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A Comparison of the Lifecycle Cost and Environmental Impact of Military Barracks Huts in Deployed Environments Constructed from Structural Insulated Panels (SIPs) versus Traditional Techniques

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by

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Abstract

For many years, housing for US Military personnel at forward operating bases has consisted of poor quality, shed-like buildings constructed of dimensional lumber and plywood. These buildings are commonly referred to as Barracks Huts or B-Huts. B-Huts have a number of shortcomings, including complicated construction operations, poor durability, and poor insulative properties. These characteristics lead to slow base camp commissioning, poor lifespan, and high fuel consumption rates. To address these shortcomings, the US Army is currently investigating a different housing system based on structural insulated panels (SIPs); it is referred to as the SIP-Hut. Initial findings suggest that the SIP-Hut offers improved performance with respect to construction, durability, and insulation. To ensure proper use of the SIP-Hut, the lifecycle costs and environmental implications should be understood and compared with those of the B-Hut. This study set out to make this comparison. The results of the study show that the use of SIP-Huts will result in lower operating greenhouse gas emissions (32% - 51% less across the scenarios considered), lower operating costs (as much as $14,505 less per year, per hut), and lower risk of casualties. Although the upfront costs and emissions associated with the SIP-Hut are greater than those of the B-Hut, they are paid back within a reasonable timeframe (1 month to 5 years, depending on the scenario considered). The SIP-Hut also shows potential for use in non-military applications, such as disaster relief operations.

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List of Nomenclature

'	Feet
"	Inches
$	US Dollars
~	Approximately
AFRL	Air Force Research Laboratory
B-Hut	Barracks Hut
BOM	Bill of Material
BTU	British Thermal Unit
CERL	Construction Engineering Research Laboratory
CMU	Concrete Masonry Unit
CO_2	Carbon Dioxide
DLA	Defense Logistics Agency
DOD	Department of Defense
DOE	Department of Energy
ECU	Environmental Control Unit
EOL	End of Life
eq	Equivalent
ERDC	Engineer Research and Development Center
FEU	Forty-foot Equivalent Unit
FOB	Forward Operating Base
ft	Feet
gal	Gallons
GHG	Greenhouse Gas
GSA	General Services Administration
HC	High Cube
HVAC	Heating, Ventilation, and Air Conditioning
in	Inches
ISO	International Organization for Standardization
JCTD	Joint Capability Technology Demonstration
JIFX	Joint-Interagency Field Experiment
KD	Kiln Dried

kPt	Kilo-Ecopoints
kW	Kilowatts
kWh	Kilowatt-hours
lb	Pounds
LCA	Lifecycle Assessment
LCI	Lifecycle Inventory
LCIA	Lifecycle Impact Assessment
LTC	Lieutenant Colonel
LVL	Laminated Veneer Lumber
mpg	Miles per Gallon
MWh	Megawatt-hours
NREL	National Renewable Energy Laboratory
OSB	Oriented Strand Board
PT	Pressure Treated
PV	Photovoltaic
SE	South East
SERDP	Strategic Environmental Research and Development Program
SIP	Structural Insulated Panel
SIPA	Structural Insulated Panel Association
SIP-Hut	Structural Insulated Panel Hut
SO_2	Sulfur Dioxide
TEMPER	Tent Expandable Modular Personnel
TEU	Twenty-foot Equivalent Unit
tmi	Ton-miles
TROPEC	Transformative Reductions in Operational Energy Consumption
UDM	Uniform Dispersion Molding
ULCANS	Ultra Lightweight Camouflage Net Systems
US	United States
USCENTCOM	United States Central Command
USD	United States Dollars
USLCI	United States Life Cycle Inventory
USMA	United States Military Academy

1. Introduction

Base camps commissioned and operated by the United States Military in areas of armed conflict (referred to as theaters) consume numerous resources in order to sustain daily operations. There have been many efforts to reduce the resource consumption rate of these base camps. One aspect of base camps that has been targeted for improvement is the shelters. There are many different types of shelters, which vary depending on the type of base camp, mission requirements, geographic location, and climate. This research focuses on the assessment of a newly developed shelter unit, which is expected to have many beneficial characteristics that could lead to appreciable reductions in resource consumption if adopted in replacement of existing systems. This research analyzes the new shelter unit from a lifecycle perspective and provides conclusions with respect to the appropriateness of its use.

2. Background

2.1. The Importance of Sustainability in DOD Operations

The sustainability of the United States Military's operations has lately been of growing concern. The United States Department of Defense (DOD) understands that a reduction in their operational footprint will not only reduce their overall environmental impact, but will increase their mission effectiveness through lower operational costs, reduction in the need of physical manpower, reduction of material flow (less fuel, building materials, etc.), and lower physical impact to local environments. A US Army Engineer Research and Development Center (ERDC) report stated that "Recent US contingency operations have demonstrated the vulnerability of forward operating base (FOB) logistical supply lines" (Angerson et al., 2013). These bases have large material and energy footprints that are resupplied by "risky ground convoys, expensive airlifts, or airdrops" (Angerson et al., 2013). This problem is aggravated by inefficient base operations, resulting in the need for more risky fuel and material transport than should be necessary (Angerson et al., 2013).

A report submitted to the Strategic Environmental Research and Development Program (SERDP) stated that "The sustainability of our FOBs in Iraq, Afghanistan, and around the world has never been a more relevant issue. Recent troop surges and extended operations in multiple theaters underscore the urgency for improved FOB sustainability to reduce costs, logistic support, force exposure, and casualties" (Noblis, 2010). Additionally, the DOD recognizes the importance of sustainability in every aspect of their operations and stresses its importance to those responsible for developing US Military base camps (US Army, 2010). With regards to US Military bases, sustainability can be defined as the ability to "achieve and sustain effectiveness within the means of available resources (materials, labor, energy, and funds) without placing unnecessary strain on existing sustainment systems" (US Army, 2010). According to the US Army, sustainability "is primarily achieved through reduced demand and cost-effective consumption of resources" (US Army, 2010).

2.2. Incorporating Sustainability into Base Camps

In response to the desire of improving the sustainability of base camps, much research has been performed evaluating options to reduce their energy consumption. Some of this research focuses on effective energy generation techniques utilizing renewable energy technologies (i.e. photovoltaic (PV) panels and wind turbines), while the rest focuses on the source of the problem, energy efficiency of buildings and equipment. One such example of these efforts is the Net Zero Joint Capability Technology Demonstration (JCTD) that identified, deployed, and assessed a wide range of technologies for potential implementation into US Army base camps. These technologies were evaluated by the United States Central Command (USCENTCOM) over a 3-year period at the National Training Center in Fort Irwin, California (USCENTCOM, 2011). Many of these technologies were found to have great potential to improve the sustainability of US Military bases through energy demand reductions, reduced reliance on fossil fuel based electricity, and improved solid waste handling practices. The types of technologies evaluated in this study include facility support technologies, power management systems, and waste disposal systems (USCENTCOM, 2011).

A report completed by the Air Force Research Laboratory (AFRL) stated that the primary electrical power generation provider for military bases is diesel fueled generators (Keith, 2012). These generators require continuous refueling by risky fuel convoys, presenting significant safety concerns for soldiers. According to the AFRL report, the largest electrical power consumer for base shelters is the environmental control unit (ECU). In a typical expeditionary shelter unit, 80% of all energy produced is consumed by the ECU to provide air conditioning (Keith, 2012). The cost of air conditioning these shelters has been so problematic that many shelters were coated with spray-on foam insulation. Though this helped reduce energy use associated with the air conditioning of the shelters, it caused concerns for ventilation and fire safety, resulted in the elimination of the option for shelter reconstitution, and caused many problems with shelter disposal (Keith, 2012).

In response to the energy issues associated with the existing shelter units, the AFRL conducted a research effort to create a quickly deployable (tent-type) shelter with integrated PV electricity generation and improved thermal efficiency (Keith, 2012). The results from the 2 year study

concluded that the application of solar barriers (flys), to reduce direct solar loading, and the installation of insulated liners, to improve shelter efficiency, provided peak demand period energy reductions of 15-50% depending on the type of insulated liner that was utilized (Keith, 2012). With the incorporation of thin film PV cells into the shelter fly, an additional 20% reduction in generator electrical peak power demand was observed. The final conclusion from the study was that if these insulated, power producing shelters were deployed throughout a base camp, and if the latest (more efficient) ECUs were to be utilized, a potential overall power reduction of 40% is possible (Keith, 2012). This level of efficiency not only has the potential to greatly reduce financial expenditures, but also is likely to save many soldiers' lives, by reducing risk exposure associated with fuel transport.

2.3. Base Camps

According to the Base Camps manual published by the US Army, "a base camp is an evolving military facility that supports the military operations of a deployed unit and provides the necessary support and services for sustained operations" (US Army, 2010). There are three sets of standards for base camps, which have varying usage periods that are derived from the base's expected design life. These include: initial, temporary, and semipermanent. The differences between these three standards include: operational design life, robustness of facilities and services, and intricacy of construction methods (US Army, 2010). Initial construction standards are characterized by austere facilities that require minimal engineering effort. They are intended for immediate use and are limited to 6 months of operation. Temporary construction standards are characterized by austere facilities that are designed for increased operational efficiency, and require engineering oversight. They are intended to be used for up to 2 years, but are authorized to be utilized for up to 5 years if necessary to fulfill mission requirements. Semipermanent construction standards allow for the efficient selection of materials and equipment to provide improved energy efficiency and reduced maintenance and lifecycle costs. Expected design life is between 2 and 10 years (US Army, 2010).

The life cycle of a base camp includes four phases which directly relate to the lifespan of the base camp; these are: planning and design, construction, operations, and transfer and closure. Generally, these phases are sequential, but they can overlap because of the dynamic nature of

base camps. Base camps can be continuously modified based on threat, mission requirements, and the need for relocation, expansion, or reduction (US Army, 2010). Due to these characteristics, it is beneficial for base camps to be quickly and efficiently modified and transferred. In order to achieve this, buildings and equipment that are easily disassembled, relocated, and reassembled are important.

2.4. The Key to Successful Incorporation of Sustainability

The chance of successfully incorporating sustainability into any base camp is related to the expected duration of use (US Army, 2010). Therefore, due to the extended design life of semipermanent bases, the success of incorporating sustainable components is more likely. Regardless, it remains important that smaller, shorter-duration base camps consider implementing sustainable design components whenever possible, because frequently these bases become longer-duration as operations progress (US Army, 2010).

Since incorporating sustainable components into longer-duration base camps (i.e. 2-10 years) is more feasible, this research has focused on temporary and semipermanent base camps. In addition, the types of structures being evaluated in this research are only practical for base camps that have an expected duration of 2 years or more (Hart, 2013a).

2.5. The Potential of Structural Insulated Panels

The United States Military Academy (USMA) at West Point and the US Army Engineer Research and Development Center (ERDC) has been developing a potential alternative to the typical inefficient and problematic semipermanent military barracks (commonly known as Barracks Huts or B-Huts). B-Huts are built to similar standards as US building codes describe, but generally do not include insulation or interior/exterior finishes. This results in unnecessarily high thermal loads and poor acoustic performance, which leads to poor operational efficiency and occupant comfort (Hart, 2013a). Initial tests have shown that the alternative being developed by the USMA and ERDC will likely resolve many of the problems that are characteristic of B-Huts. The potential solution is to utilize structural insulated panels (SIPs) to construct housing units. The USMA and ERDC refer to these structures as SIP-Huts (Baker et al., 2013). SIPs

have a high insulating value (both thermal and acoustic), are structurally rigid, and provide for quick assembly/disassembly (Murus; SIPA). Although these SIP characteristics present a credible argument in favor of SIP-Huts, many characteristic problems remain unaddressed. SIPs have a high relative shipping volume, they currently cannot be sourced locally in deployed environments, and they are produced using large quantities of petroleum based foam (Hart, 2013a; Murus). In order to determine if constructing barracks with SIPs is a feasible alternative, it is important that the entire lifecycle of these structures be analyzed from an economic, environmental, and operational perspective.

3. Literature Review

3.1. SIP-Hut

The USMA, in West Point, New York, has spent the last year developing and testing their redesign of the Barracks Huts (B-Huts) that are used overseas by the US Military for soldier housing. Initial tests have shown that their redesign, the SIP-Hut, has the potential to greatly increase energy efficiency and soldier quality of life. They accomplish this through the use of structural insulated panels (SIPs) (Baker & Leemans, 2013). They have sourced their SIPs from The Murus Company, Inc., a SIP manufacturer based in Mansfield, Pennsylvania. Murus utilizes a patented high impact plastic Cam-Lock system in their polyurethane SIPs, which provides for exceptionally quick erection times and a tight positive seal between panels (Murus). By utilizing these panels the SIP-Hut can be built more rapidly and heated and cooled more efficiently (Baker & Leemans, 2013). According to the USMA's initial findings, the SIP-Hut takes one-third the time to construct and is twice as energy efficient as the current B-Huts. However, the capital costs involved with purchasing and shipping the materials for the SIP-Hut are significantly higher. Despite the increased capital cost, initial modeling has suggested that the SIP-Hut will provide approximately a one year payback over the current B-Huts (Baker & Leemans, 2013). The USMA has built two full-size models, one of each, and has been actively testing them to help verify the accuracy of their energy models (Baker & Leemans, 2013).

The USMA's design focused on satisfying the following customer needs of the Army and soldiers. The Army's needs are focused around logistics, improved efficiency, and

constructability. The soldiers' desires include adequate force protection, ease of construction, and quality of life. These customer requirements were extracted from a survey sent out to junior Army officers, of which 28 responses were collected (Baker & Leemans, 2013).

3.1.1. Energy Analysis

The energy modeling for the B-Hut and SIP-Hut was performed in eQUEST 3-64. In this software, each building model contains over 120 variables. Many of these were known, based on building geometry and materials. However, the USMA was forced to make many assumptions, because of the many unknowns (Baker & Leemans, 2013). The software provided fuel and electricity requirements based on the inputs. The USMA used the model to predict energy usage in Afghanistan. From the first revision of the model, the results indicated that the SIP-Hut would not require any heating load during the winter months and significantly less cooling compared to the B-Hut during the rest of the year. The results from the model in regards to heating and cooling can be found in Table 1. Values are for a single, 16' wide by 32' long, single-story building (Baker & Leemans, 2013).

Table 1 - Barracks Thermal Load in Afghanistan Based on eQUEST Model

	B-Hut	SIP-Hut
Annual Heating Load (kWh)	3,000	0
Annual Cooling Load (kWh)	7,050	4,940
Total Annual Thermal Load (kWh)	10,050	4,940

It can be seen from Table 1 that the SIP-Hut will likely require 50% of the thermal conditioning load, compared to the B-Hut. These savings equate to 5,110 kWh or 409 gallons of diesel fuel annually, per building (Baker & Leemans, 2013). These savings are significant and could vary depending on the deployment location. It has been determined that the ideal location for the SIP-Hut is one that experiences extreme temperatures (Baker & Leemans, 2013). This structure would not likely pay back quickly enough in a more temperate environment, making it less feasible for deployment in these types of locations.

From the initial energy model results, the USMA determined that due to the lower thermal conditioning demand of the SIP-Hut it will only require a 36,000 BTU environmental control

unit (ECU) instead of the 60,000 BTU ECU commonly used to condition B-Huts (Baker & Leemans, 2013). Subsequent energy modeling of the SIP-Hut actually suggests that a smaller 9,000 BTU ECU will be sufficient (Leemans, 2013). Requiring a smaller ECU has the benefit of reducing capital costs and shipping costs associated with the deployment of the ECUs (Baker & Leemans, 2013).

3.1.2. Lifecycle Analysis

The USMA determined that a major issue related to the deployment of the SIP-Hut is the transportation of its materials. According to the USMA, the total volume of the SIP-Hut's materials is six times that of the B-Hut, and the weight of SIP-Hut's materials is nearly 50% greater than the B-Hut's (Musser & Hennessy, 2013). This is due to the polyurethane and polystyrene foam that is used in the SIPs to provide their structural and insulative properties. As will be seen later, these figures are actually incorrect, the volume of the SIP-Hut's materials is only four times the B-Hut's and material weights are nearly identical. Regardless, the volume increase makes transporting the materials for the SIP-Hut more costly. According to the USMA, one standard 40' long shipping container, used by the Army for transportation, will only be able to fit the materials to construct two SIP-Huts, as opposed to twelve B-Huts (Musser & Hennessy, 2013). Another issue with the SIP-Hut is the material cost. The first SIP-Hut cost the USMA $14,500 in materials while the B-Hut only cost them $6,500. They stated that the cost of the SIP-Hut was for just one prototype and would likely come down significantly with mass production (Musser & Hennessy, 2013). However, they did not offer any insight in regards to the magnitude of that cost reduction.

According to the USMA report from the SIP-Hut project's civil engineering team, the prices stated above do not include the cost of the roofing, doors, electrical, HVAC systems (ECUs), or labor. Their reasoning for excluding these items is that (with the exception of labor) they are identical between the SIP-Hut and B-Hut (Musser & Hennessy, 2013). This statement may be true for the roofing, doors, and electrical, but it is not for the HVAC systems. As described previously, the mechanical engineering team on the project stated that the size of the ECU for the SIP-Hut could be reduced from that of the B-Hut (Baker & Leemans, 2013). This would provide a potentially significant cost reduction for the SIP-Hut. Though not entirely necessary, it would

also have been wise of them to include the roofing, doors, and electrical systems in the cost analysis to provide a more realistic cost per unit. Including all of the costs would provide for a comparison that is not deceiving in nature. Currently, at first glance it looks as though the SIP-Hut costs over twice the price to construct as the B-Hut. If all of the other costs are incorporated though, the initial cost differential is not as dramatic. This is an especially important concept when trying to “sell” the idea of deploying SIP-Huts to the DOD.

The USMA made some crude conclusions regarding the lifecycle costs of the SIP-Hut and B-Hut. Table 2 outlines these conclusions (Baker & Leemans, 2013).

Table 2 - Barrack's Lifecycle Results

	SIP-Hut	B-Hut	Annual Fuel Savings per SIP-Hut	Break Even Point
Shipping Weight	8,262 lb	5759 lb	2986 lb	10 months
Shipping Volume	1,075 ft^3	175 ft^3	54.7 ft^3	16.5 years
Cost (Material and Labor)	$15,300	$8,740	$5726 (at $14/US Gallon)	1.2 years

The USMA’s methodology for determining lifecycle costs of each option is rudimentary in nature. Some metrics are very unconventional. For example, the shipping volume comparison suggests that, based on transportation volume alone, the breakeven point between the SIP-Hut and B-Hut will be 16.5 years. To make this conclusion it has to be assumed that the construction materials to build the SIP-Huts are transported in an identical manner as the diesel fuel being used to power them. This is an unrealistic assumption for a number of reasons. Firstly, the transportation vehicles used will be different and will have vastly different volumetric capacities. Secondly, the source of the fuel and building materials will likely be entirely different, resulting in dissimilar transportation distances. The shipping weight metric provides a similar problem. The density of building materials is significantly less than that of diesel fuel. Therefore, many more vehicles will be required to transport equivalent weights of building materials and fuel. The proper way to make this lifecycle comparison is to evaluate the total shipping costs unique to the SIP-Hut, B-Hut, and diesel fuel, and include these as one portion of the total lifecycle cost. The analysis made for the material and labor cost metric seems accurate, but is likely lacking in detail.

Additionally, the assumption of $14 per gallon of diesel fuel may be an accurate average for fuel costs in theater, but only provides for a basic evaluation under average conditions. According to the USMA, the fuel costs in theater can vary significantly with location and base size (Baker & Leemans, 2013). Diesel fuel can range from $10 per gallon in standard Battalion size locations in Iraq to $400 per gallon on small outposts in Afghanistan (Hodge, 2011). If fuel costs can be better predicted for specific situations and included in the lifecycle analysis, the return on investment of installing SIP-Huts will be better known.

3.1.3. Construction

The USMA determined that the construction of the SIP-Hut is significantly faster than the B-Hut and requires fewer tools, equipment, and skills. It took an eight soldier squad 28 hours to construct the B-Hut, while the SIP-Hut only took 10 squad hours to build (Musser & Hennessy, 2013). This significant difference comes from the modular nature of the SIP-Hut. There are far fewer individual pieces, most of which are prefabricated panels that just need to be joined together and erected. The SIP-Hut has 153 total pieces, 58 of which are panels. To contrast, the B-Hut has 567 pieces (not including fasteners) (Musser & Hennessy, 2013). Furthermore, the SIP-Hut requires significantly less skilled labor than the B-Hut to construct. This is due to the panelized, modular nature of the materials, the Cam-Lock fastening system, and the lack of required tools. The SIP-Hut only requires an Allen wrench (for the Cam-Locks) and a screw gun. The B-Hut requires saws, hammers, tape measures, and other miscellaneous tools, along with skilled soldiers to use these tools. B-Huts also commonly require engineering oversight to ensure proper construction procedures are followed (Musser & Hennessy, 2013). The USMA has concluded that the reduced construction effort will yield many benefits. The cost of construction will be significantly less. Also, rapid construction will reduce the time required to get a base camp fully up and running. This will allow for more time to execute the missions that the soldiers are being deployed to complete. This will ultimately increase mission effectiveness, which is of utmost importance to the US Military (Musser & Hennessy, 2013). Figures 1-7 demonstrate the differences between the B-Hut and SIP-Hut (Musser & Hennessy, 2013).

Figure 1 - Squad Placing SIP Floor Panels

Figure 2 - Inserting B-Hut Joists

Figure 3 - Squad Erecting First SIP Wall

Figure 4 - B-Hut Wood Framed Walls

Figure 5 - SIP-Hut Roof Panels

Figure 6 - B-Hut Trusses

Figure 7 - SIP Hut (Left) and B-Hut (Right)

The USMA did an adequate job outlining the benefits of the SIP-Hut with respect to construction. The analysis is not complete though. They provided very little documentation of the costs associated with the construction of the housing units. Also, the support (security, facilities, etc.) for the soldiers constructing the housing was not considered in the analysis. Furthermore, construction times of these housing units were derived from inexperienced cadets constructing the B-Hut and the SIP-Hut prototype. Due to this fact, the construction times documented by the USMA are likely not accurate to what reality will yield in theater. In many instances, it is likely that the soldiers constructing these buildings in theater will have experience. Therefore, construction times should be an average that the Military estimates based on past experiences.

3.1.4. Occupant Safety and Comfort

The USMA believes that the SIP-Hut will be a safer building and provide for higher quality soldier living conditions. According to the USMA, fires are a major concern in B-Huts. The SIPs have an additive that makes them six times more fire resistant than typical plywood (Musser & Hennessy, 2013). Improved fire resistance will greatly increase the safety of the building and provide a better chance for a fire to be extinguished before significant damage is caused.

In addition to fire safety, the panels also dampen sound very well. Improved sound dampening will make for a quieter living space for soldiers in an otherwise noisy environment (Musser & Hennessy, 2013). This attribute has great potential to increase mission effectiveness by increasing the mental stability of soldiers in theater, allowing them to operate at peak

performance. Though this claim would be difficult to quantify, it has the potential to yield substantial benefits to the effectiveness of the Military's operations.

3.1.5. End of Life

Typically, B-Huts are in poor condition at the end of the initial use phase. When the US Military decommissions a base camp, these buildings must be demolished. Since the SIP-Huts are durable and easily disassembled, they have potential salvage value. The SIP-Huts could be disassembled and relocated to a new base camp or they could be sold to citizens of the host nation (Musser & Hennessy, 2013). This will not only help preserve the local environment, but could also provide an economic reimbursement to the Military. The USMA's analysis only briefly states these potential end of life (EOL) options. In order to better understand the SIP-Huts, the EOL of these structures should be analyzed further.

3.2. 2nd Generation SIP-Hut

In August 2013, the US Army Engineer Research and Development Center (ERDC) and USMA constructed their second SIP-Hut prototype as part of a Joint-Interagency Field Experiment (JIFX) organized by the Naval Postgraduate School in Monterey, California (Hart, 2013b). The revisions made to the original prototype reduced the total number of pieces and total construction time. The structure's construction time was only 7.3 squad hours (vs. 10 squad hours for the 1st generation SIP-Hut). The total number of pieces was reduced from 153 to 105 (50 of which are panels), thus allowing for a decrease in handling and construction time (Hart, 2013b). This updated design has been used in the research being discussed in this document.

3.3. Other Sustainable Military Housing

As discussed in Chapter 2, the Net Zero Plus Joint Capability Technology Demonstration (JCTD) was used as a means to identify, deploy, and assess a wide range of energy efficient technologies relative to military operations in theater, specifically related to forward operating bases (FOBs) (USCENTCOM, 2011). The United States Central Command (USCENTCOM) assessed 40 technologies over a 3-year period, many of which were found to have military

utility. The USCENTCOM believes that if fielded, many of these technologies have the ability to positively impact operations in theater, by lowering fuel demand and providing renewable means of energy production. Additionally, there is a potential for the improvement of infrastructure and reduction in overall equipment footprint of FOBs (USCENTCOM, 2011). Based on each proposed technology's functionality, they were grouped into the following areas: facility support technologies, power management systems, and waste disposal systems. This review will only discuss technologies from the facility support technologies group, because they are most relevant to this research. The specific technologies reviewed include: improved liners and solar barriers for expeditionary shelters, urethane foam treatments for enduring structures, and permanent monolithic domes. Each technology is appropriate for specific types of FOBs. There are three levels of FOBs. Fleeting/Tactical, which consists of mobile units; Enduring, which consist of all requirements to be in operation for up to 5 years; and Permanent (USCENTCOM, 2011). The purpose of this review is to demonstrate the potential benefits associated with the increased thermal performance of base camp shelters.

3.3.1. Liners and Solar Barriers

Insulated liners and solar-blocking shades are designed to be easily integrated into existing tents. They are appropriate for fleeting/tactical FOB structures. They have been found to provide a reduction in energy demand without adversely affecting the expeditionary capability of the shelter (USCENTCOM, 2011). Table 3 shows the results for adding a quilted liner and Ultra Lightweight Camouflage Net Systems (ULCANS) to a Tent Expandable Modular Personnel (TEMPER) Shelter, which is the standard Army field tent. As can be seen in Table 3 and Figure 8, adding these liners and solar barriers to a typical tent will yield up to approximately a 50% decrease in power demand needed for heating and cooling. The quilted liner and ULCANS solar barrier combination is referred to as the NZ+ combination (USCENTCOM, 2011). By making these modifications, a 600 soldier FOB could see an overall 40% fuel savings and a reduction in annual fuel consumption of 94,286 gallons. This equates to 13 less fuel deliveries by tanker truck per year (USCENTCOM, 2011).

