FINAL REPORT

Energy Reduction through Real Time Electricity Monitoring

ESTCP Project EW-201258

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14. ABSTRACT

The intent of this study was to determine whether providing real-time electrical use feedback to building occupants and facility managers would result in decreased electricity use. Current transformers (CT) were installed on circuits in 14 barracks buildings at Fort Bliss and 13 work buildings at AMARG. Measurements from the CTs were transmitted via local gateways and cell phone networks to a cloud based software platform. Electrical usage information was displayed in various formats on a web based application that could be viewed by building occupants. Representative examples of data formats include charts and graphs for facility managers and competitive leaderboards for barracks residents. The key performance objectives and results are summarized in this report. Significant findings and implementation issues are also included.

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Acronyms

3M: 3M Company

ACEEE: American Council for an Energy-Efficient Economy

AFCEC: Air Force Civil Engineer Center

AFB: Air Force Base

AMARG: 309th Aerospace Maintenance and Regeneration Group

ANOVA: Analysis of Variance

API: Application Programming Interface

BMS: Building Management Systems

CDD: Cooling Degree Days

DoD: Department of Defense

DoE: Department of Energy

DOE: Design of Experiment

DPW: Director of Public Works

ECC: Energy Control Center

ECM: Energy Conservation Measures

EMS: Energy Management Systems

EPRI: Electric Power Research Institute

ESTCP: Environmental Security Technology Certification Program

ETL: Engineering Technical Letter

HDD: Heating Degree Days

HQ: Headquarters

HVAC: Heating, Ventilation, Air-Conditioning

IMCOM: Installation Management Command

kVAh: Kilovolt Amp Hours

kW: Kilowatt

kWh: Kilowatt hour

MDMS: Metered Data Management System

MTU: Measuring Transmitting Unit

NEMA: National Electrical Manufacturers Association

OPSEC: Operations Security

OSHA: Occupational Safety and Health Administration

PLC: Power Line Communication

SIR: Savings-to-Investment Ratio

SQL: Structured Query Language

TED: The Energy Detective

UEPH: Unaccompanied Enlisted Personnel Housing

VAC: Volts Alternating Current

W: Watt

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Executive Summary

The intent of this study was to determine whether providing real-time electrical use feedback to building occupants and facility managers would result in decreased electricity use. Current transformers (CT) were installed on circuits in 14 barracks buildings at Fort Bliss and 13 work buildings at AMARG. Measurements from the CTs were transmitted via local gateways and cell phone networks to a cloud based software platform. This fully-integrated set of hardware and software is referred to as the 3M™ Energy Analyzer. Electrical usage information was displayed in various formats on a web based application that could be viewed by building occupants. Representative examples of data formats include charts and graphs for facility managers and competitive leaderboards for barracks residents.

After a baseline data collection period, displays were mounted in half the Fort Bliss barracks representing the experimental group. Residents were informed of the existence of the displays and their purpose. During the experimental period, differences in energy use between the barracks with the displays versus the control group, with no knowledge of the study, were compared. No difference in behavioral based energy reduction was observed between the experimental group and the control group. Several factors contributed to this result including high occupant variability due to field deployments, lack of intrinsic motivation among the resident population, and low levels of support from the chain of command to include extrinsic motivators in the study. One of the significant non-controllable variables was barrack occupancy level. Uncontrolled occupancy levels resulting from unexpected field deployments caused highly unpredictable data patterns and eventually caused termination of the study before completion.

Early in the study it was determined that a control versus experimental design would not be viable at AMARG due to significant differences in size, purpose, and function between the buildings selected at AMARG which resulted in very high variability in electrical use. Instead the demonstration plan proposed to perform energy conservation experiments within and between buildings over short periods of time. The 3M™ Energy Analyzer was installed and commissioned in 13 buildings, and baseline data was collected. Before the displays could be installed, Davis-Monthan AFB required an Operations Security (OPSEC) review. The review resulted in full system shutdown pending additional review and compliance with Engineering Technical Letter (ETL) 11-1. Planned energy use experiments could not be performed due to the shutdown. However, during the data collection period, interesting observations were made including higher electrical use in one building with an old air conditioning system compared to a similar building with a newer system, and a period of reduced energy use during the 2013 sequestration.

At both Fort Bliss and AMARG, the system provided the first usable view of electrical use in the demonstration buildings. This was exciting and useful for the resident energy managers who were able to easily view data by building and circuit, and over varying, comparative time periods.

Although the performance objectives were not fully met, useful learning from this demonstration may inform future work:

- the technology was reliable, and was easy to install and commission

- the technology is sensitive to changes in electrical use as demonstrated during occupant deployments, during sequestering, and in correlation to ambient temperatures
- single soldier barracks residents have little intrinsic motivation to change their electricity use behavior
- stronger command hierarchy support is likely required to produce energy saving behavioral changes in the barracks population
- access to data is not the only necessary component of a successful behavioral energy reduction effort

1. INTRODUCTION

Since the 1970s, the United States Congress has mandated improvement in building efficiencies and a reduction in energy consumption by all federal agencies. The Department of Defense is the largest energy consumer in the United States and accounts for approximately 63% of the energy consumed by federal facilities and buildings.[i] With more than 500 major installations, the DoD faces tactical as well as strategic risks in executing critical missions due to its reliance on the commercial grid to deliver electricity. Consequently, developing a strategic approach to energy was recently outlined as a high priority for the DoD in the 2010 Quadrennial Defense Review.[ii]

In order to achieve the greater DoD energy reduction goal, each branch of the U.S. Military has set forth specific strategies and objectives. As outlined in the Army Energy Security Implementation Strategy, the Army faces an increasing challenge to reduce consumption and increase energy efficiency.[iii] As an example, Fort Bliss seeks to become a "net zero" energy installation while at the same time tripling soldier population. Similarly, the Air Force Energy Plan is based on the foundation of "Make(ing) Energy a Consideration in All We Do." [iv] Creating soldier engagement and awareness of energy usage is an important factor that should be highly prioritized in an overall reduction plan. The Air Force Energy Plan is built upon three primary pillars: Reduce Demand, Increase Supply, and Culture Change. Within, the plan further states that "increasing energy awareness drives culture change."

The motivation of this project was to demonstrate the value of having real-time electrical use data available to building occupants and building facility managers. For building occupants, the demonstration attempted to explore whether real-time feedback enabled immediate and sustained behavioral changes leading to reductions in electrical use. For facility managers, the demonstration explored whether real-time feedback can enable evaluation of proposed building infrastructure and work process changes. Demonstrations were conducted at two locations, one concentrating on living quarters (Fort Bliss, TX) and the other on work places (309th Aerospace Maintenance and Regeneration Group, Tucson, AZ). The project commenced in August 2012 with the start of baseline measurements in summer of 2013, followed by experimental measurements in fall/winter of 2013/14. Measurements concluded in March of 2014.

Although the full intent of the demonstration was not realized due to a number of factors, the project did demonstrate an efficient method of collecting and reviewing electrical use data in both residential and work settings.

1.1. Background

Awareness of electricity use for many building occupants and/or facility managers consists of reviewing a monthly electric bill. For those who do not see the electric bills of the buildings where they work or live, there is not even the opportunity for review. Generally, this leaves encouragement to conserve energy to awareness campaigns, motivational slogans and posters as the only options for creating awareness to reduce consumption. These methods are "static" in nature and do not link specific behaviors with results. Even when given access to monthly electricity bills, many people have difficulty interpreting them and using them to conserve energy. In the end, even if the electricity bill is understood thoroughly and general guidelines for energy

conservation are available, there is usually no information available on any given person's real-time electricity use.

Conversely, creating real-time awareness of electricity consumption has been shown to result in energy conservation behaviors. The behavioral changes predicated on implementing real-time electricity measurement are supported by a 2006 study by Oxford University which concluded that households receiving direct feedback about electricity use reduced electric power consumption by 5 – 15%.[v] In February 2009, the Electric Power Research Institute (EPRI) similarly highlighted that a real-time understanding of electricity consumption could result in up to a 20% energy conservation effect.[vi]

Based on information obtained during early site visits to Fort Bliss and AMARG, it was clear there were no easy methods to dynamically monitor electricity use in buildings. For example, all electricity use at AMARG is consolidated into a single monthly value which is used by Davis-Monthan AFB to bill AMARG. No building or electrical panel level detail is provided. Furthermore, although there are meters installed in various AMARG buildings, none of the meters observed during the site visit were actually recording use.

At Fort Bliss, WattNode® systems are installed in various buildings. These systems collect electrical energy use over time from breaker panels. The raw data from these systems are captured in a database, but facility personnel state that it is difficult to retrieve and use the data. The data may be downloaded into a spreadsheet, but there are no applications available to display or manipulate the data into usable information. This makes dynamic monitoring nearly impossible. Furthermore, data from the WattNode® system contains a high number of anomalies (missing data, unrealistic low and high values, etc.). As such, there are insufficient human resources available to analyze the sources of the anomalies due to amount of time it would require to manipulate the data. Finally, the WattNode® data have a resolution of 15 minutes, which was insufficient to perform the types of usage assessments outlined in this study.

Thus, building occupants and facility managers have little or no knowledge of specific aspects of electrical energy use. Without this information, it is difficult to change occupant energy use behaviors, perform short term concept or prototype testing of energy saving initiatives, and assess the long term value of implemented changes.

The 3M™ Energy Analyzer provides near-real-time (1 minute resolution) electrical use feedback to building occupants and facility managers. For building occupants, displays can show building level performance and allow occupants to compare their usage to similar buildings. If interested, the occupants can interact with the display to gain a better understanding of electrical use over time. For facility managers, the system provides a way to easily access electrical use data for the buildings under their management. The data is presented in an easy to understand format consisting of charts, graphs, and other types of comparison dashboards. The system also addresses issues associated with anomalous data (missing data, unrealistic low and high values, etc.) as observed in the historical WattNode® data via automatic smoothing. The data smoothing methodology is described in Section 5.6.2.1 Post-Processing Statistical Analysis.

It was expected the system would increase awareness of energy usage for building residents, and allow facility managers to easily test and analyze proposed building energy modifications.

1.2. Objective of the Demonstration

The objective of this project was to demonstrate that providing real-time electrical use information to building occupants would induce behavioral change to reduce use, and assist building facility managers with evaluating modifications to reduce energy use. The 3M™ Energy Analyzer was installed in selected buildings by qualified electricians. The goal was to provide a means for analyzing energy use by providing a common, practical platform for DoD personnel to understand, experiment, and manage facility/process energy use modifications and the implementation of Energy Conservation Measures (ECMs).

The demonstration employed a "design of experiment" (DOE) approach to compare energy use between control and experimental settings, and to compare shorter term before/after or side-by-side controlled experiments. A desired outcome was to extrapolate results from the two scenarios described to a broader implementation of the technology.

The project objective was not met because the demonstration was terminated at both sites for unrelated reasons that will be described in detail within this report.

1.3. Regulatory Drivers

The following legislations, executive orders and DOD directives state a variety of plans, programs, and approaches all aimed at reducing energy consumption.

- Energy Policy Act of 2005 (P.L. 109-58)
- Energy Independence and Security Act of 2007 (P.L. 110-140)
- National Defense Authorization Act for FY 2007 (P.L. 109-364)
- National Defense Authorization Act for FY 2008 (P.L. 110-181)
- National Defense Authorization Act for FY 2009 (P.L. 10-417)
- Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management
- Executive Order 13514 – Federal Leadership in Environmental, Energy, and Economic Performance
- Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding

Various sections of these drivers address the overarching goals of increasing energy efficiency and conservation.

Specifically, Executive Order (EO) 13243 requires all federal agencies to improve energy efficiency and reduce greenhouse gas emissions through reduction of energy intensity. The EO sets a goal of energy reduction of three percent annually through the end of fiscal year 2015 or 30 percent by the end of fiscal year 2015 relative to the baseline of the agency's energy use in fiscal year 2003. EO 13514 requires all new federal buildings to achieve zero-net-energy by 2030.

While capital improvements to install energy efficient lighting, HVAC and other equipment are clearly important to achieve overall energy conservation objectives, only smarter, more informed building occupants can actively manage energy resources. No matter what capital energy improvements have already been made to a building, active monitoring and awareness helps building occupants and facility managers identify events that increase energy use. Furthermore, it is through an improved level of awareness that new opportunities to reduce energy will be identified.

2. TECHNOLOGY DESCRIPTION

2.1. Technology Overview

In January 2010, 3M purchased equity in Energy, Inc., a South Carolina start-up. Energy, Inc. designed and manufactures the TED5000, aka The Energy Detective, a real-time electricity monitor for single-phase, 100-127 volt / 60 hertz residential electrical systems. Under an exclusive agreement with 3M, Energy, Inc. designed an equivalent monitor for 3-phase electrical systems. Intertek Group plc ("Intertek") issued ETL approval for the 3-phase device on July 31, 2010 and FCC Part 15, Subpart B approval on November 2, 2010. Twenty (20) prototypes were designed, manufactured, and tested by 3M in both laboratory and small commercial installations. Following the results of this prototype testing, a second-generation 3-phase electricity monitor was developed to include enhanced power line communication and to be operative at a wider range of electrical services. The hardware is now designed to work on most 3-phase 50-60 hertz electrical services worldwide including 3-phase-4W Wye, 3-phase-3W Delta 1 or 3-phase-4W Hi-Leg Delta services where the line-line nominal voltage is between 200VAC and 600VAC. The hardware is suitable for services of 400 amps or less, or up to 1200 amps with parallel 400 amp feeds.

Additionally, 3M developed a proprietary software visualization graphical interface for use with both systems. The software platform aggregates data from any number of single- or 3-phase monitors, allowing the user to visualize electric energy usage, cost, and estimated carbon emissions on a real-time basis. Users can also view the historical data over time (by minute, hour, day, week) and look at cumulative data by time of day or day of week. Additionally, the software platform allows users to benchmark themselves against other users to compare performance.

The integrated hardware and software system are referred to as the 3M™ Energy Analyzer.

The solution is comprised of four major components:

1) measuring transmitting unit (MTU) including current transformers (CTs) and direct-wire power supply including means of measuring voltage
2) gateway, or energy control center (ECC)
3) a cloud-based visualization software platform
4) tablet displays to provide feedback to building occupants

Due to local area network access limitations, 3M utilized cellular network technology to transfer data from the gateway to the cloud based platform.

The system is depicted in Section 5.3 Design and Layout of System Components. The CTs are clipped to the main incoming wire conductors of the breaker panel and are sensitive to one watt. The MTU communicates with the ECC via either power line carrier signal or Ethernet. The ECC contains flash memory and a microprocessor allowing it to receive and store detailed electrical data. The ECC holds one hour of data summarized in seconds, 48 hours of data summarized in minutes, 90 days of data summarized in hours, and two years of data summarized in days. The ECC plugs into any three-pronged outlet and communicates directly to a network, or wirelessly to

a local router/modem. Data is accurate to within 2% and can be viewed on-site or remotely using an internet connected personal computer, a tablet computer, or a mobile device.

