Feasibility Study of Photovoltaic Panels in Military Temporary Housing Structures

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Abstract – **Energy consumption by the US Army is becoming an increasingly important issue. The cost of providing fuel to Army outposts in deployed environments is particularly expensive due to numerous precautions required to defend fuel convoys from enemy attacks. This work is part of the Army's Construction Engineering Research Laboratory (CERL) efforts to reduce the amount of energy consumed by temporary barracks structures commonly referred to as "B-Huts". A prototype is being developed utilizing structurally insulated panels (SIP) and is referred to as a "SIP-Hut". This paper explores the benefits of incorporating photovoltaic (PV) panels into the SIP-Hut's power system. Powering a SIP-Hut is a unique challenge because SIP-Huts are typically located in remote and dangerous locations and, in addition, are temporary structures. A main thrust of this work was to examine if PV could be economically beneficial within this unique environment and short time span. However, the findings from this study can be applied to other remote locations where fossil fuels are not readily available. The SIP-Hut was modeled, solar resources estimated and analysis was performed using Hybrid Optimization Model for Electric Renewable (HOMER) software available from the National Renewable Energy Laboratory (NREL). Our analysis indicates that PV incorporation can have a significant positive impact on the amount of diesel fuel consumed and the overall cost of energy production.**

Index Terms—**Photovoltaic system, Renewable energy, Solar energy.**

I. Introduction

A reliable power system is critical to Army outposts in deployed environments. A commander's main concern is that a power system is reliable because a loss of power can have crippling effects which could put soldiers' lives in danger. Often this reliability is maintained by using numerous diesel generators which are sized to handle any power contingency. This often leaves generators operating inefficiently because generators operate most efficiently when fully loaded, a very unlikely situation given the sizing methodology. This strategy uses a great deal of diesel fuel which has become more difficult to ship throughout a theater as the Army has had to deal with more insurgent threats. According to the Defense Logistics Agency (DLA) the commodity price of a gallon of regular diesel fuel is $4.10 [1]. The cost of fuel can be significantly higher in a deployed environment primary due to the cost of security and transportation through hostile and sometimes difficult terrain. The fully burdened cost of fuel (FBCF) factors in all additional costs. Estimates used by the Pentagon's Comptroller office have placed the FBCF as high as $600 per gallon [2]. A high FBCF could incentivize photovoltaic (PV) energy sources. PV does not require the logistical support that diesel fuel delivery calls for. However, PV cannot supply all power needs due to the uncertainty and variability in power output. A hybrid power system with both PV panels and a diesel generator is more suitable and could significantly reduce the amount of diesel fuel needed by Army outposts in deployed environments.

In deployed theaters a B-Hut is often used as a barracks for soldiers for anywhere between six months and two years. The Army's Construction Engineering Research Laboratory (CERL) is looking at ways to upgrade B-Huts with the key objective being reduced energy and diesel consumption. A multi-disciplinary group at the United States Military Academy (USMA) at West Point, consisting of faculty and cadet members in various departments, is part of this CERL effort. This effort includes the design and construction of a prototype B-HUT replacement using structurally insulated panels (SIP). This prototype is referred to as the SIP-Hut. This paper presents one of the proposed improvements from the Electrical Engineering team, the incorporation of PV energy.

Incorporating PV panels into the SIP-Hut could significantly reduce the amount of diesel fuel used to provide power to these housing structures. Hybrid Optimization Model for Electric Renewable (HOMER) software available from the National Renewable Energy Laboratory (NREL) was used to analyze the benefits of incorporating PV panels into the SIP-Hut's power system [3]. More specifically, the impacts of fuel reduction and cost of integration and operation were investigated. Analysis was performed over a range of generation levels and fuel prices in order to find optimal levels of PV and diesel generation.

The following section provides an overview and modeling methodology for the SIP-Hut power system. This is followed by the methodology of cost estimation used. Simulation results and analysis is then presented followed by discussion and conclusions.

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II. Hybrid System Description

The power system modeled in HOMER can be viewed in Fig. 1. An AC load is being supplied by both a diesel generator and PV panels. In order to ensure an accurate simulation two major concerns are the solar resources available based on location as well as the load profile of the SIP-Hut.