Table 3 - Power Demand for TEMPER Tent Shelter

Season	Baseline TEMPER Shelter (kW)	TEMPER + ULCANS/Quilted Liner (kW)	Power Reduction
Winter (heating)	9.6	6.5	32%
Spring/Fall (heating)	13.5	7.0	48%
Spring/Fall (cooling)	9.0	5.5	39%
Summer (cooling)	14.5	7.0	52%

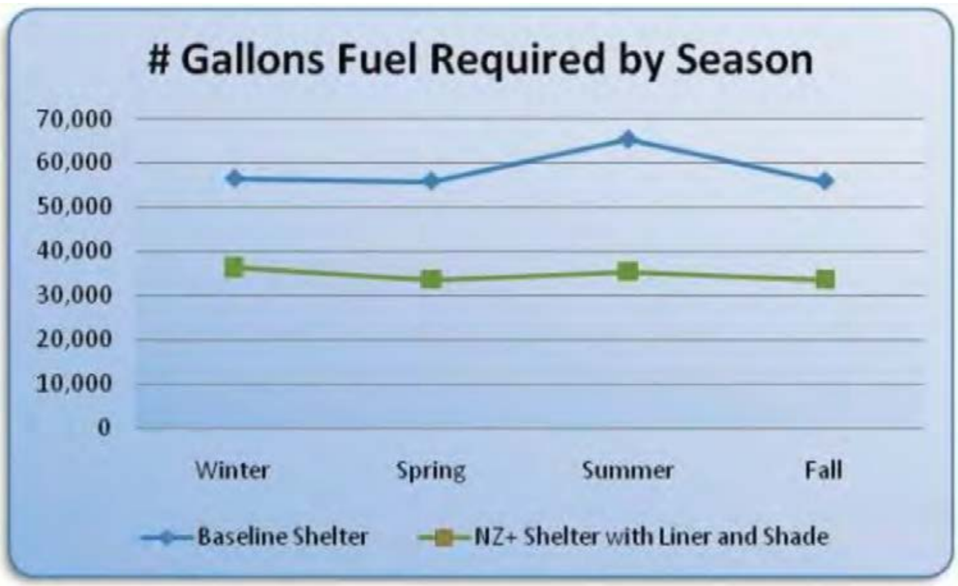

Figure 8 - Fuel Demand of TEMPER Shelter Variations by Season

The JCTD report included a basic analysis regarding the potential return on investment for implementing the ULCANS and Quilted Liner into the TEMPER shelters of a 32 tent base camp. The in theater cost of fuel delivered to a FOB was assumed to be $20 per gallon (USCENTCOM, 2011). The following is an outline of this analysis:

Initial Cost: ($12,500 per tent) x (32 tents) = $400,000

Fuel Savings: (258 gal/day) x ($20/gal) = $5,160/day

Breakeven Point: $400,000 / $5,160 = 77 days

3.3.2. Foamed Tents

Foamed tents are appropriate for enduring or permanent FOBs because the process of foaming the tents essentially transforms a temporary structure into a permanent one. In order to foam the tents properly the process must be performed by a specialized contractor. There are also many issues with foamed tents including inadequate ventilation and difficulties with disposal (USCENTCOM, 2011). As can be seen in Table 4 and Figure 9, the foaming of tents can significantly decrease the power demand of the structure by greatly increasing the structure's insulative properties. If foamed structures are employed, generator capacity can be downsized from 200 kW to 30 kW. It has been determined that with this reduced energy demand, FOBs could experience up to 87 percent fuel savings. A 1,350 soldier enduring camp could see an estimated fuel reduction of 869,795 gallons (124 tanker trucks) per year.

3.3.3. Monolithic Domes

Monolithic domes are constructed from the ground up and are only appropriate for permanent FOBs. These structures are permanent and well insulated. As can be seen by Table 4 and Figure 9 they are even more energy efficient that the foamed tents (USCENTCOM, 2011).

Table 4 - Power Draw for FOB Structures

Season	Un-foamed Tent 7,410 ft^2 (kW)	Foamed Tent 7,410 ft^2 (kW)	2-story Monolithic Dome 6,500 ft^2 (kW)
Winter (heating)	102	11	4.9
Spring/Fall (heating)	78	6	2.2
Spring/Fall (cooling)	176	22	12.3
Summer (cooling)	238	32	24.3

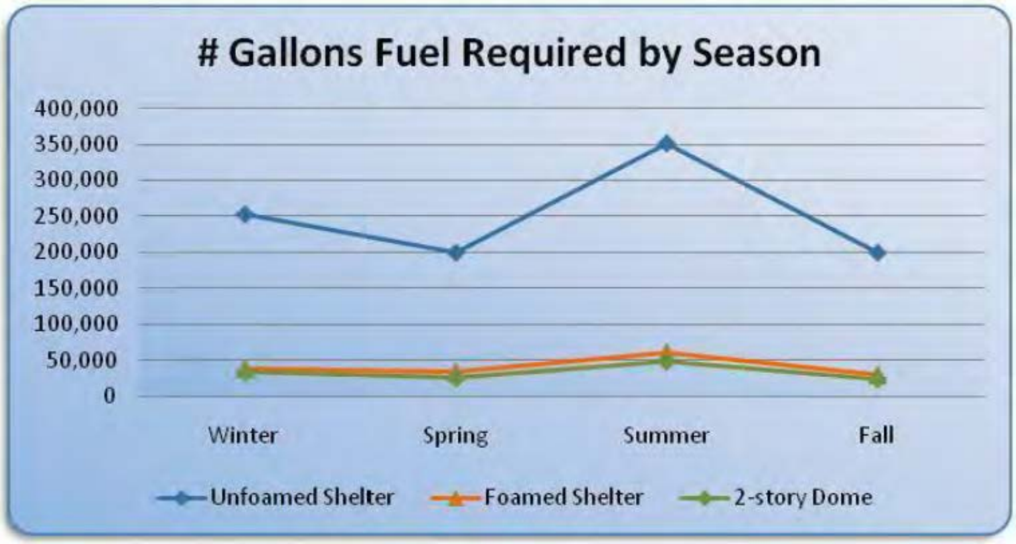

Figure 9 - Fuel Demand of FOB Structures by Season

Solar barriers, tent liners, foamed tents, and monolithic domes are examples of technologies that have been deployed to help reduce energy demand associated with buildings in US Military base camps. Though these technologies may have some flaws, they all provide a significant increase in thermal efficiency over their traditional counterparts. These technologies demonstrate the effort being put forth by the DOD to increase the sustainability of their operations through efficiency improvements. The fact that these studies have been conducted and present promising results provides assurance that further research on the SIP-Hut is of importance to the DOD.

4. Problem Statement and Research Question

Many of the presently utilized forms of temporary and semipermanent military housing in deployed environments are inefficient and ineffective. Climate controlling them is highly wasteful, thermal and acoustic comfort is poor, and generally, they have little to no EOL value. The USMA's proposal to construct barracks using SIPs may be a practical solution.

From the initial research performed by the USMA, SIP-Huts seem to be a feasible alternative to traditional B-Huts. To evaluate whether their use will be an effective means of improving deployed military housing, it must be evaluated from a lifecycle perspective. This research set out to perform an economic and environmental lifecycle analysis comparing the two options. In addition, various aspects of the operational implications of deploying SIP-Huts have been addressed. This analysis provides a more accurate means to assess the appropriateness of constructing SIP-Huts in deployed environments than what previously existed.

The ultimate research question that this study was based on is as follows. Will replacing traditional wood framed temporary and semipermanent military housing units with units constructed of SIPs be economically competitive and environmentally beneficial? If so, under what specific deployment scenarios and to what degree will this be true?

5. Significance

It is intended that the results of this research will aid the US Department of Defense in understanding the effects that deploying SIP-Huts in theater will have on its budget, operational effectiveness, and the local and global environment. This should aid in the appropriate and effective deployment of SIP-Huts in theater. This research also provides insights into potential non-military applications for SIP-Huts.

The approach utilized by this research had not previously been used to evaluate SIP-Huts. The preexisting cost analysis of the SIP-Hut was simplistic and inaccurate for deployed environments, such as Iraq or Afghanistan. Furthermore, prior to this research an environmental lifecycle analysis (using lifecycle assessment (LCA) methodologies) had not even been attempted. This study closes many of these gaps, and provides a more systematic understanding of this technology and its effects throughout all phases of its lifecycle.

6. Research Methodology

6.1. Overview of the Study

This study involves a detailed comparison of the lifecycle of SIP-Huts with that of traditional B-Huts. The study looks at the economic, environmental, and operational impacts of the two options in order to provide a better understanding of their implications throughout each option's lifecycle. It is imperative to take this lifecycle approach to help ensure that false and incomplete data for a system does not drive the decisions for its implementation. Understanding the implications of a system at every stage of its lifecycle will allow for more informed decision making and will help predict the manner in which the system will interact with other systems throughout its life.

6.2. Economic Analysis

The purpose of the economic analysis is to provide insight with respect to how much each shelter type will cost the organization installing them, throughout the shelters' lifecycles. Economic data has been documented and analyzed in Microsoft Excel. All costs have been derived from reliable sources, including: the US General Services Administration (GSA), RSMeans, equipment and material suppliers, shipping service providers, and the US Army.

Information that was obtained to complete this analysis includes: initial costs (materials, equipment, shipping, construction/installation), operational costs, and end of life (EOL) costs (demolition/deconstruction, landfilling). The desired outputs of this analysis were total one-time costs (initial + EOL costs) and recurring costs (yearly operational costs). Though not commonly done, the decision was made to combine EOL costs with the initial costs for two reasons. (1) The EOL cost ended up being minimal compared to the sum of the initial costs. (2) The life span of the shelters can vary significantly (2-10 years), so accurately applying a time-value methodology to the EOL costs would be impractical.

Using the one-time and recurring costs of the SIP-Hut and B-Hut, a break-even analysis was performed. Since, from the literature, the SIP-Hut's initial costs were expected to be greater and

its operational costs were expected to be lower than the B-Hut, the break-even analysis was used to determine the timeframe within which the SIP-Hut's reduced operational cost pays back its increased initial cost. To address any issues with respect to cost uncertainty, a sensitivity analysis was performed. The sensitivity analysis provided insight into which line items in the cost breakdown have the potential to significantly affect the end results due to cost uncertainty.

6.3. Environmental Analysis

The purpose of the environmental analysis is to provide insight with respect to the magnitude of environmental impacts that each shelter causes throughout its lifecycle. This analysis was performed using the lifecycle assessment (LCA) software package SimaPro, developed and maintained by PRé Consultants. The methodologies used in this environmental lifecycle analysis were very similar to the standards published by the International Organization for Standardization (ISO), ISO 14040:2006 "Environmental management - Life cycle assessment - Principles and framework" and ISO 14044:2006 "Environmental management - Life cycle assessment - Requirements and guidelines." Despite the fact that the methodologies were quite similar, there were some marked differences. For example, due to the short timeframe of this study, it could not be reviewed by other LCA practitioners, as is required by ISO 14044. Due to the differences, this study is not claiming to be an LCA, and as a result does not use the term. The majority of the methodology employed by the environmental analysis in this study is identical to that described by the standard LCA approach. The LCA methodologies adopted by this analysis will be described in this section.

6.3.1. LCA Framework

Figure 10 describes the framework employed by a standard LCA, it comes from ISO 14040. This framework was used to guide this study's environmental analysis.

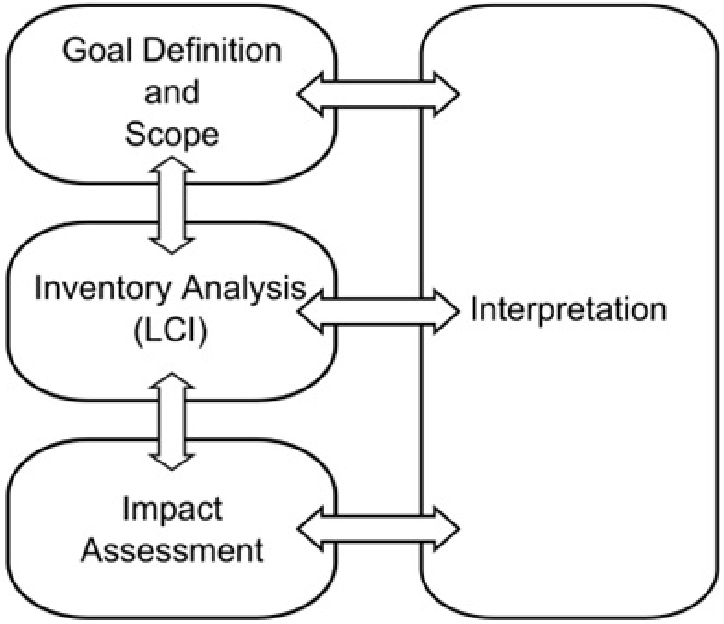

Figure 10 - Lifecycle Assessment Framework

6.3.1.1. Goal and Scope Definition

Developing the goal and scope definition is the first step in carrying out an LCA study. According to ISO, the goal definition "shall unambiguously state the intended application, the reason for carrying out the study, and the intended audience (Baumann & Tillman, 2004)." This study is intended to be utilized by any organization interested in the implications that result from replacing traditional wood structures with structures constructed from SIPs. Its purpose is to inform the audience of how traditional wood structures and structures constructed from SIPs can impact the environment (both negatively and positively). This study should be used to compare the implications of the two structure types to help guide the decision of what type of structure to construct. Although this study can apply on a general basis, the specific reason for its completion was to provide a comparison of the SIP-Hut and B-Hut for the US Army. The intent of this study was to provide the Army with sufficient information regarding the lifecycle of these two shelter types to allow them to make educated decisions with respect to the deployment of the shelters.

The purpose of the scope definition is to identify what will and will not be included in the study. The choices that are made in this step of the LCA process include: (1) which options to model, (2) defining a functional unit, (3) choosing impact categories and methods for impact

assessment, and (4) defining the system boundaries and data quality requirements (Baumann & Tillman, 2004). This study has modeled both shelter types as thoroughly as possible. For the purposes of this environmental analysis, only the shelters' structures were considered (i.e. building materials). Electrical equipment and materials, ECUs, and generators were considered to be outside the scope of this analysis for two reasons: (1) data was not available and (2) differences between these items are expected to provide negligible variations in environmental impacts. The functional unit considered in this analysis is "climate controlled housing support for 6 soldiers for a varied number of years." Time was varied between 2 and 10 years. The inventory and impact metrics that have been reported include: embodied energy (kWh), greenhouse (GHG) gas emissions (lb CO_2 equivalent), and total environmental impact (Ecopoints). Ecopoints are a measure of the total environmental impact, which can be applied to any material, product, process or service (Edge Environment). The quantification of environmental impact in Ecopoints provides a simple comparison between the B-Hut and SIP-Hut that includes a weighted average of all the environmental impact categories. The quantification of embodied energy and greenhouse gas emissions allows for a comparison using metrics that are already well understood in industry. These metrics provide an effective basis to understand the impacts of each option. The system boundaries of this study are outlined beginning on page 26. No specific data quality requirements have been established. Simply, data of the highest available quality was used and in cases that low quality data had to be used, the associated uncertainty was estimated and included in the sensitivity analysis.

6.3.1.2. Inventory Analysis

Lifecycle inventory (LCI) analysis establishes the types and quantities of material and energy inputs required by a system throughout its lifecycle. It also calculates the resulting material outputs and environmental emissions at each stage of the lifecycle. The general steps required to complete an LCI include: (1) construction of a flow chart outlining the system boundaries, (2) collect and document data for all activities in the system under consideration, and (3) calculation of the environmental loads of the system in relation to the functional unit (Baumann & Tillman, 2004).

Since, for this study, SimaPro was used to conduct the environmental analysis, the LCI process was simplified. The simplification came from the software having much of the LCI data readily available for materials and processes. SimaPro extracts information from various LCI databases that are integrated into the software. The majority of LCI data for this study came from the USLCI database. This database was chosen because it is up to date and was produced by the National Renewable Energy Laboratory (NREL) to aid in the environmental modeling of systems in the US (NREL, 2012). One of the other major databases that SimaPro provides access to is the ecoinvent database. This data was only used for a few select components and processes that the USLCI database did not have data for. The LCI data in the ecoinvent database has been developed for European systems, and therefore was only used out of necessity (ecoinvent Centre).

6.3.1.3. Impact Assessment

The goal of lifecycle impact assessment (LCIA) is to describe the environmental consequences associated with the loads placed on the environment from the system under consideration. The LCIA is achieved by "translating" the environmental loads defined in the inventory results into environmental impacts. Examples of such impacts include: global warming potential, ozone depletion, acidification, eutrophication, and effect on biodiversity. There are several reasons to perform this translation. (1) Impact assessments are generally easier to relate to, for example, providing acidification consequences rather than just stating SO_2 emissions. This provides results that are more environmentally relevant and easier to communicate. (2) Impact assessments significantly reduce the number of metrics that must be viewed to holistically compare options. Inventory results can have 50 to 200 (or more) parameters, while impact assessment results only have approximately 15. This reduction is achieved because when translating inventory data to environmental impacts, the inventory data is grouped into impact categories. Further reduction can be achieved by weighting all impact categories to produce one single score. For the purposes of this study, this is the main form that the LCIA data is presented. As mentioned in the "Goal and Scope Definition" section, the unit for the single score metric used in this study is referred to as an Ecopoint. (3) LCIA also proves helpful in making the results of an environmental study more comparable to one another. Comparability of multiple options can be a problem when each has a very different environmental profile. For

example, one option may result in a sizable quantity of low toxicity emissions, while another option may result in a low quantity of high toxicity emissions. Comparing the emissions directly will provide no useful conclusions, but translating these emissions into the same impact categories will provide a simple means of direct comparison (Baumann & Tillman, 2004).

6.3.1.4. Interpretation

After the inventory and impact assessment results have been obtained, there is generally a large quantity of data available. In the interpretation step of the LCA framework all of this data is organized, filtered, and displayed in various forms that allow for simple interpretation. Interpretation in LCA terminology is commonly defined as "the process of assessing results in order to draw conclusions" (Baumann & Tillman, 2004). Interpretation can be achieved in many ways. Generally, the use of various types of diagrams and other visual aids provides for simple results interpretation (Baumann & Tillman, 2004). To carry out the interpretation step of this study, multiple approaches were used. To provide the raw data necessary to perform a basic comparison between the two shelter systems the LCI and LCIA data from the SimaPro model was extracted and imported to Microsoft Excel. The benefits of having the data in Excel included: (1) having complete control over the production of visual aids such as graphs and tables, (2) having access to the raw data to allow for break-even analysis, and (3) having the ability to easily vary the data while testing the results of different system scenarios.

SimaPro has the capability to filter the results as desired and produce a variety of visual aids, such as flowcharts, graphs, and tables. For the purposes of this study, SimaPro was used to produce visual aids that (1) provide direct comparison between the two shelter types and (2) display impact results by category for each shelter type (as opposed to a single impact score).

6.4. Operational Analysis

The purpose of the operational analysis is to provide insight with respect to how each shelter option affects the operations involved with establishing, operating, and decommissioning a base camp. This data is of particular interest to the US Military, because it provides insights with respect to the planning and logistics of their operations. The information presented for this

analysis, for both shelter types, installed at a battalion size base camp, includes: (1) number of material transport vehicles to commission the shelters in the base camp, (2) number of annual fuel transport vehicles, (3) gallons of fuel consumed annually, (4) shelter construction times for the base camp, and (5) an estimation of annual fuel-related supply convoy casualties for the base camp. Further work includes a break-even analysis to determine when the increased number of truck shipments required to commission a base camp with SIP-Huts is paid back by the reduction in annual fuel truck shipments. According to the US Army, this metric would heavily influence the decision of which type of shelters to install.

6.5. System Boundaries

System flow diagrams detailing the system boundaries and lifecycle phases for each shelter type can be seen in sections 11.1 and 11.2 of the Appendix. The following two sections describe the system boundaries assumed by the economic and environmental analysis in this study.

6.5.1. Economic Analysis Boundaries

Everything from initial material cost to disposal cost has been included. Total cost of each SIP-Hut has come directly from Murus, the manufacturer. The costs of B-Hut materials have come from the *US General Services Administration (GSA) and Defense Logistics Agency (DLA) Central Asia and South Caucasus Supply Catalog*. The transportation costs have been provided by the commercial shipping company NEX Worldwide Express (NEX) and additional assumptions have been made to account for expenses incurred due to shipping in theater. The costs of construction have been estimated to be the base pay of the soldiers who would be constructing the huts plus 25% for overhead and additional construction related costs. Only the cost to build the SIP-Huts and B-Huts has been estimated, no site work (constructing roads, leveling ground, etc.) or construction of other buildings has been included. Construction crew support facilities and soldiers have been excluded from the analysis due to lack of data; their costs are expected to be covered by the estimated overhead expenses. The costs for operation have been determined by utilizing the energy consumption data for the SIP-Hut and B-Hut that has been extracted from the eQUEST model generated by the USMA. Furthermore, an average fuel cost of $15/gallon has been used, because it is the standard planning cost for fuel in theater

(Hart, 2013c). The EOL costs, associated with the decommissioning of base camps, for the B-Hut have been estimated using *RSMeans: Building Construction Cost Data (2012)*. The EOL cost of the SIP-Hut has been assumed to be half of the cost of the B-Hut. This is because it is likely that the SIP-Huts would only have to be deconstructed, and not landfilled, upon base decommissioning, since they would have potential for reuse or resale. No resale value of the SIP-Huts has been included in the analysis.

6.5.1. Environmental Analysis Boundaries

SimaPro processes (primarily sourced from the USLCI database) have been used to represent all raw materials that go into the finished building products (i.e. dimensional kiln dried lumber, plywood, etc.) that are used to construct the shelters. Evaluating the processes and raw material inputs for those products was outside the scope of this analysis, therefore the inputs to the SimaPro processes are assumed to be representative of reality. The transportation distances for these materials from their point of manufacture to the final manufacturing facility or construction site have been estimated and included in the analysis.

For both the SIP-Hut and the B-Hut, the electrical components (i.e. wires, breaker box, outlets, lights, etc.), HVAC equipment (ECU, air ducts, etc.), and protective coatings (i.e. paints, roofing, etc.) have not been included in the environmental LCA. The justification for the exclusion of the electrical components is that there is a negligible difference between the components used in the B-Hut and SIP-Hut. The reasoning for not including the HVAC equipment is that LCI data for the ECUs was unavailable, and producing it was outside the scope of this analysis. The justification for not including the protective coatings is that the exact nature of these materials is not identified in the construction documents. Furthermore, it is likely that these materials would be similar (if not identical) between each of the shelter types.

Energy consumption with respect to construction activities that are directly attributed to building the SIP-Huts and B-Huts has been included. The energy consumption figures used are rough estimates that are meant to represent the approximate energy expended from the act of constructing the buildings (including running generators, equipment, etc.). Since the energy expended during this lifecycle phase is expected to be minimal in comparison to the overall

lifecycle of the shelters, this level of uncertainty will have negligible effects on the results of the analysis.

Maintenance has not been included in any aspect of the study, because, according to LTC Steven Hart of the US Army, very minimal maintenance operations actually exist for the current B-Huts (Hart, 2013a). It is assumed that the SIP-Hut will be managed in the same manner.

With respect to EOL, it is being assumed that the B-Hut will be landfilled immediately after the Military decommissions the base camp. It is assumed that the SIP-Hut will have an opportunity for Military reuse or local sale, providing some additional benefits beyond the initial use phase. Since it is quite uncertain what the value of these opportunities will be, the benefits have not been included in the analysis. The final EOL for the SIP-Huts is assumed to be landfill. This is a reasonable assumption because there is no cost effective way to recycle the components, and incineration would be a poor option from an air quality perspective.

6.6. Bill of Materials

6.6.1. Overview

In order to appropriately model each shelter system in SimaPro and to allow for an accurate material cost estimate, detailed bills of materials (BOMs) had to be produced. The complete BOMs can be seen in sections 11.3 and 11.4 of the Appendix, starting on pages 91 and 95, respectively. These BOMs were compiled by referencing fabrication and construction documents for both shelter types. The SIP-Hut documents were provided by the SIP manufacturer, the Murus Company, Inc., which the USMA has contracted to manufacture the materials for their prototype SIP-Huts (Murus, 2013). The B-Hut documents were representative of a typical B-Hut that would be constructed at semipermanent base camps, in theater. The referenced document was produced by the ERDC Construction Engineering Research Laboratory (CERL) in 2012 (ERDC, 2012). Some minor variations were present between these documents and the SIP-Hut documents with regards to shape and size. To allow for a fair comparison, minor changes to material quantities were made to the B-Hut BOM.

6.6.2. Building Materials

In order to accurately model the B-Hut and SIP-Hut in SimaPro, the materials had to be quantified in terms of weight. All processes in SimaPro that represent materials had to be in mass units for the analysis to work properly. In order to determine how many SIP-Huts and B-Huts could fit into one shipping container, it was also necessary to determine the volume of all materials. In order to calculate the volume of wood, the actual dimensions (not nominal, i.e. for dimensional lumber a 2x4 would be 1-1/2" x 3-1/2") were used. For each individual piece, the actual dimensions were multiplied together to obtain per piece volumes. The volume per piece was then multiplied by the total quantity for each member to obtain the total volume for each member type. Particular attention was paid to keeping units consistent and converting when necessary; the volumetric unit of cubic feet (ft^3) was used. In order to quantify these materials in terms of weight, common density values were multiplied by the volumes. Values used include: oriented strand board (OSB) = 45 lb/ft^3, plywood = 37 lb/ft^3, kiln dried (KD) lumber = 35 lb/ft^3, polyurethane (PUR) foam = 2.2 lb/ft^3, expanded polystyrene (EPS) foam = 1.0 lb/ft^3.

For metallic materials (such as fasteners and metal brackets) the weights of these individual materials were measured and recorded at the local Lowe's Home Improvement. To ensure an accurate weight, the average weight of 3 trials was used. The weights that were recorded are accurate to 0.01 ounce. The fasteners and brackets that were used to determine weights are representative of the ones that are used in the actual shelters. Any variations to reality are negligible. The weights of the metallic components were measured and recorded in ounces for each individual piece. The individual weights were then multiplied by the total quantity and converted to pounds (using the conversion 1 ounce = 0.0625 pounds). The packaged volume of fasteners and brackets was determined by estimating the packaged density of the materials. For the fasteners this was done by determining the volume of the package and dividing by its weight. The dimensions of a typical 5 pound box of nails and screws are 4.5" x 4.5" x 6". The volume of this size box is 121.5 in^3 (0.0703 ft^3). This provides a packaged density of 71 lb/ft^3 ((5 lb) / (0.0703 ft^3)) for the fasteners. The packaged density of the brackets is known to be less than the fasteners due to a higher quantity of void space caused by the brackets' awkward shape. The exact packaged density could not be determined, but has been estimated as 50 lb/ft^3. Even if this

estimate was off, the effect that it would have on the total volume would be negligible (<0.05%), and thus would have little effect on the results.

6.6.3. HVAC and Electrical

Also included in the BOM were all of the HVAC and electrical components. This list of equipment and materials was provided by LTC Steven Hart, because these systems were not detailed in the SIP-Hut and B-Hut fabrication and construction documents. The inclusion of these components is mainly for the cost analysis. The costs of these equipment and materials came from a variety of sources. The prices of the environmental control units (ECUs), which are the main pieces of equipment required for the HVAC systems, were provided by Larry Donohoe, from the military supply company HDT Global. For the B-Hut, a 60,000 BTU ECU is required. For the SIP-Hut, only a 9,000 BTU ECU is required (due to the reduced heating and cooling demand) (Hart, 2013a). The 60,000 BTU (5 ton) unit produced by HDT is model number 2003841-P2 and costs $18,822. The 9,000 BTU unit produced by HDT is model number GSQ396ZABNWFX21 and costs $9,500 (Donohoe, 2013). In addition to the 9,000 BTU ECU, the SIP-Hut would require either an exhaust hood or a heat recovery air exchange unit. This equipment would be necessary to provide adequate fresh air intake to the SIP-Hut. Currently, only an exhaust hood is being considered, because the USMA and ERDC have not found an acceptable heat recovery air exchange unit. Not having a heat recovery air exchange unit will lead to a slight decrease in the thermal efficiency of the SIP-Hut (Hart, 2013a). This decrease is expected to have minimal effects on the accuracy of this study.

The electrical components for both the SIP-Hut and B-Hut include everything required to wire the shelters to code. These components include: wiring, breakers, switches, outlets, lighting fixtures, work boxes, covers, etc. Many of the prices for these components were provided by LTC Steven Hart. The prices for any components that were not provided came directly from Lowes Home Improvement. These prices are assumed to be representative, because it is expected that the materials would be shipped from the US.

6.6.4. SIP-Hut Structure Costs

The cost of the SIP-Hut building shell and doors was provided by Murus as $16,000. This figure is based on a detailed quote that Murus developed for the USMA (Bloom, 2013a). The only additional material cost that had to be determined was for the foundation (which is $274.26). This provided a total material cost for the SIP-Hut structure (foundation, building shell, doors) of $16,274. The volume, density (where applicable), and weight of all materials that go into the SIP-Hut structure can be seen in Table 5.