The electricity monitor hardware is designed for low maintenance. The MTU is powered via direct wiring into circuits within the electrical service panel. Therefore, there is no need for either battery strength monitoring or battery replacement. The ECC is powered through a three-pronged wall outlet. The MTU and ECC automatically resets following any disruption in power.

The unique feature of the 3M™ Energy Analyzer is the incorporation of behavioral science and game mechanics into the visualization software. While a building facility manager may understand and have motivation to reduce energy use, the enlisted ranks typically have no understanding of or motivation to reduce energy. The 3M™ Energy Analyzer contains video-gaming elements in order to educate building occupants about, and ultimately turn energy usage into a head-to-head competition. Military operations are rooted in planning and executing contests between groups of adversaries. Enlisted soldiers and their chain of command are highly trained in these methods. Applying these same methods to energy reduction is logical. The 3M™ Energy Analyzer was designed to create transparency, empowerment and competition for energy management.

Finally, outside DoD the functionality built into the 3M™ Energy Analyzer could be valuable for any number of market verticals, including but not limited to, quick serve restaurants, convenience stores, vehicle repair shops, medical clinics, other small commercial businesses, or multi-family housing.

2.2. Technology Development

A beta version of the 3M™ Energy Analyzer software had been developed and successfully tested in both laboratory and small commercial operations prior to this demonstration.

There were several software changes that were incorporated through the funding of this demonstration. Originally, the system required a computer to continuously query the ECC for data. The ECC now posts data to a web service using a third-party posting that resides on the ECC. In order to integrate this firmware change, 3M developed a data logger system. The data logger is comprised of two processes; the data catcher and the data processor. The data catcher is the service which takes the original ECC dataset and saves it to table storage. The data processor is a separate service that reads the dataset from table storage, processes the data into readable minute consumption data, and executes the rollup functions. The purpose of this design is to keep "whole" the original dataset should it be needed for reprocessing, and/or debugging reasons.

The analytic engine was enhanced to include the competitive elements of the experiment. The system was designed to allow building occupants to score points for reducing electricity use, and interacting with the system. These enhancements are further detailed in Section 5.0 Test Design.

A new secure login portal was developed to preclude the different demonstration sites from seeing the other's data.

Finally, the user interfaces were designed and tested using accepted graphical user interface testing techniques for facility manager and barrack occupant user cases.

2.3. Advantages and Limitations of the Technology

A wide range of Energy Management (EMS), Demand Response, and Building Management Systems (BMS) are commercially available. However, these products are expensive and require dedicated personnel for monitoring and maintenance. Furthermore, they do not provide immediate feedback to educate energy users on how their behaviors impact energy usage, nor do they include competitive elements to socialize the information.

The 3M™ Energy Analyzer costs significantly less than traditional metering, EMS and BMS systems and provides real-time electricity feedback directly to the people consuming the energy. The 3M™ Energy Analyzer also incorporates behavioral science and game mechanics into the feedback provided.

Because the system posts data to a web service using a third-party posting, it does not provide finer granularity than one minute of consumption. This did not result in any limitations for this demonstration nor is it expected to result in limitations in other uses.

Generally, there should be few barriers to implementing this technology. However, within DoD, a very significant barrier to implementation was the ability to obtain budget, certification and approval to operate the 3M™ Energy Analyzer on a wired or wireless network which is the preferred communication method. These challenges will be detailed in later sections of this report. Due to local area network access limitations, 3M utilized cellular network technology to transfer data from the gateway to the cloud based platform. The cellular network proved to be the least reliable and most expensive component of the overall system.

The 3M™ Energy Analyzer system employs the commercially available TED Pro series three-phase hardware as its data collection methodology. The TED Pro was not designed for, nor intended to be a direct digital control system. The equipment does not communicate with open protocol and was not designed to operate within the Unified Facilities Criteria 3-410-02 guidelines.

3. PERFORMANCE OBJECTIVES

Performance objectives are split into two sections: quantitative and qualitative. Both sets of objectives are summarized in the table below. Text following the table discusses the metrics and provides supporting information necessary to interpret the results.

Table 1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Overall facility energy use	Energy Use: kWh	Primary electric use data from the 3M™ Energy Analyzer. Building occupancy levels (Fort Bliss barracks only), and on-going temperature data	5% reduction compared to baseline and/or control group/area	**Did not meet**
Increase in energy use following a measured decrease; i.e."Backsliding"	After initial electrical use reduction, evidence of return to former levels	Same as above	Continued difference between experimental and control groups through the experimental period.	**N/A**
Energy reduction due to facility management directed site changes, enabled by monitoring (AMARG)	Energy Use: kWh	Controlled before/after facility management directed site modifications are made, experimental results obtained from the 3M™ Energy Analyzer database.	5% reduction between before/after periods	**N/A**
Projected energy reduction due to facility management directed site changes enabled by monitoring (AMARG)	Projected energy use: kWh	On/off use data from the 3M™ Energy Analyzer	Projected 5% reduction based on potential facility modification	**Partially met**
System economics	Payback period (years) SIR (Savings to Investment Ratio)	Cost of hardware, materials, installation labor, and maintenance over usable life, value of projected energy savings ($/kWh)	Payback period < 3 years SIR > 1.0	**Did not meet based on behavioral objective.** **Hypothetical payback may be < 3 years in certain cases.**

Performance Objective	Metric	Data Requirements	Success Criteria	Results
System availability	Percent uptime	Component uptime / server uptime from system monitoring (from system database)	> 95% uptime per building	**Partially met** **Fort Bliss 98.7%** **AMARG 92.1%**
User satisfaction	Degree of satisfaction with user interface	Survey (rating scales)	> 60% top-two-box score	**Did not survey**
System usability	Level of ease of use	Survey (rating scales)	> 60% top-two-box score	**Did not survey**
Qualitative Performance Objectives				
User satisfaction	Degree of satisfaction with user interface	Survey comments and interviews	List of suggestions for improvement	**Did not survey**
System usability	Level of ease of use	Survey comments and interviews	List of suggestions for improvement	**Did not survey**
Behavior change	Summary of behavioral changes observed	Observation / survey / interview	List of recommendations for system placement, settings, incentives, etc.	**N/A**
Assessment of system utility by facility management	Summary of activities enabled by the system	Interview	List of tasks enabled by the system	**Fully met**

3.1. Performance Objectives Descriptions

3.1.1. Overall Facility Energy Usage

The main objective of this project was to demonstrate a reduction in electrical energy use due to implementation of an energy monitoring feedback system. The study explored both building occupant behavioral changes resulting from near real-time feedback as well as the impact of facility/process modifications made by facility managers.

Metric: Electrical energy use in kWh measured at electrical panels.

Data:
- Data collected via the 3M™ Energy Analyzer
- Fort Bliss barracks occupancy
- Mappings between meter collection areas and number of residents/workers (required for competitive comparisons between experimental groups)

- Weather Underground™ outside temperature data, Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Analytical Methodology: Standard statistical methods were used for comparing data for both within and between comparisons (e.g., T-tests, ANOVA, etc.) Data was adjusted to account for variables such as number of residents. Weather Underground™ API was used to obtain the previous days outside temperature data, as well as the HDD and CDD for the weather station nearest each demonstration site. This data was used to normalize energy consumption if needed.

Success Criterion: Success was defined as a 5% relative reduction compared to baseline and/or control group/area.

Results: Did not meet. There was no significant impact of the experimental treatment on behavior based electricity use changes (see ANOVA results and discussion in Sections 5.6 and 6.0.) Aside from the shortened duration of the experiment, and the absence of extrinsic motivators, the experiment was carried out according to plan at Fort Bliss. Due to the lack of conformity in building size and function, and high variability in electricity use between buildings, the overall controlled experiment was not conducted at AMARG. Because of the mandatory shutdown of the system for security review, the smaller scale experiments were not implemented at AMARG.

3.1.2. Increase in Energy Use Following a Measured Decrease; i.e. "Backsliding"

The purpose of this objective was to determine whether or not backsliding occurred in the experimental building occupant groups when compared to the control groups. Backsliding is defined as a subsequent increase in energy use after a measured reduction in energy use. A plateau in energy use after a measured reduction would not have been considered backsliding. In the literature, the absence of backsliding may also be referred to as "persistence."

Metric: Electrical energy use in kWh measured at electrical panels

Data:
- Data collected via the 3M™ Energy Analyzer during the experimental period
- Weather Underground™ outside temperature data, Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Analytical Methodology: Because a significant decrease in *Overall Facility Energy Usage* was not measured, this metric was not assessed.

Success Criterion: Continued difference between experimental and control groups through the entire experimental period.

Results: N/A. Because there was no initial effect due to behavior change, this metric was not relevant. There was a significant difference in use over time, but it was similar for both control and experimental groups and was the result of factors such as temperature and occupancy.

3.1.3. Energy Reduction Due to Facility Management Directed Site Changes Enabled by Monitoring

The purpose of this objective was to show actual energy savings due to facility/tool/process changes that were enabled due to having real-time electrical use information available. The intent of this objective was to study energy conservation measures that were implemented above and beyond the building occupants' control.

Metric: Electrical energy use in kWh measured at electrical panels

Data:
- Data collected via the 3M™ Energy Analyzer during the experimental period
- Weather Underground™ outside temperature data, Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Analytical Methodology: This performance objective could not be evaluated because the demonstration was terminated before experiments could be conducted.

Success Criterion: 5% reduction in energy between before/after periods or between specific matched control and experimental buildings.

Results: N/A. After it was determined that a controlled experiment would not be practical at AMARG, this became the main objective for that site. Based on observations of activities/conditions and electricity use patterns analyzed, a number of mini-experiments were explored for the demonstration buildings. Due to the system shut down none were implemented. The system did show the air conditioning system in the Command building was operating inefficiently. When compared to the similar Start building, it is estimated that electricity use for Command could be reduced by 20-25% if the air conditioning system was repaired or replaced.

3.1.4. Projected Energy Reduction Due to Facility Management Site changes Enabled by Monitoring

The purpose of this objective was to show projected energy savings due to proposed facility/tool/process changes that were enabled due to having real-time electrical use information available. The intent of this objective was to model the impact of energy conservation measures that could be implemented above and beyond the level of building occupants' control. This Performance Objective would project savings extrapolated from the building sample included in the demonstration.

Metric: Baseline electrical energy use in kWh measured at electrical panels on a short term or long term basis, as well as estimates of energy savings from baseline due to proposed modifications.

Data:
- Data collected via the 3M Energy Analyzer for baseline use and during prototype or other short term test periods
- Data from published research and manufacturers reports

Analytical Methodology: Simple arithmetic calculation. Data was obtained from monitoring baseline and short term test periods. This data was used to calculate savings from full implementation of improvements that were not feasible during the experimental period.

Success Criterion: Projected 5% reduction in energy

Results: Partially met. Hypothetical projections for this objective are described in Section 6.0.

3.1.5. System Economics

The purpose of this objective was to demonstrate the economic viability of the 3M™ Energy Analyzer.

Metrics:
- **Payback period:** The estimated simple payback is the number of years for the cumulative value in energy cost savings to equal the investments cost, without consideration of discount rates.
- **Savings-to-Investment Ratio (SIR):** The ratio of the present value of an energy saving stream with respect to the present value of the cost of making the energy efficiency modification.

Data:
- Value of projected energy savings ($/kWh)
- Cost of hardware, materials, installation labor, facility operational costs and maintenance over usable life

Analytical Methodology: This calculation considered all costs associated with the installation and on-going operations and maintenance of the 3M™ Energy Analyzer. Network costs assumed use of a cellular network. Calculations were based on an agreed upon notional barracks or building.

Success Criterion: Payback < 3 years, SIR > 1.0

Results: Did not meet. Because there was no significant effect due to behavioral changes in energy use, no payback period could be calculated based on that factor. Hypothetical simple payback periods based on savings due to facility modifications are included in Section 6.0. These simple calculations show a possible payback under certain conditions of 5.5 years for Fort Bliss and over 10 years for AMARG.

3.1.6. System Availability

The purpose of this objective was to demonstrate the reliability of the system over time.

Metric: Percent system uptime

Data:
- Component uptime (e.g., MTUs, ECCs, etc.)
- Server uptime

Analytical Methodology: Availability data was recorded over the course of the experimental data collection period. Additionally, instances and periods of equipment failures were recorded over the same period. System availability was calculated as the percent total minutes reported, but not smoothed, over the entire experimental period, by MTU. The percent available minutes accounts for MTU, ECC, and cellular modem failures.

Success Criterion:
> 95% up time per MTU

Results: Partially met. Overall system availability at Fort Bliss was 98.7%, while overall system availability at AMARG was 92.1%. Excluding cellular network failures at AMARG yielded an overall system availability of 97.6%.

3.1.7. User Satisfaction and System Usability (Quantitative and Qualitative)

The purpose of this objective was to determine the degree of user satisfaction and ease of use of the 3M™ Energy Analyzer, and to solicit comments and suggestions for improvement, if any.

Metrics:
- Top-two-box scores; i.e. the two most favorable response options for a given question (quantitative)
- Open-ended comments

Data:
- Raw user survey rating scale data
- Survey comments

Analytical Methodology: Neither quantitative nor qualitative assessments were conducted because the total number of users was so low. However, opinions and improvement suggestions were captured in the *Assessment of System Utility by Facility Management* performance objective.

Success Criteria:
- > 60% Top-two-box score for level of satisfaction
- > 60% Top-two-box score for system usability
- List of suggestions for improvements

Results: N/A. Due to the premature shut down of the study, this objective was not assessed. The data analysis did show that very few individuals actually interacted with the system.

3.1.8. Behavior Change

The purpose of this objective was to determine the types of behavioral changes induced by introduction of the system, and to assess the perceived change in awareness of energy conservation and attitudes towards energy saving.

Metric: Feedback from end users in surveys and interviews.

Data:
- Survey comments
- Interview comments
- System data showing specific changes in use
- Observed instances of behavioral change

Analytical Methodology: This performance objective could not be evaluated because the demonstration was terminated before results could be measured.

Success Criteria:
List of recommendations for system placement, implementation, user interface, system settings, incentives, methods used to increase and sustain awareness of energy use, etc.

Results: N/A. Due to the premature shut down of the study, this objective was not assessed.

3.1.9. Assessment of System Utility by Facility Management

The purpose of this objective was to determine how facilities management personnel used the 3M™ Energy Analyzer, and list the tasks enabled by the system.

Metric: Assessment of facility manager attitudes towards dynamic energy monitoring, and a summary of activities enabled by the system.

Data: Interview results

Analytical Methodology: Content analysis of the interview answers.

Success Criteria: List of tasks enabled by the system with actual or projected savings.

Results: Fully met. Both energy managers at Fort Bliss and AMARG were pleased with the system and desired to implement it at their sites should it be commercially available. A detailed description of their feedback is provided in Section 6.0.

