

Since the power demands are dependent on location, climate classification, and orientation relative to the sun, we are able to estimate the shelter's power demands for a given location. Appendix B has the average power generation and consumption for the countries involved in the power demand analysis calculations performed for the 40 cities in Europe and the United States. The assembly of an actual shelter deployment are subject to change, as rapid deployment may result in supply shortages

[4] National Oceanic and Atmospheric Administration (NOAA)

and alterations to original specifications. Assuming that equipment with similar performance characteristics are utilized, we'll review the two worse case result extremes, Greece and Estonia.

Shelter operations in Estonia will prove to be difficult to maintain the power consumption demains using only the designed sustainable solar generation resources. This is due to Estonia's northern latitude, deficiency in accessible solar irradiance, and Estonia's Köppen climate classification. Estonia's Köppen climate classification is Dfb, which is defined as having a warm summer, is humid, the coldest month average below −0 °C (32 °F), at least four months average above 10 °C (50 °F), and all months average below 22 °C (71.6 °F), with no significant difference in precipitation between seasons.

Shelter operations in Estonia will require either additional panels to be added to the designed solar array, or an alternative form of backup power generation, in order to satisfy the power consumption demands. Power demand will be met 70.8% of the time on a 90% confidence interval with the prescribed solar array configuration; another source of power will be required in order to meet the other 29.2% power demand. The difference between power generation and power consumption may easily be compensated if the shelter is able to connected to the local grid system. Allowing the shelter to be connected to the grid would allow for the removal of the energy storage system and incentivize the local utility by providing the excessive power generation to be plugged back into grid. Otherwise, a backup generator, or similar source of power, will need to be provided for the shelter to operate adequately in the colder months of Estonia.

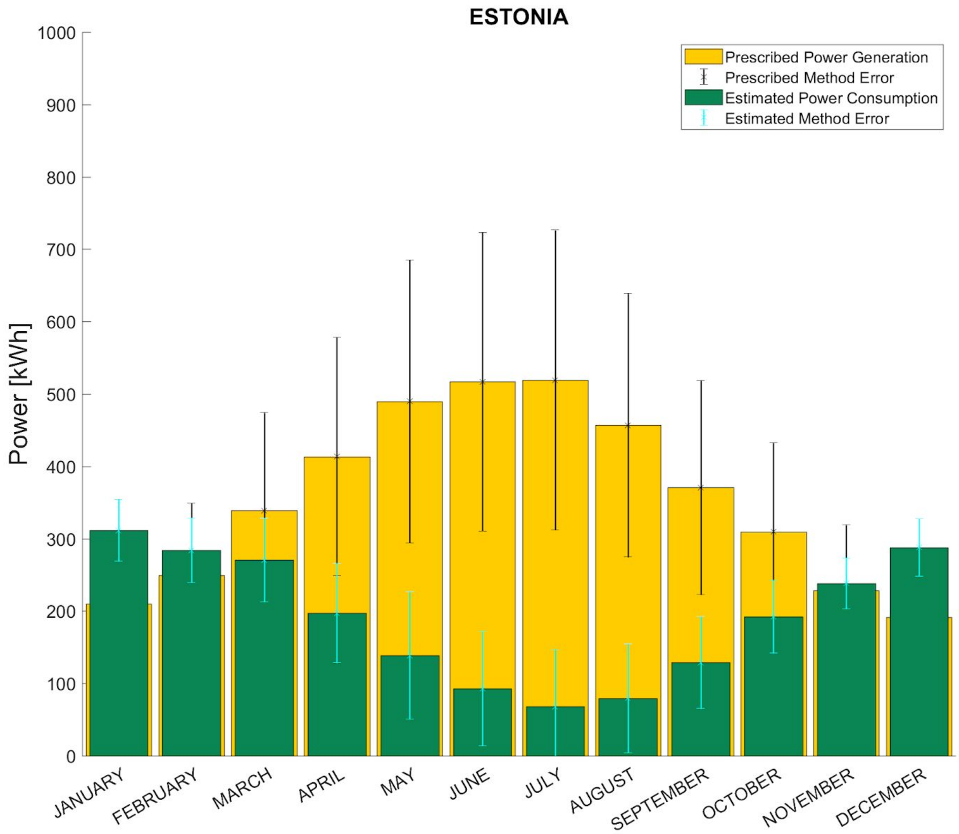

Figure 5: Power demand average details by month for Estonia. Figure shows the details of Estonia from Appendix B. With the Prescribed Solar Design, the shelter on average can be reliably powered throughout the months of May to September in Estonia. The months of January and December the power generation will not meet the power consumption demand. In the months of February, March, April, October, and November the power generation may meet the power consumption with permitting weather.

Shelter operation in Greece will reliably provide the shelter with sustainable power generation and maintain the power consumption demands by utilizing the prescribed solar generation design. Power demands will be met 100% of the time on a 90% confidence interval with the prescribed solar array configuration. Greece is located closer to the equator and has more accessible solar irradiance than most of the other locations surveyed and has a Köppen climate classification of Csa. The Köppen climate classification of Csa is defined as a Mediterranean climate having a hot summer, the coldest months average above 0 °C (32 °F), at least one month averages above 22 °C (71.6 °F), and at least four months average above 10 °C (50 °F), with three times as much precipitation in the wettest month of winter as of the driest month of summer, and the driest month receives less than 30 mm (1.2 in) of precipitation. With the climate of Greece being a more temperate climate, there is less power demand for heating and cooling the shelter and meeting the thermal environmental conditions for human occupancy requirement.

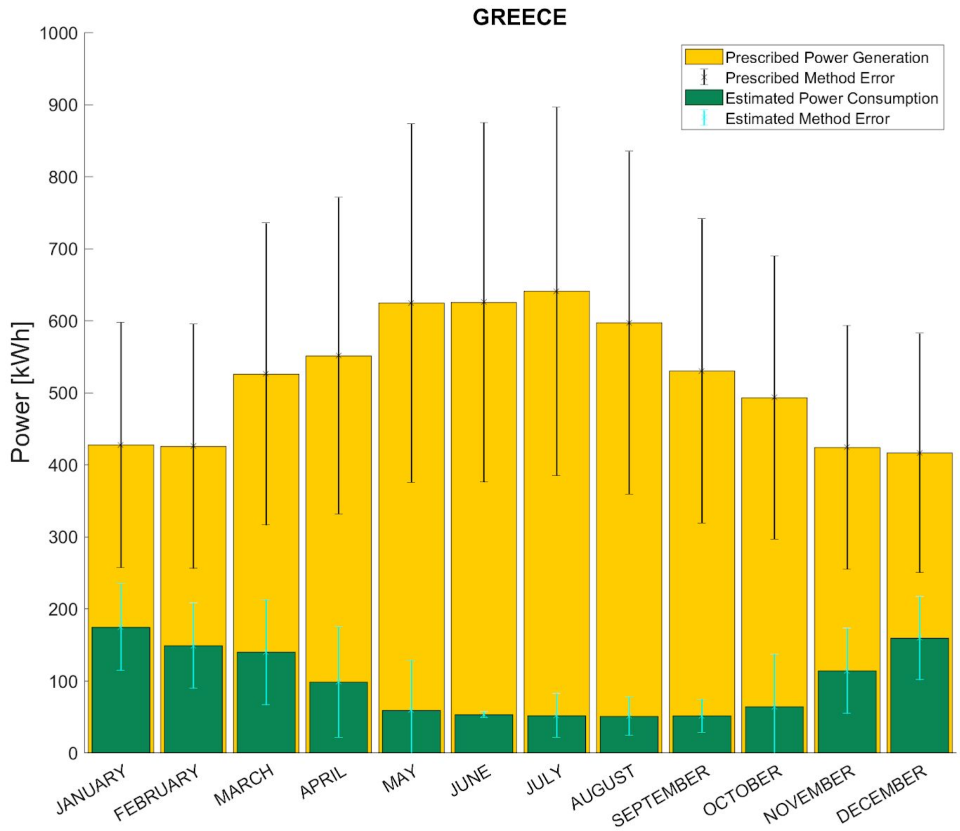

Figure 6: Power demand average details by month for Greece. Figure shows the details of Greece from Appendix B. With the Prescribed Solar Design, the shelter on average can be reliably powered throughout the months of January to December in Greece.

Shelter operations between the two extreme case of Estonia and Greece, will be able to provide sustainable power generation above 70.8% of the time on a 90% confidence interval with the prescribed solar array configuration. Which is expected, as we didn't expect all the shelter's power consumption demand to be met by the prescribed solar array configuration for worse case situations; due to the limited amount space and high power demand. Providing more than 70.8% of power demands from the prescribed power generation and storage system for the majority of the worse case situations, satisfies our intentions of providing sustainable power generation for the shelter and reliability of the system.

