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# THESIS

**COST BENEFIT ANALYSIS OF INTEGRATED COTS ENERGY-RELATED TECHNOLOGIES FOR ARMY'S FORCE PROVIDER MODULE**

by

Allen Rivera

September 2009

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This study evaluates the capability of several energy efficient and renewable technologies that will potentially improve the operational readiness of the current Army expeditionary shelter system. The two major motivations of this objective are decreasing the shelter's heavy dependence on generator use and lessening the tactical vulnerabilities in operating the systems in austere environments. Furthermore, this study determines whether a portfolio of these commercial-off-the-shelf (COTS) technologies is a good financial decision and estimates its return on investment (ROI).

The results of this analysis found that the technologies associated with improving insulation of deployable shelters systems have the most profound effect in reducing overall generator fuel consumption. One of the largest consumer of generator-produced power is the environmental control units that provide the air conditioning and heating needs for expeditionary field shelters. The insulations evaluated in this study have high annualized returns on investments and payback periods of less than two years.

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# COST BENEFIT ANALYSIS OF INTEGRATED COTS ENERGY-RELATED TECHNOLOGIES FOR ARMY'S FORCE PROVIDER MODULE

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# ABSTRACT

This study evaluates the capability of several energy efficient and renewable technologies that will potentially improve the operational readiness of the current Army expeditionary shelter system. The two major motivations of this objective are decreasing the shelter's heavy dependence on generator use and lessening the tactical vulnerabilities in operating the systems in austere environments. Furthermore, this study determines whether a portfolio of these commercial-off-the-shelf (COTS) technologies is a good financial decision and estimates its return on investment (ROI).

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# EXECUTIVE SUMMARY

The Net Zero Plus Joint Concept Technology Demonstration (JCTD) is an initiative by the Army's Rapid Equipping Force (REF) to make forward operating bases (FOB) and remote tactical units as energy independent as possible from power generation. The Net Zero JCTD will model, measure and assess a variety of commercial-off-the-shelf (COTS) technologies that could collectively consume less energy than they provide. The results of the demonstration will determine which, if any, of these technologies should be recommended for inclusion in sustainable design efforts in DoD installations and tactical bases. The emphasis is on replacing temporary billeting, administrative, and operational facilities with enduring energy efficient structures (E3S) and integrating renewable energy technologies with improved energy generation to power those structures. From an operational perspective, a logical area for design improvement in a temporary FOB is the United States Army Force Provider—the Army's Premier Base Camp.

There are several commercial-off-the-shelf (COTS) energy related technologies identified by U.S. Army Soldier Systems Center Natick as promising candidates for integration in the current Expeditionary Force Provider system. This study determines if the energy efficient configuration produces statistically significant differences in energy consumption, compared to the currently deployed shelters. Furthermore, this study determines whether a portfolio of COTS energy efficient and renewable technologies is a good financial decision and estimates its return on investment (ROI).

The results of this analysis found that the technologies associated with improving insulation of the shelter systems had the most profound effect in reducing overall generator fuel consumption. Because 40% of the power produced by the Force Provider generators is consumed by the shelter's environmental control unit, applying technologies that reduce the air conditioning and heating power requirements yields the best return on investment. The following is the summarized results of the business case analysis:

Economic Analysis Summary

| Technology | Annualized ROI | Payback Period |
|---|---|---|
| **ULCANS** | 7.2% | 5.4 years |
| **TEMPER Liner** | 24.3% | 2.0 years |
| **Aerogel** | 40.4% | 1.1 years |

Aspen Aerogel insulation has the highest annualized ROI among the three strongest technology candidates and has a payback period of about one year. This means that if actual findings show that Aerogel reduces the Environmental Control Unit (heating, ventilation and air-conditioning) power requirements by 50%, this technology gives the largest return on benefits (in terms of energy savings only) as compared to the other two candidates. The TEMPER Liner achieves an annualized ROI of 24.3% with a payback period of two years. Although the investment does not return as high as Aerogel, actual field data from the National Training Center Fort Irwin field demonstration reveals this technology's true performance with respect to energy savings. Ultra Light-Weight Camouflaged Net System (ULCANS) has the lowest annualized ROI of 7.2% and the longest payback period of 5.4 years. From a financial perspective, ULCANS is the weakest of the three top technology candidates.

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AMC | US Army Materiel Command |
| CASCOM | Combined Army Support Command |
| COTS | commercial-off-the-shelf |
| COP | Coefficient of Performance |
| E3S | enduring energy efficient structures |
| EFRK | Expeditionary Force Provider Kit Base Camp |
| FOB | Forward Operating Base |
| FP | Army Force Provider |
| JCTD | Joint Concept Technology Demonstration |
| LCCE | Life Cycle Cost Estimate |
| REF | Rapid Equipping Force |
| ROI | Return on Investment |
| SOF | Special Operating Forces |
| TEMPER | Tent Expandable Modular Personnel |
| TRADOC | U.S. Army Training and Doctrine Command |
| TSA | Theatre Support Areas |
| TQC | Tactical Quiet Generator |

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# I. INTRODUCTION

## A. PURPOSE

The objective of this study is to evaluate the capability of several energy efficient and renewable technologies that will potentially improve the operational readiness of the current Army expeditionary shelter system. The two major motivations of this objective are decreasing the shelter's heavy dependence on generator use, and lessening the tactical vulnerabilities in operating the systems in austere environments. Furthermore, this study determines whether a portfolio of these commercial-off-the-shelf (COTS) technologies is a good financial decision and estimates its return on investment (ROI).

This study develops a methodology for evaluating and analyzing the costs and benefits of several demand reduction and renewable technologies in support of the energy requirements of deployable Army forces. U.S. Army Soldier Systems Center Natick is taking a holistic approach by identifying promising energy efficient, renewable, and power distribution technologies that enhance the current Force Provider module. This research specifically addresses these technologies by examining the level of value added in terms of energy savings and reduction of the fuel required to support a Force Provider.

Energy security is a prominent issue in today's world of volatile energy prices and increased reliance on foreign countries for energy needs. In response, the U.S. Army is currently engaged in making its force more energy efficient in order to increase strategic responsiveness while reducing logistical support requirements. Through the adoption of new energy policies, procedures and initiatives, the U.S. Army is responding to the challenges of reducing fossil fuel consumption and augmenting renewable sources in support of the energy needs of deployable forces.[1]

[1] Department of the Army, Army Energy Program, *Army Energy Security Implementation Strategy (AESIS)*, January 2009.

The Net Zero Plus Joint Concept Technology Demonstration (JCTD) is an initiative by the Army's Rapid Equipping Force (REF) to make forward operating bases (FOB) and remote tactical units as energy independent as possible from power generation.[2] The Net Zero JCTD will model, measure and assess a variety of commercial-off-the-shelf (COTS) technologies that could collectively consume less energy than they provide. The results of the demonstration will determine which, if any, of these technologies should be recommended for inclusion in sustainable design efforts in DoD installations and tactical bases. The emphasis is on replacing temporary billeting, administrative, and operational facilities with enduring energy efficient structures (E3S) and integrating renewable energy technologies with improved energy generation to power those structures.[3] From an operational perspective, a logical area for design improvement in a temporary FOB is the United States Army Force Provider—the Army's Premier Base Camp.

[2] H. Ong, "Conducting a Business Case Analysis for Net Zero Plus—Joint Concept Technology Demonstration (JCTD)," (Master's thesis, Naval Postgraduate School, 2007).

[3] R. Trahan, Jr., "Geothermal HVAC Systems—A Business Case Analysis for Net Zero Plus," (Master's thesis, Naval Postgraduate School, 2009).

## B. ARMY FORCE PROVIDER OVERVIEW

### 1. Description

Figure 1. The seven billeting facilities in the Expeditionary Force Provider Kit are mission essential for the 585th Engineer Company at Forward Operating Base Logar. (From U.S. Army, 2007)

The Army Force Provider (FP) is a transportable base camp system that provides housing and operation space for a variety of military missions ranging from support of a small military outpost to fully operational, forward deployed base camps and airbases. The FP is often referred to as a “city in a box” with a hybrid of military and commercial products that provide climate-controlled billeting, quality dining facilities, hygiene services and morale, welfare and recreation facilities for deployed troops. A typical FP module has a capacity to support 550 personnel and 50 operators (either civilian or military). The basic building block is the Tent Expandable Modular Personnel (TEMPER), each with a dedicated environmental control unit. The size of FP camps can vary to accommodate anywhere form 150 soldiers, in a single Expeditionary Force Provider Kit Base Camp (EFPK), up to 3,600 soldiers in support of a Brigade

Combat Team, with an interconnected system of typical FP modules. The FP module comes complete with water and fuel storage, power generation and distribution, and wastewater collection sub-systems. Furthermore, they are containerized and preconfigured to facilitate convenient transport from any combination of land, air and sea mode.

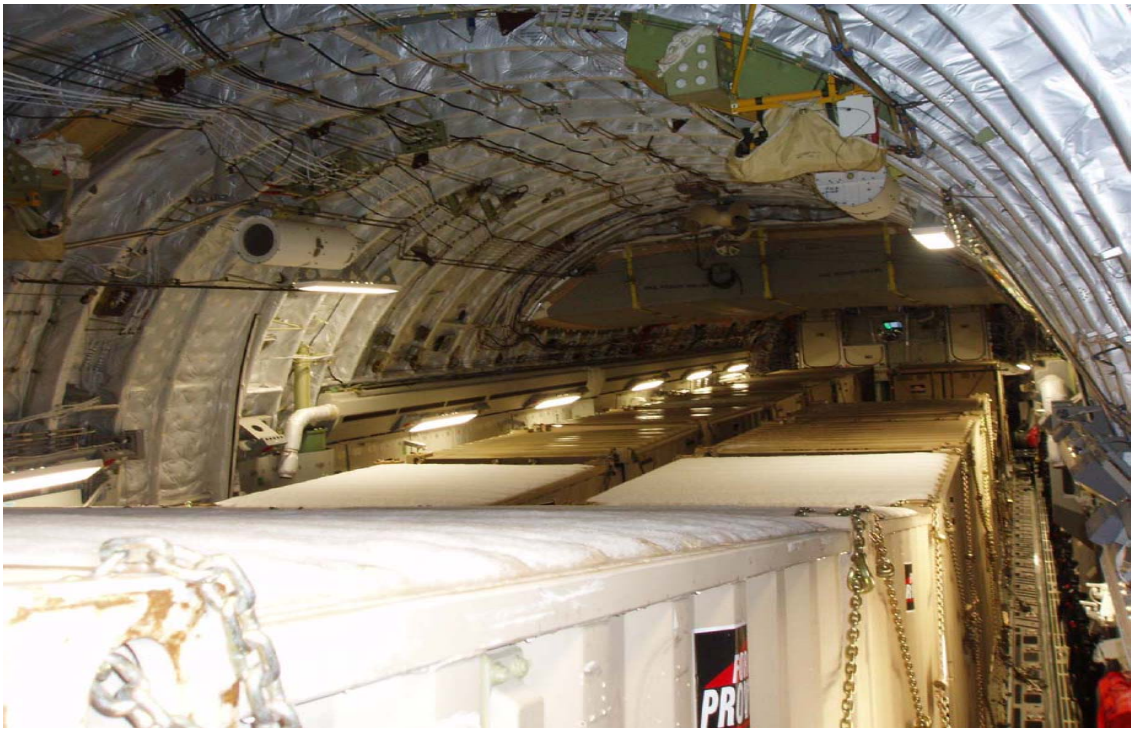


Figure 2. A complete EFPK Base Camp on one C-17 aircraft (18 pallet positions). Photo courtesy of Sustainment Division Materiel Systems Directorate Combined Army Support Command (CASCOM) November 2008.

### 2. History and Background

Operation Desert Shield and Desert Storm revealed the lack of emphasis by the United States Army on field facilities and shelters. Unlike the Air Force, the Army did not have enough tents to meet its operational needs. Consequently, to meet the immediate requirements, the Army purchased and deployed highly complex and costly equipment, which did not provide adequate protection from the harsh climate. Some of these emergency procurements included festival tents, clamshell buildings, sprung structures, and K-Span structures. In July 1991, after Desert Storm and under the direction of Army Chief of Staff General Gordon R. Sullivan, the Army FP concept was established to improve soldiers' living conditions in austere environments.[4] The responsibility to develop the concept was delegated to the U.S. Army Training and Doctrine Command (TRADOC) and the US Army Materiel Command (AMC). In November 1991, the project was assigned to TRADOC's U.S. Army Quartermaster Center and School (USAQMC&S) at Fort Lee, VA, and to AMC's Research, Development and Engineering Center in Natick, Massachusetts.

The primary and overarching mission of the Force Provider is to provide support for "rest and refit" to soldiers operating in forward deployed conflict zones. More specifically, the FP was originally designed to improve the soldiers' combat readiness by providing them a brief rest from combat. However, even at its inception, the FP has sustained "mission creep" and its deployment is used in a multitude of missions including:

1) Reception location for personnel entering/exiting theatre of operations;
2) Staging base for units transitioning to operational areas;
3) Temporary facilities supporting natural disaster and humanitarian relief efforts;
4) Military command for peacekeeping and enforcement operations.[5]

The versatility of Force Provider offers operational commanders flexibility in planning force movements in and between theater operational areas regardless of mission type.

The Army's need for an expeditionary FP system in support of the Global War on Terrorism led to a re-design and the development of the 150+ soldier

[4] GlobalSecurity.org, "Force Provider (FP)," n.d., http://www.globalsecurity.org/military/systems/ground/force-provider.htm.

[5] C. Correia et al., "The Challenges Associated with Accounting for the Army's Force Provider (FP) System when Deployed in Support of Military Operations" (Master's thesis, Naval Postgraduate School, 2008).

Expeditionary Force Provider Kit Base Camp (EFPK) in 2007. Mobile units operating in hostile and austere environments, particularly in Iraq and Afghanistan, require the ability to rapidly deploy and employ capability to an operational area without the increased burden of sustaining a large logistical footprint. Unlike the legacy FP design, the new Expeditionary FP system requires days (versus weeks) to set up and needs significantly less maintenance, fuel and manpower to sustain it in an operational environment. The application of Vertigo Inc. AirBeam technology to TEMPER tents has also improved the deployability of shelter systems. This technology replaces the traditional aluminum tent framing with braided or woven high-strength, three-dimensional fabric sleeves over air bladders.[6] Nevertheless, the overall mission for both the original FP and the Expeditionary FP (along with its EFPK Base Camp) has remained relatively constant.

### 3. Components and Capabilities

A current FP 600+ soldier camp system consists of 4 EFPK Base Camp kits, 1 Kitchen Complex kit, 1 Administrative kit, 1 Waste Water (WW) kit, and 1 Morale, Welfare and Recreation (MWR) kit. There are over 38,000 line items within this integrated collection of major and subcomponents with an acquisition cost of over $6.64M (FY08).[7] Additionally, there are two primary add-on kits available: the Cold Weather kit ($1.52M FY08) and the Prime Power kit. The cold weather kit provides additional heating capability into the billeting, administrative and MWR facilities when operating at temperatures below 32 degrees Fahrenheit. The prime power kit is designed to connect to a host nation power source and minimizes the need to rely on the many tactical generators that would otherwise be used to provide electricity to the camp.

[6] Airbeam by Vertigo, "Airbeams & Shelter Programs," Vertigo Inc., http://www.vertigo-inc.com/airbeams/.

[7] Luz H. Diaz, Project Director. APM Force Provider, *EFP Model Buy Report*, November 2008.

The overall FP interchangeable modular design allows customers to tailor their base camp system to meet their specific operational requirements. Furthermore, each major subcomponent offers stand-alone functionality, and if necessary, the components can be deployed independently versus deploying the entire system. This provides added flexibility to the customer while enhancing the system's transportability. When deployed an Expeditionary FP 600+ soldier camp system can provide the following services to the tenant unit:

(1) Climate-controlled billeting for 550 tenant personnel plus 50 billets for FP operators using Air Beam TEMPER tents.

(2) Sanitary climate-controlled showers sufficient for 10-minute showers per person/per day.

(3) Eight climate-controlled latrines with 4 commercial toilets and 2 urinals each.

(4) Food services including cooking and dining facilities that include three cook-prepared meals daily (1,650 meals per day).

(5) Laundry services capable of laundering 200 pounds per hour.

(6) MWR, medical, chaplain, and administrative support facilities and equipment.

Its flexibility and capabilities make the Expeditionary FP system ideal for operating environments from Theater Support Areas (TSA) to employment as far forward as the Brigade Combat Team. It can even perform the role of a temporary Forward Operating Base (FOB) for contingency operations that do not require an extensive operational timeframe.

## C. RESEARCH QUESTIONS

There are several commercial-off-the-shelf (COTS) energy related technologies identified by U.S. Army Soldier Systems Center Natick as top candidates for integration in the current Expeditionary Force Provider system. More specifically, the technologies will provide several enhancements to the soldiers' billeting and administrative TEMPER tent structures. The potential benefits of installing these technologies include:

- lowering the tent system's energy demand through efficient lighting and effective insulation,
- correctly identifying the energy consumption for optimal power distribution, and
- supplementing the system's energy supply with flexible photovoltaics.

This study determines if the energy efficient configuration produces statistically significant differences in energy consumption, compared to the currently deployed shelters. Furthermore, this study determines whether a portfolio of COTS energy efficient and renewable technologies is a good financial decision and estimates its return on investment (ROI). The work is done in conjunction with the National Training Center Fort Irwin field demonstration.

