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MODELING AND ASSESSMENT OF ALTERNATIVE COOLING METHODS OF THE COMBAT OPERATION CENTER

by

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The Marine Corps' Combat Operations Center provides formidable situational awareness and command and control capability using a robust mobile data center. This capability incurs a cost in fuel and restricted mobility due to the size and weight of the cooling and electrical generation. Enhancing the energy efficiency through alternative cooling methods will enhance the Marine Corps tactical flexibility on the battlefield. In both Iraq and Afghanistan, the Improvised Explosive Device threat is of grave concern. Reducing the frequency of fuel convoys may reduce the associated casualties that result.

In this research, a model was created to predict potential reduction in fuel consumption by using alternative methods of cooling. The model considers all the sources of heat load introduced into the Combat Operations Center environment and estimates the amount of electricity required to maintain a set point temperature. An alternative method of cooling is introduced to determine whether it has the potential to reduce fuel consumption.

A substantive increase in efficiency indicates further research has merit. The model offers an analytical method for exploring alternative cooling methods that may be used either individually or in concert to reduce the fuel required by the Combat Operations Center.

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MODELING AND ASSESSMENT OF ALTERNATIVE COOLING METHODS OF THE COMBAT OPERATION CENTER

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

ΔT	Difference in Temperature
A	Area
ACM	Alternative Cooling Method
BLT	Battalion Landing Team
Btu	British Thermal Units
C2PC	Command and Control Personal Computer
C4I	Command, Control, Communications, Computers, and Information)
COC	Combat Operations Center
COP	Coefficient of Performance
COTS	Commercial Off-The-Shelf
CPOF	Command Post of the Future
DoD	Department of Defense
E2O	Expeditionary Energy Office
ECU	Environmental Control Unit
ENIAC	Electronic Numerical Integrator and Calculator
EETD	Environmental Energy Technologies Division
FBCB2	Force Battle Command, Brigade and Below
FLOPS	Floating Operations per Second
FOB	Forward Operating Base
FWD	Forward
GETT	Generator, ECU and Tent Trailer
ICD	Initial Capabilities Document
IEDs	Improvised Explosive Devices
IPS	Instructions per Second
IT	Information Technology
ITEG	Integrated Trailer-ECU-Generator
JROC	Joint Requirements Oversight Council
KPP	Key Performance Parameter
LBNL	Lawrence Berkeley National Laboratory
LED	Light Emitting Diode

MDAP	Major Defense Acquisition Program
MEF	Marine Expeditionary Force
MROC	Marine Requirements Oversight Council
OPS	Operations per Second
OT	Operational Trailer
PC	Personal Computer
Q	Heat Flow
QDR	Quadrennial Defense Review
SOP	Standard Operating Procedure
SPEC	Standard Performance Evaluation Corporation
SUT	System Under Test
U	Heat Transfer Coefficient
UPS	Uninterruptable Power Supply
U.S.	United States
VM	Virtual Machine
WSARA	Weapons System Acquisition Reform Act

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I. INTRODUCTION

This thesis investigates the potential to increase the energy efficiency of the Marine Corps' Combat Operations Center (COC). More specifically, it deals with version 4 (v4), which is the root component of a design intended to be modular in nature. The focus is not only on investigating whether ways exist to increase the energy efficiency of the COC, but also to create a model that may serve as tool to explore the potential of a variety of measures.

This thesis is intended to be the beginning of a large volume of future research in the area of expeditionary energy efficiency. As a result, it is an attempt to be a starting point—a foundation to build upon and an attempt to encourage additional research. Being among the first to tackle this subject, it is likely that the suppositions made regarding some of data contained herein will be challenged for accuracy. In fact, the intent, and therefore, the assertions made in this document should be challenged to enhance their validity.

A. THE PROBLEM

The current configuration of the Marine Corp's COC (v4) is inefficient in terms of energy consumption. This inefficiency is likely a result of a lack of requirements during initial capabilities development that would have made energy efficiency a priority. Regardless of the reason, the fact is that the Marine Corps is a tactically and operationally nimble institution. That being the case, the more systems fielded that require electrical energy, the more it is essential to generate that energy in ways that do not restrain the ability to remain nimble on the battlefield.

A balance must be struck between providing commanders with the best possible information in near real time and keeping them flexible by not overloading them with capabilities that come with a high sustainment requirement—as most Information Technology (IT) systems do. The modern Marine Corps' niche on the battlefield is to move from ship to shore to project force, gain a foothold, and prepare for follow-on forces as required. The basic element of this capability is the Marine Expeditionary Unit

(MEU) that is designed to project force from ship to shore with limited resupply requirements. Any system a battalion landing team must bring ashore must justify its existence in terms of cost versus benefit. In this case, does the command and control benefit created by the COC IT systems justify the restrictive impact on mobility caused by the wait and fuel sustainment cost it incurs? The more efficient the COC becomes, the better the cost/benefit ratio will be. The problem is in the current level of efficiency, not because it prevents the Battalion Landing Team (BLT) from executing its mission, but because it prevents the BLT from performing its mission better.

B. OBJECTIVES

A detailed analysis of the potential increases in efficiency that may be gained by applying proven techniques currently used in commercial settings is conducted. Application of these techniques in a modeled environment will provide the ability to expose deficiencies and identify areas in need of further testing and evaluation, which may result in a limited redesign of the most inefficient elements of the COC system. The goal is to determine analytically whether these efficiency measures merit further testing and evaluation. The model itself is of equal importance. A model fundamentally sound and flexible enough to incorporate the effectiveness values of variable efficiency measures should be a result of this research.

The broader application of the examination and assessment is the potential development of a comprehensive model that has applicability to other command and control nodes both in the Marine Corps and throughout the Department of Defense (DoD).

C. HYPOTHESIS

Cooling of the Operational trailer (OT) tent may be unnecessary or perhaps reduced. All of the required cooling can be offloaded to an Alternate Cooling Method (ACM), and thus, reduce the need to cool the OT tent. The resultant reduction in power consumption because of reduced Environmental Control Unit (ECU) use will be significant.

D. RESEARCH QUESTIONS

Will the use of an ACM to remove the heat created by the OT eliminate the need to cool the OT tent by the ECU? Will the reduction of cooling load translate to a meaningful reduction in fuel consumption? Can a model be produced that has applicability to this scenario and also to other similar scenarios?

E. RESEARCH METHODOLOGY

Two methods were used to develop this thesis: a comprehensive literature review, and in internship and subsequent collaboration with the Lawrence Berkeley National Laboratory. In the absence of a large body of work regarding tactical IT systems efficiency, these methods proved critical to developing the basis for this thesis.

The literature review focuses on both the DoD's mandate to increase the efficiency of combat systems and the civilian sector's research on enhancing the energy efficiency of data processing as a means of reducing cost.

The internship at LBNL was at the behest of the Marine Corps Expeditionary Energy Office (E2O) as a way to explore what knowledge could be gained from their research on similar foci in the civilian sector. The internship developed into a collaboration that provided LBNL with information regarding Marine Corps equipment and procedures while simultaneously applied their expertise in addressing the problems of energy efficiency.

F. ORGANIZATION

This thesis is organized in the following chapters.

Chapter I provides the introduction.

Chapter II is an overview of the literature regarding this topic.

Chapter III is a discussion of research focus and methods.

Chapter IV describes a COC cooling method model and the assessment of the alternative cooling method.

Chapter V contains the conclusions and results.

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II. OVERVIEW: ENERGY SECURITY

Energy security is a top priority of the DoD. As of the writing of this thesis, the DoD does not have an official definition of what “energy security” means, which does not mean that careful thought has not been given to the concept; but rather, that the subject has many definitions in various contexts. The 2010 Quadrennial Defense Review (QDR) states, “Energy security for the Department means having assured access to reliable supplies of energy and the ability to protect, and deliver sufficient energy to meet operational needs” (Gates, 2010). This definition does not do much to clarify the meaning of energy security as it may have many interpretations depending on the perspective.

At the strategic level, the QDR definition implies an imperative to ensure the management and production of energy to support a wide variety of needs. These needs may include energy requirements for facilities, fuel to move U.S. forces around the world, and future energy requirements of an increased load on existing infrastructure created by the inevitable migration to increased reliance on IT systems.

At the operational and tactical level, energy security means reducing the risk associated with delivering sufficient fuel for energy to shoot, move, and communicate on the battlefield. A direct relationship exists between the capability to execute the warfighting functions and the available supply of fuel.

This chapter discusses the importance of energy efficiency, how it may be possible to leverage private sector techniques to realize similar gains, how economies of scale can be created for advantage within the DoD, and why energy efficiency techniques need be applied.

A. THE NEED FOR ENERGY EFFICIENCY FOR SECURITY

In a speech given at the Energy Security Forum by Admiral Mike Mullen, chairman of the Joint Chiefs of Staff in 2010, he underlined the responsibility of the DoD in reducing U.S. consumption of energy. He pointed out that the fully burdened cost of delivering diesel fuel to remote locations in Afghanistan approaches $400 per gallon and required 1.3 gallons of fuel to use per gallon delivered at some forward-operating locations (Mullen, 2010). He continued to use India Company, 3D Battalion, 5th Marines as an example of how the DoD is enhancing energy efficiency through the use of solar-powered, electricity-generation, insulated tents, and ultra-efficient electronics (Mullen, 2010).

The point of these energy efficient techniques is to decrease the sustainment burden that accompanies less efficient systems. On the modern battlefield, a tendency occurs toward more reliance on technology; therefore, the expectation is that the need for electricity production will continue to increase. The ability to flatten the curve of technology dependence to electricity demand will, in essence, increase efficiency.

To realize the true importance of an energy security strategy, the traditional attitudes regarding the cost of energy for defense must be challenged. In the past, the cost of energy in terms of dollars was reviewed. In operational environments, cost in terms of dollars is rather unimportant when compared with the benefit purchased. Those benefits include battlefield mobility, and electric power generation, amongst many others.

The United States (U.S.) has a firm tradition of funding its military well to perform the mission at hand. Simply put, money is no object. On the other hand, this nation is currently experiencing an economic reality that has caused many to reassess the need for more efficient means to provide for the warfighter. Fiscal austerity measures are likely to impact all functions of government with across the board budget cuts. The Budget Control Act, which was signed into law in August 2011, is expected to reduce spending by $2.1 trillion between 2012 and 2021. The bill contains cuts in many areas including the DoD (Government Accountability Office, 2011). The challenge created by this new reality is to continue to provide the necessary energy required by the warfighter in a shrinking budget space.

Cost reduction comes to the forefront as a hurdle to overcome when attempting to maintain the current level of capabilities in a smaller budget space. It may be possible to do more with less in some respects. Acquisition of current systems employed by the warfighter was done in a budget environment that did not put the same emphasis on efficiency during requirements development. At the time, both technological maturity of complex systems and the lack of sensitivity in achieving higher levels of efficiency resulted in the fielding of systems much less efficient than that produced today. In fact, in August 2006, the Joint Requirements Oversight Council published a memorandum that endorsed selectively applying an Energy Efficiency Key Performance Parameter (KPP) for Major Defense Acquisition Programs (MDAPs), as well as for select lower level acquisition category programs (Giambastiani, 2006). The implication of the memorandum is that a need exists to enhance energy efficiency in the systems being fielded. The Joint Requirements Oversight Council (JROC) agreed to (1) define the "fully burdened" cost of delivered fuel to price the logistics fuel delivery chain fully, (2) establish overarching policy mandating fuel efficiency considerations to fleet purchases and operational plans, consistent with mission accomplishment, and (3) mandate life cycle cost analysis for new capabilities to include the "fully burdened" cost of fuel during analysis of alternatives and evaluation of alternatives (Giambastiani, 2006). Whether specifically for the goal of reducing cost or not, it is most assuredly a means to do so.

The one cost that Americans are reluctant to pay is that of human lives. Many cases have occurred in which the risks to U.S. warfighters cannot be reduced to zero. However, this does not mean that many opportunities do not exist to reduce the frequency of such cases. Effective situational awareness brought about by today's advanced IT infrastructure plays a vital role in reducing these cases. On the modern battlefields of Iraq, Afghanistan, and wherever else combat power must be projected, command and control systems are increasingly dependent on IT infrastructure. This infrastructure requires a great deal of electricity that must be generated using mobile electric power; in other words, generators that consume diesel. In Iraq, generated electric power is so relied upon that up to 70% of the supply convoys on Iraqi roads were carrying fuel to forward operating bases and remote outposts that used diesel generators to produce electricity (Defense Industry Daily, 2012). Lieutenant General Richard Zilmer, Commander, Multi-National Force—West in Al Anbar province, Iraq, recognized that something must be done to reduce the reliance on diesel fuel for the generation of electricity. According to Representative Roscoe Bartlett of the House Armed Services Seapower and Expeditionary Forces subcommittee, "…convoys to deployed forces add costs to the logistical chain and create targets for IEDs, the single greatest source of casualties in Iraq.” Lieutenant General Zilmer likely recognized the same because in 2006, he made a request to address this situation (Defense Industry Daily, 2012).

Both Representative Roscoe and Lieutenant General Zilmer realized the correlation between the number of logistics convoys and the incidents of Improvised Explosive Devices (IED) attacks. Given that 70% of the convoy tonnage was fuel, it was obvious that U.S. dependence on diesel fuel is directly linked to the number and severity of IED casualties. Clearly, greater efficiency amongst systems that use electricity is an appropriate place to focus to reduce the quantity of fuel required to power them.

B. LEVERAGING THE PRIVATE SECTOR

A great deal of research has been done to address the power consumption of data centers. A reduction in energy related costs has become a focus as a means to reduce operating expenses. The application of energy saving techniques applied to mobile devices has been used as a model for increasing the efficiency of servers; however, some doubt exists as to whether a direct application of the same technology in the server space occurs. Research has found that the most common modes of operation of servers are also the most inefficient in terms of energy consumption (Barroso & Holzle, 2007, pp. 33–37). Techniques designed to create proportionality between computing and energy consumption have become a focus of data center design (Barroso & Holzle, 2007, pp. 33–37).

