

HUMAN OCCUPIED MODULAR ENVIRONMENT

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In an increasingly globalized world, international aid is an ever-present concern. Victims of disaster who are forced to flee their homes due to political strife or natural disaster, but remain within their country's borders, are referred to as internally displaced persons. In 2009, there were an estimated twenty-seven million internally displaced persons, over a million more than in 2007 and 2008, and about ten million more than in 1997.[1] These people need immediate shelter from the elements. Their governments often cannot or will not provide the aid they need, due to barriers created by the disasters, or lack of funds and resources. The responsibility for their shelter and care falls to international organizations.

The Human Occupied Modular Environment project, or HOME, was suggested as a multi-school, multidisciplinary capstone engineering design project proposed by an external client. The client had spent a number of years in the conceptualization of the idea, but never took the project further than the concept stage. The ultimate goal of the HOME is to provide an alternative to the disaster relief housing currently available on the market. Design specifications from the client included requirements for simplicity in setup, space to house three to four people, and modularity such that units may be combined to accommodate larger families. The shelter also incorporates systems to address human needs such as water and electricity. The HOME design was completed using a systems engineering approach that included the capstone design teams simultaneously working on the structural, water and electrical systems as well as their interfaces.

To accomplish this, the client engaged two groups of undergraduate senior engineering students, one group from Roger Williams University (RWU) and the other from the University of Rhode Island (URI). This project became the capstone design project for each group at their respective school. The URI team consisted of four mechanical engineers, and the RWU team consisted of two civil engineers, one electrical engineer, and a computer scientist. The teams took the client's original concept and brought it to the next level of preliminary design. Ultimately the two teams furthered the conceptual design of the project, built scale prototypes of the systems, and performed tests on the systems as a proof of concept. The URI team was in charge of the exterior structure, while the RWU team took the lead on the water and electrical systems.

As an educational project, this multidisciplinary approach yielded tremendous benefits. The experience offered a holistic view of a real-world engineering project while reinforcing the complexity and diversity of real applications. It also emphasized the importance of effective communication and teaming skills, especially where diverse teams with varying skill sets and backgrounds were engaged in different aspects of the same problem. Furthermore, the HOME project impressed that new and innovative engineering designs are greatly improved by multidisciplinary teams.

System Requirements

In designing the HOME, there were extensive and multidisciplinary requirements. The scope of the requirements encompassed cost, ease of assembly and use, durability, longevity, and human factors. The primary engineering disciplines influencing design decisions included structural, industrial, environmental, and electrical; each of these disciplines was affected by all of the aforementioned requirements.

Structural

From a structural perspective, the design of the structure needed to be strong enough to withstand wind, rain, snow, and high temperatures. This was accounted for in the material used and the interfaces between the panels that reinforced the durability and longevity of the structure. The interfaces, while strong, were designed to provide an ease of assembly and include no loose parts such as fasteners, bolts, and screws. Fewer parts reduce failure points as well as maintenance. The HOME must accommodate up to four people; a hexagonal shape (as viewed in Figure 1, below) was used to maximize floor space as well as standing room.