# II. BACKGROUND

> An area of particular interest is energy—which is essential to military operations. Our in-theater fuel demand has the potential to constrain our operational flexibility and increase the vulnerability of our forces. Thus, your Armed Forces continue to seek innovative ways to enhance operational effectiveness by reducing total force energy demands. We are also looking to improve energy security by institutionalizing energy considerations in our business processes, establishing energy efficiency and sustainability metrics, and increasing the availability of alternative sources.

**Posture Statement of Admiral Michael G. Mullen, USN,**
**Chairman of the Joint Chiefs of Staff**
**—Senate Committee on Armed Services, May 2009**

## A. DEPARTMENT OF DEFENSE ENERGY FACTORS

The U.S. Department of Defense continues to be the single largest energy consumer in the world. According to the U.S. Department of Defense FY2008 Annual Energy Management Report, the delivered energy consumption for that year was 889 trillion British thermal units (BTU).[8] In 2007 and 2006, it was 865 trillion BTU and 832 trillion BTU, respectively. This translates to an approximate 2.8% increase from last year and 6.9% increase from two years ago. Almost 75% of site delivered energy was consumed by tactical vehicles, 23% by buildings and other structures, and the other 2% by exempt facilities and non-tactical vehicles. DoD consumption by energy type has not changed much in the last few years and Figure 3 illustrates the FY2008 allocation. The three main allocations were aviation fuel and all other petroleum products at 76%, electricity 11%, and natural gas at 8%.

[8] Department of Defense, Office of the Deputy Under Secretary of Defense (Installations and Environment), *Annual Energy Management Report, Fiscal Year 2008*, January 2009.

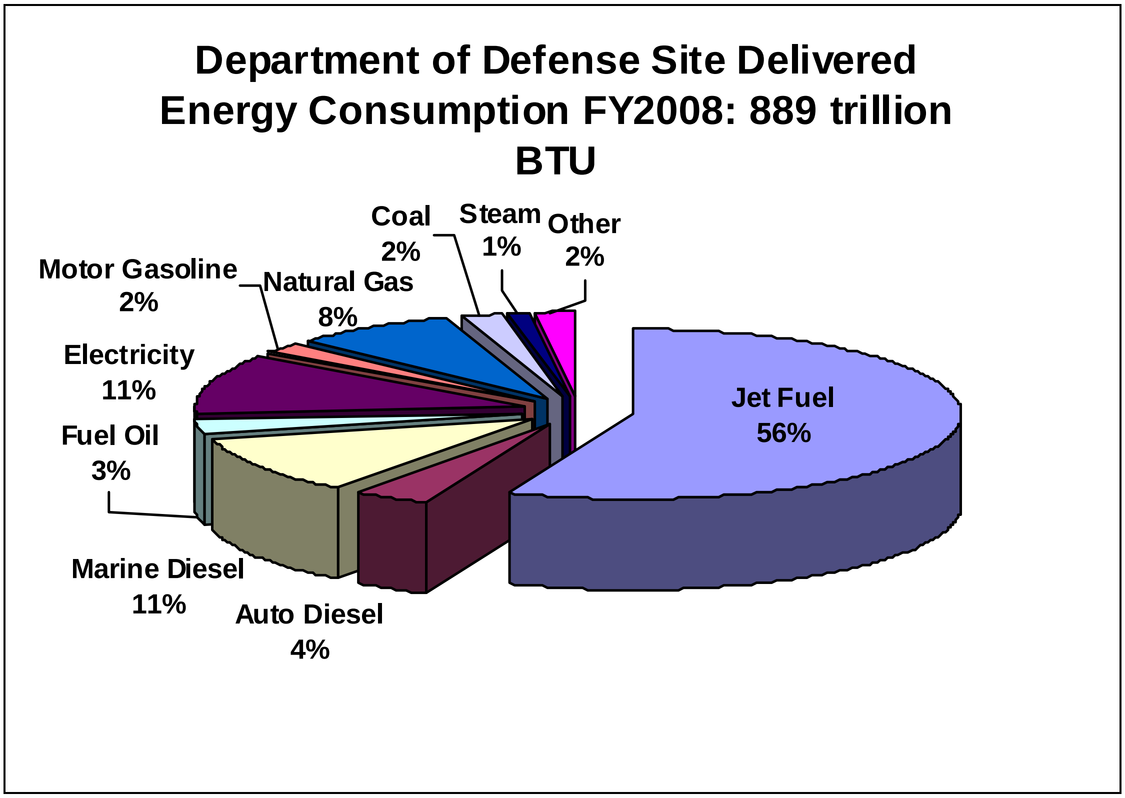



Figure 3. Delivered energy consumption. Data from DOD FY2008 Annual Energy Management Report.

In 2006, the Department of Defense spent $13.6 billion to buy over 110 million barrels of petroleum fuel (about 300,000 barrels/daily), and $3.8 billion kWh of electricity.[9] Compared to 2008, DOD spending increased to $16.5 billion for fuel (about 350,000 barrels/daily), but decreased to $2.5 billion kWh of electricity.[10] The decrease in electricity expenditure (usage measured in BTU/sq ft) was mainly due to the closures of inefficient buildings and structures, increased energy conservation initiatives for existing and new facilities, and increased energy supply from renewable sources.[11] Although these figures

[9] Department of Defense, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on DoD Energy Strategy: "More Fight—Less Fuel,"* February 2008.

[10] Department of Defense, *Annual Energy Management Report, Fiscal Year 2008,* 2009.

[11] Alan R. Shaffer, Principal Deputy Director OSD/DDR&E, "OSD Latest Initiatives in Alternative Energy" (keynote address, Alternative Energy for Defense Conference, Vienna, VA, June 24–26, 2009).

represent less than 2% of total U.S. energy consumption, they do account for approximately 78% of energy consumption by the Federal government.

Despite the long-growing trend of increased operational energy demand and consumption, energy security entails much more than just the direct cost of fuel. Even during current periods of seemingly low oil prices, energy remains important to warfighters because of a number of other dimensions. The energy consumed today affects the current maintenance budgets and program costs of future weapons systems. The increased logistics and distribution burden of energy resupply directly affects force security. Energy use influences operational commanders' ability to maneuver. Finally, consumption affects energy supply chain flexibility from potentially unreliable suppliers. All totaled, energy affects most aspects of the Department of Defense.

### 1. Energy Costs

#### *a. Direct Costs versus Fully Burdened Cost of Fuel*

There is an obvious and undeniable surge in energy demand during combat operations due to today's sophisticated and powerful weapon systems. However, according to the testimony of William M. Solis, Director of Defense Capabilities and Management, the "single largest battlefield fuel consumer is generators, which provide power for base support activities such as air conditioning, heating, lighting, refrigeration, and communications."[12] Simply looking at the effect of U.S. wartime OPTEMPO on Army power generation, generator fuel usage increases by a factor of 14, going from 26 million gallons during peacetime operations to 357 million gallons.[13] According to the Army's Project—Mobile Electric Power office, the Army uses more fuel on generators than on combat vehicles, aircraft, or any other tactical vehicle. A 60-kW generator consumes fuel at a rate of 4.5 gallons per hour for an annual total well

[12] Director William M. Solis, speaking for the Defense Capabilities and Management team, March 3, 2009, to the U.S. House, Committee on Armed Services, Subcommittee on Readiness.

[10] Department of Defense, *Report of the Defense Science Board Task Force on DoD Energy Strategy: "More Fight—Less Fuel,"* 2008.

over 39,000 gallons.[14] Therefore, if the purchase price for fuel were only $2.15, a single 60kW Tactical Quiet Generator (TQG) would have a direct fuel cost in excess of $84,000 annually to operate (assuming continuous operation). It is conceivable that a single Forward Operating Base, depending on its size and mission requirements, could require approximately 5,400 gallons of fuel daily. The direct cost to power the FOB annually through its associated generators, would be just under $5 million.

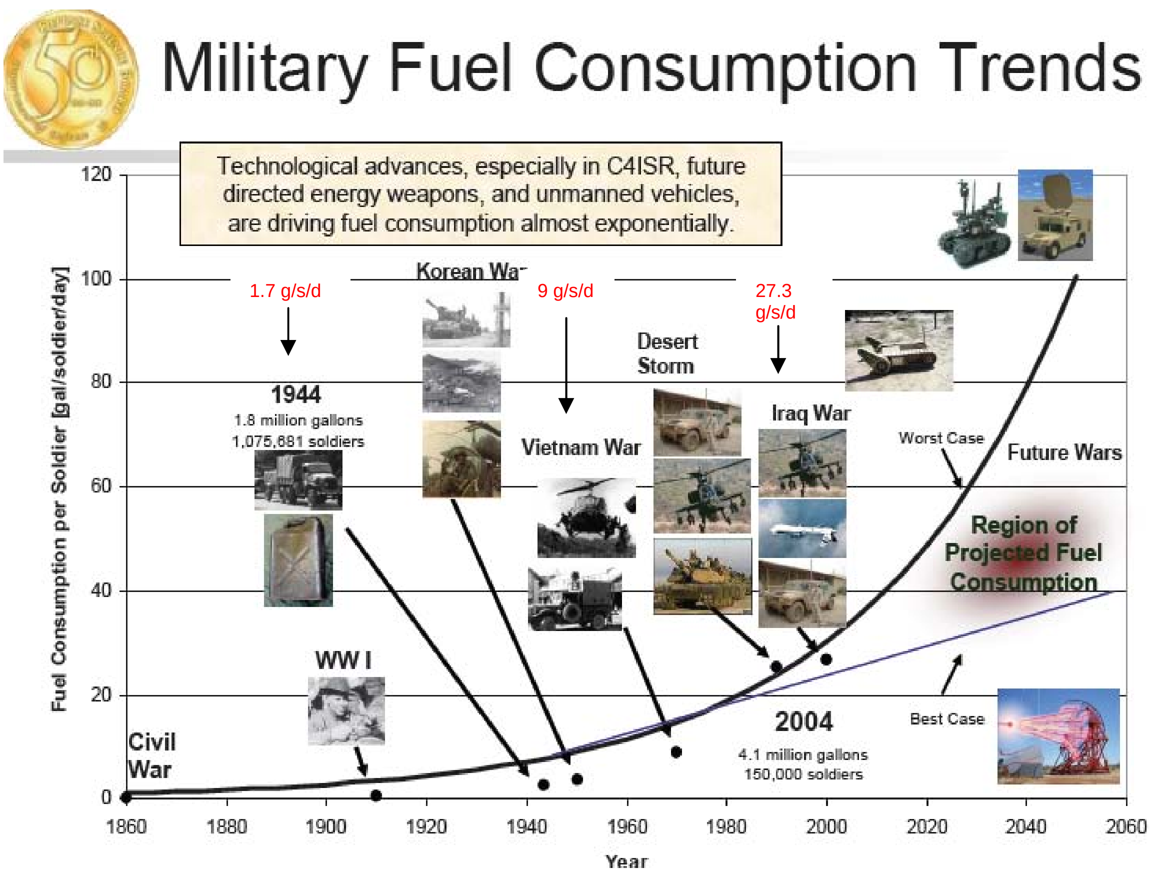



Figure 4. Added to the figure are estimates of average daily gallons of fuel consumed per soldier. (After Morehouse, 2008, 17)

[14] J. Cross and P. Richard, "Alternative Energy Strategies: Joint Stand Renewable Energy Mobile Power Generating Sources" (briefing, Pentagon, Arlington, VA, March 27, 2007).

At the tactical level, there also has been a tremendous boost in energy demand. Soldier systems with augmented high-powered electronics for improved communications, protection and combat effectiveness, have resulted in a higher density of batteries. As the dismounted soldier becomes more technologically sophisticated, batteries will further increase the weight and requirement for storage space. According to Natick Soldier RD&E (NSRDEC), approximately 15–20% of the total weight for today's soldier field pack is already comprised of batteries. The Marine Corps shares similar concerns from the increasingly heavier forces at the tactical level. Comparing USMC battalion force structures on September 11th, 2001 to their forces today, average radio density has increased from 175 to 1220 radios per battalion, 32 un-armored High Mobility Multipurpose Wheeled Vehicles (HMMWV) have been replaced by 55 armored HMMWV, and the 12 CH-46 helicopter squadron has transitioned to the higher consuming MV-22 Osprey.[15]

The direct cost of fuel has often received much of the attention and is the easiest to quantify. The U.S. military services, through the Defense Energy Support Center, buy fuel on the open market at a standard price. The standard price, unlike the marketplace price, is a fixed rate that provides the services and the Office of the Secretary Defense with budget stability. Despite commodity market swings, the market gains or losses are absorbed by a revolving fund called the Defense Working Capital Fund (DWCF).[16] The standard price is established well in advance of the fiscal year in which it is used, and is built by assembling the following blocks:

[15] Michael Gallagher, Program Manager-Expeditionary Power Systems, Marine Corps Systems Command, "Tactical Energy Needs: Marine Corps Tactical Renewable Energy Efforts" (briefing, Alternative Energy for Defense Conference, Vienna, VA, June 24-26, 2009).

[16] Defense Energy Support Center, http://www.desc.dla.mil/.

- A projection of the price of fuel 18 months in the future. (In the late fall, the standard price is determined for fuel that will be sold to our customers during the Fiscal Year. As an example, in the fall of 2009 the price is set that will be in effect from October 2010 through September 2011.)
- The budgeted cost of transporting, storing, and managing the government fuel system, including war reserve stocks, and some adjustment to these costs that reflects whether the revolving fund lost or gained money during the previous years.[17]

However, in the past decade, more emphasis has been placed on the Fully Burdened Cost of Fuel (FBCF), which is substantially more difficult to quantify. The 2001 DSB report "More Capable Warfighting Through Reduced Fuel Burden" found that the Department of Defense was systematically underestimating the true cost of supplying fuel to its battlespace forces because FBCF was not utilized. FBCF is the commodity price plus the total life-cycle cost of all people, assets and infrastructure required to move and protect fuel from the point of sale to the end user. As Chris DiPetto, Deputy Director Systems & Software Engineering OUSD (AT&L) explains, "FBCF takes into account all the indirect costs that consume a huge amount of resources and are often under-appreciated."[18] The indirect costs are sometimes referred as the "hidden" costs illustrated in Figure 5. As mentioned earlier, the costs incurred between Points A to D are included in the standard price DESC charges to its customer. Costs incurred after Point D are typically incurred by the military service through the support force structure they maintain, operate, and sustain.

[17] Defense Energy Support Center, http://www.desc.dla.mil/.

[18] Chris Dipetto, Deputy Director System & Software Engineering OUSD (AT&L), "Energy & Military Effectiveness: Energy Consideration in DoD Planning & Business Processes" (presentation, Alternative Energy for Defense Conference, Vienna, VA, June 24–26, 2009).

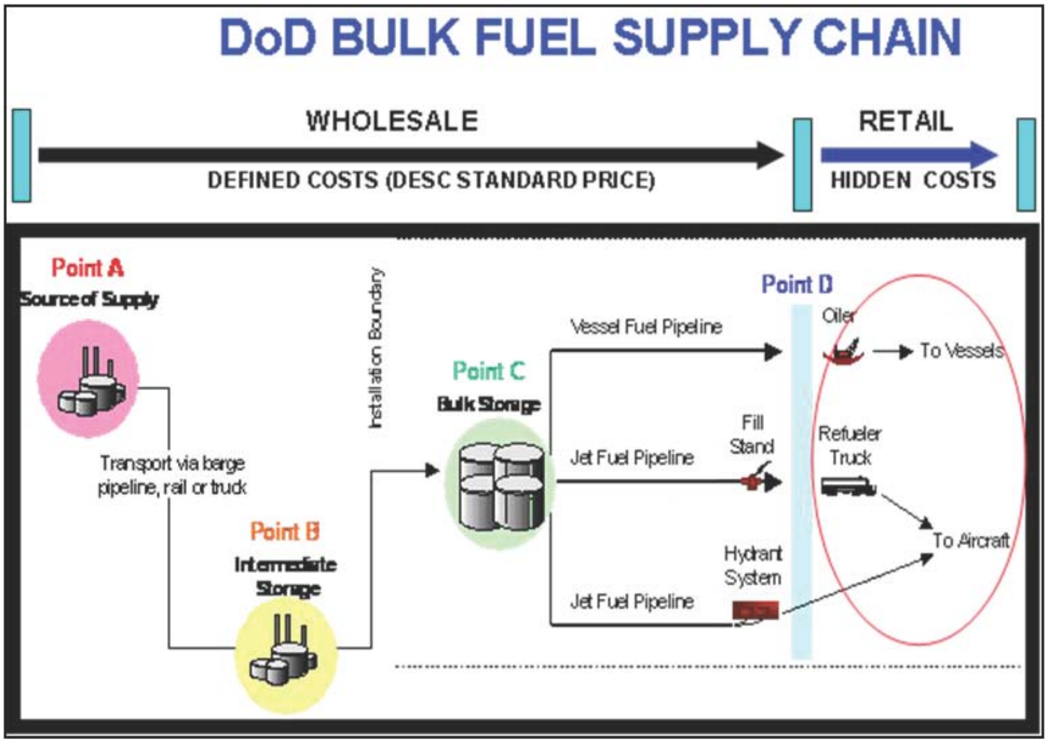



Figure 5. DoD Fuel Delivery Cost Responsibility. (From Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, February 2008, 15)

These "hidden" costs realized after Point D are absorbed by budgets not attributed to fuel. They include the total military ownership costs of transportation assets such as tanker aircraft, fuel trucks, oiler ships; and the personnel, repair parts, training and fuel to keep them operational.[19] Protection costs that assure delivery of fuel to the end user are also included. These are difficult to derive and often are not monetary costs, yet make up a significant portion of the Fully Burdened Cost of Fuel. They include physical security assets, contractor and military force protection and more ambiguous examples such as reduced combat effectiveness, risk to mission, and casualties.