The advent of cloud computing has created new opportunities to increase the efficiency of client-server data infrastructures greatly in terms of power consumption. The research has identified many levels at which higher efficiency can be realized—computation; data processing, power distribution at the rack level and server level, power generation and transmission, etc. (Nagothu et al., 2010, pp. 1–7). Data center power inefficiencies are typically due to a tendency to load many severs lightly with client requests. As an alternative, tools that adaptively predict loading through signal monitoring can more precisely determine how many servers need to be in use. The use of this method results in fewer servers turned on, which are loaded at a target of 80–90% of processing capacity (Nagothu et al., 2010, pp. 1–7). Unused machines remain in low power modes, and thus, maximize their potential efficiency.

In an attempt to reduce power requirements for data centers, the concept of low-power systems versus systems designed for high-efficiency, has been analyzed in an attempt to determine which is more efficient. The research suggests that high-efficiency systems are better because limiting the power envelope will eliminate points in design that may be more efficient (Meisner & Wenisch, 2011, pp. 109–114). Efficiency in design can be constrained by a reduced power budget. The mobile computing space has driven the impetus of low-power design; however, the benefits realized do not transfer to the server space. Research has discovered that a weak correlation exists between peak power (high or low) and efficiency. On the other hand, a strong correlation does exist between efficiency and features, such as energy required at peak utilization, dynamic range, peak performance, and number of cores per socket (Meisner & Wenisch, 2011, pp. 109–114).

A second benefit found in the use of high-efficiency over low-power systems is the reduced cooling requirements. Low-power systems are typically weaker, and thus, require scaling of software to run on them. The result is a larger number of machines to do the same work, which not only negates the power consumption advantage but also creates an increased cooling requirement (Meisner & Wenisch, 2011, pp. 109–114). The increased need for cooling translates into increased power usage.

The research concerning power usage goes beyond hardware methods of reducing power consumption. A distinct software approach to enhancing the efficiency of hardware systems occurs, and thus, reduces power consumption. Server virtualization provides the capability to consolidate the processes performed on multiple servers onto a single large server (perhaps several). Following the concept of eliminating the need for many servers that run at low capacity, virtualization assists in achieving the goal of forcing servers to operate closer to their available capacity. When these servers are designed for high efficiency rather than low power consumption, the net power needed to operate and cool them is reduced.

At the server level, virtualization provides the capability to consolidate task-specific jobs within virtual machines (VMs), which requires a smaller number of hosts to accommodate the load. Additionally, not all available hosts may be required for the number of VMs in use; therefore, dynamic load balancing among hosts allows those unused to remain in hibernation mode (Humphries & Ruth, 2010, pp. 75:1–75:6). The resulting increase in efficiency occurs because a host running at or near 100% capacity uses less electricity than multiple hosts at or near 50% capacity due to the use of multiple core processors. The quantity of electricity required to activate a single core is less than an additional host's base electricity requirement. Therefore, a host becomes comparatively more efficient as it approaches maximum capacity (Humphries & Ruth, 2010, pp. 75:1–75:6).

The search for methods to increase power efficiency does not end at the data center. In fact, a source of great inefficiency in client-server networks is the traditional personal computer (PC). An average desktop computer uses anywhere from 60–250 watts and a typical laptop uses 15–45 watts depending on use (Bluejay, 2011), which does not take into consideration the power consumed by peripheral devices, such as monitors, attached storage, and other devices. In the same manner that virtualization allows the consolidation of server functions onto fewer physical machines through the use of VMs, PC functionality can be consolidated as well. Desktop virtualization takes the processes that normally occur on a desktop computer and moves them to a set of severs running virtualization software in the data center (Kochut, 2009, pp. 1–10). The end user then uses a thin client or zero client (stateless method of viewing desktop operating system) to access the desktop via the network.

As discussed earlier, server consolidation using VMs provides a significant increase in power efficiency. The use of desktop virtualization is an extension of the same procedure. By replacing PCs with thin client machines that use up to 85% (Greenberg, Anderson, & Mitchell-Jackson, 2001) less power, energy consumption can be drastically reduced. Furthermore, the energy consumption required for data processing that would normally occur on less efficient PCs is reduced by placing the burden for data processing on energy efficient servers in the data center.

C. ECONOMIES OF SCALE

The DoD, as an enterprise, has sought to deploy IT in a manner that leverages the concept of economies of scale, which in many ways is an unavoidable scenario due to the ubiquitous nature of IT within defense systems. Nearly every acquisition made by the DoD has an IT component with the relative percentage of IT within each acquisition steadily increasing over time. The total output derived from these systems increases at an increasing rate while the costs year over year increase in a more linear fashion.

The economy of scale effect achieved by this model makes reliance on IT in defense systems very attractive. The perhaps unintended consequence is the proportional increase in energy required to support these systems. The DoD is already the single largest consumer of energy within the U.S. government accounting for 78% of the total usage. $10 billion was spent on fuel for combat and combat related systems alone (Keberl, 2009). This fact implies that energy consumption by IT in combat systems should be analyzed to determine whether these systems can be operated in a more efficient manner that can reduce their electricity, and thus, fuel requirement.

D. ENERGY EFFICIENCY WITHIN OVERALL STRATEGY

The DoD has made energy efficiency a high priority. It has successfully tied energy efficiency into overall strategy by pointing out the inherent threat to security posed by the inefficient use of available energy.

The DoD has created an $18 million fund for the purpose of developing and rapidly transitioning to more energy efficient technologies for combat forces. The goal is to improve capabilities, reduce energy-related casualties and lower costs to the tax payer (U.S. Department of Defense, 2012). By funding such initiatives, the DoD is beginning to leverage the comparable efforts in the private sector that have been successful in creating energy efficient technologies with the goal of cost reduction. A distinct market comparable to the DoD’s effort to increase energy efficiency exists albeit for different reasons. The profit driven private sector must attempt to reduce its inefficient use of electricity due to the year over year increases in the price of electricity. In the context of reducing electricity consumption, the natural place to look for savings has to be within the areas of organizations that consume the most electricity. The IT departments of most organizations are the most intensive users of electricity—either through direct use by data systems or through indirect requirements to keep them cool with the latter comprising an extraordinary share of the overall consumption.

The near future will reveal whether the DoD will accept proposals from small businesses that have been funded to develop new methods to reduce the potential exposures created by inefficient use of energy consumption. The techniques used by private sector organizations to reduce electricity consumption by their IT departments seem like logical methods to attain similar increases in efficiency.

A force likely to push the DoD in the direction of using innovation from the private sector is entities within the services charged with finding techniques to enhance energy efficiency. E2O is one such entity. E2O has approached the issue of reduced energy consumption with an all of the above strategy that attempts to leverage every possible technique to reduce the necessity to use fuel to generate electricity. In fact the official strategy states, “By 2025 we will deploy Marine Expeditionary Forces that can maneuver from the sea and sustain its C4I and life support systems in place; the only liquid fuel needed will be for mobility systems which will be more energy efficient than systems are today” (Expeditionary Energy Office, 2011).

The goal of eliminating the need for generators is very aggressive. At present, the demand for electricity to run U.S. Command, Control, Communications, Computers, and Information (C4I) systems is so great that it is difficult to see how it will be possible to reach E2O’s goal. The beginnings of such a mission must begin with a preparation of the battlefield, so to speak. An analysis of what techniques are already feasible, and which will have to be engineered based on operational needs, are subsequently formalized in an Initial Capabilities Document (ICD).

On August 1, 2011, the ICD was created under the oversight of the Deputy Commandant, Combat Development and Integration and the Marine Requirements Oversight Council (MROC). In compliance with the Weapons Systems Acquisition and Reform Act of 2009 (WSARA), great effort is being made to identify requirements of systems sufficiently that will be intended to enhance the efficiency of C4I systems. Stakeholders have been given the opportunity to add to the ICD to enhance its fidelity in presenting the most complete set of requirements. Additionally, technology readiness is a prime area of focus due the innovative approaches being sought to help achieve E2O's strategic goal (United States Marines Corps, 2011).

III. RESEARCH FOCUS AND METHODS

The reduction in overall power consumption of IT systems is the main concern. IT systems are the fastest growing consumers of electricity within the DoD. It is likely that their use will continue to grow at an increasing rate, which in turn, increases the burden to provide the required power. Concern regarding the ability to provide the required power for these systems is mounting. In garrison environments, concerns about the cost and availability of electricity exist. Some of these costs are direct in the form of electricity needed to power servers and computers, while others are indirect in the form of cooling requirements for data centers. In tactical environments, the costs are considered in both financial terms, as well as in human terms. The fully burdened cost of delivering fuel to remote areas is extraordinarily high. Of equal concern is the mounting numbers of casualties directly associated with delivering fuel for electricity generation (Cobb, 2009). Additionally, tactical environments are not exempt from the requirement to effectively cool IT systems—in fact, the cooling concern may even be greater at times due to the extreme operating temperatures found in desert climates. In reality, however, cooling for the COC has much less to do with the electronics and much more to do with cooling the people in the tent spaces; however, if the electronics are in the same spaces then cooling is much more difficult and requires more electricity.

For the purposes of this thesis, the assumption is made that costs must be reduced regardless of whether they are in financial or human terms. Henceforth, the term “cost” or “reduction in cost” will indicate reduced power consumption per unit of output. Reduced power consumption is not the measure of efficiency that really matters however. Reducing power is a means to an end, which is reducing fuel consumption. In the final analysis, it reduces the cost be it financial or human.

A. DISCUSSION

The term efficiency is a highly volatile word. Taken in different contexts, it has widely varying meaning. For the sake of clarity, the term “efficiency” is not solely a matter of using less electricity in total, even though that is the overarching goal.

Efficiency, in this context, implies a ratio of output per unit of power consumed that may not have any direct correlation to an aggregate reduction in fuel consumption. Therefore, the assumption is made that increasing efficiency of the COC will lead to an overall reduction in demand for fuel.

The term performance indicates output per unit of energy and is synonymous with performance. As the ratio of output to watts consumed increases so does the efficiency of the system as a whole, which is strictly focused on processing itself and does not include indirect energy required to eliminate the heat produced by the system. The heat load produced by the electronics and the people operating them is of great concern and is discussed later.

In some circumstances, metrics are available that quantify, in absolute terms, some quantity, frequency, distance, and so forth. For example, watts are a simple and uniform unit of measure used to quantify volume of electricity. A watt is defined as the rate at which work is done when an object’s velocity is held constant at one meter per second against constant opposing force of one newton. No debate is raised as to whether a watt of electricity is used or how much energy is contained in a watt; it is simply a matter of measuring the number of watts required. On the other hand, performance is not so straight forward; it is a bit more subjective in terms of uniformly describing what performance is and how it will be measured in all contexts.

It is not sufficient simply to refer to the number of processor cycles per second as a direct measure of performance. One processor may use less electricity to generate cycles than another. Computers may be designed with multiple processors or multiple core processors. The allocation of these resources to tasks may be different among computers based on operating systems, bios, and physical configuration. Furthermore, two identical computers doing different tasks may not be equally efficient if their configuration is not optimized to the task. The conversion of cycles per second to quantity output is neither a direct conversion nor a standardized ratio among different processors and associated components. Rather, a unit of performance, such as floating operations per second (FLOPS), instructions per second (IPS), operations per second (OPS), or some benchmark that allows a comparison among different hardware sets, is required to quantify performance.

Benchmarking becomes quite important when attempting to estimate power usage and heat load. It is very difficult to generalize about these specifications due to the variance in demand under different circumstances. Even within one organization, it is very difficult to say what typical usage is without doing a vast amount of testing. Without knowing the power usage and heat load, it is be very difficult to estimate how much heat dissipation is required to keep servers at the appropriate operating temperature and budget for the costs of electricity. Manufacturers, such as Cisco, benchmark test its servers to provide a typical power usage value. Subsequent metering is required to verify the accuracy in a given application but the estimation allows for a reasonable planning factor. The importance of using a benchmark in the context of making assumptions about typical performance is discussed later.

B. STANDARDIZATION

Improvement in efficiency implies the comparison of one state to another. In the case of the COC, it is designed as a modular system. The very nature of the modular approach is designed to make the system extremely customizable, which is in keeping with Marine Corps' tradition that implicitly encourages units to use doctrine as a starting point for operational actions rather than a rigid methodology. Each unit that employs a COC does so in accordance with the standard operating procedure (SOP) of that particular unit. Not only does the SOP vary from unit to unit, it also varies within a single unit based on current leadership, command philosophy, task organization, and mission.

Configuration of the system is a critical factor when attempting to conduct a comparative analysis. What is the baseline configuration that can be used as a reference point? The modular design of the COC allows for an assumed baseline in that the smallest version (v4) is the fundamental building block of the larger versions. Theoretically, the v4 can be used as a system under test (SUT) and the data gained can be reasonably scaled to extrapolate to potential gains in the larger systems, which leads back to the concept of benchmarking. To standardize configuration to enable comparative analysis, a typical state is important to define.

C. BENCHMARKING

The use of a benchmark as a comparative tool makes assessment of efficiency more valid—or at least more standardized, which leads to the question: What is the proper benchmark? This question does not necessarily require answering as much as the following, What should be contained in a benchmark? The key is to have the proper attributes and have consistency in use. It is also important to remember that performance benchmarks require three things: (1) an application or specification representing an application, usually satisfying a particular business model, (2) a method for driving the application in a consistent way, including ways to ensure that the SUT is in a similar state at the start of each benchmark run, and (3) a definition of the metrics of the benchmark and how they are derived (Standard Performance Evaluation Corporation, 2011).

The Standard Performance Evaluation Corporation (SPEC) recognized the dilemma and acted to standardize measures of performance to allow comparison. It is important to note that benchmarks can be broad instruments or they can be very specific. For example, two different computers performing the same task, such as mail servers, can use the same benchmark to determine which performs better. Another example would be at the processor level where a benchmark can be applied to compute-intensive floating-point performance (Standard Performance Evaluation Corporation, 2012).

Benchmarks are able to provide these comparisons by defining a set of conditions a component will work under and then measuring how well it does it. In the case of power usage, SPEC uses a benchmark known as SPECpower_ssj2008. This benchmark works by running a server side java applet to put a specified workload on a system (Standard Performance Evaluation Corporation, 2012).