A. *Solar Resources*

Solar resource estimation is calculated in HOMER based on the user input of variables related to the geographical location of the system as well as the orientation of any PV panels used. The latitude of the location is a key variable which determines how much solar radiation a PV panel array may receive throughout the year. For this simulation the latitude and longitude coordinates were entered for West Point, New York (41° 23' N, 73° 57' W). West Point was used as the location because the prototype SIP-Hut will be constructed and tested at West Point. Using West Point as the location allows for experimental data to be compared with the simulation results to determine the accuracy of the simulation.

With the location specified HOMER software generates a clearness index and solar radiation profile for that location based on solar radiation databases already available in the HOMER software and on the internet. This profile can be seen in Fig. 2. The HOMER software used this data with the PV panels in the system to determine how much PV energy was available to the system every hour for the duration of the project lifetime.

B. *Load Profile*

The load profile was a critical aspect of the simulation because it dictates how much energy was consumed by the SIP-Hut's power system at any given hour. The load profile for the SIP-Hut, seen in Figures 3 and 4, was based on the fact that a SIP-Hut is designed to house soldiers. Soldier's electricity consumption while deployed consists primarily of various electronic devices, lighting, and the environmental control unit (ECU). The ECU is an important part of the load profile because it consumes a large amount of energy. ECU energy consumption exceeds the energy consumption of all other devices in the load profile.

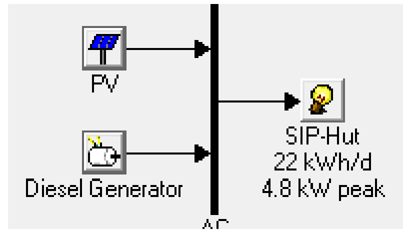

Fig. 1: System Layout

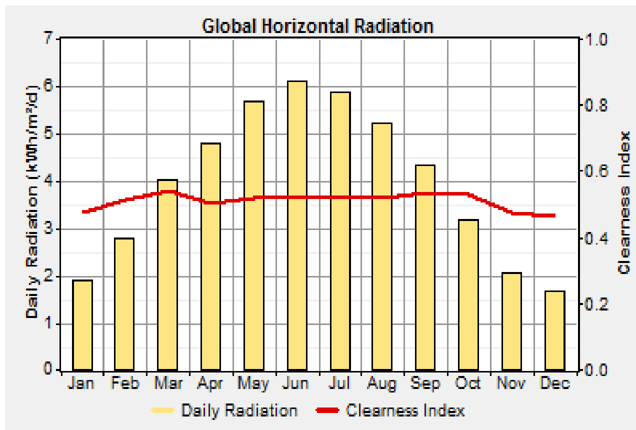

Fig. 2: Solar Resources Available

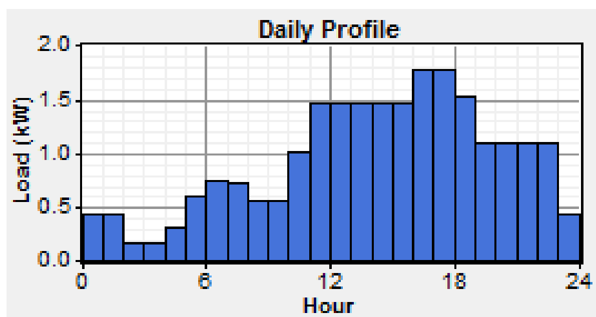

Fig. 3: Hourly Load Profile for an Average Day in June

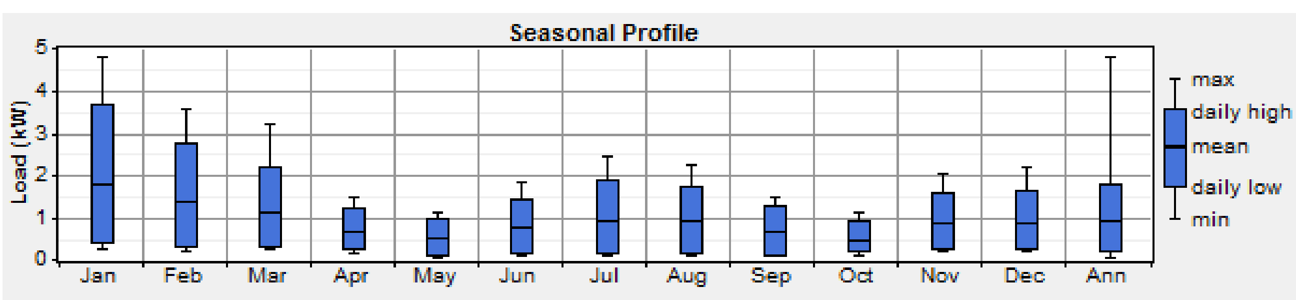

Fig. 4: Monthly Load Profile

Electronic devices might consist of laptops, monitors, projectors, and various chargers. Typical power draws for the majority of items were determined by gathering data with a “kill-a-watt” power meter on numerous items on hand in a cadet room at West Point [5]. Fig. 3 displays the load profile for a typical day in July.