Early estimates by the 2001 DSB, JASON (DOD scientific advisory board), OSD (PA&E), Institute for Defense Analyses and Service cost groups revealed

[19] Department of Defense, *Report of the Defense Science Board Task Force on DoD Energy Strategy: "More Fight—Less Fuel,"* 2008.

delivered costs for fuel to range from a low $4 per gallon for ships on the open ocean, $42 per gallon for in-flight refueling to several hundred dollars per gallon for combat forces and forward operating bases deep within combat zones. The Army has centralized its FBCF analysis function to its Sustain the Mission Project (SMP) I and II under the 2004 Army Strategy for the Environment (ASE). In 2006, SMP I developed an analytic methodology for calculating the fully-burdened costs of fuel resources to sustain Army missions in theaters of operation and the training base. Later on in 2008, SMP II developed a user-friendly alpha version decision support model for calculating the fully burdened costs of fuel using the SMP methodology and for evaluating energy technology investments. The SMP cost components include the material, personnel, commodity, transportation, and garrison resources needed to provide fuel and drinking water to sustain a Brigade Combat Team (BCT) in theater and training base missions as the SMP base case.

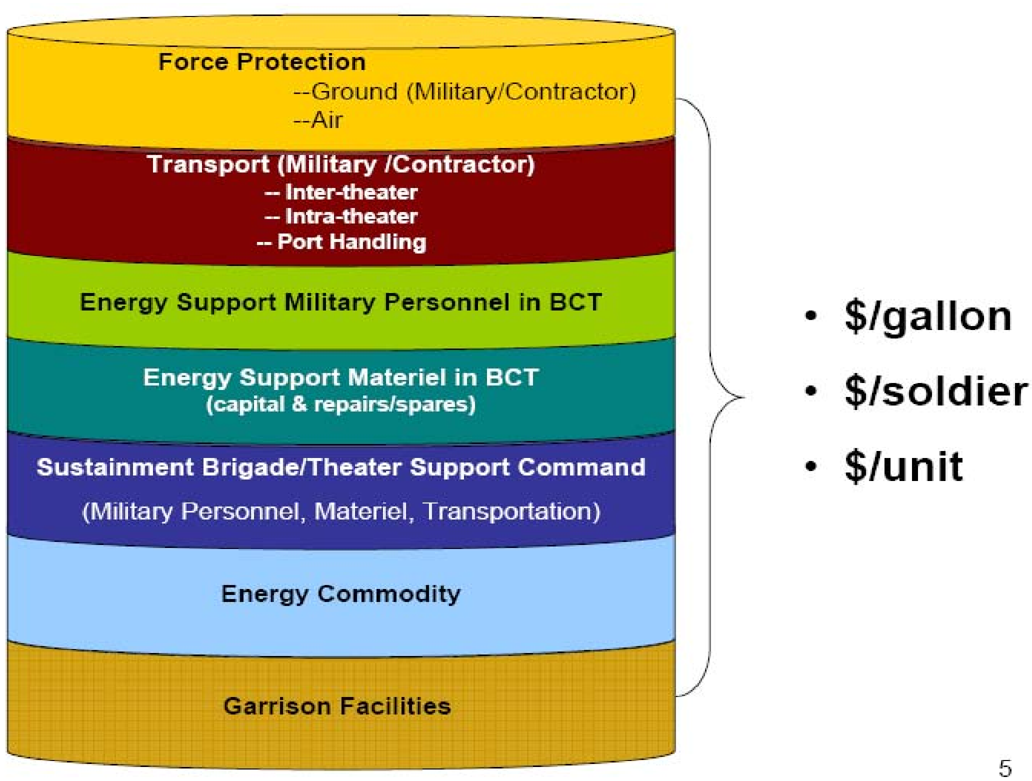



Figure 6. SMP Energy Costing Methodology: Cost Components. (From Siegel, August 2008, 5)

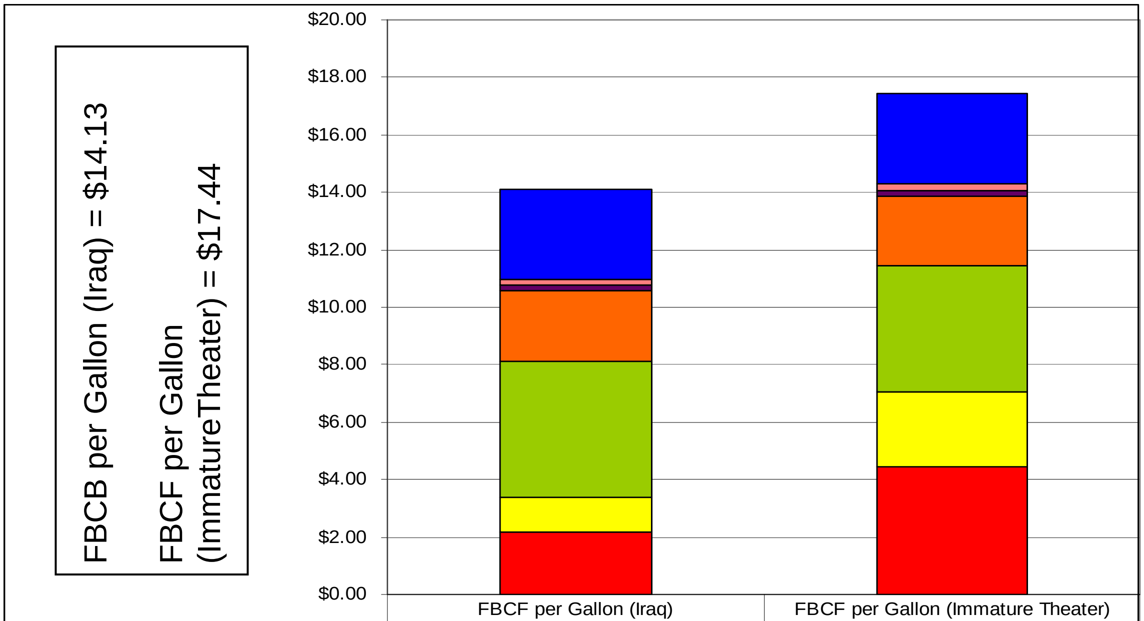
Some of the metrics the SMP II decision tool provides include payback period, net present value, estimated fuel savings, decreased transportation miles, and reduction in force protection assets and hours. It provides an opportunity to analyze the impact on FBCF with changes to numerous input parameters and initial assumptions provided by the Army G-4. A demonstration during the National Defense Industrial Association (NDIA) Fully Burdened Cost of Fuel Workshop on August 2008 compared the FBCF for a Stryker Brigade Combat Team (SBCT) in Iraq and in an immature base case scenario. The results illustrated in Figure 7 demonstrate a FBCF of $14.13/gallon in Iraq and $17.44/gallon in an immature theater (in FY08$).[20]

| Cost Components | Annual Cost Base Case | % of FBCF | $ Per Gallon |
|---|---|---|---|
| Force Protection (Air) | $ 5,163,788.99 | 15.5% | $ 2.19 |
| Force Protection (Ground) | $ 2,823,413.83 | 8.5% | $ 1.20 |
| Transport | $ 11,189,210.80 | 33.6% | $ 4.75 |
| Resupply | $ 10,564,739.00 | 31.7% | $ 4.48 |
| Initial Deployment | $ 579,656.31 | 1.7% | $ 0.25 |
| Relocation | $ 44,815.50 | 0.1% | $ 0.02 |
| Return | | 0.0% | $ - |
| Fuel Support Military Personnel in SBCT | $ 5,737,231.63 | 17.2% | $ 2.43 |
| Fuel Support Equipment in SBCT | $ 432,488.07 | 1.3% | $ 0.18 |
| Sustainment Brigade/TSC | $ 571,155.90 | 1.7% | $ 0.24 |
| Fuel Commodity | $ 7,402,829.15 | 22.2% | $ 3.14 |

| Summary Statistic | Value |
|---|---|
| FBCF Annual Cost for SBCT | $ 33,320,118 |
| Annual Gallons Consumed by SBCT | 2,357,589 |
| FBCF per Soldier | $ 8,389 |
| FBCF per SBCT | $ 33,320,118 |
| FBCF per Gallon | $ 14.13 |

Figure 7. Base Case FBCF in Theater (Iraq) FY08$. (From Eady, 2008, 8)

[20] David S. Eady et al., Army Environmental Policy Institute, *Sustain the Mission Project: Energy and Water Costing Methodology and Decision Support Tool*, July 2008.




| | FBCF per Gallon (Iraq) | FBCF per Gallon (Immature Theater) |
|---|---|---|
| Fuel Commodity | $3.14 | $3.14 |
| Sustainment Brigade/TSC | $0.24 | $0.24 |
| Fuel Support Equipment in SBCT | $0.18 | $0.18 |
| Fuel Support Military Personnel in SBCT | $2.43 | $2.43 |
| Transport | $4.75 | $4.41 |
| Force Protection (Ground) | $1.20 | $2.60 |
| Force Protection (Air) | $2.19 | $4.43 |

Figure 8. FBCF comparison using FY08$. (From Eady, 2008, 12)

### 2. National Energy Security

From a national security perspective, energy security is complex in that the associated risks the U.S. faces from its oil energy dependence are widely diverse and continuously intensifying. It is important to briefly discuss some of the major threats that could directly or indirectly undermine U.S security and prosperity. However, the primary focus of this study is to address energy security factors at the operational battlefield. These factors are discussed in the following section.

#### *a. Stability of Oil Supply*

The Energy Information Administration (EIA) states that the United States imported about 58% of the petroleum (crude oil and all petroleum products combined) that it consumed in 2007.[21] The organization, which provides official energy statistics form the U.S. government, points out that about half of these imports come from the Western Hemisphere (mostly from Canada, Mexico and Venezuela). However, close to 44% (or roughly the other half of petroleum imports) come from OPEC countries and African countries. From a geo-strategic perspective, a majority of countries exporting oil are far from free, democratic and stable (e.g., Saudi Arabia and Iraq), are hostile to the United States (e.g., Venezuela and Algeria) and are corrupt or fragile (e.g., Nigeria). The susceptibility to internal vulnerabilities and external threats of some of these countries has a significant impact to the stability of U.S. supply sources.

#### *b. Resource Depletion*

There have been numerous studies conducted to estimate the point in time at which roughly half of the extractable oil on the globe has been used and further production enters terminal decline. This point in time is often referred as peak oil or “Hubbert’s peak”. The theory is named after American geophysicist Dr. M. King Hubbert with Shell Oil, who created a method of modeling the production curve given an assumed ultimate recovery volume. His prediction of when U.S. oil production would peak was relatively accurate. However, Hubbert’s prediction in respect to ultimate U.S. oil production was inaccurate due to his initial assumptions of technology advances and oil prices.[22] There have been recent studies like Dr. Robert L. Hirsch 2005 study for the Atlantic Council entitled “Peaking of World Oil Production: Impacts, Mitigation, and Risk Management” and the Government Accountability Office 2007 study called “Uncertainty about Future Oil Supply Makes it Important to Develop a Strategy

[21] Energy Information Administration, *How dependent are we on foreign oil?* May 2008.

[22] Kenneth S. Deffeyes, *Beyond Oil: The View from Hubbert’s Peak* (New York: Hill and Wang, 2005).

Addressing a Peak and Decline in Oil Production". Both of the studies concluded projected global peak oil between 2006 to approximately 2025 [23] and between today and 2040[24], respectively.

### *c. Energy as a "Weapon"*

Outside the context of conventional warfare, denial of energy is becoming an economic weapon of choice for those countries that possess it. The effects of this kind of weapon are less lethal than military force; nevertheless, the economic impact is immediately profound and long lasting.[25] Although oil and natural gas embargos are not new, there has been a recent interest by several countries in leveraging their interests against import-dependent nations. Iran, which exports to the U.S.'s European and Asian allies, has threatened to use the "oil weapon" to retaliate against efforts to deter the country's nuclear program in recent years. Similarly, Hugo Chavez has issued threats of an oil export embargo against the United States if economic sanctions are imposed on Venezuela. Russia's growing regional assertiveness can be associated to the leverage it enjoys because of its oil and gas resources. Russia's denial of natural gas into Ukraine in the winter of 2006 in order to force them to pay higher prices had devastating effects, not only on Ukrainians but also on several energy dependent countries throughout Europe.

### *d. Geopolitics*

Energy imbalances are allowing regimes in countries that are rich in oil and natural gas to avoid democratic reforms, and insulate themselves from

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[23] R.L. Hirsch, R.H. Bezdek, and R.M. Wendling, *Peaking of World Oil Production: Impacts, Mitigation and Risk Management*, DOE NETL, February 2005.

[24] GAO Report to Congressional Requesters, *Crude Oil: Uncertainty about Future Oil Supply Makes it Important to Develop a Strategy Addressing a Peak and Decline in Oil Production*, February 2007.

[25] Edward Morse and Gal Luft, "Oil and Politics, Thirty Years after the Arab Oil Embargo" (address, The Washington Institute for Near East Policy, October 17, 2003).

international pressure as well as the aspirations of their own people.[26] State-controlled national oil companies abroad have a profound impact on the world's oil reserves. According to Federal Trade Commission estimates, national oil companies control around 79% of the reserves.[27] As a result, the vast amount of wealth being directly transferred to many repressive regimes is undermining democratic reform in those countries. This wealth has not appeared to have improved the lives of the people, but rather allowed more opportunities for corruption at the highest levels of government. Senator Lugar points out, "the influx of energy wealth also can destroy the impetus to diversify or reform an economy in ways that ensure the benefits flow to the people. In addition, energy wealth can fund foreign adventurism, regional mischief, and terrorism."[28]

#### *e. Price Volatility*

Constraints on petroleum supplies and strong consistent demand have characterized the oil market in the past decade. Using monthly prices of West Texas Intermediate (WTI) crude (an industry economic marker), oil prices have fluctuated within a narrow band for most of the 1990s with an exceptional spike related to the first Persian Gulf War, and a large run-up in prices from December 2001 (US$19.39/barrel) to February 2008 (US$95.39/barrel).[29] DESC, in fiscal year (FY) 2007, was compelled to change its standard price mid-year for the first time. This was a response to the predominantly increasing prices for petroleum products between FY04 and FY06 when fuel sales more than doubled from $5.9B to $13.6B. The six-year Future Year Defense Plan (FYDP), on which the Department of Defense operates, subsequently needs

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[26] Richard G. Lugar, U.S. Senator for Indiana, "U.S. Energy Security-A New Realism" (inaugural speech, Brookings Institution's 90th Anniversary Leadership Forum series, March 13, 2006).

[27] Federal Trade Commission, "Oil and Gas Industry Initiatives," http://www.ftc.gov/ftc/oilgas/.

[28] Lugar, "U.S. Energy Security-A New Realism," March 13, 2006.

[29] Robert Bacon and Masami Kojima, *Energy Security: Coping with Oil Price Volatility*, Energy Sector Management Assistance Program (Washington, DC: The International Bank for Reconstruction and Development/The World Bank Group, 2008.)

large funds to be re-programmed to meet the higher unexpected operating costs. The rapid increases in price have a profound effect on not only current budgets but also on future defense programs.

## B. ENERGY SECURITY AT THE OPERATIONAL LEVEL

> Reducing the military's dependence on fuel for power generation could reduce the number of road-bound convoys.…Without this solution [renewable energy systems], personnel loss rates are likely to continue at their current rate. Continued casualty accumulation exhibits potential to jeopardize mission success…
>
> **2006 Joint Urgent Operational Need statement to JCS from Major General Rick Zilmer, former Commander of US forces in Al Anbar province**

In late 2007, approximately 80 convoys, protected by uniformed forces, were traveling continuously between Kuwait and Iraq destinations.[30] During the same timeframe, over 70 percent of all convoys in Iraq and Afghanistan were for transporting fuel and water.[31] An effective decrease of energy demand in forward locations has a direct impact of lessening the operational burden in fewer convoys, fuel delivery assets, and associated force protection requirements. Lower frequency and lighter convoys help to lower soldier exposure to roadside attacks, makes crucial manpower and assets available for combat operations, and decreases the need to rely upon the Host Nation for energy needs.

Halfway through 2008, there were only 93 attacks on roughly 6,100 logistic convoys, for a convoy-attack rate of about 1.5%, which suggests that there continues to be a decrease in attacks on U.S. convoys (in Iraq).[32] However, convoys will continue to be favorable targets for insurgent forces due to their potential to produce significant casualties, supply loss, and disruption in

30 Department of Defense, *Report of the Defense Science Board Task Force on DoD Energy Strategy: "More Fight – Less Fuel,"* 2008.