4. FACILITY/SITE DESCRIPTION

4.1. Facility/Site Location and Operations

4.1.1. Fort Bliss – El Paso, TX

Demonstration Site Description: Fort Bliss contains a large number of 2008 and newer Unaccompanied Enlisted Personnel Housing (UEPH) barracks for the residential study. The site is currently motivated to achieve Net Zero Energy by 2015. The following barracks were included in the demonstration: 21205, 21206, 21208, 21210, 21220, 21222, 21223, 20305, 20310, 20315, 20340, 20345, 20355, and 20365. In addition, displays were placed at several locations including the dining facility, Brigade HQ, and DPW offices.

Key Operations: No activities beyond normal operations to support training, mobilization, and deployment of military personnel occurred in the demonstration buildings. Buildings were selected based on highest expected occupancy levels over the experimental period.

Command Support: There was strong support for this project at Fort Bliss from the Directorate of Public Works.

Communications: The system was fully stand-alone. Hard wiring was used between local components, i.e. within a breaker box area, and a cellular network was used for conveying information to the cloud database. Use of a wired or wireless local area network would be a more cost effective method of communication. However, the barracks had neither.

Location/Site Map: The locations of the demonstration buildings at Fort Bliss are shown in Figure 1.

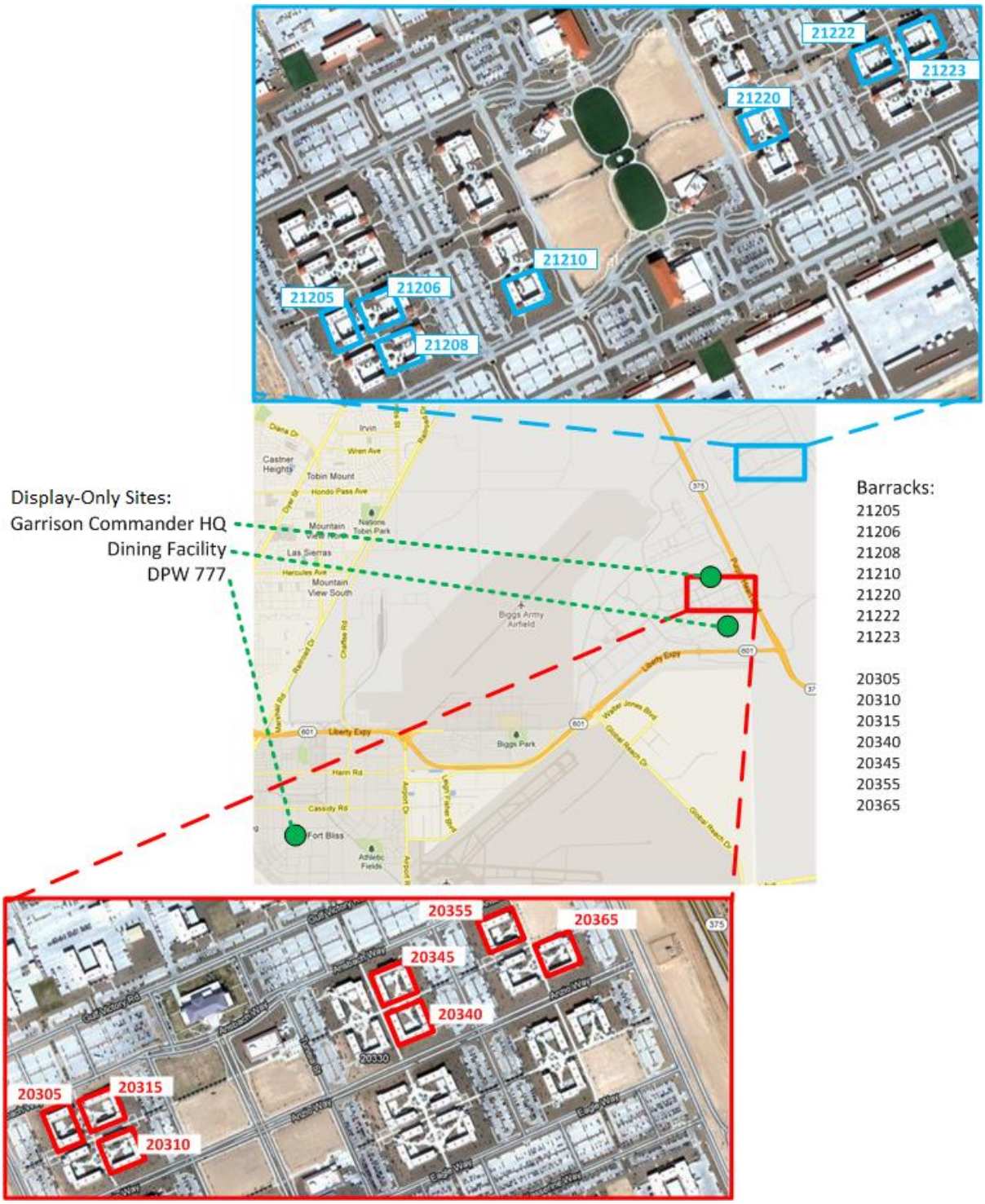

Figure 1. Fort Bliss Site Map

4.1.2. AMARG – Tucson, AZ

<u>Demonstration Site Description</u>: AMARG contains a wide variety of buildings (function, size, age, construction, etc.) to support the work building demonstration. The following buildings were

included in the demonstration: IT (7328), supply (7328), reclamation (7391), wing shop (7401), hangar (7408), woodmill (7431), avionics (7439), welding (7441), hangar (7506), start (7507), support (7513), command (7514), shelter 1 (7432), shelter 2 (7433).

Key Operations: The site supports a wide variety of aircraft regeneration, maintenance, and parts reclamation activities. Buildings were selected to represent typical usage over the experimental period. No activities beyond normal operations listed above occurred during the demonstration.

Command Support: There was strong support at AMARG including facility managers and the commanding office.

Communications: Similar to Fort Bliss, the system was fully stand-alone. Hard wiring was used between local components, i.e. within a breaker box area, and a cellular network was used for conveying information to the cloud database. Use of a wired or wireless local area network would be a more cost effective method of communication. However, none of the buildings used in this demonstration had either category 5 cabling installed near the breaker box or a local wireless network installed.

Location/Site Map: The locations of the buildings used in the AMARG demonstration are shown in Figure 2.

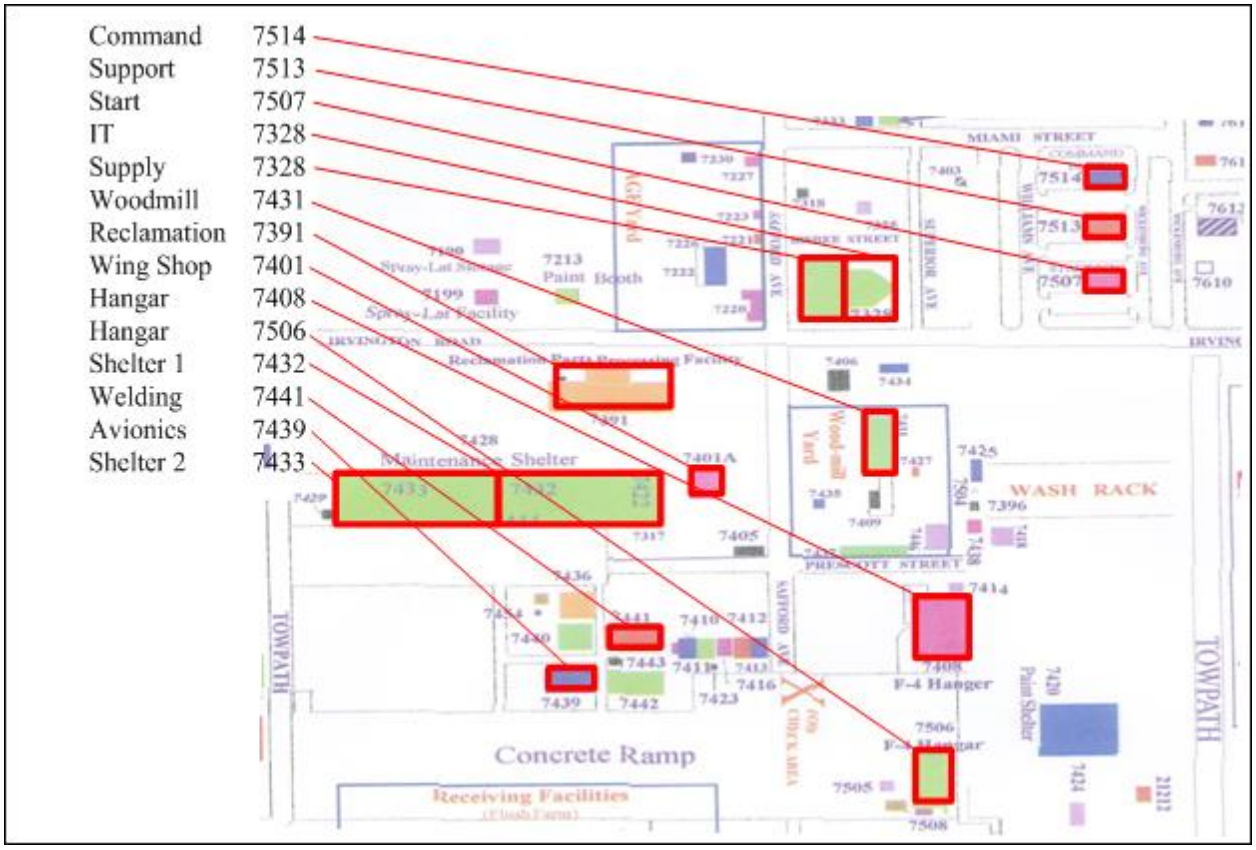

Figure 2. AMARG Site Map

4.2. Facility/Site Conditions

At the time they were selected, the demonstration buildings met the following criteria:

1. No significant energy improvement projects or initiatives were planned during the baseline data collection period.
2. No significant energy improvement projects or initiatives were planned during the experimental period.
3. Significant occupant activity; i.e., active living quarters with high occupancy levels or work areas that are operating near or close to capacity.

There were no specific geographic or climate zone criteria of interest for this study.

For the residential building occupant study, barracks were selected so as to reduce the expected variability due to non-study variables. To that end, newer buildings using the post-2008 construction guidelines were included. For the facility manager study, a wide variety of buildings were selected.

The building design or specific work done in the buildings was not as important as the notion of using the system to evaluate and support energy saving projects. The system itself should be implementable in nearly every facility.

The final consideration for selection was the willingness of facility personnel to participate and support the project. An effort was made to include personnel who had a stake in energy savings at their facility and who could appreciate and benefit from implementation of an energy monitoring system.

5. TEST DESIGN

The two main questions the study addressed were: 1) Will access to real-time electrical use information enable energy saving behaviors of building occupants? 2) Will access to real-time electrical use information enable facility managers to perform practical, inexpensive, and quick evaluations of building/device/process changes within buildings to facilitate long term improvements? For both questions, the intention was to translate the results into potential cost and energy savings and calculate payback periods.

5.1. Conceptual Test Design

The main independent variable at Fort Bliss was whether or not building occupants received real-time electrical use feedback or not. The occupants of control buildings were not aware that monitoring was occurring in their buildings. The occupants of experimental buildings had access to displays showing their energy use relative to other buildings.

The main dependent variable at both sites was electrical use over time recorded as kilowatt hours. 3M had also planned to collect qualitative information about attitudes, behavior change, sustainability, etcetera via survey and interview, but this was eliminated after premature termination of the demonstration and the low number of overall users.

At Fort Bliss, the most critical uncontrolled variable was the occupancy level of the monitored barracks. The barracks selected for the study were those most likely to remain fully or mostly occupied during the experimental period. Should occupancy vary highly, the plan had been to normalize electrical energy use per occupant. Unfortunately, there was high occupancy variability but there was no way to obtain accurate occupancy levels.

Because comparisons were made between a control and experimental group over the same time periods, outside temperature levels were monitored but not controlled for. Building size/type was similar across all of the selected barracks.

At AMARG, the buildings selected for study were variable with regard to size, function, age, occupancy level, etc. As such, it was planned to select buildings for the control and experimental groups so that their baseline use would be as close as possible. Similar buildings would be paired into each group (e.g., one office building in each group, one hangar in each group, etc.) It was anticipated that changes in control building function or work content during the demonstration period would result in significant changes in energy consumption. As needed, these changes could be assessed and corrected for.

The fundamental hypothesis this demonstration aimed to prove at both sites was that access to real-time electrical usage information can result in a reduction in electrical use when compared to a control group. Any changes observed in the control group would be the result of non-experimental variables, e.g., outside temperature, which would be used to normalize changes seen in the experimental conditions. Additionally, the secondary hypothesis at Fort Bliss was that following the initial reduction (after perhaps the first one to two months) the level of electrical consumption would remain stable unless there is evidence of backsliding behavior. At AMARG, a decrease in electrical use in experimental buildings may have varied during the course of the

experimental period as different functional use studies or prototype installations were done and as more permanent changes were implemented. Unfortunately, these studies could not be implemented before the system was shut down.

5.1.1. Test Design and Phases

The following experimental design approach and phases were used:

1. **Pre-test pilot installations:** Monitoring equipment was installed in several buildings at each site to confirm the system would operate as planned. Collected data was used internally at 3M for software user interface analysis. Displays were not installed at the sites and data was not available to site personnel.

2. **Monitoring system installation in all test buildings:** After system operation was confirmed via the pilot test, equipment was installed and tested in the rest of the buildings. No display monitors were installed at that time.

3. **Baseline data collection:** The main purpose of this phase was to collect building baseline electrical use data. The data was used to assess the level of expected variability during the balance of the study and to provide a baseline use level for making relative comparisons during the experimental phase.

   Data collection began following installation and testing. For analysis, data were consolidated into one week bins. One-minute resolution data were kept in the database to be used, if necessary. During the baseline period, variability of the data (both point-in-time, and over time) was examined. If there were large differences between similar buildings, an attempt was made to understand the root causes. This led to elimination of some baseline collection, for example during the temporary field deployment of control building occupants at Fort Bliss.

   For the Fort Bliss barracks, an attempt was made to correlate electrical use and occupancy level, although the lack of real occupancy levels made this impractical.

4. **Building assignments to test groups:** Buildings at the Fort Bliss site were assigned based on location. The barracks design was similar between the two groups with slightly lower occupancy in the control barracks. This did not have an effect on results since the critical variable was the measure of relative change in energy use. After observing the highly variable building functionality, types, and sizes of buildings at AMARG it was decided not to split the buildings into control and experimental groups.

5. **Display installation:** Once buildings were assigned, displays were installed in the experimental group buildings at Fort Bliss. Displays were located in highly visible, high traffic areas of the buildings near the front desks. Displays were also installed at a cafeteria, a headquarters building, and the DPW.

6. **Training:** The occupants of the Fort Bliss experimental buildings were provided an explanation of the test and directions for use via email. Paper instructions were also taped

to every room door and next to the displays. It was intended that specific extrinsic incentives for high performance would be determined with the advice and approval of the Fort Bliss command structure. No information or training was given to the occupants of the control group buildings.

7. **Experimental period:** The main dependent variable was the relative percent change difference between the control and experimental groups. The relative difference in usage between an experimental building and its baseline was calculated each week and adjusted by normalizing to the control's change from baseline for the same period.