Table 5 - SIP-Hut Structure BOM Summary

Item	Volume (ft^3)	Density (lb/ft^3)	Weight (lb)
7/16" OSB	133.19	45	5,993.3
PUR Foam	518.28	2.2	1,140.2
EPS Foam	314.67	1.0	314.7
KD Lumber	32.19	35	1,126.6
BC Grade Plywood	1.40	37	51.7
Laminated Veneer Lumber	8.53	41	349.8
2" Galvanized Screws	0.24	71	16.8
3" Galvanized Screws	0.05	71	3.5
Panel Screws	0.31	71	21.8
Simpson PC46 Bracket	0.008	50	0.4
Doors	6.80	30	204.0
Foundation	24.61	N/A	948.22
Total	1,040.3		10,171.0

6.6.5. B-Hut Structure Costs

The cost of the B-Hut structure was determined by extracting costs from the *GSA and DLA Central Asia and South Caucasus Supply Catalog*. This catalog has costs for many types of items, including construction materials. The purpose of this catalog is to provide access to local materials to the US Military and civilian agencies that are located in Afghanistan and the surrounding areas (GSA, 2013). The construction prices reflected in this catalog are close to the prices that would be paid in the US for material (for example the price of 8 foot 2x4's in the US range from $2.50-$3.50, and the GSA catalog price is $3.54). Even though the bulk of this

analysis considers these construction materials to be transported from the US, the GSA prices have been used for three reasons. The first reason is that they are very similar to average US prices. The second reason is that the catalog provides one single price, versus the large range of prices that could be seen from US suppliers. The third reason is that, although this analysis is assuming that the materials are being shipped from the US, it is likely that for the construction of a larger base camp, the materials would be sourced locally to Afghanistan. It is important that these results can be easily applied to other situations in the future. There are some items (other than electrical and HVAC) that were priced using US prices (which came from Lowes Home Improvement). These include the foundation blocks, foundation beams, and man doors. The costs per unit were multiplied by the quantity of each item to obtain the total cost for each item. This process can be seen in Table 6.

Table 6 - B-Hut Building Shell Itemized BOM Summary

Item	Quantity	Cost/Unit (/ lb for nails)	Total Cost (USD)	Volume/ Unit (ft^3)	Total Volume (ft^3)	Density (lb/ft^3)	Weight/ Unit (lb)	Total Weight (lb)
KD 2x4x8'	120	$3.54	$424.20	0.29	35.00	35	10.2	1,225.0
KD 2x6x8'	125	$5.67	$708.13	0.46	57.29	35	16.0	2,005.2
KD 2x6x12'	38	$8.50	$323.00	0.69	26.13	35	24.1	914.4
KD 1x6x12'	6	$8.50	$51.00	0.34	2.06	35	12.0	72.2
1/2"x4'x8' plywood	32	$32.23	$1,031.36	1.33	42.67	37	49.3	1,578.7
5/8"x4'x8' plywood	27	$39.00	$1,053.00	1.67	45.00	37	61.7	1,665.0
3/4"x4'x8' plywood	16	$46.96	$751.36	2.00	32.00	37	74.0	1,184.0
16d common nails	666	$0.81	$11.10				0.021	13.7
12d common nails	75	$0.85	$1.04				0.016	1.2
10d common nails	1768	$0.90	$23.87				0.015	26.5
8d common nails	3479	$0.97	$35.67				0.011	37.0
10d galv (1-1/2") hanger nails	708	$1.00	$5.31				0.008	5.3
8d galv box nails	114	$1.00	$13.68				0.12	13.7
2x6 joist hangers	46	$1.00	$46.00				0.27	12.2
Rafter ties	34	$2.00	$68.00				0.21	7.3

The costs were then grouped into categories and the price was summed for each category. The total cost of the B-Hut structure was determined to be $5,198.91 and can be seen in Table 7. The table also displays the volume and weight per category and, if applicable, the density that was used to determine the weight from volume, or vice versa.

Table 7 - B-Hut Structure BOM Summary

Item	Total Cost (USD)	Volume (ft^3)	Density (lb/ft^3)	Weight (lb)
KD Lumber	$1,506.33	120.48	35	4,216.8
Plywood	$2,835.72	119.67	37	4,427.7
Nails	$71.67	1.10	71	78.4
Galvanized Nails	$18.99	0.27	71	19.0
Hangers	$46.00	0.24	50	12.2
Rafter Ties	$68.00	0.15	50	7.3
Doors	$377.94	6.80	30	204.0
Foundation	$274.26	24.61		948.2
Total	$5,198.91	248.7		9,913.6

Costs, volume, and weight of the SIP-Hut and B-Hut by category can be seen in Table 8 and Table 9.

Table 8 - Complete SIP-Hut BOM Summary

Item	Total Cost (USD)	Volume (ft^3)	Weight (lb)
Structure	$16,274.26	1,040.3	10,171.0
HVAC	$9,522.55	5.8	155.0
Electrical	$1,126.29	80.0	300.0
Total	$26,923.10	1,126.0	10,626.0

Table 9 - Complete B-Hut BOM Summary

Item	Total Cost (USD)	Volume (ft^3)	Weight (lb)
Structure	$5,198.91	248.7	9,913.6
HVAC	$18,822.00	34.3	540.0
Electrical	$1,057.35	80.0	300.0
Total	$25,078.26	363.0	10,753.6

6.6.6. Generators

Due to the SIP-Hut's highly insulated nature it will require a lower peak electrical demand to operate the building. This reduction in peak demand comes from a reduction in the magnitude of

required heating and cooling. Based on the USMA's eQUEST model results, in Kandahar, Afghanistan, the peak demand for the B-Hut is in December at 6.48 kW (5.64 kw for heating). In the same location, the SIP-Hut has an estimated peak demand of 1.89 kW (1.29 kW for cooling), in June and July (Leemans, 2013). Further refined analysis should be performed before drawing any operational conclusions from this with respect to the required generator capacity, but for the purposes of this analysis, these numbers have been used. As can be seen in Table 10, the required generator capacity for a 120 hut base camp (for only the huts) will be 777.6 kW if B-Huts are used and 226.8 kW if SIP-Huts are used. These requirements would likely be fulfilled by using three 400 kW generators for a base camp with B-Huts (2 would be in use and 1 would be on standby as a backup) and six 60 kW generators for a base camp with SIP-Huts (4 in use and 2 as backups) (Hart, 2013a).

One of the benefits to reducing the demand for generator capacity is that the generator size can be reduced, leading to simpler logistics with respect to moving the generators. The operational logistics of moving 60 kW generators (weighing 4,431 pounds) is simpler because they can be unloaded and relocated using a forklift, which most base camps have (Hart, 2013a). In order to move the 400 kW generators, which weigh 14,430 pounds (Caterpillar, 2013), a larger piece of equipment (potentially a crane) would be required. For this analysis, enclosed site generators (referred to by the manufacturer, Caterpillar, as Rental Generators) are being considered. Specifications for these generators have been extracted from their corresponding specification manuals. These manuals and the pricing of these units were provided by Jeff Horwath, an employee of Milton Cat in Batavia, NY. The model numbers of the specific units used are CAT XQ400 and CAT XQ60. The numbers in the model number refer to the capacity of the generator in kilowatts (Caterpillar, 2013). These units generally come with trailers, but pricing and dimensions used in the analysis are based on the generators only (excluding the trailers), because they would not likely be shipped to Afghanistan with the trailers attached.

Reduced capital cost is the main benefit to having a reduced demand for generator capacity. The cost of the generators, including approximate shipping costs, is as follows. The XQ400 costs $245,000 and the XQ60 costs $76,667. The resulting generator cost per hut for 120 hut base camps would be $6,125 for the B-Hut and $3,833 for the SIP-Hut. This results in a capital cost

reduction of $2,292 per hut, for installing SIP-Huts. A detailed breakdown of generator requirements and costs can be seen in Table 10.

Table 10 - Base Camp Generator Information

	SIP-Hut	B-Hut
Required capacity per hut (kW)	1.89	6.48
Capacity for 120 huts (kW)	226.8	777.6
Generator Size (kW)	60	400
Number of Generators	6	3
Cost per Generator (USD)	$75,000	$240,000
Generators per 40' Shipping Container	6	2
Shipping Cost per 40' Container	$10,000	$10,000
Shipping Cost per Generator (USD)	$1,667	$5,000
Total Cost per Generator (USD)	$76,667	$245,000
Total Generator Cost (USD)	$460,000	$735,000
Generator Cost Per Hut	$3,833	$6,125

6.7. Transportation

The transportation of the B-Hut and SIP-Hut will be in 40' standard and 40' HC (high cube) containers, respectively. The total volume and weight of one SIP-Hut (including all materials and equipment) is 1,126.0 cubic feet and 10,626 pounds. The SIP-Hut will require a HC container to effectively ship two complete SIP-Huts at once. Although the calculated volume of two SIP-Huts with all materials and equipment is 2,251 cubic feet and the 40' standard container has a volumetric capacity of 2,350 cubic feet (Conex, 2013), packaging inefficiencies will not allow for 2 SIP-Huts to fit in one 40' standard container (Bloom, 2013b). Furthermore, it has been discussed that the most effective way to load these containers would be to package the materials for each SIP-Hut on skids and slide them into the container with a forklift or similar piece of equipment. This additional skid material will add further volumetric inefficiencies to the packaging process. Therefore, it will be assumed that 40' HC shipping containers will be used. These containers have an additional foot of height, providing an internal height of 8'-10". A height greater than 8' should allow for more efficient packing because all of the SIP's are 4' wide, allowing for SIPs to be packaged on edge, two high, without much wasted space.

The total volume and weight of one B-Hut (including all materials and equipment) is 387.1 cubic feet and 10,753.6 pounds. Since the capacity of a 40' standard shipping container is 2,350 cubic

feet and 58,425 pounds (Conex, 2013), 5 B-Huts will be able to be packed into one container at a total volume and weight of 1,935 cubic feet and 53,768 pounds.

6.7.1. Shipping Costs

Transportation costs have been obtained from the shipping company Nex Worldwide Express. The company provided a shipping quote for one 40' shipping container transported from Mansfield, PA, US to Port Qasim, Karachi, Pakistan. The company charges identical rates for standard and HC containers, so no distinction was made. They could not provide a quote for the shipment from Port Qasim to Kandahar, Afghanistan. They claimed that they are not currently shipping to Afghanistan because of expected border complications. This was common to the other company for which a quote was solicited, Maersk. The solution to determine this cost was to normalize the cost of (one-way) land transport in the US on a per mile basis and multiply it by the round trip distance from Port Qasim to Kandahar, Afghanistan. The normalized cost was determined to be $4.59/mile. This may be an overestimate for a longer haul, but the cost of shipping in Pakistan and Afghanistan is likely higher than in the US, so an overestimate is warranted.

The difference in diesel fuel prices between the US and Afghanistan and Pakistan was considered in the estimate. The US diesel fuel prices are $1.05/liter ($3.97/gal), the Pakistan and Afghanistan diesel fuel prices are $1.20/liter ($4.54/gallon) and $1.21/liter ($4.58/gallon), respectively (The World Bank, 2012). The average fuel cost for a truck in the US (assuming 5.9 mpg fuel efficiency (Winebrake, 2012)) is $0.673/mile (($3.97/gal) / (5.9 miles/gal)). The average fuel cost for a truck in Afghanistan and Pakistan is $0.773/mile (($4.56/gal) / (5.9 miles/gal)). This is a difference of $0.10 per mile of transit. This was added to the $4.59/mile US truck transit cost for a total per mile cost of $4.69. The distance from Port Qasim to Kandahar, Afghanistan is 1,150 miles round trip. The round trip distance was used because it is unlikely for there to be return cargo from a FOB during commissioning. Furthermore, return cargo from other sources is considered unlikely because of the large number of shipments that would be occurring during the commissioning of a base camp. US military shipments in theater generally require gun-truck escorts to provide force protection against potential enemy attacks. Therefore, it was important to include the fuel costs incurred by operating the gun-trucks. The

round trip cost of an escort gun-truck has been determined by estimating a per mile fuel cost. The per mile fuel cost has been estimated as $1.50. This figure is being used because the fuel economy of a gun-truck is on average 10 miles per gallon (mpg) and the cost of fuel in theater is $15/gal on average (($15/gal)/(10 miles/gal) = $1.50/mi) (Hoy, 2008). The round trip cost was divided by 4 because one gun-truck is needed for every four shipping trucks (each carrying one container). It is assumed that the shipping trucks will only be escorted to the FOB. There will be no escort during the shipping trucks' return trip. The cost breakdown for one 40' container can be seen in Table 11.

Table 11 - Shipping Cost Estimate

	Cost	Comments
Mansfield, PA to New York Port:	$1,193	260 miles
New York Port to Port Qasim:	$2,090	9,176 miles
Port Qasim to Kandahar, Afghanistan:	$5,392	1150 miles (round trip) (@ $4.69/mile)
Gun-truck fuel (assume $1.50/mile)	$431	1150 miles/4
Total Shipping Cost per 40' (or 40' HC) Container:	$9,106	

The total transportation cost of one 40' container has been rounded up to $10,000. The reasoning for this is that there are likely other costs that have not been accounted for in the above estimate. For example, there may be costs to cross the border into Afghanistan, formal or informal (i.e. bribes). In addition, if the shipping trucks were delayed in any fashion, the shipping company would likely charge more. Furthermore, due to the risky nature of the shipment, the company would likely charge an extra premium for their services. Most international shipping companies will not currently ship in Afghanistan under normal circumstances, so increased rates are certainly not out of the question.

6.7.2. Environmental Implications of Shipping

All transportation efforts have been accounted for in the SimaPro model to allow for the evaluation of the environmental impacts associated with delivering the shelter materials to the FOB.

6.7.2.1. Road Transport

In environmental modeling, material shipments are typically tracked in mass-distance units. In the case of this study, the road transport for moving the packed shipping containers from the US to Afghanistan has not been tracked in mass-distance units (ton-miles). The reasoning for this is because the low packed density of the SIP-Hut would skew the results. Instead, a process has been created in SimaPro to represent this transportation effort on a per mile basis. It is likely that since a SIP-Hut container would weigh less overall (21,252 pounds versus 53,768 pounds for a B-Hut container), the fuel economy would be greater for an identical truck towing a SIP-Hut container versus one towing a B-Hut container. Although this is likely the case, due to the uncertainty of the magnitude of this potential fuel efficiency increase, the fuel efficiency of the vehicle is being considered to be identical between for each situation. Furthermore, accounting for this increased fuel efficiency would benefit the SIP-Hut in terms of environmental impacts, and it is preferred that this analysis be conservative for the representation of the SIP-Hut's benefit. With a slightly conservative approach, it can be expected that actual benefits will be slightly better than predicted.

The SimaPro process that has been created is based on the USLCI process for truck transportation in ton-miles (*Transport, combination truck, diesel powered/US*). The new process uses the same ratio of emissions to unit of diesel fuel combusted. The fuel consumption per mile of truck transport for this new process was determined by obtaining the average efficiency of a combination truck in the US (in miles per gallon) and inversing it. It is assumed that the efficiency of the trucks used in Pakistan and Afghanistan have a similar fuel efficiency rating. The fuel efficiency assumed is 5.9 mpg (Winebrake, 2012). This means that the fuel consumption is assumed to equal 0.1695 gallons per mile.

A SimaPro process has also been created to represent the gun-truck escort that would be used when transporting in theater. This has been done in the same manner as the transportation truck process. The fuel economy of the gun-truck is estimated to be 10 mpg (Hoy, 2008). This provides a fuel consumption of 0.10 gallons per mile. According to the US Army, for every four shipping vehicles one gun-truck is required (Hart, 2013c).

6.7.2.2. Ocean Transport

Similar to road transportation, ocean transportation has not been tracked in ton-miles (tmi) either. To recap, this is because the low packing density of the SIP-Hut would lead to inaccurate results. Since weights of the SIP-Hut and B-Hut are each approximately the same, this method would lead to nearly equivalent impacts for each option. In actuality, the SIP-Hut requires 2.5 times as many containers as the B-Hut to ship the equivalent number of them. This means that the impact of shipping one SIP-Hut should be approximately 2.5 times as great as shipping 1 B-Hut. The efficiency of an ocean freighter is very minimally affected by weight. The efficiency of moving materials by sea is more dependent on the density of those materials, because as long as the containers are within their own weight capacity, the ships are volumetrically limited.

To make this analysis more accurate, the number of transport miles that each hut is accountable for has been determined. This has been determined by dividing the total 9,176 mile transportation distance (this route can be seen in Figure 11 (Searates, 2013)) by the 40' container capacity of the ship, then by the number of huts per container. A 10,000 TEU (twenty-foot equivalent unit) shipping vessel is being considered. This is a typical mega-post-Panamax shipping vessel capacity (Nottebom, 2001). The justification for using this vessel size is as follows. The most constricting canal that the shipment would have to traverse is the Suez Canal in Egypt, which connects the Mediterranean Sea and Red Sea. The post-Panamax vessels have been designed to be able to fit through the new lock (opening in 2014) in the Panama Canal. To ensure that this size vessel has the ability to traverse the Suez Canal, the dimensional restrictions of the new Panama lock were compared with the dimensional restrictions of the Suez Canal. The Suez Canal has been expanded over the years. At its current state (since 2010) the Suez Canal's capacity is as follows: a maximum ship draft (dimension from bottom of the ship to the water's surface) of 66 feet, a width of 205 feet, and no length restrictions (there are no locks) (Suez Canal Authority, 2010). This is greater than the capacity of the newest lock in the Panama Canal, which is restricted to a draft of 49.9 feet, width of 160.7 feet, and a length of 1,200 feet (Maritime Connector, 2012).

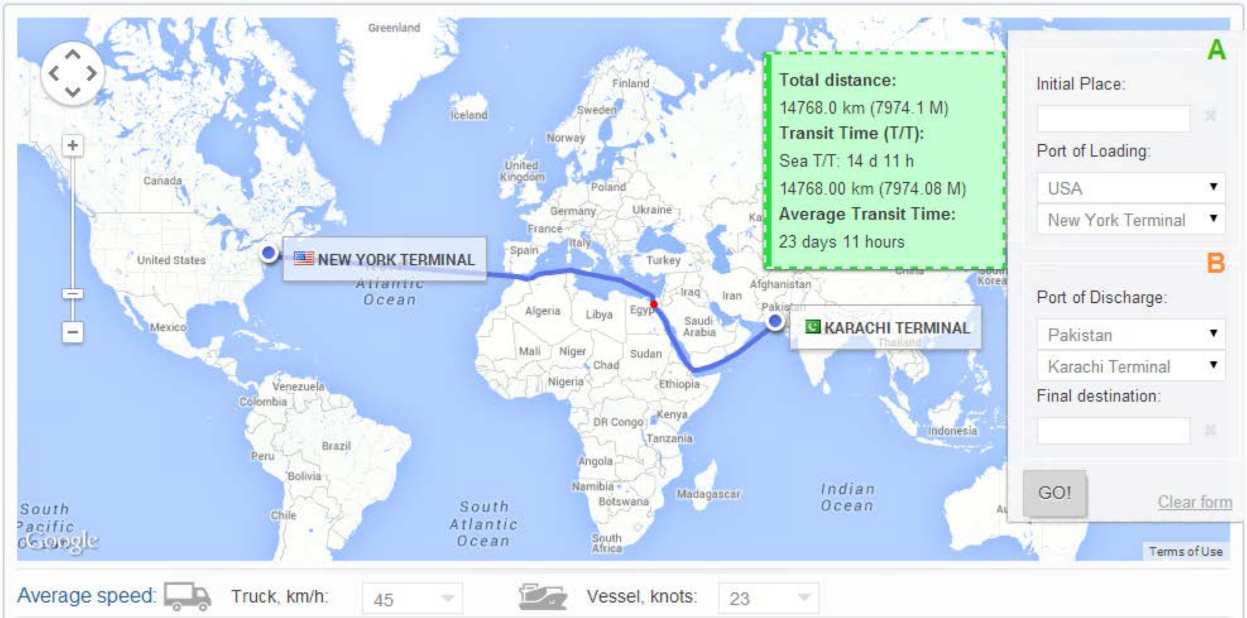

Figure 11- Oceanic Transit Route

The 10,000 TEU ship has the capacity to carry 5,000 forty-foot containers. This can also be expressed as having a 5,000 forty-foot container equivalent units (FEU) capacity. Since the TEU (and FEU) is a non-precise unit of volume, the height of the container generally is not considered (Interfreight, 2006). Therefore both 40' standard (8'-6" height) and 40' HC (9'-6" height) containers are typically considered to each be 2 TEUs (or 1 FEU). This methodology has been adopted for this analysis. For the purposes of this analysis, it has been assumed that the ship would be loaded to 80% capacity, or 4,000 FEUs.

The fuel consumption per mile of this ship has been estimated using Figure 12. According to the article in which Figure 12 originated, the normal operating speed of a containership is 20-25 knots (23.0-28.8 mph) (Hofstra University, 2009). Assuming an average operating speed of 22.5 knots (25.9 mph), the fuel consumption for a 9,000-10,000 TEU containership would be approximately 210 short tons per day of bunker fuel (heavy fuel oil). It has been assumed that the Marine Residual Fuel RMA 30 would be used as fuel oil in the ocean freighter. The specific gravity of this fuel is 0.960 (density = 59.9 lb/ft^3) (Swiss Bunkers).

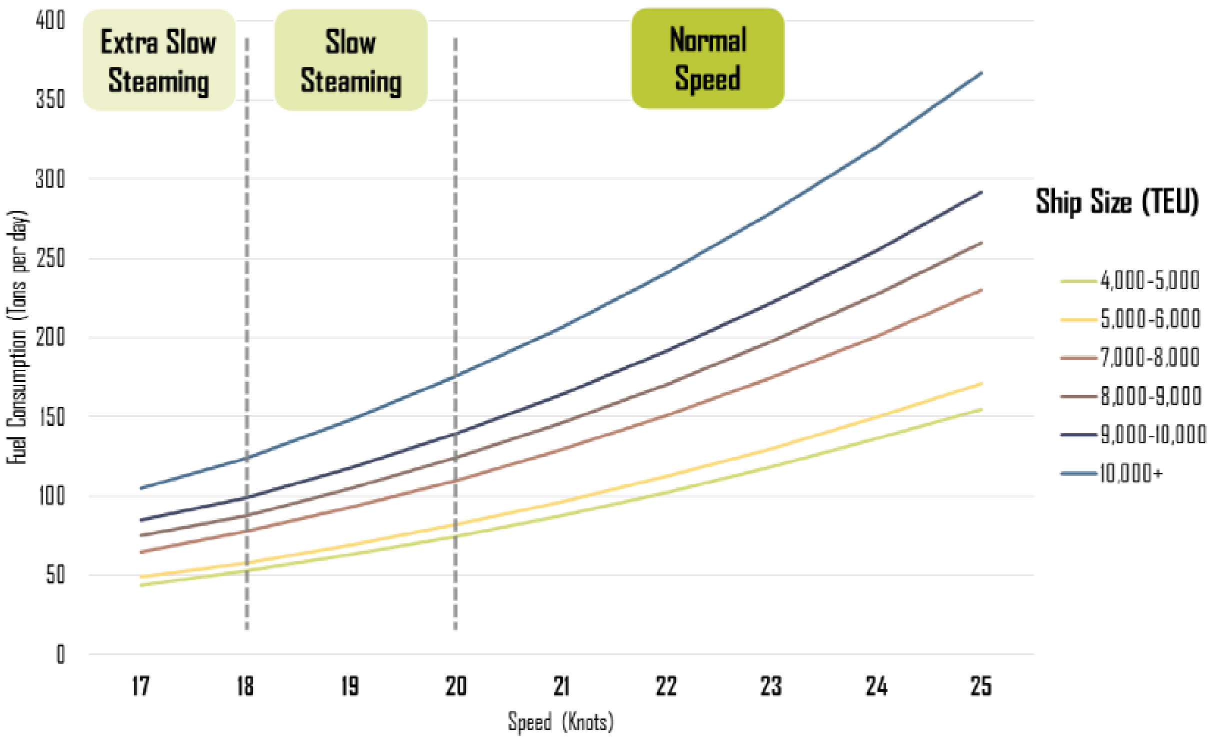

Figure 12 - Fuel Consumption by Containership Size and Speed

Equation 1 shows the calculation used to obtain the fuel consumption rate of the particular containership in question:

$$Fuel\ Consumption\ Rate = \frac{\dfrac{210\ \dfrac{ton}{day} * 2{,}000\,\dfrac{lb}{ton}}{59.9\ \dfrac{lb}{ft^3} * \dfrac{1\ ft^3}{7.4805\ gal}}}{25.9\,\dfrac{mi}{hr} * 24\,\dfrac{hr}{day}} = 84.38\ \frac{gal}{mi} \tag{1}$$

In order to determine the quantity of fuel that each 40' container is responsible for, the total transit distance was divided by the number of containers onboard and multiplied by the fuel consumption rate. This is shown by equation 2:

$$Fuel\ Use\ per\ FEU = \frac{9{,}176\ mi}{4{,}000\ FEU} * 84.38\ \frac{gal}{mi} = 193.6\ \frac{gal}{FEU} \quad (2)$$

Since each 40’ container can fit 2 SIP-Huts and 5 B-Huts, each SIP-Hut is responsible for 96.8 gallons of fuel use and each B-Hut is responsible for 38.7 gallons of fuel use. The per container fuel consumption rate and fuel economy can be seen in equations 3 and 4:

$$Fuel\ Consumption\ per\ FEU\ mile = \frac{84.38\frac{gal}{mi}}{4{,}000\ FEUs} = 0.0211\ \frac{gal}{FEU * mi} \quad (3)$$

$$FEU\ Fuel\ Economy = \frac{4{,}000\ FEUs}{84.38\frac{gal}{mi}} = 47.40\ FEU\ \frac{mi}{gal} \quad (4)$$

These fuel efficiency numbers have been adopted by the ocean freighter SimaPro process that was created to account for the impacts of transporting the SIP-Hut and B-Hut from the US to Pakistan via sea.

6.8. Construction

6.8.1. Construction Costs

According to Kent Crossley (former US Army Corps of Engineers Colonel), in-theater construction time and cost can vary drastically depending on location, safety risks, and who is doing the construction (i.e. local contractors, sustainment brigade, or typical soldiers).

The nature of base camp construction efforts in theater vary widely with location, available resources, level of conflict, and a number of other variables. Due to this fact, making an accurate statement with respect to the construction costs in theater is impossible without further understanding the specific circumstances of the operation. For the purposes of carrying out this analysis, the following assumptions have been made.

- Hut construction will be carried out by an 8 soldier squad.

- The costs of construction only include the base pay of the soldiers (based on 2013 pay scales) (US Military, 2013), plus 25% to account for auxiliary costs (such as pay benefits, costs to sustain soldiers during construction, costs to transport soldiers, overhead costs, etc.).
- Time to construct the SIP-Hut structure is one 8 hour squad day (64 man hours) (Hart, 2013b).
- Time to construct the B-Hut structure is two 8 hour squad days (128 man hours) (Veach, 2013).
- The foundation is identical between the SIP-Hut and B-Hut. The estimated time to construct the foundation is 1 squad hour (8 man hours). It includes site grading, laying concrete blocks, and setting foundation beams. In reality, this number could vary with site conditions.
- The electrical and HVAC systems, though not identical, are similar in nature between the SIP-Hut and B-Hut. The time to install the electrical and HVAC systems is 2 squad hours (16 man hours) (Hart, 2013b).

In order to determine the soldier cost to construct the shelters, the rank and years of service of each member of a typical squad had to be determined and cross-referenced with the US Military pay tables. This information was provided by LTC Steven Hart (Hart, 2013d). Soldier information and corresponding costs can be seen in Table 12.

Table 12 - Information for an Average Squad

Soldier	Rank	Years of Service	Base Pay per Month (USD)	Hourly Cost Equivalent (USD/Hour)
1	E-6	12	$3,495.30	$21.85
2	E-5	6	$2,707.50	$16.92
3	E-5	6	$2,707.50	$16.92
4	E-4	4	$2,304.90	$14.41
5	E-4	4	$2,304.90	$14.41
6	E-4	4	$2,304.90	$14.41
7	E-2	2	$1,699.80	$10.62
8	E-2	2	$1,699.80	$10.62
		Hourly Squad Cost		$120.15

This information was used to determine an hourly squad cost that could be applied to the construction times of the shelters. A summary of construction times can be seen in Table 13. The application of the hourly squad costs to the shelter construction times provided estimated construction costs for each shelter. This process can be seen in Table 14.