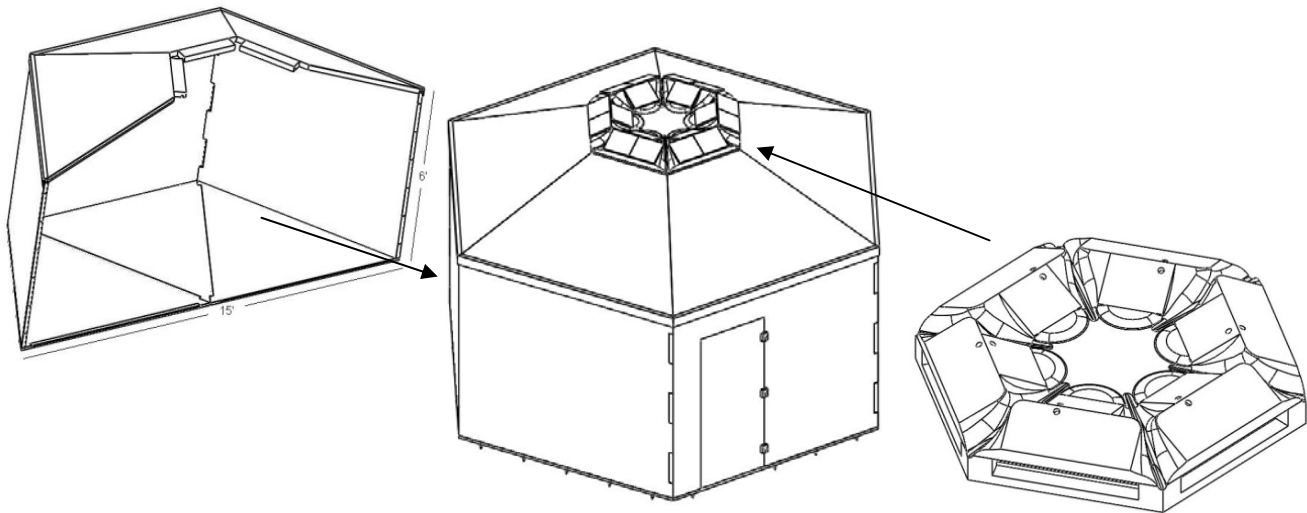


Figure 1: Conceptual design of HOME structure. Each wall is 7.5' long and 6' tall. Cap will house solar paneling as well as interior lighting and wiring. It was designed to maximize the solar collection area while also allowing for rainwater runoff.

The on-site assembly process was simplified by incorporating as few unique panels as possible. These panels were also created such that two average people can carry and lift them into place, in accordance with the NIOSH lifting limits.[2] During the assembly, the panels fit together without the use of tools. Due to the wide range of locations in which the HOME may be used, any instructions required must be limited and portrayed pictorially. A minimum number of unique parts allows for the modularity of units, such that they can be connected to accommodate larger families.

Water System

The three functions of the water system include the collection of rainwater, filtration, and storage. The filtration system has been implemented to provide potable water which meets the drinking water standards of groups such as the World Health Organization. The storage tank material was selected to resist rust and prevent sunlight from allowing algae growth within the water. Overall, the water system is designed to last three to five years with little to no maintenance.

Power Generation

Power generation and use are among the most important requirements of the HOME. Sustainable power generation was a major factor differentiating this structure from traditional emergency housing. The first step in designing the power system was to determine the load demands through power usage. Adhering to the concept of low-wear parts, the requirements stated that the HOME could not have windows; the only sources of natural light were the small holes for ventilation in the wall panels, or door panel if the door was left open. To compensate for this lack of natural light, occupants require a source of lighting for approximately ten to twelve hours each day. Due to the hexagonal shape of the structure, it was calculated that six lights, one corresponding to each wall panel, would be added to the interior of the power cap. Recessed lighting was selected for its simple integration into the cap design. Lights will be installed during manufacturing to minimize occupant setup. Light-emitting diode (LED) bulbs were chosen due to their extremely low wattage and long life-span, in comparison to traditional incandescent bulbs. This should minimize, if not eliminate, the need for occupants to change light bulbs. Use of six bulbs, each five Watts, for twelve hours a day created a daily electrical load demand of three hundred sixty Watt-hours for lighting. The design also included an outlet for the powering of small electronic devices, which was located in the center column. Assumptions were made that the outlet will be used for five hours per day at the rate of twenty Watts, for an outlet use of one hundred Watt-hours per day. The combined load of lighting and the outlet is four hundred sixty Watt-hours each day.

Power Sources

As stated in the requirements, the HOME must be off-grid and include systems for creating its own power. This power must also result from sustainable sources; the client recommended the use of solar, wind, and human generated power. Fuel cells were also included in the research of sources for the purpose of a well-rounded study.

Fuel Cell

A means of power production considered was the use of fuel cells. Electrochemical reactions between fuel and an oxidizing agent are used to generate electrical power. The most common combination of fuels and oxidants is hydrogen and oxygen, but hydrocarbons, alcohols, and chlorine dioxide can also be used. As long as the fuel and oxidant are made consistently available, the fuel cell can operate continuously. The fuel cell is by far the most efficient means of power generation considered for this project, and fuel cells are fairly compact. Also, the only byproduct produced by the use of fuel cells is water. This water might in fact be useful to the occupants. However, the use of fuel cells poses a major concern. The safety of the occupants is a primary concern, and maintaining standing reserves of hydrogen poses a fire danger.