Assuming that the occupants have more moderate system utility habits, moderate power demands, shelter location within the designed climate classification of Dfb, and a latitude location less than that of 58°N. The prescribed power generation system will be able to met these power demands nearly 100% of the time. If the occupants require higher system utility, or have high power demands, or if shelter is outside the designed climate classification. The prescribed power generation system will only be able to provide about 70% of the power demands for the countries surveyed in this verification analysis.

7.0 Project Planning

The first semester of this project was to ensure the team would compete in the ASHRAE Applied Engineering Challenge; Table 8 lists the major milestones and their completion dates. The first semester of this project didn't prvoke too many revisions dates and all milestones where complete in their estimated time allocation. The team members had some issues with rendering the CAD model and responded appropriately by pushing the CAD completion date out. Closer to the competition submission date the team did push the report compilation to the submission deadline. This was to ensure all necessary components were adequately and appropriately portrayed within the 25 page technical report ASHRAE defined in the format of the competition submission.

ASHRAE Applied Engineering Challenge - Primary Milestones Schedule			
Milestones	Planned Completion Date	Revised Completion Date	Completed
Understanding Project Scope	02/08/18	--	02/08/18
Finalize ASHRAE Customer Needs and Assumptions	02/01/18	--	02/01/18
Finalize Shelter Design Brainstorm Ideas	02/22/18	--	02/22/18
Finalize Shelter Design Idea Selection	03/02/18	--	03/02/18
Finish Preliminary CAD Model	03/08/18	--	03/08/18
Finalize Essential System Integration Analysis	03/22/18	--	03/22/18
Finalize Shelter Design Engineering Calculations	03/22/18	--	03/22/18
Finalize HVAC Design Engineering Calculations	03/22/18	--	03/22/18
Complete Full ASHRAE Shelter CAD Design	04/19/18	05/15/18	05/15/18
Submit ASHRAE Technical Report Compilation	04/19/18	06/01/19	06/01/18

Table 8: Primary ASHRAE Applied Engineering Challenge milestone schedule with necessary revision dates.

The second semester of this project was to design a sustainable power generation system and storage system for the designed shelter submitted to the ASHRAE Applied Engineering Challenge. The second semester major milestones and their completion dates are listed in Table 9. The milestones listed at the beginning of the semester were pushed to a later date to adequately define what was to be expected and completed for the second phase of the ASHRAE Temporary Shelter design. After that the only dates pushed were the CAD design and Design Review II. Due to the CAD design taking longer than expected, and the Design Review II presentation being rescheduled to another date.

Temporary Shelter Sustainable Power Generation - Primary Milestones Schedule			
Milestones	Planned Completion Date	Revised Completion Date	Completed
Complete Estimate for Shelter Power Demand	09/19/18	09/21/18	9/21/18
Feasibility of Renewable Wind Energy Sources	09/19/18	09/21/18	9/21/18
Feasibility of Renewable Solar Energy Sources	09/19/18	09/21/18	9/21/18
Feasibility Analysis of Alternative Power Options	09/19/18	--	9/14/18
Power Calculations for Renewable Energy Capacity	09/28/18	--	09/28/18
Finalize Power Sources for Shelter	09/28/18	--	09/28/18
Present Midterm Prototype Design Review	10/04/18	--	10/04/18
Complete Midterm Paper	10/05/18	--	10/05/18
Finalize the Power System Design and Calculations	11/12/18	--	11/12/18
Submit Draft of Poster for Review	11/15/18	--	11/15/18
Complete Solidworks Design of System	11/16/18	11/26/18	11/26/18
Complete Full System Power Analysis	11/16/18	--	11/16/18
Present Design Review II	11/20/18	11/08/18	11/08/18
Finalize Poster Design	11/30/18	--	11/20.18
Present Shelter Design at Design Day	12/04/18	--	12/04/18
Submit Final Design Report	12/10/18	12/10/18	12/10/18

Table 9: Primary Temporary Shelter Sustainable Power Generation milestone schedule with necessary revision dates.

8.0 Budget

The estimated budget to implement the shelter varies greatly depending on the location of the shelter or camp. Different countries allocate very different amounts of funds for refugees. In eastern europe, this budget can range from as low as $1,054 to as high as $12,800 per refugee. In addition, these funds cover all of the costs of housing and caring for each refugee. For the purposes of this assessment, we assumed that 50% of the available funds would go towards housing, with the ramain money going towards food, water, medical care, and other resources. With the capacity of the shelter ranging from 6-8 people, the total available funds per shelter were estimated to be between $4,216 at the low end, and $51,200 on the high. The cost of materials for the shelter is $33,446.26 This means that the ability to fully fund and implement the shelter would very much depend on the country the shelter is being used in, with some countries able to allocate the proper funds, and others coming up short.

The academic budget for this project was $0, as all of the design work was done in Solidworks, and no actual building or materials purchasing was done. All calculations were executed using Matlab, or Excel.

9.0 Conclusions

This project achieved a great deal of its goals across both semesters. In the first semester, we successfully competed in the ASHRAE 2018 Design Challenge. Our shelter met the requirements defined by ASHRAE, providing structural integrity and insulation from the elements , an effective HVAC system capable of handling the climate in Eastern Europe, and waste and water management systems. These systems, and all assumptions made to justify their design, were presented to the competition judges in the form of a 25 page technical report. Our report won third place internationally in the competition.

In the second semester, we chose to design a practical renewable energy system. The system featured a solar panel array, and was able to reliably power the shelter in most European locations. In combination with an energy storage system, we felt confident that our system could provide power year round in south-eastern Europe. We had planned on providing power regardless of location, however we were not able to provide reliable, year round power in north eastern Europe. The winter climate in north-eastern Europe was not conducive to generating solar power, and we were not able to overcome this challenge. In order to fulfil the goal of location independent power, improvements would need to be made to the energy generation and storage systems. These improvements could include more storage capacity, a larger solar panel array, or an alternative form of energy generation that would be less affected by the northern winter.