Percent Usage Difference from Control =

$$(((W^nT^C / WB^C) * WB^{E1\text{-}m}) - W^nT^{E1\text{-}m}) / WB^{E1\text{-}m}$$

Where:

WB^C = Weekly baseline period usage (kWh) averaged over all control buildings and all baseline weeks

W^nT^C = Test week usage (kWh) averaged over all control buildings for that week; where n identifies the week, which may begin at any point during the test period

$WB^{E1\text{-}m}$ = Weekly baseline period usage (kWh) averaged over all baseline weeks for one experimental building; where 1-m identifies the building: Exp^1, Exp^2, … Exp^m

$W^nT^{E1\text{-}m}$ = Test week usage (kWh) for one experimental building; where n identifies the week, and 1-m identifies the experimental building: Exp1, Exp2, … Exp^m

A theoretical example calculation follows:

Over the baseline period, the seven control barracks measured an average weekly use per barrack of 2,100 kWh. Over the same period, experimental barrack #2 measured an average weekly usage of 2,025 kWh. During one of the experimental test weeks, the seven control barracks measured had an average use of 2,300 kWh. The outside temperature was warmer than the baseline period and more air conditioning was consumed that week. Over the same period, experimental barrack #2 was aware of their usage and lowered their thermostat by one degree resulting in a measured usage of 2,075 kWh. What is the relative percent energy savings for barrack #2 compared to the control group?

$$(((2300 / 2100) * 2025) - 2075) \ / \ 2025 = 0.07 \text{ or } 7\% \text{ relative savings for barrack \#2}$$

Although barrack #2 used more electricity during the test week than for the baseline (2,075 versus 2,025), they still demonstrated a relative saving compared to the control group. In this case, the warmer weather increased everybody's use, but the increase in barrack #2 was less due to the actions of the occupants (assuming all else remains constant.)

Correcting for independent influences on measurements:

Occupancy: 3M had expected that accurate official occupancy levels would be available at Fort Bliss so that correlation factors between energy use and occupancy could be calculated in order to normalize results over time. Unfortunately this information was not available and there was greater than expected variation in occupancy level. 3M addressed this issue by eliminating data from highly variable periods.

Building function or work content changes: This factor was only relevant at AMARG. The intention was to correct for major changes in work performed in the buildings. This correction was not needed due to the elimination of the control / experimental building test design.

Display of meaningful information:

During the experimental period at Fort Bliss, near-real-time electrical use data was displayed in the experimental group buildings. Displays were mounted near the barracks where the heaviest building occupant traffic was expected. Information was presented in a meaningful and engaging way so that occupants could understand their building's status relative to other experimental, competing barracks. The displays were configured so that a building occupant could drill down to see more detailed information or data from other time periods.

The display was set up as a competition between barracks. Points were awarded based on relative energy use compared to baseline and also for performing specific information awareness activities (such as reading energy tips or taking quizzes.) Table 2 outlines the points awarded for specific categories.

Table 2. Award Category Descriptions and Points

Category	Description	Points
Better Stronger Faster	Points awarded when a barrack scores better than the previous week.	100
Page Views	Points awarded for interacting with the system, viewing multiple screens, etc. Points capped each day.	5
Weekly Wins	Bonus points awarded for the barrack with the most points that week.	1000
Hourly	Points awarded when a barrack uses less energy than expected in a given hour. This achievement could be unlocked up to 24 times each day.	50
Primetime	Points awarded when a barrack uses less energy than expected for an hour during a peak demand period.	50
Best Week Yet	Bonus points awarded each time a barrack beats its own high score.	500
Best of Day	Bonus points awarded to the barrack in first place each day.	500
Multimedia	Points awarded for scanning a QR code to view the 3M™ Energy Analyzer on a mobile device.	50
Quizzes	Points awarded for taking a multiple choice and true/false quizzes. Points were capped each day	40
Tips	Points awarded for reading energy reduction tips. Points were capped each day	25

Occupants could observe how their barrack was doing compared to the six other experimental barracks. A new competition began each week so there would be repeated chances for a barrack to "win" and to eliminate the chance that one or two barracks would dominate the competition by getting too far ahead of the other barracks.

The display screen was divided into three areas. The upper left-hand side displayed the Leaderboard. The lower left-hand side displayed a screen which scrolled between the current weather conditions, a chart of the current energy usage, the total points awarded for the past five weeks for a single barrack, and a bar chart showing the number of times each barrack was a “Weekly Winner.” The right-hand side of the screen outlined how occupants could earn points by category, and how many they had already earned during the competition. An example Leaderboard is shown in Figure 3. Appendix C shows further examples of the various screens.

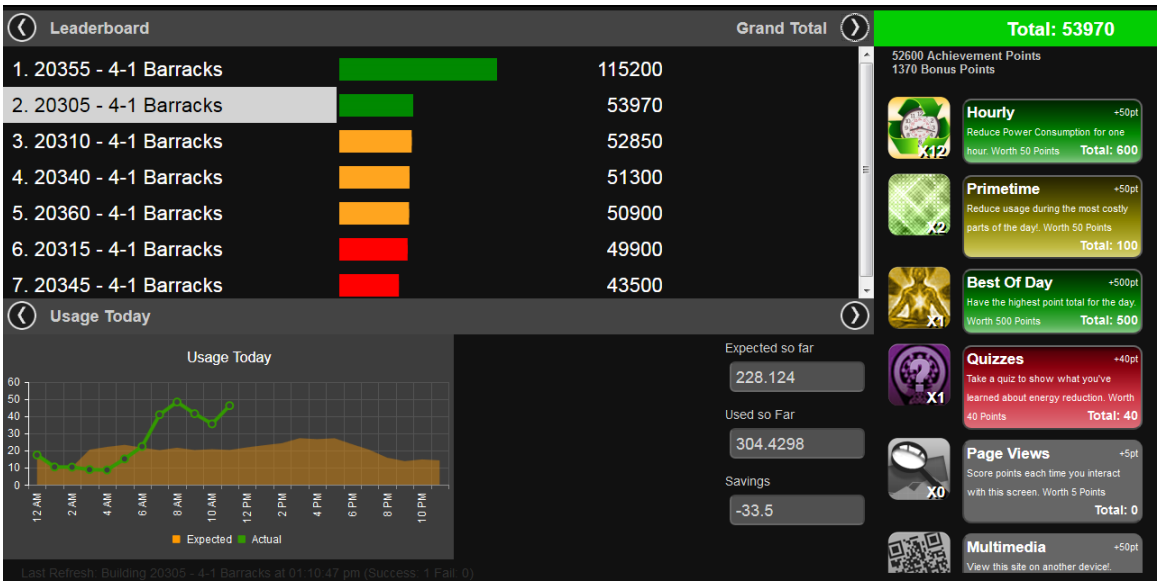

Figure 3. Sample Leaderboard Display

At AMARG, more "traditional" energy usage information was to be displayed. Competition in this environment was of less interest to facility managers. The default display presented hourly data use for the subject building. An example display is shown in Figure 4.

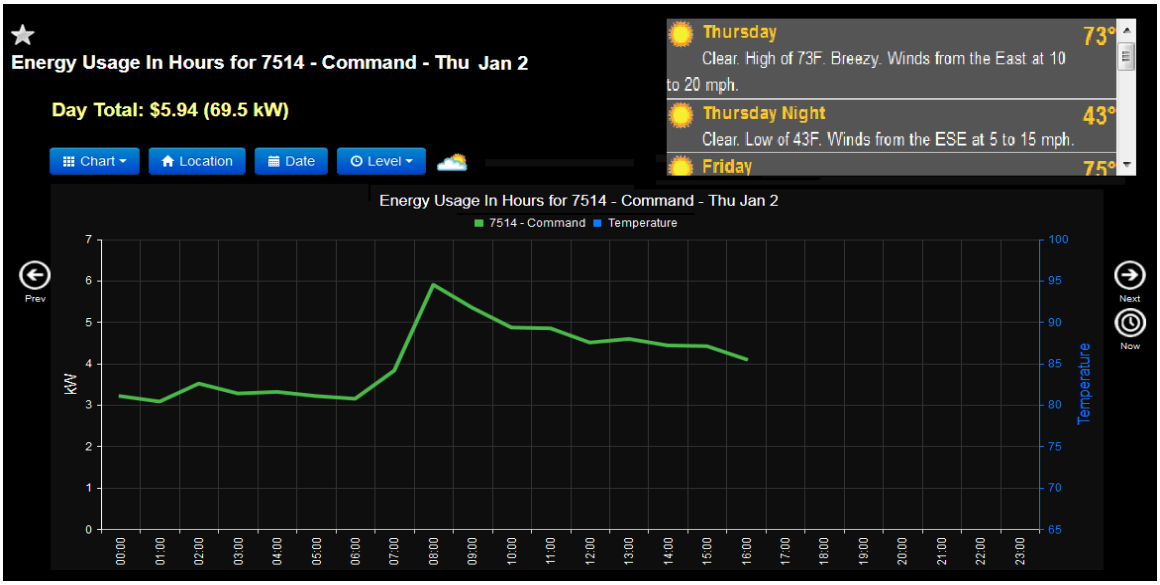

Figure 4. Energy Use Each Hour for 7514 - Command

During the experimental period, study progress was assessed at regular periods. At Fort Bliss, the assessments focused on understanding variability in energy use and whether variability would be low enough to show a significant difference between groups.

At AMARG, a higher level of variability was expected and observed since individuals had limited control over electrical use in their work buildings. Comparisons were made within a building over time and/or between similar buildings during the same time period.

8. **Final data analysis and reporting:** At the end of the experimental period a repeated measures ANOVA was performed on the Fort Bliss data. This analysis tested the hypothesis that access to real-time electrical use information would lead to reduced electrical use compared to the group that did not receive feedback, and whether behavioral backsliding occurred over time.

5.2. Baseline Characterization

The study was designed to include control and experimental building groups. The electrical use data for the control buildings was to serve as the reference for assessing differences with the experimental group as described in Section 5.0 Test Design. This approach allows for control of the important uncontrollable variables including external temperature and normal occupancy variation (as opposed to vacancy due to deployment.) Baseline energy use was collected directly using the 3M™ Energy Analyzer for a period of 14 weeks of which four weeks were ultimately eliminated due to field deployments.

5.3. Design and Layout of Technology Components

The 3M™ Energy Analyzer captures individual building energy data and sends it to a cloud based web site. Users with the proper security credentials had access to the data via a software interface. Various security credentials were created to allow users to view the data relevant to their building or site, and to allow administrators to set-up system users, define ECCs and MTU's and grant group permissions.

The system is described in detail in Section 2.1 and is comprised of a measuring transmitting unit (MTU) which measures voltage, three to nine current transformers (CTs) which measure current, a gateway (aka energy control center, or ECC) which processes and stores the data, a cloud-based application which runs the 3M™ Energy Analyzer software, and tablet displays for data visualization.

Commercial products used in the demonstration system are TED Pro Commercial electricity monitors (MTUs, CTs, and ECCs), Cisco 16-port switches, CradlePoint COR IBR650 cellular modems, and Apple iPads.

The system is depicted in Figures 5 and 6.

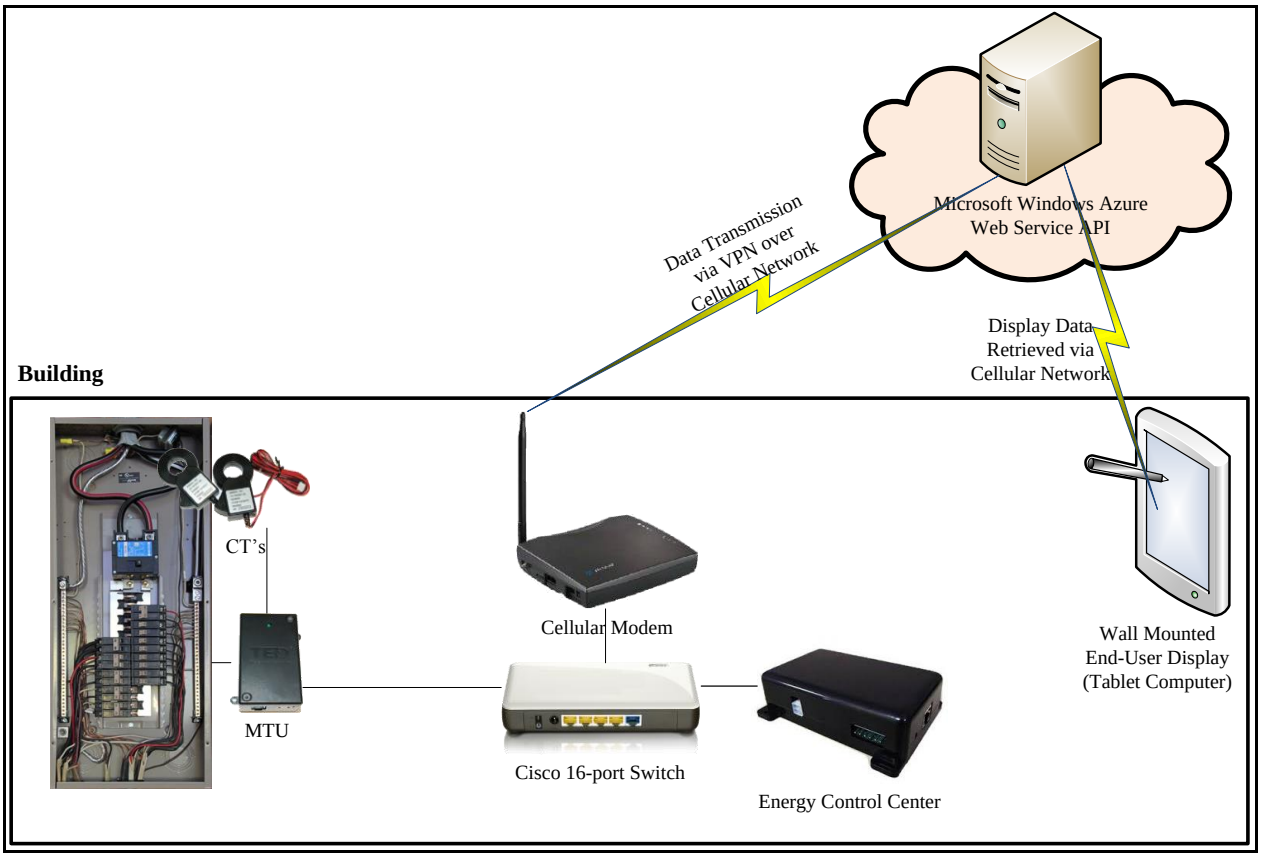

Figure 5. Building Hardware Configuration

Figure 6. Actual Hardware Installation at Fort Bliss

The system is completely isolated from power grid and has no impact on any other components. Component failures of the MTUs, ECCs, cellular modems and displays were monitored as part of the experimental protocol and notifications were sent when data was not being captured. In the case of power disruptions the MTU, ECC, and cellular modem automatically reset. Displays had a battery backup that was always fully charged in case of a power failure.

5.4. Operational Testing

Operational testing was broken down into three phases: pre-installation, installation, and steady-state data collection.

