# USMC Expeditionary Energy Office Report on Expeditionary Energy Data Collection within Regional Command Southwest, Afghanistan

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## Administrative Information

The work described in this report summarizes the collection of power and energy data of forward deployed USMC locations in Afghanistan in the Fall of 2011. Test data analysis was performed by Code 616 of the Naval Surface Warfare Center Carderock, and was supported by the Expeditionary Energy Office (E2O), who sponsored the effort and led data collection efforts in the field.

## Summary

On 1 October 2009, the Commandant of the Marine Corps created the USMC Expeditionary Energy Office (E2O), with the mission to “analyze, develop, and direct the Marine Corps’ energy strategy in order to optimize expeditionary capabilities across all Warfighting functions.” To get a better understanding of the actual power demands of Marines the E2O deployed a liaisons officer (LNO) assigned to Regional Command Southwest (RC (SW)) from the Fall of 2010 to the Spring of 2012. The information in the report was collected by the E2O LNO.

This report is focused on three distinct topics. First, the results of the recent Expeditionary Energy Office metering efforts in RC(SW), Afghanistan. Second, presenting the lessons learned from the ExFOB 2010-2 Extended User Evaluation (EUE) focused on efficient powering and cooling of Command Operations Centers (COCs). Lastly, presenting an explanation of variable power demand and how probability profiles can be used to understand the impact of USMC operating procedures on fuel consumption.

From July 2011 through January 2012, power and temperature metering at PB SW has enabled the Marine Corps to understand the power demand for small units, Company and below. Now the Expeditionary Energy Office can generate data driven load profiles based on what systems these small units choose to employ. This enables pre-deployment and pre-operation analysis of what power sources will be most effective in meeting the USMC needs, considering the performance of program of record systems. The temperature metering discussed in this report effectively shows some of the technological and behavioral challenges that lead to inefficiencies.

The ExFOB 2010-2 EUE based on efficient heating and cooling of COCs effectively demonstrated that hybrid power systems and efficient air conditioning could greatly reduce the energy/fuel demand on the battlefield. The results of the power portion of the EUE directly led to the Mobile Electric Hybrid Power Systems (MEHPS) Analysis of Alternatives (AoA), which is focused on the proper scaling of hybrid power systems across the wide array of power demands on the battlefield. The efficient cooling portion of the EUE led the ExFOB Executive Integrated Product Team (EIPT) to focus ExFOB 2012-2 solely on efficient heating and cooling capabilities.

Finally, variable power demand is one of the greatest hurdles to efficiency on the battlefield. While utilities Marines are trained to size generators to match the peak load of the systems requiring power, generators in Afghanistan are routinely observed having loads of less than 50%. Understanding how ECUs inherently cause seasonal and daily variable power demand is critical to scoping the problem. Additionally this shows that the inefficiency of ECUs and the lack of power generation systems that can effectively match load to demand create significant operational inefficiency.

## Introduction

Marine Corps Expeditionary Energy Office (E2O) and Naval Surface Warfare Center – Carderock Division (NSWCCD) collaborated with the RC (SW) E2O LNO, to collect power and temperature data of forward deployed patrol bases by utilizing power and temperature meters. This report represents the data collected, lessons learned, and recommendations from this effort.

In early summer 2011, E2O and NSWCCD set out to find mobile metering capabilities which could meter power demand and environmental control unit (ECU) performance in different locations. The equipment had to be as transparent as possible to the warfighters on the ground, to reduce any additional burden to Marines in an operational environment.

Due to these requirements, two simple devices, the *Watts Up? 120VAC* power data loggers and *Lascar Temperature Monitors* were chosen. These systems are shown in Figure 1.

The metered data represented within this report comes from a number of metering sessions at a Patrol Base (PB) within RC (SW) from Jul 2011 to Jan 2012. All analysis was a collaborative effort between the E2O LNO and NSWCCD, both during and after the deployment.


**Figure 1. Metering Equipment Utilized.**

This report summarizes lessons learned from three distinct areas. Analysis of power and energy data gathered at a PB is summarized. This is followed by an impact study of several technologies fielded following a EUE at the same PB. Lastly, broader lessons related to how the Marine Corps operates, and how these methods impact fuel consumption is discussed at length.

# I. METERING

This section is focused on the metered data captured by the E2O LNO. Both electrical demand and environmental control unit (ECU) performance were the critical data targeted by this effort. All metered data was captured at PB in RC (SW), which will be referred to in this report as PB Southwest (SW). However, the data is applicable to numerous other units and locations on the battlefield.

One of the greatest shortcomings of current Department of Defense (DoD) and Marine Corps operational/expeditionary energy efforts has been the lack of true power and energy demand requirements for systems in an operational environment. While specification sheets for systems often list peak power demand, they do not reflect power profiles tied to actual utilization of the equipment. What is needed is a typical 24 hour load profile for each system on the battlefield. To track systems power demands during real world operations has always been a challenge due to the complexities of measuring system performance without impeding critical operations. Making use of the E2O LNO’s deployment was an opportunity to facilitate effective data collection as a secondary mission.

## A. Patrol Base SW

RC (SW) selected PB SW for the integration and evaluation of Experimental Forward Operating Base (ExFOB) equipment. PB SW was the first location to receive ExFOB related, Marine Corps Systems Command (MCSC) fielded Program of Record (POR) systems, which resulted from the first ExFOB (2010-1), and are listed below. See Appendix B for a description and anthology of ExFOB.

PB SW was also the location for the ExFOB 2010-2 Extended User Evaluation (EUE), which focused on efficient powering and cooling of COCs. The systems used for this EUE included a hybrid system and direct current air conditioners.

PB SW was eight km from Camp Leatherneck, the largest RC (SW) camp. It was considered a platoon PB and often had two platoons on site. However, the amount of systems was actually more representative of a Company Command Outpost COP primarily due to the close proximity to Leatherneck. The number of structures, generators, and ECUs are shown in Figure 2.

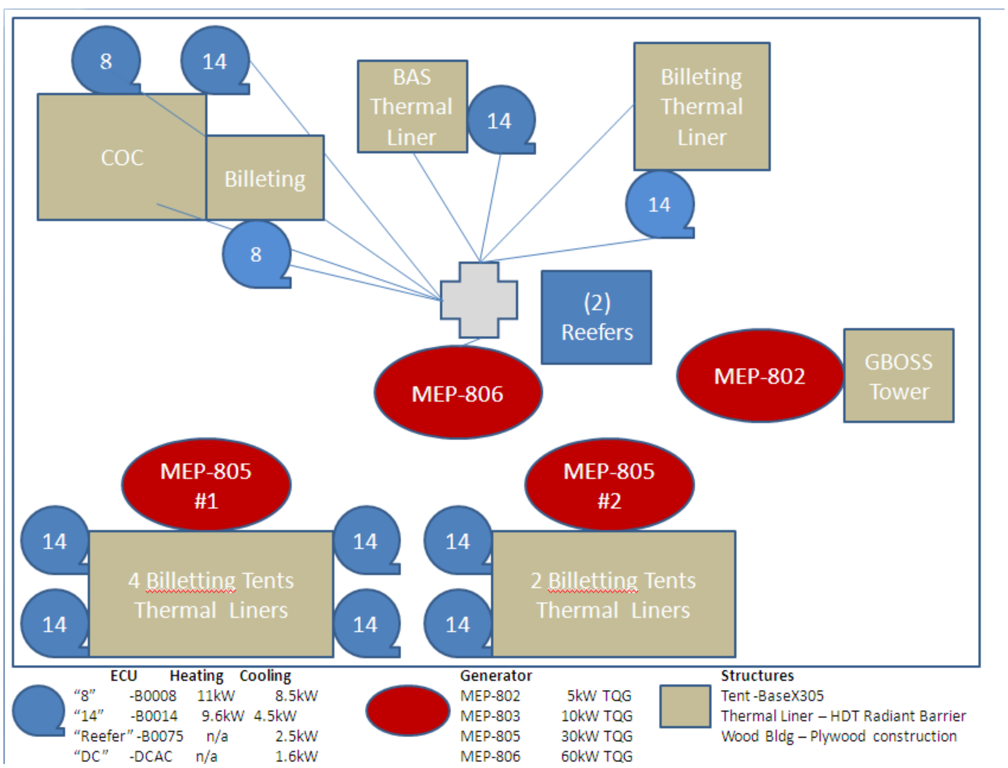



**Figure 2. Visual representation of structures, generators, and ECUs at PB SW**

At the time data was gathered, PB SW had roughly 45 Marines on site. The substantial environmental control capability for this size PB was atypical. This in turn led to a high number of generators to support those large loads. Table 1 shows how the ECU and generator capabilities at PB SW compared to typical Company Command Outpost (COPs) and Platoon PBs. Despite the generic titles, Company COP 1 & 2 and Platoon PB were actual locations visited by the E2O LNO.

**Table 1. ECU and Generator Comparison**

| LOCATION | # OF MARINES | # OF ECUS | ECU CAPACITY (KBTU) | ECU CAPACITY PER MARINE (KBTU) | # OF GENERATORS | POWER CAPACITY (KW) | POWER CAPACITY PER MARINE (KW) |
|---|---|---|---|---|---|---|---|
| **PB SW** | 45 | 11 | 444 | 9.9 | 5 | 125 | 2.8 |
| **Company COP 1** | 44 | 2 | 96 | 2.2 | 2 | 35 | .8 |
| **Company COP 2** | 75 | 5 | 276 | 3.7 | 3 | 120 | 1.6 |
| **Platoon PB** | 25 | 1 | 36 | 1.4 | 2 | 35 | 1.4 |

This demonstrates that PB SW was unusual in terms of ECU and generator capacity which suggests that metered power requirements would show an overestimate for a given PB or COP. PB SW was unique because of both its close proximity to Camp Leatherneck, and the fact that it was the only PB requiring support from the parent unit. Both of these factors contributed to an atypical ECU and generator distribution. Despite this deviation from standard equipment, PB SW provided a great opportunity to draw conclusions from the many individual components, such as system power profiles, ECU power profiles, and behavioral patterns.

## B.  Electrical Loads

*Command Operations Center*

The Command Operations Center (COC) is always the most critical power demand on the battlefield.  The systems within the COC provide the command and control capabilities required to support the warfighting capability of the unit.  While there are uniform sets of equipment, called Capability Sets or CAPSETs, fielded to Battalions and larger sized headquarters, there is no uniform COC equipment set for Companies and below.  Usually one will find a varying array of systems at these smaller unit locations throughout the battlefield. The equipment found at PB SW is indicative of what would typically be found at a Company level.  Therefore it is recommended that the PB SW COC systems and power demand be considered Company-level, rather than Platoon level.

The set of equipment found and metered in the PB SW COC is shown in Figure 2. Multiple images of each piece of equipment represent the quantity of those items in the COC.

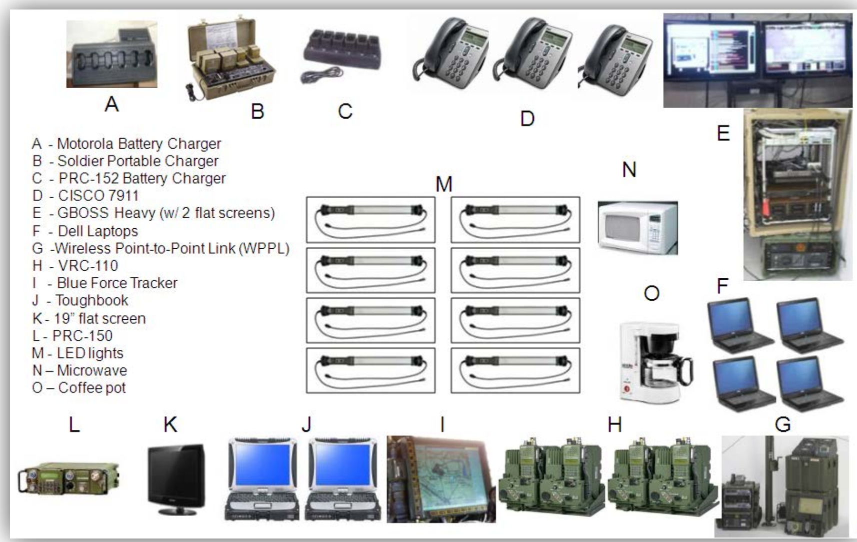



**Figure 3. Overview of equipment found in PB SW COC**

Additionally, Table 2, compares the quantities of each piece of equipment with other Company and Platoon sized COPs or PBs.  PB SW contained more radios, laptops, and pieces of communications equipment in addition to the greater number of ECUs and generators.