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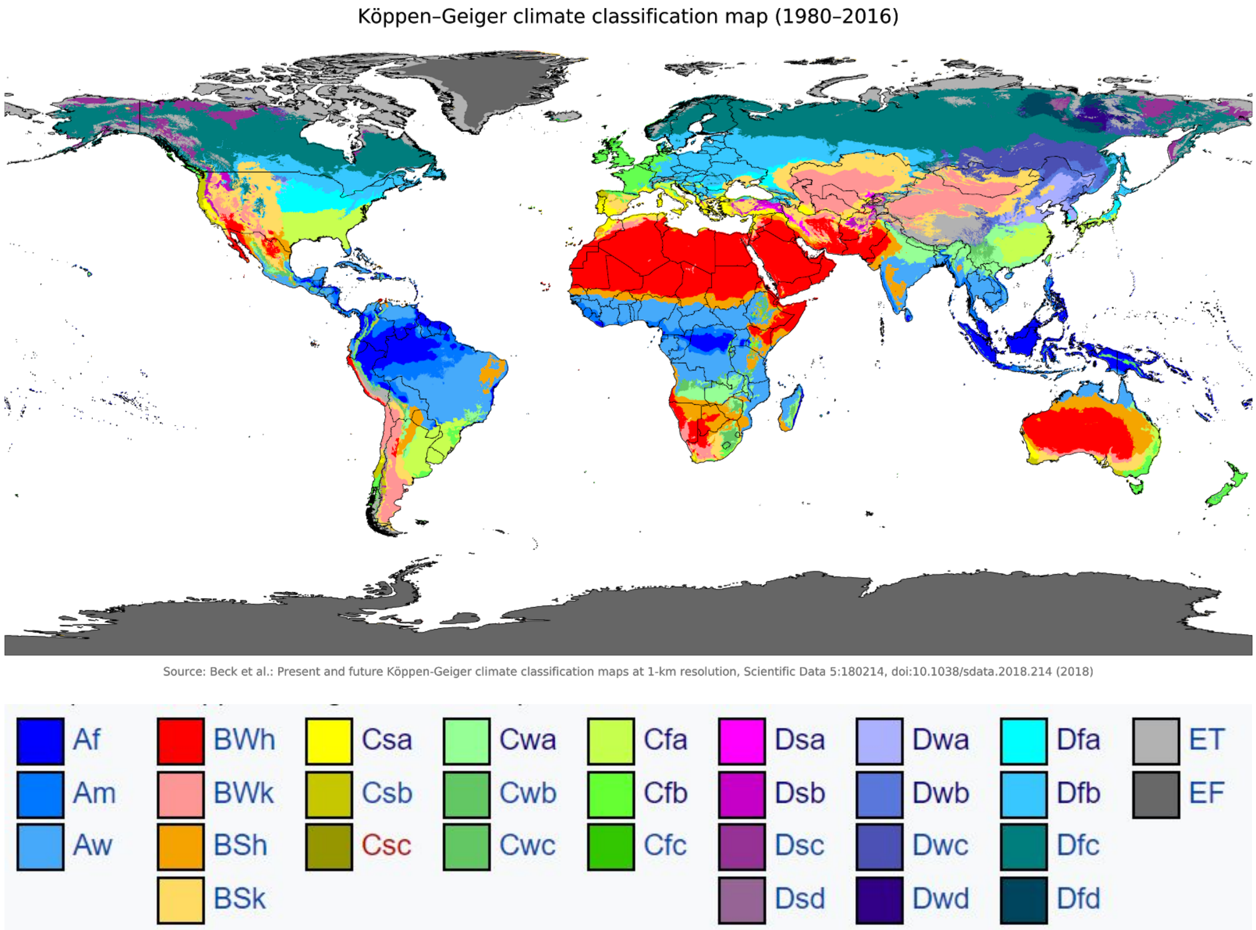
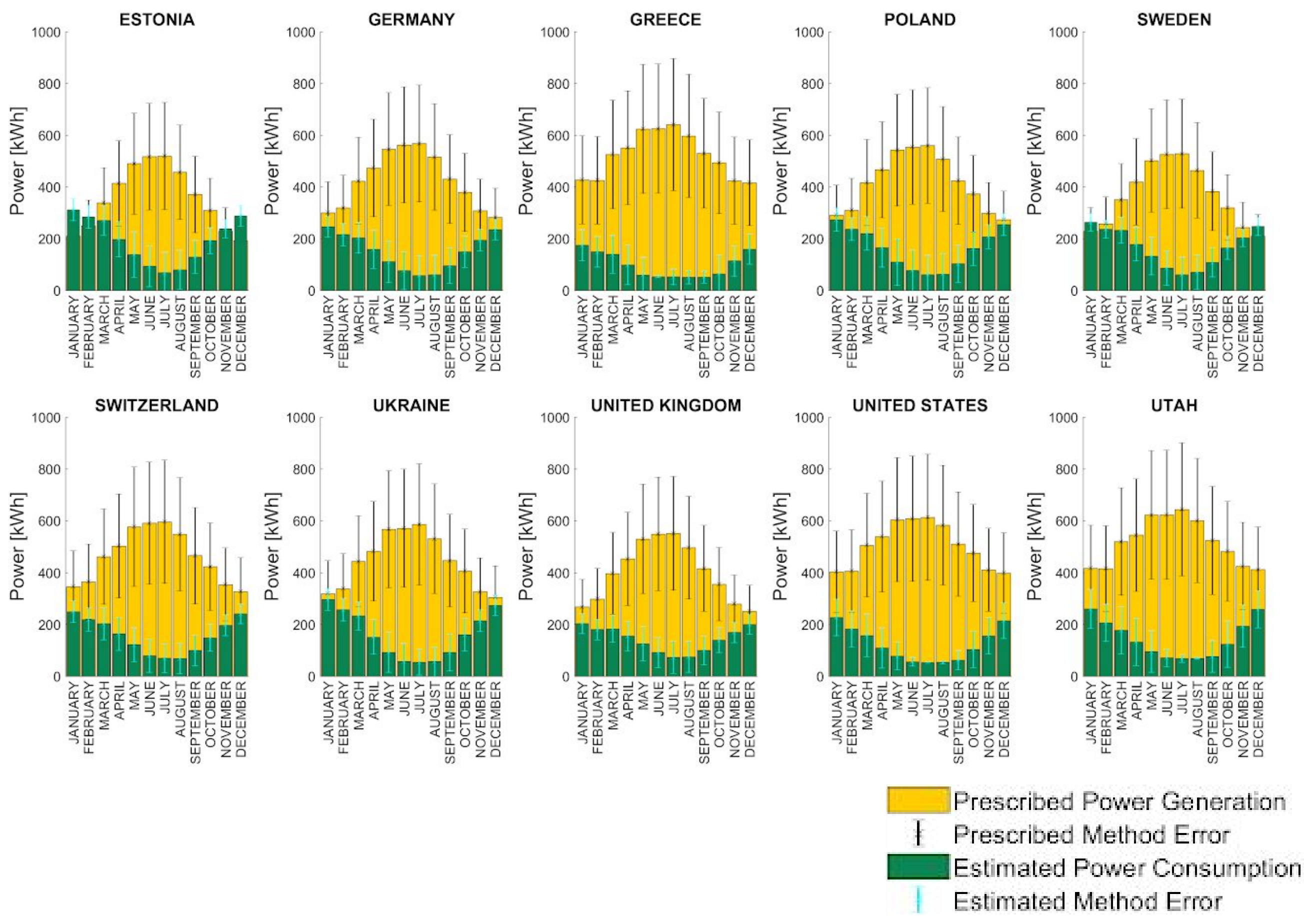
10.0 Appendix

Appendix A: Köppen Climate Classification Geographic Map[5]

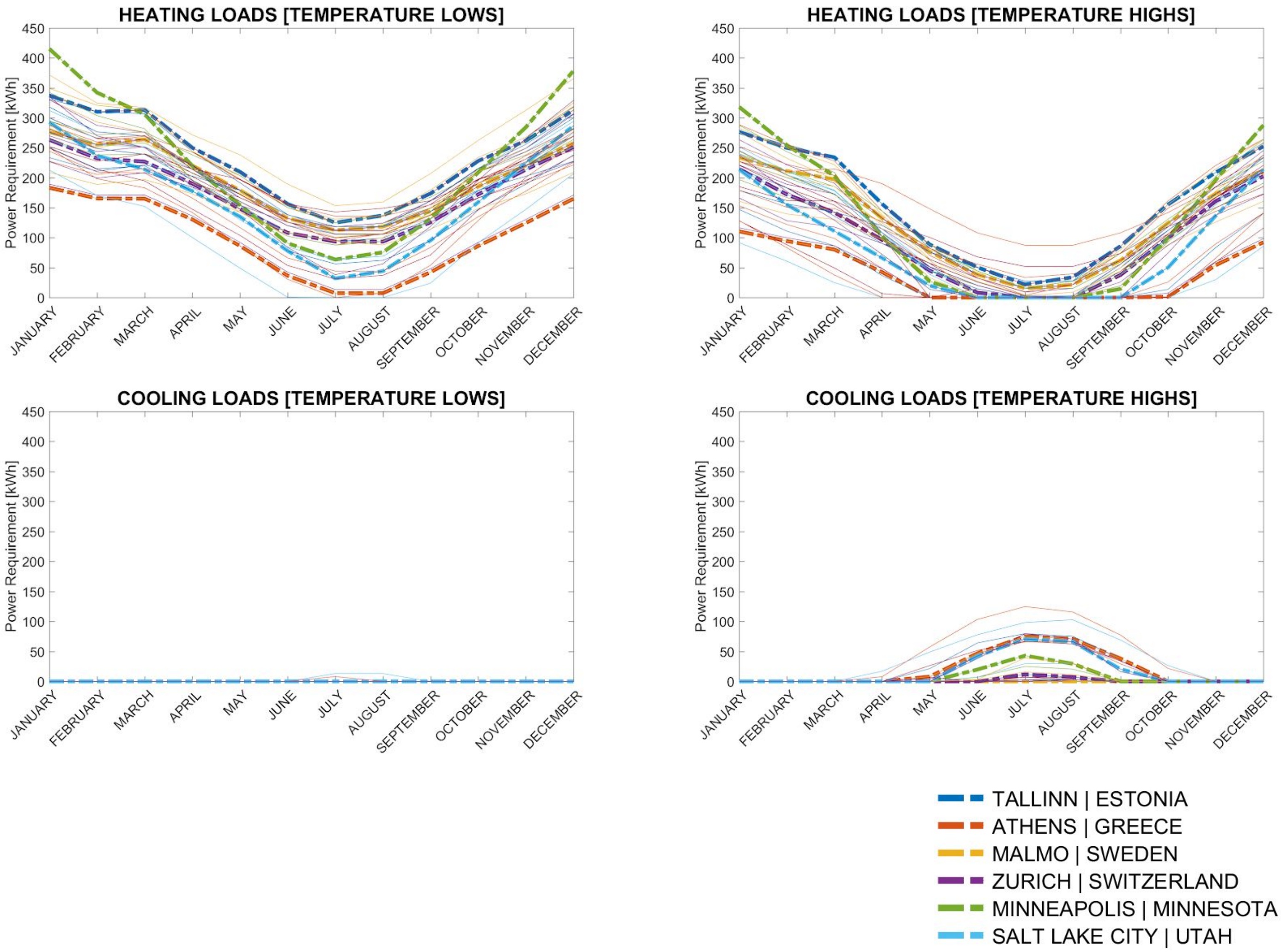


[5]"Köppen-Geiger Climate Classification Map of the World"
https://upload.wikimedia.org/wikipedia/commons/d/d5/K%C3%B6ppen-Geiger_Climate_Classification_Map.png
Accessed 9 Dec. 2018