5.4.1. Pre-Installation

Before installing any equipment, the MTUs, ECCs, switches and cellular modems were tested and pre-configured. The ECC, switch and cellular modems were mounted in a communication box and tested as described in the sections below. The pre-configured systems were shipped directly to the demonstration sites for installation.

5.4.1.1. Hardware Testing

Pre-installation hardware tests are outlined in the following subsections.

5.4.1.1.1. Remote Firmware and Administration Upgrades

The cellular modem firewalls were configured to allow port forwarding. This granted 3M the ability to access each device to upgrade the firmware or modify the configurations as needed. 3M confirmed the ability of each MTU, ECC, and cellular modem to accept remotely-pushed firmware upgrades. Additionally, 20 percent of the devices were sampled to ensure that a standard configuration could be successfully applied.

5.4.1.1.2. Data Consistency Verification

The system was tested to verify the consistency of capturing energy consumption for any given minute. The test ensured the watts consumed and the exact minute period of time were consistent when passed from the MTU to the ECC, from the ECC posting to the 3M™ Energy Analyzer application, and finally from the 3M™ Energy Analyzer application to the display.

5.4.1.1.3. Cellular Modem Load

A simulation was performed to confirm the cellular modem could process the expected volume of data. The system was loaded as if all buildings, as defined by the appropriate number of ECCs and MTU's, were posting data through one modem.

5.4.1.2. Software Testing

Pre-installation software tests are outlined in the following subsections.

5.4.1.2.1. Data Logger

The scalability of the data logger, consisting of both the data catcher and data processer, was verified.

5.4.1.2.2. Notifications

The system was tested to confirm the efficacy of the notification system for the following monitored events; 3M™ Energy Analyzer system down, data logger queue size beyond an acceptable length, SQL database down, missing MTU, ECC, or display, missing display heartbeat, and new ECCs and/or MTU's.

5.4.1.2.3. Environmental Testing

The system was tested in an environmental chamber to verify its ability to withstand temperature fluctuations. The hardware, as mounted inside a NEMA type 3R enclosure, underwent two temperature cycles from 0 to 75 degrees Celsius over a 24 hour period for 2 days.

5.4.2. Installation

Qualified electrical sub-contractors installed the pre-configured communication boxes, clamped the CTs on the main incoming wire conductors of the breaker panel, and wired the MTUs into the appropriate power phase. The MTU's were then be connected via Ethernet cables to the switch in the communication box. 3M verified the installed equipment functioned as intended.

5.4.3. Steady-State Data Collection

There were no special system start-up requirements or adjustments. The system began to operate and collect electric usage data upon installation.

Site buildings were checked daily for missing data. When data was missing, corrective action was taken that included restarting the MTU, ECC and/or cellular modem remotely.

Display locations were verified daily via cellular service location tracking.

The notification system was tested weekly to ensure it was running as expected.

5.5. Sampling Protocol

The 3M™ Energy Analyzer automatically samples data from each MTU every minute. Baseline data were collected for 14 weeks (although four of those weeks were eliminated due to field deployments in the control barracks) and experimental data was collected for 24 weeks (although 13 of those weeks were eliminated due to a sharp occupancy level decrease in the control barracks.) Each sample of cumulative watts collected had a unique timestamp associated with it. Data was stored in a SQL database and was backed up via Microsoft Windows Azure cloud services.

5.5.1. Equipment Calibration and Data Quality Issues

Energy metering equipment was calibrated at the factory point of origin. Additional steps to verify the accuracy of the calibration and manage data quality are described in the following sections.

5.5.2. Equipment Calibration and Verification

The following sub-sections describe calibration and verification procedures for the MTU and CT clamps.

5.5.2.1. MTU Calibration

MTU calibration occurred at the factory by the manufacturer before shipment to 3M. The manufacturer follows a documented procedure to validate calibration against a Fluke meter to an accuracy level of ±0.5 percent. The calibrated MTUs are field tested at various instantaneous kW loads, voltages and power factors and then allowed to run for one week. The kWh and kVAh are compared to the calibrated Fluke meter over the same period. The calibration factors on the energy measurement processing chip are then adjusted to match the Fluke. The manufacturer asserts that calibrating MTUs in the factory at a set instantaneous kW load and voltage to within ± 0.5% results in an overall calibration within ± 1%.

Upon receipt from the manufacturer, each MTU was checked during setup to verify accuracy of calibration via an independently-calibrated CT simulator. Each MTU was connected to the simulator and subjected to a given kW load and the readings were verified to be correct within ± 1%.

5.5.2.2. CT Clamp Verification

The CT verification occurs at the factory before shipment to 3M. Each CT is clamped around a constant current source. The voltage is measured at different current levels, and confirmed to be within +/-1% accurate. No additional calibration or verification was conducted by 3M.

5.5.2.3. Quality Assurance Sampling

Sampling was taken every minute from each MTU of the past minute's energy consumption in watts. Missing data was smoothed as discussed in the next section.

5.5.2.4. Post-Processing Statistical Analysis

Analyses were done to ensure that anomalous data were appropriately filtered from the data stream. Three methods for handling anomalous data are described in the following sections.

5.5.2.4.1. Small Scale Smoothing

Small scale smoothing addressed data missing for a period of up to ten minutes. This method averages the number of watts consumed since the last recorded reading over the number of minutes missed and inserts the average value into the missing minute time span. This process ran automatically every minute. A notification was sent to 3M when greater than one percent of the minutes were missing for any given day at which time the root cause of the problem was identified and addressed.

5.5.2.4.2. Large Scale Smoothing

Large scale smoothing addresses data missing for a period of 11 minutes up to two days. This method calculates the average minute for that particular day of the week, and does this for each minute of missing data. It then creates a ratio based on average minutes over total minutes in the time span. The total watts consumed is then allocated based the minute ratio. This method results in a more representational smoothed curve based on past history of that building or MTU. This process ran automatically at 3:00 A.M each day.

5.5.2.4.3. Manual Removal of Outlying Data

3M collaborated with the site POCs to remove anomalous data as needed. See next Section 5.6 Sample Results for a description of the time periods removed.

5.6. Sampling Results

5.6.1. Fort Bliss

Pre-baseline data collection began on June 2, 2013 for the 4-1 barracks and on June 23, 2013 for select buildings in the 3-1 barracks. All barracks were consistently reporting by August 4 and that week marked the beginning of the baseline period.

Figure 7 shows the average electricity use per barrack in kWh for the experimental (4-1 barracks) and the control (3-1 barracks) groups. Figure 8 shows the heating and cooling degree days over the course of the experiment.

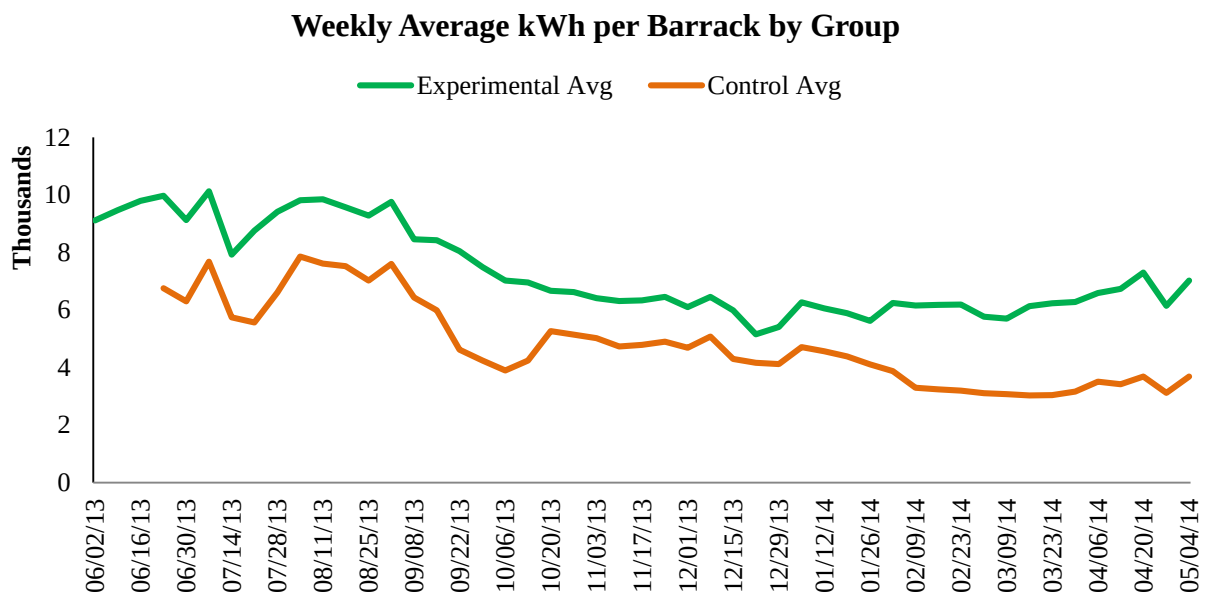

Figure 7. Fort Bliss Weekly Average kWh per Barrack by Group

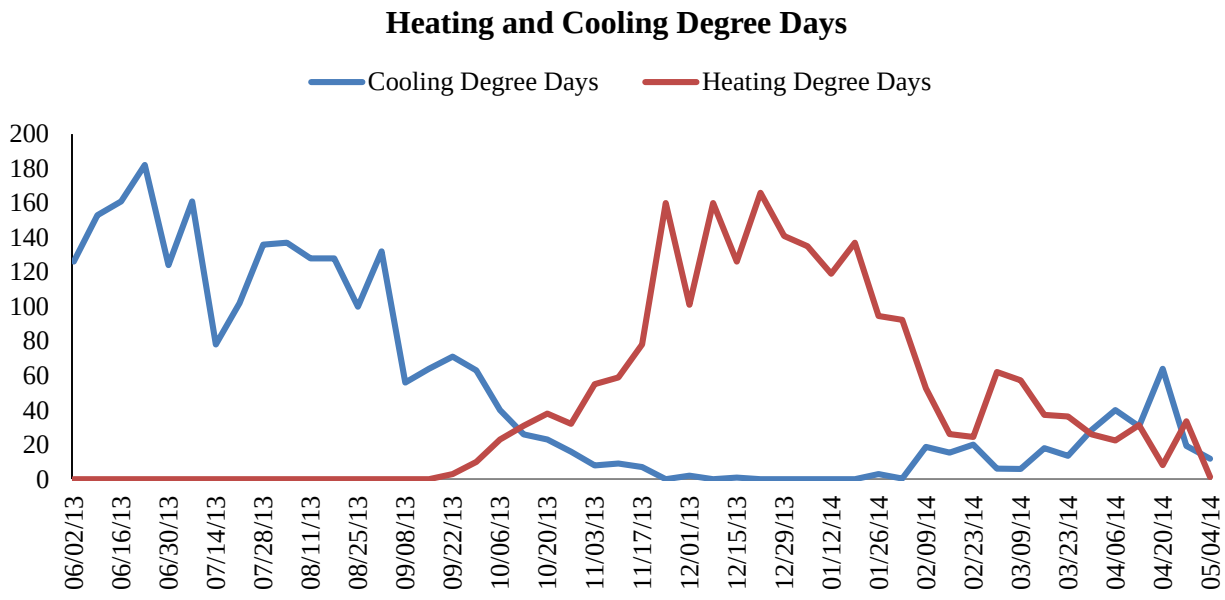

Figure 8. Heating and Cooling Degree Days, Fort Bliss

Correlations were only performed for the experimental group because of the occupancy anomalies in the control group as described below. As expected, there was a very strong correlation (0.96) between cooling degree days and electricity use caused by the use of air conditioning. Because the barracks use non-electric heat, only a weak negative effect (-0.71) between heating degree days and electricity use was measured.

Furthermore, there was a high correlation (0.87) between electrical use when comparing the experimental and control groups. This can be observed in Figure 7 throughout most time periods aside from two anomalous periods where the patterns between the experimental and control groups differed. The first anomalous period began mid-September 2013 and lasted approximately four weeks. During this period, electricity use in the control group dropped more steeply than the experimental group before returning to its original level.

The second anomalous period began near the beginning of February 2014. During this period, electricity use remained fairly constant for the experimental group and then gradually increased (with warmer temperatures). For the control group, electricity use gradually decreased and then stabilized.

After both of the anomalous periods, inquiries were made to the site to determine if there had been a change in situation. 3M learned that during the first anomalous period there had been a series of temporary field deployments from within the control group barracks. These occupancy reductions had not been included in the official occupancy levels reported to 3M so there is no way to reliably calculate the expected change in use due to occupancy level. These deployments ended in mid-October with control use rising back to "expected" levels. Therefore, 3M removed the data from the weeks beginning September 8, 2013 through October 13, 2013 from baseline calculations for both the control and experimental groups.

For the second anomalous period, 3M learned that permanent deployments were being implemented for the occupants in the control group. By January 2014, the official occupancy statistics received by 3M began to reflect these changes in level as shown in Figure 9. Over the same period, occupancy levels in the experimental group remained fairly constant as shown in Figure 10. Maximum occupancy was 128 for experimental barracks and 120 for control barracks.