At the end of the day, it is simply important to realize that more than one measure of performance of a CPU exists. Given this fact, it is critical to use a benchmark of performance when comparing different configurations of an IT system to compare the efficiency of one to another. It is unlikely that a new benchmark will be defined in the course of this research; however, it is important to define the conditions in a manner that allow the creation of a benchmark that may capture typical performance of the COC as a system. In reality, given the variety of methods of employment under varying mission profiles, multiple benchmarks are likely necessary.

D. THE REAL PROBLEM

It can be said that a reduction in electricity consumption has occurred because of the application of more efficient methods of data processing. It is true that a reduction in consumption of electricity will occur when higher rates of efficiency are achieved. However, unless the output demand on a system remains unchanged, then the consumption of electricity will still increase albeit at a lower rate. Claims of reduced electricity requirements would be better stated as increased efficiency levels. As mentioned earlier, the rate at which IT systems are employed is increasing. This increase is a function of higher output requirements based on the need for better information to make faster decisions that translate into battlefield advantage.

The idea is to focus on the real problem rather than a symptom. The symptom, which many misinterpret as the problem, is that too much electricity is consumed by IT systems. The “too much” problem ignores the reality that the demand for increased automation, and therefore, faster information processing necessarily requires increased electricity to power the increased number of systems—and increased output. It is not feasible to assume a finite level of automation exists in which no additional technology will be desired. The nature of competition dictates that technological advance will continue as a means to find an advantage. Therefore, a corresponding increased requirement for electricity to power these technologies will always exist.

The best to hope for is a reduction in the rate of increase in the electricity requirement by increasing efficiency, which is the real problem on which to focus: Efficiency of current U.S. IT systems is too low. This statement is made empirically and is the subject of this research; however, by increasing the efficiency of existing systems, it is then possible to realize the best case scenario in which demand will not outpace the supply of electricity—even better, perhaps the supply can be reduced.

E. NARROWING THE SCOPE OF THE PROBLEM

Simply stated, the efficiency of IT systems in both garrison and tactical environments is too low. The reason it is considered too low is that given the growth in automation, unless efficiency in electricity utilization increases as an offset, the power requirement will eventually outpace the rate at which it is provided, which is an untenable situation that if taken to its natural conclusion, results in power shortages.

The supply of electricity will always be a constraint. However, the degree to which it constrains the use of IT systems, and thus, command and control capability, is the focus. If it is assumed that no system can be made so efficient that electricity consumption is not a concern, then the focus must be on making systems much more efficient to slow the approach to the constraint bound of the supply of electricity.

F. MANIFESTATION OF THE PROBLEM

Since the 1950s, when the utility of computing became critical to the increase in work output, the focus on increased computing power was the priority. In fact, it was such a priority that the constraints of size and electricity consumption were ignored insofar as they would be supplied in the required quantities to continue to improve performance. The result was computers as big as rooms.

The impetus for this drive toward enhanced computing power emanated from a defense need, as do many IT initiatives today. During World War II, computers calculated the firing tables for artillery. These computers were women who manually performed the required calculations to build the tables. John Mauchly and J. Presper Eckert received funding from the war department to build the Electronic Numerical Integrator and Calculator (ENIAC) in 1943 (Kopplin, 2002), which was not only considered a forefather of today’s computers, but it also represents the beginning of DoD funding of such programs. The computer that Mauchly and Presper built filled a 20 x 40 foot room and weighed 30 tons. It is unknown how much electricity this computer used but it suffices to say it was a considerable amount and was not a consideration beyond ensuring an adequate supply.

The point is that the desire for enhanced computing capability made the consideration of power and space nearly irrelevant, which is a luxury not afforded today in the search for enhanced capability. Space and weight limitations are important considerations on the battlefield, as well as a limit on how much an IT system can weigh and how big it can be to fit within standard military equipment. More importantly, the supply of energy is the critical constraint. The least austere environments of Iraq and Afghanistan consistently require large volumes of fuel to maintain their viability and functionality. The logistical process to transport fuel to these locations is complex and formidable. It is even more critical to smaller and more austere environments at which the delivery of fuel is more difficult and more dangerous.

The "last mile" of fuel delivery is logically the least secure and most challenging. This concept dictates that reducing the volume of fuel is required, and thus, the frequency of its delivery increases security.

1. Identifying the Efficiency Problem

If the "last mile" represents the danger zone then how can exposure in this area be reduced? The answer is to reduce the need to be in it by reducing the consumption of fuel.

This concept may seem to contradict the earlier point that as automation increases; the need for electricity will continue to increase, which is certainly still true. However, that idea is the long run view at the problem in which variables may be changed to improve the efficiency of IT systems. In the short run (to borrow the economic terminology), the output and other variables are relatively fixed. For instance, assume a battalion forward operating base (FOB) will be established to perform a security mission. The output requirement of the IT systems will likely change very little during the period of time the FOB exists. In other words, the driver of increased IT system output is not the operational tempo but rather the output the current configuration produces. In reality, the use of IT systems during a one-year mission does not vary greatly. Continuous use is the norm while the daily battle rhythm determines the load on the IT systems more than the operational tempo. As a planning factor, the systems are considered to be in relatively consistent use at all times; thus, a benchmark for typical electrical demand would be valuable for estimating the requirement for electricity supply, and as such, fuel supply.

Development and implementation of command and control tools, such as Command and Control Personal Computer (C2PC) or Command Post of the Future (CPOF), produce higher output levels, and therefore, justify increased employment of IT systems. When the capacity of a server to host a new service is exceeded, the answer is either to install a higher capacity server or to add an additional server. The decision regarding which course of action to follow is likely based on the constraints of performance, but the corresponding demand for electricity and space must also be considered. In the context of a tactical data system, both are critical constraints. The objective is to maximize the use of the available server space. In the context of reducing fuel consumption by increasing efficiency, employing the most efficient method of providing service is critical. However, the solution is actually more complicated. Can the services running on the servers also be modified to improve the performance of the server itself? For example, by maximizing the server’s utilization via dynamic load balancing, the number of active servers can be reduced and the spares are only brought up as needed, which has the added effect of reducing the heat load emitted into the environment.

Increases in the efficiency of IT systems, while certainly worthwhile, may not be the effort that produces the best results. IT systems used in military applications are simply Commercial Off-the-shelf (COTS) equipment that has had the benefit of design pressures to enhance their efficiency to reduce their cost of ownership. With that force in place, how much more efficiency could possibly be gained by further focusing on it? As mentioned earlier, a tendency exists to take back efficiencies gained by reallocating newly available resource to additional capability. In the tactical context, stacking tasks on a single server rather than multiple allows for either a redundancy or an additional capability. Either way, the reduced power consumption gained by eliminating a server may be taken back quite easily. Other consumers of power within a data processing system may have more potential for increases in efficiency.

A consistent requirement for all IT systems is the need to cool them. In commercial applications, many techniques are available to cool data centers efficiently. The benefit of having a fixed structure makes efficiency in cooling possible. Initially, data centers were rooms with rows of vertical cabinets that housed servers. The entire room would be cooled with air flowing in from either the floor or the ceiling, and subsequently, flow out the opposite direction. Large air conditioning units were used to provide the massive amount of cooling required to perform in this manner. As the costs to cool data centers has risen in relation to the number of servers typically employed, greater focus has been placed on reducing these costs.

It used to be common to enter a data center and find the air temperature very cool, which would be the first indication that the cooling of the data center has the potential to gain efficiency. The data center at the LBNL, in contrast, is very warm. Rather than cooling the entire room, the cooling is distributed to the server cabinets. Furthermore, the flow of air is managed so that it enters on one side of the server cabinet rows and exits on the other, which creates warm isles and cool isles that reduce the total volume of chilled air required to keep the IT equipment cool. Fixed sites enjoy this sort of engineering potential. A lot of flexibility results when the facility configuration does not suffer from the constraints of size, weight, and mobility.

Fixed sites may also employ alternative methods for providing cooling to the data center. Techniques, such as cooling towers and liquid cooling, provide heat dissipation without the large quantities of electricity required to compress gasses, such as Freon. Both types of cooling employ pumps and fans to move liquid and air to and from IT equipment. What makes air conditioning so much more energy intensive is the electricity required to compress a gas back to a liquid state; thus, eliminating the heat from it. If air or water can eliminate heat without such a technique, then electricity consumption can be greatly reduced, which is the concept behind cooling towers and liquid cooling. Cooling towers use evaporation to transfer the heat into the environment while closed circuit systems, such as dry coolers, use water and fans to exchange heat. These systems have not yet been applied in a tactical setting and may not provide enough cooling to eliminate air condition units completely; however, they may be able to reduce the load placed on the air conditioner, and thus, save electricity.

In returning to the identification of the problem in the context of where opportunities exist to realize potential efficiency increases, it appears that reducing power consumption required to provide cooling is the logical place to focus the analysis. Furthermore, focusing on a subset of the heat load producers makes cooling towers and dry coolers potentially feasible. A problem that has arisen while researching this subject is that not much data has been collected on heat loads and other factors affecting the power required to cool COC IT systems. Despite this lack of data, it is possible to model the configuration of the COC, and thus, apply a measure to increase its efficiency. As better data becomes available, the predictive accuracy of such a model will likely improve.

2. Possible Solutions to the Problem

Any measure to increase the efficiency of the COC must be focused on the largest power consumer—the ECU. The Integrated Trailer-ECU-Generator (ITEG) for the COC, which provides both the environmental control and the electricity, provides 22 (rated at 22 kilowatts but actually produces 25 kilowatts) kilowatts of electricity and up to 120,000 Btu/hrs of cooling (British Thermal Units) (Morris, 2007). Of the 22 kilowatts, only five to seven watts are exportable with a full ECU load. Therefore, 15 to 17 kilowatts are required to power the ECU at full capacity, which represents 60% to 68% of the capacity of the generator.

As mentioned earlier, measures, such as evaporation and dry cooling systems, can reduce the load placed on the ECU. Reducing heat loads into the area being cooled by the ECU would result in a reduced need for electricity requirement, and thus, less fuel sustainment. To validate whether an alternative method of cooling is worthy of exploration, a great deal of data must be gathered regarding the different heat loads present inside the COC. As mentioned earlier, very little data is currently available that can substantiate estimations of heat load. As a result, many assumptions must be made regarding environmental conditions, configuration, electronics load, and behavior; however, the fundamental approach to building the model should create a good starting point for analysis. Regardless of these assumptions, a model can be built based on what is known about the COC, such as tent size, tent material, composition of electronics, user behavior, and ECU specification. Once the model is constructed, the limited data collected from other COC tests can be applied to the equipment in the COC (v4). This analysis should at least help make the case for whether alternative approaches to cooling are worth the time and expense to explore.

G. PROCEDURE FOR TESTING PROPOSED SOLUTIONS

1. The Model

A model must be constructed that reasonably represents the performance of the COC with particular interest focused on the generator and ECU under varying conditions. Variables, such as air flow, heat flow, electronics heat load, and cooling load, must be represented in the model. The model must demonstrate sensitivity to these variables, and as such, create outputs of merit. The output of the model must be in terms that can be related to decreased fuel consumption. For example, it must demonstrate that reduced cooling load through alternative measures reduces or fails to reduce generator load in kilowatts. Furthermore, it must differentiate between load generated through electronics, the resulting heat dissipation via cooling, and heat dissipation of other heat loads added to the tent environment.

2. The Inputs

The quality of the outputs of the model is naturally dependent on the quality of inputs. As mentioned earlier, the state of data collection at this time is rather immature. Hence, the inputs are made on assumptions and previous testing in differing configuration. The inputs will have no effect on the model itself. The fundamental principles that make the model effective dictate that as the inputs improve, the outputs will also become more valid. Three main categories of inputs exist: electrical load, direct heat loads, and ECU load.

Electrical load is simply the amount of power the electronic systems in the COC use, which is important in terms of measuring the amount of load placed on the generator when these systems are in use. More importantly, however, a direct heat load is produced as a result.

Direct heat load is produced in three main ways. As mentioned, the electronics turn the electricity they use into heat, which is essentially a one-to-one ratio of kilowatts used to kilowatts required to be removed by the ECU. Secondly, humans add heat to the tent environment as well. Finally, the external environment also has the capacity to add direct heat load. All these heat loads contribute to the ECU load.

ECU load is the amount of cooling required to maintain a set point temperature inside the tent environment. In commercial applications, this number is expressed in tons of cooling required that can be converted into Btus/hour, and ultimately, kilowatts. The cooling load in kilowatts is presumably equal to the heat load produced by electronics, people, and the environment. The ECU cooling load will be reduced through the employment of a measure designed to remove heat load at a lower rate of power consumption than an ECU.

3. The Simulation

To test the proposed method of alternative cooling, its estimated effects on the cooling load will be entered into the model under varying conditions. These conditions will demonstrate the result of pure use of the ECU for cooling the tent and electronics, as well as a graduated use of alternative cooling methods (ACM). The desired result is to determine whether, under a give set of circumstances, it is advantageous to use a dry cooler to reduce the load on the ECU, and thus, reduce the amount of fuel required for sustainment.

IV. COC COOLING METHODS MODELING AND ASSESSMENT

A. EXPLANATION OF THE MODEL

The model is a demonstration of a method to simulate how some changes in design can result in significant decrease in power consumption, and thus, likewise, decrease fuel consumption. In this case, two methods are incorporated into the model assumed to reduce power consumption. These variables are not the only ones that can be incorporated into the model. Any measure whose effect can be expressed in terms of kilowatts or Btus can be incorporated to simulate an efficiency increase.

The model incorporates the concept that the measure used to provide heat dissipation through an alternative method that uses less electricity may not be 100% effective. As a result, the model illustrates this concept by scaling its effectiveness in increments of 20 percent.

The model is not intended to be presented as a final solution for modeling the COC power efficiency. It is quite the opposite—it is a beginning example of a construct that can be useful in determining whether a measure meets a threshold for effectiveness that would justify further analysis.