**Table 2. Equipment inventory at PB SW and several other locations**

| | PB SW | CO COP #1 | CO COP #2 | PLT PB #1 |
|---|---|---|---|---|
| A - Motorola Battery Charger | 1 | 1 | 1 | 1 |
| B - Soldier Portable Charger | 1 | 1 | 1 | 1 |
| C - PRC-152 Battery Charger | 2 | 1 | 1 | 1 |
| D - CISCO 7911 | 3 | 3 | 3 | 2 |
| E - GBOSS Heavy (w/ 2 flat screens) | 1 | 1 | 1 | 1 |
| F - Dell Laptops | 4 | 9 | 6 | 1 |
| G -Wireless Point-to-Point Link (WPPL) | 1 | 1 | 1 | 0 |
| H - VRC-110 | 2 | 1 | 2 | 1 |
| I - Blue Force Tracker | 1 | 0 | 0 | 0 |
| J - Toughbook | 2 | 2 | 5 | 2 |
| K - 19" flat screen | 1 | 1 | 1 | 0 |
| L - PRC-150 | 1 | 1 | 0 | 0 |
| M - LED lights | 8 | 4 | 4 | 3 |
| N - Microwave | 1 | 1 | 0 | 0 |
| O - Coffee Pot | 1 | 1 | 1 | 1 |

Figure 3, shows the overall power demand of the PB COC electronic equipment. This does not represent ECUs connected to the COC. Six days worth of data was captured. Each piece of equipment was outfitted with an individual power monitoring unit. Data for each piece of equipment was then analyzed and one 24 hour period was chosen as a median or "typical" day for that piece of equipment. All individual power profiles were then combined to yield the overall COC profile shown. (See Appendix for profiles of individual systems)

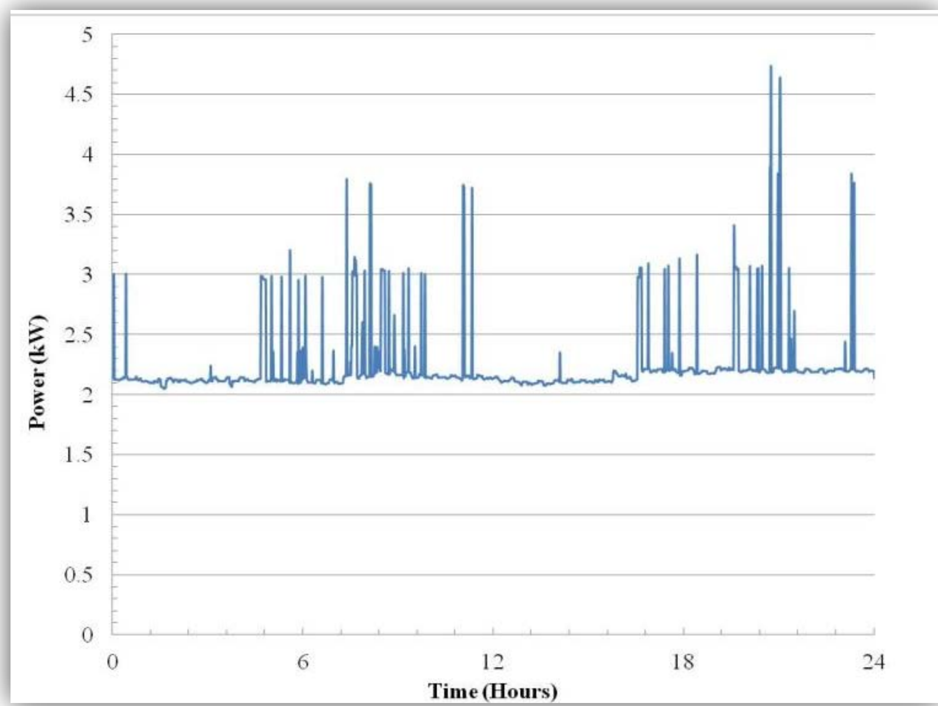



**Figure 4. PB SW 24 hour COC power profile**

Notice that power demand remains very consistent throughout the day, with short duration transient spikes. In the past, conventional wisdom led many to believe that the demand would greatly vary with the time of day, based on drastic changes in the number of occupants in the COC. It was believed that the load would decrease at night when only a couple of Marines were active. Instead what can be seen is that for much of the day the average load is dictated by pieces of equipment which draw steady state power. Monitors, laptops, TVs, lights, and network equipment all draw very consistent amounts of power. The transient spikes which are seen during different periods of the day result from variable loads such as microwaves, coffee pots, radios, battery chargers, and printers which can draw substantial amounts of power, albeit for short periods of time.

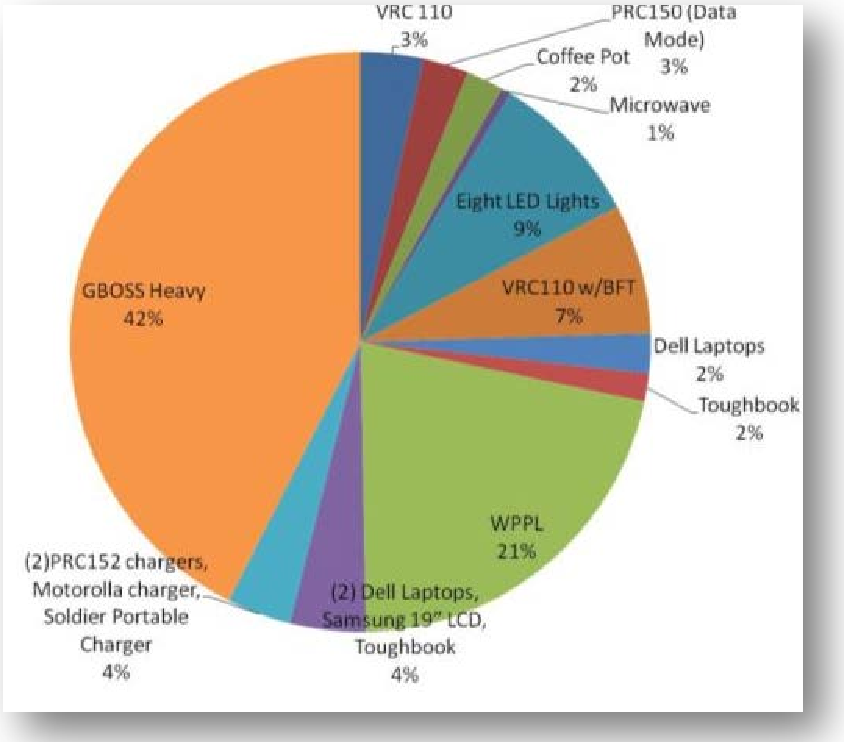



**Figure 5. PB SW Energy use distribution from COC equipment**

The pie chart in Figure 4 shows a distribution of all the energy consumers within the COC at PB SW. The top two energy consumers were the Ground Based Operation Surveillance System (GBOSS) and the Wireless Point-to-Point Link (WPPL). Both represent consistent power demands. In fact, the only true varied loads within the COC were the coffee pot, microwave, radios and battery chargers. These represent the spikes seen on the profile in Figure 3, most of which are attributed to the coffee pot and microwave. One can see that these spikes often occur in the late morning and around dinner time, which is when Marines will typically require the most coffee and microwave use.

*Billeting*

Three different billeting tents were metered for electrical loads. These loads typically consisted of lights and personal electronics that varied greatly from day to day. Therefore tents were metered as a whole, rather than at the component level. Each of the three billeting tents monitored, were BaseX-305s. The number of daily occupants in each tent varied between two and nine Marines depending on the day. Figure 5 shows the “typical” day for each of the three tents.

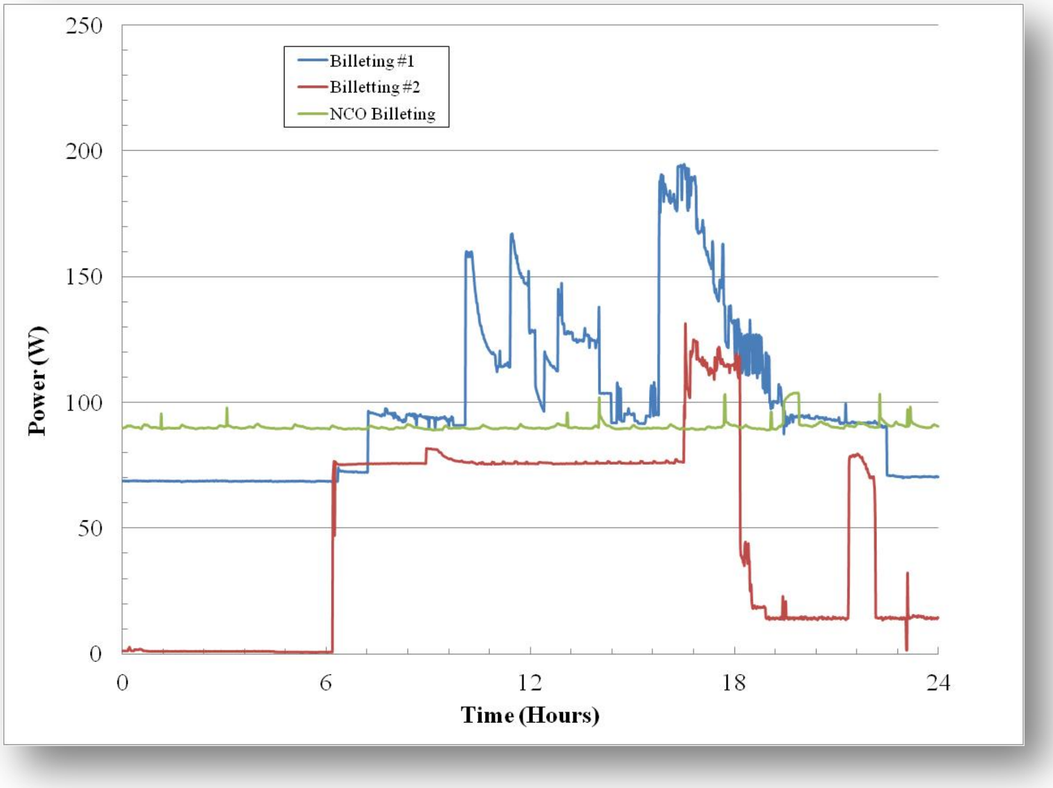



**Figure 6. Typical billeting tent load demands for three different Base-X 305 tents**

Steady state loads represent between one and four LED lights on during the day and night. Although personal electronics were not logged, it is expected that additional loads seen during different parts of each day consisted of radios, personal laptops, and iPod charging. It is important to note that loads in each billeting tent did not exceed 200W at any time, and were often below 100W, for these representative days.

## B. Environmental Control

*Procedure*

The procedure for metering Environmental Control Units (ECUs) was based on tracking ECU inlet temperatures. Two outdoor ambient temperatures were metered, direct-sun and shade, which provided context for the ECU performance. Additionally indoor ambient and plenum temperatures were metered for multiple tents/ structures. The combination of these temperatures provided insights into human behavior in controlling the ECUs and how the ECUs performed. The overall intent was to track the power demand profile of an ECU under operational conditions. Because of the transient response of the temperatures sensors used, the one sample per minute data acquisition rate, and variables such as thermal losses through ducting and varying instrument location, analysis of ECU usage contains some level error.

*Marine In The Loop*

What was revealed through metering was the basic inefficiency of Marine in the loop controls. Temperature was metered in a Base-X 305 tent used for billeting over a three day period. Figure 6 is a photo of such a billeting tent. The tent was outfitted with Radiant Barrier Thermal Liners to increase the insulation and was covered with “camie” netting to reduce solar loading.

**Figure 7. Representative billeting tent**

Figure 7 shows the ambient temperature inside the tent routinely drops to 60ºF or below on three consecutive nights. Understanding that this low temperature is uncomfortable for any time of the day suggests the Marines are either unwilling or unable to maintain a more reasonable temperature.

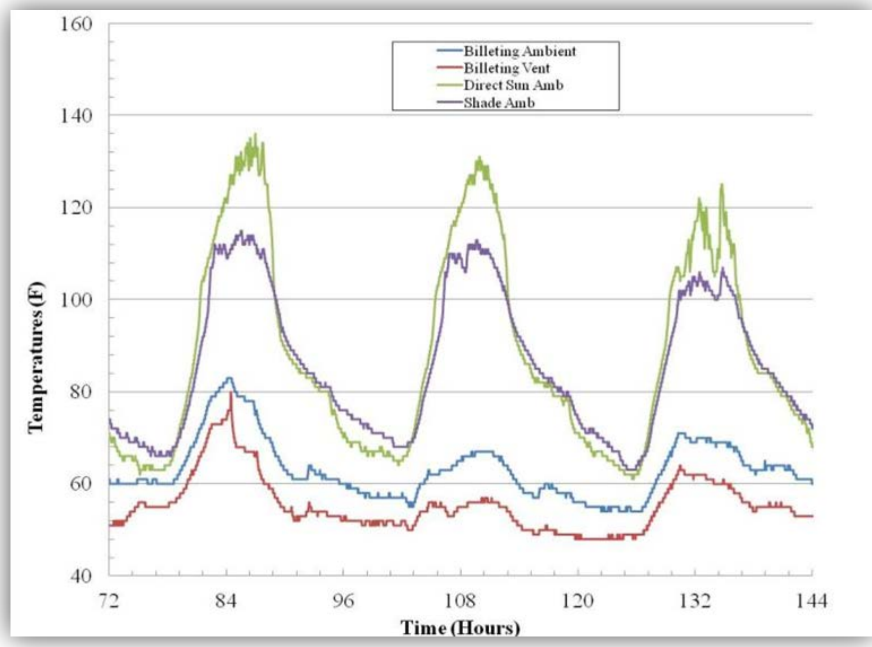



**Figure 8. Three days of temperature monitoring for a single billeting tent at PB SW**

If we assume the Marines are unwilling to make an effort to adjust temperature, it might be logical to assume the Marines do not appreciate the ramifications of their actions on logistics needs. However, in discussions with Marines who have returned from the field, this does not appear to be true.

All B0014 ECUs operate based on two simple turn dial thermostats, shown in Figure 8. One exists on the ECU itself, and the other remote thermostat can be setup inside the cooled/heated tent. When the remote thermostat is setup inside the tent, temperature control on the ECU is set to "Remote" mode and operation is based on indoor temperature, via a thermistor on the remote. When the "Remote" is not used, the ECU is set to "Local" mode. In "Local" mode, the ECU is utilizing a thermistor within the intake of the unit to determine when to turn the compressor on and off. Not surprisingly, data suggests that the remote is the more efficient controller as it more closely tracks the ambient temps as well as giving the Marines a control capability that doesn't require them to go outside. Unfortunately, remotes are often not used due to being lost or broken.


**Figure 9. B0014 ECU temperature dial**

The tent metered for Figure 7 does not have a remote. Therefore, the Marines had to go outside to change the control dial. If a thermostat similar to the type found in residential homes, with desired temperature as the key indicator was used, tents would never be cooled to the degree they were in this figure. However, a dial that only indicates “hotter” or “colder” will show these results.