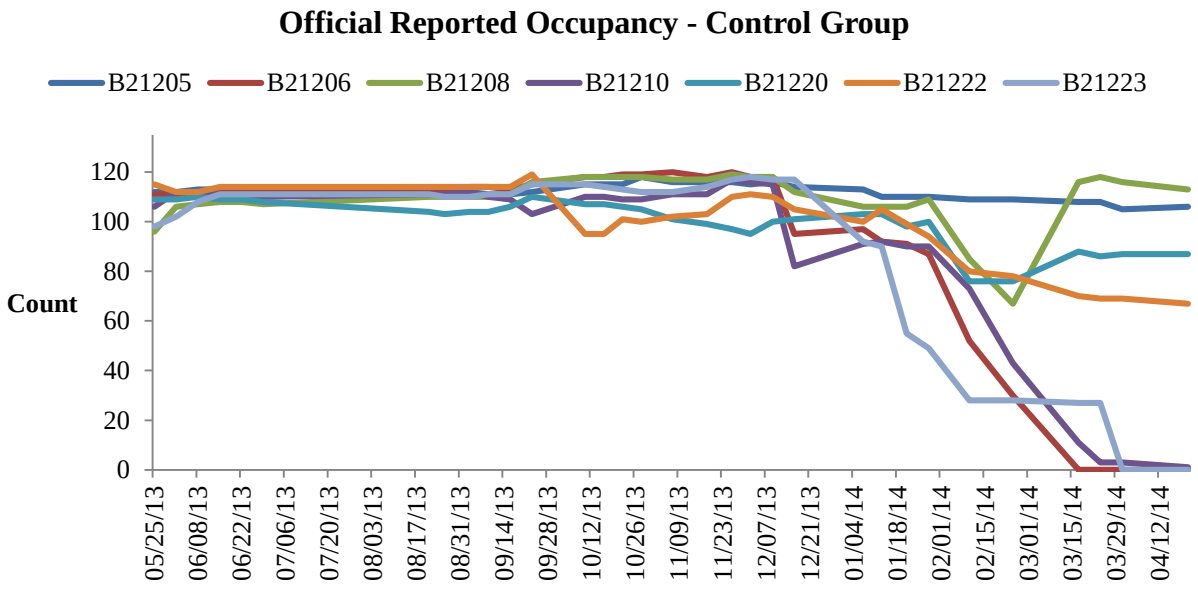

Figure 9. Fort Bliss Official Reported Occupancy, Control Group

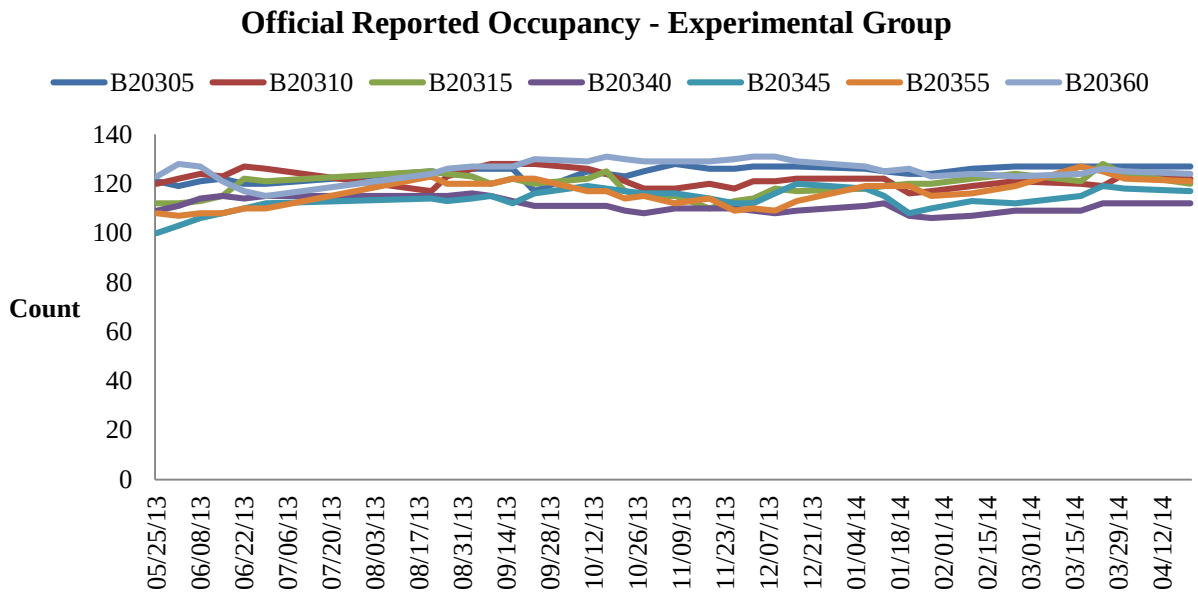

Figure 10. Fort Bliss Official Reported Occupancy, Experimental Group

By the end of the study only one control barrack (21205) consistently stayed near full occupancy over the entire recording period. Three of the barracks (21223, 21206, and 21210) declined to zero occupancy. Two barracks (21220, 21222) declined significantly and maintained a reduced occupancy level. The remaining barrack (21208) declined significantly before returning to near full occupancy.

Given the reduced occupancy levels and high degree of variability, all data after January 2014 was excluded from the statistical analysis.

Therefore, the baseline period for statistical analysis included data from August 4 to September 8, 2013 plus the weeks from October 13 to November 3, 2013. The experimental period was November 10, 2013 to January 26, 2014. Both periods of time were shorter than anticipated or desired for the study.

Figure 11 shows all barracks data with key timestamps for the study.

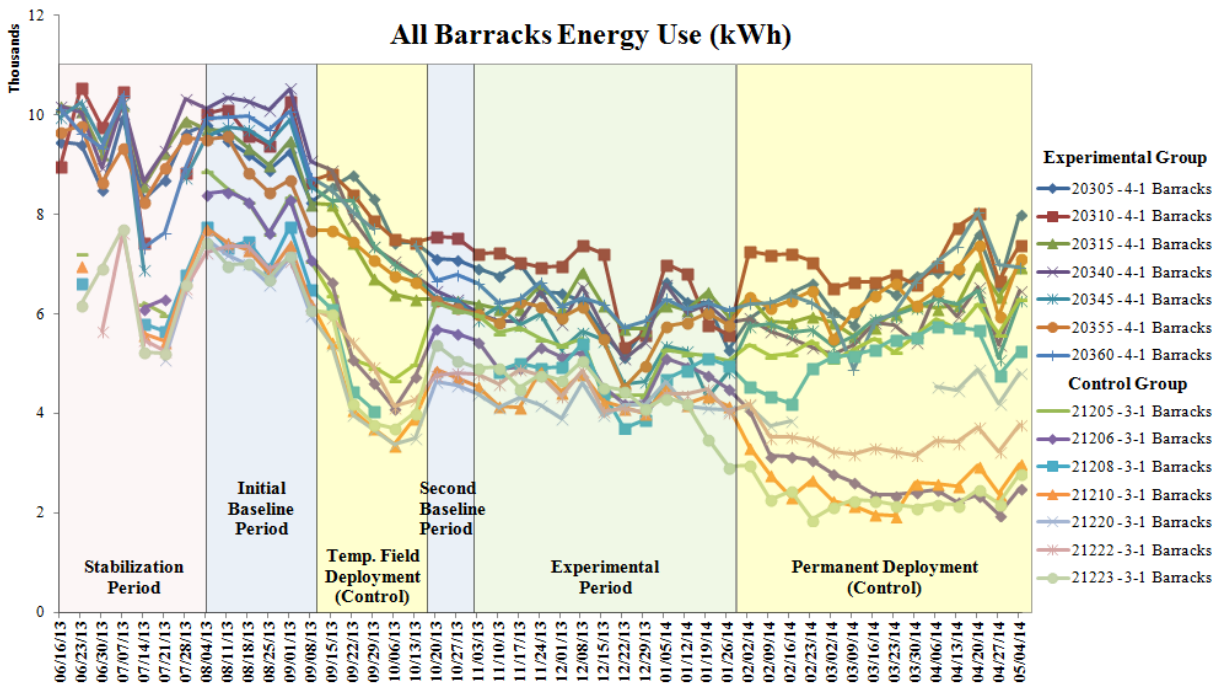

Figure 11. Fort Bliss Barracks Energy Use

Using the formula provided in Section 5.1.1, the relative percent difference between expected and actual energy use per week was calculated for each experimental barrack. Table 3 summarizes the differences during the experimental period, and Table 4 summarizes the differences during the period of significantly reduced occupancy of the control group. In both tables, a negative result represents an increase in energy use, and a positive result represents a decrease in energy use. Figures 12 and 13 represent the same data in graphical format.

Table 3. Relative % Energy Savings during Experimental Period - Experimental Barracks

Barrack → Exp Week ↓	20305	20310	20315	20340	20345	20355	20360	Average
11/10/2013	-6.9	-8.1	-1.4	4.2	0.5	4.6	-0.2	**-1.0**
11/17/2013	-8.9	-5.1	-0.8	4.9	5.8	0.4	-0.4	**-0.6**
11/24/2013	-0.3	-2.1	-4.9	-0.2	4.9	3.4	-2.7	**-0.3**
12/01/2013	-3.3	-5.8	-2.7	4.1	10.1	2.5	-0.2	**0.7**
12/08/2013	4.8	-4.6	-5.6	1.2	11.9	5.8	3.9	**2.5**
12/15/2013	0.1	-14.6	-9.4	-1.3	1.9	1.6	-6.8	**-4.1**
12/22/2013	3.9	4.7	-5.7	4.2	10.2	11.2	-3.2	**3.6**
12/29/2013	-3.8	0.9	-6.2	-0.4	8.9	5.1	-5.7	**-0.2**
01/05/2014	-5.7	-5.8	-2.9	-5.0	9.6	5.1	-1.7	**-0.9**
01/12/2014	-3.3	-6.0	-3.9	-0.5	8.5	1.8	-1.5	**-0.7**
01/19/2014	-4.1	4.6	-9.6	-3.7	18.7	-1.6	-3.9	**0.0**
01/26/2014	3.4	3.2	-7.3	-3.3	8.6	-2.5	-6.2	**-0.6**
Average →	**-2.0**	**-3.2**	**-5.0**	**0.3**	**8.3**	**3.1**	**-2.4**	**-0.1**

Table 4. Relative % Energy Savings after Permanent Deployment - Control Group

Barrack → Exp Week ↓	20305	20310	20315	20340	20345	20355	20360	Average
2/2/2014	-6.5	-18.5	-14.6	-6.6	-4.8	-11.7	-10.2	-10.4
2/9/2014	-18.4	-25.9	-16.8	-11.9	-13.5	-17.4	-18.8	-17.5
2/16/2014	-21.6	-26.9	-17.2	-10.8	-12.2	-19.8	-21.1	-18.5
2/23/2014	-23.2	-24.2	-18.0	-7.9	-12.1	-21.5	-18.5	-17.9
3/2/2014	-18.8	-20.3	-18.6	-8.4	-10.3	-12.3	-17.3	-15.1
3/16/2014	-24.8	-21.6	-17.2	-15.7	-16.7	-22.3	-15.6	-19.1
3/23/2014	-23.4	-24.1	-21.3	-15.7	-18.1	-26.0	-18.8	-21.1
03/30/14	-25.1	-19.1	-20.9	-9.1	-17.6	-18.0	-23.6	-19.1
04/06/14	-21.5	-19.1	-15.5	-16.5	-15.0	-17.2	-24.1	-18.4
04/13/14	-22.9	-29.3	-17.9	-12.3	-15.4	-24.0	-29.2	-21.6
04/20/14	-27.7	-27.9	-23.5	-14.9	-14.0	-25.1	-33.1	-23.7
04/27/14	-24.0	-21.4	-24.5	-10.1	-6.7	-16.9	-29.4	-19.0
05/04/14	-32.3	-20.4	-22.8	-13.9	-11.6	-21.6	-19.5	-20.3

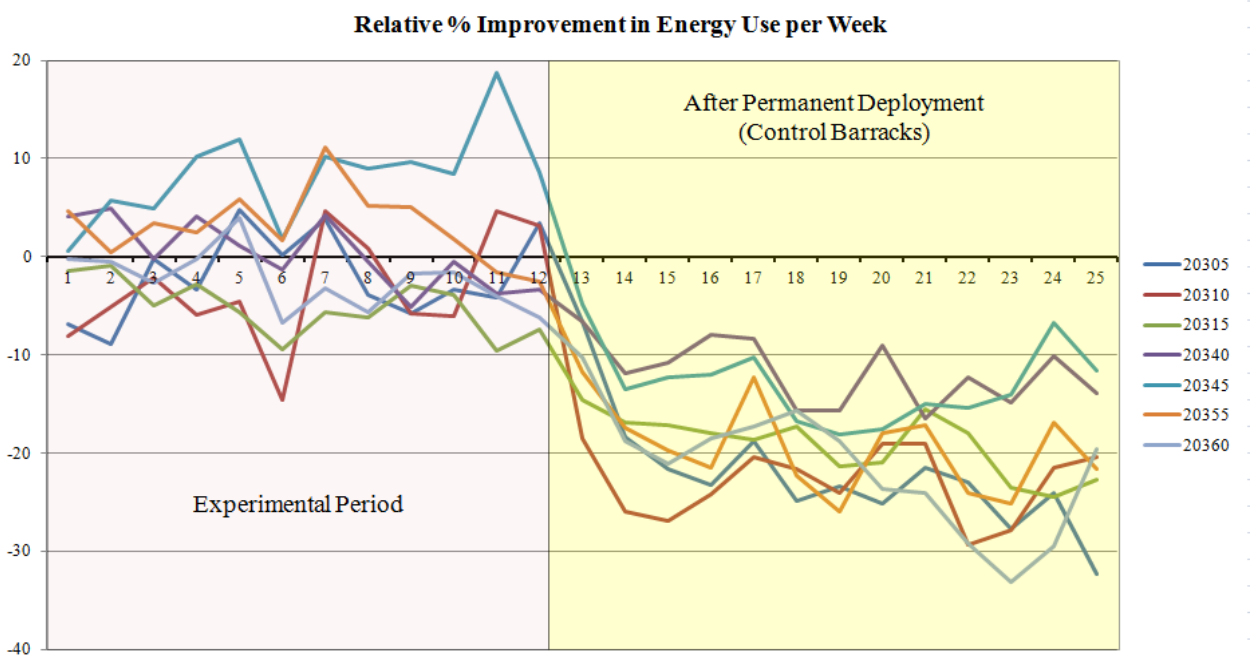

Figure 12. Relative % Improvement in Energy Use Per Week

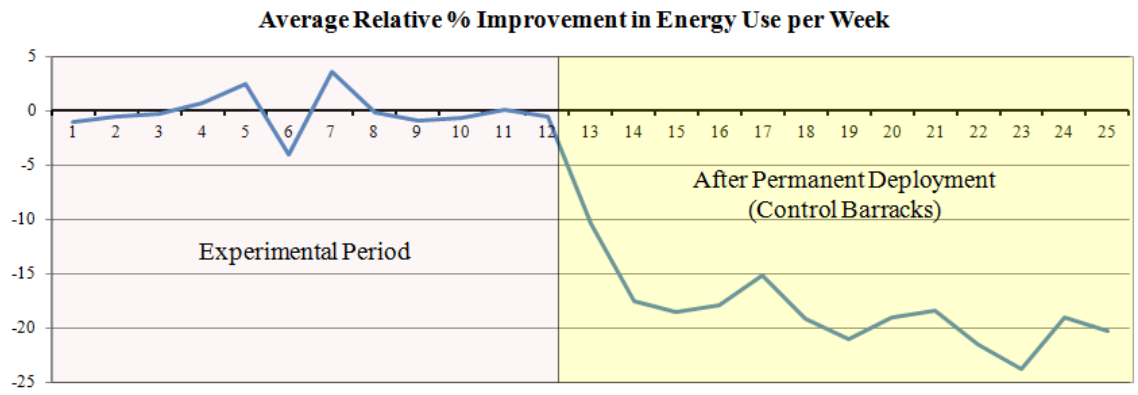

Figure 13. Relative % Improvement in Energy Use Per Week – Average of All Experimental Barracks

There was a moderate amount of variability between barracks as evidenced by a few barracks measuring energy savings nearly every week versus others showing the reverse. If non-controlled variables (e.g., occupancy level) had no impact on the results one would expect to see results range from zero to some positive value for each barrack. Any values below zero represent some amount of uncontrolled for variability. In other words, with all else controlled, there would be no reason to expect a barrack to use more energy than expected due to the experimental treatment. In this case, there was as much "savings" as "loss" and similar amounts of variability above and below zero, with an overall average of 0.05 percent.

Figure 14 shows the percent difference of baseline values minus experimental week values for all 14 barracks. The values are all positive due to the fact that the baseline occurred during the summer months, reflecting heavy air conditioning usage, and the experimental weeks occurred in the late fall/early winter. The additional increase in energy savings shown in weeks seven and eight is likely due to lower occupancy levels near the end of December. The figure clearly illustrates the magnitude of variability and no pattern of energy saving for the experimental barracks.