Table 13 - Shelter Construction Times

	Man Hours for Foundation	Man Hours for Structure	Man Hours for Electrical	Man Hours for HVAC	Total Man Hours	Total Squad Hours
SIP-Hut	8	64	12	4	88	11
B-Hut	8	128	12	4	152	19

Table 14 - Shelter Construction Costs

	Hourly Squad Cost (USD/Hour)	Time for Squad to Construct (Hours)	Cost of Soldiers (USD)	Auxiliary Costs (USD)	Total Cost to Construct (USD)
SIP-Hut	$120.15	11	$1,321.69	$330.42	$1,652.11
B-Hut	$120.15	19	$2,282.92	$570.73	$2,853.65

The process described above that was used to estimate the shelter construction costs has likely resulted in costs that are on the low end of the possible range. In any military situation it should be expected that the shelter construction costs will be equal to or greater than the costs used in this study.

6.8.2. Environmental Impacts of Construction

In order to represent the construction activities in SimaPro, some assumptions were made with respect to energy use. Since these buildings are relatively simple and all materials can be handled by hand, they do not require any machinery, such as cranes or forklifts, to construct. The base camp may have a dedicated piece of equipment, such as a forklift to unload containers and move stacked material into place, but this is not necessarily required and would be a negligible source of environmental emissions if it was used, so this has not been accounted for. The energy use was estimated by making the assumption that the B-Hut would require a 5 kW generator running at full capacity during the entire construction process. This generator would

power saws and other tools that require electricity. For the SIP-Hut, a 1kW generator is assumed to run during the entire construction process. The reasoning for the assumption of a smaller capacity generator is due to the fact that the SIP-Hut requires minimal use of power tools to assemble. The generator would only likely be used to run a drill or charge portable drill batteries. The assumed generator efficiency (fuel to electricity) in the process is 27.5%, resulting in an electricity to fuel conversion factor of 10 kWh to 1 gallon of diesel fuel (TROPEC, 2014). The results of the construction fuel consumption analysis can be seen in Table 15.

Table 15 - Estimated Energy Consumption during Shelter Construction

	Hours to Construct One Hut	Estimated Generator Size (kW)	Electricity Consumed per Hut (kWh)	Fuel Consumed per Hut (gallons)
SIP-Hut	11	1	11	1.1
B-Hut	19	5	95	9.5

6.9. Use Phase

Energy use data was provided by the USMA. This data came from the models that they developed in the energy simulation tool eQUEST. The energy data being utilized was from their first update on August 21, 2013 that incorporated the results from the blower door test that was performed on the SIP-Hut and B-Hut in West Point, NY (Leemans, 2013). Although the energy data being used has not been fully verified by empirical evidence, there is a “high level of confidence” in its accuracy (Hart, 2013e). The annual energy use for each B-Hut in Kandahar, Afghanistan is estimated to be 18,820 kWh. The annual energy use for each SIP-Hut in Kandahar, Afghanistan is estimated to be 9,150 kWh (Leemans, 2013).

The conversion efficiency of generators used at FOBs is typically approximated to be 10 kWh of electricity per 1 gallon of JP-8. JP-8 is a fuel used by the US Military in place of diesel fuel. The conversion efficiency factor used is equivalent to a generator efficiency of 27.5% (TROPEC, 2014). With a $15/gallon fuel cost this provides an electrical cost of $1.50/kWh. Taking this conversion efficiency into account, the annual fuel use of one B-Hut and one SIP-Hut in Kandahar, Afghanistan is 1,882 gallons and 915 gallons, respectively. The properties of

JP-8 that are used in the analysis come from a fuel properties table published by Stanford University (Stanford University, 2004).

6.10. End of Life

6.10.1. B-Hut Demolition and Disposal

In order to estimate the EOL costs for the B-Hut, the *RSMeans Building Construction Cost Data (2012)* manual was utilized. The manual has a section devoted to building demolition. The data for the following demolition type was used: "small building, no salvage value included, wood." This provided data for the time required and costs per cubic foot of demolishing a standing building. The per unit quantities were extracted and multiplied by the total volume of the building which was determined to be 4,787.2 cubic feet. The volume calculation can be seen in equation 5.

$$B - Hut\ Volume = Crossectional\ area * Length = \left((16' * 8') + \frac{(16' * 2.7')}{2} \right) * 32' \qquad (5)$$

Since the building has no interior walls the costs were reduced by 50%. This procedure is stated in the manual as "for buildings with no interior walls, deduct 50%."

The total cost to demolish the B-Hut using standard practices in the US has been determined to be $838. This cost includes 20 miles of hauling, but does not include dumping fees. It has been assumed that the in-theater demolition cost of each B-Hut will be 50% greater than the US cost. It has also been assumed that the dumping site is 20 miles away and that there would be no cost for dumping the demolition debris.

6.10.2. SIP-Hut Deconstruction

The EOL cost for the SIP-Hut is assumed to be 50% of the B-Hut's demolition and disposal cost. The reasoning for this is because it is extremely likely that the SIP-Hut will be reused in some fashion; either by the Military or by local contractors. The cost being considered here is assumed to account for the deconstruction cost of the SIP-Huts. Since they will likely be reused

they would not need to be landfilled, negating the costs associated with doing so. Salvage value of the SIP-Huts is not being accounted for, due to the uncertainty of the exact nature of the SIP-Huts' reuse.

6.10.3. Shelter Impacts at EOL

In order to account for the EOL environmental impacts of the shelters, it was assumed that both shelter types would be ultimately landfilled. Although the SIP-Hut may be reused after its initial use phase, it is assumed that it would eventually be landfilled when it no longer serves its intended function. The EOL impacts for each shelter type have been characterized in SimaPro. They include the impacts from transportation of the materials to the landfill and environmental impacts of the landfill attributed to the shelters' materials. Further details regarding this analysis can be seen in sections 10.6.5 and 10.7.5 of the Appendix on pages 109 and 115 respectively.

6.11. Sensitivity Analysis

In order to understand how strongly certain variables affected the results of the study, a basic sensitivity analysis was performed. The first step of performing the sensitivity analysis was to determine the extent to which each high-level variable affected the total cost of each shelter. Table 16 describes the percent contribution that each high-level variable provides to the total cumulative cost at 2 years of operation. Table 16 shows that the operational costs ("use") account for a majority of the cumulative cost for both the SIP-Hut and B-Hut. It also shows that the building materials, ECU, and transportation costs are the three highest contributors (respectively) to the one-time cost of the SIP-Hut. Additionally the table shows that the ECU, building materials, and generator costs are the highest contributors (respectively) to the one-time cost of the B-Hut.

Table 16 - Percent Contribution to Cumulative Costs at 2 Years

	SIP-Hut	B-Hut
Materials	26.57%	6.67%
ECU	14.54%	20.07%
Generators	5.85%	6.53%
Transportation	7.64%	2.13%
Construction	2.52%	3.04%
Use (2 years)	41.92%	60.21%
End of Life	0.96%	1.34%

The next step of the sensitivity analysis was to apply the estimated uncertainties that are inherent to the data. Table 17 shows how sensitive the results of the analysis are to potential changes in each high-level variable. The percentage change made to each variable (Δ) corresponds with the estimated level of uncertainty that exists. For example, the material costs are quite certain for the SIP-Hut, so only a 5% change was used. On the opposite end of the spectrum, there is a large amount of uncertainty with construction costs, so a 200% change was used.

Table 17 - Sensitivity of Variables to Total Cost

	SIP-Hut		B-Hut	
	Δ	Influence	Δ	Influence
Materials	5%	2.3%	15%	2.5%
ECU	10%	2.5%	10%	5.0%
Generators	25%	2.5%	25%	4.1%
Transportation	50%	6.6%	50%	2.7%
Construction	200%	8.7%	200%	15.3%
Use (2 years)	30%	12.6%	30%	7.6%
End of Life	100%	1.7%	100%	3.4%

Table 17 shows that uncertainty within the transportation, construction, and use variables has a great potential to influence the final results of the analysis.

6.11.1. Calculations

All of the percent influences (percent change in total hut cost with change in a given variable) were calculated using equation 6 (except for the "use" variable).

$$\% Influence = \frac{T_C + \Delta * V_C}{T_C} - 100\% \tag{6}$$

T_C = total one-time cost of hut

V_C = variable cost

Δ = percent of variable change (based on level of uncertainty)

The "use" variable's influence was determined as the percent influence on the total cost after two years of use. This was calculated using equation 7.

$$\% Influence = \frac{T_C + 2F_{AC}(\Delta + 1)}{T_C + 2F_{AC}} - 100\% \tag{7}$$

T_C = total one-time cost of hut

F_{AC} = annual fuel cost

Δ = percent of variable change (based on level of uncertainty)

6.11.2. Explanation of Estimated Uncertainties (Δ)

The material costs of the SIP-Hut are extremely certain because they were provided directly by the manufacturer, Murus. Therefore the percentage change that was analyzed was only 5%. This means that 5% of the SIP-Hut's building material cost was added to the total SIP-Hut cost and the percent increase of the total SIP-Hut cost was observed. The B-Hut material costs are relatively certain because they came directly from the GSA's global supply catalog (which lines up relatively well with US retail costs). There is still a small level of uncertainty due to the fact that GSA prices have the potential to fluctuate based on a variety of circumstances. To account for the uncertainty inherent to these fluctuations a percent change of 15% was used.

For both ECUs the prices were obtained directly from the military supplier provided by the USMA, HDT Global. Therefore, the costs used for the ECUs are quite certain. To account for potential price changes a percent change of 10% was used.

The costs of the generators that would potentially be used to power the huts came from Caterpillar. The units that were priced are close to what would likely be used by the Military, but

not exact. Furthermore, uncertainty within the energy analysis affects the certainty of the generator costs, because if the energy analysis was off, a different generator capacity may be required. This change would directly affect cost. To account for this moderate level of uncertainty a percent change of 25% was used.

While determining the total transportation costs, many assumptions were made with respect to the in-theater transportation costs. These assumptions result in a relatively high level of uncertainty. For this reason a percent change of 50% was used.

There is a large amount of uncertainty with the construction costs that were used. Most of this uncertainty comes from the fact that these huts may be constructed by the Army or by local contractors. The Army would likely pay much more for a local contractor to build the huts than it would cost them to build the huts themselves. In some cases this method may be necessary. So to account for this scenario and the high level of uncertainty that comes with it, a percent change of 200% was used.

The use cost is directly proportional to the energy consumption data that was provided by the USMA. As mentioned earlier, there is a moderate level of uncertainty in this data. To account for this moderate level of uncertainty, a percent change of 30% was used. The percent influence on the total costs accrued after 2 years of use was analyzed. 2 years was selected because it is the minimum time that these types of shelters would be in operation.

The EOL costs were determined using the RSMeans manual for a base price, and then some assumptions were made to modify the costs to better fit the particular situation. There is a high level of uncertainty in these assumptions. Therefore a percent change of 100% was used.

6.12. Scenarios

6.12.1. Method for Testing Scenarios

The Excel spreadsheet that was being used to track and analyze data was set up to allow simple manipulation of the high-level variables. These variables include: building material cost, environmental control unit (ECU) cost, generator cost, hut transportation cost and environmental

impacts, construction cost, fuel usage rate, fuel cost per gallon, and EOL (decommissioning) costs and environmental impacts.

6.12.1.1. Use Phase Variation

Fuel consumption rate during the use phase affects the cost, environmental, and operational results. It was important to evaluate the effects that varying the fuel consumption rates had on the results the analysis. The fuel consumption rates that were used came from the USMA eQUEST model, which bases results off of historical weather averages in the geographic area of interest. It is very possible that in the 2-10 year period that is under consideration, weather conditions could vary relatively significantly from historical averages. This would yield results that do not line up with the conclusions made by the analysis. Furthermore, this data has only been partially confirmed using empirical evidence. Further empirical testing must be performed to verify the accuracy of the model results. In addition to potential model inaccuracies, the location of these shelters will vary greatly with the Military's operational needs. Only Kandahar, Afghanistan has been used as a case study. The shelters will be deployed where there is a need. Since location has the potential to be so variable and the eQUEST model results may not line up directly with reality, it was imperative to be able to evaluate the effect that changes in energy performance of the SIP-Hut and B-Hut has on the results of the analysis.

6.12.2. Developing the Scenarios

To help provide some perspective into how the results of the analysis change in various situations, a series of different cases were developed. Each case attempts to model a potentially realistic scenario. The determination of which variables to modify within each case has been made by considering the results of the sensitivity analysis. Modification has been focused on the variables whose uncertainty has the potential to significantly affect the results of this study. In addition to variable modifications, the inclusion of ECU and generator costs was varied. This is because there are situations in which this equipment may not need to be purchased. Furthermore, some of the cases present modifications to the energy performance of the huts. These modifications come from changes in the huts' thermal conditioning requirements, which lead to changes in the required size of the ECUs and generators. Since the modifications

presented here are just estimates, and the main focus of this analysis is on the shelters, a detailed evaluation of ECUs and generators is outside the scope of this analysis. Therefore, their implications on the analysis were not considered for any of the cases that adjust energy demand.

6.12.3. Description and Justification of Scenarios

The following subsections provide an overview of, and rationale for, the scenarios that were developed. The explanation of each scenario is accompanied by a table that outlines the changes made to the scenario in relation to the Base Case. The results of these scenarios will be discussed in Chapter 7.

6.12.3.1. Base Case

The results for the Base Case can be expected to be relatively close to reality for the case study under consideration in this analysis (a base camp in Kandahar, Afghanistan for a battalion size military unit, consisting of 120 huts). All phases of the lifecycle are considered. Additionally, all equipment and materials are included in the analysis.

6.12.3.2. Case 1

Case 1 is identical to the Base Case except it does not consider the economic impacts of the ECUs or generators. This case represents a situation in which the huts at an existing base camp are being replaced, but the ECUs and generators are not, because they are in acceptable operating condition. Although this case is not as likely as the Base Case, it is still important to understand the appropriateness of deploying SIP-Hut’s in this situation and whether or not they would be economically preferable. This case does not affect the results of the environmental analysis, because the impacts of the ECUs and generators were not considered in the environmental model, due to lack of data.

The conditions for this case are outlined in Table 18.

Table 18 - Case 1 Conditions

	SIP-Hut		B-Hut	
Materials	100%	$17,401	100%	$6,256
ECU?	N	$0	N	$0
Generator?	N	$0	N	$0
Transportation	100%	$5,000	100%	$2,000
Construction	100%	$1,652	100%	$2,854
Use (gal/year)	100%	915	100%	1,882
Fuel Cost (/gal)	100%	$15.00	100%	$15.00
End of Life	100%	$628	100%	$1,257

6.12.3.3. Case 2

Case 2 is identical to Case 1 except the energy demand of the huts was modified to represent a situation in which the energy models were inaccurate. The annual energy consumption rates were modified in the following fashion. Since the uncertainty with the energy consumption rates (with respect to thermal performance) of the SIP-Huts and B-Huts was estimated to be 30%, the energy consumption rate attributed to heating and cooling was increased by 30% for the SIP-Hut and decreased by 30% for the B-Hut. As can be seen in Table 19, this results in an overall energy consumption rate change of +12.75% for the SIP-Hut and -18.86% for the B-Hut (Leemans, 2013).

Table 19 - Energy Use by Category (30% Change)

	SIP-Hut	B-Hut
Heating/Cooling (kWh/year)	3,890	11,830
Lighting, equipment, etc. (kWh/year)	5,260	6,990
Total Energy Use (kWh/year)	9,150	18,820
Total w/ 30% Heat/Cool Δ (kWh/year)	10,317	15,271
Percent Change in Annual Energy Use	+12.75%	-18.86%

The ECUs and generators were not considered in this case, since it results in notable changes to the energy demand of the SIP-Hut and B-Hut. As a result, the required thermal and electric capacities will be unknown. In a realistic situation, where the ECUs and generators will still need to be purchased, it should be expected that the SIP-Hut would perform better economically than is portrayed here.

The conditions for this case are outlined in Table 20.

Table 20 - Case 2 Conditions

	SIP-Hut		B-Hut	
Materials	100%	$17,401	100%	$6,256
ECU?	N	$0	N	$0
Generator?	N	$0	N	$0
Transportation	100%	$5,000	100%	$2,000
Construction	100%	$1,652	100%	$2,854
Use (gal/year)	113%	1,032	81%	1,527
Fuel Cost (/gal)	100%	$15.00	100%	$15.00
End of Life	100%	$628	100%	$1,257

6.12.3.4. Case 3

Case 3 is an unlikely, worst-case scenario for the case study of constructing a FOB in Kandahar, Afghanistan. Every variable that was changed was adjusted in favor of the B-Hut. The idea was to evaluate whether the SIP-Hut will make economic sense in a worst-case scenario. The material costs were increased 5% for the SIP-Hut and decreased 15% for the B-Hut. These changes are in line with the expected level of uncertainty. The costs of the ECUs and generators (which are financially in favor of the SIP-Hut) were not included. The construction costs (which are also financially in favor of the SIP-Hut) were not included. The transportation costs and emissions for the B-Hut were reduced by 90%, while the SIP-Hut transportation costs were kept the same. This represents a scenario in which the B-Hut materials were to be sourced locally and did not have to be shipped from the US. The energy consumption rates attributed to heating and cooling were modified in the same manner as Case 2, +30% for the SIP-Hut and -30% for the B-Hut. This change accounts for potential inaccuracies in the energy model and/or minor variations in the climate from average conditions. The fuel costs were reduced from $15 per gallon to $10 per gallon, which is the lowest cost that is likely to be observed at a FOB in Afghanistan (TROPEC, 2014). Finally, EOL costs were not considered.

The conditions for this case are outlined in Table 21.

Table 21 - Case 3 Conditions

	SIP-Hut		B-Hut	
Materials	105%	$18,271	85%	$5,318
ECU?	N	$0	N	$0
Generator?	N	$0	N	$0
Transportation	100%	$5,000	10%	$200
Construction	0%	$0	0%	$0
Use (gal/year)	113%	1,032	81%	1,527
Fuel Cost (/gal)	67%	$10.00	67%	$10.00
End of Life	0%	$0	0%	$0

6.12.3.5. Case 4

The purpose of Case 4 is to provide some insight into what results might be expected if the SIP-Hut was to be compared against an insulated B-Hut. To represent this scenario the SIP-Hut was not changed in any manner. The B-Hut observed a 20% increase in material, transportation, construction, and demolition costs and a 21.09% decrease in total annual energy consumption. The reasoning for the energy use decrease is as follows. The annual energy consumption attributed to the heating and cooling load of an insulated B-Hut was estimated to be half way between the consumption of the SIP-Hut and the non-insulated B-Hut. This estimation comes from the following logic. The insulative capacity (R-value) of the wall panels for the SIP-Hut is R-26 (Murus). The insulative capacity of the non-insulated B-Hut walls (containing only ½" plywood) is R-0.62 (Structall). The insulative capacity of a 2x4 fiberglass insulated wall is approximately R-13 (DOE, 2012). Since the expected insulative capacity of an insulated B-Hut wall is approximately half way between the insulative capacity of the SIP-Hut wall and the non-insulated B-Hut wall, it could be expected that the energy consumption due to thermal conditioning would approximately follow the same trend. This is certainly not a perfect estimate, but it is sufficient to provide some insight to how the operation of SIP-Huts would compare to insulated B-Huts.

This estimation method provided an energy consumption attributed to heating and cooling of 7860 kWh/year for the insulated B-Hut ((11,830 kWh/year + 3,890 kWh/year) / 2). This provides a 33.56% heating and cooling energy demand reduction as compared to the non-insulated B-Hut (((11,830 kWh/year – 7,860 kWh/year) / 11,830 kWh/year) * 100%). This

provides a total annual energy consumption of 14,850 kWh/year (7,860 kWh/year + 6,990 kWh/year). This is a total energy consumption reduction of 21.09% as compared to the non-insulated B-Hut ((1 – ((14,850 kWh/year) / (18,820 kWh/year))) * 100%).

Similar to Case 2 and 3, the ECU and generator costs were not considered. The reasoning is similar to that in Case 2 and 3; the energy demand for the SIP-Hut and B-Hut are much closer and it would be hard to make an accurate estimate with respect to the new thermal and electric capacity requirements for the B-Hut. As in Case 2 and 3, in reality, where ECUs and generators would need to be purchased, the case for the SIP-Hut would be improved.

The conditions for this case are outlined in Table 22.

Table 22 - Case 4 Conditions

	SIP-Hut		B-Hut	
Materials	100%	$17,401	120%	$7,508
ECU?	N	$0	N	$0
Generator?	N	$0	N	$0
Transportation	100%	$5,000	120%	$2,400
Construction	100%	$1,652	120%	$3,424
Use (gal/year)	100%	915	79%	1,485
Fuel Cost (/gal)	100%	$15.00	100%	$15.00
End of Life	100%	$628	120%	$1,508

6.12.3.6. Case 5

Case 5 is an attempt to evaluate the appropriateness of deploying SIP-Huts in a region that has a mild climate, low fuel prices, is closer to the material source location, and has a low level of conflict. In order to attempt the simulation of this situation the following modifications were made to the model. To account for a milder climate than is typical in Afghanistan, the annual energy use attributed to the heating and cooling for both the SIP-Hut and B-Hut were reduced by 50%. As can be seen in Table 23, this amounts to a total energy use reduction of 21.25% and 31.43% for the SIP-Hut and B-Hut, respectively.

Table 23 - Energy Use by Category (50% Change)

	SIP-Hut	B-Hut
Heating/Cooling (kWh/year)	3,890	11,830
Lighting, equipment, etc. (kWh/year)	5,260	6,990
Total Energy Use (kWh/year)	9,150	18,820
Total w/ 50% Heat/Cool (kWh/year)	7,205	12,905
Percent Reduction in Annual Energy Use	21.25%	31.43%

To account for the lower fuel prices, the diesel fuel prices in the model were modified to be $4 per gallon, from the baseline of $15 per gallon. $4 per gallon was chosen because it is a rough average of the market price of diesel fuel in many countries (The World Bank, 2012). To account for this case being located geographically closer to the US and in an area of lower conflict than Afghanistan, the transportation costs and associated emissions were reduced by 50%. Having a lower trip distance for shipping (assuming ocean freight would still be required) would likely reduce the cost only slightly, perhaps by 10-20%. The majority of the estimated transportation savings in this case are attributed to the destination being in a low conflict zone. The majority of the transportation cost (and much of the emissions) in the Base Case can be attributed to the transportation segment in Pakistan and Afghanistan. In an area of low conflict the shipping company would likely charge less and the Military would not likely need to provide gun-truck escorts to protect the shipping vehicles. These reductions are just estimates, but they would likely reflect reality in many situations.

Additionally, in this case, the cost of the ECUs and generators are not being considered. Similar to Case 1-4, if the cost of the ECUs and generators were to be considered, the benefits for using SIP-Huts in this type of situation would be improved.

The conditions for this case are outlined in Table 24.

Table 24 - Case 5 Conditions

	SIP-Hut		B-Hut	
Materials	100%	$17,401	100%	$6,256
ECU?	N	$0	N	$0
Generator?	N	$0	N	$0
Transportation	50%	$2,500	50%	$1,000
Construction	100%	$1,652	100%	$2,854
Use (gal/year)	79%	721	69%	1,290
Fuel Cost (/gal)	27%	$4.00	27%	$4.00
End of Life	100%	$628	100%	$1,257

7. Results and Discussion

7.1. Base Case

The overall results for this analysis can be seen in Table 25.

Table 25 - Base Case: Summary of Results

	One-time		Recurring (/year)		Payback (Years)
	SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	$38,037	$37,314	$13,725	$28,230	0.05
Embodied Energy (kWh)	51,945	12,301	45,978	94,569	0.82
GHG Emissions (lb CO_2 eq)	22,001	6,560	23,914	49,187	0.61
Total Impacts (Ecopoints)	1,456	371.1	1,187	2,442	0.86

7.1.1. Economic Results

A cost breakdown can be seen in Table 26 and Figure 13.

Table 26 - Cost Summary

Description	SIP-Hut	B-Hut
Materials	$17,401	$6,256
ECU	$9,523	$18,822
Generator	$3,833	$6,125
Transportation	$5,000	$2,000
Construction	$1,652	$2,854
Use (/year)	$13,725	$28,230
End of Life	$628	$1,257

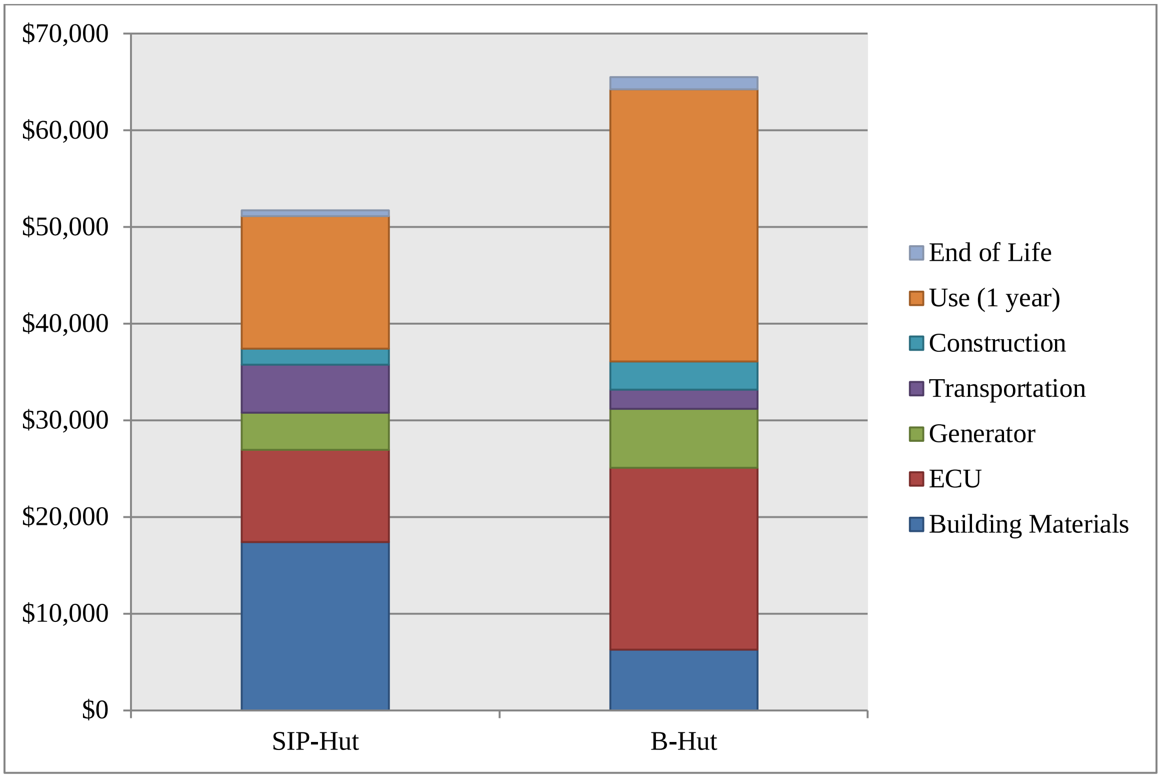

Figure 13 - Shelter Costs by Category

Table 25 shows that the one-time costs (capital plus EOL costs) are nearly equivalent for the SIP-Hut and B-Hut. The increased one-time cost is only $723 per SIP-Hut. As can be seen in Table 26 and Figure 13, the material cost is much greater for the SIP-Hut. This is due to the fact that it requires relatively specialized building materials to construct, which must be custom made by a SIP manufacturer. The modular, panelized nature of SIPs combined with the fact that they are custom manufactured before arriving to the construction site, leads to a low construction cost for the SIP-Hut. The B-Hut's relatively inexpensive, readily available, and nominally sized materials lead to a low material cost, but yield an increased construction cost due to construction complexities and the requirement for having skilled builders on the construction team. The Base Case assumes that all materials for both the SIP-Hut and B-Hut would be shipped from the US. Since only two SIP-Huts can be packaged in one 40' shipping container, while the same container could hold 5 B-Huts, the cost to transport each SIP-Hut is significantly increased ($5,000 versus $2,000). Consideration of the cost of the ECUs and generators greatly lends to

benefit the SIP-Hut's capital cost. The fact that the SIP-Hut has a significantly reduced heating and cooling capacity requirement, as compared to the B-Hut, allows for a significantly smaller ECU. The smaller ECU leads to a significant drop in electricity capacity requirements, which, in theater, is typically supplied by diesel generators. The reduced cost from being able to use smaller ECUs and generators leads to a capital cost reduction of $11,591 per SIP-Hut, compared to the B-Hut.