To illustrate, consider a Marine who has spent much of his time outside in ambient temps above 100 degrees. It is not a surprise that this Marine would enter a tent with the mindset of making the tent as cold as possible. The product of this mindset can be seen in Figure 7. The tent was cooled to a considerably low temperature during the period. In this case, the B0014 did a more than adequate job of cooling as the indoor ambient was rarely above 70ºF. In fact, the B0014 may have been too large for the job, now that thermal liners had been added to the tent. The increased insulation, greatly enhanced the thermal effectiveness of the tent-ECU system, most likely rendering the B0014 oversized for the need. While the Marine assuredly appreciated the cool tent as a reprieve from the outside heat, cooling tents to 70ºF when the outdoor ambient is in excess of 100ºF may not be a sustainable or expeditionary requirement. Considering the 2$^{nd}$ and 3$^{rd}$ order affects of an ECUs impact on fuel demand and the inherent risk to life and cost of supplying that fuel, the ECUs were certainly oversized.

Returning to the Marines behavior, the problem is not their mindset, as the 2$^{nd}$ and 3$^{rd}$ order affects are very intangible to them. The problem is that they are the most important factor in this Marine in the Loop control strategy. Consider that they have the ECU on max cool throughout the day. As the outdoor ambient temp decreases into the night, they have no impetus to change the control dial until they reach a point of discomfort. In a residential home, the home owner is prompted by the discomfort of his electrical bill and ensures he is not wasteful of energy. However in a deployed environment, the Marine that uses energy is not impacted in any way by the fuel demand at his patrol base unless the fuel supply is exhausted, which the Logistics Officer is expected to prevent, regardless of demand. It is not clear to him that there are 2$^{nd}$ and 3$^{rd}$ order affects of excess fuel usage. Therefore, the only discomfort he feels is becoming too cold. However, sleeping bags and beanies provide the Marine the ability to easily control his temperature, while not affecting the others in one’s tent. That is exactly what happens.

Figure 7 reveals uncomfortably cold conditions within the tent at night. Marines simply utilized the individual warming layers issued to them to make themselves more comfortable. Some of that can be attributed to the nature of cohabitation where no one is in charge of the temperature dial. Another source of the problem is the fact that Marines that find themselves in distant lands, with long and delayed supply chains, simply do not like altering their equipment when they don’t have to. They have experienced the failure of systems which cannot be easily replaced which creates a tendency to leave operating equipment alone. The final, and most substantial, source of the problem is that the cooler-warmer dial gives them no indication of what the temperature inside the tent is. It can only address the immediate. Therefore, if a Marine takes an active role in trying to control the indoor ambient, he has no confidence that it will not require him to change the dial every 10 minutes. Marines often complain of getting up in the middle of the night because they are freezing. After changing the dial and returning to their rack, they wake up again 30 minutes later because they are sweating, causing them to change the dial again. Or one could imagine two different Marines playing those two roles. The first Marine wakes up because he is hot. He takes off his beanie, unzips his sleeping bag, and moves the dial to warmer. The second Marine wakes up 30 minutes later sweating. He removes his warming layer and moves the dial to cooler; and the cycle continues.

*Heating*

Temperature was also metered for a period during the winter. Figure 9, Figure 10, and Figure 11 show that the Marine in the loop control strategy is equally ineffective in the winter. Marines would routinely complain that they were either sweating or freezing, with rarely a mention of comfort. These three graphs show three different structures metered. The first is the PB SW COC. Recall that the COC unconventionally had two ECUs supporting it, a three ton and a five ton. The data gives no indication which ECU was on at any given time, but it does show that indoor ambient temperature was fairly consistent averaging in the upper 70s both day and night. It could be argued that upper 70s is too warm when fuel is at a premium and Marines should be to deal with lower indoor temps when the outdoor ambient is in the 40s. The consistency of the indoor ambient is more indicative of having an "on duty" Marine present at all times.

It shows that an alert Marine will maintain some consistency even if he has to utilize temperature dial controls to do so. It would seem likely that the Marines in the COC had to alter the dial on one of the two ECUs tens of times throughout the day due to ever changing external ambient temperatures.

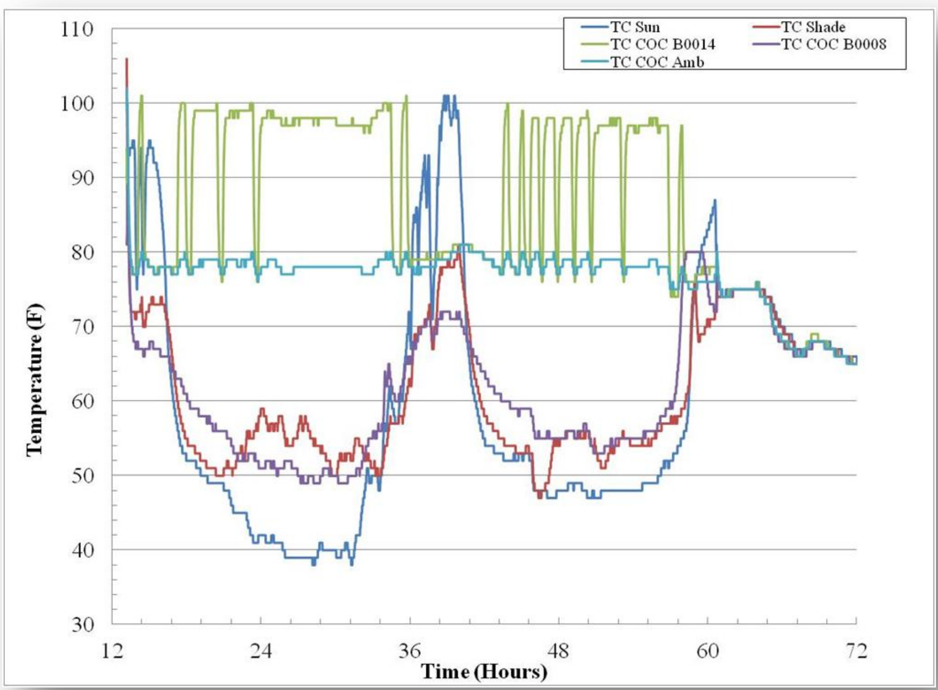



**Figure 10. COC tent temperatures**

We can now compare this behavior observed in the COC with the behavior in two billeting tents shown in Figure 10 and Figure 11. Each graph is an example of user behavior in spaces that are not occupied as frequently. The billeting tent #1 indoor ambient varies between 55ºF to 90ºF, but much is often in the upper 80s. This temperature is both inefficient and uncomfortable. It is likely the Marines in this tent slept on top of their sleeping bags and stripped off layers of clothing.

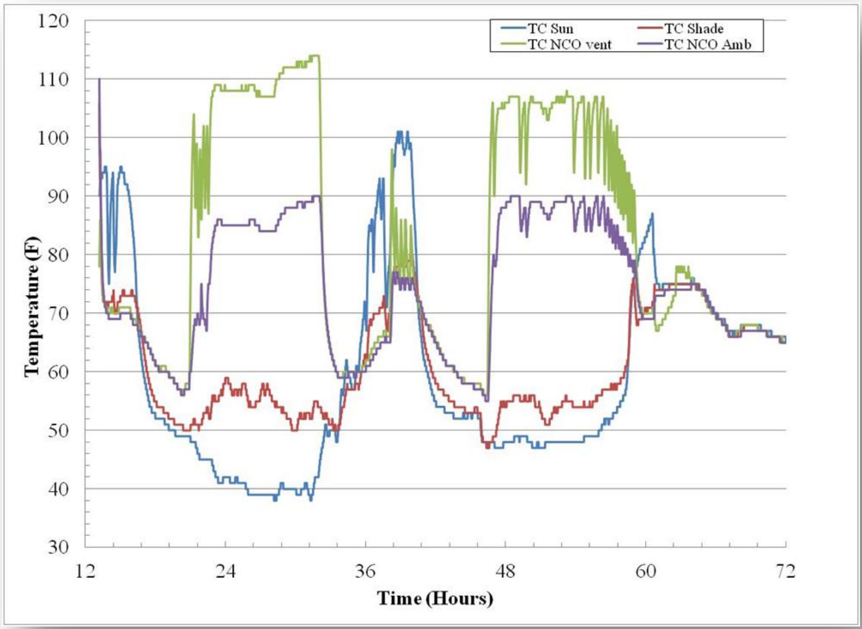



**Figure 11. Billeting tent #1 temperatures heated by a B0014**

Figure 11 represents data taken from a different billeting tent on the same days. It is obvious that the Marines are more effective at maintaining a reasonable and comfortable temperature as much of the days are spent between 65ºF and 75ºF. It is unclear why this tent is controlled more effectively, as there could be many factors such as the use of a remote versus no remote on the other tent, more Marines were present in the tent, the Marines were less willing to put up with discomfort, or one Marine simply a had conservation mindset and saw excessive ECU usage as excessive fuel.

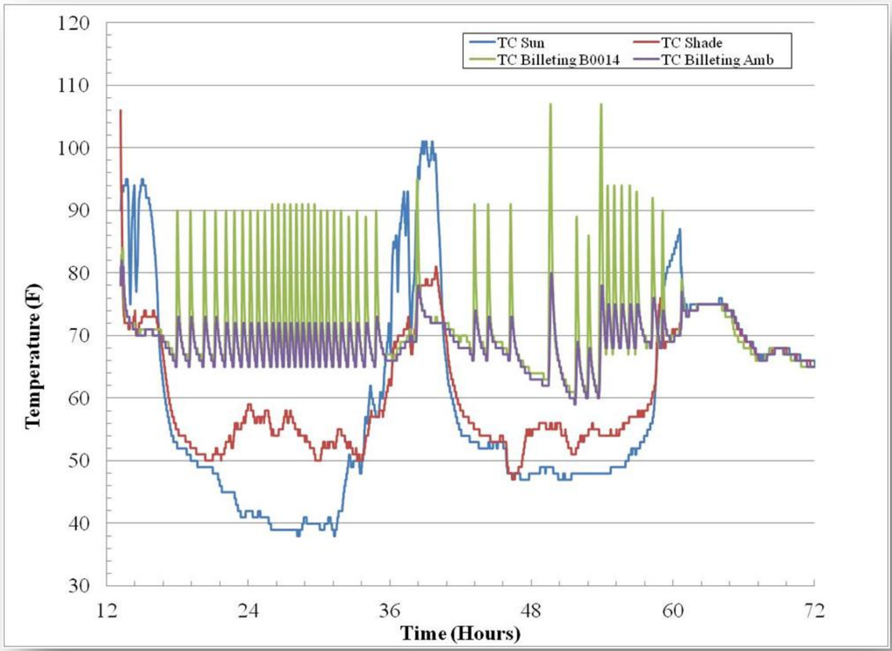



**Figure 12. Billeting tent #2 temperatures heated by a B0014**

*Environmental Control Conclusion*

It is evident that the turn dial / Marine in the Loop control strategy of current ECUs is very inefficient. The simple cost effective method to improving efficiency of current POR ECUs may be to modify them with a digital thermostat / controller capability. Additionally, there are other energy efficient techniques of providing environmental control. One such technology will be discussed in the following section detailing the ExFOB Extended User Evaluation.

# II. ExFOB EUE

ExFOB 2010-2 focused on efficient powering and cooling of COCs. Following the ExFOB process described in Appendix B, two of the systems demonstrated at ExFOB 2010-2 at Marine Corps Air Ground Combat Center (MCAGCC) were the hybrid system and the Direct Current Air Conditioner (DCAC). The ExFOB EIPT purchased two hybrids and three DCACs for further demonstration. The systems were integrated with POR generators and power distribution and setup at Marine Corps Tactical Operations Group (MCTOG) aboard MCAGCC in June 2011 for safety checks and metering as a pre-EUE effort. The report for this data collection can be found at https://ehqmc.usmc.mil/sites/E2O/Reports/110715%20NSWC%20Carderock%20ExFOB%20Phase%20Four%20Follow%20On%20Test%20Report.pdf

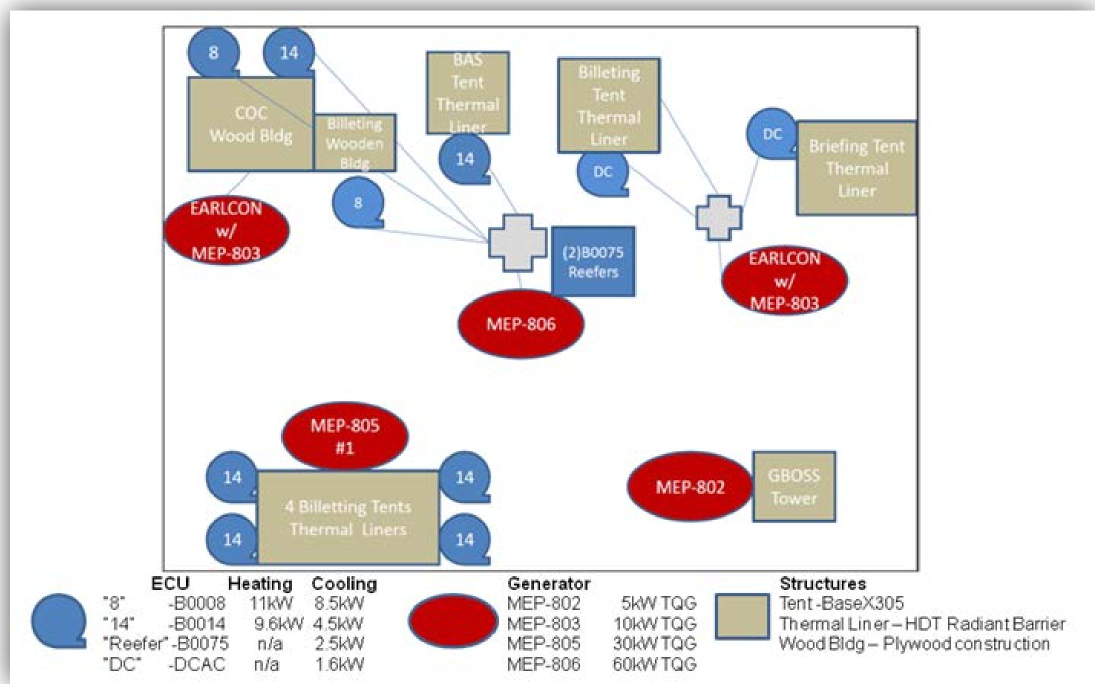



**Figure 13. EUE equipment implementation at PB SW**

### A. Hybrid Power System

Hybrid power systems combine generators, batteries, and sometimes secondary power sources such as photovoltaic solar panels, all with controls designed to automate the performance of the system. The second iteration of ExFOB focused on hybrid power. The system utilized throughout the ExFOB process and was deployed to Afghanistan for a EUE, was the hybrid system.