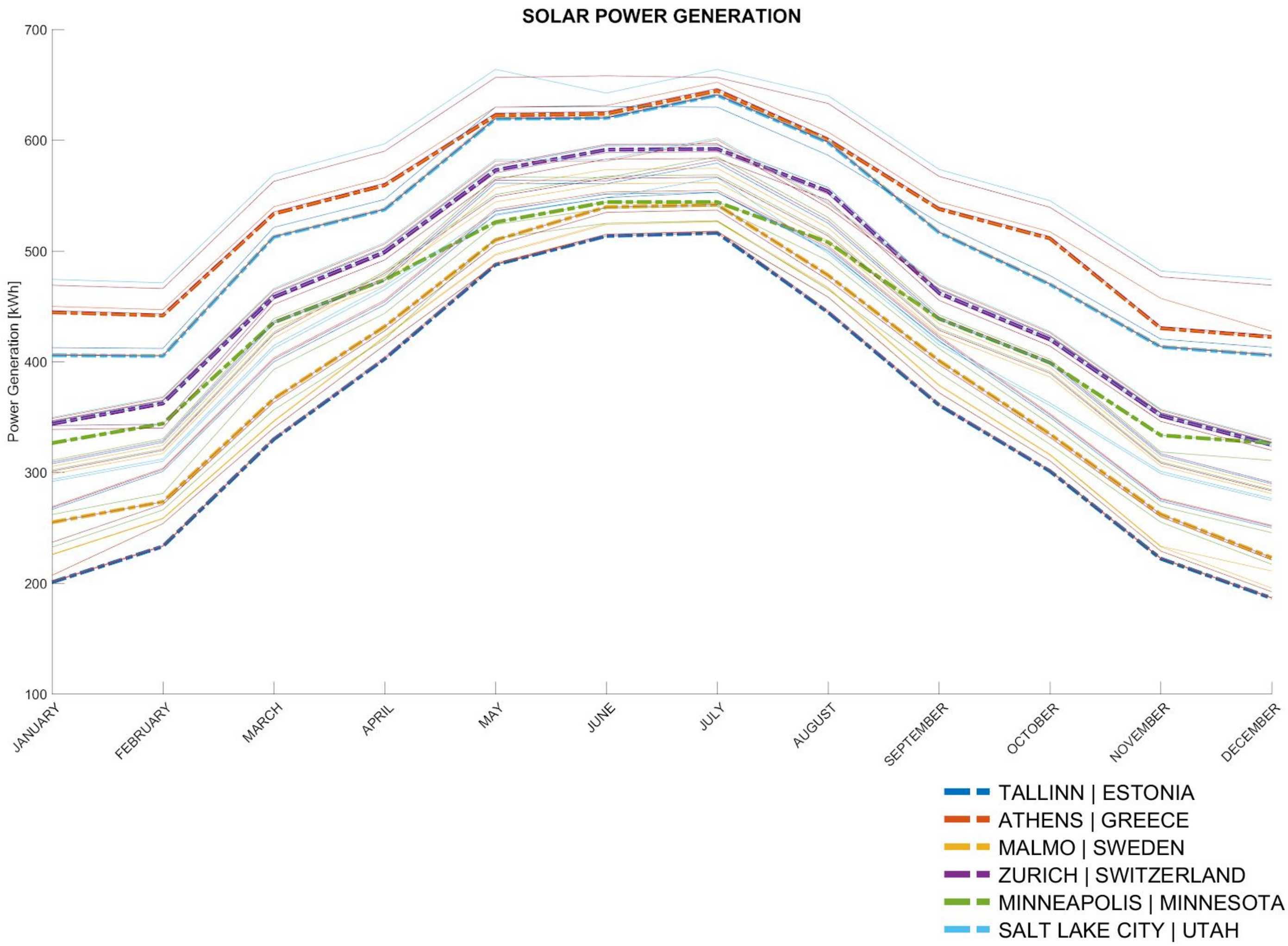
Appendix B: Power Demand Estimates for Surveyed Cities



Attachment 1. Monthly Solar Power Generation and Power Consumption Estimates for countries with surveyed cities.



Attachment 2. Monthly Power Consumption Estimates by heating type for 40 cities across Europe and the United States; six countries are highlighted for comparison.



Attachment 3. Monthly Power Generation Estimates for 40 cities across Europe and the United States; six countries are highlighted for comparison.

Appendix C: Concept Selection Charts

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.