The annual cost to operate each hut can be seen in Table 25. Due to the fact that the SIP-Hut requires approximately 50% of the fuel to operate, compared to the B-Hut, the annual operating cost is essentially half. The costs displayed in Table 26 assume a fuel cost of $15 per gallon, which is average for FOBs in Afghanistan (TROPEC, 2014). The annual operational cost differential between the SIP-Hut and B-Hut is $14,505 ($1,209/month). This operating cost difference leads to a nearly instantaneous payback of the SIP-Hut's minimal increased one-time cost.

Figure 14 shows the cumulative per hut cost of each hut type for up to 10 years of use.

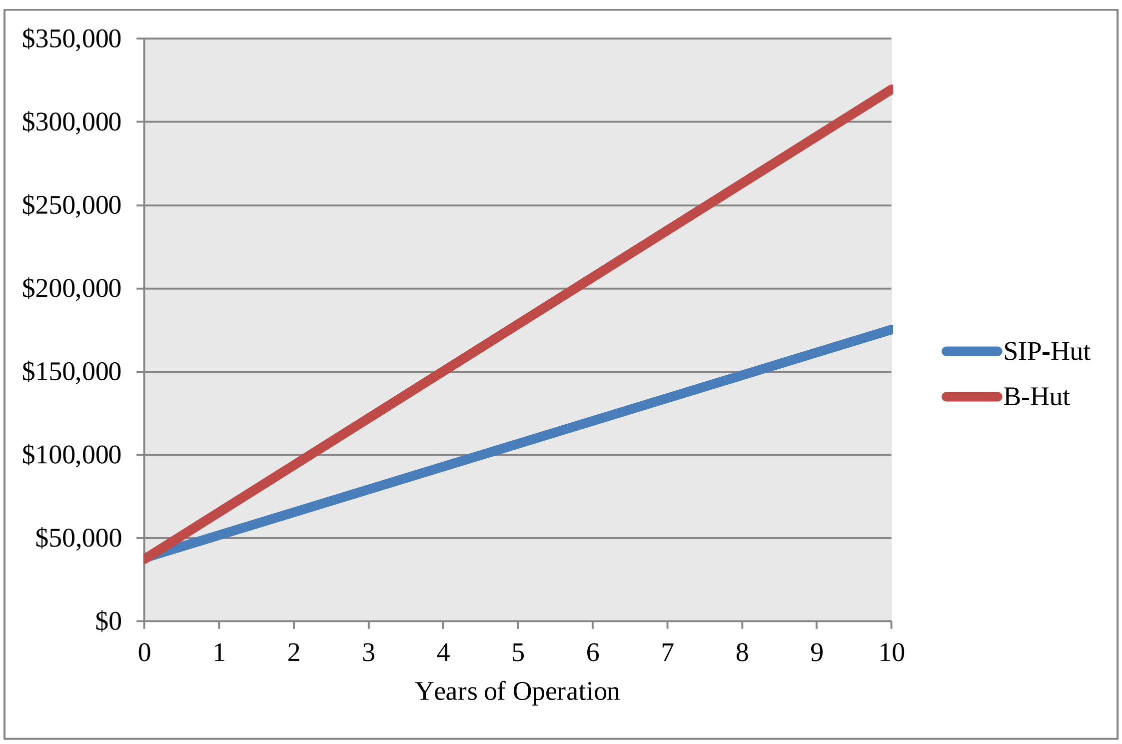

Figure 14 - Base Case: Cumulative Cost per Hut

7.1.2. Environmental Results

The environmental impacts of the SIP-Hut and B-Hut can be seen in Table 25. These impacts come from the results of the SimaPro models. Impacts are broken up into three categories: embodied energy, GHG emissions, and total environmental impacts (using the ReCiPe Endpoint Hierarchical methodology). These impacts account for the entire lifecycle of the building structure for the SIP-Hut and B-Hut. The electrical systems, ECUs, and generators are not accounted for, due to the lack of LCI data. All environmental impact categories show that the SIP-Hut is significantly more impactful (3-4 times) to manufacture and deliver to the FOB than the B-Hut. This can be mainly attributed to the significant energy inputs required to manufacture the materials for the SIP-Hut, the large impacts associated with producing the petroleum based insulative foam core of the SIPs, and the impacts associated with shipping the SIP-Hut's materials. Although the upfront impacts of the SIP-Hut are significantly higher than the B-Hut, these impacts are quickly offset by the reduction in operational fuel consumption. Take the energy category as an example. The SIP-Hut has 51,945 kWh of embodied energy, compared to the B-Hut's 12,301 kWh. The embodied energy of the fuel that is used annually to operate the SIP-Hut and B-Hut is 45,878 kWh and 94,569 kWh respectively. This means that the SIP-Hut is responsible for 48,691 kWh less of operational embodied energy per year than the B-Hut. This leads to an embodied energy payback that is less than one year. As can be seen in Table 25, all environmental impact categories show a payback that is less than one year.

Figure 15, Figure 16, and Figure 17 show the embodied energy, greenhouse gas emissions, and total environmental impacts, of each shelter type, categorized by lifecycle phase. Since the use phase of the shelters may vary from 2-10 years, the figures only show the impacts of a single year of use. This makes the results easy to extrapolate to a particular situation.

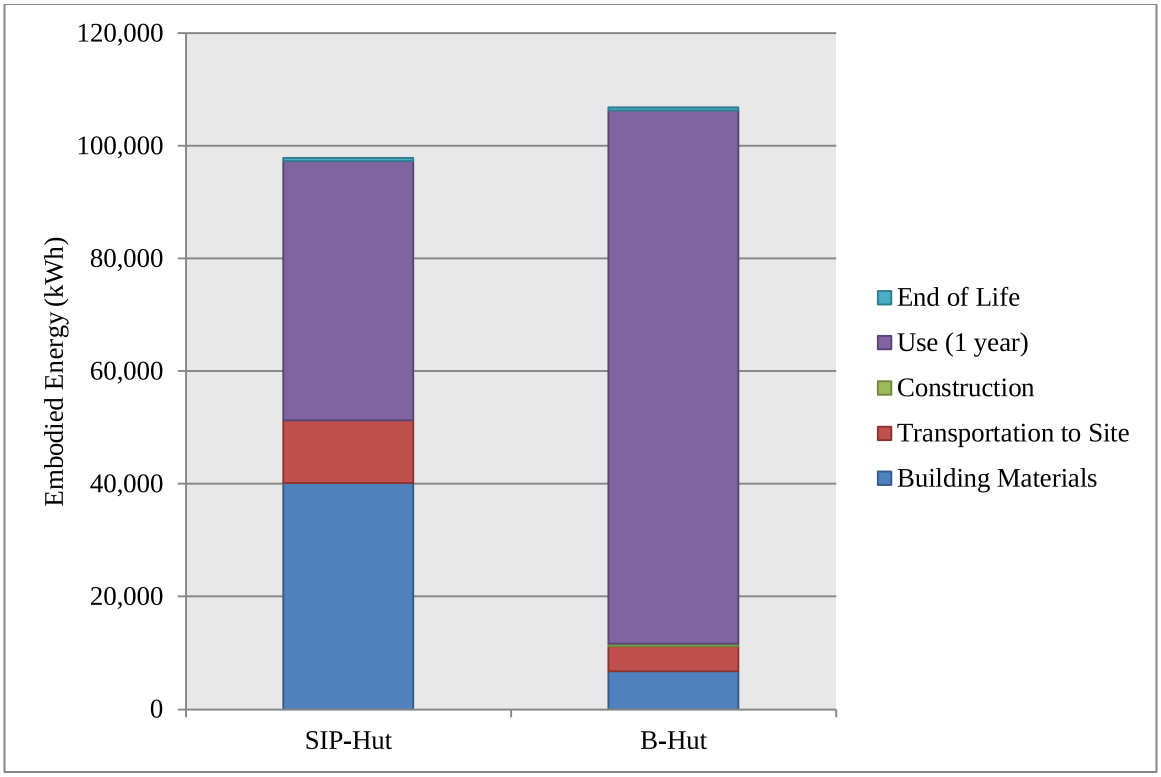

Figure 15 - Embodied Energy by Lifecycle Phase

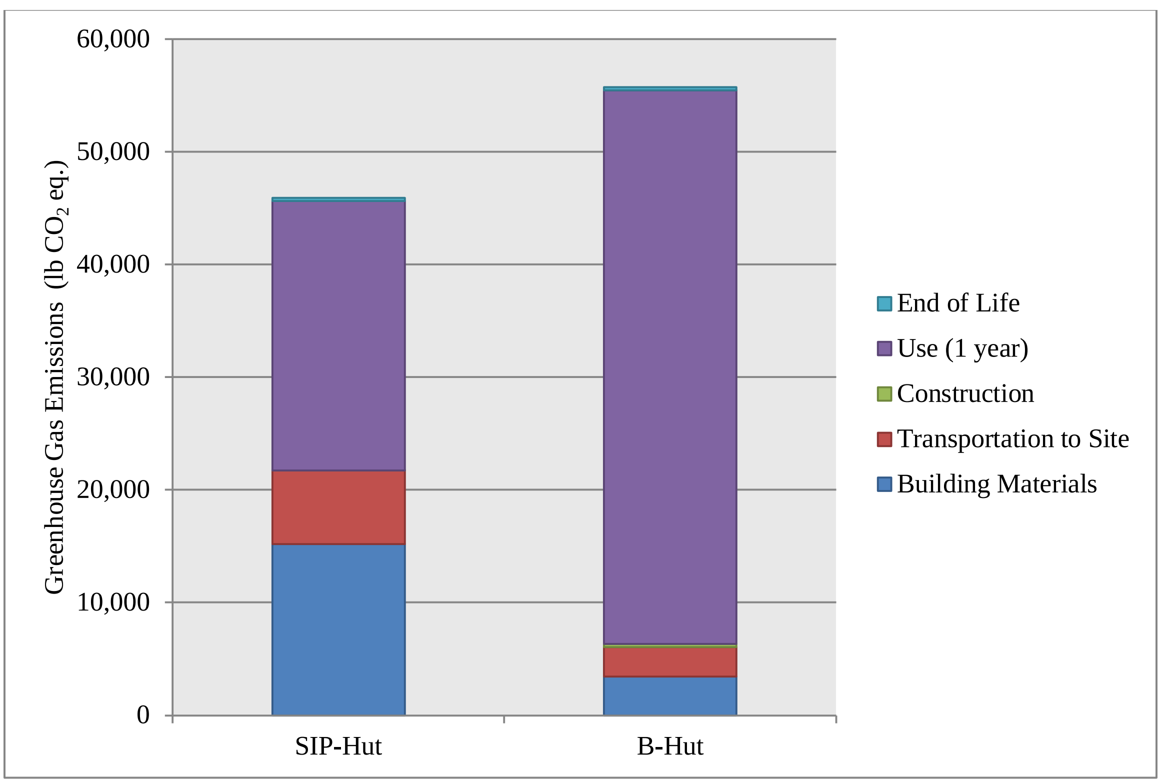

Figure 16 - Greenhouse Gas Emissions by Lifecycle Phase

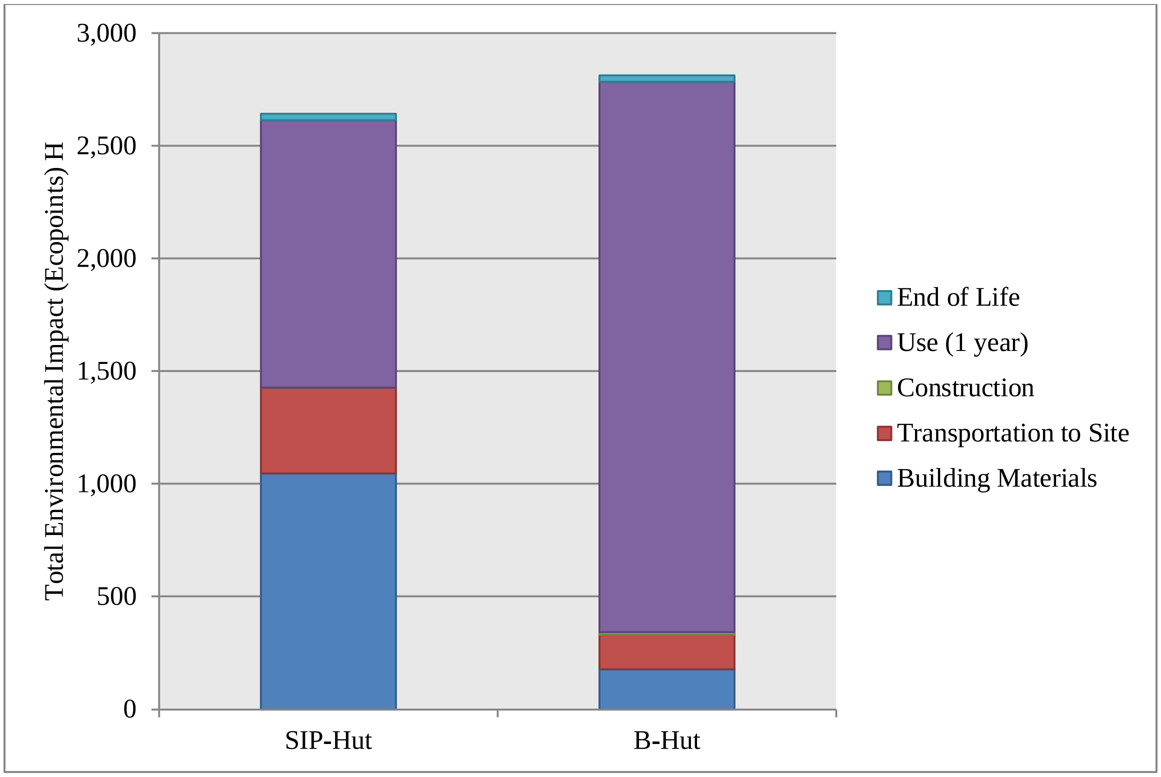

Figure 17 - Total Environmental Impacts by Lifecycle Phase

Figure 18, Figure 19, and Figure 20 are graphs produced in SimaPro that show the total environmental impacts in kilo-Ecopoints (kPt) for 2, 5, and 10 years of operation. The series in each graph are broken into the three general impact categories: Human Health, Ecosystems, and Resources. The impacts were quantified using the ReCiPe Endpoint H methodology.

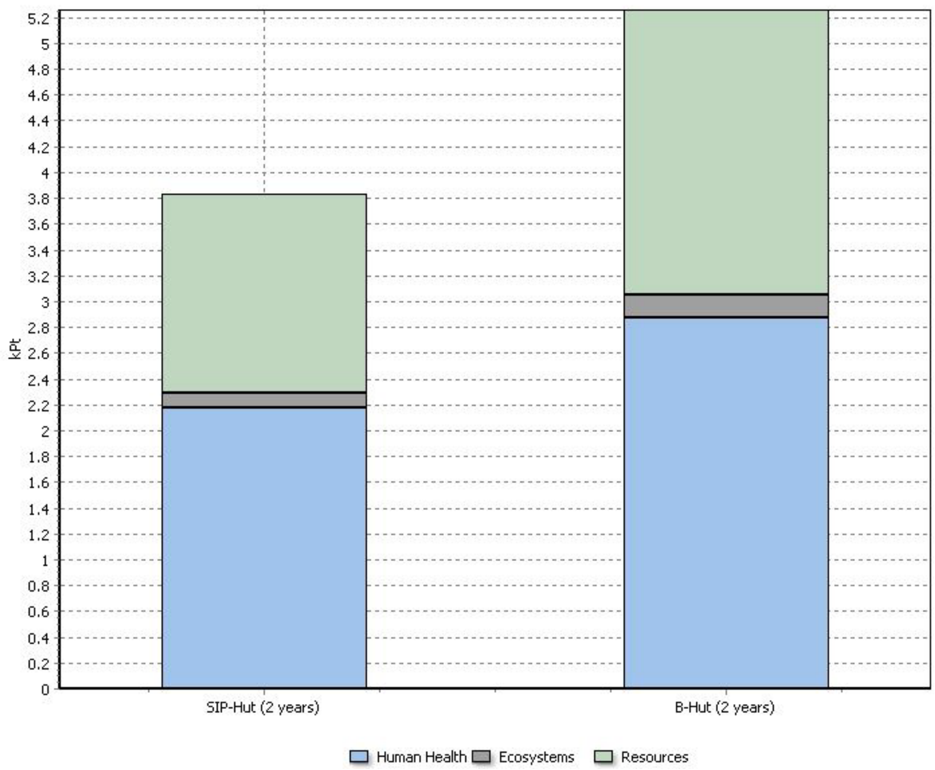

Figure 18 - Total Environmental Impacts at 2 Years (by Impact Category)

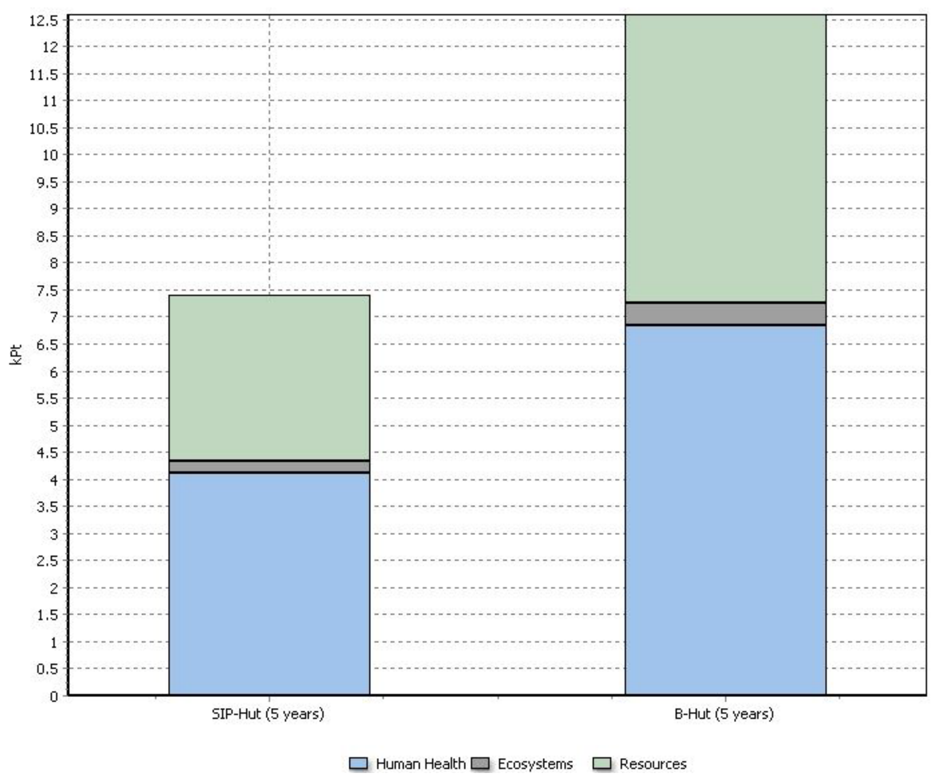

Figure 19 - Total Environmental Impacts at 5 Years (by Impact Category)

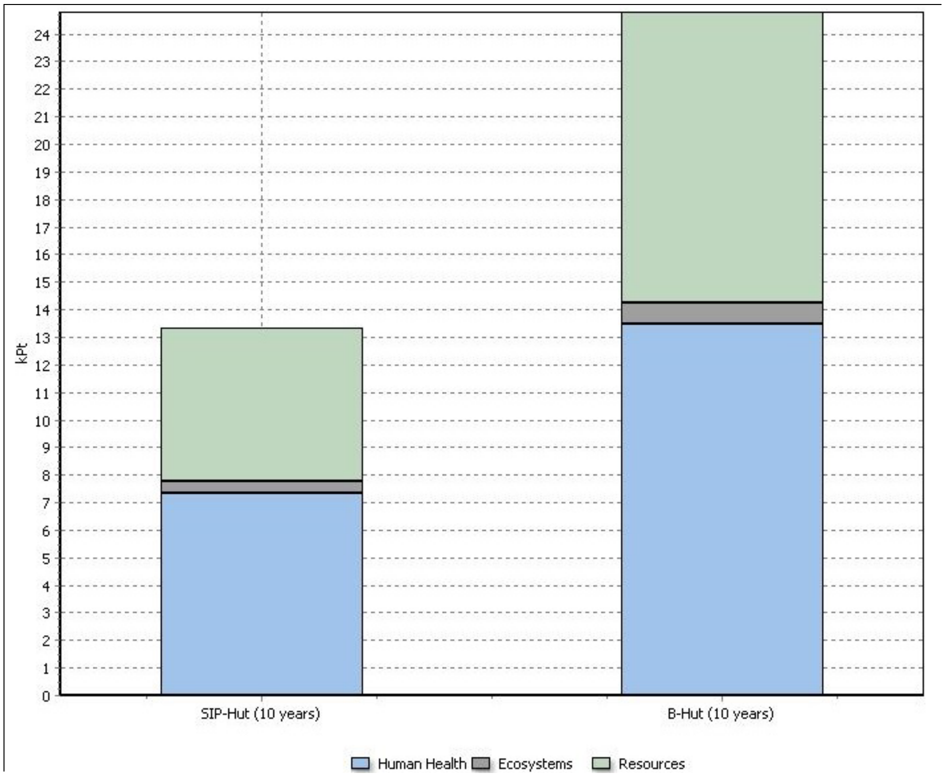

Figure 20 - Total Environmental Impacts at 10 Years (by Impact Category)

7.1.3. Summary of Savings

Table 27 displays the cumulative economic, environmental, and fuel related savings, on a per hut basis, of deploying SIP-Huts instead of B-Huts, at 2, 5, and 10 years.

Table 27 - Total Savings from Deploying One SIP-Hut

	2 years	5 years	10 years
Costs (USD)	$28,287	$71,802	$144,327
Diesel Fuel (gallons)	1,934	4,835	9,670
Embodied Energy (kWh)	57,538	203,311	446,267
GHG Emissions (lb CO_2 eq)	35,105	110,925	237,290
Total Impacts (Ecopoints)	1,425	5,190	11,464

Table 27 shows that the use of SIP-Huts will provide sizable monetary savings, reduce fuel consumption, and help avoid significant environmental impacts. To put these numbers on the scale of a battalion size base camp, they should be multiplied by 120. At just 2 years, a base

camp for a battalion size unit could see economic savings of $3.4 million, fuel savings of 232,080 gallons (equivalent to 39 fuel trucks), and energy expenditure avoidances of 6,905 megawatt-hours (MWh).

7.1.4. Operational Results

7.1.4.1. Base Camp Commissioning

Table 28 describes the vehicle requirements that coincide with delivering the housing shelters (either SIP-Huts or B-Huts) to a battalion size FOB. It can be seen in Table 28 that if SIP-Huts were to be installed, a total of 60 shipping trucks and 15 military escort gun-trucks would be required to transport all shelter materials to the FOB. Typically, these supply operations occur by having up to 16 shipping vehicles (and their military escorts) move together in convoys. To move the materials for the SIP-Huts, a total of 4 separate convoys would be required. Since the materials for the B-Huts are inherently lower in volume, they would require only 24 shipping trucks and 6 military escorts to deliver the shelter materials for the same size FOB. This would require a total of 2 supply convoys.

Table 28 - Shelter Transportation Operations Required During Base Camp Commissioning

Shelter Type	Number of Huts	Shipping Trucks Required to Move Huts in Theater	Required Military Escort Trucks	Total Number of Supply Convoys
SIP-Hut	120	60	15	4
B-Hut	120	24	6	2

Table 29 shows the logistical requirements for constructing the shelters at a battalion size FOB. The results in Table 29 show that by deploying SIP-Huts a significant time savings will be observed during the FOB construction process. If 60 squads (~500 soldiers) partook in constructing the shelters, a FOB with SIP-Huts would only take 3 days to construct as opposed to 5 days. Depending on the situation, this sizable time savings could provide vital advantages to the occupying military unit, potentially improving its overall effectiveness.

Table 29 - Shelter Construction Operations Required During Base Camp Commissioning

Shelter Type	Number of Huts	Squad Hours per Hut	Squad Hours per Base	Total Man Hours per Base	Hours to Construct Base (w/ 60 Squads)	Days to Construct Base (w/ 60 Squads)
SIP-Hut	120	11	1,320	10,560	22	3
B-Hut	120	19	2,280	18,240	38	5

7.1.4.2. Supply Logistics

The US Military is not only concerned with the number of truck shipments that are made to commission a base camp, but also the required shipments to sustain operation of a base camp throughout its use phase. The reason for this concern comes from the fact that every truck shipment creates risks and requires military resources. If a base camp requires fewer fuel shipments to operate, then this leads to a decrease in the risk of operations being hindered by lost fuel supply. Furthermore, the number of supply related casualties would likely decrease. In Iraq and Afghanistan from 2003 to 2007 the US Military reported 3,046 casualties related to resupply operations, half of which were fuel related (Eady et al., 2009).

Table 30 and Figure 21 describe the number of truck shipments that are required for a battalion size base camp, with 120 huts, throughout its lifetime. The truck shipments at year 0 are the shipments related to moving materials into the base camp during commissioning. All additional shipments after year 0 are fuel related.

Table 30 - Cumulative Number of Truck Shipments per Base

Years of Operation	SIP-Hut	B-Hut
0	60	24
1	78	62
2	97	99
3	115	137
4	133	175
5	152	212
6	170	250
7	188	287
8	206	325
9	225	363
10	243	400

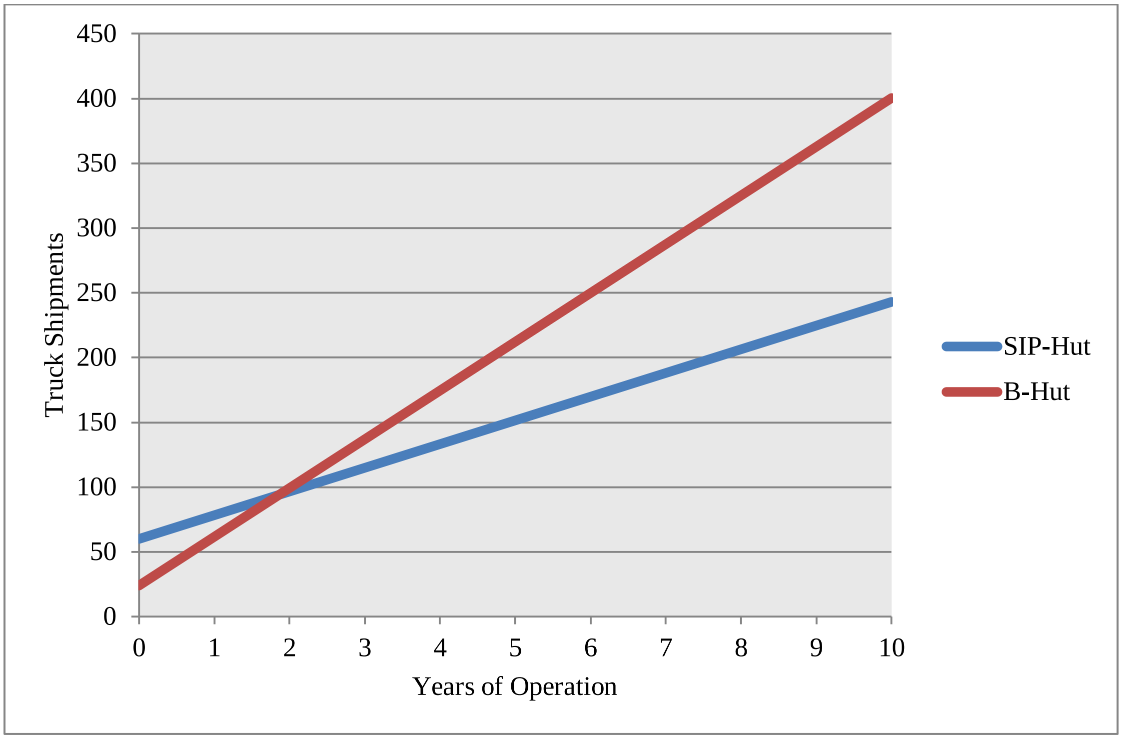

Figure 21 - Cumulative Truck Shipments per Base

It can be inferred from Table 30 and Figure 21 that the number of fuel shipments required to maintain operation at a base camp with SIP-Huts is approximately half as many as is required by a base camp with B-Huts. Figure 21 also shows that just prior to 2 years of operation the number of truck shipments for a base camp with SIP-Huts and B-Huts are equivalent. If a base camp with SIP-Huts were to be operated for 10 years, it would have required nearly half as many fuel shipments as a base camp with B-Huts. These results lead to the conclusion that if the number of truck shipments is of concern to the officials in charge of base camp operations, then, with this fact alone, SIP-Huts should be considered for use in place of traditional B-Huts.