31 Ibid.

32 Peter Eisler, "Attacks on U.S. convoys decline," *USA TODAY*, July 21, 2008.

operations. This is clearly apparent as our military forces shift focus towards Afghanistan and the Taliban continue to attack supply lines heading to U.S. and NATO troops. Afghanistan is an extremely mountainous country with more dirt roads than paved, few airports and a poor railway system, which offers challenges for resupply operations. The long distances on difficult terrain alone are challenging, especially in the winter months, according to LTC Weinand former CENTCOM staff. Re-supply can take up to 45 days from source supply to end user.[33]


Figure 9. Afghanistan Supply Routes. (From STRATFOR, 2009)

Several studies have looked at reducing energy demand and the dependence on fossil fuel generators at the operational and tactical level. A

[33] LTC Kurt Weinand, Former Army Petroleum, Oil and Lubricants (POL) Officer for CENTCOM, pers. comm., 2008.

study conducted by the Air Force Research Lab in 2006 found that the use of thermal coverings reduced environmental control unit (ECU) demand by 26%. When thermal coverings with photovoltaics (PV) were integrated into the power distribution system, ECU demand was reduced by approximately 40%.[34] A more recent evaluation conducted by Soldier System RD&E at Natick, Massachusetts, revealed that a high performance gel insulation called Aspen Aerogel had the potential to significantly reduce the amount of fuel required to heat Army shelters using Improved Army Space Heaters (IASH). During a five-day winter evaluation, the key findings revealed an actual fuel savings of 34.1%, taking into account the IASH BTU efficiencies of 81.5% in the non-insulated shelter and 77.1% in the Aerogel insulated shelter.[35] Moreover, when shelter systems require less energy, the supporting generators are operated less often, decreasing maintenance requirements.

In addition to reducing ECU demand for shelter systems, other studies have looked at solutions for mission load (communications and navigation equipment, night vision, chemical agent detector and alarm, laser markers, etc.) energy demands. The July 2000 study, Analysis of Deployable Application of Photovoltaics in Theater (ADAPT), conducted a field demonstration with the 504th Parachute Infantry Regiment, 82nd Airborne Division at Fort Bragg, NC. The study examined the deployment of a photovoltaic power station in a simulated field environment and its potential to provide power for the battery recharging mission. The key finding from the field demonstration was that, with some modifications of the deployable unit, PV could reduce tactical field generators' workload and maintenance by 80%.[36] This meant PV had the potential to be the

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[34] Miriam V. Keith, Air Force Research Laboratory, Airbase Technologies Division, *BEAR Solar Power Demonstration at Holloman AFB Summer 2008* (Tyndall Air Force Base, FL, July 2009).

[35] Elizabeth Swisher, Chris Aall, and Ben LaPointe, NATICK Solder Systems RD&E, “Aspen Aerogels, Cold Weather, Thermal and Fuel Savings Test Report” (in-house report, NATICK, 2008).

[36] Hugh W. Jones and Ken R. Mitchell, Jr, Center for Army Analysis, *Analysis of Deployable Applications of Photovoltaics in Theater (ADAPT)*, (Fort Belvoir, VA, July 2000).

primary power to support the mission load of a battalion-sized, Airborne Infantry tactical operations center (TOC). The use of PV converter chargers and rechargeable batteries can significantly reduce Army and Marine Corps infantry combat load with an economic breakeven point at the 220 operational-hour mark compared to disposable batteries.[37]

The benefits of reducing energy demand and the dependency on fossil fuel generators at forward locations extend beyond the savings on the direct and fully-burdened costs of fuel. The reduction of generator maintenance and support improves the employment of human resources. The use of efficient and renewable energy systems allows ground commanders longer sustainability on station and improved deployability in austere environments. After correctly identifying the correct power requirements, the number, size and weight of currently deployed generators can be minimized to match the new lower demands. This further reduces the logistic footprint and provides operational units greater maneuverability. Renewable energy systems significantly decrease the chance for petroleum product spills and associated public relations issues, decrease carbon dioxide (CO2) emissions, and are environmentally more sound and friendly compared to diesel generators.[38]

Another significant contribution to operational effectiveness is the overall reduction of generator noise and heat signature. According to the ADAPT report, since PV technology is silent, daytime and nighttime security operations make the battalion less vulnerable. During the field demonstration, generators running at night could be heard a considerable distance beyond the defensive perimeter of the battalion TOC, which made it an easier target.[39] Similarly, the heat signature from generators and the heat loss from poorly insulated tents expose

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[37] James S. Whiteker, Jason A. Hamilton, and Steven A. Sablan, “Logistical Impact Study of Photovoltaic Power Converter Technology to the United States Army and the United States Marine Corps” (master’s thesis, Naval Post Graduate School, 2004).

[38] Gordon D. Kuntz, Army Environmental Policy Institute, *Use of Renewable Energy in Contingency Operations*, (Arlington, VA, March 2007).

[39] Jones and Mitchell, Jr., *Analysis of Deployable Applications of Photovoltaics in Theater (ADAPT)*, July 2000.

the operational units, especially at night. Figure 11 illustrates the heat signatures of two Force Provider tent shelters during a field evaluation at Natick, February 2008.

Figure 10. Non-insulated tent (left) and Aerogel insulated tent (right). Backside views of AirBeam TEMPER shelters. Evaluation conducted in Natick, MA.

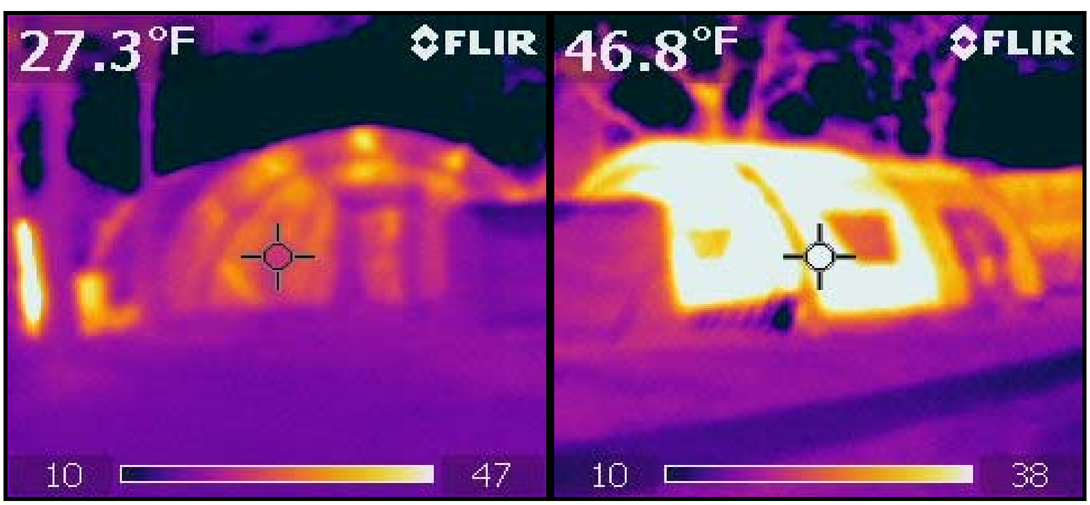


Figure 11. Thermal signature of Aerogel tent (left).Thermal signature for non-insulated tent (right).

The figures illustrate the difference in the amount of heat loss from a standard non-insulated AirBeam TEMPER shelter system and an insulation enhanced shelter system in a cold weather environment. The amount of loss significantly increases the thermal signature and provides insight to the amount of energy wasted through the shelter walls.

## C. NATIONAL TRAINING CENTER FIELD DEMONSTRATION

In support of the Net Zero Plus Joint Capabilities Technology Demonstration (JCTD), a Natick Shelter System technology evaluation is currently ongoing at the Special Operating Forces (SOF) compound site at the National Training Center (NTC) Fort Irwin, California. Several TEMPER and AirBeam tents were set up in late February 2009 with a schedule of interchanging different commercial-off-the-shelf efficient and renewable technologies throughout an 18-month timeframe. The length of the schedule allows Natick to evaluate all applicable technologies during the most extreme desert conditions in the summer and winter months. The purpose of the demonstration is to quantitatively measure the energy efficiency and tactical effectiveness of several lighting, insulation, solar covering and photovoltaic technologies. The demonstration is also designed to allow Army SOF soldiers to interact with the technologies in order to provide operator feedback on maintainability and survivability.

Concurrent with the Natick demonstration is the assessment of the Army's Rapid Equipping Force (REF) ESKIMO project which looks at externally insulating shelter systems using a two-part polyurethane spray foam system at the FOB Miami and LSA Warrior site. With the assistance of PM-Mobile Electric Power, the following are the demonstration objectives:

- Install Power Assessment and Temperature Data Logging systems in all the TEMPER and AirBeam shelter systems at the SOF compound (FOB Seattle).

- Capture power consumption data from the Environmental Control Units, lighting systems and mission loads for all the shelter systems under various configurations.
- Record the amount of converted electrical power from the flexible photovoltaic solar coverings from its associated power management system.
- Analyze the data and provide a comparative report on the different technologies.

The technologies being evaluated during the Natick and the ESKIMO demonstrations are as follows:

**Flexible Photovoltaics**

PowerFilm Power Shade 2kW system

**Lighting**

TECHSHOT Shelter Lighting System (SLS)

Physical Optics Corporation SOSIL System

Jameson LED Lighting System

Crosslink SuperFlex Lighting

**Insulation**

Aspen Aerogel

TEMPER Insulated Liner

**Passive Thermal Cooling**

Solar TEMPER Thermal Fly (Solar Shade)

Saab Barracuda Ultra Light-Weight Camouflage Net Systems (ULCANS)

### 1. Thin-film Photovoltaic Technology

Several concepts for thin-film PV started emerging during the oil crisis in the early 1970s. Today, several mature thin-film technologies exist such as Amorphous Silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium Gallium (di) Selenide (CIGS), all with their respective advantages and disadvantages. However, a-Si is now the most studied and applied material for thin-film solar cells. One of the advantages of silicon material is its abundance as a natural resource; therefore, following the trends of crystalline silicon (typical wafer-based solar panels) technology, a-Si has developed over the years into an industrially mature technology.[40] Relative to crystalline silicon, a-Si offers cheaper processing, lower material costs, and is free of the environmental and health hazard issues of cadmium. Amorphous silicon coupled with durable, flexible modules and substrates allows these products to come in different shades (even semi-transparent), shapes, sizes, and thicknesses for low to medium range power applications. The assessment indicator primarily used in PV systems is based on efficiency of cells. This is the measure of solar energy absorbed that can be converted into electricity minus system energy losses (i.e. heat, light reflection, internal resistance of the cell, etc.).

#### *a. Flexible Amorphous Silicon Solar Cells*

Unlike single- or poly-crystalline silicon (c-Si) which is mostly grown using the Czochralski process, a-Si has no distinct crystal structure.[41] Instead, a-Si units are made by depositing ("spraying") very thin layers of vaporized silicon in a vacuum onto a support of glass, plastic, or metal substrate. Since the layers of silicon allow some light to pass through, multiple layers can be

[40] B. Rech and H. Wagner, "Potential of amorphous silicon for solar cells," *Applied Physics A* 69, no. 2 (1999): 155–167.

[41] D. Y. Goswami, F. Kreith, and J. F. Kreider, *Principles of Solar Engineering,* 2nd Ed. (Philadelphia: Taylor and Francis, 2000).

deposited. The added layers increase the amount of electricity the photovoltaic cell can produce and each layer can be "tuned" to accept a particular band of light wavelength.

This technology is much less expensive to manufacture than crystalline silicon technology and PowerFilm's roll-to-roll technique further reduces production costs. The roll-to-roll technique requires fewer raw materials, is conducted at lower temperatures therefore less energy intensive, and utilizes existing coating and printing equipment. However, there is a tradeoff. The efficiency of amorphous silicon photovoltaic modules (5–7%) is less than half that of the other thin-film technologies. For this reason, research is currently ongoing to improve a-Si performance while maintaining its lightweight, flexible and durable characteristics, the same features found in PowerFilm Power Shade products.

Figure 12. PowerFilm 2kW Power Shade (left). Amorphous Silicon PV module from PowerFilm (right). (From PowerFilm Inc., 2009)

### 2. Efficient Lighting

The lighting system deployed with the current Force Provider module utilizes fluorescent lamps with electronic ballasts. Of the four lighting systems being evaluated during the NTC demonstration, three use LED lamps. These include TECHSHOT SLS, Physical Optics SOSIL and Jameson LED system.

The fourth lighting system, Crosslink SuperFlex, uses electroluminescent panel lamps. One way to evaluate lighting system performance is in terms of efficacy. Typically, the ratio of the amount of light emitted (lumens) to the power (watts) drawn by the system (lumens per watt or LPW) is measured. This study, as explained in a later chapter, evaluates the systems' efficacy similarly using foot-candles and amps, for light emitted and power drawn, respectively, as its units of measurement.

#### *a. Light-emitting Diodes (LED)*

LEDs are semiconductor diodes that emit light when current flows through them. The quality of light produced from this technology is excellent with color temperatures ranging from 3200 to 12,000ºK and color rendering index (CRI) ranging from 60 to over 90. Color temperatures greater than 3500ºK emit cool white light that appears bluish in color; CRI ≥ 70 is a good score indicating little difference in perceived surface color compared to a reference lamp source of the same color temperature. Rated efficacies range from 30 to 60 LPW, which is superior to incandescent lamps and equal to smaller fluorescent lamps.

There are many advantages LEDs have over the current fluorescent lighting system. The average service lifetime for a typical LED is approximately 100,000 hours, versus 10,000–15,000 hours for a full-size fluorescent lamp (4 feet long with a 1-inch diameter). LEDs are more durable, lightweight and compact than fluorescents, making them easier to install, maintain and store in theater. They also have tactical advantages by providing increased brightness with even, non-dazzling light, beam control and "blackout" mode for light emission control. However, LEDs have low maximum wattage per unit and have high unit costs compared to other light sources. The present effective retail cost per watt is between $2.50 to $3.00 per watt.[42]

[42] Department of Energy, "Energy Efficiency and Renewable Energy: Solid-State Lighting," http://www1.eere.energy.gov/buildings/ssl/using_leds.html.

#### *b. Electroluminescence (EL)*

An EL lighting system is a thin panel that is composed of a light-emitting material sandwiched in between two insulating layers. This structure, in turn, is placed between two conducting electrodes. The light emitter or phosphor—typically zinc sulfide doped with manganese—is placed in between the insulating layers. Aluminum and indium tin oxide (ITO), which is a transparent conductive metal, are used as the electrodes. When the voltage exceeds a well-defined threshold, the emitter breaks down and conducts current. The current excites the manganese ions in the phosphor, which give off light.

Color temperature ranges from 3800–6500 ºK and CRI from 78–84 for the EL panels being evaluated. However, efficacy is substantially low at 1–4 LPW, and the light emitted is dispersed with limited brightness compared to both LED and fluorescent lamps. Regardless, EL provides numerous tactical advantages including durability, easy deployability, low weight and volume dimensions and large area light source coverage.

Figure 13. TECHSHOT SLS LED (top). POC SOSIL LED (bottom left). Crosslink SuperFlex EL (bottom right).

### 3. Insulation and Solar Shades

A major cause of energy waste is air entering or leaving a shelter structure. The unintentional air transfer toward the inside is referred to as infiltration, while air transfer toward the outside is referred to as exfiltration. For the purpose of this study, the term infiltration will be used to imply air leakage both into and out of the shelter systems. In a poorly-sealed shelter, infiltration of cold or hot air will increase heating and cooling energy use. An indicator of performance to compare the internal insulation (Aspen Aerogel and TEMPER Insulated Liner) will be based on their respective R–values. R–value is a measure of thermal resistance (prevention of heat infiltration) used in the building and construction industry. Aerogel, which is a nano-sized porous highly flexible silica, has a laboratory tested R–value of 10.3 per inch. The current Army PF shelter with the TEMPER Insulated 2–inch liner has an R–value of 3.2. The PolyFoam external insulation evaluated under Project Eskimo is sprayed foam that permanently bonds to the applied surface. It has an R-value of 7.14 per inch and creates a thick rigid barrier after it is dry.

Figure 14. Gaco Western Polyfoam (left) sprayed application. FOB King at Fort Irwin. Aspen Aerogel (right) sheets applied to a building wall. (From Aspen Aerogels, 2006)

#### a. Solar Shading

Although not considered a form of insulation, solar coverings are discussed briefly in this section. The two products evaluated (Solar thermal fly and ULCANS) reduce the radiant heat produced by direct solar radiation that strikes the roof and walls of the shelters. This is a simple way to keep shelters cooler during the extreme summer months with minimal equipment. The thermal fly is a PVC-coated scrim (mesh) material that attaches to and rests on the external frame of the TEMPER tent. ULCANS is a system of multiple hex and diamond shaped camouflaged screens that can be joined together to cover larger areas and various types of equipment. Several thermocouples were placed in and above the participating shelters to measure various temperature points and calculate temperature differences. Additionally, ECU demand was investigated at each of the shelters outfitted with the different solar coverings.

Figure 15. Solar TEMPER thermal fly (left). Ultra–Lightweight Camouflage Net System (right).