Appendix D: Critical Matlab Script Portion


```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% TEAM SANDL | ASHRAE ENGINEERING CHALLENGE
% ESTIMATED POWER DEMANDS
% ESTIMATED ENERGY CONSUMPTION | HEATING & COOLING
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% {SHORT NOTES ON WHAT THIS SRIPT PREFORMS ... }

%% INITIAL SCRIPTING PARAMETER CONDITIONS
% % LIST OF REFERENCE PROPERTIES AND CHARATERISTICS
AIR_CP = 1.006;                     % SPECIFIC HEAT OF AIR [kJ/kg-C]
AIR_RHO = 1.202;                    % DENSITY OF AIR [kg/m^3]
AIR_VOLUME_FLOW = 1;                % AIR VOLUME FLOW [m^3/s]
COMFORTABLE_WARMTH = 21.1;          % THE WORLD HEALTH ORGANISATION STANDARD [C]
COMFORTABLE_HUMIDITY = 0.4;         % RELATIVE HUMITIY FOR HEALTH AND COMFORT
OCCUPANTS = 6;                      % NUMBER OF OCCUPANTS PER SHELTER
RVALUE_WALL = 10;                   % EFFECTIVE R-VALUE OF SHELTER [m^2K/W]
UVALUE_WINDOW = 0.300;              % WINDOW U-VALUES [W/m^2-K]
SHGC_WINDOW = 0.300;                % SOLAR HEAT GAIN COEFFICIENT OF WINDOWS
WALL_AREA = 67.68;                  % EFFECTIVE SURFACE AREA [m^2] 74
WINDOW_AREA = 6.32;                 % EFFECTIVE WINDOW AREA [m^2]
COP_HEATPUMP = [3.46 4.68];         % COEFFICIENT OF PERFORMANCE [HEATING COOLING]
E_MISCELLANEOUS = 3.0;              % ENERGY LOADS NOT RELATED TO HVAC (LIGHTS, COOKING, ↙
ETC) [KWH]
SOLAR_COLLECTION_EFF = 0.80;        % RELATIVE SOLAR COLECTION [%]
% % PRELIMINARY UNIT CONVERSION CALCULATIONS
Q_OCCUPANTS = OCCUPANTS*175/1000;   % HEAT LOAD DUE TO OCCUPANTS [kW]
UVALUE_WALL = 1/RVALUE_WALL;        % HEAT TRANSFER COEFFICIENT [W/m^2-K]
WALL_RATIO = WINDOW_AREA/WALL_AREA; % WINDOW AREA TO SURFACE AREA
EFFECTIVE_SOLAR_AREA = 3.56;        % EFFECTIVE SOLAR AREA [m^2] - WINDOW AREA FACING SUN
OCCUPANCY_HOURS = 14;               % ESTIMATED HOURS OF OCCUPANCY
% % SOLAR EQUIPMENT PARAMETERS
PRESCRIBED_PANELS = 9;              % NUMBER OF PANELS FOR COMPARISON ANALYSIS
PANEL_WATTS = 325;                  % WATTS PER INSTALLED PANEL [W]
PANEL_VOLTAGE = 37.0;               % OPERATING VOLTAGE [V]
PANEL_CURRENT = 8.78;               % OPERATING AMPS [A]
BATTERY_VOLTAGE = 12.8;             % BATTERY VOLATAGE [V]
BATTERY_AMP = 105;                  % BATTERY AMP HOURS [Ah]
BATTERY_EF = 0.80;                  % BATTERY DISCHARGE EFFICIENCY AT FREEZIING
CHARGE_DEPTH = 0.93;                % BATTERY CHARGE DEPTH DISCHARGE
STORAGE_DAYS = 5;                   % WANTING TO STORE ENERGY FOR 5 DAYS
% % % STORAGE_DAYS = 2;                   % WANTING TO STORE ENERGY FOR 5 DAYS
SYSTEM_VOLTAGE = 24;                % SYSTEM OPERATION VOLTAGE [V]
OPPERATION_EF = 0.97;               % TOTAL OPPERATION EFFICIENCY
% % COUNTRY NUMBER ALLOCATION
ESTONIA = 1; GERMANY = 2; GREECE = 3; POLAND = 4; SWEDEN = 5;
SWITZERLAND = 6; UKRAINE = 7; UNITED_KINGDOM = 8; UNITED_STATES = 9; UTAH =10;
% % INTERATION COUNTERS
i = 1; j = 1; k = 1; l = 1;
% % REFERENCE FILE NAMES & LOCATION DEFINITIONS
FILE_NAMES = ["ESTONIA.xlsx"; "GERMANY.xlsx"; "GREECE.xlsx"; ...
```

```
    "POLAND.xlsx"; "SWEDEN.xlsx"; "SWITZERLAND.xlsx"; "UKRAINE.xlsx"; ...
    "UNITED KINGDOM.xlsx"; "UNITED STATES.xlsx"; "UTAH.xlsx"];
LOCATION = categorical({'ESTONIA', 'GERMANY', 'GREECE', 'POLAND', ...
    'SWEDEN', 'SWITZERLAND', 'UKRAINE', 'UNITED KINGDOM', ...
    'UNITED STATES', 'UTAH'});

%% WHERE THE REAL MAGIC HAPPENS
% % RUNS SCRIPT TO GRAB EXCEL DATA
GRAB_DATA;
% % RUN SCRIPT WITH ENERGY CALCULATIONS HEATING AND COOLING LOADS
ENERGY_CALCULATIONS;
% RUN SCRIPT TO DISPLAY APPROPRIATE PLOTS
DISPLAY_PLOTS;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% TEAM SANDL | ASHRAE ENGINEERING CHALLENGE
% ESTIMATED POWER DEMANDS
% ESTIMATED ENERGY CONSUMPTION | HEATING & COOLING
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% THIS SCRIPT WILL CALCULATE THE HEATING AND COOLING LOADS USING
% AMBIENT TEMPERATURES NESSECARY TO MAINTAIN THE DEFINED COMFORTABLE_WARMTH

% DISPLAYS THE RELATED PLOTS FROM RUNNING SCRIPT HEATINGLOADS.m

%% CALCULATING SHELTER LOADS FROM AVERAGE AMBIENT TEMPERATURES
l = 1; k = 1;
while l <= size(SOLAR_HOURS, 1)
    k = 2;
    while k <= size(SOLAR_HOURS, 2)
        % TEMPERATURE INDEPENDENT HEATING LOADS
        Q_SOLAR = SHGC_WINDOW*cos((90-LATITUDE{l,2})*pi/180) ...
            *(EFFECTIVE_SOLAR_AREA); % HEAT GAIN FROM SOLAR ENERGY [kW]
        % AVERAGE HIGH TEMPERATURES
        LATENT_EVAPORIZATION_HIGH = (2454 - 2.2 * ...
            AMBIENT_TEMP_HIGH{l, k})/1000;  % h_fg OF WATER [kJ/kg]
        QH_LATENT = AIR_RHO*AIR_VOLUME_FLOW*LATENT_EVAPORIZATION_HIGH* ...
            COMFORTABLE_HUMIDITY;           % LATENT HEAT GAIN [kW]
        QH_SENSIBLE = AIR_CP*AIR_RHO*AIR_VOLUME_FLOW*(COMFORTABLE_WARMTH ...
            - AMBIENT_TEMP_HIGH{l, k});     % SENSIBLE HEAT GAIN [kW]
        QH_INFILTRATION = (UVALUE_WINDOW * WINDOW_AREA + ...
            UVALUE_WALL * WALL_AREA)*(COMFORTABLE_WARMTH - ...
            AMBIENT_TEMP_HIGH{l, k})/1000;  % SUM OF WALL AND WINDOW GAINS [kW]
        QH_INPUT = QH_SENSIBLE + QH_LATENT + Q_OCCUPANTS + Q_SOLAR ...
            + QH_INFILTRATION;     % SUM OF HEATING INPUT [kW]
        % AVERAGE LOW TEMPERATURES
        LATENT_EVAPORIZATION_LOW = (2454 - 2.2 * ...
            AMBIENT_TEMP_LOW{l, k})/1000;   % h_fg OF WATER [kJ/kg]
        QL_LATENT = AIR_RHO*AIR_VOLUME_FLOW*LATENT_EVAPORIZATION_LOW* ...
            COMFORTABLE_HUMIDITY;           % LATENT HEAT GAIN [kW]
        QL_SENSIBLE = AIR_CP*AIR_RHO*AIR_VOLUME_FLOW*(COMFORTABLE_WARMTH ...
            - AMBIENT_TEMP_LOW{l, k});     % SENSIBLE HEAT GAIN [kW]
        QL_INFILTRATION = (UVALUE_WINDOW * WINDOW_AREA + ...
            UVALUE_WALL * WALL_AREA)*(COMFORTABLE_WARMTH - ...
            AMBIENT_TEMP_LOW{l, k})/1000;  % SUM OF WALL AND WINDOW GAINS [kW]
        QL_INPUT = QL_SENSIBLE + QL_LATENT + Q_OCCUPANTS + Q_SOLAR ...
            + QL_INFILTRATION;
        % DEFINE SHELTER LOADS BY AVERAGE HIGH TEMPERATURES
        if QH_INPUT < 0           % Q_IN NEED FOR COOLING
            COOLING_LOADS_HIGH(l, k-1) = QH_INPUT/COP_HEATPUMP(2)*eomday(2018,k-1);
            HEATING_LOADS_HIGH(l, k-1) = 0;
        elseif QH_INPUT > 0       % Q_IN NEED FOR HEATING
            COOLING_LOADS_HIGH(l, k-1) = 0;
            HEATING_LOADS_HIGH(l, k-1) = QH_INPUT/COP_HEATPUMP(1)*eomday(2018,k-1);
        else                     % NEITHER HEATING OR COOLING NEEDED
```

```
            COOLING_LOADS_HIGH(l, k-1) = 0;
            HEATING_LOADS_HIGH(l, k-1) = 0;
        end
        % DEFINE SHELTER LOADS BY AVERAGE LOW TEMPERATURES
        if QL_INPUT < 0           % Q_IN NEED FOR COOLING []
            COOLING_LOADS_LOW(l, k-1) = QL_INPUT/COP_HEATPUMP(2)*eomday(2018,k-1);
            HEATING_LOADS_LOW(l, k-1) = 0;
        elseif QL_INPUT > 0       % Q_IN NEED FOR HEATING []
            COOLING_LOADS_LOW(l, k-1) = 0;
            HEATING_LOADS_LOW(l, k-1) = QL_INPUT/COP_HEATPUMP(1)*eomday(2018,k-1);
        else                     % NEITHER HEATING OR COOLING NEEDED []
            COOLING_LOADS_LOW(l, k-1) = 0;
            HEATING_LOADS_LOW(l, k-1) = 0;
        end
        k = k + 1;
    end
    l = l + 1;
end
% LABELLING TABLE VARIABLES APPROPRIATELY
COOLING_LOADS_HIGH = [cell2table(LATITUDE{:,1}), array2table(COOLING_LOADS_HIGH)];
COOLING_LOADS_HIGH.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS
HEATING_LOADS_HIGH = [cell2table(LATITUDE{:,1}), array2table(HEATING_LOADS_HIGH)];
HEATING_LOADS_HIGH.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS
COOLING_LOADS_LOW = [cell2table(LATITUDE{:,1}), array2table(COOLING_LOADS_LOW)];
COOLING_LOADS_LOW.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS
HEATING_LOADS_LOW = [cell2table(LATITUDE{:,1}), array2table(HEATING_LOADS_LOW)];
HEATING_LOADS_LOW.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS

%% DEFINING THE ENERGY REQUIREMENTS AND POWER GENERATION
i = 1; j = 1;
while i <= size(SOLAR_HOURS, 1)
    j = 2;
    while j <= size(SOLAR_HOURS, 2)
        if abs(COOLING_LOADS_HIGH{i,j}) > abs(COOLING_LOADS_LOW{i,j})
            COOLING_KWH = abs(COOLING_LOADS_HIGH{i,j});
        else
            COOLING_KWH = abs(COOLING_LOADS_LOW{i,j});
        end
        if abs(HEATING_LOADS_HIGH{i,j}) > abs(HEATING_LOADS_LOW{i,j})
            HEATING_KWH = HEATING_LOADS_HIGH{i,j};
        else
            HEATING_KWH = HEATING_LOADS_LOW{i,j};
        end
```