The hybrid was connected to a MEP-803 10 kW TQG with the capability of auto-starting the TQG. The TriCon contained 84 kWh of energy storage in the form of 48 deep cycle lead acid batteries, although only 50% of the energy storage was utilized to support a longer lifespan. Additionally the system utilized a 4.8 kW photovoltaic (PV) array comprised of twenty 240W panels. The system output 208V three phase power and connected to the Marine Corps POR distribution boxes, Mobile Electric Power Distribution System Replacement (MEPDIS-R),. A graphical depiction of the system operation can be seen below. The hybrid was deployed for this EUE to evaluate operational tradeoffs of hybrid systems on the battlefield.

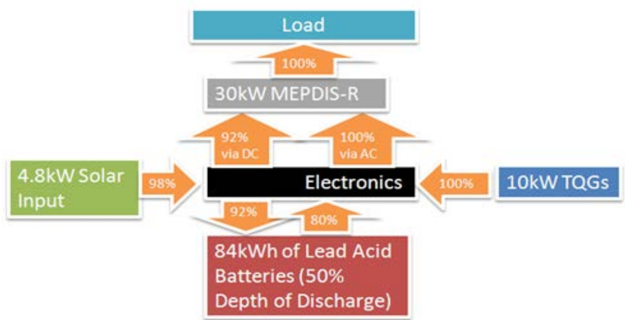



**Figure 14. Hybrid system diagram**

To demonstrate the capability, let us focus on the hybrid system's role at PB SW. The hybrid was powering the COC electrical load as shown in the PB SW diagram in Fig 2. Remember from Fig 4, the COC average load was about 2.2 kW. For the sake of this example, let us assume that it is a constant 2 kW load.

**Figure 15. 10 kW hybrid system**

Let us walk through the performance of the system in phases. First, when it is initially set up and the COC is plugged in, and let us assume the batteries are at low level of charge. The system auto-starts the TQG and runs it at 80% load (8 kW is generated). The 2 kW power demand within the COC is being met, while the excess 6 kW is converted to DC and stored in the batteries. After about 6 hours, the energy storage would achieve the desired charge capacity and the system would auto-stop the TQG.

Instantly, the system switches to the batteries meeting the power demand of the COC. Power is inverted from DC to AC and current flows to the COC. During this simplistic example, the 42 kWh of usable storage could support a 2 kW power demand in the COC for 21 hours. Of course, this does not take into account losses due to DC to AC inversion, chemical to electrical conversion, and distribution, each of which are ignored for the sake of the example. Once the system senses the batteries have discharged the pre-determined 50%, the TQG once again receives an auto-start signal. Figure 15 below illustrates this behavior over a period over a six day period during pre-deployment testing. Slight increases to battery buss voltage are indicative of solar power charging, while steep increases are indicative of the MEP803 auto-starting to provide charging.

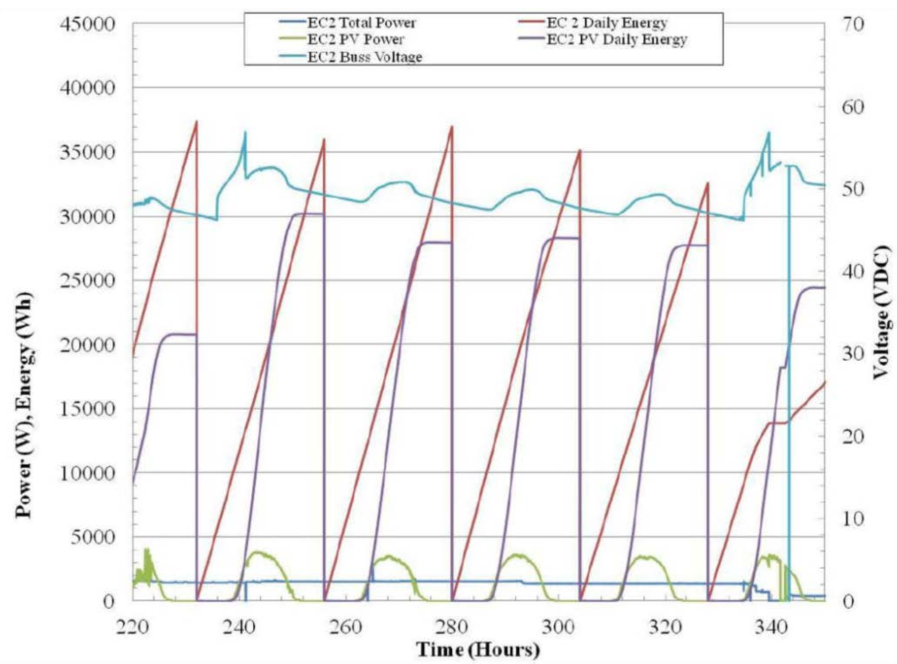



**Figure 16. Hybrid system charge discharge cycling with a MEP803 TQG**

Notice in 6 hours, the TQG produced enough energy to support the COC load for 27 hours, while running at optimal fuel efficiency, decreasing the odds of maintenance, and reducing the run time on the generator by 78%.

Of course the above example did not take into account the solar energy harvested by the PV. On average, the 4.8 kW of rated PV, harvested about 25 kWh of energy a day. Each day an additional 25 kWh of energy was directed to the DC bus regardless of the state of the TQG; on or off. Notice, in this simplistic example, negating losses, that is enough energy to power the COC load for an additional 12 plus hours without requiring the TQG to turn on. Therefore, using the example above the TQG would remain off for an additional 12 hours, increasing the off-time from 21 to 33 hours.

Table 3 below represents a modeled comparison of the hybrid powering the PB SW COC as compared to a standalone MEP-803a10kW TQG. Over a four month period, the hybrid system powering the COC electrical load would require only 459 gallons of JP-8 as compared to the 1040 gallons the standalone TQG would require, for a 56% reduction. Additionally, the hours on the TQG would reduce by 80%, from 2928 to 585 hrs. This along with the lack of maintenance problems due to the increased load on the generator, would ensure an increased lifespan of the TQG.

**Table 3. Hybrid System vs. MEP-803 fuel savings comparison**

| | MEP-803a | Hybrid |
|---|---|---|
| Generator Usage (hrs) | 2928 | 585 |
| Average Percentage of Rated Load (%) | 22 | 80 |
| Total Fuel Consumed (gal) | 1040 | 459 |

## B. Efficient Cooling

Part of the ExFOB EUE was based on efficient air conditioning. A direct drive air conditioner called Direct Current Air Conditioner, DCAC, was deployed to Afghanistan during this evaluation. The advantage of this lower power 1.7 ton unit is that it is a variable speed system, which ensures variable power draw. By incorporating this capability, energy draw, and subsequent fuel usage can be minimized during times when the outside ambient temperature is not vastly different from the intended tent temperature. Additionally, the use of a basic digital thermostat controller provides efficiency gains as discussed in the ECU section.

**Figure 17. DCAC unit**

At PB SW, one DCAC was used to replace a B0014, three ton POR system. The swap to a lower cooling capacity was facilitated by incorporating a Radiant Barrier thermal liner on the BaseX305 tent. The increased insulation allowed for less cooling power. Additionally, the variable speed nature of the DCAC is believed to be a more efficient cooling strategy than the on/off nature of the POR system. Table 3 shows a specification comparison between DCACs and B0014s.

**Table 4. Comparison of a B0014 ECU with a DCAC**

| | B0014 | DCAC |
|---|---|---|
| **Btu** | 36k | 20k |
| **Tonnage** | 3 | 1.7 |
| **Max Power (Cooling)** | 4.5 kW | 1.6kW |
| **Heat Capable** | Yes | No |

Figure 16, below, shows the temperature profile of the billeting tent cooled by the DCAC. The DCAC was replaced by a B0014 around the 100 hr mark. This series of measurements effectively shows some of the contrast between the two systems. By switching the B0014 for the DCAC, data collection was accomplished with a reduced number of variables. With the same tent, same location, and same users, only the variation in weather was different between the two periods.

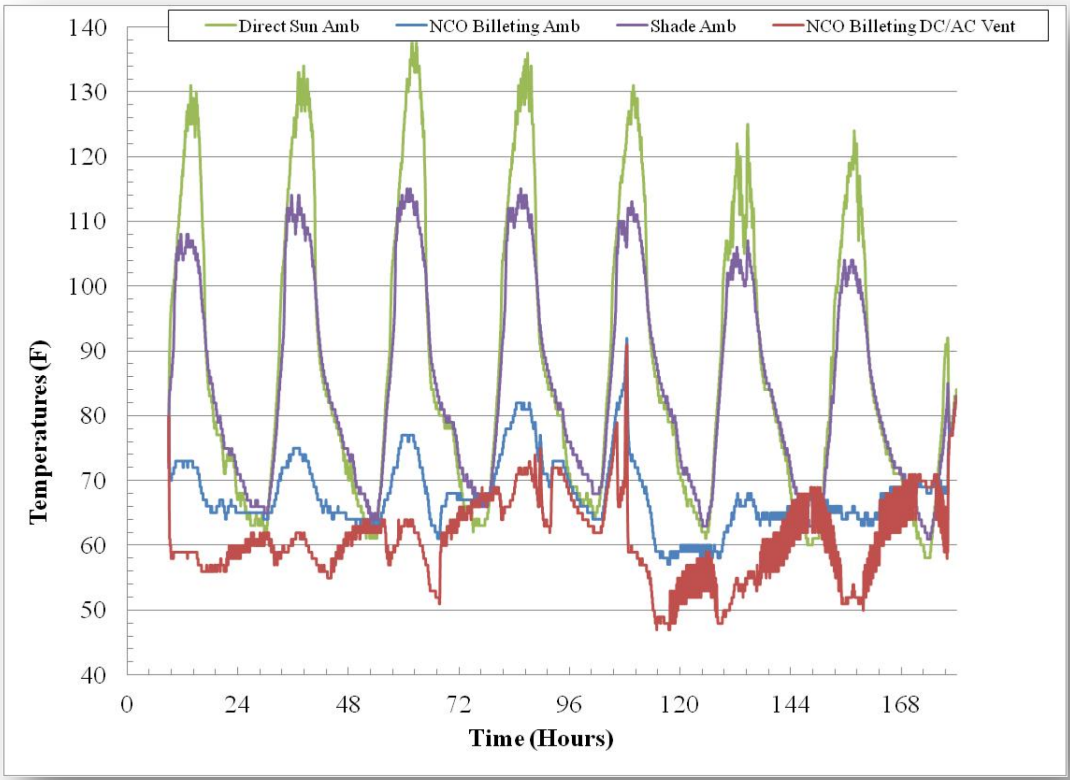



**Figure 18. DCAC and B0014 cooled Base-X305**

Notice that despite outdoor ambient temperatures in excess of 100ºF in the shade, the DCAC effectively cooled the tent to between 70ºF and 80ºF, while the B0014 consistently overcooled the tent with indoor ambient temperatures below 70ºF over the entire three day period. Additionally, during nighttime operation while the DCAC ensured a "cool" mid-60s, the B0014 dropped the temperature to below 60ºF on occasion. Regardless of the power draw differences between the two ECUs, tracking the indoor ambient shows that the DCAC offers a more efficient control strategy by allowing the user to set a desired indoor temperature, similar to typical homes in the United States.

To estimate ECU power and energy consumption, a combination of experimental data was used. The power and performance data of DCACs at MCTOG was utilized to estimate the power draw of the DCACs at PB SW.