The load of the ECU over the course of the day was determined by first gathering a baseline set of hourly ECU load values and then scaling them to meet monthly energy consumption figures as shown in equation (1). The baseline set of hourly ECU load data was gathered from a report by the Marine Corp Expeditionary Energy Office on their Experimental Forward Operating Base project [6]. Monthly load figures were provided for the SIP-Hut ECU based on simulations done by the Mechanical Engineering team in eQuest software [7].

$$E_{scaled,i} = E_{baseline,i} \cdot \left(\frac{E_{SIP,j}}{E_{Baseline}} \right) \quad (1)$$

where:

$E_{scaled,i}$ = Scaled energy consumption value for a specific hour, *i*. Measured in kWh.

$E_{baseline,i}$ = Baseline energy consumption value for a specific hour, *i*. Measured in kWh.

$E_{SIP,j}$ = Energy consumption in a single month, *j*, in kWh. This data was provided by the Mechanical Engineering team.

$E_{Baseline}$ = Average monthly energy consumption for baseline case in kWh. Energy magnitudes stayed consistent for each month.

Only one baseline 24 hour ECU load profile was available from [6]. To develop profiles for other months, the hourly energy baseline values were shifted with respect to time based on the time of year. More specifically, this varied based on whether heating or cooling was the primary ECU function. For example, time values for a heating load were shifted by twelve hours compared to a cooling load.

In a real world application, the load would not follow the same exact pattern every day. To model this, variability was added to the load profile depicted in Fig. 3. HOMER accomplishes this by multiplying all 8760 hour values for a given year by a scaling factor α.

$$\alpha = 1 + \delta_d + \delta_h \quad (2)$$

where:

δ_d = Daily perturbation factor which varies the magnitude of the load profile over time while keeping the shape intact. Randomly changes for each day in simulation.

δ_h = Hourly perturbation factor which varies the shape of the load profile over time while keeping the magnitude intact. Randomly changes for each hour in simulation.

The perturbation factors used were a normal distribution of values with a zero mean and the standard deviation is equal to a specified variability value. For this work a daily variation of 10% was used while an hourly variation of 10% was used in order to better simulate realistic variability in the load profile that would actually occur over the lifetime of the SIP-Hut.

III. Cost Analysis of the SIP-Hut in HOMER

The HOMER simulation software performed an analysis of the specified power system by simulating system operation for every hour of the project’s lifetime. This simulation collected data on capital expenses, emissions, fuel consumption, as well as some efficiency metrics. For this simulation of the SIP Hut’s power system the key variables which were examined were the PV panel sizing, the generator sizing, and diesel fuel prices. The objective of this simulation was to determine which configuration of this hybrid energy system is optimal based on cost and diesel fuel savings.

A. PV panels

Up to six kW of PV capacity was tested in the SIP-Hut simulations. The HOMER software was set to run a simulation of the SIP-Hut with no PV capacity as well as a simulation with every one kW increment up to six kW. One kW for every one hundred square feet of roof space was used as a guideline for the panel size limit in the simulation. The SIP-Hut is 16 ft.by 32 ft. with a 4:12 pitch roof which means there is approximately 615 feet of roof space. This allows for at least six kW of PV capacity based on this guideline. Pricing was based off of a Clean Technica article which estimated the installed price of solar power at about \$7/Watt in residential applications [8]. The equation below describes how HOMER calculates the cost of PV panels in this simulation. HOMER also factors in replacement costs, but this did not affect this simulation because the project lifetime was less than the lifetime of the PV panels. Full pricing figures can be seen in Table 1.

$$C_{PV}(P_{PV},t) = C_{PVinit}(P_{PV}) + C_{PVO\&M}(t \cdot P_{PV}) - S_{PV} \quad (3)$$

where:

$C_{PV}(P_{PV},t)$ = Cost of PV panels in dollars(\$) as a function of time and PV capacity

$C_{PVinit}(P_{PV})$ = Initial capital cost of PV panels in dollars(\$).