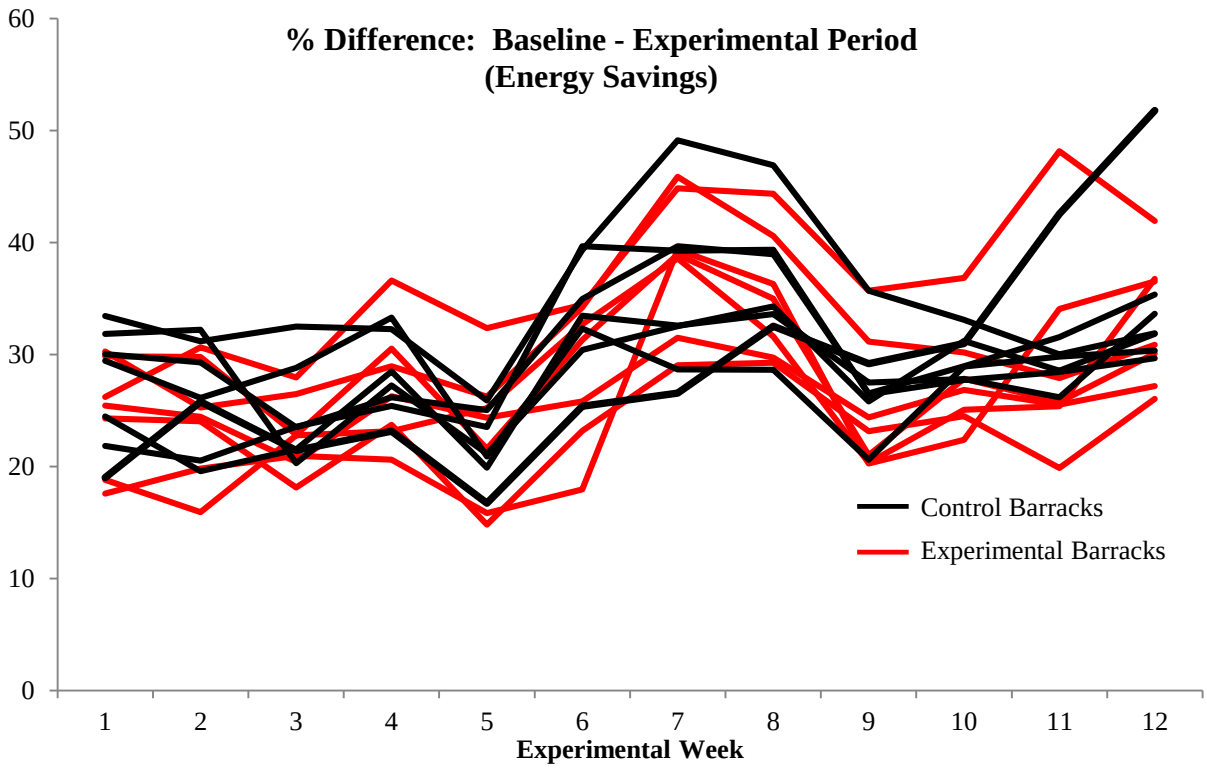

Figure 14. % Difference: Baseline Minus Experimental Period

A repeated measures ANOVA was run to determine if there were any significant effects due to the experimental treatment.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Ctl vs Exp	47.96975	1	47.96975	1.599692	0.208175	3.912875
Week	3164.09	10	316.409	10.55158	0.000	1.903115
Interaction	153.4562	10	15.34562	0.511745	0.879446	1.903115
Within	3958.267	132	29.98687			
Total	7323.783	153				

There was no effect due to control versus experimental treatment. There was a significant effect of Week, most likely attributable to lower occupancy during the holiday weeks. There was no interaction of the two variables.

5.6.2. AMARG

Pre-baseline data collection started the week of June 2, 3013 for several buildings with most buildings installed and running by the week of June 9. Figure 15 shows the average electricity use by building in kWh for all buildings until the system was shut down the week of March 9, 2014. Figure 16 shows the heating and cooling degree days during that same period.

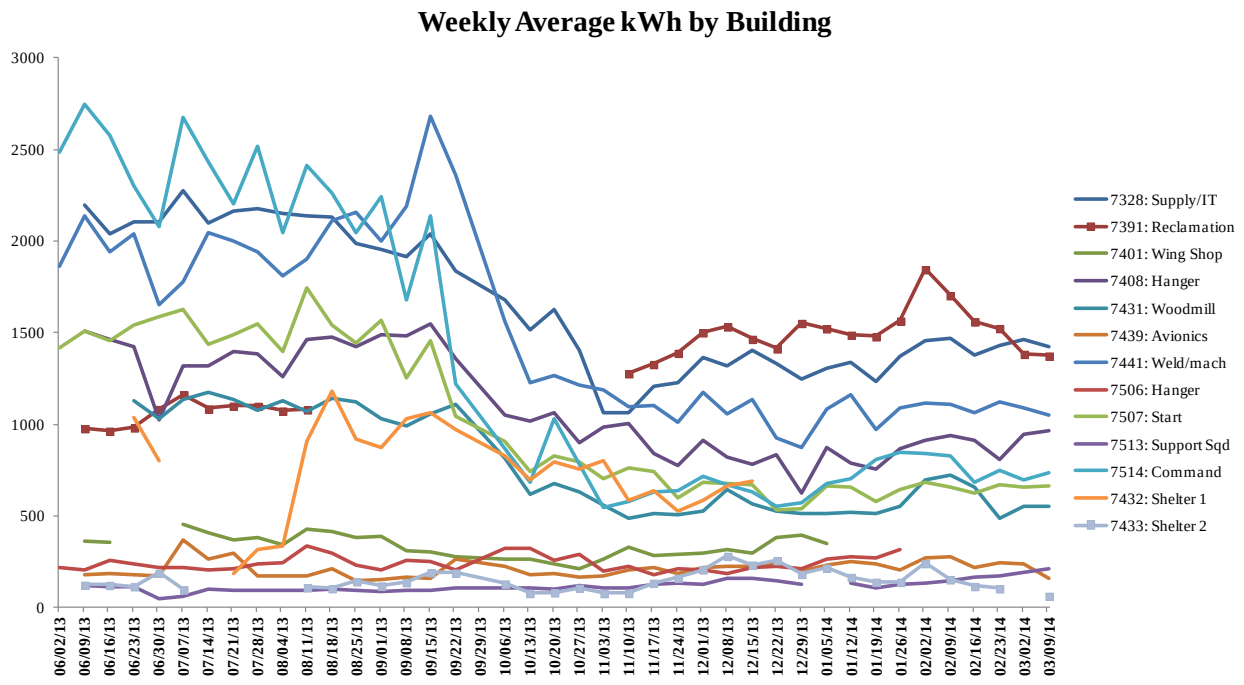

Figure 15. Weekly Average kWh by Building, AMARG

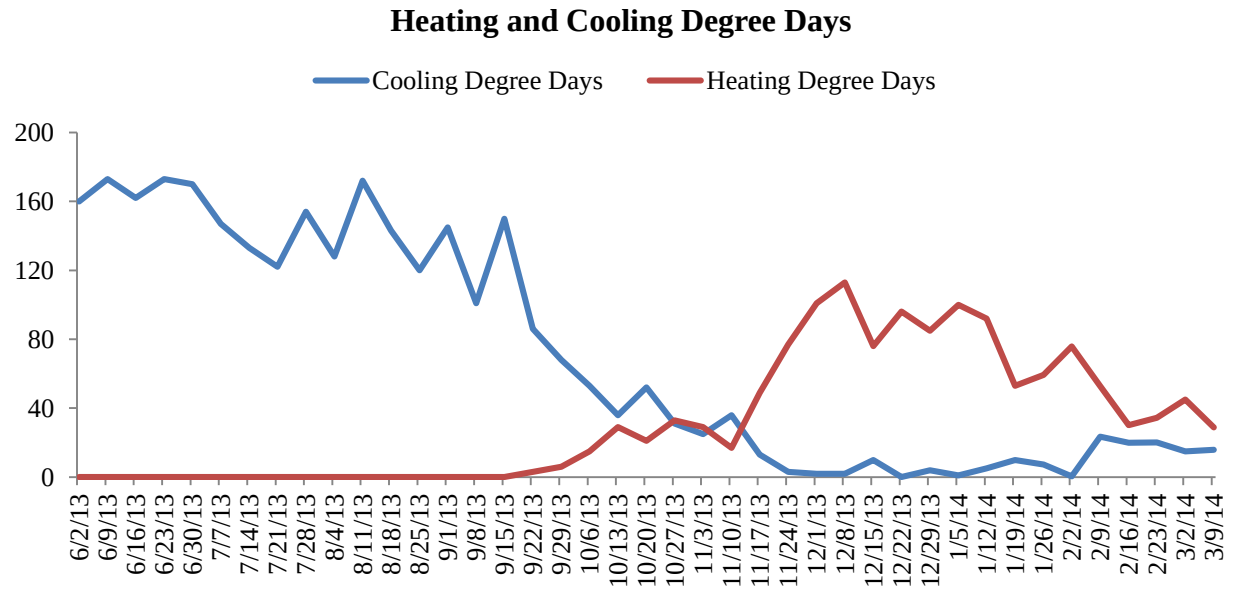

Figure 16. Heating and Cooling Degree Days, AMARG

Figure 15 illustrates the degree of variability between buildings resulting from two factors: building use and air conditioning use in the months of June – September 2013. With regard to building use, there was a wide spread in the amount of electricity used among the 13 buildings ranging from an average weekly use of 147 kWh for Shelter 2 to 1,657 kWh/week for the Supply/IT building. Also, patterns of use varied across the buildings due to variation in the work

being performed. Due to this variability, 3M determined it was impractical to divide the buildings into control and experimental groups and do a formal experiment based on occupant behavior change. Instead, as outlined the demonstration plan the intention was to attempt a number of small scale experiments in different buildings to explore potential energy conservation measures. Unfortunately, before these experiments could be run, the 3M™ Energy Analyzer was shutdown.

During the period the systems were operational, 3M made several observations of interest. One was an early demonstration that the system was sensitive to changes in day-to-day building use. During the summer of 2013 civilian workers were sequestered on Fridays for several weeks. Figure 17 illustrates these events. The green line shows energy use before sequestration when workers were employed Monday through Friday. The yellow line shows energy use during sequestration. Electricity use was reduced to weekend levels on each of the sequester Fridays.

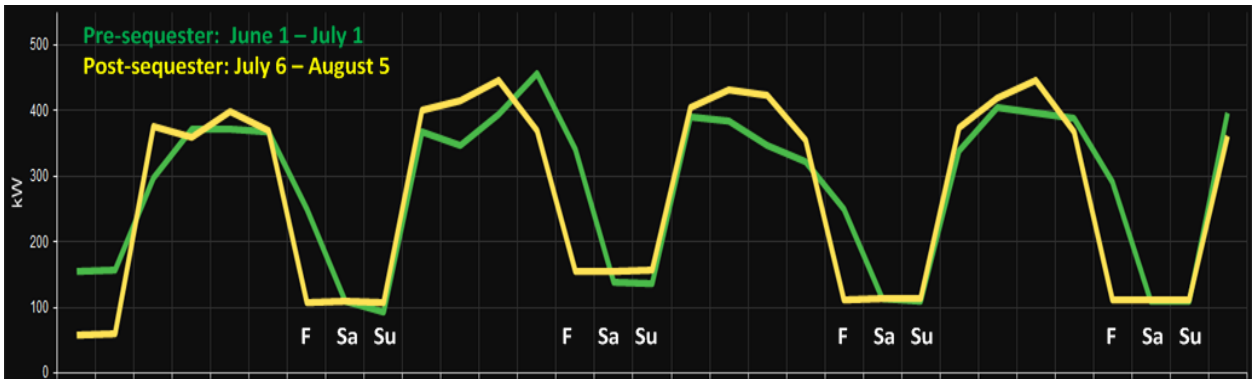

Figure 17. Electricity Use by Day, Welding Building

Another interesting finding resulted when doing a side-by-side comparison of the Command and Start buildings. These buildings are nearly identical in size and configuration. The average weekly electricity use was 1,018 kWh for Start, and 1,388 kWh for Command; roughly one third more. Most of this difference was noted in the summer months (average of 1,425 for Start building and 2,203 for Command building) indicating that the difference was mainly due to cooling. 3M confirmed there were no significant changes in occupancy or type of work during this period.

Figures 18 and 19 illustrate electricity use by hour for a typical weekday and a typical weekend where the green line represents the Command building and the yellow line represents the Start building.

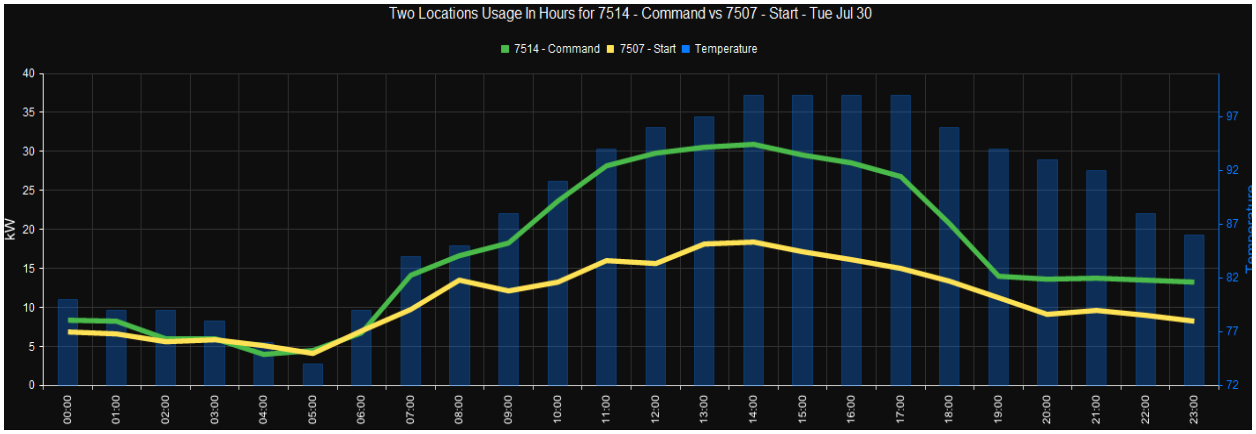

Figure 18. Electrical Use by Hour Command versus Start Buildings on Tuesday, 7/30/13

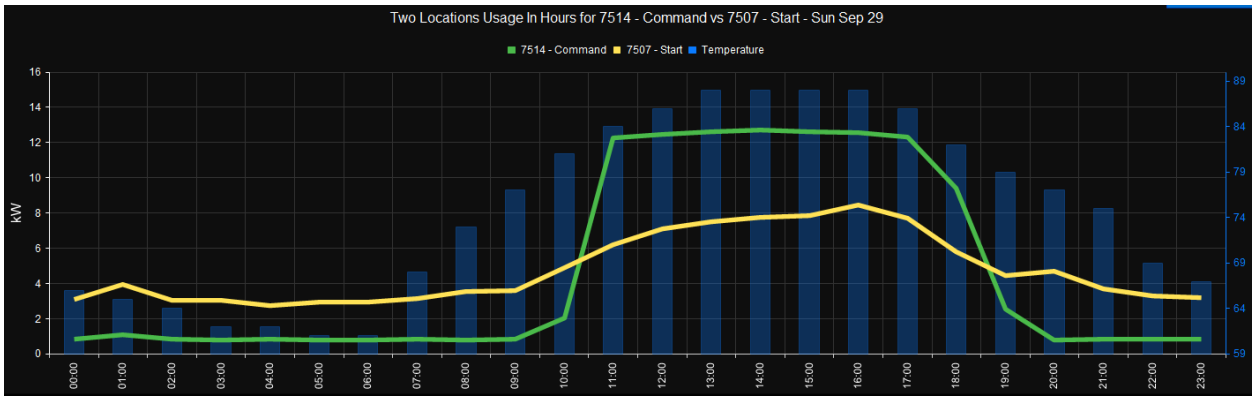

Figure 19. Electrical Use by Hour Command versus Start Buildings on Sunday, 10/29/13

In both cases during the hottest part of the day, electrical use was greater for Command. On the weekend it appears that nearly all electrical use was eliminated for the Command building in the evening and that the air conditioning started up at approximately 10 AM.