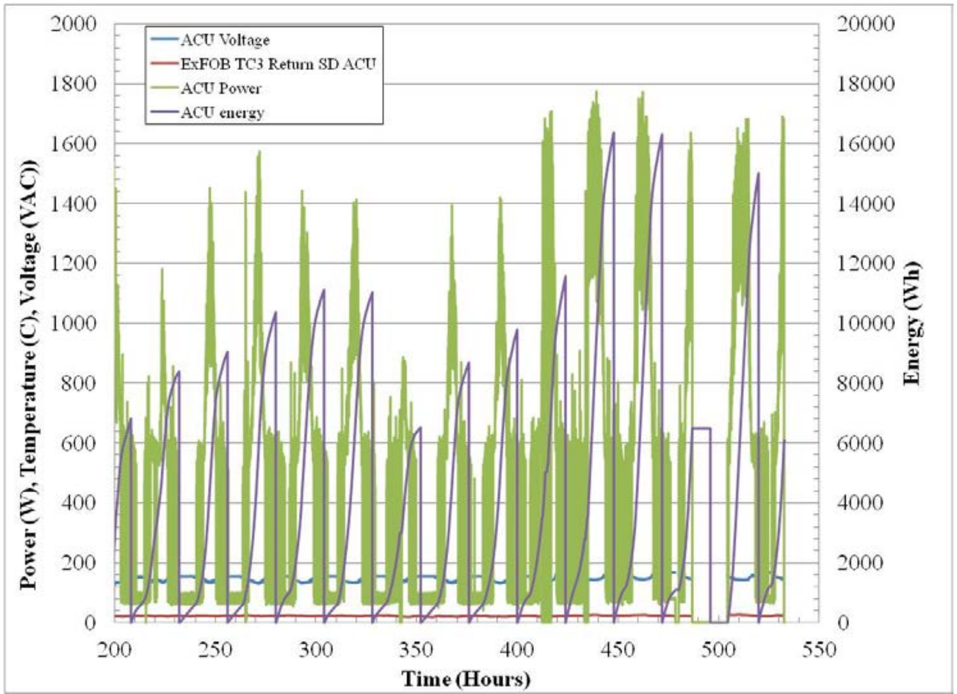



**Figure 19. DCAC performance at MCTOG at 29 Palms**

Some of this power and performance data is shown in Figure 17. The data demonstrates how during peak cooling the DCAC required anywhere from 900 to 1600 watts. While in the lower cooling range, the DCAC required between 100 and 650 watts. To simplify the DCAC power estimation for PB SW, 1600 W was used for peak cooling periods and 600 W for lower cooling periods. Both numbers are on the high end of the respective ranges shown in Figure 10, but this strategy ensure the DCAC power requirements from PB SW are not under estimated These constant power values are utilized below in Figure 18 in relation to the metered temperatures from the billeting tent at PB SW.

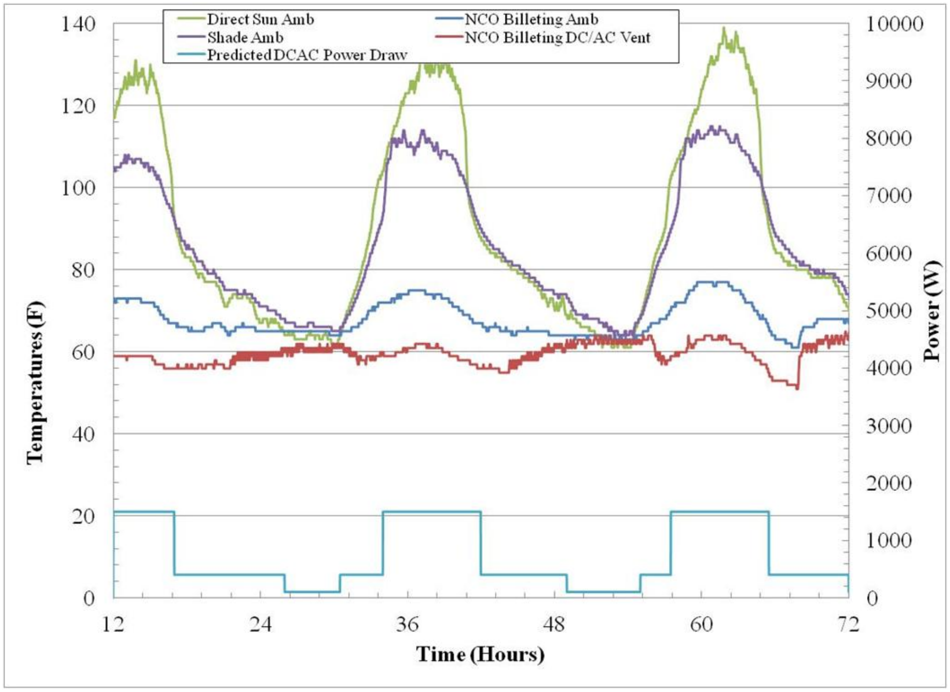



**Figure 20. Tent temperatures on a Base-X305 cooled by the DCAC**

The average power draw over these three days is 0.73 kW, with a total energy draw of 17.5 kWh per day. Notice that the average indoor ambient temperature is 68ºF. Unfortunately a similar estimation of the power draw of the B0014 performance in Figure 16 above was not possible due to limited historical data on the different stages of performance of B0014s and the related power draws.

Based on Figure 18, the total energy used by the DCAC each day is less than four times the max power draw of the B0014. This means that if the B0014 is cooling for four (4) hours a day, the DCAC would have used required less energy. We know from the plenum temperature of Figure 16 that max cooling occurred for a much longer period each day. All quick drops in temperature within the plenum indicate an increase in cooling by the B0014. This could be from fan to compressor or off to fan. Figure 16 indicates that the B0014 is in some varying stage of performance in excess of 20 hours throughout the day. Although conclusions cannot be made regarding how much energy was required by the B0014, it is very likely from this simplistic analysis that it would have been substantially greater than the DCAC. However, considering that B0014's drew 4.5 kW during peak cooling and inspecting Figure 9 confirms the B0014 drew substantially more energy per day.

### C. ExFOB EUE Conclusion

The performance of both the hybrid and the DCAC at PB SW, proved hybrid power and efficient cooling could provide substantial energy and fuel savings on the battlefield. While, the systems themselves were not sufficiently hardened and reliable to meet Marine Corps standards, the capabilities should be pursued via the requirements process. To that end the Marine Corps initiated an Analysis of Alternatives (AoA), titled Mobile Electric Hybrid Power Source (MEHPS), to determine the utility and appropriate scale of hybrid power systems should be developed. The results of the MEHPS AoA are expected by the end of 2012.

# III. Variable Power Demand

## A. Background

A great deal of the inefficiency on the battlefield is due to low loads on generators. Although diesel generators are a reliable lightweight power source on the battlefield, the efficiency and reliability of those generators decrease significantly when they are under-loaded. Generators running at low loads cause three major problems:

1) Poor fuel efficiency
2) Increased maintenance
3) Decrease in lifespan of the system

In any first world country, right-sizing generators to demand would be relatively easy. Generators are readily available for swapping out when it is found that the generator in use is too large. However, in austere locations logistics limit equipment flexibility and availability. As a result, deployed Marines are focused on having a reliable source of power, which drives them to oversize their generators. Utilities Marines are trained to sum the peak power demand of all known systems and choose a generator that will support the summed load at 80%. Eighty-percent is used as an objective to account for any additional equipment which is plugged in, and transient spikes characteristic of ECUs.

PdM –Expeditionary Power Systems (EPS), Marine Corps Systems Command is the acquisition agent for generators on the battlefield. To meet the diverse range of power requirements on the battlefield, PdM-EPS field a family of solutions including 10, 20, 30, 60, and 100 kW generators. This ensures varying size options to help utilities Marines achieve the 80% goal.

If all equipment loads were constant, then the problem of right-sizing generators would not prove very challenging. The peak power tabulation would be a constant load, meaning once the utilities Marines selected the right generator, they could be confident of an efficient and reliable power supply. Unfortunately, the largest loads on the battlefield have the most significant changes in power demands.

Earlier it was shown how coffee pots, microwaves, radios and battery chargers create spikes in power demand for Company-sized COCs. These are some of the smaller variable loads encountered on the battlefield and can cause problems when sizing generators for small power requirements. However, because cooling electronics is a requirement found even at austere locations on the battlefield, the same problem occurs with an even larger impact when ECUs are required.

The maximum power draw from an ECU occurs when providing resistive heat for internal fans to distribute. In the case of B0014s, utilities Marines in Afghanistan used 8 kW as their planning factor for max power draw. Therefore, if the only system they had to power was a B0014, they would choose a MEP-803a, 10 kW Tactical Quiet Generator (TQG), as it fits perfectly with the 80% load planning factor.

However, this presents a very large and very common problem; the load is drastically variable throughout the day and the year. In order to illustrate the problem, let us consider the B0014 discussed above. Even in the winter time, when the heater is on most of the day, when a heated tent reaches the value set on the remote temperature dial, the power drops from 8 kW to about 0.5 kW. During these periods, the 10kW generator would be running at 5% of rated load causing greatly decreased fuel efficiency and greatly increased maintenance requirements.

Similar problems can be observed in the summertime. Typically, the B0014s drew 4.5 kW when providing max cooling and near 1kW while idling (45%-10% load). In the spring and fall, this statement remains true, however much more time is spent with the B0014 off or idling.

Figure 19 illustrates the concept of this variable load. Although in reality ECU performance is in part driven by ambient temperature, this simplistic analysis demonstrates how generator load is strongly dictated by the season. Let us assume that the TQG is also powering the lights within the tent. While the lights are a minimal load, they do require that power be available even when the ECU is off. In this sense, the meager power requirements of ancillary equipment create a need for 24 hour generator operation, at locations which do not necessarily need an ECU running.

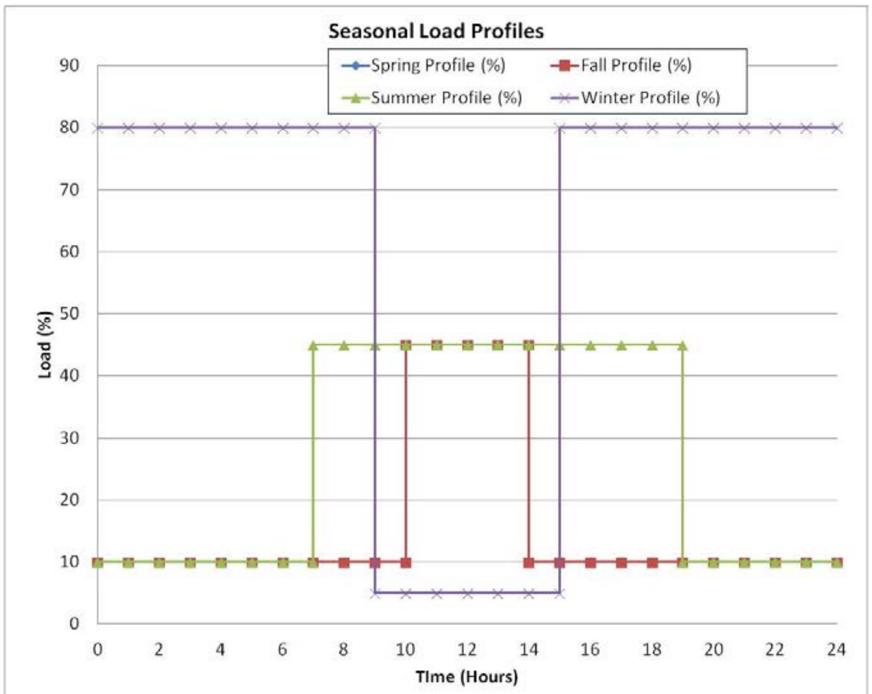



**Figure 21. Seasonal load profiles for a B0014 operating on a 10kW TQG**

Figure 19 shows how little time the TQG is required to provide the desired 80% load. Continuing this simplistic analysis it is possible to determine the likelihood the 10kW generator, described above, will be at a given load throughout the year. Figure 20 below illustrates this likelihood by showing the probability the 10kW TQG will support the theoretical load at any given time, based on these seasonal profiles.

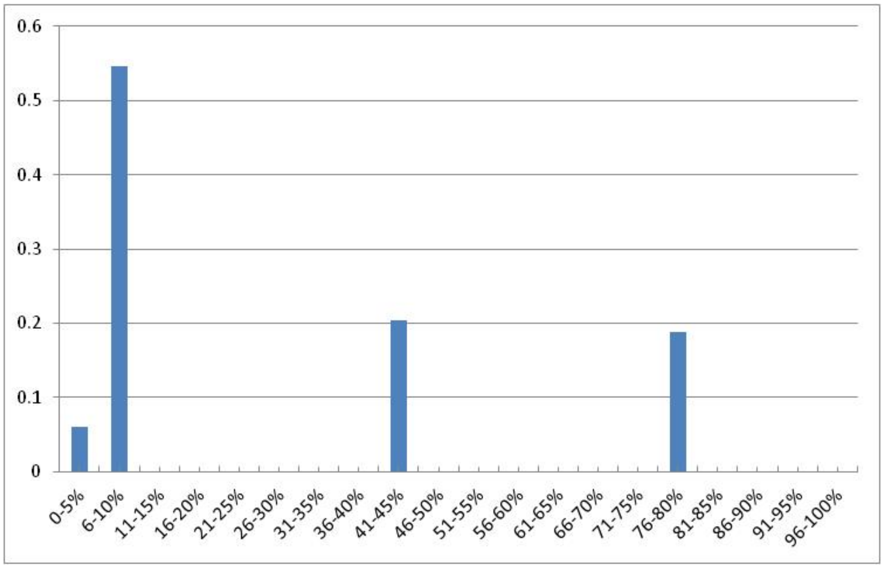



**Figure 22. The probability a 10kW TQG is at a given load powering a B0014 over one year**

As stated earlier and shown above, the amount of time during the year the generator is under loaded is significant. This generator/ECU relationship, which is believed to be widespread, is the primary reason for inefficient operation in the field.

## B. Probability Profiles

Now let us focus on the same variable load principle presented above but leave behind the simple example. ECUs reportedly represent 60% of the ground power demand on the battlefield in RC (SW), Afghanistan [1]. For example, let us consider the MEP-806 60kW TQG at PB SW. As shown in Figure 2, the MEP-806 powered the following system; (2) B0008s, (2) B0014s, (2) B0075 refrigerators, or reefers, and Hotel Loads. Let us assume the following power draws below.

**Table 5. Various loads on a 60kW TQG**

| | **Winter Peak Demand** | | | **Summer Peak Demand** | | |
|---|---|---|---|---|---|---|
| | **kW/ System** | **System Qty** | **Total kW** | **kW/ System** | **System Qty** | **Total kW** |
| **B0008** | 11 | 2 | 22 | 8 | 2 | 16 |
| **B0014** | 8 | 2 | 16 | 4.5 | 2 | 9 |
| **Reefers** | 2 | 2 | 4 | 2 | 2 | 4 |
| **Hotel Loads** | 2 | 1 | 2 | 2 | 1 | 2 |
| **TOTAL** | | | **44** | | | **31** |

Under these assumed loads, during the winter when every system is pulling maximum power, the total load on the generator is 44 kW, or 73% load on the MEP-806 TQG. However, as shown in the example of the 10kW TQG above, that peak power is rarely seen. In fact, in the warmer months, the peak power draw only sums to 31 kW, just over 50% load. Certainly this 60 kW TQG spent the majority of the year well below 50% load.