$C_{PVO\&M}(t \cdot P_{PV})$ = Operations and Maintenance cost of PV panels in dollars (\$).

S_{PV} = Salvage value of PV panels at the end of project in dollars(\$).

P_{PV} = PV capacity (kW)
t = time in years

B. Generator size and diesel prices

The generator in the HOMER simulation was initially tested at sizes between one kW and seven kW in one kW increments. HOMER determined generator pricing for various sizes based on at least one user designated generator size and price, assuming that the price and generator size are roughly linearly related. In practice a large diesel generator would probably be providing power to multiple SIP-Huts. CERL is conducting an additional study which looks at designing military power systems to better achieve load balanicing between generators. The focus of this work was to reduce energy and fuel consumption of SIP-Huts. Later the results will be merged with the generator leveling component. In this simulation the generator cost is based off of a Woodcraft seven kW generator which costs approximately $1,400 [9]. For this simulation any extra installation prices for generators was assumed to be negligeble as there are already numerous contracts in place to set up diesel generators for energy production. Moreover, the majority of generation cost is from fuel.

Table 1: Cost Figures and Economics

PV panels	
Initial Capital	$7,000/kW
O & M costs	$10/yr/kW
Lifetime	20 years
Derating	80%
Diesel Generator	
Initial Capital	$200/kW
O & M costs	$.030/hr/kW
Lifetime	25,000 hours
Minimum Load Ratio	10%
Economics	
Interest Rate	6%
Project Lifetime	2 years

$$C_{GEN}(P_{GEN},h) = C_{GENinit}(P_{GEN}) + C_{GENO\&M}(h \cdot P_{GEN}) - S_{GEN} + C_{fuel} \quad (4)$$

where:

$C_{GEN}(P_{GEN},h)$ = Cost of the generator in dollars($) as a function of time and generator size
$C_{GENinit}(P_{GEN})$ Initial cost of diesel generator in dollars($).
$C_{GENO\&M}(h \cdot P_{GEN})$ = Operations and Maintenance cost of diesel generator in dollars($).
S_{GEN} = Salvage value of diesel generator at the end of project in dollars ($)
P_{GEN} = Generator sizing in kW
h = time of generator operation in hours
C_{fuel} = Cost of diesel fuel in dollars($).

The simulations were conducted for wide range of diesel prices. The amount of fuel consumed depended on the load and how it corresponded to the generator size. Fig. 5 below shows the relationship between generator loading and efficiency for diesel fuel.

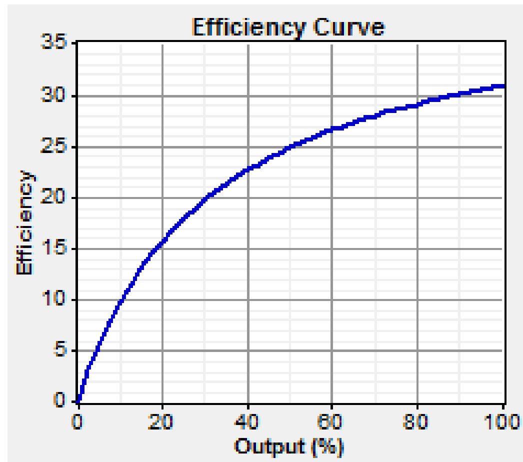

Fig. 5: Diesel Fuel Efficiency Curve

The simulations were conducted with diesel fuel prices between one and ten dollars, tested in one dollar increments. In gallons this corresponds to a price range of $3.78 to $37.85. This sensitivity variable was used to determine the economic feasibility of PV panel incorporation when compared to a purely diesel generator system.

C. Net Present Cost

The concept of Net Present Cost (NPC) of a project was used in HOMER to determine which sizes of generators and PV panels make the most economically feasible system. The NPC is a measure of the money required at the start of the project to fund it for its designated lifetime. This calculation takes interest and the project lifetime into account when making calculations. The formula describing this relationship can be seen below.

$$C_{NPC} = \frac{C_{ann,tot}}{\frac{i(1+i)^N}{(1+i)^N - 1}} \quad (5)$$

where:

C_{NPC} = Net present cost in dollars ($).