7.1.4.3. Expected Casualty Rates

Considering the 2007 Afghanistan fuel-related supply convoy casualty rate factor of 0.042 (Eady et al., 2009), a battalion size base camp with SIP-Huts can expect 0.05 fuel-related resupply casualties per year, while a base camp with B-Huts could expect 0.10 fuel-related resupply

casualties per year. Since these are not whole numbers, up-scaling is necessary to provide a logical result. If 20 battalion size base camps that deployed SIP-Huts were operating for 5 years, it would be expected that a total of 5 soldiers' lives could potentially be saved, just from the substitution of B-Huts with SIP-Huts. This figure does not account for the risk associated with the increased number of trucks required during the commissioning of a base camp with SIP-Huts. The logic behind this exclusion is because it is likely that these convoys would not be targeted at as high of a rate.

This analysis will not prescribe any estimated dollar figure to the life of a soldier, because this is a controversial and debatable practice. Regardless, the number of lives that could potentially be saved from using SIP-Huts is significant, and therefore should be a major consideration during the selection process of base camp shelters.

Figure 22 shows the total projected fuel-related resupply casualties for 20 battalion size base camps (or equivalent variation; approximately 14,000 soldiers).

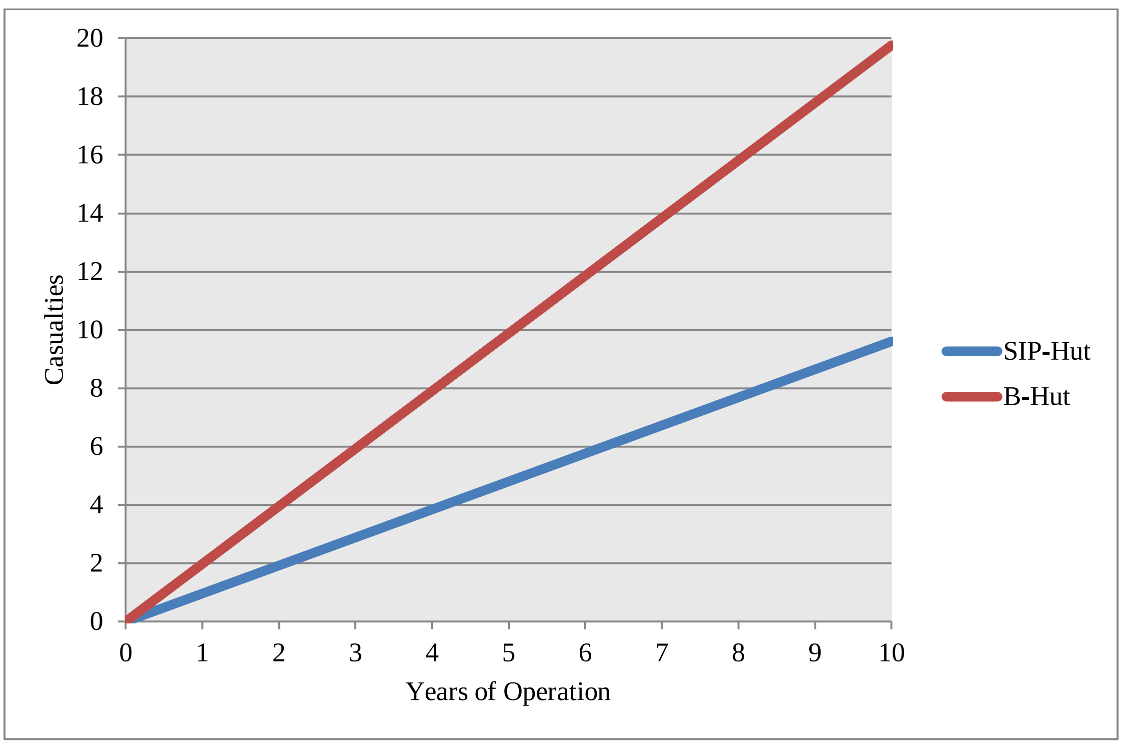

Figure 22 - Expected Fuel Resupply Casualties for Operation of 20 Battalion Base Camps

7.2. Case 1

The results for this case can be seen in Table 31.

Table 31 - Case 1: Summary of Results

	One-time		Recurring (/year)		Payback (Years)
	SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	$24,681	$12,367	$13,725	$28,230	0.85
Embodied Energy (kWh)	51,945	12,301	45,978	94,569	0.82
GHG Emissions (lb CO_2 eq)	22,001	6,560	23,914	49,187	0.61
Total Impacts (Ecopoints)	1,456	371.1	1,187	2,442	0.86

Cumulative cost per hut for this case can be seen in Figure 23.

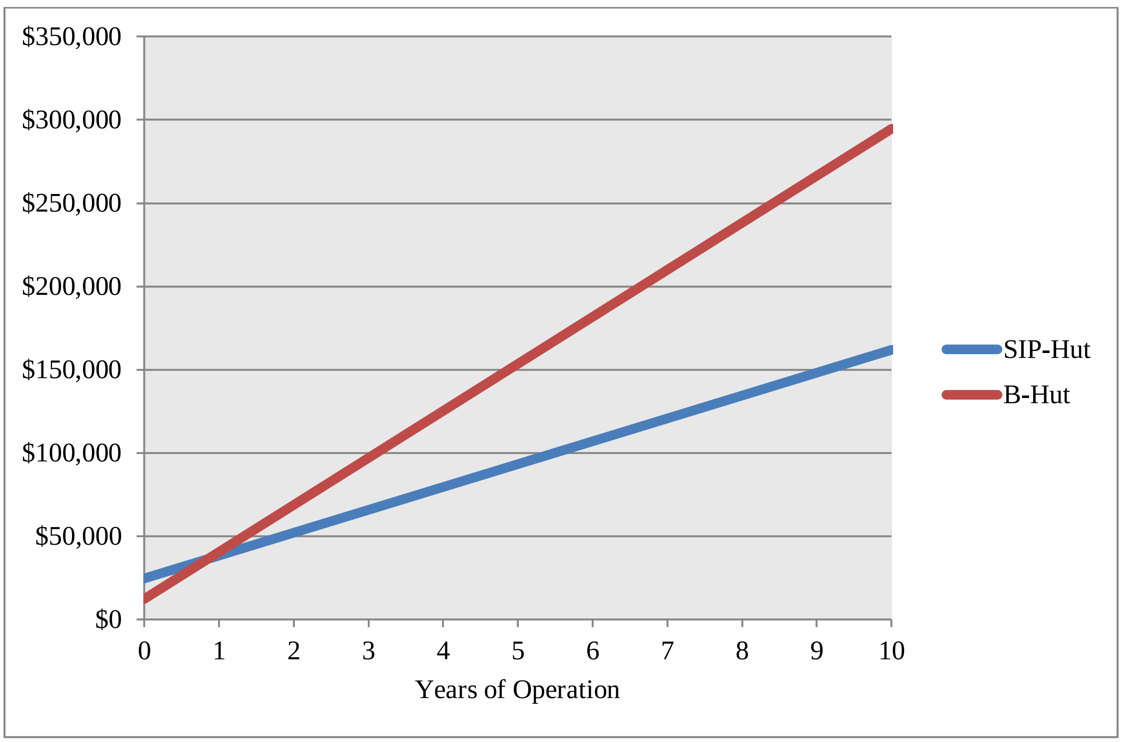

Figure 23 - Case 1: Cumulative Cost per Hut

As can be seen in Table 31, the initial cost differential between the SIP-Hut and B-Hut is much larger than in the Base Case (+$12,314). The environmental and operational analysis is identical to the Base Case. In this scenario, the SIP-Hut will take 0.85 years to pay back economically and 0.61-0.86 years to pay back environmentally, depending on the impact category of interest.

Since these structures would only be constructed for military housing at a base camp that is expected to be in operation for 2 or more years, SIP-Huts should be deployed in situations that mirror Case 1.

7.3. Case 2

The results for this case can be seen in Table 32.

Table 32 - Case 2: Summary of Results

	One-time		Recurring (/year)		Payback (Years)
	SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	$24,681	$12,367	$15,475	$22,906	1.66
Embodied Energy (kWh)	51,945	12,301	51,840	76,733	1.59
GHG Emissions (lb CO_2 eq)	22,001	6,560	26,963	39,910	1.19
Total Impacts (Ecopoints)	1,456	371.1	1,339	1,982	1.69

Cumulative cost per hut for this case can be seen in Figure 24.

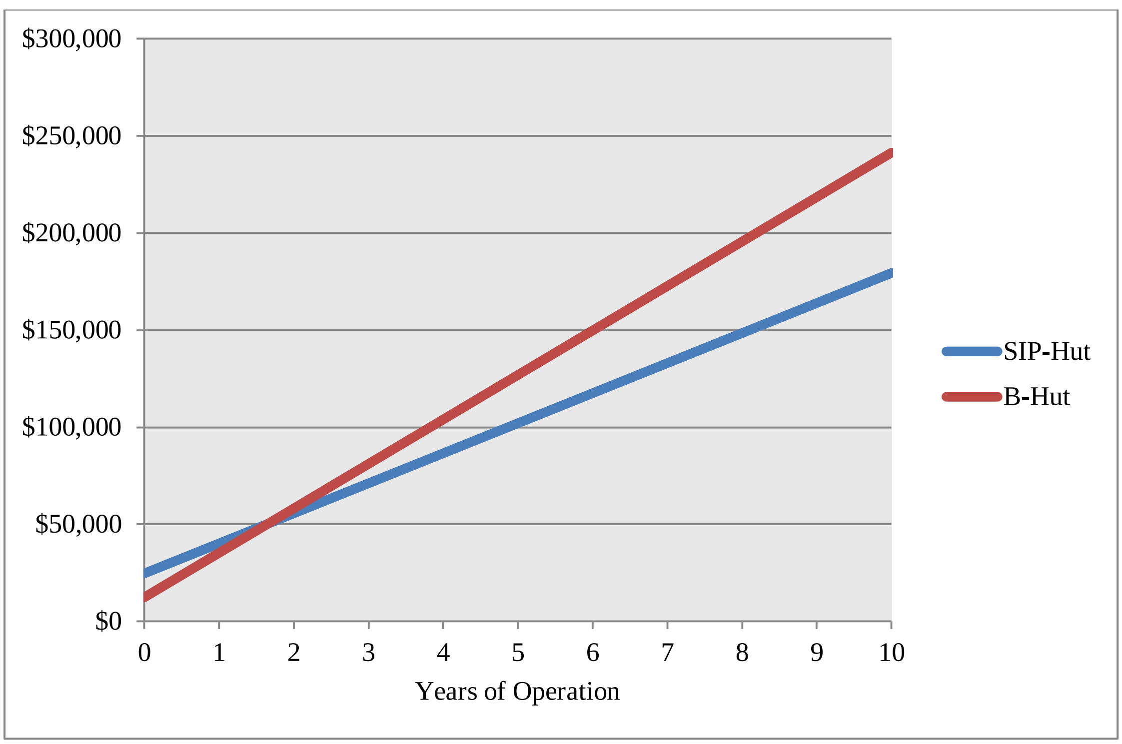

Figure 24 - Case 2: Cumulative Cost per Hut

Under the assumptions of Case 2, the annual operational cost differential between the SIP-Hut and B-Hut is $7,431, rather than the $14,505 assumed under the Base Case and Case 1. Despite this significant reduction in savings generated by the use of SIP-Huts, in a situation similar to this scenario, economic payback occurs in 1.66 years and environmental payback occurs somewhere between 1.19 and 1.69 years. As was the case with the Base Case and Case 1, if a realistic situation closely mimics Case 2, SIP-Huts should be deployed instead of B-Huts.

7.4. Case 3

The results for this case can be seen in Table 33.

Table 33 - Case 3: Summary of Results

	One-time		Recurring (/year)		Payback (Years)
	SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	$23,271	$5,518	$10,317	$15,271	3.58
Embodied Energy (kWh)	51,315	7,686	51,840	76,733	1.75
GHG Emissions (lb CO_2 eq)	21,741	3,964	26,963	39,910	1.37
Total Impacts (Ecopoints)	1,428	206.0	1,339	1,982	1.90

Cumulative cost per hut for this case can be seen in Figure 25.

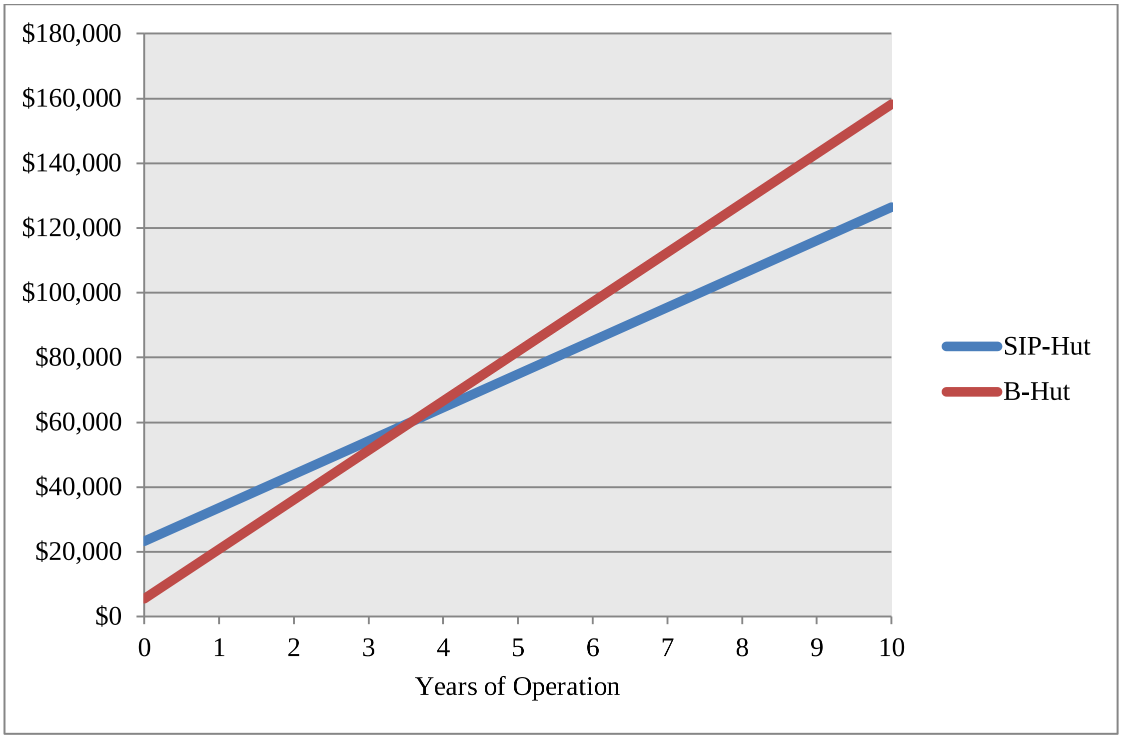

Figure 25 - Case 3: Cumulative Cost per Hut

Case 3 describes a worst-case scenario for SIP-Huts, a scenario that is not likely to actually materialize. Here, the one-time costs of the SIP-Hut are significantly higher than the B-Hut (nearly 4 times) and the recurring costs of the two options are much closer than in the previous cases. Despite the extreme nature of this scenario, the SIP-Hut would still pay back in a potentially acceptable time frame, 3.58 years. In a situation similar to this scenario, the installation of SIP-Huts would be financially warranted if the base camp was expected to be in use for at least 3-4 years. The actual observed payback would likely be quicker than 3.58 years if the ECU and generator costs were included in the capital costs of the installation. If this case occurs and the environmental impacts of the operation are of concern, then the SIP-Huts will be the preferred option, because the environmental paybacks are all less than 2 years. The results from this case demonstrate that even if the worst possible scenario for the SIP-Hut was observed, it would still yield potentially acceptable economic and environmental paybacks.

7.5. Case 4

The results for this case can be seen in Table 34.

Table 34 - Case 4: Summary of Results

	One-time		Recurring (/year)		Payback (Years)
	SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	$24,681	$14,840	$13,725	$22,276	1.15
Embodied Energy (kWh)	51,945	13,313	45,978	74,625	1.35
GHG Emissions (lb CO_2 eq)	22,001	7,132	23,914	38,813	1.00
Total Impacts (Ecopoints)	1,456	407.1	1,187	1,927	1.42

Cumulative cost per hut for this case can be seen in Figure 26.

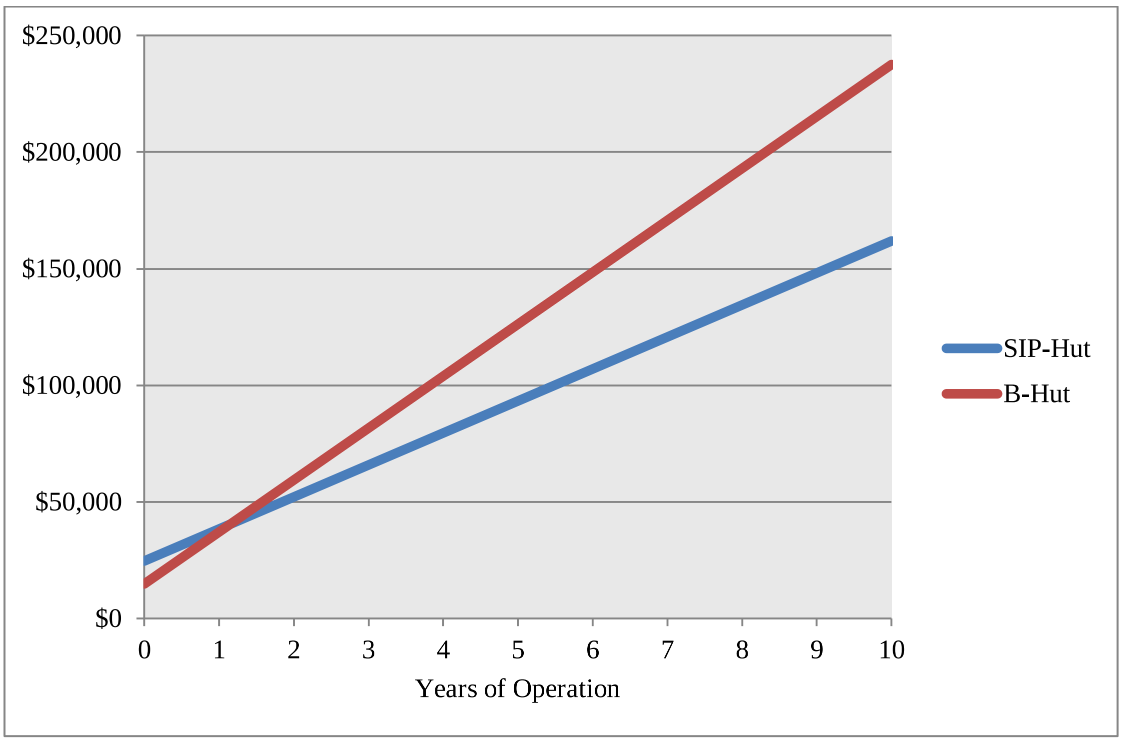

Figure 26 - Case 4: Cumulative Cost per Hut

The results for Case 4 show that if a decision had to be made whether to install insulated B-Huts or SIP-Huts at a base camp in Afghanistan, or area with similar climate and conflict level, then SIP-Huts should be constructed. The SIP-Huts would pay back the additional one-time costs and environmental impacts in well under two years, even without consideration of the ECUs and

generators. Although it is standard practice to leave B-Huts uninsulated, the evaluation of this case was important because there have been circumstances in which insulation has been installed.

7.6. Case 5

The results for this case can be seen in Table 35.

Table 35 - Case 5: Summary of Results

	One-time		Recurring (/year)		Payback (Years)
	SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	$22,181	$11,367	$2,882	$5,162	4.74
Embodied Energy (kWh)	46,377	10,074	36,208	64,846	1.27
GHG Emissions (lb CO_2 eq)	18,739	5,255	18,832	33,727	0.91
Total Impacts (Ecopoints)	1,266	295.0	935	1,675	1.31

Cumulative cost per hut for this case can be seen in Figure 27.

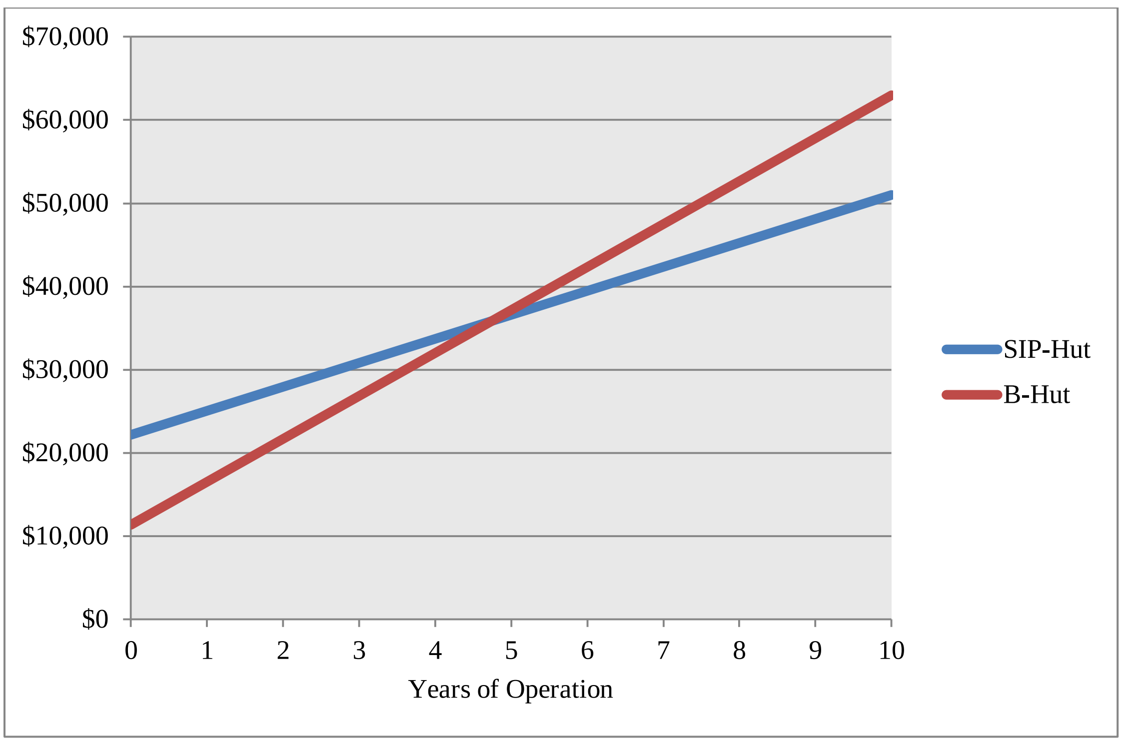

Figure 27 - Case 5: Cumulative Cost per Hut

Case 5 describes a low risk military application in a geographic area relatively close to the US that has a mild climate and access to low cost fuel. Under these assumptions, the SIP-Hut will still perform relatively well compared with the B-Hut. From an environmental perspective, the SIP-Hut should be selected. From an economic perspective, the decision becomes more difficult. If it was ensured that the huts would be in use for at least 5 years, then the SIP-Hut should be chosen. If the use duration of the huts was unknown, or expected to be less than 5 years, then perhaps some of the SIP-Hut's unquantified additional benefits should be considered to aid the decision.

The results for Case 5 also provide some insight for the use of SIP-Huts in other applications, such as for domestic or international disaster relief shelters. If SIP-Huts were used for disaster relief situations, then their quick assembly and potential for quick disassembly and reuse would be a great benefit. Before making any clear conclusions with respect to using SIP-Huts in these types of non-military situations, a more in-depth analysis is required, but on the surface their potential is promising.

7.7. Summary

Table 36 is a summary of the economic and environmental results for each case.

Table 36 - Summary of Results (All Cases)

		One-time		Recurring (/year)		Payback (Years)
		SIP-Hut	B-Hut	SIP-Hut	B-Hut	
Costs (USD)	Base Case	$38,037	$37,314	$13,725	$28,230	0.05
	Case 1	$24,681	$12,367	$13,725	$28,230	0.85
	Case 2	$24,681	$12,367	$15,475	$22,906	1.66
	Case 3	$23,271	$5,518	$10,317	$15,271	3.58
	Case 4	$24,681	$14,840	$13,725	$22,276	1.15
	Case 5	$22,181	$11,367	$2,882	$5,162	4.74
Embodied Energy (kWh)	Base Case	51,945	12,301	45,978	94,569	0.82
	Case 1	51,945	12,301	45,978	94,569	0.82
	Case 2	51,945	12,301	51,840	76,733	1.59
	Case 3	51,315	7,686	51,840	76,733	1.75
	Case 4	51,945	13,313	45,978	74,625	1.35
	Case 5	46,377	10,074	36,208	64,846	1.27
GHG Emissions (lb CO_2 eq)	Base Case	22,001	6,560	23,914	49,187	0.61
	Case 1	22,001	6,560	23,914	49,187	0.61
	Case 2	22,001	6,560	26,963	39,910	1.19
	Case 3	21,741	3,964	26,963	39,910	1.37
	Case 4	22,001	7,132	23,914	38,813	1.00
	Case 5	18,739	5,255	18,832	33,727	0.91
Total Impacts (Ecopoints)	Base Case	1,456	371	1,187	2,442	0.86
	Case 1	1,456	371	1,187	2,442	0.86
	Case 2	1,456	371	1,339	1,982	1.69
	Case 3	1,428	206	1,339	1,982	1.90
	Case 4	1,456	407	1,187	1,927	1.42
	Case 5	1,266	295	935	1,675	1.31

Table 37 displays the time, in years, for the deployment of SIP-Huts to payback economically, operationally (i.e. truck shipments), and environmentally for each case.

Table 37 - SIP-Hut Payback (Years)

	Simple Cost	Truck Shipments	Embodied Energy	GHG Emissions	Total Environmental Impacts (ReCiPe H)
Base Case	0.05	1.86	0.82	0.61	0.86
Case 1	0.85	1.86	0.82	0.61	0.86
Case 2	1.66	3.63	1.59	1.19	1.69
Case 3	3.58	3.63	1.75	1.37	1.90
Case 4	1.15	3.16	1.35	1.00	1.42
Case 5	4.74	3.16	1.27	0.91	1.31

Table 38 displays the increased one-time cost and the total cost savings, at 2, 5, and 10 years, for deploying SIP-Huts for each case. At 2 years, the cost savings are negative for Cases 3 and 5. This means that the increased one-time cost of the SIP-Hut for those cases has yet to be recouped at that point in time.

Table 38 - Summary of Increased One-time Cost and Ongoing Savings

	Increased One-time Cost of One SIP-Hut (USD)	Total Cost Savings from Deploying One SIP-Hut (USD)		
		2 years	5 years	10 years
Base Case	$723	$28,287	$71,802	$144,327
Case 1	$12,314	$16,696	$60,211	$132,736
Case 2	$12,314	$2,547	$24,840	$61,994
Case 3	$17,753	-$7,845	$7,017	$31,786
Case 4	$9,841	$7,261	$32,915	$75,672
Case 5	$10,814	-$6,255	$584	$11,983

7.8. Additional Considerations

There are some positive characteristics of the SIP-Hut that were not quantified in this study. For example, the reduced construction time of SIP-Huts would lead to quicker base camp commissioning. Less commissioning time leads to a reduction in risk and an increase in mission effectiveness, because the occupying military unit can spend less time constructing their base camp and more time focusing on defending it and carrying out the missions that they were deployed to complete.

Furthermore, the increased insulative capacity of the SIP-Hut makes it more thermally and acoustically comfortable for the occupying soldiers. An increase in soldier comfort has the potential to promote greater soldier wellbeing, which can increase their effectiveness.