The model assumes the inputs are accurate; however, a fundamental problem exists with the current state of data collection as far as the COC is concerned. Very little measurement of heat loads in the COC environment has been done during practical application. In fact, the idea of measurement presupposes a complete understanding of the how different operating conditions will affect the data collected. This lack of baseline is a fundamental problem that this model begins to address. The model will allow for the incorporation of environmental factors, which makes it flexible, and therefore, relevant in most conditions in which the Marine Corps is likely to operate. As the data inputs regarding heat load produced by the IT systems in typical operating scenarios becomes better known, the outputs of the model will better reflect power used and saved, as well as fuel conserved. The following sections explain the elements of the model and the data collected.

B. ASSUMPTIONS

1. July 2010 COC (v2) test

A large amount of the data used in this research was collected from the July 2010 test performed on the COC (v2). The assumption is that regardless of the environmental conditions, the load placed on the individual IT components is a reasonable instantiation of a typical operational load. As a result, the heat load produced is also reasonably typical.

Although the SUT in July 2010 was a different version of the COC than the one discussed in this research, it is assumed that by cross referencing the individual IT systems found in each version and using the data available for those components that match, a reasonable estimation of performance can be made.

Not all the systems present in the in COC (v2) were tested in a manner in which the specific power load could be deduced. For example, some of the measurement was done at junctions in which multiple systems' power draw was measured. In these cases, an inference was made as to what portion of the power was drawn by the component in question by subtracting the known power draws of the other components measured. The remaining value was assumed to be that which belonged to the component in question.

In some cases, it was not possible to isolate, and thus infer, the power draw of some systems from the COC (v2) data. In these cases, the vendor data was used. An example would be the uninterruptable power supply (UPS). In this case, the vendor was contacted and information gathered that reflects typical states of operation likely applicable to steady state operation in a COC.

Some equipment had absolutely no data available. The assumption is that these systems were so rarely used during testing that data could not be collected. However, this lack of data does not necessarily mean that their impact on power consumption is negligible, but as of the time of this research, no data was available. Future research will have to attempt to collect more complete data on these systems' power consumption.

Appendix A contains the list of equipment from the COC (v4) for which data was available. Appendix B contains the data collected on the COC (v2) which was used as a reference for data collection for the COC (v4).

2. Alternate Cooling Method

In this research, the assumption is that the alternate cooling method is a dry cooler, closed circuit system that circulates water to the electronic components on the OT, and thus, removes the heat and reduces the need to cool the tent. The effectiveness of such a method is in question because the method has not been tested. A dry cooler is expected to remove heat adequately because water is much more efficient at removing heat than chilled air. The problem with this assumption is the assertion that the dry cooler will able to cool every component on the OT, which may be the case. However, because the system has not yet been engineered for this application, a range of effectiveness must be considered. The model illustrates the percentage of cooling moved by the ACM and the resultant reduction of power required by the ECU.

3. Miscellaneous Plug Loads

The COC is usually the only source of electricity beyond inverters that are generally plugged into vehicles. As a result, miscellaneous yet mission critical items, such as cell phones, satellite phones, and coffee makers will be plugged into available outlets in the system. The assumption is that, on average,.2 kilowatts of miscellaneous power will be drawn by each tent, respectively.

C. MODEL DECOMPOSITION

1. Physical Description of COC (v4)

The COC (v4) is typically composed of two tents, an OT, a GETT (Generator, ECU and Tent Trailer) and associated electronics equipment used for operations, such as projectors, laptops, and smart boards. . One of the tents (Base-X 303) is used to house the OT while the other (Base-X 305) is used for operations. Henceforth, they will be referred to as the OT tent and the ops tent.

To model the COC accurately as a system, it is divided into separate pieces that correspond to sources of heat load that must be removed by cooling methods that require power. The model delineates these sources of heat as electronics, personnel, and environmental. Power required for cooling is modeled as a separate factor affecting power consumption. Figure 1 illustrates the physical attributes that correlate with the model.

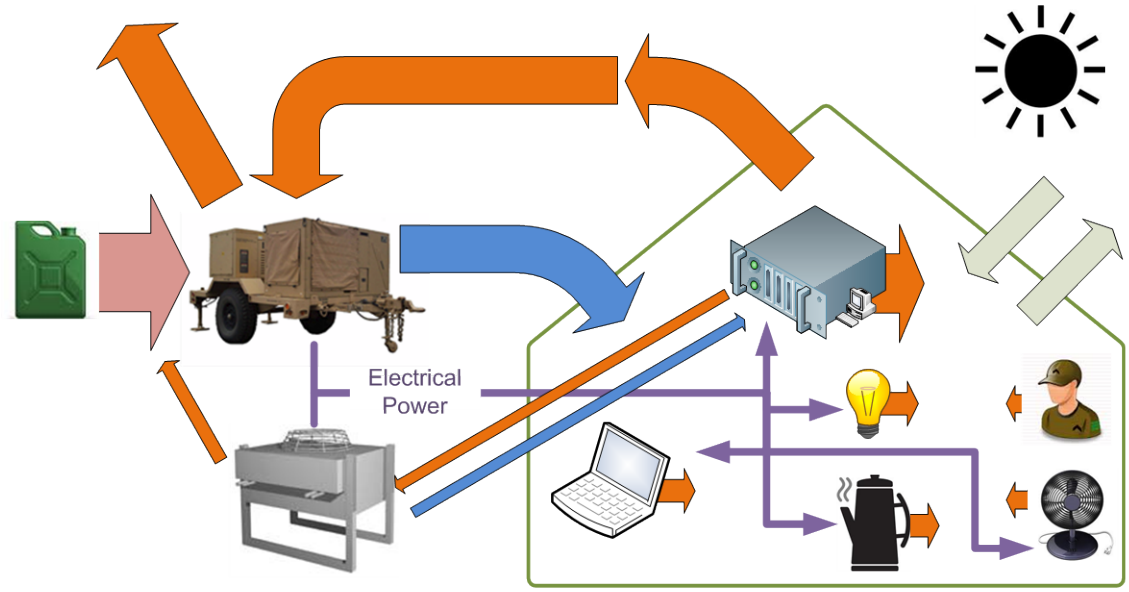

Figure 1. Physical depiction of the model

2. Inputs

The inputs for the model are the variables that can be changed to analyze the effect of different conditions and heat loads. It is essential to account for any variable that causes a change in the amount of power required to sustain the COC. Table 1 contains a list of the variables currently incorporated into the model.

Input	Units
Tent Skin Delta Temperature	Degrees Fahrenheit
OT Tent Skin R Value	Unitless
OPS Tent Skin R Value	Unitless
Tent Surface Area	Square Feet
OT IT Equipment Power	Kilowatts
Laptop Power OT Tent	Kilowatts
Laptop Power OPS Tent	Kilowatts
All Other Electrical Loads OT Tent	Kilowatts
All Other Electrical Loads OPS Tent	Kilowatts
Personnel Heat	Kilowatts
Cooling Load Gain Via Ducting	Kilowatts
ECU Coefficient of Performance	Unitless
Cost of Fuel	$/Gallon

Table 1. Summary of inputs

3. Operational Trailer Tent

The OT tent portion of the model provides a subtotal of the power required by the entire COC. It captures secondary variables, such as the reduction in total power consumed as the heat load is removed from the tent using the ACM. The latter does not affect some of the variables because they are not considered a target for alternate cooling. Items, such as light, laptops, and personnel fall into this category. The final outputs of this portion of the model are total power needed for electronics, total heat load added by personnel, total environmental heat load, and total heat load required to be removed by the ECU. Table 2 displays all the categories in the OT portion of the model.

Category	Units
Percent IT Cooled via ACM	%
Plug Load	Kilowatts
Laptop Load	Kilowatts
OT Power Load	Kilowatts
Total Power Load	Kilowatts
Number of Personnel	Unitless
Heat Load from Personnel	Kilowatts
Total Skin Area	Square Feet
Heat Load from Tent Skin	Kilowatts/BTUs
Accumulation in this Tent	Kilowatts/BTUs

Table 2. OT tent model categories

4. Operations Tent

The operations tent portion of the model is similar to the OT tent portion in that many of the inputs are similar. The values may differ but the categories are essentially the same. The main difference is that the ACM does not affect the operations tent since in this particular case, the focus is on the OT trailer, not the operations trailer. The operations tent still draws a significant amount of power and represents a large amount of the cooling power required of the entire COC. As a result, accurate modeling of this portion of the system is significant. Table 3 illustrates the categories in the operations tent portion of the model.

Category	Units
Plug Load	%
Laptop Load	Kilowatts
IT Equipment Power Load	Kilowatts
Total Power Load	Kilowatts
Number of Personnel	Kilowatts
Personnel Heat Load	Unitless
Total Tent Skin Area	Kilowatts
Heat Load from Tent Skin	Kilowatts
Accumulation in this Tent	Kilowatts/BTUs

Table 3. Operations tent model categories

5. Alternative Cooling Method

The alternate cooling method of the model pertains to the reduction in power consumption by replacing some of the cooling provided by the ECU with an ACM (dry cooler). As state earlier, the capacity of a dry cooler to remove sufficient heat may be reduced under some environmental conditions. As a result, the effect of the cooler is scaled in increments of 20 percent. The dry cooler incurs a cost in power, as does the ECU. The estimate of power required by the dry cooler is a function of the amount of work it is doing and is estimated to be approximately 10% of the heat load it is removing. Table 4 illustrates the categories of ACM portion of the model.

Category	Units
IT Heat Load Removed	Kilowatts
Fan & Pump Power Required	Kilowatts

Table 4. ACM model categories

6. Summary of Outputs

The summary portion of the model reflects the final outputs of all the variables. It demonstrates the outputs at 20% increments of ACM reduction to overall power consumption. Table 5 illustrates the categories that the summary of outputs contains.

Category	Units
Total IT Load	Kilowatts
Total Electrical Load	Kilowatts
Tent Cooling Load	Kilowatts
Ducting Heat Gain	Kilowatts
Total Cooling Load	Kilowatts
ECU Electrical Consumption	Kilowatts
Total Generator Load	Kilowatts
Fuel Reduction	%
Fuel Cost	$/Year
Fuel Consumeed	Gal./Year

Table 5. Model summary categories

D. MECHANICS OF THE INPUTS

The outputs of each of the portions of the model are based on the previously mention assumptions. The inputs should be considered in the context of those assumptions, and thus, the outputs as well. The model itself is the critical element. The results are only as applicable as the model's fundamental soundness. As a result, the model and the results should be considered critically. The results displayed in this section do not illustrate every output from the model but rather the seminal elements that will allow conclusions to be drawn.

The input values reflect assumed conditions, as well as measured values. The inputs in this case are reflective of a situation similar to that of conditions experienced during operations in Iraq or Afghanistan. Table 6 illustrates the input values.

Model Inputs		
Variable	Value	Units
Tent Skin Delta Temperature	20	F
OT Tent Personnel	2	People
OT Tent Skin R Value	5.1	ft² °F h/Btu
OT IT Equipment Power	2.65	kW
OT Tent Laptop Power	0.083	kW
OT Tent Other Electrical Loads	0.2	kW
OT Tent Surface Area	1034.89	ft²
OT Tent Personnel	15	People
OPS Tent Skin R Value	5.1	ft² °F h/Btu
Ops Tent IT Equipment Power	0.6583	kW
OPS Tent Other Electrical Loads	0.4	kW
Ops Tent Surface Area	1602.36	ft²
Personnel Heat	0.0125	kW/each
Cooling Load Gain Via Ducting	30	percent of total of both tents
HVAC ECU Performance	2	COP
Cost of Fuel	10.2	$/gallon

Table 6. Input values

1. Temperature Delta

For the purposes of this research, the assumption is that the temperature inside the tent is 20 degrees cooler than that outside the tent. This assumption is not intended to precisely reflect the average difference in temperature during continuous operations, but rather to serve as an example of how the model will perform under these conditions.

2. R-value

The input of R-Value is a necessary component used to determine heat flow (heat load) into the tent. R-value is the measure of resistance of the material in question to heat transfer. The higher the R-value, the more resistance the material has to heat conduction. The National Renewable Energy Laboratory (NREL) analyzed the tent material, and was determined to have an R-value of 2.5 (S. Gorin, personal communication, November 8, 2012), which is a composite of the entire tent and incorporates the space between the tent layers. The inverse of the R-value, also known as the U-value, is the overall heat transfer coefficient. The U-value expresses the material in question's conductivity. The U-value is needed to determine the heat load added through the tent.

3. Surface Area

Surface area is also an input that contributes to the heat flow formula. Heat flow is not only a factor of R-value but also the amount of area exposed to the environment that results in a larger heat load via conduction. Each of the tents has its own heat load; however, it sums to the total heat load produced by the environment. The OT tent surface area is approximately 1,034 square feet and the ops tent has approximately 1,602 square feet. The measurement of surface is not just a simple calculation of six sides exposed to the environment. The typical configuration of the COC (v4) positions the tents end-to-end, which results in a reduction in the total surface area by twice the area of the end wall of each of the tents that is accounted for in the calculation of total area exposed to the environment, and thus, the heat load added to the tents.

4. IT Heat Load and Direct Power Consumption

The inputs that determine both the heat load produced by IT systems, as well as the direct power consumption of IT systems, are split into five categories: OT IT equipment power, ops tent IT equipment power, OT tent laptop power, OT tent other electrical loads, and ops tent other electrical loads. These inputs are categorized individually because they can be addressed separately for the purposes of analyzing increases in efficiency pertinent to each category. For instance, the systems on the OT are a relatively self-contained set of systems, which provides the opportunity to address them collectively as they are in this model. Attempts to address the OT are unlikely to have any impact on heat load produced by the other IT systems. If an ACM is proposed that addresses all the heat load producers equally, then their respective heat loads can be aggregated in the model. Furthermore, the tents are considered separately to facilitate addressing circumstances in the tents individually. Again, this model examines the OT within the OT tent without affecting anything in the ops tent. Appendix C contains both the summary of the COC (v4) heat loads, as well as the data from the July 2010 COC (v2) test used to generate the summary table.