$C_{ann,tot}$ = Total annualized cost in dollars ($). Consists of PV cost and generator costs which are adjusted to take the interest rate and time value of money into account.

N = project lifetime in years

i = real interest rate

IV. Simulation Analysis

The results of the simulation indicate that a hybrid system with PV incorporation is economically viable at diesel prices above 1$/Ltr (7.57$/gallon). Fig. 6 displays the results of the most cost effective systems as measured by their net present cost (NPC). As can be seen in Fig. 6 the only data point where it is cost effective to have no PV capacity is when diesel fuel is 1$/ltr. At any diesel fuel price two dollars and above the most cost effective system was a hybrid system with a four kW diesel generator and some level of PV capacity. All of the most cost effective systems in Fig. 6 used a four kilowatt generator because anything smaller would not be able to supply the load with continuous power, a specified constrain, while anything larger would have added unnecessary expense. The only difference between the systems was the amount of PV panel incorporation present based on the price of diesel fuel.

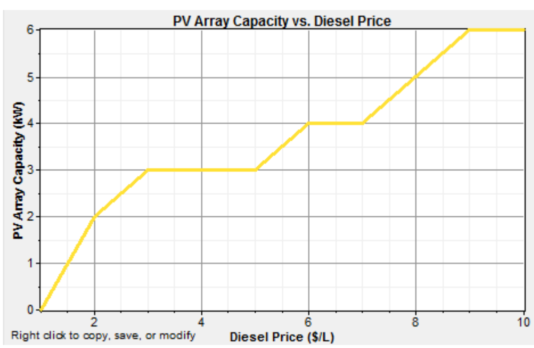

Fig. 6: Optimal PV Capacity vs. Diesel Fuel Price

The other key variable of interest is the amount of diesel saved by using a hybrid PV system. Fig. 7 depicts the relationship between PV capacity and the amount of diesel fuel saved compared to a purely diesel generator powered system. One point to note is that this diesel fuel saved number does not include diesel saved in transportation costs, only the amount of diesel which does not need to be consumed by the generator to supply the necessary amount of energy for the SIP-Hut system.

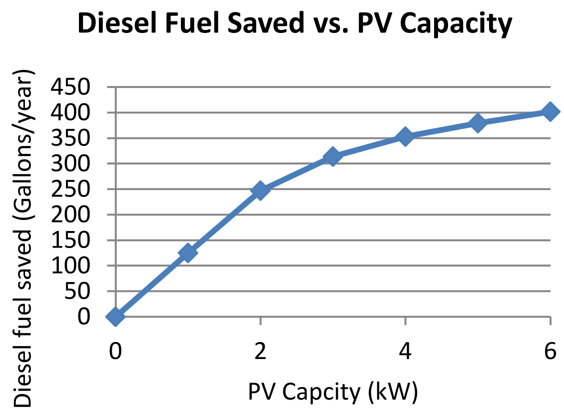

Fig. 7: Diesel Fuel Savings vs. PV Capacity

Fig. 7 shows that for this application there are diminishing returns in the amount of diesel fuel saved once two kW of PV capacity is exceeded. This likely is occurring because adding one or two kW of PV capacity offsets the load, however, additional capacity is not able to be utilized as efficiency due to excess PV generation. Fuel saving gains will not continue to increase linearly unless each additional kW of PV capacity adds generation that can be utilized on demand. The addition of PV panels could also allow for smaller generator sizing. In this simulation the load and solar resources for a single SIP-Hut did not present a situation where a smaller generator could power the SIP-Hut at all times within a hybrid system without storage. In a situation with multiple SIP-Huts this smaller generator sizing per SIP-Hut might be possible because there is not as much load variation when aggregated across many SIP-Huts. A SIP-Hut as part of a larger power system would be able to handle any major power fluctuation in PV energy supplied because it could be mitigated by extra energy generation or consumption in other parts of the system.

Another benefit of PV panel incorporation is that it allows for generators to be shut off during some periods of operation. The generator can be shut off when PV panels provide a sufficient amount of energy to the SIP-Hut's load. Over the course of a SIP-Hut's lifetime of two years this results in a reduction of generator run time. The benefits of a generator running less include a longer lifetime and lower maintenance costs. Fig. 8 below shows the number of generator operation hours saved as a function of PV capacity. A similar diminishing return was seen beyond 2kW of PV capacity.