Finally, during base camp modification or decommissioning, SIP-Huts can be more easily altered, relocated, or salvaged than traditional B-Huts. These characteristics align well with the dynamic nature of typical base camps. As described in Chapter 2, many base camps must be modified in order to align themselves with current threats, mission requirements, and the need for relocation, expansion, or reduction (US Army, 2010). SIP-Huts can meet this need much more effectively than traditional B-Huts.

8. Conclusions and Recommendations

This study evaluated the economic, environmental, and operational implications of the SIP-Hut and B-Hut throughout their lifecycles. It has provided a direct means by which to fairly compare the lifecycle implications of the two shelter systems. A variety of scenarios were fabricated to provide a means to compare the performance of these two systems in situations that were different than the baseline scenario. The results of this study show that, overall, the newly designed SIP-Hut provides superior performance over the traditional B-Hut, from an economic, environmental, and operational perspective. It is shown through this study that in most military situations and potentially in some disaster relief situations, the SIP-Hut is a viable alternative to shelters constructed using traditional materials and techniques. This shelter system is quickly erectable, highly efficient, and easily reused. If adopted by the US Military for use in base camps, large fuel savings will be observed, leading to appreciable long term cost savings, reduced environmental impact, and reduced risk of soldier casualties. In addition to the benefits that were quantified in this study, the Military could potentially observe numerous other benefits, such as quicker base commissioning, increased mission effectiveness, and end of life reuse opportunities. The SIP-Hut should certainly be considered for implementation into US Military base camps where deemed appropriate, and its potential for non-military use should be further explored.

9. Future Work

The results of this research could be expanded in several ways. (1) The Excel model that was developed for this study should be re-run after the eQUEST simulation results are verified by further empirical data. If there is a significant change in the eQUEST results, this would likely affect the results determined by this study. (2) The variables that presented relatively high levels of uncertainty could be evaluated in more detail. If these variables were to be reevaluated and were found to be significantly different than this study has suggested, they should be adjusted in the Excel model. (3) Other potential deployment locations should be determined and evaluated in detail. The Excel model could be utilized to perform these analyses. The model is setup to allow for easy data adjustment, which provides the means for simple data input to help simulate other deployment scenarios. (4) The application of SIP-Huts for non-military uses, such as providing temporary shelter for disaster relief, should be studied in more detail. This study's Excel model could potentially be adapted to aid in this analysis.

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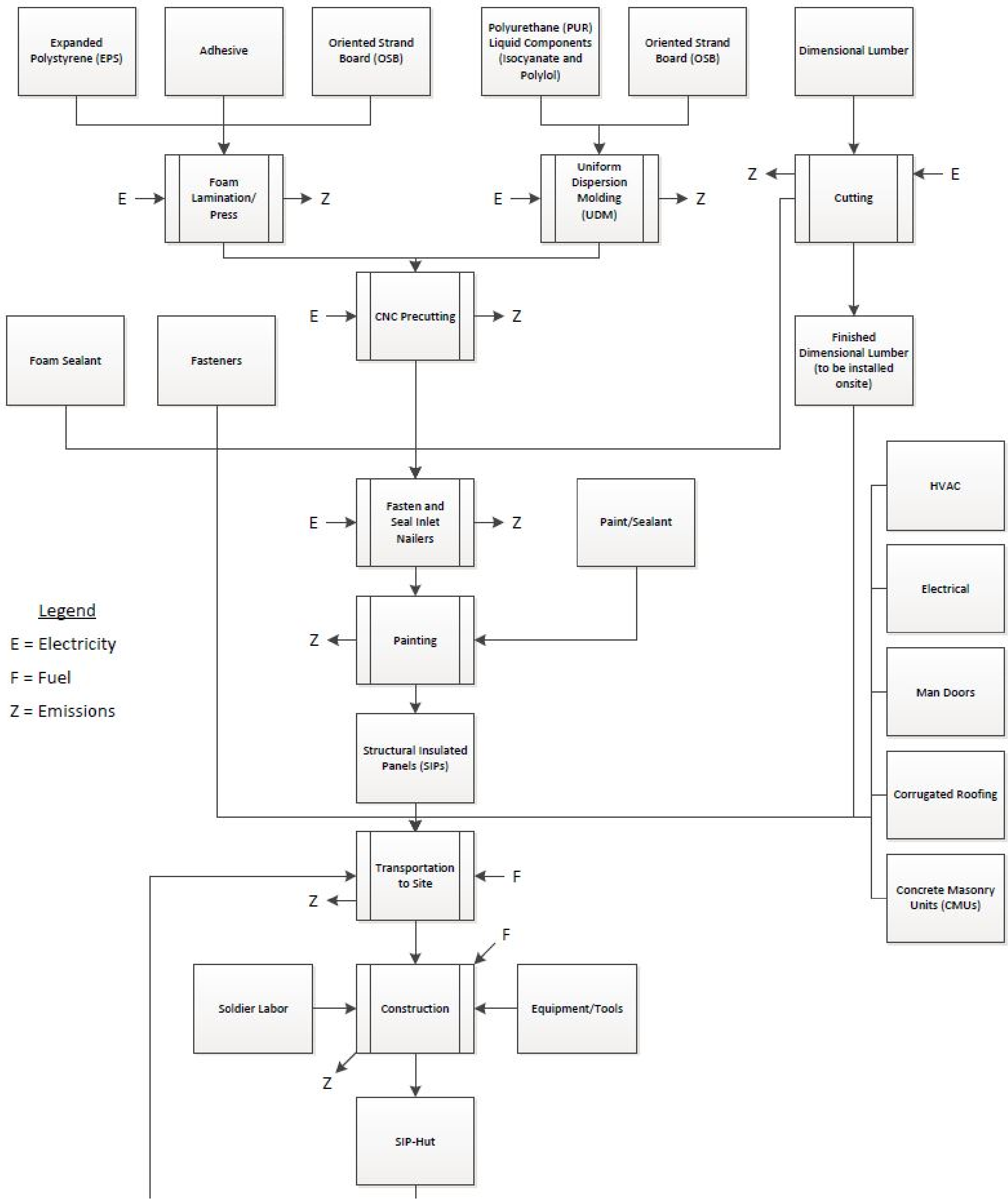
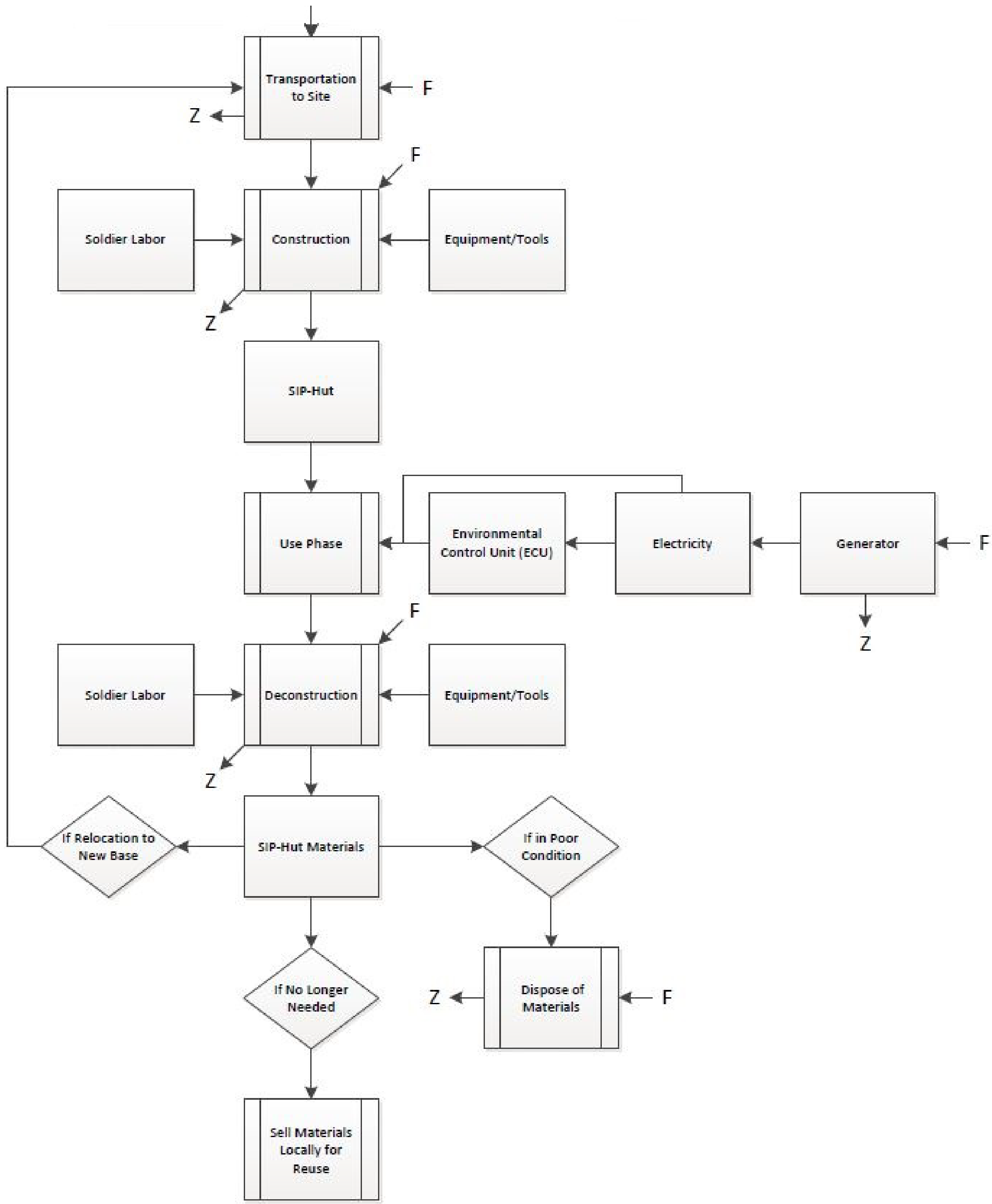
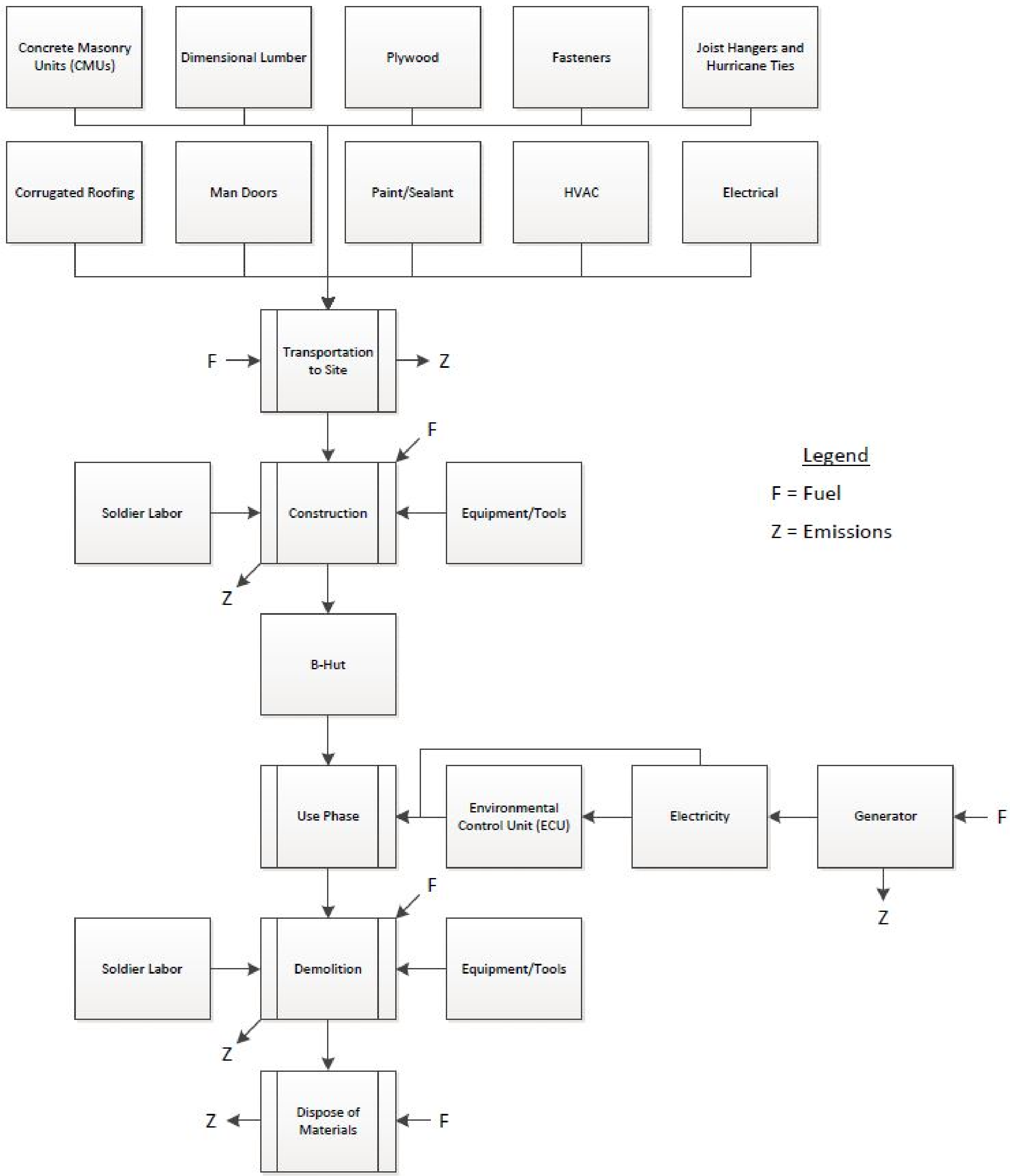
11. Appendix

11.1. SIP-Hut System Flow Diagram




Transportation to Site
F
Z
F
Soldier Labor
Construction
Equipment/Tools
Z
SIP-Hut
Use Phase
Environmental Control Unit (ECU)
Electricity
Generator
F
Z
F
Soldier Labor
Deconstruction
Equipment/Tools
Z
If Relocation to New Base
SIP-Hut Materials
If in Poor Condition
If No Longer Needed
Z
Dispose of Materials
F
Sell Materials Locally for Reuse

11.2. B-Hut System Flow Diagram



11.3. SIP-Hut Bill of Materials

Floor					
Item	**Quantity**	**Final Volume/ Piece (ft^3)**	**Final Total Volume (ft^3)**	**Weight/ Piece (oz)**	**Total Weight (lb)**
8-1/4" EPS Floor Panels (4'x16')	8				1971.20
KD 2x8x4'	16	0.30	4.83		
KD 2x8x16'	4	1.21	4.83		
KD 2x8x16'	4	1.21	4.83		
5/8"x2-7/8"x8' Plywood Keyspline	14	0.10	1.40		
2" Galvanized Screws (for keyspline)	231			0.12	1.73
2" Galvanized Screws (for keyspline)	231			0.12	1.73
2" Galvanized Screws (for end nailers)	256			0.12	1.92
3" Galvanized Screws (for long wall outer nailer)	64			0.22	0.88
10" Panel Screws (floor to floor beam)	96			1.40	8.40

Note: Material costs are covered in the quote provided by Murus

Walls					
Item	**Quantity**	**Final Volume/ Piece (ft^3)**	**Final Total Volume (ft^3)**	**Weight/ Piece (oz)**	**Total Weight (lb)**
4-5/8" PUR Wall Panels (4'x7')	16				1769.60
Polyurethane (PUR) Foam		8.75	140.00		*308.00*
7/16" Oriented Strand Board (OSB)		2.04	32.67		
Cam-Locks	70			6.25	*27.34*
4-5/8" PUR Wall Panels (4'x(7' to 8'-3"))	4				481.90
Polyurethane (PUR) Foam		9.53	38.13		*83.88*
7/16" Oriented Strand Board (OSB)		2.22	8.90		
Cam-Locks	10			6.25	*3.91*
4-5/8" PUR Wall Panels (4'x(8'-3" to 9'-6"))	2				280.45
Polyurethane (PUR) Foam		11.09	22.19		*48.81*
7/16" Oriented Strand Board (OSB)		2.59	5.18		
Cam-Locks	6			6.25	*2.34*
4-5/8" PUR Wall Panels (4'x(8'-3" to	2				106.65

9'-6")) (w/ door)					
Polyurethane (PUR) Foam		4.47	8.94		19.67
7/16" Oriented Strand Board (OSB)		1.04	2.09		
Cam-Locks	6			6.25	2.34
KD 2x4x16' Floor Nailer	6	0.58	3.50		
KD 2x4x10' Inlet Roof Nailer (Gable walls)	4	0.36	1.46		
KD 2x6x16' Beveled Inlet Roof Nailer (Long walls)	4	0.23	0.92		
KD 2x4x10' (for end posts)	6	0.36	2.19		
KD 2x4x8' (inlet wall nailer)	8	0.29	2.33		
KD 2x4x12' (inlet nailer for door opening)	2	0.44	0.88		
2" Galvanized Screws	576			0.12	4.32
2" Galvanized Screws	512			0.12	3.84
3" Galvanized Screws	192			0.22	2.64
6" Panel Screws (wall to wall at corners)	32			0.88	1.76

Note: Material costs are covered in the quote provided by Murus

Roof					
Item	**Quantity**	**Final Volume/ Piece (ft^3)**	**Final Total Volume (ft^3)**	**Weight/ Piece (oz)**	**Total Weight (lb)**
6-5/8" PUR Roof Panels (4'x9'-5 13/16")	16				2640.45
Polyurethane (PUR) Foam		18.18	290.85		*639.88*
7/16" Oriented Strand Board (OSB)		2.77	44.26		
Cam-Locks	84			6.25	*32.81*
6-5/8" PUR Roof Panels (2'x9'-5 13/16")	2				165.03
Polyurethane (PUR) Foam		9.09	18.18		*6.09*
7/16" Oriented Strand Board (OSB)		1.38	2.77		
Cam-Locks	6			6.25	*2.34*
2x6x10' (inlet nailer)	4	0.57	2.29		
2x6x8' (inlet nailer)	9	0.46	4.13		
3-1/2" x 9-1/4" x 16' LVL Ridge Beam	2	3.60	7.19		
3-1/2" x 5-1/2" x 10' LVL Post	1	1.34	1.34		
Simpson PC46 Bracket	1			6.20	0.39
2" Galvanized Screws	160			0.12	1.20
2" Galvanized Screws	272			0.12	2.04
8" Panel Screws	162			1.15	11.64

Note: Material costs are covered in the quote provided by Murus

HVAC System			
Item	**Quantity**	**Cost/Unit**	**Total Cost**
Alex Plus 10oz caulk SKU 984590	2	$2.28	$4.56
6" exhaust hood with flapper Model EX-HPG	1	$17.99	$17.99
HDT Nordic 9K EEECU	1	$9,500.00	$9,500.00
		Total	**$9,522.55**

Note: volume and weight from HDT, included in final BOM summary (Table 8)

Electrical			
Item	**Quantity**	**Cost/Unit**	**Total Cost**
100 amp, 20 space, 20 circuit main breaker	1	$210.00	$210.00
Red wire nuts (100 pack)	0.5	$7.98	$3.99
3/4" staples (250 pack)	1	$5.79	$5.79
1 gang 3 hole electrical box (exterior)	2	$21.76	$43.52
Silver 1 hole rectangular lamp holder cover	2	$16.36	$32.72
Metal Weather Resistant Lamp Holder	2	$2.39	$4.78
15 amp duplex outlets	15	$1.75	$26.25
3 gang new work boxes	6	$2.33	$13.98
2 gang new work boxes	2	$0.94	$1.88
1 gang new work box	1	$0.39	$0.39
single pole switches	8	$0.47	$3.76
2 outlet, 1 switch cover plate	6	$2.39	$14.34
2 outlet cover plate	1	$0.57	$0.57
2 switch cover plate	1	$2.52	$2.52
1 duplex outlet cover plate	1	$0.38	$0.38
plastic lamp base holders	6	$1.39	$8.34
4" octagonal boxes	6	$2.04	$12.24
12-2 with ground wire (250' roll)	2	$67.00	$134.00
14-2 with ground wire (250' roll)	1	$44.00	$44.00
The following items are for the service entrance:			
100 FT 6 AWG Wire THHN	1.5	$87.00	$130.50
60 AMP Disconnect	1	$212.00	$212.00
60 amp fuse	4	$11.50	$46.00
10 ft. conduit rigid, 1"	1	$52.00	$52.00
HUDS	1	$15.00	$15.00
service head 1"	1	$11.50	$11.50
9 W LED lights	8	$11.98	$95.84
		Total	**$1,126.29**

Note: volume and weight estimated, included in final BOM summary (Table 8)

Other Items			
Item	**Quantity**	**Cost/Unit**	**Total Cost**
Foundation Blocks	15	$1.50	$22.50
6x6x16' PT Foundation Beams	6	$41.96	$251.76
Metal Man Door (insulating core)	2	Included in Murus's Quote	

11.4. B-Hut Bill of Materials

Floor					
Item	**Quantity**	**Volume/ Piece (ft^3)**	**Total Volume (ft^3)**	**Weight/ Piece (oz)**	**Total Weight (lb)**
KD 2x6x8'	66	0.46	30.25		
16d common nails	162			0.33	3.34
12d common nails	75			0.26	1.22
2x6 Joist hangers (galv)	46			4.25	12.22
10d galv (1-1/2") hanger nail	368			0.12	2.76
3/4"x4'x8' ply	16	2.00	32.00		
8d common nails	784			0.17	8.33

Note: Material cost applied in the itemized BOM summary (Table 6)

Walls					
Item	**Quantity**	**Volume/ Piece (ft^3)**	**Total Volume (ft^3)**	**Weight/ Piece (oz)**	**Total Weight (lb)**
KD 2x4x8'	120	0.29	35.00		
16d common nails	504			0.33	10.40
1/2"x4'x8' ply	28	1.33	37.33		
8d common nails	1372			0.17	14.58

Note: Material cost applied in the itemized BOM summary (Table 6)

Roof					
Item	**Quantity**	**Volume/ Piece (ft^3)**	**Total Volume (ft^3)**	**Weight/ Piece (oz)**	**Total Weight (lb)**
KD 2x6x8'	59	0.46	27.04		
KD 2x6x12'	38	0.69	26.13		
1/2"x4'x8' ply	4	1.33	5.33		
10d common nails	1768			0.24	26.52
rafter ties (galv)	34			3.42	7.27
10d galv (1-1/2") hanger nail	340			0.12	2.55
KD 1x6x12'	6	0.34	2.06		
8d galv box nails	114			0.12	0.86
5/8"x4'x8' ply	27	1.67	45.00		
8d common nails	1323			0.17	14.06

Note: Material cost applied in the itemized BOM summary (Table 6)

HVAC System			
Item	**Quantity**	**Cost/Unit**	**Total Cost**
HDT: F100-60K (5 Ton) ECU w/ 6' Duct	1	$18,822.00	$18,822.00

Note: volume and weight estimated, included in final BOM summary (Table 7)

Electrical			
Item	**Quantity**	**Cost/Unit**	**Total Cost**
100 amp, 20 space, 20 circuit main breaker load center	1	$210.00	$210.00
Red wire nuts (100 pack)	0.5	$7.98	$3.99
3/4" staples	1	$5.79	$5.79
1 gang 3 hole electrical box (exterior)	2	$21.76	$43.52
Silver 1 hole rectangular lamp holder cover	2	$16.36	$32.72
Metal Weather Resistant Lamp Holder	2	$2.39	$4.78
15 amp duplex outlets	15	$1.75	$26.25
3 gang new work boxes	6	$2.33	$13.98
2 gang new work boxes	2	$0.94	$1.88
1 gang new work box	3	$0.39	$1.17
single pole switches	8	$0.47	$3.76
2 outlet, 1 switch cover plate	6	$2.68	$16.08
2 outlet cover plate	1	$0.57	$0.57
2 switch cover plate	1	$2.52	$2.52
plastic lamp base holders	6	$1.39	$8.34
4" octagonal boxes	6	$2.04	$12.24
12-2 with ground wire (250' roll)	2	$67.00	$134.00
14-2 with ground wire (250' roll)	1	$44.00	$44.00
The following items are for the service entrance:			
100 FT 6 AWG Wire THHN	1.5	$87.00	$130.50
60 AMP Disconnect	1	$212.00	$212.00
60 amp fuse	4	$11.50	$46.00
10 ft. conduit rigid, 1"	1	$52.00	$52.00
HUDS	1	$15.00	$15.00
service head 1"	1	$11.50	$11.50
60W incandescent lights	8	$0.38	$3.04
220V, 20A outlets	2	$5.86	$11.72
Cover plate for single 220V, 20A outlet	2	$5.00	$10.00
		Total	$1,057.35

Note: volume and weight estimated, included in final BOM summary (Table 7)

Other Items						
Item	**Quantity**	**Cost/Unit**	**Total Cost**	**Volume/ Piece (ft^3)**	**Total Volume (ft^3)**	**Total Weight (lb)**
Foundation Blocks	15	$1.50	$22.50	0.30	4.44	222.22
6x6x16' PT Foundation Beams	6	$41.96	$251.76	3.36	20.17	726.00
Metal Man Door (solid core) 3' x 6'-9"	2	$139.00	$278.00	3.40	6.80	204.00
Door Hardware	2	$49.97	$99.94	Included in door volume and weight		

11.5. SimaPro Impact Assessment Parameters

The following methods were used for each impact category when calculating the impacts of the B-Hut and SIP-Hut in the SimaPro model. Information is also provided detailing if and how the impact units were adjusted:

11.5.1. Total Environmental Impact (Ecopoints)

Recipe Endpoint (H) V1.07 / World ReCiPe H/A

The default ReCiPe endpoint method is the Hierarchist version, with European normalization and average weighting set: *ReCiPe Endpoint (H), Europe ReCiPe H/A*. The method that has been used is the *Recipe Endpoint (H) V1.07 / World ReCiPe H/A* method because the analysis is not focused in Europe.

Two other methods were also considered:

Recipe Endpoint (E) V1.07 / World ReCiPe E/A

Recipe Endpoint (I) V1.07 / World ReCiPe I/A

11.5.2. Embodied Energy (kWh)

Cumulative Energy Demand V1.08

The results from the SimaPro model were in mega-joules (MJ). In order to convert the results to mega-watt-hours (kWh) the following conversion was used: 0.2778 kWh/MJ.

11.5.3. Greenhouse Gas Emissions (lb CO_2 eq)

Greenhouse Gas Protocol V1.01 / C02 eq (kg)

The results from the SimaPro model were in kilograms (kg) of CO_2 equivalent. In order to convert the results to pounds (lb) of CO_2 equivalent the following conversion was used: 2.2046 lb/kg.

11.6. SIP-Hut SimaPro Model Notes and Descriptions

The following information details the materials, assemblies, and processes modeled in SimaPro. The intent of providing this information is to provide transparency of the data and procedures used in this analysis.

Exclusions from the analysis include: site preparation, roofing materials, and protective coatings. In addition, the ECUs and generators were not considered in the SimaPro model due to lack of LCI data. Mass and volumetric data was available for the ECU, so the weight and volume of the ECU was considered in the transportation phase of the analysis.

Note: All *italicized* phrases refer to the actual name of the process used in the SimaPro model.

11.6.1. Materials

1. Foundation
    a. Concrete blocks (CMUs)
        i. *Concrete block, at plant/DE U*
        ii. The transportation distance to the packaging site has been estimated to be 200 miles. The following process was considered for this transportation.
            1. *Transport, combination truck, diesel powered/US*
    b. Pressure Treated (PT) 6x6 foundation beams
        i. Since there is no pressure treated wood process available in any of the databases that SimaPro references, this material will be considered to be typical kiln dried, untreated lumber (see below "softwood" process). Neglecting the treatment process will have negligible effects on the analysis because it is a minor part of a large system. Furthermore, it is possible, that non-treated lumber could be used in place of the PT lumber in reality. Finally, the foundation beams are identical between the two options being analyzed.