5. Personnel Heat Load

Heat from personnel inside the tent is a consideration as an input because the number of people in the tents over time has a significant impact on the amount of cooling required to offset that heat load. The amount of heat emanated by an individual varies but a good average for an individual has been suggested at approximately .0140 kilowatts per person Huehn, Couvillon, Coleman, Suryanarayana, Ayub, & Parson, 2005). The number of personnel actually in the respective tents is an assumption but is typically approximately 17 with two in the OT tent and 15 in the ops tent. The number of personnel in the OT tent is simply of matter of system administration, which typically requires two Marines continuously. The ops tent accounts for the remaining 15 and is comprised of at least two Marines for each of the six war fighting functions plus watch officer, watch chief, and clerk. These numbers are not synonymous with all units and are typically tailored to the standard operating procedure (SOP) of the unit. In this case, the maximum heat load is used for a worst-case scenario.

6. Gain from Ducts

The cooling load gained input is an estimate of the amount of additional cooling required because of heat added to the air transported in the ductwork that carries air back and forth to the tents. The ductwork typically lies on the ground and is warmed by the ground and the air around the ducts. It is estimated that this situation may account for as much as a 30% increase in the temperature of the air that must be chilled before it is returned to the tent. This input accounts for a significant increase in cooling load required. This value is purely empirical and requires more study and measurement. In the absence of accurate data to assess the heat load added to the air that is returned to the ECU, and that which is added to the air entering the tent, 30% is estimated. The input will be significantly more accurate once further study is conducted.

7. Coefficient of Performance

The performance of the ECU itself is a variable, and thereforr, is an input to the model. The performance is expressed as a coefficient of performance (COP) and indicates a ratio of kilowatts of cooling provided to kilowatts of electricity consumed by the ECU. In the case of the COC (v4), the ECU had a COP of 1.904. It could produce 96,000 Btus of cooling at 14.5 kilowatts (J. Thousand, personal communication, November 30, 2012). This value is a variable in the calculation of electricity consumed, and thus, the amount of fuel required. The current version of the COC (v4) is using a 120,000 Btu ECU, and therefore, an assumption of similar performance is made.

8. Cost of Fuel

The cost of fuel as a variable and an input into the model is only necessary when assigning cost in financial terms. It is a useful exercise to put the results of the model in that context if for no other reason than to use terms more easily understood. To the average person gallons of fuel delivered has significantly less meaning than the cost of that fuel. For the purposes of this research, $15 per gallon is used as the estimate for the cost. This number is a weighted average of costs to deliver bulk fuel to I MEF (FWD) (Marine Expeditionary Force) (Forward) in Afghanistan during May 2012 (E2O, 2012). Approximately 94 % of fuel delivered cost $9.56 per gallon. The remaining 6% delivered averaged $19.87 per gallon. The resulting weighted average per gallon is $10.20 per gallon.

E. RESULTS

The model is broken down to represent the physical layout of the COC. As mentioned earlier, it consists of an OT Tent, an ops tent, as well as the ACM. The following sections contain a detailed description of each portion of the model and how the outputs are calculated. These outputs form the basis for the summary table that contains the results of the model.

1. OT and Ops Tents

The OT and ops tent portions of the model incorporate the applicable values to determine the total electricity demanded by the tents. Some of the electricity demand is direct in the form of power to run items, such as the OT and anything else that consumes electricity. The other consumer of electricity in relation to the OT and ops tents is the ECU. The ECU must eliminate any heat added to the tent above the set point that is assumed to be approximately 85 degrees. The more heat needed to be eliminated, the more power the ECU requires. The three basic contributors of heat to the tents are items that use electricity, people, and the heat conducted through the tent from the outside environment.

The power demanded by the electricity consumers is a simple summation of the electricity consumption of the OT, laptops, IT equipment, and the miscellaneous items plugged into outlets (coffee makers, iPods, etc.). The calculation of heat loads is a little more complex. Heat loads from electricity consumers, and people, are a simple summation of both the electricity consumed (which is equal to the heat produced), and the total heat load added by the people in the tent, however, the heat load added by the environment requires additional calculation.

As mentioned earlier, R-value and surface area are variables in the calculation of heat flow. Also, the difference in temperature from inside to outside is a key factor in determining how much heat load is added, and thus removed, by the ECU. The following formula is used to measure heat load from the tent skin.

$$Q = U \times A \times \Delta T$$

where, Q is heat flow, U is the reciprocal of the R-value or the heat transfer coefficient, and ΔT is the difference between the outside temperature and the inside temperature (PexUniverse.com, 2012).

The surface area is a calculation of the area of the tent actually exposed to the environment. The assumption is that camouflage netting or shade cloth would shade the tent, and thus, eliminate the radiant heat load that would normally be a factor. Tables 7 and 8 illustrate the complete results of the OT and ops tent models.

OT Tent										
Percent IT Cooled via ACM (%)	Misc. Plug Load (kW)	Laptop Load (kW)	OT Power Load (kW)	Total Power Needed (kW)	Number of Personnel (#)	Heat from Personnel (kW)	Total Tent Skin Area (ft^2)	Heat Load from Tent Skin (Btu/hour)	Heat Load from Tent Skin (kW)	Total Heat Accumulation (Cooling Needed) in this Tent (kW)
0	0.2	0.083	2.65	2.933	2	0.028	1034.88803	8279.104	2.426	5.387
20	0.2	0.083	2.12	2.403	2	0.028	1034.88803	8279.104	2.426	4.857
40	0.2	0.083	1.59	1.873	2	0.028	1034.88803	8279.104	2.426	4.327
60	0.2	0.083	1.06	1.343	2	0.028	1034.88803	8279.104	2.426	3.797
80	0.2	0.083	0.53	0.813	2	0.028	1034.88803	8279.104	2.426	3.267
100	0.2	0.083	0	0.283	2	0.028	1034.88803	8279.104	2.426	2.737

Table 7. OT tent model

OPS Tent								
Misc. Plug Load (kW)	IT Equipment Power Load (kW)	Total Power Load (kW)	Number of Personnel (#)	Personel Heat Load (kW)	Total Temt Skin Area (ft^2)	Heat Load from Tent Skin (Btu/hour)	Heat Load from Tent Skin (kW)	Total Heat Accumulation (Cooling Needed) in this Tent (kW)
0.2	0.6583	0.8583	15	0.21	1602.36005	12818.880	3.757	4.825
0.2	0.6583	0.8583	15	0.21	1602.36005	12818.880	3.757	4.825
0.2	0.6583	0.8583	15	0.21	1602.36005	12818.880	3.757	4.825
0.2	0.6583	0.8583	15	0.21	1602.36005	12818.880	3.757	4.825
0.2	0.6583	0.8583	15	0.21	1602.36005	12818.880	3.757	4.825
0.2	0.6583	0.8583	15	0.21	1602.36005	12818.880	3.757	4.825

Table 8. Ops tent model

The OT tent portion of the model has one significant difference from the ops tent portion. The OT is used as the target to demonstrate a potential increase in efficiency through an ACM. Hence, the electricity demanded by the ECU is reduced by the assumption that the heat load produced by the OT is removed by the ACM. Additionally, the effect of the ACM is graduated in increments of 20% to account for the possibility that it may not be able to remove all the heat produced, as well as to show the sensitivity to this method of cooling. The ops tent is not the target of the ACM, and therefore, the electricity consumption remains the same as the ECU provides all the cooling. Note that the last column in Table 8 does not change as a result whereas the last column in Table 7 (cooling load on the ECU) decreases as the ACM contributes to the cooling of the OT.

2. Alternative Cooling Method

The ACM in this case is a dry cooling unit that pumps water to the OT, and subsequently, uses a radiator to exchange the heat back into the environment with the use of fans. Dry coolers are typically very effective and efficient due to the enhanced conductivity of water over air. The calculation of power required to run the dry cooler was based upon the amount of heat it was removing. Approximately 10% of the heat removed is required to remove it. Table 9 illustrates the amount of heat removed and the corresponding use of electricity.

Alt. Cooling Method		
Percent IT Cooled via ACM (%)	IT Equip. Heat Load Removed (kW)	Fan & Pump Power Required (kW)
0	0	0
20	0.53	0.053
40	1.06	0.106
60	1.59	0.159
80	2.12	0.212
100	2.65	0.265

Table 9. Power consumption of ACM

3. Summary of the Model

To recap the model thus far, the inputs, OT tent, ops tent, and ACM portions of the model have been presented. Each contributes to Table 10, which summarizes the results of the model.

Summary													
Percent IT Cooled via ACM (%)	Total IT Load (kW)	Total Electrical Load (kW)	Cooling Load (kW)	Ducting Heat Gain (kW)	Total Cooling Load (kW)	ECU Electrical Consumption (kW)	Total Generator Load (kW)	Generator Fuel Flow Rate (gph)	Fuel Reduction	Fuel Cost ($/hour)	Fuel Cost ($/year)	Fuel Consumed (Gal./Year)
0	3.3913	3.791	10.213	3.064	13.276	6.973	10.764	0.709647589	0%	$ 7.24	$ 63,408.43	6216.512876
20	2.8613	3.844	9.683	2.905	12.587	6.611	10.455	0.691115404	2.6%	$ 7.05	$ 61,752.54	6054.170937
40	2.3313	3.897	9.153	2.746	11.898	6.249	10.146	0.672583219	5.2%	$ 6.86	$ 60,096.66	5891.828997
60	1.8013	3.950	8.623	2.587	11.209	5.887	9.838	0.654051034	7.8%	$ 6.67	$ 58,440.77	5729.487058
80	1.2713	4.003	8.093	2.428	10.520	5.525	9.529	0.635518849	10.4%	$ 6.48	$ 56,784.88	5567.145118
100	0.7413	4.056	7.563	2.269	9.831	5.163	9.220	0.616986664	13.1%	$ 6.29	$ 55,128.99	5404.803179

Table 10. Summary of model results

The total IT load, which is also the heat load added to the tent from IT systems, depends on the effectiveness of the ACM. The actual IT heat load does not change although it appears to in Table 10. The reason for this lack of change is that as the ACM removes heat load that would normally be required to be dissipated by the ECU, the load on the ECU is reduced.

Total electrical load subsumes the total IT load, as it is the sum of all the IT loads, as well as the miscellaneous plug loads. This value represents every item that draws electricity except the ECUs.

The cooling load is the total amount of heat from all factors (IT, environment, and personnel) that the ECU must remove. Note this number also is reduced as the ACM effectiveness increases because as the ACM reduces the burden on the ECU, the latter draws less power.

The ducting heat gain is essentially a best estimate value, which is not a source of heat load about which much data could be gathered. An estimate of 30% was used to approximate the amount of heat transferred into the ductwork as it lies on the ground. Ducting heat gain is added to the cooling load to determine the total cooling load, which is the value required to be removed by the ECU.

Using the ECU coefficient of performance, it is possible to determine how much electricity is required to generate the proper cooling load for the tents. The cooling load is multiplied by the ECU COP to determine how many kilowatts of electricity are required by the ECUs. As mentioned earlier, the more the ACM provides in cooling, the less electricity the ECU requires.

With the total electricity demand for the electricity consumers inside the tent, as well as that of the ECU, the amount of fuel required to produce the necessary electricity can be determined by analyzing the fuel flow rates for the 22-kilowatt generator at expected loads. Actual rates for generator could not be determined through research. In lieu of actual data, deductive methods were used to determine the fuel flow. The fuel flow rate for 10- and 30-kilowatt generators was analyzed and the curves illustrating fuel consumption per kilowatt generated for both generators were rather linear and the slope of the best fit trend lines were nearly identical. As a result, the performance data of the 30-kilowatt generator was scaled back by 17% to simulate the fuel consumption of a 22-kilowatt generator. Appendix C provides the fuel consumption curves from which this assumption was derived. The equation representing the line is $Y = 0.0006X + 0.0638$, and therefore, is used to calculate fuel consumption based on load.

The remaining columns in Table 10 show the reduction in fuel consumption and the cost saved over the period of a year.

4. The Final Analysis

Figure 2 illustrates that the use of an ACM fully capable of cooling the OT trailer results in a significant reduction in power consumption, as well as fuel costs over the period of a year. In total, fuel consumption is reduced by 13.1% for a savings of $8279.44 per year or $.95 per hour. Additionally, fuel consumption is reduced by 811.71 gallons. As the percentage of OT heat load is reduced by the ACM, a corresponding reduction in power and fuel consumption also occurs.

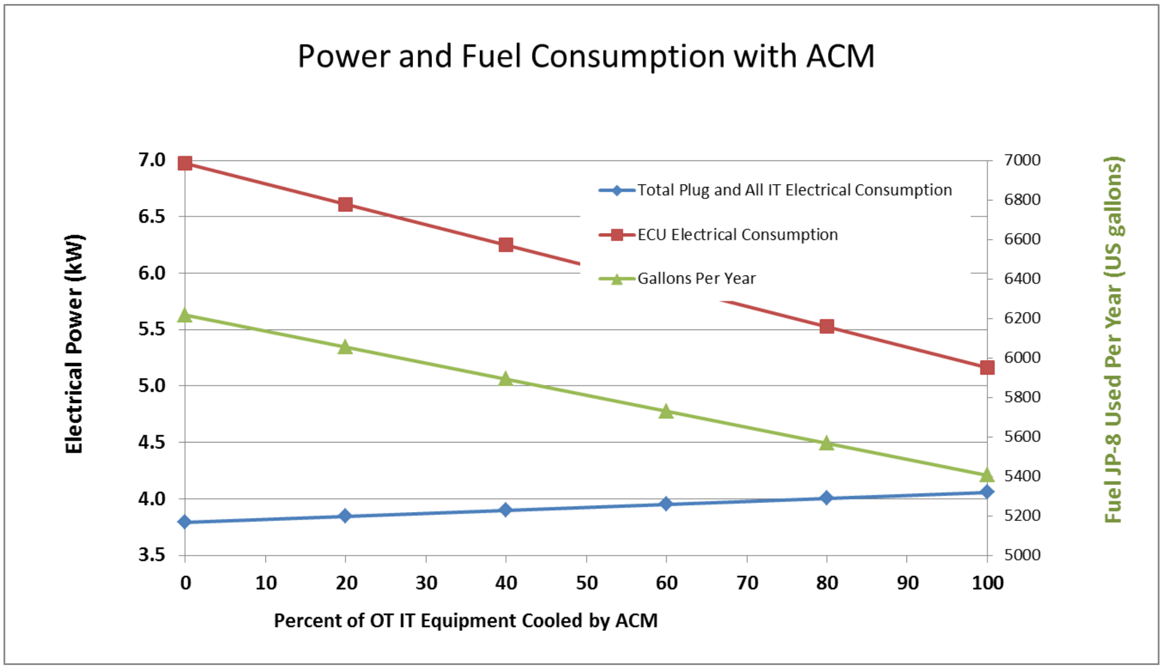

Figure 2. Power and fuel consumption with ACM

This savings is multiplied by the number of COCs (v4) in use, as well has the number of modular equivalents that comprise the larger versions of the COC (v1. v2, and v3). The sum of these, if measured, would result in the total savings.