# III. DATA AND METHODOLOGY

## A. NATIONAL TRAINING CENTER FIELD DEMONSTRATION

### 1. Design and Setup

Ongoing testing is being conducted at U.S. Army National Training Center, Fort Irwin, CA. Five 32–foot TEMPER tents and two 32–foot AirBeam tents are installed at the Special Operating Forces compound site (near FOB Seattle) to evaluate the different technology products. It is also interesting to note that another product, Gaco Western Polyfoam insulation, is being concurrently tested at FOB Miami on large multi-purpose tents. This technology evaluation is part of the REF Project ESKIMO initiative and is not a Natick technology candidate. Although unassociated to the Force Provider demonstration, early testing of the polyfoam insulation by the U.S. Army Communications—Electronics Research, Development, and Engineering Center shows promising results for permanent FOB tent structures.

All seven tent shelters are oriented in the same direction with doors facing north and south. They are deployed into columns with a spacing of no less than 20 feet between tents to minimize “shadowing” effect. Figures 16 and 17 depict the layout of the shelters at the demonstration site. All the shelters are equipped with identical F-100 60,000BTU ECUs, AC and temperature data loggers, and rated power cables. The overall demonstration is powered with a single 220kW generator set (Genset) and custom-built power distribution panels.

The Project ESKIMO demonstration layout has six large multi-purpose tents (150 ft. length X 50 ft. width X 21.5 ft. height). Three are un-foamed at the LSA Warrior site and three are foamed at the FOB Miami site. Similar to the Natick setup, the multi-purpose tents were installed with uniform orientations and are equipped with homogenous measurement devices. However, due to the large tent volume (118,560 cubic feet), each of these tents has a dedicated 840kW generator for power requirements.

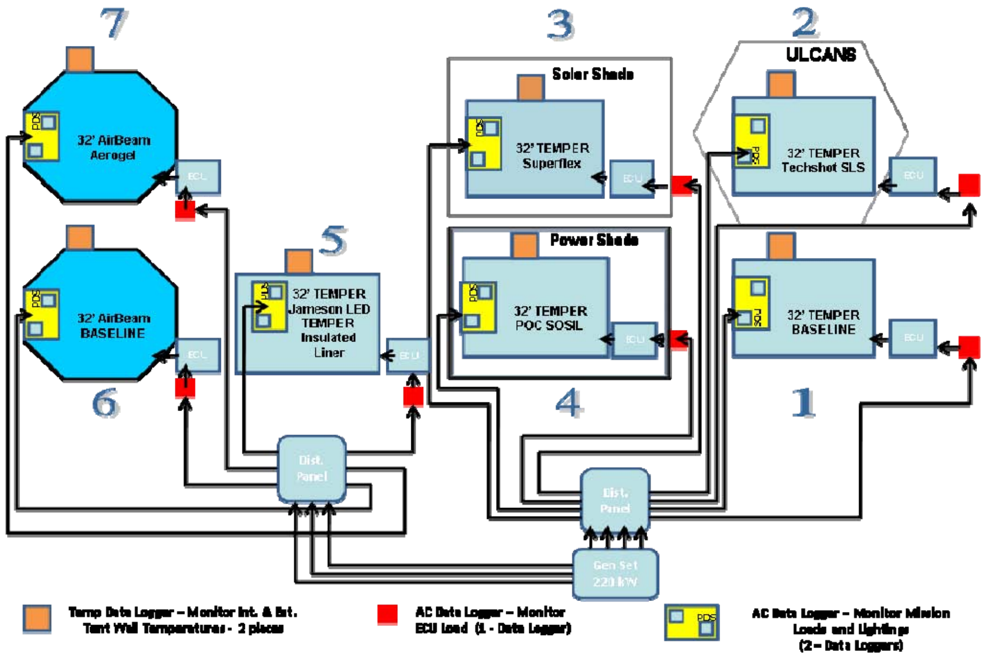


Figure 16. Natick shelter layout and data logger locations.


Figure 17. Aerial view of demonstration layout.

### 2. Measurement and Data Collection

Field data for the systems under study are collected to assess performance and efficiency. The same measurement devices and analog data loggers are installed at each shelter system. Data points are taken in 15–minute increments, with a maximum storage capacity of up to 39 days of data points before requiring onsite download and re-initialization of loggers. The data collected from these devices includes shelter lighting loads, power consumed by the ECUs, several ambient outdoor temperatures at the site, shelter interior temperatures, and power generated from PV. Single-phase transducers measure the single-phase (lighting and mission) loads and the three-phase power transducers measure the shelter ECU power demands. Each shelter system is outfitted with thermocouple probes to measure several temperature points inside and on the rooftop surface of the tents. Thermocouple probes are also placed on the exterior of each shelter to measure several ambient and shade top temperatures. The voltage and the amperage for the Power Shade are also measured. Although the PV system is not tied into the power distribution panels, the associated PowerShade batteries are tied together and a singular outlet is attached to a dummy load of security lights outside the shelter.

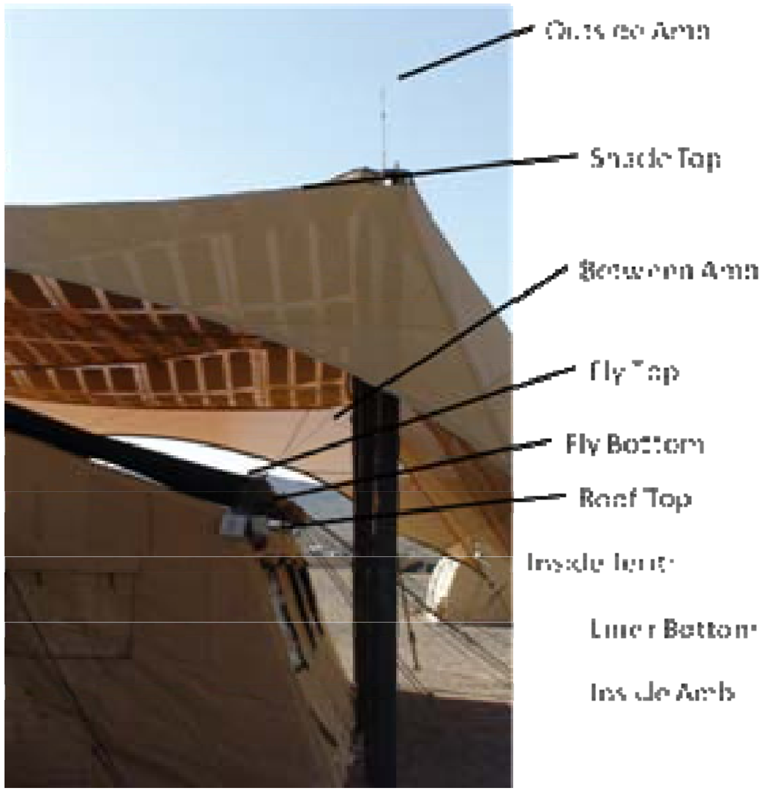


Figure 18. Placement of thermocouples.

## B. ANALYSIS APPROACH

Analysis of the final data set is conducted in two phases. The first phase evaluates and compares similar technologies within their respective group (lighting, insulation, solar shade) in order to rank them on overall performance. The analytic hierarchy process (AHP) is a method that will help compare lighting alternatives with multiple attributes of importance. Statistical analysis will be used to compare all other technologies, which for the purpose of this study, have only a single relevant attribute—reduction in ECU power demand. Nevertheless, all the attributes or indicators relate to the study's two measures of effectiveness: increasing operational performance and decreasing generator energy demand.

After prioritization, the top candidate from each category is identified for the second phase of the analysis. Phase two is a simple business-case analysis. The life-cycle cost estimate (LCCE) for the Force Provider system, specifically investment and operations & maintenance, are examined with the additions of the top technology candidates. For this business case, investment focuses on the unit procurement costs and the installation costs. Operations & maintenance is limited to the estimated recurring maintenance costs and estimated fuel costs.

### 1. Analytic Hierarchy Process

The analytic hierarchy process (AHP) is a method that helps decision makers compare alternatives with multiple attributes.[43] It requires focusing on one attribute at a time, and conducting a pairwise comparison between alternatives. This study employs the AHP method with the lighting technologies as follows (Table 1).

| LIGHTING SYSTEM | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INTENSITY OFFSET 30" | AVG. LIFETIME | LIGHT QUALITY | PRICE |
|---|---|---|---|---|---|---|
| System 1 | 1.95 | 119.32 | 12.08 | 100,000 | (.3774, .3671) | $4,080.00 |
| System 2 | 2.1 | 88.46 | 8.87 | 100,000 | (.3439, .3627) | $23,000.00 |
| System 3 | 2.97 | 136 | 37.23 | 100,000 | (.3251, .3257) | $8,800.00 |
| System 4 | 9.29 | 8.19 | 3.78 | 1,300 | (.3380, .3798) | $9,300.00 |
| System 5 | 2.45 | 131.12 | 18.51 | 10,000 | (.4241, .4134) | $777.00 |

Table 1. Natick specified attributes of importance.

Let *n* be the number of lighting systems. For each performance attribute, an *n* x *n* matrix is constructed by comparing two systems at a time. Using Soldier Systems Center Natick minimum engineering specifications and performance results from Natick lab testing, lighting systems can be quantifiably compared in order to assess how much better one system is over the other. This study assumes a linear relationship where as an attribute improves, so does the overall lighting system. Therefore, if lab testing results show that lighting system #1 provides 1.5 times more foot-candles than system #2 under specified conditions, then 1.5 and 2/3 are entered at their respective positions to indicate this relation. This study ignores any possible diminishing return on lighting performance from increasing attribute performance.

[43] Thomas L. Saaty, *Mathematical Methods of Operations Research* (New York: Dover Publications, 1988), 415-432.

The priority vector for each attribute is then computed. For each row *i* of the matrix, the product of the ratios in that row are found and denoted by $\prod_i$ . The corresponding geometric means, $P_i = \sqrt[n]{\prod_i}$ , are calculated and then $P_i$ is normalized so that $p_i = P_i / P$, where $P = \sum_{i=1}^{n} P_i$ . An example is provided in Table 2.

| POWER DRAW | System 1 | System 2 | System 3 | System 4 | System 5 | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| System 1 | 1.000 | 1.080 | 1.520 | 4.760 | 1.260 | 9.846 | 1.580 | 0.256 |
| System 2 | 0.926 | 1.000 | 1.410 | 4.420 | 1.170 | 29.842 | 1.972 | 0.319 |
| System 3 | 0.658 | 0.709 | 1.000 | 3.130 | 0.820 | 1.198 | 1.037 | 0.168 |
| System 4 | 0.210 | 0.226 | 0.319 | 1.000 | 0.260 | 0.004 | 0.331 | 0.053 |
| System 5 | 0.794 | 0.855 | 1.220 | 3.846 | 1.000 | 3.182 | 1.260 | 0.204 |
| | | | | | | | 6.179998247 | 1 |

Table 2. AHP comparison and priority vector for Power Draw.

This method requires that the attributes be compared on their level of importance. With more than two attributes of interest, the similar pairwise comparison approach is used to find the priority vector. For the purpose of this study, this measure of importance is dependent on subject matter expertise from Natick engineers. Although this comparison of attribute importance is mostly subjective, the model inherently allows a decision-maker the flexibility to weigh the attributes differently to meet their respective needs. Lastly, by computing the composite hierarchical priority for each lighting system, the model can provide insight on ranking and the top alternative with respect to the identified attributes.

# IV. FINDINGS AND A BUSINESS CASE ANALYSIS

## A. FIELD DEMONSTRATION PRELIMINARY RESULTS

### 1. Comparison of Lighting Systems

The initial AHP analysis started with six important attributes for lighting system evaluation. These include:

- Power draw measured in amps, as an indicator of energy efficiency.
- Light intensity (or Illumination power) measured in foot-candles 18 inches from light source, as an indicator of general purpose lighting performance.
- Light intensity 30 inches from light source, as an indicator of tactical purpose lighting performance.
- Average service lifetime measured in hours, as an indicator of the acceptable period of use in service.
- Color light quality measured in the International Commission on Illumination (CIE) XY chromaticity diagram coordinates, as an indicator of lighting ergonomics.
- Cost of lighting system.

The preliminary test results from the Natick Labs revealed no significant difference in color light quality among the alternatives. All the lighting systems registered very similar perception of white color emissions with minimal variations in tint. Therefore, for this study, the color light quality was removed because of the inability to conduct a meaningful pairwise comparison with this attribute. Another initial finding, highlighted in Table 2, revealed that System #4 failed minimum engineering specifications for power draw and had considerably poorer performance measurements in light intensity at 18," light intensity at 30" and average service lifetime hours. This system was included in the initial AHP analysis but removed for a second analysis. The reason for this removal is due to the major drawback of AHP not meeting the independence of irrelevant alternatives property.

Table 3 shows the results from the AHP analysis using the following attribute priority vector:

| ATTRIBUTES | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INTENSITY ( | AVG. LIFETIME | PRICE |
|---|---|---|---|---|---|
| POWER DRAW | 1.000 | 1.500 | 1.250 | 1.750 | 3.000 |
| LIGHT INTENSITY 18" | 0.667 | 1.000 | 0.800 | 1.500 | 4.000 |
| LIGHT INTENSITY OFFSET 30" | 0.800 | 1.250 | 1.000 | 1.500 | 4.000 |
| AVG. LIFETIME | 0.571 | 0.667 | 0.667 | 1.000 | 1.500 |
| PRICE | 0.333 | 0.250 | 0.250 | 0.667 | 1.000 |

| | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INTENSITY ( | AVG. LIFETIME | PRICE | COMPOSITE PRIORITY |
|---|---|---|---|---|---|---|
| **LIGHTING SYSTEM** | 0.286 | 0.229 | 0.259 | 0.149 | 0.077 | |
| System 1 | 0.256 | 0.240 | 0.147 | 0.321 | 0.134 | 0.224 |
| System 2 | 0.319 | 0.171 | 0.112 | 0.321 | 0.023 | 0.209 |
| System 3 | 0.168 | 0.300 | 0.463 | 0.321 | 0.062 | 0.289 |
| System 4 | 0.053 | 0.017 | 0.047 | 0.004 | 0.058 | 0.036 |
| System 5 | 0.204 | 0.272 | 0.231 | 0.032 | 0.723 | 0.241 |

Table 3. AHP analysis results with all lighting systems.

The results summarized in Table 3 show that System #3 is the best candidate with the highest composite score of .289 and System #4 is the worst candidate. System #4 was removed and the same attribute priority vector was used yielding the following results (Table 4).

| | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INTENSITY OFFSET 30" | AVG. LIFETIME | PRICE | COMPOSITE PRIORITY |
|---|---|---|---|---|---|---|
| **LIGHTING SYSTEM** | 0.305 | 0.230 | 0.270 | 0.135 | 0.059 | |
| System 1 | 0.296 | 0.243 | 0.154 | 0.323 | 0.142 | 0.240 |
| System 2 | 0.274 | 0.172 | 0.118 | 0.323 | 0.024 | 0.200 |
| System 3 | 0.194 | 0.311 | 0.486 | 0.323 | 0.066 | 0.310 |
| System 5 | 0.235 | 0.274 | 0.242 | 0.032 | 0.767 | 0.250 |

Table 4. AHP analysis without lighting system #4.

Again, System #3 is still the best candidate and System #2 is now the worst candidate. The current assignments to attribute importance gives System #3 the top ranking because of its dominance in two of the three most heavily weighted attributes—light intensity at 18” from source and light intensity 30” offset from source.

There are several limitations to this preliminary AHP analysis with regards to the outputs. First, outputs are not intended for any purpose other than ranking. In addition, AHP cannot model the interaction between attributes. For this particular part of the study, it is assumed that no interaction between the given attributes exists. In other words, the attributes do not substitute each other nor do they compliment each other. If there is interaction between new attributes of interest, then it would be appropriate to use a utility function of a multi-linear form.

### 2. ECU Power Demands

The data recording and collection process began in March 2009. However, due to numerous setbacks in this part of the field demonstration, only one week of a continuous data set for power usage and temperature readings was acquired for preliminary analysis. This data set includes approximately 700 fifteen-minute increment readings of average kilowatt (KW) power usage placed on each of the five TEMPER tents ECUs and temperature readings at each tent. The data set ranges from April 29, 2009 to May 6, 2009. During this timeframe, as illustrated in Figure 19, the TEMPER tents were set up to evaluate only one technology per tent at a time, with the exception of the complimentary lighting systems. This study assumes negligible effects from lighting system heat loss that might contribute to the overall ECU power demand load. During this timeframe, several soldiers performed administrative work in the tents and human heat loss has an affect in ECU power demand load.