Additionally, the logistics of providing a continual supply of fuel would increase overhead dramatically.[3-5]

Wind

Wind turbines use the force of moving air to turn a propeller which is attached to a drive shaft and generator. The generator then produces electricity which can be harnessed and stored in batteries, or directly used with the help of an inverter.[6] Wind energy meets the clean and sustainability requirements for power sources, but also includes a number of substantial drawbacks. An initial concern was the complexity of a wind turbine, as comprehensive wind studies are required prior to installation for maximum efficiency. Typical wind studies take one to two months, a timeframe that disaster victims do not have. In addition, these studies require tools and background knowledge which would not be available to the displaced persons.[7] Most significantly, the scale required of the wind turbine proved to be completely impractical; the tower must place the wind turbine a minimum of twenty feet above any obstructions.[8] The complexity of the wind turbine also suggests substantial cost. Finally, maintenance and potential failures could pose significant problems for the occupants, which impacts negatively on human factors. These considerations quickly ruled out wind power as a viable source for our needs.

Solar

Solar power was included in the requirements by the client as a primary means of power generation. Like wind, solar power accounts for human factors and renewability. Solar power is extremely simple for the occupants, who need only keep the panels clear of debris to maintain high efficiency. The geographical target areas for our product generally provide consistent sunlight.

Solar energy is typically harnessed and converted to electricity in one of two methods. On a large scale, it is completed at Concentrating Solar Power Plants, which use heat from many solar thermal collectors to heat a fluid and produce steam. The steam is then used to turn and power a generator. This method requires a vast area and in the United States is only used successfully in the Southwest, with nine plants in California, one in Arizona, and one in Nevada.[9] For HOME purposes, a concentrating solar power plant is impractical.

The more common and household process of converting solar energy into electricity is through photovoltaic (PV) devices, or solar cells. Solar cells convert sunlight directly to electricity and are grouped into panels and arrays of panels. These panels are most often viewed on the roofs of houses and buildings. The size of panels and arrays is driven by the efficiency of the individual panels, power of sunlight at the location, as well as power needs.[10]

The three major types of photovoltaic cells are polycrystalline, monocrystalline and amorphous. Each type of cell has different characteristics and efficiency ratings. Monocrystalline has the highest efficiency, at about 16% but is the most fragile. Polycrystalline is less efficient, with an average of 14%, but is less fragile.[11-13] The most durable and flexible of the cells is amorphous, but it is by far the least efficient, with an average of 6% efficiency. Following the use of a Kepner Tragoe Analysis Trade-Off Study [14], it was decided that polycrystalline panels would be used. Polycrystalline panels were selected for the design, as they provide a good balance of adequate durability and efficiency near that of monocrystalline.[15]

Extensive research into innovative and lightweight solar arrays was completed. Some options considered were solar shingles, tracking panels, and small panels mimicking the leaves

of an ivy plant. Tracking panels are programmed to change position as the sun's position changes throughout the day. They capture the maximum amount of the sun's rays. Unfortunately, these panels would require a sun study, similar to the wind study needed for a wind turbine. They also add moving parts and a level of complexity to the power cap which may compromise the structure.[16] These aspects removed tracking panels from selection. Ivy-mimicking panels also require basic knowledge of how solar panels work as well as setup. If the "leaves" are not turned properly, no light will be collected and the system will be rendered useless. This system is also designed for a much smaller scale than what would meet the power needs of the HOME, and has been ruled as no more than an interesting concept.[17-18] Roof shingles containing photovoltaic cells were the innovative option most closely fitting the power requirements. Shingles are installed and wired during the manufacturing process, which means it is unnecessary for users to complete any wiring. With further research, several manufacturers, such as DOW Chemical, were found to be advertising such solar shingles. Unfortunately, neither company will be producing the shingles for several months and have not published specifications or cost data for their products.[19] Without this information, there is no possibility of sizing a solar shingle system and after further consideration, it was determined that shingles would be too fragile and brittle to rely on during shipment and setup. A solid surface is considerably more desirable.