V. CONCLUSIONS AND FUTURE RESEARCH

A. CONCLUSIONS

This research began with the assumption that ways existed to enhance the efficiency, and thus, reduce the fuel consumption of the COC system. This supposition emanated from experience as a communications officer with 2d Battalion, 7th Marine Regiment, 1st Marine Division. Multiple deployments to Fallujah, Iraq demonstrated that the use of ever-increasing amounts of automated data processing and service delivery were demanding a similar increase in power generation.

On the modern battlefield, situational awareness is increasingly fostered by services only made possible by deploying a robust data processing capability. Services, such as e-mail, CPOF, C2PC, and Force Battle Command, Brigade and Below (FBCB2)—more commonly known as Blue Force Tracker—all combine to produce a COP. A commander can receive a wealth of information from the COP in near real time that, when combined with instantaneous radio and digital communications, allows for fast decision making, which translates into decisive action on the battlefield.

The current generation of commanders is becoming accustomed to having these tools at their disposal, and as a result, a great deal of effort is being made to make them more accessible to lower echelons. The location of a battalion COC is seldom if ever determined by whether electricity is available; hence, a self-contained capacity to provide the required power is absolutely necessary. The term self-contained is a rather loaded term because the battalion is only self-contained if an expeditionary operation is going to persist for such a short period of time that all the fuel required can be brought to the fight with the battalion. This situation is also rarely the case, and therefore, fuel resupply is necessary. The requirement to resupply, even for short duration operations, results in exposure to the enemy. As previously mentioned, a large number of casualties have been associated with the delivery of fuel in the "last mile." A central question of this research was “How can exposure be reduced in the last mile of fuel delivery?” The answer to this question created a focus on the efficiency of electricity consumers among expeditionary systems.

It appeared that the COC system’s central components were the likely place to focus. The COC is essentially a mobile data center that serves multiple users with a variety of services, which is analogous to the way private firms deliver services. The key difference, however, is that private firms are unconstrained by the design restrictions required for tactical delivery of similar services. For instance, in the private sector, the supply of electricity, although constrained by cost and quantity available from public utilities, is reliable and is not correlated with fuel delivery. The space required to establish a data center to deliver services is only limited by the budget available to lease or build it. Cooling requirements in the private sector are of particular concern in terms of cost required to provide them; however, the flexibility afforded by fixed sites allows easier access to alternative methods to provide cheaper cooling. Fixed sites provide an additional benefit of not having to make mobility a concern. When a system does not have to move, it may sprawl vertically and horizontally within the limits of the infrastructure.

The tactical delivery of services is constrained by size, weight, mobility, and power production. Due to these design constraints, the relative efficiency is likely significantly reduced. From a purely empirical point of view, making a system smaller, lighter, and ruggedized, would seem to suggest a tradeoff in its efficiency in power consumption. This viewpoint, is, in fact, the case, but not in the manner expected.

For the past decade, significant design pressures have occurred in the private sector surrounding the more efficient delivery of data services. The increasing cost of electricity coupled with the desire to reduce the footprint maintained by firms has created a competitive market for providing smaller IT equipment and a more efficient means of delivering services. The idea of having multiple lightly loaded servers has given way to VMs that not only reduce the number of physical machines required, but also make each one more efficient by loading them more heavily. Techniques like virtualization have compressed the size of the data centers and made them more efficient.

These techniques were easily adapted to military applications. The employment of virtualization made saving space on the OT a simpler matter. Additionally, a more efficient set of servers reduces the amount of fuel required to generate electricity. Other techniques employed in the private sector were also easily adapted to tactical application, such as light emitting diode (LED) lighting that produces less heat to be dissipated.

The one area in which the need for lightweight, compact and ruggedized solutions hampers efficiency, is in the production of electricity and environmental control. Generators and ECUs suffer the greatest impact of size and weight constraints. As a result, the ECU became the primary area of focus. Given the efficiency constraints of the ECU, how can the cooling requirements be reduced?

1. Reducing the ECU load through ACM

An enormous amount of electricity generation is dedicated to supporting the ECUs—anywhere from 68% to 77% of the generator's capacity. The use of an ACM seems to be a good start toward reducing the amount of load placed on the ECU. The model showed that by using a dry cooler, a predicted 13.1% reduction in fuel consumed occurred in an environment in which the external temperature was 20 degrees hotter than the internal temperature. Alternative cooling methods that perform the function of cooling should be pursued. The core capability of these undefined methods of cooling must be a more efficient method of removing heat from the spaces being cooled. In the case of the dry cooler, water is used in a closed circuit because of its enhanced ability to conduct heat away from IT systems. The drawback to this method is that it must be engineered. Similar systems have been employed in the private sector with varying degrees of success, and thus, an adaptation to a military application may be possible sooner rather than later. A tipping point will come in which the cost to design and employ a dry cooler solution will be outweighed by the cost of fuel savings. The point may have already been reached at which it is necessary to consider the lives that may be saved by reducing the number and frequency of fuel convoys.

2. Procedural Considerations

The current procedure for erecting a COC (v4) is putting the 303 and 305 tent end to end, which effectively creates one long tent. The OT trailer is placed in the 303 tent and the command and control operations are conducted in the 305 tent. By having the OT in the same space as the personnel, the heat load from the OT is placed into the same environment. The cooling requirement for the electronics on the OT is less than that of the personnel; however, by placing them in the same space, the OT is effectively overcooled, which creates an unnecessary burden on the ECU that causes it to have to produce more chilled air. The obvious result is more demand on the generator and more fuel consumed. The ACM is a form of distributed cooling that places the method of cooling as close to the heat source as possible. By not dumping the heat produced by the OT into the environment, the tent is cooled more efficiently. In the absence of having an ACM available to provide distributed cooling, it may be possible not to cool the 303 tent during times where the temperature is below 90 degrees. Although Marines may not find it comfortable to reside in uncooled spaces, reducing the volume of space that must be cooled reduces the load on the ECU. This procedure has the benefit of no cost and no reengineering of the COC (v4).

B. FUTURE RESEACH

1. Quality of the model

The quality of the outputs of the model is only as good as the quality of the inputs and the soundness of the model itself. For now, the inputs are as accurate as the current state of data collection. The model, on the other hand, may not account for every variable. Neither does it account for the changing environmental conditions in which the COC must operate. The development of a benchmark may be the best way to enhance the model’s accuracy, or more accurately, a set of benchmarks that correspond to operating parameters. The model serves as a good starting point for modeling the COC (v4). This model can and should be considered critically by future researchers. It is unlikely that it is complete; however, it represents a good starting point to make a better model that more closely represents the effect of techniques designed to improve the COC’s (v4) efficiency.

2. Data Collection

The state of data collection is somewhat immature, but not for a lack of effort in measuring the power consumption of the components within the COC. In fact, several tests have been performed with the goal of gathering electrical load information. The problem with the data collection is that it is not complete. Although the electrical load of the IT systems during steady state operations may experience little variance, the ECU performance is likely to vary greatly depending on the environment. As discovered during this research, a large percentage of the required power generation is due to the ECU. A great deal of study is necessary before a complete model can be generated that considers all possible heat loads. Additionally, many activities are working on similar problems. In attempting to gather information from the COC program office, it became quite clear that many activities across the United States were tackling similar problems. A complete analysis of which activities are performing what studies would provide a good foundation for enabling better data collection through better coordination. Again, this is the perception from an outside researcher and may not accurately reflect the level of coordination actually occurring. Regardless, spending time obtaining a firm understanding of the work breakdown structure would be beneficial.

3. Generators

At the time of this research, data about the 22-kilowatt generator’s fuel flow rate was not available. Therefore, some assumptions had to be made. Further study regarding the efficiency and fuel flow of the generator would help increase the predictive capability of the model.

4. ECUs

Data about the ECU was based on the 96,000 Btu model because the manufacturer of the ECU did not have data on the ne 120,000 Btu model. As mentioned earlier, the ECU is a victim of the size and weight constraint to a greater extent than other systems in terms of losses in efficiency. The ECUs sacrifice a great deal of their efficiency by reducing their size. Applied Companies, the manufacturer of the ECU, is making progress in making future ECUs much more efficient. These techniques warrant additional study.

5. Tent Material and Modeling

The Naval Surface Warfare Center in Panama City, Florida is studying the COC environment in a scientifically rigorous manner. The tent has been modeled with nothing inside as a base. Subsequent modeling is being conducted by adding individual components to the tent and performing additional measurement.

The tent material is the subject of a lot of research. The weight and size restrictions placed on a mobile system dictate that a tent must be used. Tents are not typically very efficient due to the nature of the material of which they are composed. Radiant barriers have been the subject of experiments intended to increase the R-value of the tents.

Further research on modeling and tent material enhancements are promising.

6. Alternative Cooling Methods

It is unlikely that a single alternative cooling method will ever eliminate the need for ECUs; on the other hand, the combination of several may. As discussed, ECUs use an enormous amount of power. By analyzing all the possible methods of cooling more efficient than ECUs, a combination of methods may prove to be an effective substitute for the ECU.

APPENDIX A.

Component	Model	QTY	Unit Power (W)	Sumed Power (W)	Heat Dissapation (BTU/hr)
OT Tent					
DVD	Sony RDR-GX258	1	20	20	68.24284
Admin Laptop*	Dell M6400	2	41.5	83	283.207786
Crypto	KIV-7M (x2)	1	20	20	68.24284
Video Processor	Fusion 964	1	197	197	672.191974
AC PDU	Parallel UPS	3	325	975	3326.83845
DSU 1 (OT)	01-P56353E006	1	50	50	170.6071
Mass Storage	FAS2040 (5.4TB)	1	324.5	324.5	1107.240079
1U Srvr - (Exchg,	Dell R410-COC	2	201.5	403	1375.093226
1U Srvr - CPoF	Dell R410-COC	1	201.5	201.5	687.546613
CPoF Switch	Cisco 3560G-48	1	103	103	351.450626
Ethernet Switch	Cisco 3560G-48	1	66.5	66.5	226.907443
Ethernet Switch	Cisco 3560G-48	2	68.2	136.4	465.4161688
Router (NIPR)	Cisco 3845	1	79	79	269.559218
Router (SIPR)	Cisco 3845	1	79	79	269.559218
		OT Only		2654.9	9058.895796
		OT Tent Total		2737.9	9342.103582
Operations Tent					
Projector	NEC NP50/62/64	1	5	5	17.06071
Smartboard	SB680 Case Mod2	1	11	11	37.533562
Operations Laptop	Dell M6400	14	41.5	581	1982.454502
Printer, Color	HP K8600dn	1	9	9	30.709278
Med. Format Printer	HP K8600dn	1	9	9	30.709278
Plotter	HP 510	1	18	18	61.418556
Scanner	Epson GT-2500+	1	8.7	8.7	29.6856354
Copier, Laser	Canon D1120	1	16.6	16.6	56.6415572
		Operations Tent		658.3	2246.213079
	COC Total			3396.2	11588.31666

Table 11. COC V(4) equipment and electrical load data (After E2O, 2010)

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APPENDIX B.

(V)2 Power Measurements - July 2010				Current (Amps)		Real Power (Watts)		
	Date	Time	Volts	Max	Steady	Max	Steady	pf
(V)2 OpFac Total (calculated sum of indoor measurements)							***163,323***	
(V)2 OpFac Total (calculated sum of shore power panel measurements)							***165,834***	
(V)2 Equipment Total (Equipment only - no ECU - sum of indoor measurements)							***14,649***	
(V)2 Equipment Total (Equipment only - sum of outdoor measurements minus GETTs)							***17,241***	
A1 TENT								
A1 Shore Power Panel 1 (Calculated sum of indoor measurements)					***17.08***		***31162***	
Measured at Panel (average of nine measurements over two days)							**31124**	
GETT A1A2(1) ECU							14800	
GETT A4A2(2) ECU							14500	
A1 (1) Equipment							***1862***	
PDB 1					*17.08*		*1862*	
Phase A					*7.53*		*860*	
PDB J2 -UPS J1					*7.53*		*860*	
UPS 1 OTC (A10)					7.53		860	
J2	7/26/2010	1350	115.4		5.98		684	0.97
Display System (RTOC-4200ST)					4.36		502	
Projector 3	7/26/2010	1358	115.6		2.18		250	
Projector 4	7/26/2010	1400	115.5		2.18		252	
SIPR Switch 1 OTC A81 (01-P53307P001)	7/21/2010	1020	116.1	0.64	0.598	76	68.5	
CISCO CATALYST 3560								
Fiber Switch 1 OTC A85 (01-P53331P001)	7/21/2010	1021		0.438	0.432	50.4	50.4	
CISCO FIBER SWITCH 3750								
Flourescent Lights								
Flourescent Lights								
J3					*1.55*		*176*	
Jupiter OTC (01-P54372E001)	7/21/2010	1025	116.7	2.1	1.55	253	176	
Jupiter 964 Video Processor								
Phase B					*7.93*		*832*	
J6 NEMA 5-20R					*6.84*		*747*	
Smart Table (A61) - (A64)					*3.42*		*373.5*	
DELL M6500 WORKSTATION	7/21/2010	1043	116.1	0.6	0.4		43	
DELL M6500 WORKSTATION	7/21/2010	1055	116.1	0.62	0.36		40	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
Smart Table (A65) - (A68)					*3.42*		*373.5*	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
VTC								
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
J7 NEMA 5-20R	7/16/2010	1411	117.1		1.09		85	
Smart Table (A69) - (A70)					3.04		332	
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL FLAT PANEL MONITOR								
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
DELL FLAT PANEL MONITOR								
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
VTC								
DELL M6500 WORKSTATION					0.38		41.5	
DELL M6500 WORKSTATION					0.38		41.5	
Phase C					*1.62*		*170*	
J9 NEMA 5-20R	7/26/2010	949	117.8		1.43		166	0.16
Raw AC Buss 1					0			
Flourescent Light								
Flourescent Light								
Flourescent Light								
Flourescent Light								
Flourescent Light								
Flourescent Light								
Flourescent Light								
Flourescent Light								
Flourescent Light								
External PA Speaker								
J10 NEMA 5-20R	7/26/2010	951	117.6		0.19		4	0.16
PA Amp (A97)								
A1 Shore Power Panel 2 (Calculated sum of indoor measurements)					***17.456***		***30345***	
Measured at Panel (average of nine measurements over two days)							**31734**	
GETT A1A2(2) ECU							14872	
GETT A5A2(2) ECU							14467	
A1 (2) Equipment					***8.728***		***1006***	
PDB 2					*8.728*		*1005.8*	
Phase C					*8.728*		*1005.8*	
PDB J8 -UPS 2 J1								
J2					*7.008*		*802.8*	
Display System (RTOC-4200ST)	7/21/2010	1031	116.8	4.86	4.85	550	549	0.98
Projector 1								
Projector 2								
SIPR Switch 2 OTC A82 (01-P53307P001)	7/21/2010	1011	117.2	0.632	0.59	73.7	68.2	0.98
CISCO CATALYST 3560								
NIPR Switch OTC A83 (01-P53307P001)	7/21/2010	1016	117.2	0.608	0.576	70.9	66.5	0.98
CISCO CATALYST 3560								
COAL Switch OTC A84 (01-P53307P001)	7/21/2010	1020	117.2	0.625	0.568	72.9	69	0.98
CISCO CATALYST 3560								
Fiber Switch 2 OTC A86 (01-P53331P001)	7/21/2010	1005	117.4	0.438	0.424	50.1	50.1	0.98
CISCO FIBER SWITCH 3750								