Therefore, a reasonable question could be, what is the likelihood that any generator on the battlefield will have a certain load. To that end, we have undertaken an effort to collect all observed loads encountered by individuals on the battlefield. To date we have 767 data points of Marines observing loads on 10, 30, 60, and 100 kW TQGs on the battlefield. The below probability profile displays this data.

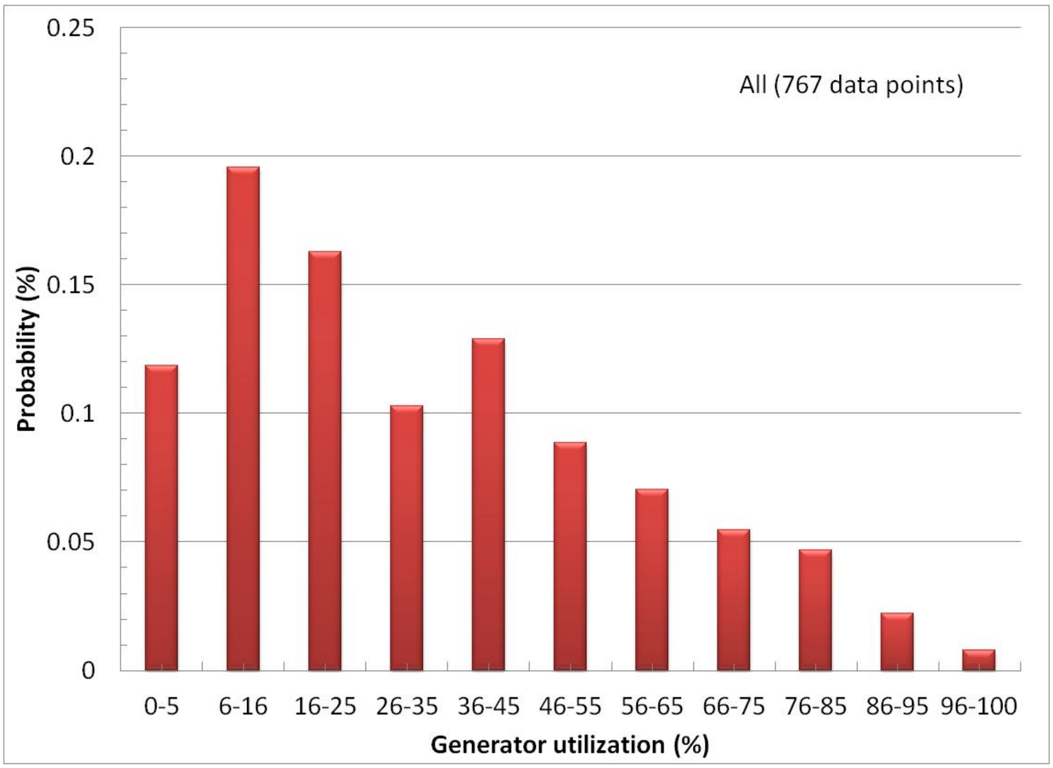



**Figure 23. Generator usage probability for 10kW, 30kW, 60kW, and 100kW TQGs**

Notice that the median is a 32% load. This implies that 50 percent of the time a generator currently in Afghanistan would have a load of 32% or below. This is consistent with several other independent studies, including the *Marine Energy Assessment Team (MEAT) Report*, which found that average generator loads encountered were 30% [2].

*Energy Storage*

As discussed at the beginning of this chapter, low loads on generators lead to three main problems; 1) poor fuel efficiency, 2) increased maintenance, and 3) decreased lifetime of the system. The most effective solution to this problem is to add energy storage in the form of batteries. By adding batteries to a generator, the generator can run at peak performance at all times. The power required to meet the demand would be distributed to the equipment, while the excess power would be stored in the batteries. Once the batteries are full, the generator can be turned off while the batteries are used to meet the demand.  When the batteries discharge to some pre-determined set point, the generator can be turned on again.

This strategy addresses all three problems previously mentioned.  The generator operates at optimal load, which in turn optimizes fuel efficiency.  Also the generator is never at low loads, the source of most maintenance issues.  Finally, the lifetime of the generator is increased both because there are less maintenance issues and the generator is run for less hours.

# IV. Conclusion

This report covers three distinct topics: recent power and temperature metering in Afghanistan; an evaluation of the ExFOB EUE efficient powering and cooling capabilities for COCs; and the contributors to variable power demand encountered on the battlefield. The results of this report will inform Marine Corps' expeditionary energy efforts for years to come.

The power metering data, especially the Company sized COC 24 hour load profile assists the Marine Corps in properly evaluating which power sources can most effectively meet the unit's needs. Additionally, this information is being utilized by the MEHPS AoA as well as programs such as Renewable Sustainable Expeditionary Power (RSEP), out of the Office of Naval Research (ONR).

The temperature metering data found presented in this report has helped the Marine Corps understand the behavioral and technological limitations of current POR ECUs. This understanding is contributing to design of future ECUs and efforts such as the September 2012 ExFOB 2012-2 focused on efficient heating and cooling.

The information presented in the second section of this report, focused on the ExFOB EUE, directly led to the current MEHPS AoA and the Marine Corps' push for hybrid power systems. Additionally, the EUE evaluation led to a recognition within the Marine Corps that non-traditional thermal management must be a top priority, leading to the focused effort of ExFOB 2012-2.

Finally, recent improvements in USMC understanding of the factors which impact variable power demand has gone a long way in scoping the problem on the battlefield of poor power management and the inability to match load to demand. The generator probability profile was utilized in the MEHPS AoA to help create the 24 hour load profiles across the Marine Air Ground Task Force (MAGTF).

It should be noted that all E2O efforts are focused on the Marine Corps Expeditionary Energy Strategy of increasing the efficiency on the battlefield by 50% in 2025. To that end, all efforts such as the information provided in this report are tied the Expeditionary Energy Water and Waste (E2W2) Initial Capabilities Document (ICD).

## References


1. Expeditionary Energy Office "United States Marine Corps Expeditionary Energy Strategy and Implementation Plan" *Office of the Commandant* 2011 http://www.marines.mil/community/Documents/USMC%20Expeditionary%20Energy%20Strategy%20%20Implementation%20Planning%20Guidance.pdf
   Date Accessed: September 12th 2012

2. Col T. C. Moore, Capt B. H. Newell, CWO2 J. L. Alderman, MGySgt R. Dickson, Mr. D. Nolan, Dr. J. W. Barnett "Report of the Afghanistan Marine Energy Assessment Team" January 2011