{Intentionally Blank}

```
        ENERGY_LOAD(i, j-1) = (COOLING_KWH + HEATING_KWH + E_MISCELLANEOUS) ...
            /eomday(2018,j-1);    % DAILY KWH [KWH]
        STORAGE(i, j-1) = ENERGY_LOAD(i, j-1)*STORAGE_DAYS ...
            /(BATTERY_EF * CHARGE_DEPTH * OPPERATION_EF);  % [KWH]
        NUMBER_BATTERIES(i, j-1) = STORAGE(i, j-1)/(BATTERY_AMP * BATTERY_VOLTAGE/1000);
% [#]
        NUMBER_PANELS(i, j-1) = ENERGY_LOAD(i, j-1) / ...
            (SOLAR_HOURS{i, j}*PANEL_WATTS/1000);          % [#]
        SOLAR_GENERATION(i, j-1) = (PANEL_VOLTAGE * PANEL_CURRENT * ...
            SOLAR_HOURS{i,j}*eomday(2018,j-1))/1000 ...
            *sin((90-LATITUDE{i,2})*pi/180)*SOLAR_COLLECTION_EFF;            % SOLAR
GENERATION BASED ON LATITUDE
        j = j + 1;
    end
    i = i + 1;
end

STORAGE = [cell2table(LATITUDE{:,1}), array2table(STORAGE)];
STORAGE.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS
NUMBER_BATTERIES = [cell2table(LATITUDE{:,1}), array2table(NUMBER_BATTERIES)];
NUMBER_BATTERIES.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS
NUMBER_PANELS = [cell2table(LATITUDE{:,1}), array2table(NUMBER_PANELS)];
NUMBER_PANELS.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS

MAX_STORAGE = max(max(STORAGE{:,2:13}));
MAX_PANELS = max(max(ENERGY_LOAD))/(min(min(SOLAR_HOURS{:,2:13})) ...
    *PANEL_WATTS/1000*0.9);
MAX_BATTERIES = max(max(NUMBER_BATTERIES{:,2:13}));
BATTERY_SERIES = SYSTEM_VOLTAGE/BATTERY_VOLTAGE;
PANEL_SERIES = SYSTEM_VOLTAGE/PANEL_VOLTAGE;

SOLAR_GENERATION = SOLAR_GENERATION*round(MAX_PANELS);
SOLAR_GENERATION = [cell2table(LATITUDE{:,1}), array2table(SOLAR_GENERATION)];
SOLAR_GENERATION.Properties.VariableNames = {'CITY', 'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'};        % COLUMN LABELS
% % SUMMARIZING EQUIPMENT CALCULATIONS
EQUIPMENT_SUMMARY = table(round(MAX_STORAGE, 2), ceil(MAX_BATTERIES), ...
    ceil(MAX_PANELS), ceil(BATTERY_SERIES), ceil(PANEL_SERIES), ...
    max(max(SOLAR_GENERATION{:,2:13})), min(min(SOLAR_GENERATION{:,2:13})));
EQUIPMENT_SUMMARY.Properties.VariableNames = {'DESIRED_STORAGE_KWH', ...
    'TOTAL_BATTERIES', 'TOTAL_PANELS' ,'BATTERIES_IN_SERIES', ...
    'PANELS_IN_SERIES', 'MAX_MONTH_SOLAR', 'MIN_MONTH_SOLAR'};
EQUIPMENT_SUMMARY
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% TEAM SANDL | ASHRAE ENGINEERING CHALLENGE
% ESTIMATED POWER DEMANDS
% ESTIMATED ENERGY CONSUMPTION | HEATING & COOLING
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% THIS SCRIPT WILL DISPLAY THE DATA CALCULATED FROM THE
% ENERGY_CALCUALTIONS.m SCRIPT

% DISPLAYS THE RELATED PLOTS FROM RUNNING SCRIPT HEATINGLOADS.m

%% INITIAL SCRIPTING PARAMETER CONDITIONS
FONT_SIZE_AXIS = 14; FONT_SIZE_TITLE = 20;      % DEFINE LABEL FONT SIZE
ERROR_BAR_SIZE = 1;                              % DEFINE WIDTH OF ERROR BARS
% % CITIES TO PLOT [TALLINN, ATHENS, MALMO, ZURICH, MINNEAPOLIS, SALT LAKE CITY]
CITIES = [1, 11, 19, 21, 34, 37];
CITY_NAMES = {'TALLINN | ESTONIA', 'ATHENS | GREECE', 'MALMO | SWEDEN', ...
    'ZURICH | SWITZERLAND', 'MINNEAPOLIS | MINNESOTA', 'SALT LAKE CITY | UTAH'};

%% PLOTS FROM ANALYSIS
% % SUBPLOTS SHOW ENERGY LOADS SPLIT INTO HEATING COOLING HIGH & LOW
% % SUBPLOT PLOTING HEATING LOADS USING AVERAGE LOW TEMPERATURES
figure;          % START NEW FIGURE
subplot(2,2,1), plot([1:12],abs(HEATING_LOADS_LOW{CITIES,2:13}), ...
    'LineWidth', 4, 'LineStyle', '-.');
legend(CITY_NAMES, 'AutoUpdate', 'off');
hold on;
plot([1:12],abs(HEATING_LOADS_LOW{:,2:13}));
hold off;
set(gca,'XTickLabelRotation',45 ,'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(HEATING_LOADS_LOW.Properties.VariableNames(2:13));
ylim([0, 450]);
ylabel('Power Requirement [kWh]');
title('HEATING LOADS [TEMPERATURE LOWS]', 'fontsize', FONT_SIZE_TITLE);
% % SUBPLOT PLOTING HEATING LOADS USING AVERAGE HIGH TEMPERATURES
subplot(2,2,2), plot([1:12],abs(HEATING_LOADS_HIGH{CITIES,2:13}), ...
    'LineWidth', 4, 'LineStyle', '-.');
legend(CITY_NAMES, 'AutoUpdate', 'off');
hold on;
plot([1:12],abs(HEATING_LOADS_HIGH{:,2:13}));
hold off;
set(gca,'XTickLabelRotation',45,'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(HEATING_LOADS_HIGH.Properties.VariableNames(2:13));
ylim([0, 450]);
ylabel('Power Requirement [kWh]');
title('HEATING LOADS [TEMPERATURE HIGHS]', 'fontsize', FONT_SIZE_TITLE);
% % SUBPLOT PLOTING COOLING LOADS USING AVERAGE LOW TEMPERATURES
subplot(2,2,3), plot([1:12],abs(COOLING_LOADS_LOW{CITIES,2:13}), ...
    'LineWidth', 4, 'LineStyle', '-.');
```