						J9 NEMA 5-20R					7/26/2010	1438	117.6		1.72		203	1
							Raw AC Buss 2											
								Flourescent Light			7/26/2010	927	117.1		0.24		28	
								Flourescent Light										
								Flourescent Light										
								Flourescent Light										
								Flourescent Light										
								Flourescent Light										
								Flourescent Light										
								Flourescent Light										
								Flourescent Light										
								Printer A32-1 (01-P53368P001)										
									HP K8600 COLOR PRINTER									
								Printer A32-2 (01-P53368P001)										
									HP K8600 COLOR PRINTER									
								External PA Speaker										
A2 TENT																		
	A2 Shore Power Panel (Calculated sum of indoor measurements)														37		35017	
	Measured at Panel (average of nine measurements over two days)																36267	
		GETT A2A2(1) ECU															15,488	
		GETT A2A2(2) ECU															15,322	
		A2 Wing Total													37.3155		4207	
			PDB A2A90												12.2		1309	
				Phase A											8.75		925	
					J3 NEMA 5-20R						7/22/2010	1600	113.8		8		875	0.96
						Raw AC Buss 2												
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Smart Table (A65)-(A68)											
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL FLAT PANEL MONITOR										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
							Printer A35 (01-P53368P001)											
								HP K8600 COLOR PRINTER										
							Printer A50 (01-P53368P001)											
								HP K8600 COLOR PRINTER										
							Plotter A39 (01-P53523P001)											
								HP DJ510 PLOTTER										
					J4 NEMA 5-20R						7/22/2010	1603	115		0.75		50	0.55
							Printer A32 (01-P53368P001)											
								HP K8600 COLOR PRINTER										
							Scanner A36 (01-P54335E001)											
								EPSON GT-2500 SCANNER										
							Copier A42 (01-P54363E001)											
								D1120 Copier										
				Phase B											0.13		7	
					J6 NEMA 5-20		Smartboard #1 (01-P54382E001)				7/22/2010	1606	116.4		0.13		7	0.42
								SMART BOARD INTERACTIVE WHITEBOARD										
							Smartboard #2 (01-P54382E001)											
								SMART BOARD INTERACTIVE WHITEBOARD										
				Phase C											3.32		377	
					J10 NEMA 5-20R						7/22/2010	1607	114.9		3.32		377	0.98
						Raw AC Buss 1												
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Smart Table (A61) - (A64)											
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL FLAT PANEL MONITOR										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
							Smart Table (SIPR Adm) (A70)											
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
								DELL M6500 WORKSTATION										
			OT PDU A2A1												25.1155		2897.8	
				J11 - AC Main Line 1											4.7395		483.8	
					J12 - UPS 1 - J13										4.7395		483.8	
						J1 UPS to Trailer									0.825		50	
							A9 DSU-1 OTC (01-P54376E001)				Average				0.825		50	
							A9 DSU-1 OTC (01-P54376E001)				7/22/2010	1546	114.7	0.96	0.8	61	50	0.55
								01-P56353E006	H Computer Assembly Accessnet Chief VI									
							A9 DSU-1 OTC (01-P54376E001)				7/22/2010	911	114.5	0.9	0.85	60	50	
								01-P56353E006	H Computer Assembly Accessnet Chief VI									
						J2 UPS to Trailer									1.07		111.5	
							A3 NIPR SWITCH OTC (01-P54368E001)				Average				1.07		111.5	

							A3 NIPR SWITCH OTC (01-P54368E001)		7/22/2010	813	112.5		1.05		113	
							A3 NIPR SWITCH OTC (01-P54368E001)		7/22/2010	1554	113.7		1.09		110	0.9
								CISCO 3560G SWITCH								
								CISCO CATALYST 3560								
								MEDIA BOX FIBER OPTIC								
								13-SLOT POINT SYSTEM CHASSIS								
								CPSMM-120 1 SNMP MGT MODULE								
								CPSMP-120 1 REDUNDANT POWER SUPPLY								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 10 BASE T TO FO								
								MEDIA CONVERTER 10 BASE T TO FO								
						J3 UPS to Trailer							*0.1445*		*12.3*	
							A1 SIPR TX OTC (01-P53361P001)		Average				*0.1445*		*12.3*	
							A1 SIPR TX OTC (01-P53361P001)		7/22/2010	854	114.1		0.145		9.6	
							A1 SIPR TX OTC (01-P53361P001)		7/22/2010	1515	113.8		0.144		15	0.61
								CHS KIV-7M Chassis								
								~~KIV-7M Encryptor~~								
								~~KIV-7M Encryptor~~								
						J4 UPS to Trailer							*1*		*105*	
							A4 SIPR SWITCH OTC (01-P54368E001)		7/22/2010	915	115.2	1.1	1	110	105	
								CISCO 3560G SWITCH								
								CISCO CATALYST 3560								
								MEDIA BOX FIBER OPTIC								
								13-SLOT POINT SYSTEM CHASSIS								
								CPSMM-120 1 SNMP MGT MODULE								
								CPSMP-120 1 REDUNDANT POWER SUPPLY								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 10 BASE T TO FO								
								MEDIA CONVERTER 10 BASE T TO FO								
						J20 UPS Aux AC							*1.7*		*205*	
							Single 1U Windows Server OTC A87 (01-P53362P001)		7/22/2010	1521	116	2.15	1.7	294	205	0.99
								DRS 1U SERVER								
							Single 2U Windows Server OTC A88 (01-P53364P001)		7/22/2010	1528	116	3.08	2.21	351	257	0.98
								DRS 2U SERVER								
				J11 AC Main Line 2									*17.7*		*2025*	
					J14 - UPS 2 -J15								*11.34*		*1268*	
						J6 UPS to Trailer							*3.05*		*339*	
							A16 Unix Server OTC (01-P53773E001)		7/22/2010	1506	113.6	3.19	3.05	350	339	0.97
								V240 UNIX SERVER								
						J7 UPS to Trailer							*2.9*		*318*	
							A11 RAID OTC (01-P54365E001)		7/22/2010	906	113.3	4.8	2.9	460	318	
								FAS2040-COC								
						J8 UPS to Trailer							*2.71*		*310*	
							A2 SIPR Data Module OTC (01-P53360P001)		7/22/2010	1540	112.7	3.56	2.71	397	310	0.98
								DRS 1U Server								
								01-P53530P001 C Cisco Router, Ruggedized								
								TrippLite Console KVM Switch								
						J10 UPS to Trailer							*2.68*		*301*	
							A10 NIPR Data Module OTC (01-P53360P001)		7/22/2010	1446	112.3	3.5	2.68	359	301	0.98
								DRS 1U Server								
								01-P53530P001 C Cisco Router, Ruggedized								
								TrippLite Console KVM Switch								
					J26 Non-UPS Aux AC - UPS 4								*6.36*		*757*	
						J2			7/22/2010	1425	115	7.5	6.36	862	757	0.98
							Flourescent Light									
							Flourescent Light									
							Flourescent Light									
							NP64 PROJECTOR									
							NP64 PROJECTOR									
							Switch OTC A14 (01-P54368E001)		7/22/2010	1611	113	1.05	1.04	117	111	0.92
								CISCO CATALYST 3560								
							Switch OTC A15 (01-P54368E001)		7/22/2010	1614	113	1.04	0.99	111	106	0.93
								CISCO CATALYST 3560								
				J11 AC Main Line 3									*2.676*		*389*	
					J17 - UPS3 - J19								*2.676*		*389*	
						J16 UPS to Trailer							*2.37*		*270*	
							A17 Single 2U Windows Server OTC (01-P53364P001)		7/26/2010	1442	116.3		2.37		270	0.98
								DRS 2U SERVER								
						J18 UPS to Trailer							*0*		*0*	
							A12 Jupiter OTC (01-P54372E001)									
								JUPITER FUSION 964 DISPLAY WALL PROCESSOR								
						J22 UPS Aux AC							*0.144*		*57*	
							A91 Streaming Video OTC		7/22/2010	1535	114.7		0.144		57	0.5
								WINDOWS MEDIA DUAL CHANNEL ENCODER APPLIANCE								
								WINDOWS MEDIA DUAL CHANNEL ENCODER APPLIANCE								
							A46 Master Server Module OTC		7/22/2010	1331	112.7	7.89	5.76	886	650	0.99
								DRS 1U SERVER								
								DRS 1U SERVER								
								DRS 1U SERVER								
								CISCO CATALYST 3560								
						J23 UPS to Trailer							*0.162*		*62*	
							A13 DVD Recorder OTC (01-P54339E001)		7/22/2010	1512	113.8		0.162		62	0.61
								RDR-GX257 - SONY DVD RECORDER								
								Avocent DSR8020 KVM SWITCH								
A3 TENT																
	A3 Shore Power Panel (Calculated sum of indoor measurements)												***40.376***		***34105***	
	Measured at Panel (average of nine measurements over two days)														**33656**	
		GETT A3A2(1) ECU													15100	
		GETT A3A2(2) ECU													14600	
		A3 Wing Total											***10.409***		***4405***	
			PDB A3A90										10.409		1066.5	
				Phase A									*6.579*		*670.3*	
					J3 NEMA 5-20R								6.01		636	
					Raw AC Buss 2											

						J3-A					7/21/2010	1512	114.4		5.5		600	
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Flourescent Light											
							Smart Table (A65) - (A68)								*3.42*		*373.5*	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL FLAT PANEL MONITOR										
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
							Smart Table (SIPR Adm) (A70)								*1.14*		*124.5*	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
								DELL M6500 WORKSTATION							0.38		41.5	
						J3-B									*0.51*		*36*	
							Printer A35 (01-P53368P001)				7/21/2010	1101	111	0.17	0.13	13	9	
								HP K8600 COLOR PRINTER										
							Printer A50 (01-P53368P001)								0.13		9	
								HP K8600 COLOR PRINTER										
							Plotter A39 (01-P53523P001)				7/21/2010	1426	114.5	0.86	0.25	60	18	
								HP DJ510 PLOTTER										
					J4 NEMA 5-20R										0.569		34.3	
						Printer A32 (01-P53368P001)									0.13		9	
							HP K8600 COLOR PRINTER											
						Scanner A36 (01-P54335E001)					7/21/2010	1442	114.5	0.16	0.139	10	8.7	
							EPSON GT-2500 SCANNER											
						Copier A42 (01-P54363E001)					7/21/2010	1420	115.3	0.16	0.3	650	16.6	
							D1120 Copier											
				Phase B											*0.14*		*6.2*	
					J6 NEMA 5-20R										*0.14*		*6.2*	
						Smartboard #1 (01-P54382E001)					7/21/2010	1447	114.8		0.07		3.1	
							SMART BOARD INTERACTIVE WHITEBOARD											
						Smartboard #2 (01-P54382E001)					7/21/2010	1450	114.8		0.07		3.1	
							SMART BOARD INTERACTIVE WHITEBOARD											
				Phase C											*3.69*		*390*	
					J10 NEMA 5-20R						7/21/2010	1515	115		3.69		390	
					Raw AC Buss 1													
						Flourescent Light												
						Flourescent Light												
						Flourescent Light												
						Flourescent Light												
						Smart Table (A61) - (A64)												
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL FLAT PANEL MONITOR											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
						Smart Table (NIPR Adm) (A69)												
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
							DELL M6500 WORKSTATION											
			OT PDU A3A1 (01-P53605E001)												*29.967*		*3338*	
				J11 - AC Main Line 1											*9.183*		*998*	
					J12 - UPS 1 - J13										*9.183*		*998*	
						J1 UPS to Trailer									*0.76*		*55*	
								A9 DSU-1 OTC (01-P54376E001)			Average				0.76		*55*	
								A9 DSU-1 OTC (01-P54376E001)			7/21/2010	1316	113.6	1	0.85	60	50	
								A9 DSU-1 OTC (01-P54376E001)			7/22/2010	1229	113.3	1	0.67	67	60	0.59
									01-P56353E006 H Computer Assembly Accessnet Chief VI									
						J2 UPS to Trailer									*1.06*		*112*	
							A3 NIPR SWITCH OTC (01-P54368E001)				Average				1.06		112	
							A3 NIPR SWITCH OTC (01-P54368E001)				7/21/2010	1353	116.7	1.05	1.03		109	0.91
							A3 NIPR SWITCH OTC (01-P54368E001)				7/22/2010	1216	114.3		1.09		115	0.91
								CISCO 3560G SWITCH										
								CISCO CATALYST 3560										
								MEDIA BOX FIBER OPTIC										
								13-SLOT POINT SYSTEM CHASSIS										
								CPSMM-120 1 SNMP MGT MODULE										
								CPSMP-120 1 REDUNDANT POWER SUPPLY										
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX										
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX										
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX										
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX										
								MEDIA CONVERTER 10 BASE T TO FO										
								MEDIA CONVERTER 10 BASE T TO FO										
						J3 UPS to Trailer									*0.173*		*20*	
							A1 SIPR TX OTC (01-P53361P001)				7/22/2010	1223	114.5		0.173		20	0.59
								CHS KIV-7M Chassis										
								~~KIV-7M Encryptor~~										
								~~KIV-7M Encryptor~~										
						J4 UPS to Trailer									*1.05*		*108*	
							A4 SIPR SWITCH OTC (01-P54368E001)				7/21/2010	1320	113.2	1.1	1.05	115	108	0.91
								CISCO 3560G SWITCH										
								CISCO CATALYST 3560										
								MEDIA BOX FIBER OPTIC										
								13-SLOT POINT SYSTEM CHASSIS										