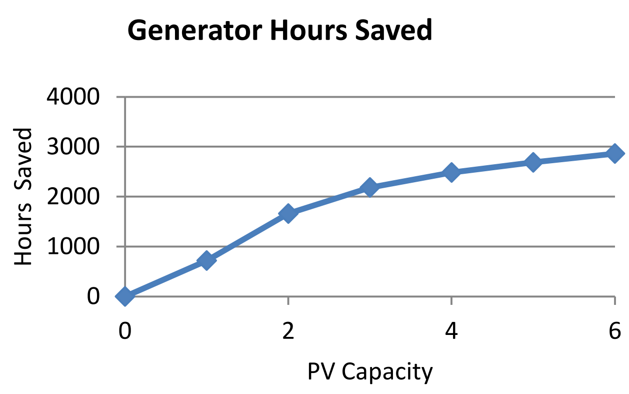

Fig. 8: Generator Hours Saved vs. PV Capacity

V. Discussion

A hybrid energy system powering SIP-Huts has some clear advantages over a purely diesel generator powered system. It should be noted that load model and PV generation profile presented in this paper was based in West Point, not an ideal location for solar power given its distance from the equator. This work focused on this location as the SIP-Hut prototype is being constructed and tested at West Point. However, the simulation indicates that PV panel incorporation would save fuel, be economically advantageous at low fuel prices, and lower diesel generator costs over the course of a SIP-Hut's lifetime which is estimated to be only two years. The economics would improve over a longer lifetime. It should be noted that this analysis factored in a residual value of the PV panels. As a result, it is assumed that this asset will be sold or repurposed at the end of the SIP-Hut lifecycle.

As seen in earlier figures, PV panel incorporation can save a great deal of diesel fuel given that energy production is being supplemented by PV panel energy production. Adding in six kW of PV capacity for a single SIP-Hut can save 402 gallons of diesel per year. In a battalion sized outpost with 65 SIP-Huts this can equate to approximately 26,000 gallons of diesel saved over the course of a year. This amount of fuel savings for a single battalion sized outpost can keep five 5,000 gallon tankers off of the roads over the course of a year. In a dangerous environment like Afghanistan this has many benefits including reduced fuel costs and reduced fuel supply missions. Fewer lives need to be put in harm's way as well.

HOMER simulations indicated that PV panel incorporation became favorable economically if the cost of diesel equaled or exceeded even 2$/Liter (7.57$/gallon). While this appears to be well above market rates, the FBCF typically exceeds this. Investing in PV panels requires a significant initial investment, but technology advances keep lowering the cost of PV panels and their associated costs. Diesel generators may prove cheap initially, but maintaining a secure and consistent supply of diesel fuel proves to be an expensive effort which consumes numerous military resources. In the HOMER simulation model PV incorporation proves to be economically advantageous very quickly, but the benefits will only continue to increase if the FBCF continues to rise for Diesel.

The benefits of reducing generator run time increase the appeal of PV panel incorporation. A generator running hundreds or thousands of hours less per year will have a longer average lifespan and will require less maintenance over time as well. As discussed earlier, diesel generators can be smaller if PV power is available to the SIP-Huts. Smaller generators will reduce costs and use less fuel. Overall PV incorporation adds even more benefits to a SIP-Hut's power system because of the benefits it provides to the diesel generator. Future work on this project will include incorporating PV panels into the prototype SIP-Hut for validation. Modeling a number of SIP-Huts, incorporating generating load leveling and potential demand response to help balance generators with available PV resources will also be investigated.

VI. Conclusion

This paper shows that PV panel incorporation will not only save a significant amount of diesel fuel in deployed environments, but it is also a cost effective method, even over a short lifespan of two years, of providing energy to a SIP-Hut provided that the PV assets can be salvaged or repurposed after two years. Additionally the energy production of PV panels will allow for smaller generator sizing, longer generator lifetimes, and reduced generator maintenance costs. Given all of these advantages, it would be beneficial to utilize PV panels into any temporary housing structure which is intended to replace the B-Hut. The SIP-Hut with incorporated PV panels would be a great upgrade to the B-Hut and would go a long way towards reducing diesel fuel consumption in deployed environments.

VII. Acknowledgements

The authors would like to thank CDT Adam Leemans (West Point Cadet) for providing estimates on ECU load data based on eQuest simulations.

VIII. References

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