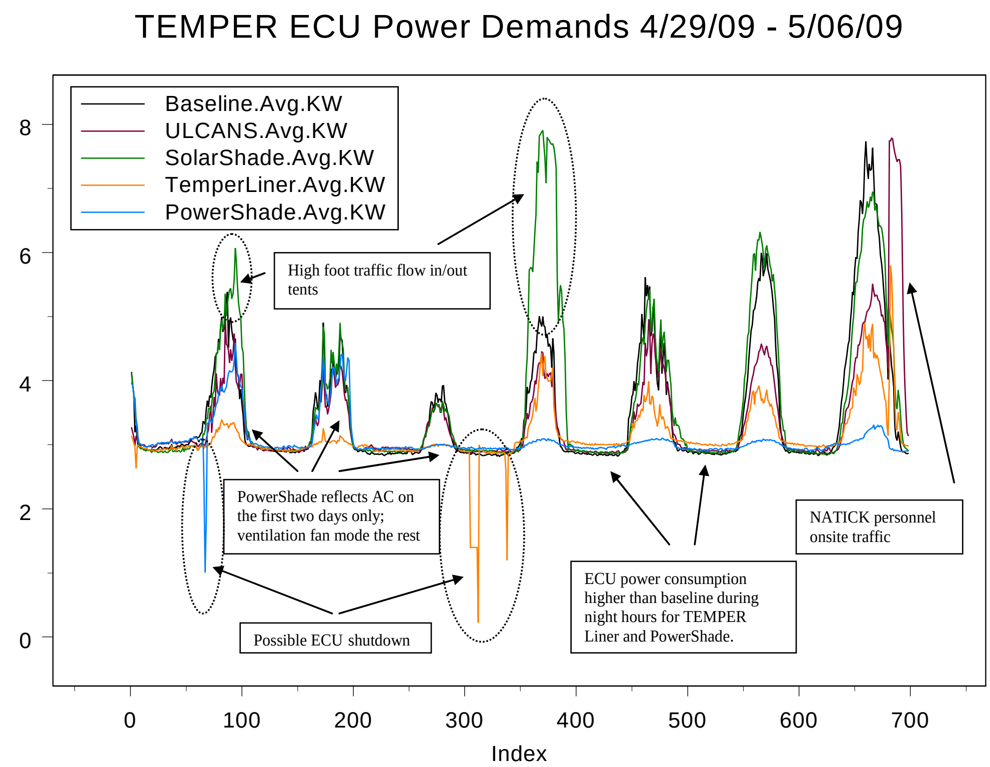


Figure 19. 15-minute average power usage (kW) versus 15-minute increments. TEMPER ECU power demands.

The average (over a 15-minute increment) kilowatt power demands are plotted on the same graph for each of the five ECUs. The fifteen-minute increments are indexed from 1 to 698 to correspond to all the recorded data points. The general trend for all five plots illustrates "peaks and valleys" that correspond to the increasing and decreasing temperatures during the daytime hours and cooler temperatures at night.

There are several extreme outliers illustrated in Figure 19. PowerShade and TEMPER Insulated Liner tents both show significant downward spikes in power demand between index 50 to 100 and 300 to 350, respectively. These outliers are the result of temporary ECU shutdowns for duration of less than 15 minutes. The cause of the shutdowns is unknown. The SolarShade tent shows a significant upward spike between index 75 to 100 and 350 and 400. According to the NATICK team, these spikes suggest an increased amount of infiltration due to high amounts of soldier foot traffic entering and leaving this particular tent. Between index 675 to 700, ULCANS tent had a high amount of NATICK personnel foot traffic. Again, infiltration is the suggested cause of ECU power spikes. The sample means and standard deviations for ECU power demands during daytime hours (Table 5) also highlight the power spikes due to the effect of infiltration. For the calculations in Table 5, this study removed the extreme outliers found in the ULCANS tent on the last few hours of Day 7 because the source of the power spikes is known.

| Kilowatts | Day 1 | | Day 2 | | Day 3 | | Day 4 | | Day 5 | | Day 6 | | Day 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** |
| **Baseline** | 4.09 | 0.68 | 3.77 | 0.54 | 3.27 | 0.36 | 3.91 | 0.75 | 4.22 | 0.74 | 4.46 | 1.12 | 5.73 | 1.37 |
| **ULCANS** | 3.74 | 0.57 | 3.57 | 0.43 | 3.21 | 0.27 | 3.61 | 0.49 | 3.86 | 0.58 | 3.77 | 0.061 | 4.41 | 0.83 |
| **SolarShade** | 4.32 | 0.97 | 3.8 | 0.59 | 3.25 | 0.28 | 5.83 | 1.8 | 4.19 | 0.75 | 4.82 | 1.25 | 5.41 | 1.37 |
| **TEMPER Liner** | 3.15 | 0.15 | 3.03 | 0.06 | 2.96 | 0.04 | 3.52 | 0.47 | 3.39 | 0.24 | 3.44 | 0.31 | 3.93 | 0.57 |
| **PowerShade** | 3.57 | 0.66 | 3.7 | 0.51 | 2.96 | 0.03 | 3.03 | 0.05 | 3.05 | 0.04 | 3.02 | 0.05 | 3.13 | 0.11 |

Table 5. Sample means and standard deviations for ECU power demands.

The ECU demand drop-off that the PowerShade tent displays after Day 2 reflected the complete shutdown of the air conditioning compressor (after index 250). The ensuing small increases in PowerShade power demand, representative of "humps," were related to the ventilation fan only. From the exploratory plot illustrated in Figure 20, the internal ambient temperatures for the PowerShade peak daylight hours were approximately 73.2° Fahrenheit (F) for Days 1 and 2. These temperatures were relatively close in matching the preset thermostat setting of 73°F. After Day 2, however, in the absence of air conditioning, the internal ambient temperatures during peak daylight hours failed to stay below the preset thermostat setting. Instead, the internal temperatures followed the external ambient temperatures by a difference of approximately 12°F. This suggests that PowerShade was providing a consistent thermal cooling effect by blocking some of the solar radiation. Nevertheless, the air conditioning was shut down, and it is unclear what caused the AC shutdown.

With only two days of relevant data for the PowerShade tent, it is difficult to draw insights on PowerShade performance with respect to power demand. The decision to exclude the PowerShade tent for this study's preliminary analysis is made based on insufficient pertinent data for ECU demand and photovoltaic power generation.

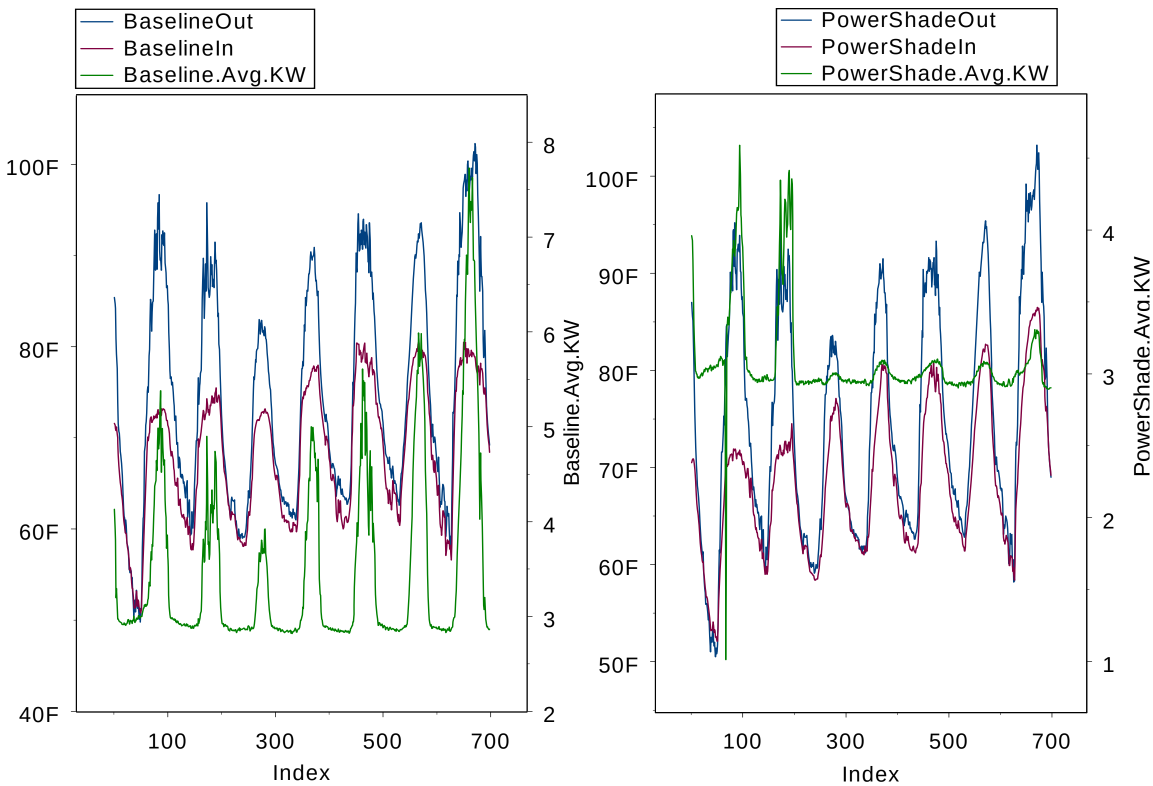


Figure 20. Baseline and PowerShade tent comparison.

After removing PowerShade, this study looked at a single factor non-parametric analysis of the remaining three technologies to investigate if there were statistically significant differences in ECU power demand. This was conducted through the use of the Friedman's test, which looked at a null hypothesis stating no difference in fifteen-minute expected average in ECU power demand for the three technologies. Because power usage for all the tents fluctuated together with ambient temperatures, this study employs Friedman's test, which is the non-parametric analogue to a two-way analysis of variance

(ANOVA), where the blocking variable is the index of the fifteen-minute increments.[44] Unlike the analysis of variance, the Friedman's test does not assume that the average ECU power demands have a normal distribution. The only assumption that has to be made is that the random deviations from the expected average ECU power demand are independent and are from the same continuous (but not necessarily normal) distribution. The test ranks each of the three technologies within date/time periods of fifteen-minutes.

**Friedman rank sum test results**

Data: Natick Demonstration ECU Demands

Friedman chi-square = 282.1782, df = 2, p-value = 0.001

alternative hypothesis: two.sided

Friedman's test gives a chi-squared test statistic with 2 degrees of freedom giving a p-value 0.001. Thus, the null hypothesis is rejected and the test reveals that the power demand differences between the three technologies are indeed statistically significant. Specific results of the test, shown in Table 6, show the technology candidates' ranking order by power usage from least to greatest for each blocking variable.

| **Rank Order** | **Occurences** |
|---|---|
| TemperLiner, ULCANS, SolarShade | 239 |
| TemperLiner, ULCANS(tied 2nd), SolarShade(tied 2nd) | 2 |
| TemperLiner, SolarShade, ULCANS | 20 |
| TemperLiner(tied 1st), SolarShade(tied 1st), ULCANS | 1 |
| ULCANS, TemperLiner, SolarShade | 26 |
| ULCANS, SolarShade, TemperLiner | 17 |
| ULCANS, TemperLiner(tied 2nd), SolarShade(tied 2nd) | 1 |
| SolarShade, TemperLiner, ULCANS | 19 |
| SolarShade, ULCANS, TemperLiner` | 24 |
| Total | 349 |

Table 6. Friedman's rank sum test ranking orders.

[44] Jay L. Devore, *Probability and Statistics for Engineering and the Sciences*, 7th ed. (Belmont: Thompson Learning Inc., 2008), 620-622.

The ranking of “TEMPER Liner, ULCANS, and SolarShade” in this order occurred more that 2/3 (approximately 68%) of the time within this data set.

The Wilcoxon signed-rank test was used to investigate where the statistical differences between pairs of technology candidates and baseline exists. The null hypothesis for this test is that the median difference between pairs of observation paired by time is zero.

**Wilcoxon signed-rank test results**

| | Signed-rank statistic | p-value |
|---|---|---|
| ULCANS and Baseline | 27 | 0.0091 |
| SolarShade and Baseline | 9 | 0.25 |
| TemperLiner and Baseline | 36 | 0.0078 |

Table 7. Wilcoxon signed-rank test results.

The low p-values of 0.0091 and 0.0078 for ULCANS/Baseline and TemperLiner/Baseline pairs, respectively, result in rejecting the null hypotheses for both at 5% significance level. The much higher p-value of 0.25 for the SolarShade/Baseline pair is attributed to the numerous outliers present in the data set.

Results from Friedman’s test, Wilcoxon signed-rank test and the visual inspection of the TEMPER ECU power demand plot (Figure 19) suggest that the TEMPER Insulated Liner is the top candidate of the three and ULCANS performs better that SolarShade. There is insufficient data to determine with confidence the percentage of ECU power reduction (from Baseline) as a function of increasing ambient temperature for each technology. The following TEMPER Insulated Liner versus Baseline plots highlight general trends over the 7 day data set.

Figures 21 through 23 show the mean, median and maximum temperatures and power usage with each day of the data set placed in ascending order by increasing temperatures. The general trend appears to show that as ambient temperatures increase, the difference in ECU power usage between TEMPER Liner and Baseline becomes more pronounced. The day with the lowest mean daytime temperature of 76.2F has approximately a 0.25 kW difference in average power usage. The day with a mean daytime temperature of 85.8F has about a 1 kW difference. The day with the highest temperature at 95.2F has the greatest difference of about 2 kW. This example illustrates that as ambient temperatures increase the differences in power usage follows an increasing non-linear growth. The highest temperature recorded during this data set was 103.3F on the last day (mean = 95.2F and median = 99F). During that day, there is an approximate 30–35% reduction in average power usage from TEMPER Liner and Baseline.

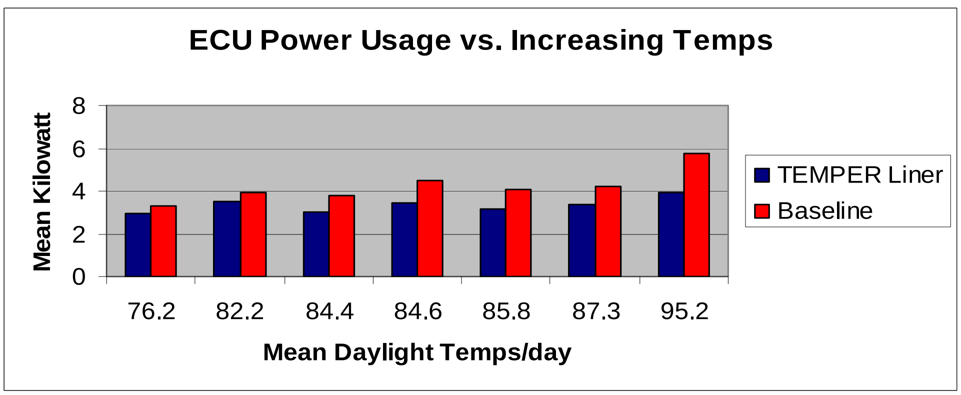


Figure 21. Mean kW differences between TEMPER Liner and Baseline.

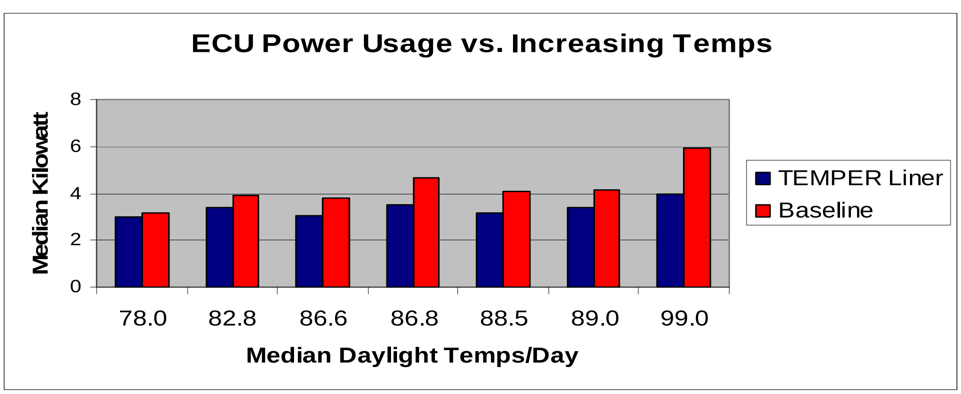


Figure 22. Median kW differences between TEMPER Liner and Baseline.

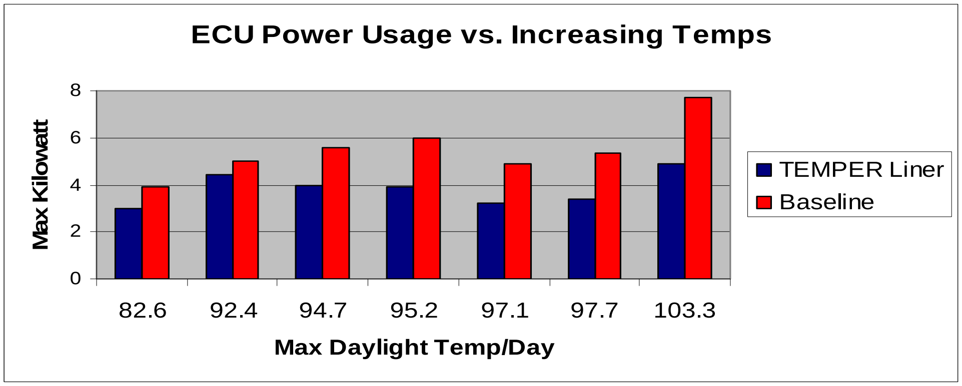


Figure 23. Maximum kW differences between TEMPER Liner and Baseline.

This study did not have the opportunity to compare the performance of Aspen Aerogel insulation and the AirBeam tent baseline due to insufficient field data. Furthermore, even with sufficient data, a meaningful comparison between the performances of Aerogel against the TEMPER Insulated Liner would be difficult because both were installed on different tents with unique structural differences. Therefore, with the assistance of U.S. Army Communications—Electronics Research, Development, and Engineering Center (CERDEC), this study takes a theoretical approach in comparing the two insulations based on their R-values. Software designed by CERDEC was used to compute the minimum ECU loads required to cool a shelter, based on the shelter structure, conditions inside the shelter and external environmental factors (Figure 24).