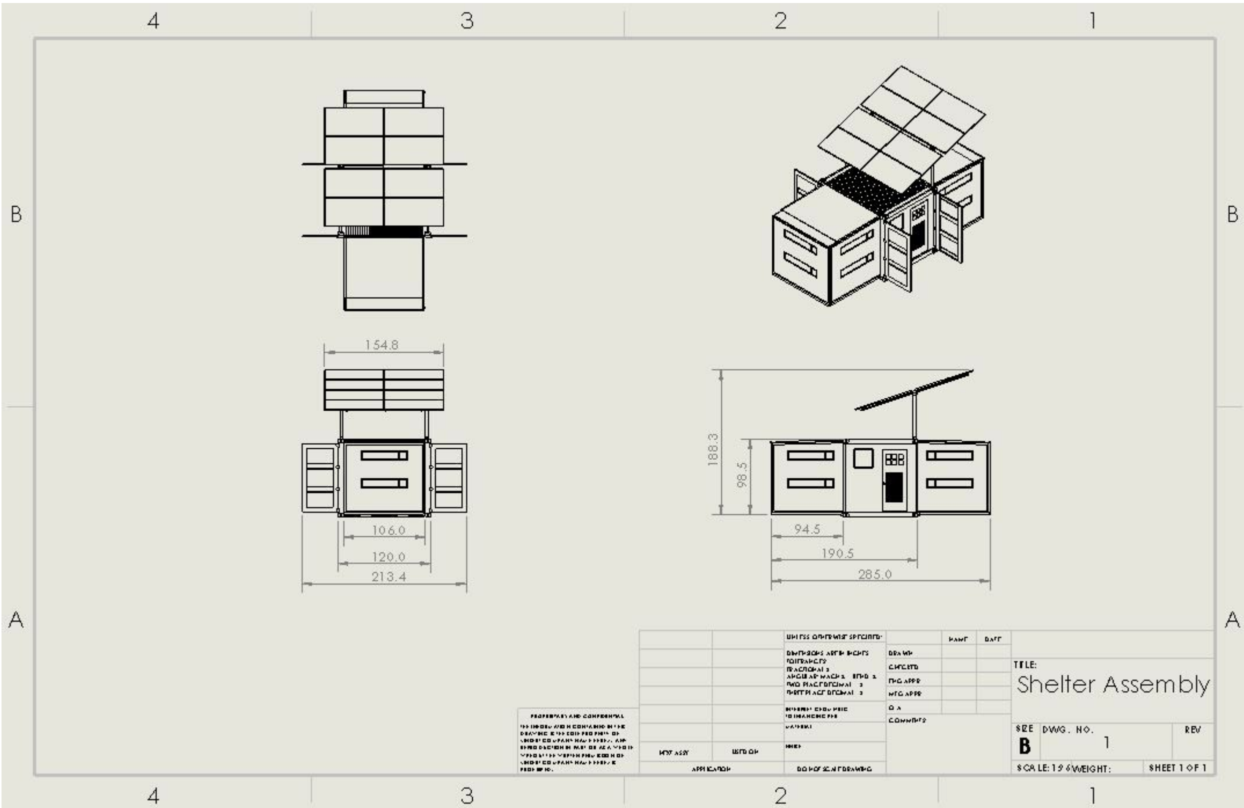
```
legend(CITY_NAMES, 'AutoUpdate', 'off');
hold on;
plot([1:12],abs(COOLING_LOADS_LOW{:,2:13}));
hold off;
set(gca,'XTickLabelRotation',45,'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(COOLING_LOADS_LOW.Properties.VariableNames(2:13));
ylim([0, 450]);
ylabel('Power Requirement [kWh]');
title('COOLING LOADS [TEMPERATURE LOWS]', 'fontsize', FONT_SIZE_TITLE);
% % SUBPLOT PLOTING COOLING LOADS USING AVERAGE HIGH TEMPERATURES
subplot(2,2,4), plot([1:12],abs(COOLING_LOADS_HIGH{CITIES,2:13}), ...
    'LineWidth', 4, 'LineStyle', '-.');
legend(CITY_NAMES, 'AutoUpdate', 'off');
hold on;
plot([1:12],abs(COOLING_LOADS_HIGH{:,2:13}));
hold off;
set(gca,'XTickLabelRotation',45,'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(COOLING_LOADS_HIGH.Properties.VariableNames(2:13));
ylim([0, 450]);
ylabel('Power Requirement [kWh]');
title('COOLING LOADS [TEMPERATURE HIGHS]', 'fontsize', FONT_SIZE_TITLE);

% % PLOT OF SOLAR GENERATION BY MONTH ON AVERAGE
figure; hold on;
plot([1:12], SOLAR_GENERATION{CITIES, 2:13}, ...
    'LineWidth', 4, 'LineStyle', '-.');
legend(CITY_NAMES, 'AutoUpdate', 'off');
plot([1:12], SOLAR_GENERATION{:,2:13});
set(gca,'XTickLabelRotation',45,'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(SOLAR_GENERATION.Properties.VariableNames(2:13));
ylabel('Power Generation [kWh]');
title('SOLAR POWER GENERATION', 'fontsize', FONT_SIZE_TITLE);
hold off;

% % COMBINEDS HEATING AND COOLING LOADS FOR HIGH AVERAGE TEMPERATURES
figure; hold on;
plot([1:12],HEATING_LOADS_HIGH{CITIES,2:13}+abs(COOLING_LOADS_HIGH{CITIES,2:13}), ...
    'LineWidth', 4, 'LineStyle', '-.');
legend(CITY_NAMES, 'AutoUpdate', 'off');
plot([1:12],HEATING_LOADS_HIGH{:,2:13}+abs(COOLING_LOADS_HIGH{:,2:13}));
set(gca,'XTickLabelRotation',45,'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(SOLAR_GENERATION.Properties.VariableNames(2:13));
ylim([0, 450]);
ylabel('Power Consumption [kWh]');
title('POWER CONSUMPTION BY AVERAGED HIGH TEMPERATURES', ...
    'fontsize', FONT_SIZE_TITLE);
hold off;
```

```
% % COMBINEDS HEATING AND COOLING LOADS FOR LOW AVERAGE TEMPERATURES
figure; hold on;
plot([1:12],HEATING_LOADS_LOW{CITIES,2:13}+abs(COOLING_LOADS_LOW{CITIES,2:13}), ...
    'LineWidth', 4, 'LineStyle', '-.')
legend(CITY_NAMES, 'AutoUpdate', 'off');
plot([1:12],HEATING_LOADS_LOW{:,2:13}+abs(COOLING_LOADS_LOW{:,2:13}))
set(gca,'XTickLabelRotation',45, 'FontSize', FONT_SIZE_AXIS);
xticks([1:12]); xlim([1,12]);
xticklabels(SOLAR_GENERATION.Properties.VariableNames(2:13));
ylim([0, 450]);
ylabel('Power Consumption [kWh]');
title('POWER CONSUMPTION BY AVERAGED LOW TEMPERATURES', ...
    'fontsize', FONT_SIZE_TITLE);
hold off;

% PLOT THE POWER CONSUMPTION BY SOURCE AND ERROR IN CALCUALTION
MONTH_CATEGORY = reordercats(categorical({'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'}),{'JANUARY', ...
    'FEBRUARY' ,'MARCH', 'APRIL', 'MAY', 'JUNE', 'JULY', 'AUGUST', ...
    'SEPTEMBER', 'OCTOBER', 'NOVEMBER', 'DECEMBER'});    % BAR CATEGORY
figure;

COMPAIR_PANELS = PRESCRIBED_PANELS/round(MAX_PANELS); % COMPAIRING PRESCRIBED NUMBER OF ↙
PANELS
for i = 1:10;
    subplot(2,5,i); hold on; colormap summer;
    set(gca,'XTickLabelRotation',45, 'FontSize', FONT_SIZE_AXIS);
    GENERATION_STD = mean(SOLAR_GENERATION{4*i-3:4*i,2:13}).*1/sqrt(2*pi) ...
        .*exp(-0.5*(std(SOLAR_GENERATION{4*i-3:4*i,2:13}) ...
        ./mean(SOLAR_GENERATION{4*i-3:4*i,2:13})).^2);
    GENERATION_STD_COMP = mean(SOLAR_GENERATION{4*i-3:4*i,2:13}*COMPAIR_PANELS).*1/sqrt ↙
(2*pi) ...
        .*exp(-0.5*(std(SOLAR_GENERATION{4*i-3:4*i,2:13}) ...
        ./mean(SOLAR_GENERATION{4*i-3:4*i,2:13})).^2);
    GENERATION_COMP = bar(MONTH_CATEGORY, mean(SOLAR_GENERATION{4*i-3:4*i,2:13}) ...
        *COMPAIR_PANELS, 0.9, 'grouped', 'y');
    GENERATION_ERROR_COMP = errorbar(mean(SOLAR_GENERATION{4*i-3:4*i,2:13}) ...
        *COMPAIR_PANELS, GENERATION_STD_COMP, 'xm', 'LineWidth', ERROR_BAR_SIZE);
    GENERATION_G = bar(MONTH_CATEGORY, mean(SOLAR_GENERATION{4*i-3:4*i,2:13}), ...
        0.9, 'grouped');
    GENERATION_ERROR_G = errorbar(mean(SOLAR_GENERATION{4*i-3:4*i,2:13}) ...
        , GENERATION_STD, 'xk', 'LineWidth', ERROR_BAR_SIZE);
    DC(1:12) = mean([mean(HEATING_LOADS_HIGH{4*i-3:4*i,2:13} ...
        + abs(COOLING_LOADS_HIGH{4*i-3:4*i,2:13}));  ...
        mean(HEATING_LOADS_LOW{4*i-3:4*i,2:13} + ...
        abs(COOLING_LOADS_LOW{4*i-3:4*i,2:13}))]);      % ARRAY OF AVERAGE LOADING
    CONSUMPTION_STD = std([mean(HEATING_LOADS_HIGH{4*i-3:4*i,2:13} ...
        + abs(COOLING_LOADS_HIGH{4*i-3:4*i,2:13}));  ...
        mean(HEATING_LOADS_LOW{4*i-3:4*i,2:13} + ...
```

```
        abs(COOLING_LOADS_LOW{4*i-3:4*i,2:13})))]);       % ARRAY OF LOADING STD
    CONSUMPTION_G = bar(MONTH_CATEGORY, DC, 0.8, 'grouped');       % BAR GRAPH OF↙
CONSUMPTION LIMIT
    CONSUMPTION_G.EdgeColor = [1 0.6471 0]; CONSUMPTION_G.FaceColor = [1 0.6471 0];
    CONSUMPTION_ERROR_G = errorbar(DC, CONSUMPTION_STD, 'xc', ...
        'LineWidth', ERROR_BAR_SIZE);
    ylim([0 1000]);
    title(char(strrep(strrep(FILE_NAMES(i), ".xlsx", ""),"_"," ")), 'fontsize', 18);
    ylabel('Power [kWh]', 'fontsize', FONT_SIZE_TITLE);
    hold off;
end
 legend({'Prescribed Panel Energy Generation', 'Prescribed Method Error', ...
     'Estimated Panel Energy', 'Estimated Method Error', ...
     'Estimated Energy Consumption', 'Estimated Energy Consumption Error'});
```