## Appendix A

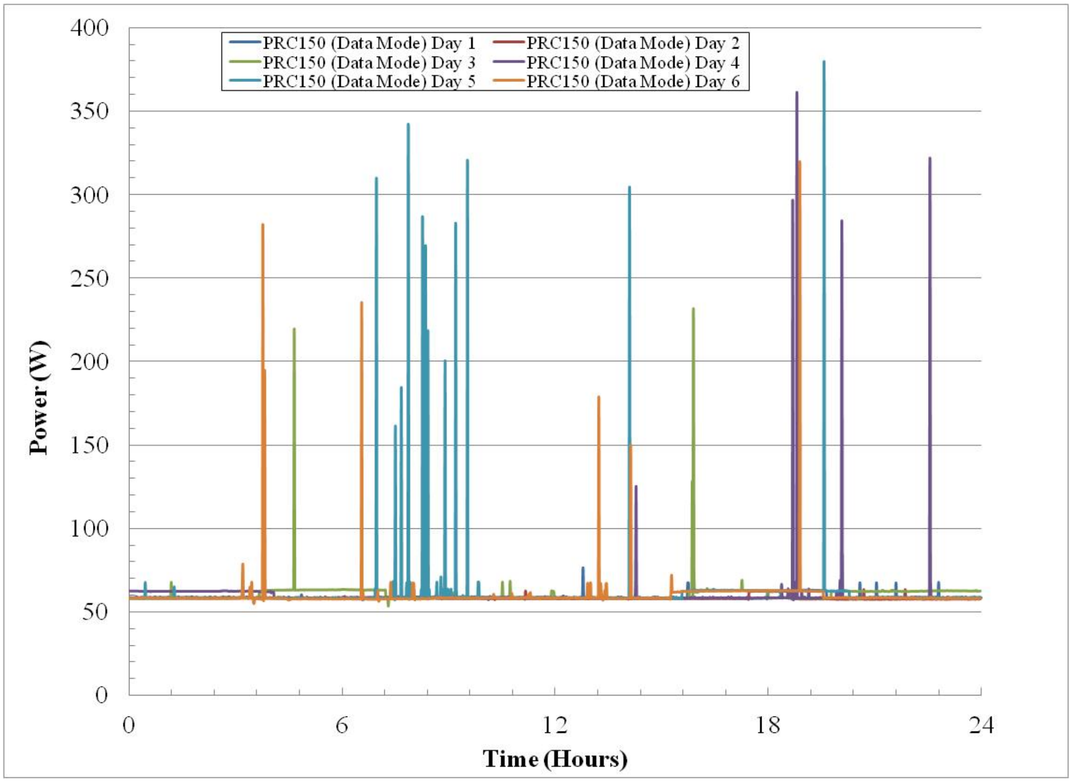



**Figure A 1. Power draw from the PRC-150 in data mode at PB SW in October**

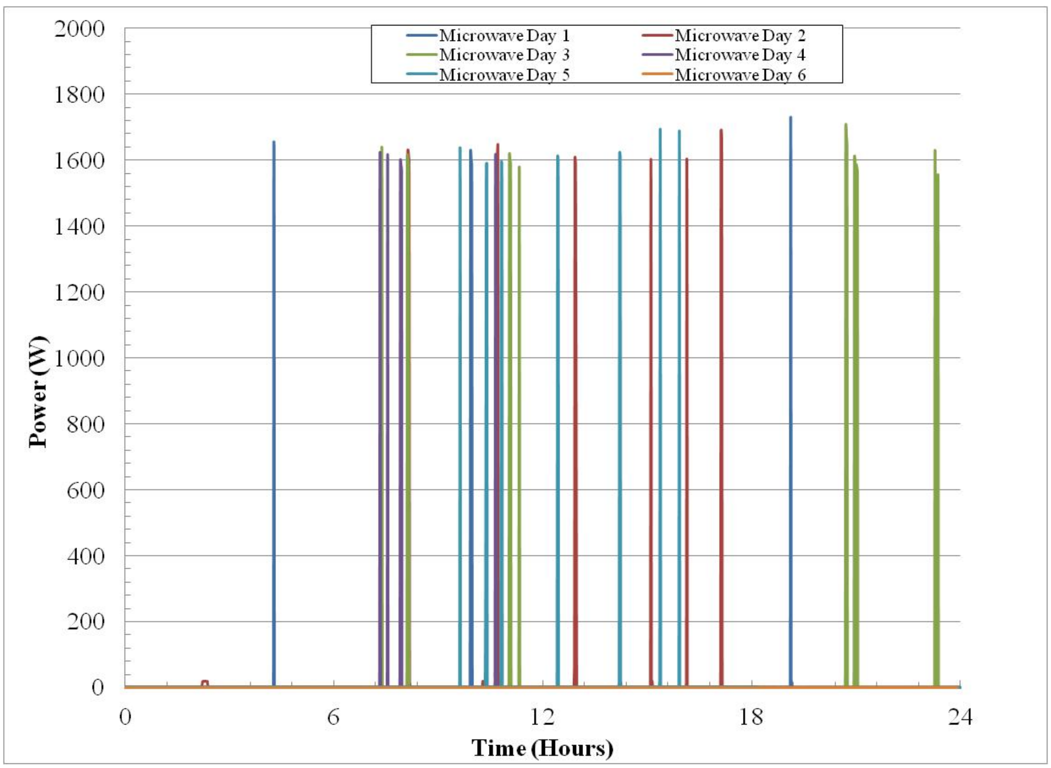



**Figure A 2. Power draw from a microwave in data mode at PB SW in October**

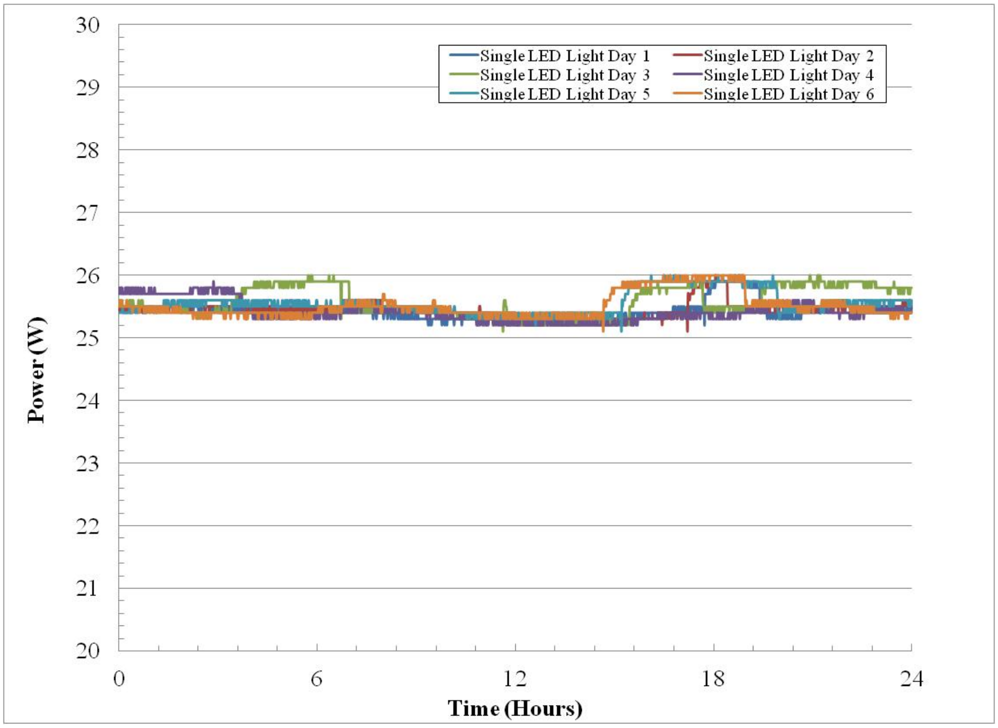



**Figure A 3. Power draw from a single LED light at PB SW in October**

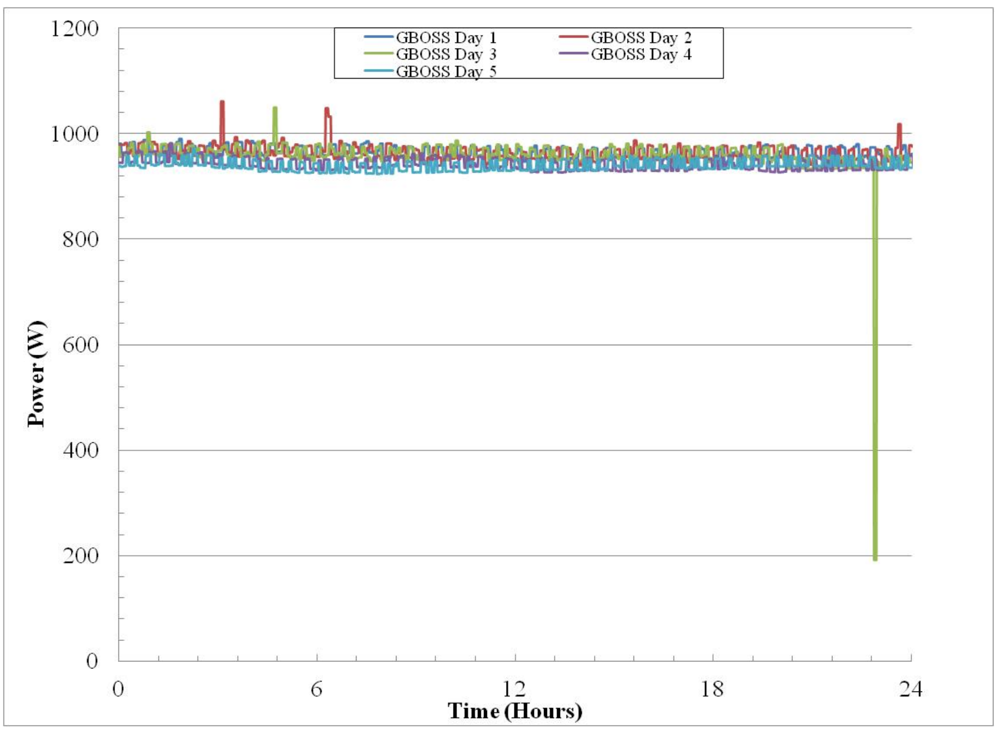



**Figure A 4. Power draw from the GBOSS with two 40" plasma screens at PB SW in October (Does not include tower power draw)**