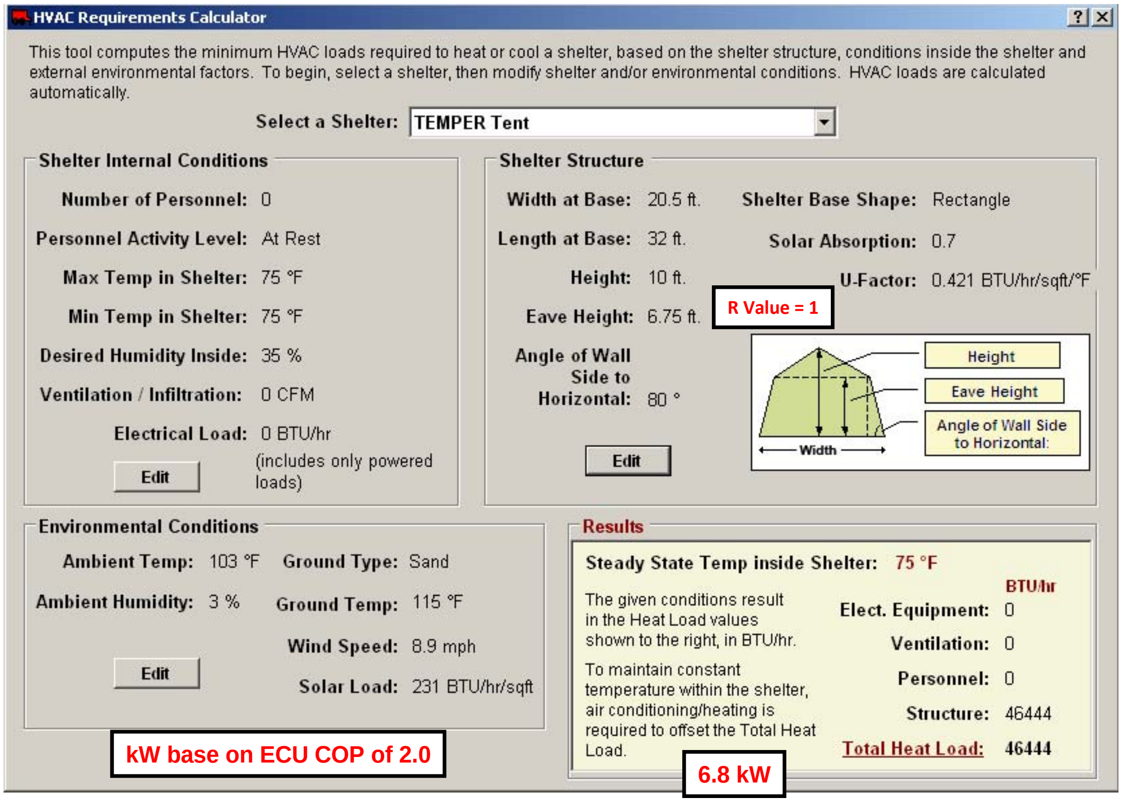


Figure 24. Base scenario ECU load requirement for a non-insulated TEMPER tent.

The base case scenario looks at a non-insulated TEMPER with the following conditions:

- R-value of 1,
- No personnel inside,
- No electrical equipment (mission load) and requirement for ventilation,
- Ambient temperature of 103F (highest recorded temperature in Natick data set) and a thermostat setting of 75F.

The F100 60K ECU coefficient of performance (COP) of 2 was derived from data provided by its manufacturer. The COP is used as a measure of efficiency of this particular ECU under preset operating conditions. Therefore, to maintain an internal temperature of 75F in a non-insulated TEMPER, the ECU must offset a heat load of 23,222 BTUs [46,444BTUs * (1/COP)]. This equates to 6.8kW.

Table 8 compares TEMPER Insulated Liner, Aerogel, and a baseline TEMPER tent in a more realistic scenario that better fits the actual conditions of the data collection timeframe. This second scenario adds the heat load values of 10 personnel conducting administrative work inside the tents and adds the values associated with minimum requirements for proper ventilation. All the other variables have the same values as the base case scenario with the exception of the R-values.

| TEMPER Tent | R-value | Total Heat Load (BTU/hr) | kW Requirement | Actual Max kW Usage |
|---|---|---|---|---|
| Baseline | 1 | 25,076 | 7.4 kW | 7.7 kW |
| TEMPER Insulated Liner | 3.2 | 12,032 | 3.5 kW | 4.9 kW |
| Aspen Aerogel | 10.3 | 7,129 | 2.1 kW | NA |

Table 8. HVAC requirement calculations.

The theoretical kW requirements with the actual maximum kW usage for the hottest day of the Natick data set are compared. Since the max kW usages during the field demonstration coincide with the maximum temperatures recorded, this study uses an ambient temperature of 103°F for comparison. The maximum is preferred over the mean or median because CERDEC model outputs are based on parameters at a steady-state, including the ambient temperature. Consequently, the basis of this comparison assumes a steady-state ambient temperature.

There is a difference of .3 kW between the theoretical requirement and actual maximum usage in the Baseline tent. In the TEMPER Insulated tent, the difference is greater at 1.4 kW. Using the theoretical results, there is an approximate 52% reduction in ECU power requirement from Baseline to TEMPER Insulated Liner. However, the actual field data suggests only a 36% reduction. The disparity between the two could be attributed to a number of factors that introduce bias such as high infiltration due to foot traffic, improper installation of insulation, varied personnel and activity inside tents, and significant mission loads.

There is no available data for an Aerogel insulated TEMPER to compute the difference between theoretical and actual kW usage on the hottest day of data set. The theoretical results show a 72% reduction in power requirement from Baseline to Aerogel. If the same factors that possibly introduced bias in the TEMPER Liner tent are present and equally likely to affect the Aerogel tent, this study estimates an actual power reduction between 50–55%.

## B. BUSINESS CASE ANALYSIS

### 1. Investment and Operations & Support Costs

All the baseline costs are provided in FY08$K. This data was gathered from the product manufacturers or from NATICK Solder Systems RD&E. The following costs are for outfitting the billeting TEMPER tents in one complete 600–man Expeditionary Force Provider module.

#### *a. TECHSHOT LED Shelter Lighting System*

- Procurement Cost—$369.6 (using prototype cost)
- Installation Cost—$0
- Estimated Recurring Maintenance Costs—$3.7

TECHSHOT expects a target goal of reducing procurement cost by 50%. This translates to a total cost of $184.8 to outfit one full 600-man FP module. There is no supporting evidence to suggest that this expectation can be met or when it can be reached. The prototype procurement cost was used for this part of the analysis.

#### *b. Ultra Lightweight Camouflage Net System (ULCANS)*

- Procurement Cost—$119.4

- Installation Cost—$0
- Estimated Recurring Costs—$6

***c. Temper Insulated Liner***

- Procurement Cost—$149.6
- Installation Cost—$0
- Estimated Recurring Costs—$7.5

***d. Aspen Aerogel Insulation***

- Procurement Cost—$64.8
- Installation Cost—$15.8
- Estimated Recurring Costs—$4

**2. Estimated Annual Fuel Costs for One 600–man Expeditionary Force Provider module**

***a. 60 kW Diesel Generator Set***

Assume: (1) Generator runs 23 hours/day

(2) Generator runs 7 days/week and 52 weeks/year

(4) Direct cost of fuel: $ 2.56 per gallon (DL-1 Diesel)

(5) Specific fuel usage estimated as follows:

**At 50% load:**

The estimated fuel usage = 2.66 gallons per hour

Estimated yearly fuel usage = 22,270 gallons

Estimated yearly fuel costs = $ 55,007

**At 75% load:**

The estimated fuel usage = 3.73 gallons per hour

Estimated yearly fuel usage = 31,228 gallons

Estimated yearly fuel costs = $ 77,133

**At Full load:**

The estimated fuel usage = 4.66 gallons per hour

Estimated yearly fuel usage = 39,014 gallons

Estimated yearly fuel costs = $ 96,365

### 3. Economic Analysis

Four of the top technology candidates—TECHSHOT LED SLS, ULCANS, TEMPER Insulated Liner and Aerogel insulation—were evaluated on three financial metrics. The metrics include:

- **Net Present Value (NPV)**—the sum of the present values of the annual cash flows. The annual cash flows are the Net Benefits (revenues minus costs) generated from the investment during its lifetime. These cash flows are discounted or adjusted by incorporating the uncertainty and time value of money. A discount rate of 3% is used for the computations because that is the approximate current return of 10-year U.S. Treasury notes.
- **Return on Investment (ROI)**—the ratio of money gained or lost on an investment relative to the amount of money invested. An annualized ROI is used here to calculate the investment over a certain period. This study is interested in an annualized ROI over a period of 10 years.
- **Payback period**—the point at which the cumulative cash inflows are equal to the cumulative cash outflows.

The economic analysis was conducted in collaboration with RDECOM Cost Analysis Activity, APG. A spreadsheet model of the analysis is found in

Appendix B and the preliminary findings from the NTC field demonstration were used to formulate inputs. The following are main assumptions made:

Assume: (1) 24 out of 26 generators in a 600-man module run continuously

(2) Fully Burdened Cost of Fuel = $13.80 per gal

(2) 52 total 600-man Force Provider modules in inventory

(3) In extreme desert environment (winter/summer), 40% of power generated is consumed by the F-100 60K BTU ECU

(4) F-100 60K BTU ECUs are used for cooling and heating requirements year round

### *a. TECHSHOT LED SLS*

The analysis reveals that TECHSHOT SLS system's high investment costs associated with replacing the current fluorescent lighting system offsets the savings provided by the longer average service life that LEDs offer. Although the service life for LED are on average 10 times longer fluorescent bulbs, the prototype acquisition cost for the SLS system ($8,800/system/tent) is approximately 11 times higher than the current fluorescent system ($777/system/tent). Preliminary engineering data suggested no significant reduction in power requirement, compared to the baseline system, by deploying the SLS system. From this study's financial perspective, it appears that there is no economic benefit to replace the current fluorescent system. However, SLS system offers numerous tactical benefits not captured in this study that require further investigation.

### *b. ULCANS*

ULCANS effectiveness in solar radiation blocking for a desert environment is maximized during daylight hours of the warmest parts of the year. Operation and Support savings from ULCANS was then limited to 10 hour days during 60% of the year to cover late spring through early fall. The results of the financial analysis are highlighted in Table 9.

| | NPV | Annualized ROI | Payback Period |
|---|---|---|---|
| Direct Cost $2.47 | 13.6$K | 7.2% | 5.4 years |
| Fully Burdened Cost of Fuel $13.80 | 75.7$K | 27.3% | 1.8 years |

Table 9. ULCANS Economic Analysis summary.

#### *c. TEMPER Insulated Liner and Aerogel Insulation*

Operation and Support savings from both insulation was limited to approximately 50% of the year to cover only the summer and winter months of a desert environment. The preliminary data from the field demonstration provides evidence that during the mild seasons, the insulation provides minimal savings.

| | NPV | Annualized ROI | Payback Period |
|---|---|---|---|
| Direct Cost $2.47 | 74.5$K | 24.3% | 2.0 years |
| Fully Burdened Cost of Fuel $13.80 | 416.5$K | 47.6% | 1.2 years |

Table 10. TEMPER Insulated Liner Economic Analysis summary.

| | NPV | Annualized ROI | Payback Period |
|---|---|---|---|
| Direct Cost $2.47 | 107.3$K | 40.4% | 1.3 years |
| Fully Burdened Cost of Fuel $13.80 | 599.5$K | 66.8% | 1.1 years |

Table 11. Aerogel Insulation Economic Analysis summary.

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# V. CONCLUSIONS AND RECOMMENDATIONS

A preliminary evaluation of several energy efficient products that could potentially improve the current Army Force Provider module was performed with the motivation of reducing the Army's heavy dependence on generator use. Statistical analysis was conducted on collected data to evaluate and compare the performance of each of the products within its respective technology category. After each of the top candidates from each category was identified, a business case analysis was performed to evaluate their ROI over a 10-year life-cycle cost.

TECHSHOT LED SLS outperforms all other lighting systems under a defined set of lighting performance attributes. Using AHP and the results form Natick lab testing, TECHSHOT SLS consistently had the highest composite priority score among the five lighting systems evaluated. This system however did not reveal any significant improvement in power reduction over the fluorescent lighting system installed in the current Force Provider module. Furthermore, although TECHSHOT SLS was the overall top performing lighting system, its high procurement cost (prototype cost) make it a questionable candidate to replace the current system at this time. Further research is required to quantify the other benefits this system offers and re-evaluate the economic analysis after applying learning curves to the prototype cost.

Using data collected from the NTC field demonstration and U.S. Army Communications—Electronics Research, Development, and Engineering Center, there is evidence to suggest that ULCANS is the top performer among the solar covering candidates. There was a lack of sufficient data and the inability to compare TEMPER Insulated Liner and Aerogel performance on the same type of shelter tent. However using the available field data, CERDEC computational software, and subject matter expertise from U.S. Army Soldier Systems Center Natick, the following are the summarized results for the percentage of ECU power requirement reduction from the baseline:

Reduction of ECU Power Requirement

| Technology | Theoretical | Actual |
|---|---|---|
| **ULCANS** | 18% | 12% |
| **TEMPER Liner** | 52% | 36% |
| **Aerogel** | 72% | Not observed |

Table 12. Percentage of ECU power requirement reduction from baseline over a year.

TEMPER Insulated Liner has the highest reduction in ECU power requirements using the data collected. However, Aerogel has a superior R-value over the TEMPER Liner and has greater potential in reducing ECU power requirements. This study estimates the actual percentage to be closer to 50% but this requires validation with field data results. With 40% of the power generated by the Force Provider module generators supporting the ECU power requirements, it is clear to see that insulation has the most profound effect in reducing overall fuel consumption.

A business case analysis was performed on these three proposed technologies to evaluate their ROI over a 10-year life-cycle cost. The results of the baseline analysis are summarized as follows:

Economic Analysis Summary

| Technology | Annualized ROI | Payback Period |
|---|---|---|
| **ULCANS** | 7.2% | 5.4 years |
| **TEMPER Liner** | 24.3% | 2.0 years |
| **Aerogel** | 40.4% | 1.1 years |

Table 13. Annualized ROI and Payback Period using Direct Cost of Fuel.

Aerogel has the highest annualized ROI among the three technologies and has a payback period of about one year. This means that if actual findings show that Aerogel reduces ECU power requirements by 50%, this technology gives the largest return on benefits (in terms of energy savings only) as compared to the other two candidates. The TEMPER Liner achieves an annualized ROI of 24.3% with a payback period of two years. Although the investment does not return as high as Aerogel, actual field data is available that demonstrates this technology’s true performance with respect to energy savings.

The technologies that are the most attractive financial solutions to Net Zero Plus, with high annualized ROI and short paybacks with regards to energy savings, are related to insulation.  The majority of energy loss in a Force Provider system occurs because of inadequate insulation of the shelter tents.  Therefore, installing insulation directly reduces the power requirements on the supporting ECUs.  This translates to the overall reduction in FP module energy demand by either reducing the number of generators required or replacing the current 60K BTU ECUs to lower power consuming units.