Following the research and discounting of innovative photovoltaic arrays, the team decided to focus on more traditional solar panels. A number of polycrystalline solar panels were researched and compared based on power output, efficiency, size, weight, durability, and cost. Some panels were ruled out immediately, and the remaining were compared using a radar chart approach as illustrated in Figure 2.

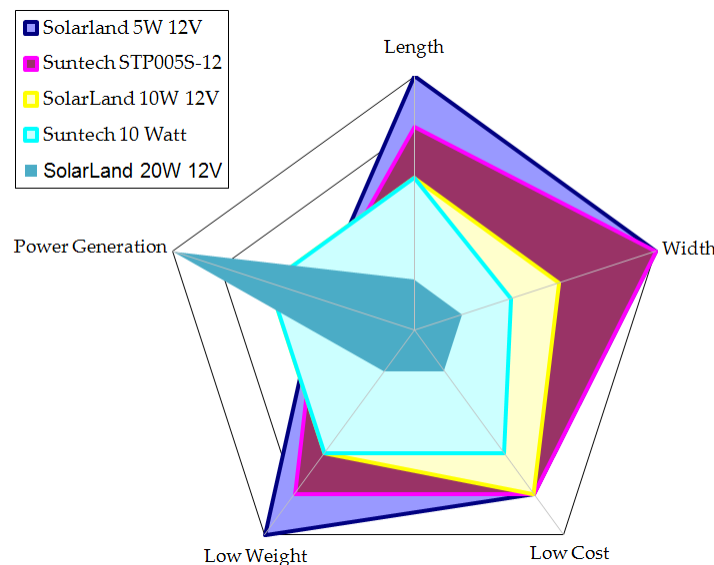


Figure 2: The above image depicts the radar chart used in the selection of solar panels products. Five products were compared based upon their power production, cost, weight, and dimensions. Length and width are in relation to the desired dimensions of 10 in x 9 in, as determined by the size of the power cap. The larger the area on the radar chart, the more desirable the product for HOME use.

The results of this tradeoff study proved that SolarLand 5 Watt 12 Volt panels would work best for our use. Using eighteen of these panels would cost \$630, weigh 29.7 lbs, and provide 90 nominal Watts of power to the HOME.

Human

The final power source requested by the client was the harnessing of human power. This would provide occupants with a means of creating their own energy, and have better control of their available power use. For example, the design requirements include charging a laptop computer or cell phone for three hours each day. However if the users don't require this amount of power they can simply spend less time generating power. Power generation will be accomplished in a manner similar to that of wind turbines. Rather than relying on the force of moving air to turn the rotor, users will turn a crank attached to a drive chain.[20] Humans can produce power in this manner at an average rate of seventy five to one hundred Watts. This number can be doubled for stronger or athletic users.[21]

However, it can be viewed as less than desirable to require occupants to crank for their own electricity. This is especially true in the cases of female and children users, as well as the possibility of injured or handicapped occupants. Under these conditions, the occupants will need to crank for 40 minutes to charge a laptop for just over an hour.[22] The drawbacks can be mitigated by incorporating multiple power systems, such that the human power system can be used as a supplementary power source.

Conclusions

The HOME project is a prime example of interdisciplinary research and design. Multiple power sources were considered, and it was determined that a combination of solar and human power sources would provide the most robust, practical, available, and sustainable system for power production. This example illustrates the depth of electrical engineering research in the project, but the system is also informed by structural, environmental, and industrial concerns; the load of the electrical components has structural ramifications, and the choice of components affects manufacturability and environmental impact. Above all, the Human Occupied Modular Environment project makes clear the interdependencies between the different subsystems in a design, and between the different branches of engineering themselves.

The Human Occupied Modular Environment project has proven to be an ideal educational experience. It provides a rich and demanding set of requirements derived from various and sometimes contradictory goals, including ease of use, provision for human needs, and low cost. Meeting these requirements requires coordination and teamwork between people with different backgrounds and skills. Many fields are relevant to the design of the HOME, including structural, environmental, electrical, and industrial engineering. The project aims to create a manufacturable commercial product with the potential to improve quality of life for people in need.

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