Appendix E: Shelter Major Components Exploded View

Appendix F: Shelter Assembly Drawing



Appendix G: Condensed Bill of Materials

ASHRAE TEMPORARY REFUGEE SHELTER POWER SUPPLY

BILL OF MATERIALS

ITEM NUMBER	PART NUMBER	PART NAME	MANUFACURE / SUPPLIER	MATERIAL	QTY.	PRICE	DESCRIPTION	WEIGHT [lb]	DIMENTIONS	ADDITIONAL NOTES	REFERENCE MATERIAL/SPEC SHEETS
E100	CS6U-P	SOLAR PANELS	CANADIAN SOLAR	POLY-CRYSTALLINE	8	$205.00	SOLAR PANELS	49.4	77.2 × 39.1 × 1.57 in	SOLAR PANELS CAN BE EXCHANGED; RECOMEND USING A 300 W PANEL WITH AT LEST 24 V VOLTAGE OUTPUT;	https://www.canadiansolar.com/fileadmin/user_upload/downloads/datasheets/v5.5/Canadian_Solar-Datasheet-MaxPower-CS6U-P-1500V-v5.52en.pdf
E101	NANT-ZINC	BATTERIES	NANTENERGY	MOSTLY ZINC AND ELECTRICAL COMPONENTS IN PLASTIC CASING;	50	$100.00	ZINC-AIR BATTERIES	25	14" x 12" x 4"	VALUES FOR BATTERIES ARE ESTIMATED; NANTSENERGY DOES NOT HAVE A MANUFACURE BROCHURE FOR THIS PRODUCT.	https://nantenergy.com/markets/
E102	PWRI150024S	INVERTER	AIMS POWER	ELECTRONIC COMPONENTS;	1	$250.00	PURE SINE POWER INVERTER; 1500W CONTINUOUS POWER, 3000W SURGE;	9.9	16" X 8" X 4"	HAS USB POWER OUTPUTS AT 5V; EFFICIENCY IS 90% FULL LOAD. 95% 1/3 LOAD;	https://theinverterstore.com/product/1500-watt-pure-sine-inverter-24-vdc-to-120-vac/?gclid=Cj0KCQiAoJrfBRC0ARIsANqkS_4NS3K6Onc_r5ffjRBdb1iM3Nwpv7WCyY78VYZ9-JxKzoAgM2M9EdIaAtALEALw_wcB
E200					1	$118.88	ELECTRICAL PANEL WITH CIRCUIT BREAKERS	10		ELECTRICAL PANEL AND CIRCUITS TO BE PLACED IN THE MAINTENENCE ACCESS	
E201					100	$0.85	ELECTRICAL WIRING	0.1		WIRING REQUIRED FOR THE SHELTER	
E202					2	$1.50	ELECTRICAL OUTLETS	0.1		OUTLETS FOR OCCUPANT UTILITY; LIMITED CURCUIT AVALIBILITY	
E203					2	$23.99	LED CAN LIGHTS	0.5			
M100	MUZ-FH06NA	AIR SOURCE HEAT PUMP	Mitsubishi		1	$1,000.00	HEAT PUMP OUTDOOR UNIT	81	21.625 x 31.5 x 11.25 in		https://www.ecomfort.com/manuals/mitsubishi-6cdf33a2cf22d9e3163d66275e95d7c7.pdf
M101	LC-097HV4	CASSETTE	LG		1	$700.00	HEAT PUMP CEILING CASSETTE	31			
M200		Lunos e2 HRV			1	$2,059.00	HEAT RECOVERY VENTILATION SYSTEM	4			
P100		100 GALLON FRESH WATER TANK			1	$152.99		20			
P101		WATER PUMP			1	$20.99		2			
P102		SINK			1	$272.99		50			
P103		GRAY WATER TANK			1	$150.00		20			
P104		PLUMBING			10	$1.18	PLUMBING PIPE	15			
S100	HCZU180554	SHIPPING CONTAINER	CTI	MOSTLY STEEL CONSTRUCTION	1	$2,000.00	STANDARD 10' SHIPPING CONTAINER [RETROFITTED]	2,850	10' X 8' X 8' 6"	COST OF SHIPPING CONTAINERS VARY; $2,000 SEEMS NOMINAL FOR 10' CONTAINER	http://containertech.com/container-sales/10ft-storage-container/
S200	FOAMULAR250-45W	RIGID FOAM BOARD	OWENS CORNING	EXTRUDED POLYSTYRENE (XPS)	27	$29.00	UNFACED RIGID FOAM INSULATION	7.78	2"x4'x8' (864 sqft)	INSULATION SHOULD BE INSTALLED TO LIMIT THE AMOUNT OF THERMAL BRIDGING AND OPTIMIZE INFILTRATION.	https://www.homedepot.com/p/Owens-Corning-FOAMULAR-150-2-in-x-4-ft-x-8-ft-R-10-Scored-Squared-Edge-Rigid-Foam-Board-Insulation-Sheathing-45W/100320352
S201	4006022200	SPRAY FOAM	TOUCH'N FOAM	POLYURETHANE INSULATION	1	$333.44	SPRAY FOAM INSULATION AND SEALANT	40.2	200 BOARD FEET	USE FOAM TO PROPERLY SEAL AND INSULATE EXPOSED SURFACES	http://www.touch-n-foam.com/cmss_files/attachmentlibrary/42007-1_TNFP%202_Component%20Data%20Sheet%20US_ENG.pdf
S300	9724	SQUARE TUBING	ONLINEMETALS.COM	6061 T6 Aluminum	28	$62.33	2"X2"X96" ALUMINUM TUBING	12.756	2"x2"x8' 3/16" thick	MAY REQURE FILLER ALUMIMUN FOR STRUCTURAL STRENGTH.	https://www.onlinemetals.com/merchant.cfm?pid=9724&step=4&showunits=inches&id=1270&top_cat=60
S400	AR551	DUAL PANE WINDOWS	ANDERSON	WINDOWS	14	$80.46	DOUBLE PANE VINYL WINDOWS	15	AR551 -1'5" X 4'11" ; A21 - 2' X 2';	MODIFIED AR551, OR JUST AR551; A21 FOR TWO SQUARE WINDOWS, CAN BE FIXED, OR OPERABLE WINDOWS	https://awwebcdnprdcd.azureedge.net/-/media/aw/files/technical-docs/parts-catalog/partscatalog-windowsincludingstormwatch-1999-present--400series-awning-perma-shieldimprovedawning.pdf?la=en&modified=20181116195816
S500		FIBERGLASS		FIBERGLASS	4435	$3.00	S-GLASS/2000 EXTERIOR WALL PANELS	1	512 SQ FT 1/8" THICK	COST WILL VARY BUT USUALLY $3 LB	
S501		INTERIOR PANELS		PLASTIC	21	$23.88	INTERIOR WALL PANELS		4'X8' 664 SQ FT		
S502	386081	SUB FLOOR	HOME DEPOT	OSB	7	$12.15	7/16"X4'X8' OSB FOR SUBFLOOR	48	7/16"X4'X8'		https://www.homedepot.com/p/7-16-in-x-48-in-x-8ft-Oriented-Strand-Board-386081/202106230
S503	5683C	VINYL FLOORING	HOME DEPOT	VINYL	200	$0.46	VINYL FLOORING	0.75	200 SQ FT	NEED 200 SQ FT AT $0.46/SQ FT	https://www.homedepot.com/p/Chaucer-12-in-x-12-in-Vinyl-Tile-Flooring-5683C/206394127
S600	710584	EXTERIOR DOOR	HOME DEPOT	STEEL	1	$134.00	36"x80" pre-hung steel	51.44	36"x80"		https://www.homedepot.com/p/36-in-x-80-in-Flush-Primed-Steel-Prehung-Left-Hand-Inswing-Front-Door-710584/202036367
S700		WINCH ASSEMBLY			1	$250.00		40		ASSEMBLY USED TO RAISE AND LOWER THE FLOOR	
SA100			MANUFACTURE	STAINLESS STEEL MOUNTS; STEEL BRACKETS;	2	$100.00	SOLAR ARRAY POLE MOUNTS	27			https://cdn.shopify.com/s/files/1/1871/2047/files/MT_Solar_Brochure_1.pdf?3387644365707894777
SA101				EXTRUDED 6061-T6 ALUMINUM;	6	$62.33	SOLAR ARRAY MOUNTING ARRAY	43.5		PART NEEDS TO BE MANUFACTURED USING 3.5" SQUARE TUBING, 4" SQUARE TUBING, AND 1.5" SQUARE TUBING; ALL TUBING SHOULD BE 1/4" THICK; END CAPS WILL NEED TO BE MANUFACTURE FROM DURABLE STRONG CYLINDRICAL SOLID BAR (ASSUMING QUALITIES OF 6061-T6)	
W100			PEEPOO BAGS		8	$0.50	PEEPOO WASTE MANAGEMENT	0.1		$0.50/person/month FOR PEEPOO	
MIS					1	$1,000.00	MISULANEOUS PARTS AND MATERIALS	100			
										ESTIMATED TOTAL GROSS COST OF SHELTER CONSTRUCTION:	$33,446.26 [1]
										ESTIMATED TOTAL WEIGHT OF SHELTER:	11129.968 [lbs]