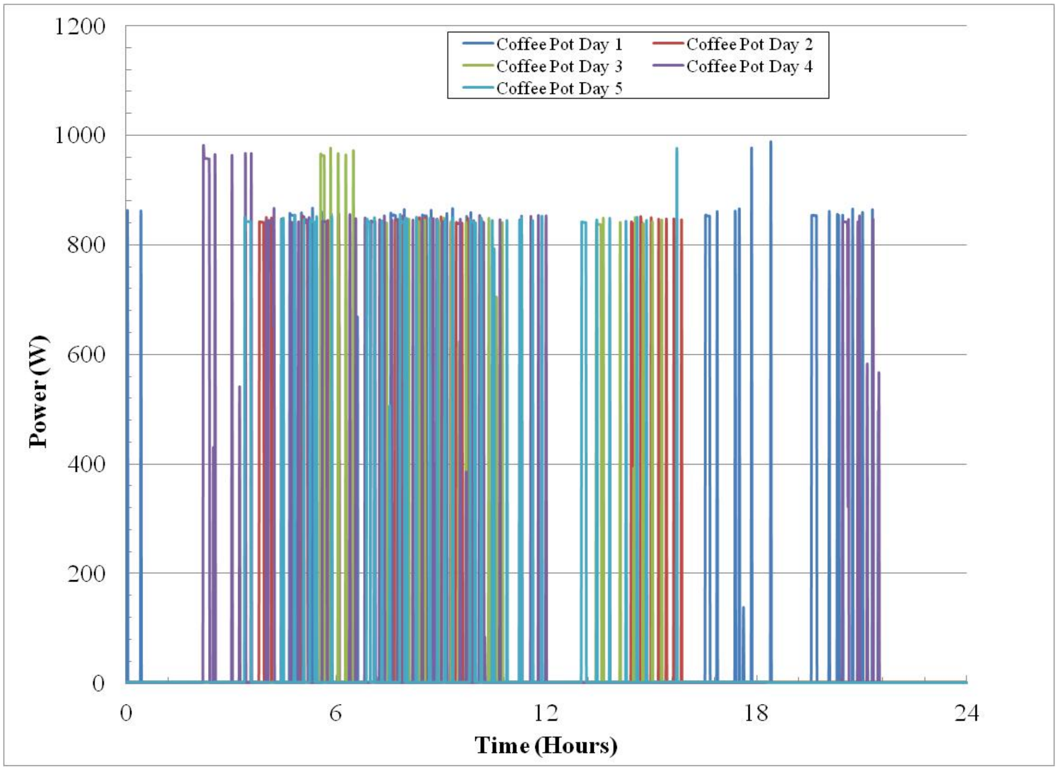



**Figure A 5. Power draw from a coffee pot at PB SW in October**

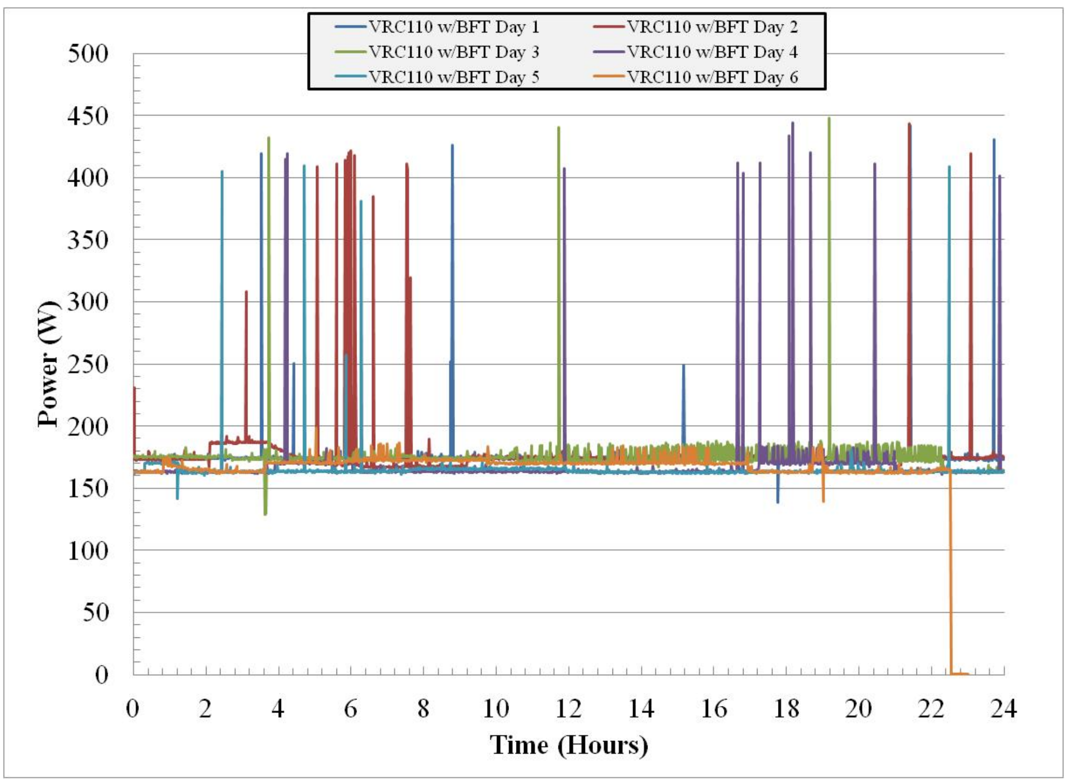



**Figure A 6. Power draw from a VRC110 with Blue Force Tracker at PB SW in October**

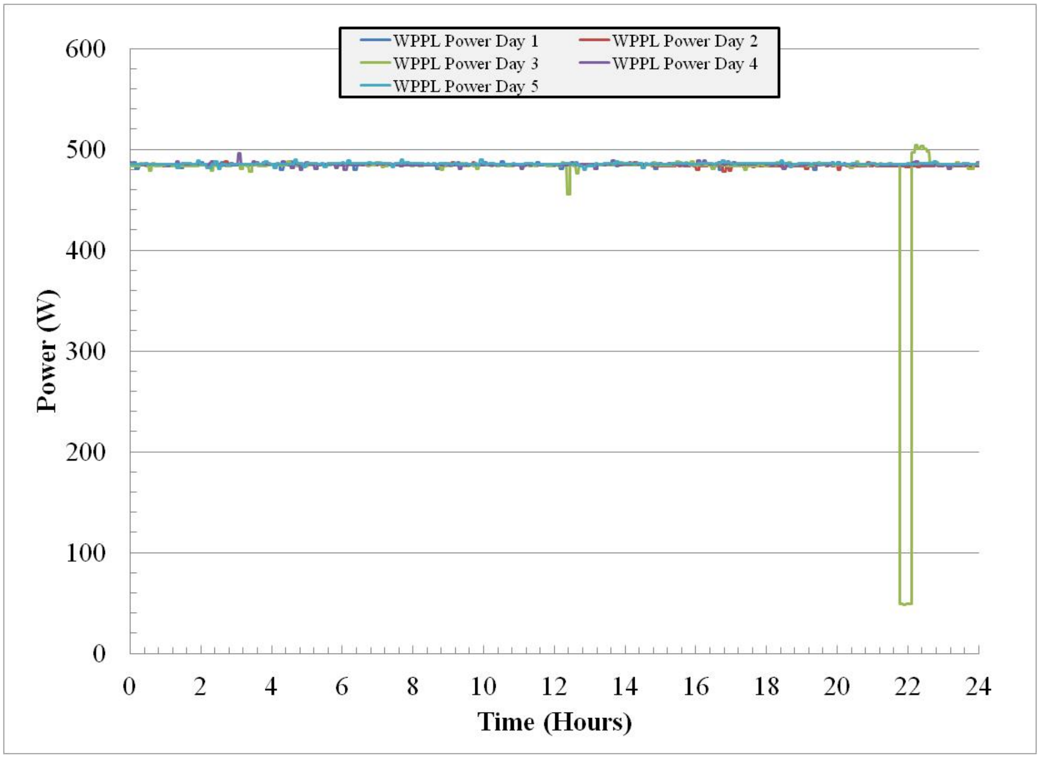



**Figure A 7. Power draw from a Wireless Point-to-Point Link at PB SW in October**

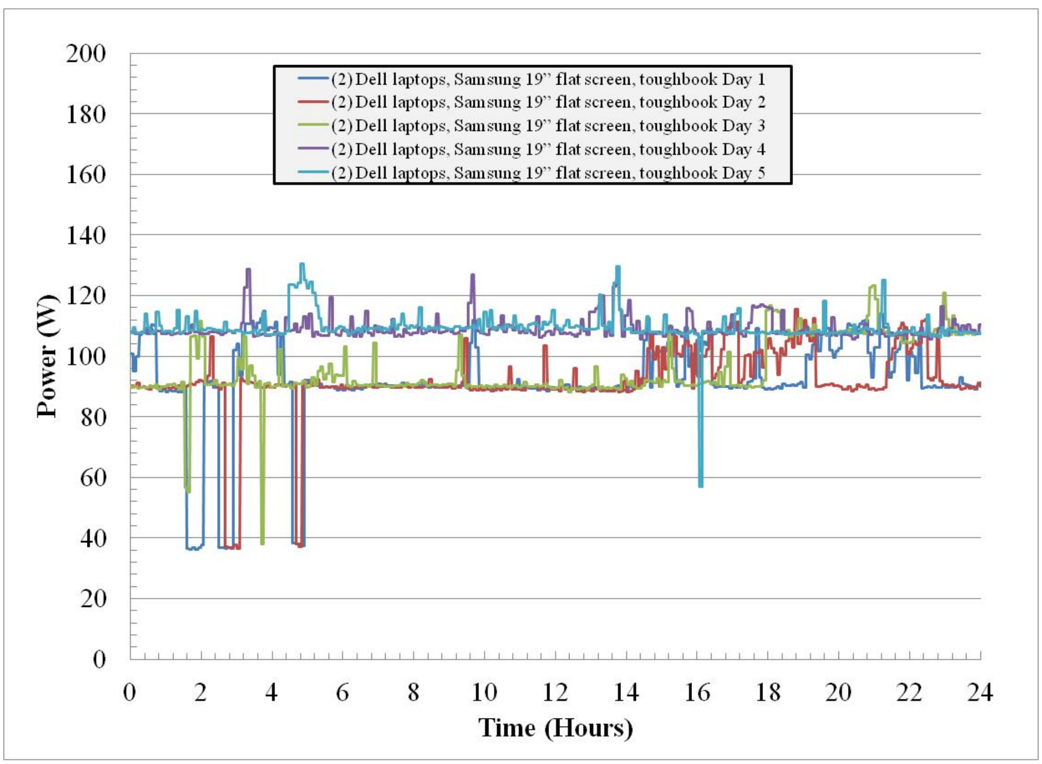



**Figure A 8. Power draw from two Dell laptops, one toughbook, and 19" monitor at PB SW in October**

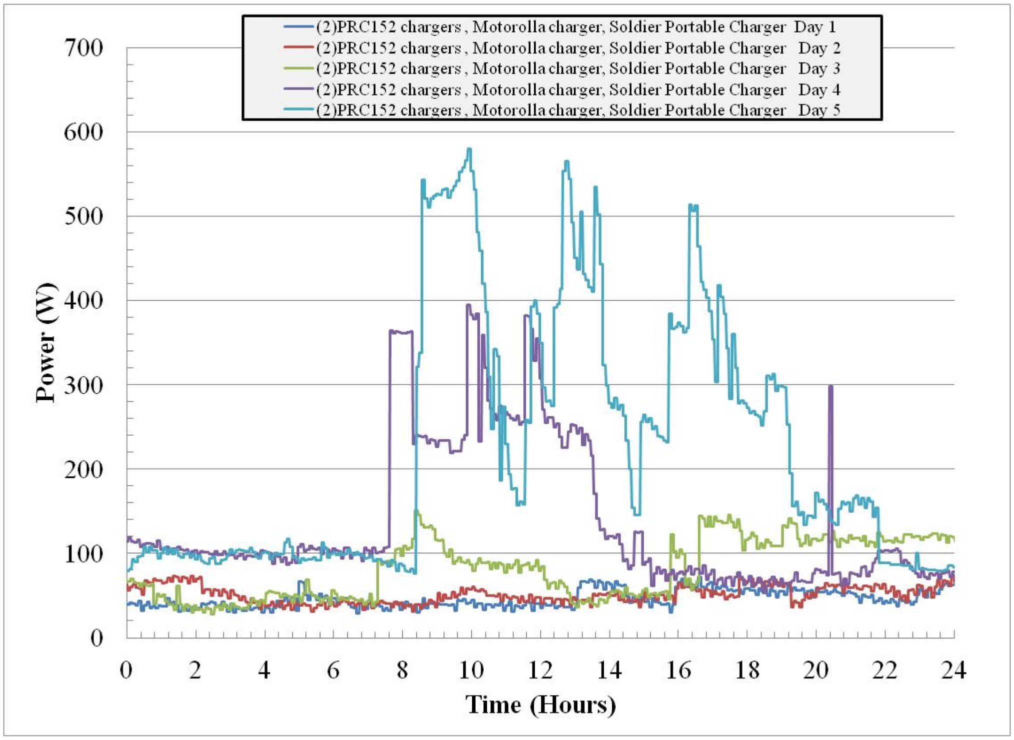


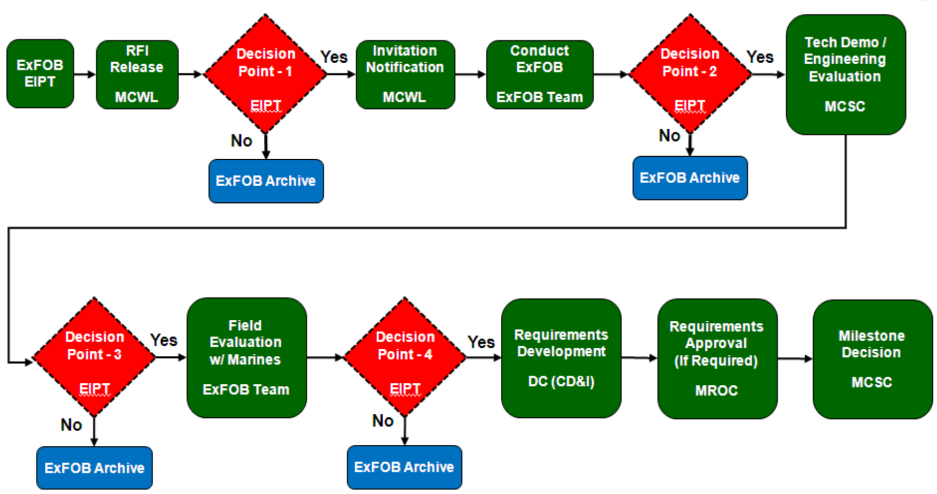

**Figure A 9. Power draw two PRC 152 chargers, one Motorola charger, and one Soldier Portable Charger at PB SW in October**

## Appendix B

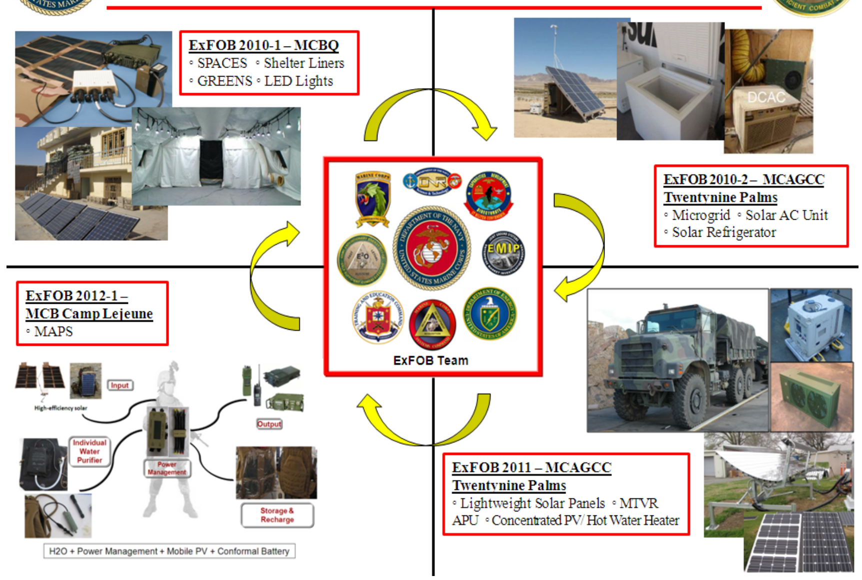
# ExFOB Overview

- Created by the Commandant in 2009, the United States Marine Corps' Experimental Forward Operating Base (ExFOB) brings together stakeholders from across the Marine Corps requirements, acquisition, and technology development communities in a dynamic process to quickly evaluate and deploy technologies that reduce our need for "liquid logistics" today, and to establish requirements for tomorrow. ExFOB guides the development of new requirements documents and informs Marine Corps investment decisions, taking new capabilities "from concept to combat."


# ExFOB Process

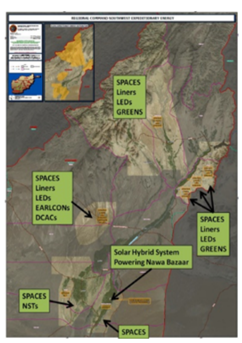


# ExFOB Technology



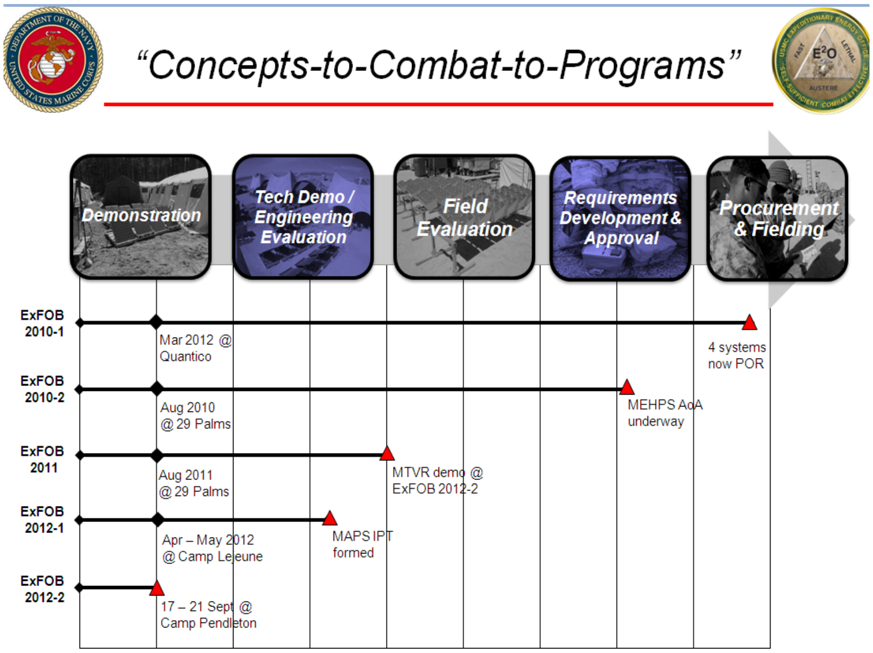

# ExFOB Results

- **Since 2009, ExFOB has:**
  - Reviewed over 250 Technologies
  - Invited and Evaluated 79 Technologies at ExFOB
  - Purchased 11 Technologies for Follow-on Evaluations
  - Transitioned 4 Technologies to Program of Record & deployed them to combat
  - Invested $56M to Conduct ExFOB and Deploy Technologies

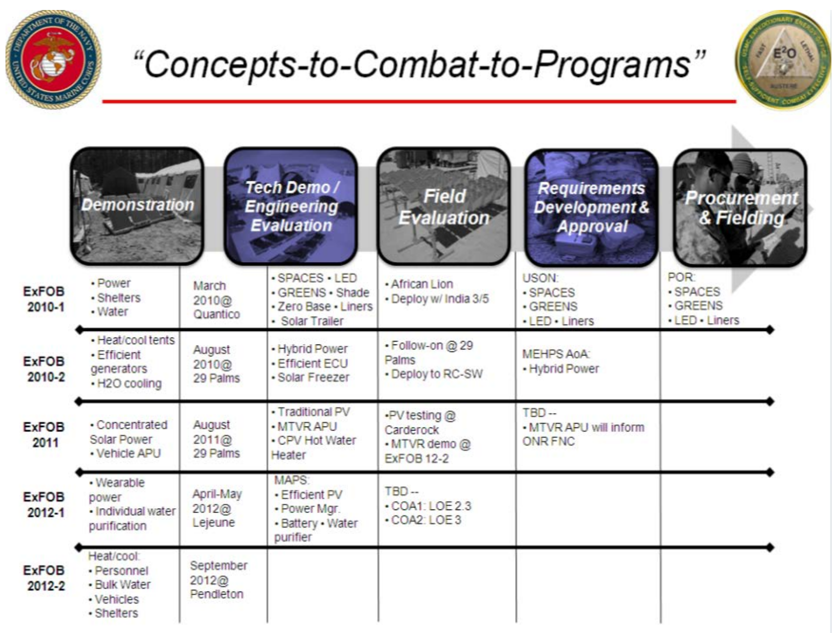



| Unit | SPACES | Liners | LEDs | GREENS |
|---|---|---|---|---|
| 1/6 | 121 | 50 | 100 | Awaiting shipment |
| 2/4 | 82 | 48 | 96 | 20 in transit |
| 3/7 | 24 | 75 | 75 | 20 in transit |
| 3/3 | 82 | 75 | 75 | |
| 1st Recon | 47 | 10 | 40 | Awaiting shipment |
| 2/11 | 16 | 11 | 76 | 1 |
| 2/6 | 126 | | | |
| 2/9 | 104 | | | |
| 3D CEB | | 2 | | |
| 5th ANGLICO | 15 | | | Awaiting shipment |
| RCT-5 | | 25 | 50 | |
| *TOTAL* | *617* | *296* | *512* | *41* |

*Distribution as of 5 January*



"Concepts-to-Combat-to-Programs"
Demonstration
Tech Demo / Engineering Evaluation
Field Evaluation
Requirements Development & Approval
Procurement & Fielding
ExFOB 2010-1
Mar 2012 @ Quantico
4 systems now POR
ExFOB 2010-2
Aug 2010 @ 29 Palms
MEHPS AoA underway
ExFOB 2011
Aug 2011 @ 29 Palms
MTVR demo @ ExFOB 2012-2
ExFOB 2012-1
Apr – May 2012 @ Camp Lejeune
MAPS IPT formed
ExFOB 2012-2
17 – 21 Sept @ Camp Pendleton

"Concepts-to-Combat-to-Programs"
Demonstration
Tech Demo / Engineering Evaluation
Field Evaluation
Requirements Development & Approval
Procurement & Fielding
ExFOB 2010-1
• Power • Shelters • Water
March 2010@ Quantico
• SPACES • LED • GREENS • Shade • Zero Base • Liners • Solar Trailer
• African Lion • Deploy w/ India 3/5
USON: • SPACES • GREENS • LED • Liners
POR: • SPACES • GREENS • LED • Liners
ExFOB 2010-2
• Heat/cool tents • Efficient generators • H2O cooling
August 2010@ 29 Palms
• Hybrid Power • Efficient ECU • Solar Freezer
• Follow-on @ 29 Palms • Deploy to RC-SW
MEHPS AoA: • Hybrid Power
ExFOB 2011
• Concentrated Solar Power • Vehicle APU
August 2011@ 29 Palms
• Traditional PV • MTVR APU • CPV Hot Water Heater
•PV testing @ Carderock • MTVR demo @ ExFOB 12-2
TBD -- • MTVR APU will inform ONR FNC
ExFOB 2012-1
• Wearable power • Individual water purification
April-May 2012@ Lejeune
MAPS: • Efficient PV • Power Mgr. • Battery • Water purifier
TBD -- • COA1: LOE 2.3 • COA2: LOE 3
ExFOB 2012-2
Heat/cool: • Personnel • Bulk Water • Vehicles • Shelters
September 2012@ Pendleton