								CPSMM-120 1 SNMP MGT MODULE								
								CPSMP-120 1 REDUNDANT POWER SUPPLY								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 100BASE-TX TO 100BASE-FX								
								MEDIA CONVERTER 10 BASE T TO FO								
								MEDIA CONVERTER 10 BASE T TO FO								
						J20 UPS Aux AC							*7.2*		*815*	
							A93 Quad Server OTC		7/22/2010	1143	115.5	9.4	7.2	1120	815	0.99
								DRS 1U SERVER								
								DRS 1U SERVER								
								DRS 1U SERVER								
								DRS 1U SERVER								
					J25 Non-UPS Aux AC								*0*		*0*	
						Shredder A37 Olympia 1300.1C										
				J11 AC Main Line 2									15.59		1755	
					J14 - UPS 2 -J15											
						J6 UPS to Trailer							*3.04*		*342*	
							A16 Unix Server OTC (01-P53773E001)		7/22/2010	1212	114.3	3.11	3.04	349	342	0.98
								V240 UNIX SERVER								
						J7 UPS to Trailer							*2.97*		*331*	
							A11 RAID OTC (01-P54365E001)		7/22/2010	1240	111.8	3.72	2.97	373	331	0.99
								FAS2040-COC								
						J8 UPS to Trailer							*2.67*		*300*	
							A2 SIPR Data Module OTC (01-P53360P001)		7/22/2010	1253	113	3.18	2.67	352	300	0.98
							DRS 1U Server									
							01-P53530P001 C Cisco Router, Ruggedized									
							TrippLite B020-008-17 Console KVM Switch									
						J9 UPS Aux AC							*4.15*		*467*	
							Single 1U Windows Server OTC A87 (01-P53362P001)		7/22/2010	1151	115.2	2.27	1.83	259	208	0.99
								DRS 1U SERVER								
							Single 2U Windows Server OTC A88 (01-P53364P001)		7/22/2010	1158	114.4	3.08	2.32	358	259	0.98
								DRS 2U SERVER								
						J10 UPS to Trailer							*2.76*		*315*	
							A10 COAL Data Module OTC (01-P53360P001)		7/22/2010	1204	114.3	3.55	2.76	376	315	0.94
								DRS 1U Server								
								01-P53530P001 C Cisco Router, Ruggedized								
								TrippLite B020-008-17 Console KVM Switch								
					J26 Non-UPS Aux AC - UPS 4								*4.86*		*546*	
						J3			7/21/2010	1407	117.6		4.86		546	
							Flourescent Light									
							Flourescent Light									
							Flourescent Light									
							NP64 PROJECTOR									
							NP64 PROJECTOR									
							Switch OTC A14 (01-P54368E001)									
								CISCO CATALYST 3560								
							Switch OTC A15 (01-P54368E001)									
								CISCO CATALYST 3560								
				J11 AC Main Line 3									*5.194*		*585*	
					J17 UPS 3 - J19								*5.194*		*585*	
						J16 UPS to Trailer							*3.25*		*359*	
							A17 Unix Server OTC		7/22/2010	1246	112.3		3.25		359	0.97
								CHS V240 Server								
						J18 UPS to Trailer							*1.78*		*197*	
							A12 Jupiter OTC (01-P54372E001)		7/22/2010	1300	112.5	2.48	1.78	275	197	0.97
								JUPITER FUSION 964 DISPLAY WALL PROCESSOR								
						J23 UPS to Trailer							*0.164*		*29*	
							A13 DVD Recorder OTC (01-P54339E001)		7/22/2010	1221	114.6		0.164		29	0.64
								RDR-GX257 - SONY DVD RECORDER								
								Avocent DSR8020 KVM SWITCH								
A4 TENT																
	A4 Shore Power Panel (Calculated sum of indoor measurements)												***13.495***		***16091***	
	Measured at Panel (average of nine measurements over two days)														**16332**	
		GETT A4A2(1) ECU													14500	
		PDB A4A90											*13.495*		*1590.5*	
			Phase A										*5.585*		*668.5*	
				PDB J2 -UPS J1									5.585		668.5	
					UPS 1 OTC (A10)											
						J2			7/20/2010	1420	116.2		5.5		680	
						J2			7/22/2010	1327	116.7		5.67		657	0.95
						J2			AVE		116.45		5.585		668.5	0.95
							Wall UPS AC Buss									
							Flourescent Light									
							Flourescent Light									
							Flourescent Light									
							A40 NP64 PROJECTOR									
							A41 NP64 PROJECTOR									
							Switch OTC A14 (01-P54368E001)		7/20/2010	1445	114.9		0.94		103	
								CISCO CATALYST 3560								
			Phase B										*4.365*		*528.5*	
Av				J6 NEMA 5-20R					Average		117.1		4.365		528.5	0.98
				J6 NEMA 5-20R					7/20/2010	1415	117.4		3.6		459	
				J6 NEMA 5-20R					7/22/2010	1333	116.8		5.13		598	0.98
					Raw AC Buss 2											
						Flourescent Light										
						Flourescent Light										
						Flourescent Light										
						Flourescent Light										
						Flourescent Light										
						Flourescent Light										
						Flourescent Light										
						Smart Table (A65) - (A68)										
							DELL M6500 WORKSTATION									
							DELL M6500 WORKSTATION									
							DELL FLAT PANEL MONITOR		7/20/2010	1440	114.9		0.6		70	
							DELL M6500 WORKSTATION									
							DELL M6500 WORKSTATION									
							DELL FLAT PANEL MONITOR									

							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
						Printer A32 (01-P53368P001)								
							HP K8600 COLOR PRINTER							
			Phase C									*3.545*	*393.5*	
				J9 NEMA 5-20R					Average		117.6	3.385	382.5	0.96
				J9 NEMA 5-20R					7/22/2010	1334	117.8	3.07	348	0.96
				J9 NEMA 5-20R					7/20/2010	1410	117.4	3.7	417	0.96
					Raw AC Buss 1									
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Smart Table (A61) - (A64)								
							DELL M6500 WORKSTATION		7/20/2010	1400	114.6	0.5	40	
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
				J10 NEMA 5-20R					7/22/2010	1337	117.8	0.16	11	0.58
					Smartboard #1 (01-P54382E001)				7/20/2010	1350	116.8	0.4	70	
						SMART BOARD INTERACTIVE WHITEBOARD								
					Smartboard #2 (01-P54382E001)									
						SMART BOARD INTERACTIVE WHITEBOARD								
A5 TENT														
	A5 Shore Power Panel (Calculated sum of indoor measurements)											***13.95***	***16605***	
	Measured at Panel (average of nine measurements over two days)												**16721**	
		GETT A5A2(1) ECU											15026	
		PDB A5A90										*13.95*	*1579*	
			Phase A									*6.075*	*658.5*	
				PDB J2 -UPS J1								6.075	658.5	
					UPS 1 OTC (A10)									
						J2			7/20/2010	1500	115.6	6.4	658	0.99
						J2			7/22/2010	1310	115.9	5.75	659	0.99
						J2			AVE		115.75	6.075	658.5	0.99
							Wall UPS AC Buss							
							Flourescent Light							
							Flourescent Light							
							Flourescent Light							
							A40 NP64 PROJECTOR		7/22/2010	1340	116	0.12	5	0.46
							A41 NP64 PROJECTOR							
							Switch OTC A14 (01-P54368E001)		7/22/2010	1446	114.2	0.95	99	0.91
								CISCO CATALYST 3560						
			Phase B									*4.115*	*490*	
				J6 NEMA 5-20R					Average		117.4	4.115	490	0.96
				J6 NEMA 5-20R					7/20/2010	1500		4.2	530	0.96
				J6 NEMA 5-20R					7/22/2010	1316	117.4	4.03	450	0.96
					Raw AC Buss 2									
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Smart Table (A65) - (A68)								
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL FLAT PANEL MONITOR							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL FLAT PANEL MONITOR							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
						Printer A32 (01-P53368P001)								
							HP K8600 COLOR PRINTER							
			Phase C									*3.76*	*430.5*	
				J9 NEMA 5-20R					Average		116.8	3.6	419.5	0.98
				J9 NEMA 5-20R					7/20/2010	1500		3.2	359	
				J9 NEMA 5-20R					7/22/2010	1318	116.8	4	480	0.98
					Raw AC Buss 1									
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Flourescent Light								
						Smart Table (A61) - (A64)								
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
							DELL M6500 WORKSTATION							
				J10 NEMA 5-20R					7/22/2010	1323	116.9	0.16	11	0.58
					Smartboard #1 (01-P54382E001)									
						SMART BOARD INTERACTIVE WHITEBOARD								
					Smartboard #2 (01-P54382E001)									
						SMART BOARD INTERACTIVE WHITEBOARD								

Table 12. COC (V)2 power measurement 2010 from (From E2O, 2010)

APPENDIX C.

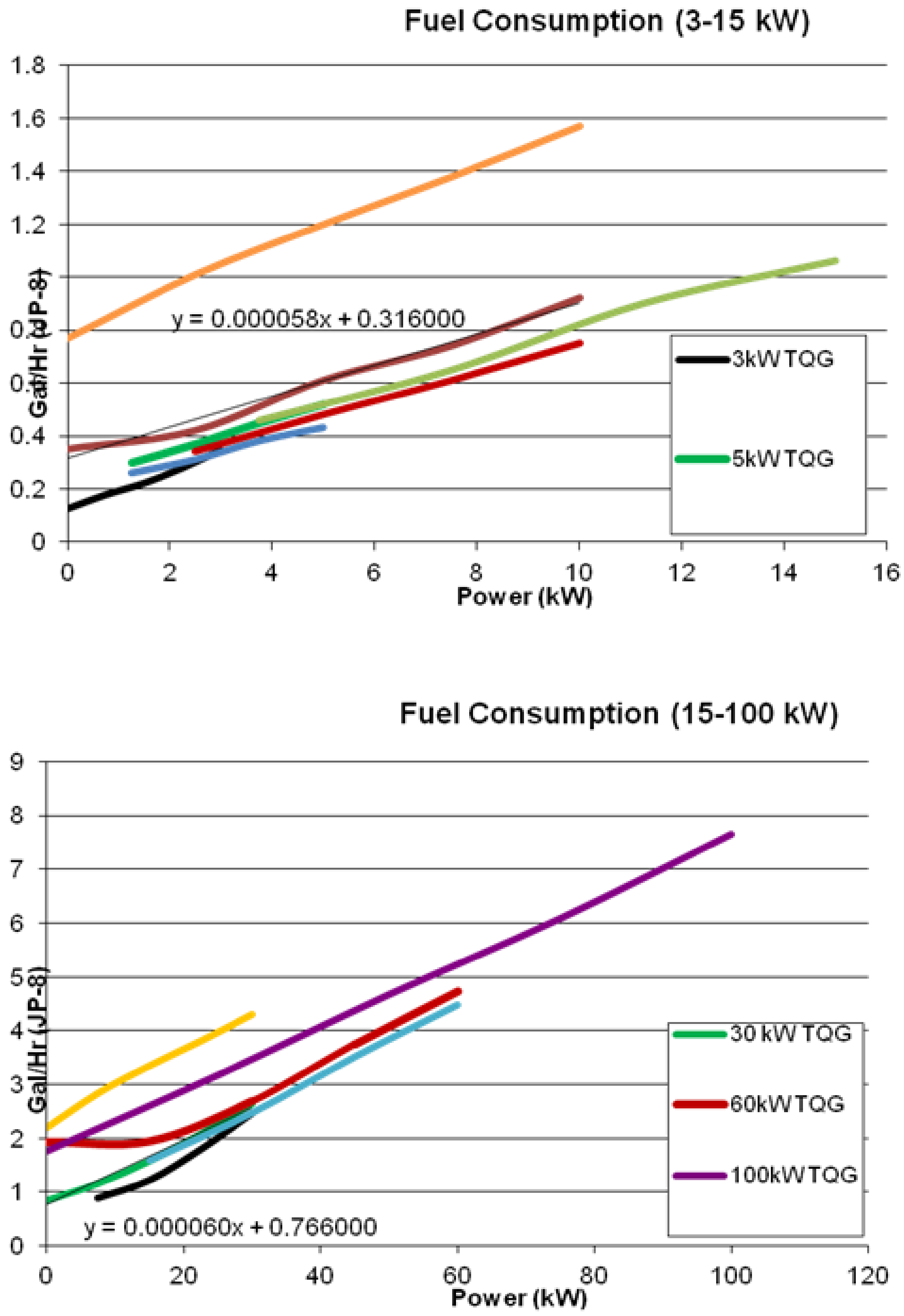

Figure 3. Generator Fuel Consumption From (From K. Schwartz, personal communication, November 1, 2012)

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