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# APPENDIX A. AHP PROCESS

AHP process with all the lighting systems included. The data was obtained from testing conducted at Natick Labs by U.S. Army Soldier Systems Center Natick.

| LIGHTING SYSTEM | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INTENSITY OFFSE | AVG. LIFETIME | LIGHT QUALITY | PRICE |
|---|---|---|---|---|---|---|
| System 1 | 1.95 | 119.32 | 12.08 | 100,000 | (.3774, .3671) | $4,080.00 |
| System 2 | 2.1 | 88.46 | 8.87 | 100,000 | (.3439, .3627) | $23,000.00 |
| System 3 | 2.97 | 136 | 37.23 | 100,000 | (.3251, .3257) | $8,800.00 |
| System 4 | 9.29 | 8.19 | 3.78 | 1,300 | (.3380, .3798) | $9,300.00 |
| System 5 | 2.45 | 131.12 | 18.51 | 10,000 | (.4241, .4134) | $777.00 |

Remove attribute. No significant difference among systems

| POWER DRAW | System 1 | System 2 | System 3 | System 4 | System 5 | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| System 1 | 1 | 1.08 | 1.52 | 4.76 | 1.26 | 9.846 | 1.580 | 0.256 |
| System 2 | 0.925925926 | 1 | 1.41 | 4.42 | 1.17 | 29.842 | 1.972 | 0.319 |
| System 3 | 0.657894737 | 0.709219858 | 1 | 3.13 | 0.82 | 1.198 | 1.037 | 0.168 |
| System 4 | 0.210084034 | 0.226244344 | 0.319488818 | 1 | 0.26 | 0.004 | 0.331 | 0.053 |
| System 5 | 0.793650794 | 0.854700855 | 1.219512195 | 3.846153846 | 1 | 3.182 | 1.260 | 0.204 |
| | | | | | | | 6.180 | 1.000 |

| LIGHT INTENSITY 18" | System 1 | System 2 | System 3 | System 4 | System 5 | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| System 1 | 1 | 1.26 | 0.86 | 14.57 | 0.9 | 14.209 | 1.700 | 0.240 |
| System 2 | 0.793650794 | 1 | 0.46 | 10.8 | 0.67 | 2.642 | 1.214 | 0.171 |
| System 3 | 1.162790698 | 2.173913043 | 1 | 16.61 | 1.04 | 43.666 | 2.128 | 0.300 |
| System 4 | 0.06863418 | 0.092592593 | 0.060204696 | 1 | 0.06 | 0.000 | 0.118 | 0.017 |
| System 5 | 1.111111111 | 1.492537313 | 0.961538462 | 16.66666667 | 1 | 26.577 | 1.927 | 0.272 |
| | | | | | | | 7.088 | |

| LIGHT INT. OFFSET 30" | System 1 | System 2 | System 3 | System 4 | System 5 | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| System 1 | 1 | 1.27 | 0.32 | 3.2 | 0.65 | 0.845 | 0.967 | 0.147 |
| System 2 | 0.787401575 | 1 | 0.24 | 2.35 | 0.48 | 0.213 | 0.734 | 0.112 |
| System 3 | 3.125 | 4.166666667 | 1 | 9.85 | 2.01 | 257.793 | 3.036 | 0.463 |
| System 4 | 0.3125 | 0.425531915 | 0.101522843 | 1 | 0.2 | 0.003 | 0.306 | 0.047 |
| System 5 | 1.538461538 | 2.083333333 | 0.497512438 | 5 | 1 | 7.973 | 1.515 | 0.231 |
| | | | | | | | 6.558 | |

| AVG. LIFETIME | System 1 | System 2 | System 3 | System 4 | System 5 | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| System 1 | 1 | 1 | 1 | 76.92 | 10 | 769.200 | 3.778 | 0.321 |
| System 2 | 1 | 1 | 1 | 76.92 | 10 | 769.200 | 3.778 | 0.321 |
| System 3 | 1 | 1 | 1 | 76.92 | 10 | 769.200 | 3.778 | 0.321 |
| System 4 | 0.01300052 | 0.01300052 | 0.01300052 | 1 | 0.13 | 0.000 | 0.049 | 0.004 |
| System 5 | 0.1 | 0.1 | 0.1 | 7.692307692 | 1 | 0.008 | 0.378 | 0.032 |
| | | | | | | | 11.759 | |

| PRICE | System 1 | System 2 | System 3 | System 4 | System 5 | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| System 1 | 1 | 5.64 | 2.16 | 2.28 | 0.19 | 5.277 | 1.395 | 0.134 |
| System 2 | 0.177304965 | 1 | 0.38 | 0.4 | 0.03 | 0.001 | 0.241 | 0.023 |
| System 3 | 0.462962963 | 2.631578947 | 1 | 1.06 | 0.09 | 0.116 | 0.650 | 0.062 |
| System 4 | 0.438596491 | 2.5 | 0.943396226 | 1 | 0.08 | 0.083 | 0.608 | 0.058 |
| System 5 | 5.263157895 | 33.33333333 | 11.11111111 | 12.5 | 1 | 24366.472 | 7.540 | 0.723 |
| | | | | | | | 10.433 | |

| ATTRIBUTES | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INT. OFFSET 30" | AVG. LIFETIME | PRICE | RATIO PRODUCT | GEO MEAN | NORMALIZE |
|---|---|---|---|---|---|---|---|---|
| POWER DRAW | 1 | 1.5 | 1.25 | 1.75 | 3 | 9.844 | 1.580 | 0.286 |
| LIGHT INTENSITY 18" | 0.666666667 | 1 | 0.8 | 1.5 | 4 | 3.200 | 1.262 | 0.229 |
| LIGHT INT. OFFSET 30" | 0.8 | 1.25 | 1 | 1.5 | 4 | 6.000 | 1.431 | 0.259 |
| AVG. LIFETIME | 0.571428571 | 0.666666667 | 0.666666667 | 1 | 1.5 | 0.381 | 0.824 | 0.149 |
| PRICE | 0.333333333 | 0.25 | 0.25 | 0.666666667 | 1 | 0.014 | 0.425 | 0.077 |
| | | | | | | | 5.522 | |

| | POWER DRAW | LIGHT INTENSITY 18" | LIGHT INT. OFFSET 30" | AVG. LIFETIME | PRICE | COMPOSITE PRIORITY |
|---|---|---|---|---|---|---|
| LIGHTING SYSTEM | 0.286 | 0.229 | 0.259 | 0.149 | 0.077 | |
| System 1 | 0.256 | 0.240 | 0.147 | 0.321 | 0.134 | 0.224 |
| System 2 | 0.319 | 0.171 | 0.112 | 0.321 | 0.023 | 0.209 |
| System 3 | 0.168 | 0.300 | 0.463 | 0.321 | 0.062 | 0.289 |
| System 4 | 0.053 | 0.017 | 0.047 | 0.004 | 0.058 | 0.036 |
| System 5 | 0.204 | 0.272 | 0.231 | 0.032 | 0.723 | 0.241 |

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# APPENDIX B. ECONOMIC ANALYSIS SUMMARY PAGE FOR THE AEROGEL INSULATION

Economic Analysis summary page for the Aerogel insulation.

**PROGRAM NAME: Project: Aspen Aerogel Insulation**

**ECONOMIC ANALYSIS FORMAT - SAVINGS**

| Evaluation Period (FY) | INVESTMENT | | | | | | | OPERATIONS | | | | SAVINGS BENEFITS | | | NET IMPACT ON FIELD BUDGET (Cur $)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Contractor Cost | | Government Costs | | Total | | | Status Quo | | Alternate | | | | | |
| | (Con $) | (Cur $)* | (Con $) | (Cur $)* | (Con $) | (Disc $)* | (Cur $)* | (Con $) | (Cur $)* | (Con $) | (Cur $)* | (Con $) | (Disc $)* | (Cur $)* | |
| 2009 | 0 | 0 | 3,465 | 3,515 | 3,465 | 3,315 | 3,515 | 24,247 | 24,464 | 24,247 | 24,464 | 0 | 0 | 0 | -3,515 |
| 2010 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 24,771 | 12,124 | 12,386 | 12,124 | 11,260 | 12,386 | 12,386 |
| 2011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 25,165 | 12,124 | 12,582 | 12,124 | 10,932 | 12,582 | 12,582 |
| 2012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 25,608 | 12,124 | 12,804 | 12,124 | 10,614 | 12,804 | 12,804 |
| 2013 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 26,069 | 12,124 | 13,034 | 12,124 | 10,305 | 13,034 | 13,034 |
| 2014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 26,538 | 12,124 | 13,269 | 12,124 | 10,004 | 13,269 | 13,269 |
| 2015 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 27,016 | 12,124 | 13,508 | 12,124 | 9,713 | 13,508 | 13,508 |
| 2016 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 27,502 | 12,124 | 13,751 | 12,124 | 9,430 | 13,751 | 13,751 |
| 2017 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 27,997 | 12,124 | 13,998 | 12,124 | 9,155 | 13,998 | 13,998 |
| 2018 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 28,501 | 12,124 | 14,250 | 12,124 | 8,889 | 14,250 | 14,250 |
| 2019 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 29,014 | 12,124 | 14,507 | 12,124 | 8,630 | 14,507 | 14,507 |
| 2020 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 29,536 | 12,124 | 14,768 | 12,124 | 8,379 | 14,768 | 14,768 |
| 2021 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2024 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2026 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2027 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2028 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2029 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2030 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Residual Value** | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | |
| TOTAL | 0 | **0** | 3,465 | **3,515** | 3,465 | **3,315** | **3,515** | 290992 | **322210** | 157,608 | **173,322** | 133,361 | **107,311** | **148,858** | 145,343 |
| | | | | | | | | Total Investment | | 3,465 | 3,515 | | 3,315 | 3,515 | |
| | | | | | | | | Project Totals | | 161,073 | 176,837 | | 103,996 | 145,343 | |
| | | | | | | | | | | | | | NPV | Net Savings | 62828.086<br>56506.828 |

NOTE: Dollar amounts are expressed in (K) dollars.

NOTE: Base year FY08 used for this analysis.

7. Summary Information for Alternative(s)

**PROGRAM NAME: Project: Aspen Aerogel Insulation**

**ECONOMIC ANALYSIS FORMAT - SUMMARY**

| Summary | Alternative |
|---|---|
| o Total Savings (Current Dollars) | 134,090 |
| o Total Benefits (Current Dollars) | 148,858 |
| o Total Investment Cost (Current Dollars) | 3,515 |
| o Net Present Value (Savings) -Discounted Dollars- | 98,933 |
| o Net Present Value (Benefits) -Discounted Dollars- | 107,311 |
| o Total Investment Cost -Discounted Dollars- | 3,315 |
| o Savings to Investment Ratio (SIR) -Based on Discount $- | 29.84 |
| o Benefits to Investment Ratio (BIR) -Based on Discount $- | 32.37 |
| o Payback (Years based on Current $ Savings) | 1.294 |
| o Net Impact on Field Budget (Based on 10 years savings) | 130,575 |
| o Net Impact on Field Budget (Based on Project Life) | 145,343 |

Economic Analysis conducted by:
RDECOM Cost Analysis Activity, APG
and LCDR Allen Rivera, SC, USN

Economic Analysis summary page for the TEMPER Insulated Liner.

**PROGRAM NAME: Project: TEMPER Insulated Liner**

**ECONOMIC ANALYSIS FORMAT - SAVINGS**

| Evaluation Period (FY) | INVESTMENT | | | | | | | OPERATIONS | | | | SAVINGS BENEFITS | | | NET IMPACT ON FIELD BUDGET (Cur $)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Contractor Cost | | Government Costs | | Total | | | Status Quo | | Alternate | | | | | |
| | (Con $) | (Cur $)* | (Con $) | (Cur $)* | (Con $) | (Disc $)* | (Cur $)* | (Con $) | (Cur $)* | (Con $) | (Cur $)* | (Con $) | (Disc $)* | (Cur $)* | |
| **2009** | 0 | 0 | 8,167 | 8,284 | 8,167 | 7,813 | 8,284 | 24,247 | 24,464 | 24,247 | 24,464 | 0 | 0 | 0 | -8,284 |
| **2010** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 24,771 | 15,825 | 16,166 | 8,423 | 7,823 | 8,605 | 8,605 |
| **2011** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 25,165 | 15,825 | 16,423 | 8,423 | 7,595 | 8,741 | 8,741 |
| **2012** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 25,608 | 15,825 | 16,712 | 8,423 | 7,374 | 8,895 | 8,895 |
| **2013** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 26,069 | 15,825 | 17,013 | 8,423 | 7,159 | 9,055 | 9,055 |
| **2014** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 26,538 | 15,825 | 17,320 | 8,423 | 6,950 | 9,218 | 9,218 |
| **2015** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 27,016 | 15,825 | 17,631 | 8,423 | 6,748 | 9,384 | 9,384 |
| **2016** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 27,502 | 15,825 | 17,949 | 8,423 | 6,551 | 9,553 | 9,553 |
| **2017** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 27,997 | 15,825 | 18,272 | 8,423 | 6,361 | 9,725 | 9,725 |
| **2018** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 28,501 | 15,825 | 18,601 | 8,423 | 6,175 | 9,900 | 9,900 |
| **2019** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 29,014 | 15,825 | 18,935 | 8,423 | 5,996 | 10,079 | 10,079 |
| **2020** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,247 | 29,536 | 15,825 | 19,276 | 8,423 | 5,821 | 10,260 | 10,260 |
| **2021** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2022** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2023** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2024** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2025** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2026** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2027** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2028** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2029** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2030** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Residual Value**** | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | |
| **TOTAL** | 0 | **0** | 8,167 | **8,284** | 8,167 | **7,813** | **8,284** | 290992 | **322210** | 198,318 | **218,763** | 92,651 | **74,553** | **103,417** | 95,133 |
| | | | | | | | | **Total Investment** | | 8,167 | 8,284 | | 7,813 | 8,284 | |
| | | | | | | | | **Project Totals** | | 206,486 | 227,047 | | 66,740 | 95,133 | |
| | | | | | | | | | | | | | **NPV** | **Net Savings** | 43648.986<br>73756.280 |

**NOTE: Dollar amounts are expressed in (K) dollars.**

**NOTE: Base year FY08 used for this analysis.**

**7. Summary Information for Alternative(s)**

**PROGRAM NAME: Project: TEMPER Insulated Liner**

**ECONOMIC ANALYSIS FORMAT - SUMMARY**

| Summary | Alternative |
|---|---|
| o Total Savings (Current Dollars) | 93,157 |
| o Total Benefits (Current Dollars) | 103,417 |
| o Total Investment Cost (Current Dollars) | 8,284 |
| o Net Present Value (Savings) -Discounted Dollars- | 68,732 |
| o Net Present Value (Benefits) -Discounted Dollars- | 74,553 |
| o Total Investment Cost -Discounted Dollars- | 7,813 |
| o Savings to Investment Ratio (SIR) -Based on Discount $- | 8.80 |
| o Benefits to Investment Ratio (BIR) -Based on Discount $- | 9.54 |
| o Payback (Years based on Current $ Savings) | 1.999 |
| o Net Impact on Field Budget (Based on 10 years savings) | 84,873 |
| o Net Impact on Field Budget (Based on Project Life) | 95,133 |

**Economic Analysis conducted by:**
**RDECOM Cost Analysis Activity, APG**
**and LCDR Allen Rivera, SC, USN**

Economic Analysis summary page for ULCANS.

**PROGRAM NAME: Project: Ultra Lightweight Camaflouge Net System (ULCANS)**

**ECONOMIC ANALYSIS FORMAT - SAVINGS**

| Evaluation Period (FY) | INVESTMENT: Contractor Cost (Con $) | INVESTMENT: Contractor Cost (Cur $)* | INVESTMENT: Government Costs (Con $) | INVESTMENT: Government Costs (Cur $)* | INVESTMENT: Total (Con $) | INVESTMENT: Total (Disc $)* | INVESTMENT: Total (Cur $)* | OPERATIONS: Status Quo (Con $) | OPERATIONS: Status Quo (Cur $)* | OPERATIONS: Alternate (Con $) | OPERATIONS: Alternate (Cur $)* | SAVINGS BENEFITS (Con $) | SAVINGS BENEFITS (Disc $)* | SAVINGS BENEFITS (Cur $)* | NET IMPACT ON FIELD BUDGET (Cur $)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 0 | 0 | 6,519 | 6,613 | 6,519 | 6,237 | 6,613 | 30,362 | 30,634 | 30,362 | 30,634 | 0 | 0 | 0 | -6,613 |
| 2010 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 31,018 | 28,831 | 29,453 | 1,531 | 1,422 | 1,564 | 1,564 |
| 2011 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 31,511 | 28,831 | 29,921 | 1,531 | 1,381 | 1,589 | 1,589 |
| 2012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 32,065 | 28,831 | 30,448 | 1,531 | 1,341 | 1,617 | 1,617 |
| 2013 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 32,643 | 28,831 | 30,996 | 1,531 | 1,302 | 1,646 | 1,646 |
| 2014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 33,230 | 28,831 | 31,554 | 1,531 | 1,264 | 1,676 | 1,676 |
| 2015 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 33,828 | 28,831 | 32,122 | 1,531 | 1,227 | 1,706 | 1,706 |
| 2016 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 34,437 | 28,831 | 32,700 | 1,531 | 1,191 | 1,737 | 1,737 |
| 2017 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 35,057 | 28,831 | 33,289 | 1,531 | 1,156 | 1,768 | 1,768 |
| 2018 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 35,688 | 28,831 | 33,888 | 1,531 | 1,123 | 1,800 | 1,800 |
| 2019 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 36,330 | 28,831 | 34,498 | 1,531 | 1,090 | 1,832 | 1,832 |
| 2020 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30,362 | 36,984 | 28,831 | 35,119 | 1,531 | 1,058 | 1,865 | 1,865 |
| 2021 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2024 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2026 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2027 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2028 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2029 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2030 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Residual Value** | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | |
| TOTAL | 0 | **0** | 6,519 | **6,613** | 6,519 | **6,237** | **6,613** | 364367 | **403455** | 347,498 | **384,622** | 16,846 | **13,555** | **18,803** | 12,191 |

| | | |
|---|---|---|
| Total Investment | 6,519 | 6,613 |
| Project Totals | 354,017 | 391,235 |

| | |
|---|---|
| 6,237 | 6,613 |
| 7,319 | 12,191 |
| NPV | Net Savings |

7936.179
134375.047

**NOTE: Dollar amounts are expressed in (K) dollars.**

**NOTE: Base year FY08 used for this analysis.**

**7. Summary Information for Alternative(s)**

**PROGRAM NAME: Project: Ultra Lightweight Camaflouge Net System (ULCANS)**

**ECONOMIC ANALYSIS FORMAT - SUMMARY**

| Summary | Alternative |
|---|---|
| o Total Savings (Current Dollars) | 16,938 |
| o Total Benefits (Current Dollars) | 18,803 |
| o Total Investment Cost (Current Dollars) | 6,613 |
| o Net Present Value (Savings) -Discounted Dollars- | 12,497 |
| o Net Present Value (Benefits) -Discounted Dollars- | 13,555 |
| o Total Investment Cost -Discounted Dollars- | 6,237 |
| o Savings to Investment Ratio (SIR) -Based on Discount $- | 2.00 |
| o Benefits to Investment Ratio (BIR) -Based on Discount $- | 2.17 |
| o Payback (Years based on Current $ Savings) | 5.385 |
| o Net Impact on Field Budget (Based on 10 years savings) | 10,325 |
| o Net Impact on Field Budget (Based on Project Life) | 12,191 |

Economic Analysis conducted by:
RDECOM Cost Analysis Activity, APG
and LCDR Allen Rivera, SC, USN

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