2. Structural Insulated Panels (SIPs)

    a. A separate SimaPro process has been created for each of the three types of SIPs used in the SIP-Hut (4-5/8” PUR, 6-5/8” PUR, 8-1/4” ESP). The output of each SIP type is based on area (ft^2), which is the preferred quantification method because the SIPs are composite materials that have a consistent thickness (per panel type).

    b. SIP waste from the manufacturing facility has not been included as process waste due to variability panel to panel. For example, the gable end panels have much more waste than the longitudinal walls. Instead, the total original SIP length (before cutting) has been inputted. The end of life waste scenario will be essentially identical to the process waste scenario (landfill), therefore the effect of not making this separation, to the accuracy of the analysis, is negligible.

    c. The oriented strand board (OSB) process in SimaPro was from the USLCI database. It includes all energy and raw material inputs and includes the transportation of the inputs to the plant. Process emissions data was not included, but has a negligible impact on the accuracy of the results.

        i. *Oriented strand board product, US SE/kg/US*

        ii. Transportation of the OSB was determined to be 1.64 ton-miles (tmi). The density of OSB was determined to be approximately 45 lb/ft^3 (Structural Board Association, 2005). The quantity of OSB per square foot of SIP in all cases is 0.0729167 ft^3 providing a weight of OSB per square foot of panel of 3.28 pounds. The average transportation distance of the OSB to Murus’s manufacturing plant is 1,000 miles (Bloom, 2013c). Multiplying the weight by the distance and converting to short tons provides the 1.64 ton-mile figure.

            1. *Transport, combination truck, diesel powered/US*

    d. The polyurethane (PUR) foam is shipped to the manufacturing facility in a 2 part liquid state. The 2 liquids are combined immediately before being injected by the machine to form the PUR SIPs. The liquid is injected directly between to sheets of 7/16” OSB using a proprietary manufacturing method called Uniform Dispersion Molding (UDM) (Murus).

i. The two chemicals that make up the polyurethane foam are isocyanate and polylol, which are both produced by the Dow Chemical Company. The specific gravity of both chemicals is 1.24. Therefore the in solution density of the two components is 77.4 lb/ft^3 (62.4 lb/ft^3 * 1.24) (Dow Chemical, 2011& 2012).

ii. Transportation of the liquid polyurethane foam to the manufacturing facility is assumed to be by: *Transport, combination truck, diesel powered/US*. The final density of PUR foam in SIPs is 2.2 lb/ft^3 (Murus). The total final volume of foam in 1 ft^2 of 4-5/8" PUR SIP is equal to 0.3125 ft^3 (3.75"/12*1'*1'). The volume of liquid is approximately 6 times less (Bloom, 2013d) than this at 0.05208 ft^3. This provides a liquid in solution weight of 4.030 lb (0.05208 ft^3*77.4 lb/ft^3). The final volume of foam per 1 ft^2 for the 6-5/8" PUR SIP is equal to 0.4792 ft^3. The liquid volume is approximately 0.07987 ft^3. This provides a liquid in solution weight of 6.180 lb (0. 07987 ft^3*77.4 lb/ft^3).

Table 39 - SIP PUR Foam Data

Panel Type	Foam Density (lb/ft^3)	Foam Thickness (in)	Foam Volume/ft^2 of SIP (ft^3)	Foam Weight/ft^2 of SIP (lb)	Liquid Volume/ft^2 of SIP (gal)	In Solution Liquid Weight (lb)
4-5/8" PUR	2.2	3.75	0.3125	0.6875	0.0521	4.030
6-5/8" PUR	2.2	5.75	0.4792	1.0542	0.0799	6.180

iii. The liquid is shipped to Murus from Marietta, GA in tanker truck (855 miles). Shipments are, on average, 40,000 pounds (Bloom, 2013c).

1. *Transport, combination truck, diesel powered/US*

e. The expanded polystyrene foam (EPS) is manufactured at a separate facility. It is expanded into large blocks and then cut down to size using a hot wire (resulting in little to no waste). The EPS is shipped (from Prospect, CT (270 miles) or Latrobe, PA (223 miles)) an average of 247 miles to Murus's manufacturing facility (assuming equal distribution) (Bloom, 2013c). Murus has specified that there is no recycled content. Approximately 3,000 ft^3 is delivered per truck load. It has been determined that each square foot of 8-1/4" EPS SIP is responsible for 0.04693 miles of truck travel.

i. *Transport, combination truck, diesel powered, mi*

1. 3,000 ft^3 / delivery = 3,000 lb / delivery (EPS density = 1.0 lb/ft^3)
2. (3,000 lb/trip)/(0.57 lb/ft^2) = 5263.157 ft^2/trip
3. 247 miles / 5263.15 ft^2 = 0.04693 miles/ft^2 of SIP

ii. The glue used to adhere the EPS and OSB is 66% polyurethane resin, 12% isocyanic acid, and 22% Methylenebis (Rohm and Haas, 2007). The glue is being represented in SimaPro (in the same proportions) by the following (respectively):

1. *Polypropylene resin, at plant/RNA*
2. *Acrylic acid, at plant/RER U*
3. *Methylene diphenyl diisocyanate, at plant/RER U*

iii. 0.069 pounds of glue is used per square foot of SIP (includes glue for both sides of the ESP) (Bloom, 2013d).

iv. *Polystyrene foam slab, at plant/RER U*

Table 40 - SIP EPS Foam Data

Panel Type	Foam Density (lb/ft^3)	Foam Thickness (in)	Foam Volume/ft^2 of SIP (ft^3)	Foam Weight/ft^2 of SIP (lb)
8-1/4" EPS	1.0	7.375	0.6146	0.6146

f. Electricity consumed at the manufacturing facility (Murus) is equal to 0.42 kWh/ft^2 of SIP (Bloom, 2013e). Total electricity consumption of the facility for one year was taken and the total square footage output of SIPs (regardless of type and thickness) was divided into it. This was the best resolution that could be determined for the data because no individual electricity metering exists at Murus's facility. The difference in energy consumption between the different types of SIPs is assumed to be negligible. This number also includes energy consumption related to operational overhead, such as running lights and operating Murus's entire facility, not just the equipment. Any energy expended using externally powered equipment (such as propane forklifts) is not accounted for, but is negligible.

i. *Electricity, medium voltage, at grid/US U*

g. The plastic Cam-Locks that are in the PUR SIPs (spaced every 24 inches on most panel edges) are made from polypropylene and are assumed to be injection molded. It is estimated that there is 1 Cam-Lock for every 4 square feet of PUR SIP. Some panels do not have them on the edge (i.e. corner SIPs); this provides a negligible difference so it has not been considered. Each Cam-Lock weighs 0.3906 pounds (6.25 ounces).

    1. *Polypropylene, granulate, at plant/RER U*
    2. *Injection moulding/RER U*

  ii. Transportation

    1. The Cam-Locks are manufactured in Elgin, IL and shipped to Murus, via truck, a distance of 700 miles (Bloom, 2013d).

        a. *Transport, combination truck, diesel powered/US*

3. Softwood Dimensional Lumber (Kilned Dried and Planed)

    a. *Surfaced dried lumber, at planer mill, US SE/kg/US*

    b. This process includes all previous processes embodied in the kiln dried (KD) rough sawn lumber and adds the planing process. 85% of the impacts are allocated to the final planed lumber because other useful byproducts are created (i.e. sawdust and planer shavings). This process assumes that all processes (i.e. sawing, drying, and planing) take place at the same location.

    c. The density of softwood KD lumber varies with wood type and moisture content, but has been assumed to be 35 lb/ft^3 (The Engineering Tool Box).

    d. From the BOM, the total volume was determined to be 32.19 ft^3.

    e. Murus sources their KD lumber from Arnot Building Supply (Mansfield, PA), which sources it from Ontario, Canada (by road) at an average transportation distance of 700 miles.

        i. *Transport, combination truck, diesel powered/US.*

4. BC Grade Plywood (used for splines to connect EPS SIPs)
    a. *Plywood, at plywood plant, US SE/kg/US*
    b. 1,000 mile transportation distance has been estimated, based on the location of multiple OSB suppliers.
        i. *Transport, combination truck, diesel powered/US.*
    c. Sawdust emissions are not considered.
    d. Electricity usage for cutting is included in the total energy use per square foot of SIPs that has been applied to the SIP manufacturing process.

5. Laminated veneer lumber (LVL)
    a. *Laminated veneer lumber, at plant, US SE/kg/US*
        i. This process assumes that the LVL material inputs are sourced from the Southeast US.
        ii. Density is assumed to be 41 lb/ft^3 (West Fraser LVL).
    b. Transportation
        i. LVLs are shipped from LP Corporation (Nashville, TN) to Universal Forest Products (Buffalo, NY) then to Arnot Building Supply (Mansfield, PA). Transportation from Arnot to Murus is negligible. All transportation is by truck. Total distance is estimated to be 865 miles.
            1. *Transport, combination truck, diesel powered/US.*

6. Fasteners
    a. Galvanized Screws (2” and 3”)
        i. The following SimaPro processes were used to represent the material and processing inputs
            1. *Iron and steel, production mix/US*
            2. *Zinc, sheet/GLO*
            3. *Cold impact extrusion, steel, 3 strokes/RER U*
                a. The actual manufacturing process does not exist in SimaPro. Since the fasteners are relatively trivial in

comparison to the whole structure, using the incorrect process will have negligible effects on the analysis.

ii. Transportation to the fastener manufacturing plant and then to Murus was assumed to be 1,000 miles.

1. *Transport, combination truck, diesel powered/US*.

b. Panel Screws (6”, 8”, 10”)

i. The following SimaPro processes were used to represent the material and processing inputs

1. *Iron and steel, production mix/US*
2. *Zinc, sheet/GLO*
3. *Cold impact extrusion, steel, 3 strokes/RER U*

a. The actual manufacturing process does not exist in SimaPro. Since the fasteners are relatively trivial in comparison to the whole structure, using the incorrect process will have negligible effects on the analysis.

ii. Transportation to the fastener manufacturing plant and then to Murus was assumed to be 1,000 miles.

7. Galvanized Steel Brackets

a. Simpson PC46 Bracket

i. The following SimaPro processes were used to represent the material and processing inputs

1. *Iron and steel, production mix/US*
2. *Zinc, sheet/GLO*
3. *Cold impact extrusion, steel, 4 strokes/RER U*

ii. Transportation to the fastener manufacturing plant and then to Murus was assumed to be 1,000 miles.

iii. There is one PC46 bracket per SIP-Hut connecting the ridge beam to the center post. The bracket weighs 0.4 pounds.

8. Metal Exterior Man-Doors
    a. *Door, outer, wood-aluminum, at plant/RER U*
    b. Due to variability in door type, it is assumed that this typical aluminum sheathed wooden core door may be used. Even if this process is not completely representative of the actual doors being used, they are equivalent for each option, so it will not greatly affect the results of the analysis.
    c. The SimaPro process includes the door, steel door frame, and installation at site. It does not include transportation to site.
    d. The transportation distance to the packaging site (Mansfield, PA) has been estimated to be 500 miles. The following process was considered for this transportation.
        i. *Transport, combination truck, diesel powered/US*
    e. The Ecoinvent door process that was used was in area units, so it was necessary to create a new process that was in mass units in order for the doors to be considered in the disposal scenario. This process was labeled "*Door, outer, wood-aluminum, at packaging site.*" This process converts the door area to mass at a rate of 102 pound per 20.25 square feet (this is representative of one 3' x 6'-9" door). It also includes the transportation to the packaging site.

11.6.2. Transportation to Afghanistan

1. The SIP-Huts will be containerized in Mansfield, PA with all components (including foundation, structure, doors, trim, HVAC, and electrical). Comparing the total volume of the SIP-Hut materials with container capacities (and accounting for packing inefficiencies), 2 SIP-Huts will be able to be packed for shipping in one 40' HC shipping container. After all the components arrive in Mansfield, PA, they will be packed into the containers.
    a. The shipping of HVAC and electrical components to Mansfield, PA for containerizing has not been included in the analysis due to lack of data. This will have a negligible impact of the accuracy of the analysis, because this shipping operation would be approximately equal for both the SIP-Hut and B-Hut.

2. From Mansfield, PA the containers of SIP-Huts will be shipped, by road, a distance of 260 miles to the New York Container Terminal in Staten Island, NY. Transportation was tracked in miles (mi). Since it is known that exactly 2 SIP-Huts will fit in one 40’ HC shipping container, and each truck will be carrying one container, the transportation distance that is attributed to each SIP-Hut is half of the truck transportation distance.
    a. *Transport, combination truck, diesel powered, mi*
        i. This process assumes a fuel economy of 5.9 mpg (Winebrake, 2012).
3. In Staten Island, NY the containers will be loaded onto an ocean freighter and shipped (via sea) approximately 14,000 miles to the Port of Qasim in Karachi, Pakistan. Each 40’ HC shipping container weighs 8,775 pounds empty (Conex, 2013). Each SIP-Hut weighs 9,474 pounds with all materials and equipment. The total (gross) weight of one shipping container with 2 SIP-Huts has been determined and rounded up to 28,000 pounds. The max gross weight of a 40’ HC shipping container is 67,200 pounds, so this is acceptable (Conex, 2013).
    a. In order to account for the impacts associated with shipping the SIP-Hut it was necessary to develop a process that was not in units of ton-miles. The SIP-Hut’s low density requires it to be shipped in more containers than the B-Hut for a similar weight. This difference would not be able to be accounted for in a process that uses ton-miles. The following USLCI process was modified to be in units of miles instead of ton-miles: *Transport, ocean freighter, residual fuel oil powered/US*. The fuel consumption per mile (per 40’ container) was approximated to be 0.0211 gallons per mile (47.4 mpg). Therefore the new process assumes a fuel consumption of 0.0211 gallons (of heavy fuel oil) per 40’ container (FEU) mile. This process has been labeled as: *Transport, ocean freighter, residual fuel oil powered/US, FEU mi.*
4. From the Port of Qasim, the containers will be loaded onto trucks and shipped via road (with US gun-trucks as escorts, 4:1 ratio of shipping trucks to gun-trucks) to the FOB. In this case, the FOB is being assumed to be in Kandahar, Afghanistan, requiring a transportation distance of 575 miles. The round trip distance has been considered in this analysis because separate return cargo is unlikely. A 20% reduction in fuel consumption has been assumed for the return trip due to increased fuel economy. Therefore the return

distance has been reduced by 20%. The round trip distance being used for analysis purposes is 1035 miles (575 miles + 575*0.80 miles). The transportation distance attributed to each SIP-Hut is half of the round trip distance, 517.5 miles.

   a. *Transport, combination truck (w/ gun-truck escort), diesel powered, mi*
      i. *Transport, combination truck, diesel powered, mi*
         1. This process assumes a fuel economy of 5.9 mpg (Winebrake, 2012).
      ii. *Transport, gun-truck escort (humvee), diesel powered, mi*
         1. This process assumes a fuel economy of 10 mpg (Hoy, 2008).

11.6.3. Construction

1. The SIP-Hut construction phase has been represented in SimaPro by the running a 1 kW generator at full load during the entire construction process, determined to be 11 hours.
   a. *Electricity, diesel, at FOB, burned in generators, kWh*
   b. Electricity consumption = 11 hours * 1 kW = 11 kWh
   c. The efficiency of the generator is assumed to be 27.5%

11.6.4. Use

1. The estimated electricity usage of a single SIP-Hut is 9,150 kWh/year (Leemans, 2013).
2. A SimaPro process was created to represent the electricity production using a typical FOB generator. This process assumes a conversion efficiency of 10 kWh per 1 gallon of fuel (27.5% generator efficiency) (TROPEC, 2014). It also assumes 1,000 miles of transportation to get the diesel fuel to the FOB, the same transportation process that was created for the SIP-Hut shipment was used here (*Transport, combination truck (w/ gun-truck escort), diesel powered, mi*). The fuel capacity of the tanker trucks was assumed to be 6,000 gallons. In order to determine how many miles of truck transport to attribute each kWh of electricity the following calculation was performed:
   a. (0.10 gallons/kWh) / ((6,000 gallons/trip) / (1,000 miles/trip)) = 0.01667 miles/kWh

11.6.5. End of Life

1. In SimaPro, the end of life (EOL) of the system being analyzed is dealt with by developing a waste scenario to identify where the waste goes (i.e. landfill, incinerator, etc.) and a waste treatment process to describe impacts and emissions from the disposing of the waste (Goedkoop et al., 2013).
2. It is being assumed that the SIP-Hut will ultimately be disposed of in a landfill at the end of its life. This disposal may be after it is reused multiple times, but in the end it is quite likely (being in Afghanistan) that the materials will ultimately go to the landfill.
3. Transportation to the landfill has been assumed to be by means of a typical combination truck (*Transport, combination truck, diesel powered/US*). The distance to the landfill site has been assumed to be 100 miles. The total material weight of one SIP-Hut (excluding electrical and HVAC, which is assumed to be recovered) is 10,171 pounds. This produces 509 ton-miles (tmi) of transport for one SIP-Hut (5.09 tons * 100 miles = 509 tmi).
4. The SimaPro processes used to account for the end of life landfilling are as follows:
    a. *Disposal, polyurethane, 0.2% water, to inert material landfill/CH U*
        i. Foam is 1455 pounds, 14.31%
    b. *Disposal, wood untreated, 20% water, to sanitary landfill/CH U*
        i. Wood is 8247 pounds, 81.08%
    c. *Disposal, steel, 0% water, to inert material landfill/CH U*
        i. Steel is 247 pounds, 2.43%
    d. *Disposal, concrete, 5% water, to inert material landfill/CH U*
        i. Concrete is 222 pounds, 2.18%
5. Although the landfill conditions may vary between the ones represented by these processes and the ones present at a rudimentary landfill in Afghanistan, it is being assumed that the processes are representative. End of life impacts of the SIP-Hut are minimal compared to the rest of its lifecycle, so slight inaccuracy should have a negligible impact on the validity of the analysis.

11.7. B-Hut SimaPro Model Notes and Descriptions

The following information details the materials, assemblies, and processes modeled in SimaPro. The intent of providing this information is to provide transparency of the data and procedures used in this analysis.

Exclusions from the analysis include: site preparation, roofing materials, and protective coatings. In addition, the ECUs and generators were not considered in the SimaPro model due to lack of LCI data. Mass and volumetric data was available for the ECU, so the weight and volume of the ECU was considered in the transportation phase of the analysis.

It has been assumed that all materials for the B-Hut are being packaged in Pennsylvania and shipped to Afghanistan from there. All distances to transport materials to the container packaging site (which has been assumed to be Mansfield, PA for analysis purposes) are assumed to be the same as the SIP-Hut materials.

Note: All *italicized* phrases refer to the actual name of the process used in the SimaPro model.

11.7.1. Materials

1. Foundation
    a. Concrete blocks (CMUs)
        i. *Concrete block, at plant/DE U*
        ii. The transportation distance to the packaging site has been estimated to be 200 miles. The following process was considered for this transportation.
            1. *Transport, combination truck, diesel powered/US*
    b. Pressure Treated (PT) 6x6 foundation beams
        i. Since there is no pressure treated wood process available in any of the databases that SimaPro references, this material will be considered to be typical kiln dried, untreated lumber (see below "softwood" process). Neglecting the treatment process will have negligible effects on the analysis because it is a minor part of a large system. Furthermore, it is possible, that non-treated lumber could be used in place of the PT lumber

in reality. Finally, the foundation beams are identical between the two options being analyzed.

2. Softwood Dimensional Lumber (Kilned Dried and Planed)
    a. *Surfaced dried lumber, at planer mill, US SE/kg/US*
    b. This process includes all previous processes embodied in the kiln dried (KD) rough sawn lumber and adds the planing process. 85% of the impacts are allocated to the final planed lumber because other useful byproducts are created (i.e. sawdust and planer shavings). This process assumes that all processes (i.e. sawing, drying, and planing) take place at the same location.
    c. The density of softwood KD lumber varies with wood type and moisture content, but has been assumed to be 35 lb/ft^3 (The Engineering Tool Box).
    d. From the BOM, the total volume was determined to be 120.48 ft^3.
    e. It is assumed that the lumber would be sourced locally from Arnot Building Supply, which sources its lumber from Ontario, Canada (by road) at an average transportation distance of 700 miles.
        i. *Transport, combination truck, diesel powered/US*.

3. Plywood
    a. *Plywood, at plywood plant, US SE/kg/US*
    b. The weight per square foot of ½” plywood has been determined to be on average 1.5 lb/ft^2 (APA, 2011). This plywood is typically used as sheathing in the B-hut’s walls. This provides a density of approximately 36 lb/ft^3. This density has been used for 5/8” (roof) and ¾” (floor) plywood as well.
    c. From the BOM, there is a total of 4,428 pounds of plywood in the B-Hut (1/2” = 1,579 pounds; 5/8” = 1,665 pounds; 3/4” = 1,184 pounds).
    d. Transportation to packaging site.
        i. 1,000 mile transportation distance has been assumed

4. Fasteners
    a. Nails
        i. The following SimaPro processes were used to represent the material and processing inputs
            1. *Iron and steel, production mix/US*
            2. *Zinc, sheet/GLO*
                a. Only used in the galvanized nail process
            3. *Cold impact extrusion, steel, 1 stroke/RER U*
                a. The actual manufacturing process does not exist in SimaPro. Since the fasteners are relatively trivial in comparison to the whole structure, using the incorrect process will have negligible effects on the analysis.
        ii. Transportation to the fastener manufacturing plant and then to the container packaging site was assumed to be 1,000 miles.

5. Galvanized Steel Brackets
    a. Joist Hangers and Rafter Ties
        i. The following SimaPro processes were used to represent the material and processing inputs
            1. *Iron and steel, production mix/US*
            2. *Zinc, sheet/GLO*
            3. *Cold impact extrusion, steel, 4 strokes/RER U*
        ii. Transportation to the fastener manufacturing plant and then to Murus was assumed to be 1,000 miles.
        iii. From the BOM, there are a total of 12.2 pounds of joist hangers and 7.3 pounds of rafter ties per B-Hut.

6. Metal Exterior Man-Doors
    a. *Door, outer, wood-aluminum, at plant/RER U*
    b. Due to variability in door type, it is assumed that this typical aluminum sheathed wooden core door may be used. Even if this process is not completely

representative of the actual doors being used, they are equivalent for each option, so it will not greatly affect the results of the analysis.

   c. The SimaPro process includes the door, steel door frame, and installation at site. It does not include transportation to site.
   d. The transportation distance to the packaging site (Mansfield, PA) has been estimated to be 500 miles. The following process was considered for this transportation.
      i. *Transport, combination truck, diesel powered/US*
   e. The Ecoinvent door process that was used was in area units, so it was necessary to create a new process that was in mass units in order for the doors to be considered in the disposal scenario. This process was labeled "*Door, outer, wood-aluminum, at packaging site.*" This process converts the door area to mass at a rate of 102 pound per 20.25 square feet (this is representative of one 3' x 6'-9" door). It also includes the transportation to the packaging site.

11.7.2. Transportation to Afghanistan

1. The B-Huts are being assumed for analysis purposes to be containerized in Mansfield, PA with all components (including foundation, structure, doors, trim, HVAC, and electrical). Comparing the total weight and volume of the B-Hut materials with container capacities, 5 B-Huts will be able to be packed for shipping in one 40' HC shipping container. After all the components arrive in Mansfield, PA, they will be packed into the containers.
   a. The shipping of HVAC and electrical components to Mansfield, PA for containerizing has not been included in the analysis due to lack of data. This will have a negligible impact of the accuracy of the analysis, because this shipping operation would be approximately equal for both the SIP-Hut and B-Hut.
2. From Mansfield, PA the containers of B-Huts will be shipped, by road, a distance of 260 miles to the New York Container Terminal in Staten Island, NY. Transportation was tracked in miles (mi). Since it is known that exactly 5 B-Huts will fit in one standard 40' shipping container, and each truck will be carrying one container, the transportation distance that is attributed to each B-Hut is one-fifth of the truck transportation distance.
   a. *Transport, combination truck, diesel powered, mi*

3. In Staten Island, NY the containers will be loaded onto an ocean freighter and shipped (via sea) approximately 9,176 miles to the Port of Qasim in Karachi, Pakistan. Each standard 40’ shipping container weighs 8,000 pounds empty (Conex, 2013). Each B-Hut weighs 10,754 pounds with all materials and equipment. The total (gross) weight of one shipping container with 5 B-Huts has been determined and rounded up to 62,000 pounds. The max gross weight of a standard 40’ Conex shipping container is 67,200 pounds, so this is acceptable (Conex, 2013).
    a. In order to account for the impacts associated with shipping the B-Hut it was necessary to develop a process that was not in units of ton-miles. The SIP-Hut’s low density requires it to be shipped in more containers than the B-Hut for a similar weight. This difference would not be able to be accounted for in a process that uses ton-miles. The following USLCI process was modified to be in units of miles instead of ton-miles: *Transport, ocean freighter, residual fuel oil powered/US*. The fuel consumption per mile (per 40’ container) was approximated to be 0.0211 gallons per mile (47.4 mpg). Therefore the new process assumes a fuel consumption of 0.0211 gallons (of residual fuel oil) per 40’ container (FEU) mile. This process has been labeled as: *Transport, ocean freighter, residual fuel oil powered/US, FEU mi.*
4. From the Port of Qasim, the containers will be loaded onto trucks and shipped via road (with US gun-trucks as escorts, 4:1 ratio of shipping trucks to gun-trucks) to the FOB. In this case, the FOB is being assumed to be in Kandahar, Afghanistan, requiring a transportation distance of 575 miles. The round trip distance has been considered in this analysis because separate return cargo is unlikely. A 20% reduction in fuel consumption has been assumed for the return trip due to increased fuel economy. Therefore the return distance has been reduced by 20%. The round trip distance being used for analysis purposes is 1035 miles (575 miles + 575*0.80 miles). The transportation distance attributed to each B-Hut is one-fifth of the round trip distance, 207 miles.
    a. *Transport, combination truck (w/ gun-truck escort), diesel powered, mi*
        i. *Transport, combination truck, diesel powered, mi*
            1. This process assumes a fuel economy of 5.9 mpg (Winebrake, 2012).

ii. *Transport, gun-truck escort (humvee), diesel powered, mi*
1. This process assumes a fuel economy of 10 mpg (Hoy, 2008).

11.7.3. Construction

1. The construction phase has been represented in SimaPro by the running a 5 kW generator at full load during the entire construction process, determined to be 19 hours.
   a. *Electricity, diesel, at FOB, burned in generators, kWh*
   b. Electricity consumption = 19 hours * 5 kW = 95 kWh
   c. The efficiency of the generator is assumed to be 27.5%

11.7.4. Use

1. The estimated electricity usage of a single B-Hut is 18,820 kWh/year (Leemans, 2013).
2. A SimaPro process was created to represent the electricity production using a typical FOB generator. This process assumes a conversion efficiency of 10 kWh per 1 gallon of fuel (27.5% generator efficiency) (TROPEC, 2014). It also assumes 1,000 miles of transportation to get the diesel fuel to the FOB, the same transportation process that was created for the B-Hut shipment was used here (*Transport, combination truck (w/ gun-truck escort), diesel powered, mi*). The fuel capacity of the tanker trucks was assumed to be 6,000 gallons. In order to determine how many miles of truck transport to attribute each kWh of electricity the following calculation was performed:
   a. (0.10 gallons/kWh) / ((6,000 gallons/trip) / (1,000 miles/trip)) = 0.01667 miles/kWh

11.7.5. End of Life

1. The B-Huts are being assumed to be landfilled at the end of their life. No environmental effects from demolition efforts have been considered. Transportation to the landfill has been assumed to be by means of a typical combination truck (*Transport, combination truck, diesel powered/US*). The distance to the landfill site has been assumed to be 100 miles. The total material weight of one B-Hut (excluding electrical and HVAC, which is

assumed to be recovered) is 9,913.6 pounds. This produces 496 ton-miles (tmi) of transport for one B-Hut (4.96 tons * 100 miles = 496 tmi).

2. The SimaPro processes used to account for the end of life landfilling are as follows:
    a. *Disposal, wood untreated, 20% water, to sanitary landfill/CH U*
        i. Wood is 9370.5 pounds, 94.52%
    b. *Disposal, steel, 0% water, to inert material landfill/CH U*
        i. Steel is 320.9 pounds, 3.24%
    c. *Disposal, concrete, 5% water, to inert material landfill/CH U*
        i. Concrete is 222.2 pounds, 2.24%
3. Although the landfill conditions may vary between the ones represented by these processes and the ones present at a rudimentary landfill in Afghanistan, it is being assumed that the processes are representative. End of life impacts of the B-Hut are minimal compared to the rest of its lifecycle, so slight inaccuracy should have a negligible impact on the validity of the analysis.