Figure 20 illustrates minute use data on Tuesday, July 30 between 2 and 3 PM. The data shows that the air conditioning for the Start building cycled every few minutes while the air conditioning for the Command building ran almost continuously representing a highly inefficient system. Upon follow-up with the site POC, it was determined the air conditioning system in the Start building was a newer, more efficient system than the one in the Command building.

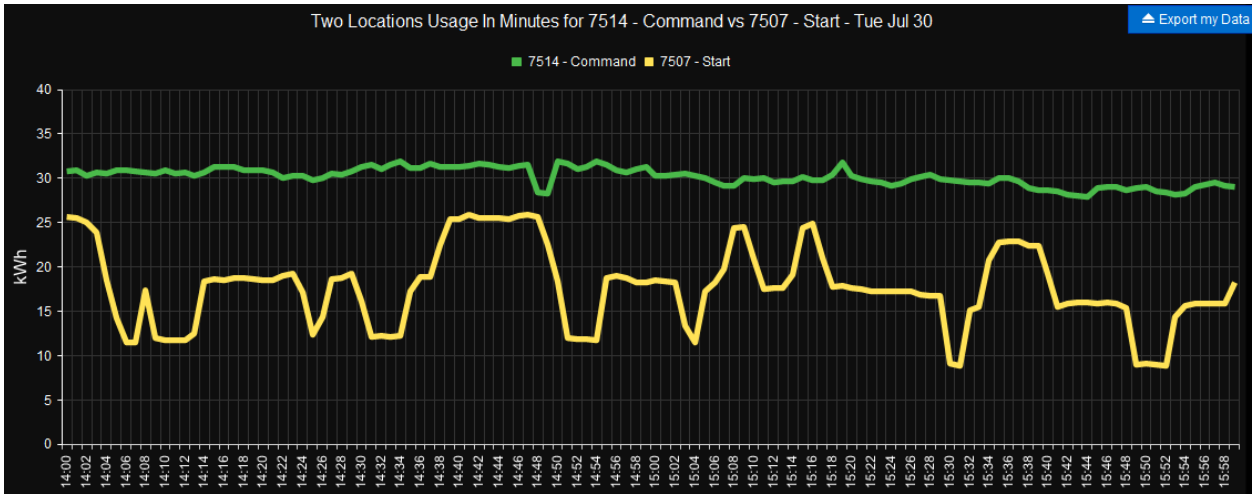

Figure 20. Electrical Use Command versus Start Buildings by Minute on Tuesday, 7/30/13

6. PERFORMANCE ASSESSMENT

6.1. Performance Objective: Overall Facility Energy Use

As described in Section 5, there was no significant impact of the experimental treatment on behavior based electricity use at Fort Bliss. Due to the lack of conformity in building size and function, and high variability in electricity use between buildings, the overall controlled experiment was not conducted at AMARG. Because of the mandatory shutdown of the system for security review, the smaller scale experiments were not conducted at AMARG.

6.1.1. Fort Bliss

At Fort Bliss, the experiment was conducted as planned aside from the absence of chain of command engagement, and shorter duration.

At Fort Bliss, the primary unknown/uncontrollable variable was barrack occupancy level. Early in the study, 3M requested and received official occupancy levels, but soon discovered these figures were not reliable or accurate. During the baseline period, the 3M™ Energy Analyzer measured an unexpected reduction in electrical use in some buildings. After inquiring with the site POC, 3M learned certain residents had been temporarily deployed to the field. The site POC was unable to provide an accurate count of the remaining occupants. 3M was also unable to get advance notification of future deployments. The system proved to be quite sensitive to measuring these occupancy variations, albeit after the fact. However, without accurate occupancy counts, 3M was unable to make precise occupancy correlations to energy use per occupant. In February 2014, a noticeable reduction in several of the control group barracks was again observed. 3M learned, again after the fact, that residents were in the process of being deployed for an extended period of time. Subsequently, the official occupancy report did reflect this deployment. Consequently, the deployment left the experiment without a control group at which time the experiment was terminated.

The secondary uncontrollable variable was extrinsic motivation. The residents are single soldiers, largely between the ages of 18-22. Based on discussions with facility personnel and officers in the chain of command, it became clear that energy saving is of no concern to any these residents. So, there is a lack of intrinsic motivation to change behavior. The soldiers are relatively short term residents who do not pay for the electricity used in the barracks. In other words, they also lack any extrinsic motivation to change. Although information was provided via email and paper signs attached to room doors, only a very small number of soldiers actually interacted with the system. The observed pattern of use for reading energy tips or doing quizzes to increase scores revealed that only 1 to 5 individuals per barrack engaged with the system over a concentrated time span. Overall engagement of residents was minimal.

As outlined in the demonstration plan, 3M desired to identify, with the help of chain of command, other extrinsic motivators to reward building occupants for winning results. For example, a small reward such as a pizza party could have been provided to weekly winners and a larger reward such as a pass or leave could have been given based on the accumulation of winning weeks. Throughout the experimental period, 3M found it difficult to schedule meetings and engage the officers. 3M

did succeed in conducting one meeting with the Command Sgt Major. He, in turn, sent an email to residents describing the displays and the "competition," but was not willing to offer any direct incentives for saving energy. Following a change in command 3M attempted to engage the new Command Sgt Major, but were unsuccessful in our attempt to arrange a meeting.

Even with more engagement, it may still have been difficult to observe a statistically significant reduction in energy use due to high variability, the few electricity reduction options available to residents within their control, and the small number of barracks included in the study. At the time the barracks were selected for the study, 3M did not have access to real-time electrical data in any of the barracks at Fort Bliss. As a result, 3M did not have an appreciation for the level of variability that could be expected within and between the barracks. Had 3M had visibility of the electrical data, modifications could have been made to the study design.

6.1.2. AMARG

In September 2012, 3M received permission to install all system components, including the cellular network, from the site POC Lt Col Andy Middione with support from USAF NEC representative, Mark Seitz. Per plan, all measuring and communications equipment was installed. As plans were being implemented for the installation of the display monitors, Davis-Monthan AFB required an unexpected OPSEC review. The outcome from the review resulted in full system shut-down pending additional review and compliance with Engineering Technical Letter (ETL) 11-1. Planned energy use experiments could not be performed due to the shutdown.

6.2. Performance Objective: Increase in Energy Use Following a Measured Decrease; i.e., "Backsliding"

Because there was no initial effect due to behavior change, this objective was not assessed. There was a significant difference in use over time, but the change was similar for both control and experimental groups and was due to factors such as temperature change and decrease in occupancy due to holidays.

6.3. Performance Objective: Energy Reduction Due To Facility Management Directed Site Changes, Enabled By Monitoring

Because the formal experiment at AMARG was determined to be impractical, the plan was to perform a number of small scale experiments in different buildings to explore potential energy conservation measures. Due to shut down of the system, none of these experiments were implemented

For example before the start of this project, a ceramic roof coating had been applied to the Support Building to block heat load and reflect radiation from the sun in order to reduce air conditioning demand. Because there was no record of electrical use before and after applying this treatment, the actual energy savings was impossible to measure. There was a plan to apply the paint to other buildings similar to the Support Building. Had this coating been applied before the system was shutdown, the intention was to compare electricity use before and after application.

Another example involved the performance of the air conditioning unit in the Command building. With data provided by the system, differences in electricity use were observed between the Command and Start Buildings which were highly correlated with temperature. It was confirmed that the air conditioning in the Command building was an older, less efficient unit and may have been malfunctioning. The plan was to have base maintenance assess the system and determine whether to repair or replace. 3M intended to compare the before and after performance and also to compare against the Start building after intervention.

Finally, lighting studies had also been planned. These studies would have included turning off unnecessary lighting or replacing inefficient lamps. For example, in the Shelter, much of the overhead lighting was on all day even though it did little to add additional light to work areas. The Welding building was also being considered for LED retrofit experiments.

Finally, patterns of use in certain buildings were to have been investigated and understood. For example in the Reclamation building during springtime, there was an increase in use at 6:00 PM and a decrease at 7:15 AM. However, during the summer months, the decrease occurred between 2:00 to 3:00 AM. Also, there was an unknown source of electricity cycling that occurred every two hours only on weekends.

6.4. Performance Objective: Projected Energy Reduction Due To Facility Management Directed Site Changes Enabled By Monitoring

An energy saving opportunity at AMARG is to replace the inefficient air conditioning unit in the Command building with a more efficient one; similar to the Start building. During the cooling season there was a weekly average difference of 778 kWh between the Command and Start buildings and during the heating system the difference decreased to an average of 71 kWh. The difference of 708 kWh is theoretically due to the inefficiency of the air conditioning system in the Command building. Using an estimated 25 week cooling season, the annual difference is 17,700 kWh. At the AMARG electrical rate of $0.85 per kWh, the savings would be approximately $1,500 per year.

6.5. Performance Objective: System Economics

6.5.1. Fort Bliss

Based on the behavioral study results at Fort Bliss, as installed and executed in this study, there is no viable payback period for installing the system in the barracks.

However, if the 5% reduction in *Overall Facility Energy Use* had been met, via facility control or behavior modification, the average weekly electrical reduction would have been 344 kWh for each experimental barrack and 260 kWh for each occupied control barrack. At Fort Bliss electricity rates vary from $0.05 to $0.14 per kWh depending on time of year and time of day. Using a rate of $0.05/kWh, the average experimental barrack would have saved $894 per year and the average control barrack would have saved $676 per year. Total savings for the 14 barracks would be almost $11,000 annually. Excluding the initial cost of cellular network equipment and on-going operating costs, the resulting payback period would be approximately 5.5 years. The cost model and drivers are discussed in more detail in Section 7.0.

6.5.2. AMARG

For the AMARG demonstration buildings, the payback period with a hypothetical 5% reduction in energy use would be greater than 10 years. Most of the buildings at AMARG do not use a lot of electricity because of their size, the absence of air conditioning systems, or the use of cooling methods that do not require much electricity (e.g., swamp coolers). Should a system similar to this be deployed, it should be installed in larger buildings using standard air conditioning such as the IT building.

6.6. Performance Objective: System Availability

System availability was calculated as the percent total minutes reported, but not smoothed, over the entire experimental period, by MTU. The majority of the smoothed minutes were in the "small scale smoothing" category and resulted from an inconsistent cell signal during which time data was not transmitted to the cloud server for a period of up to 10 minutes. The percent available minutes, therefore, includes all MTU, ECC, and cellular modem failures as well as loss of the cell signal.

Tables 5 and 6 summarize system availability for Fort Bliss and AMARG respectively. Additional details by MTU may be found in the tables located in Appendix B. Overall system availability at Fort Bliss was 98.7% with 13 of the 14 buildings meeting the availability objective. Building 21208 had a cell modem fail, and it took 28 days for the site, 3M, and the local electrician to coordinate replacement. It should be noted the actual replacement requires less than 15 minutes of labor.

Overall system availability at AMARG was 92.1% with 9 of the 13 buildings meeting the availability objective. Buildings 7391(Reclamation) and 7401 (Wing Shop) both had cell modem failures. Additionally, the Reclamation building also had one ECC suffer from infant mortality. Generally speaking, the cellular network was less reliable at AMARG and 7513 (Support Squad) suffered from an on-going erratic cell signal. Excluding cellular network failures, the overall system availability was 97.6%.

Table 5. System Availability – Fort Bliss

Building	Total Minutes Recorded	Missing Minutes	Smoothed Minutes	% Fully Available
20305	1,589,760	-	2,219	99.9%
20310	1,589,760	-	1,586	99.9%
20315	1,589,760	-	2,124	99.9%
20340	1,589,760	-	1,533	99.9%
20345	1,589,760	-	1,374	99.9%
20355	1,589,760	-	1,866	99.9%
20360	1,589,760	-	1,650	99.9%
21205	1,589,656	104	1,732	99.9%
21206	1,589,760	-	20,563	98.7%
21208	1,343,389	246,371	1,397	84.4%
21210	1,589,760	-	1,589	99.9%
21220	1,589,760	-	1,554	99.9%
21222	1,589,760	-	1,688	99.9%
21223	1,589,730	30	5,393	99.7%
Total	**22,010,135**	**246,505**	**46,268**	98.7%

Table 6. System Availability – AMARG

Building	Total Minutes Recorded	Missing Minutes	Smoothed Minutes	% Fully Available
7328	1,059,840	-	2,504	99.8%
7391	596,626	463,214	22,075	54.2%
7401	489,136	40,784	635	92.2%
7408	794,880	-	2,012	99.7%
7431	794,848	32	1,879	99.8%
7439	529,920	-	1,182	99.8%
7441	794,880	-	1,808	99.8%
7506	529,920	-	1,211	99.8%
7507	1,059,840	-	2,386	99.8%
7513	529,920	-	19,613	96.3%
7514	794,880	-	1,861	99.8%
Shelter 1	612,785	182,095	5,638	76.4%
Shelter 2	257,605	7,355	851	96.9%
Total	**8,845,080**	**693,480**	**63,655**	92.1%
Total Omitting Cell Failures	***7,759,318***	***189,482***	***40,945***	97.6%

6.7. Performance Objectives: System satisfaction/usability and behavior change

Due to the premature shut down of the study, these items were not assessed.

6.8. Performance Objective: Assessment of system utility by facility management

The 3M team interviewed the primary points of contact at both sites to gain an understanding of whether and how a system like the 3M Energy Analyzer could be useful for their facilities.

6.8.1. Fort Bliss: Interview with Don Vincent

Mr. Vincent stated that, in the current test environment, a system like 3M's would have little chance in effecting change in occupant behaviors with regard to energy use. He cited the fact that soldiers so not pay for their energy use and have little/no incentive to change. The only way to provide an incentive would be through the command chain and there was little enthusiasm for that to happen. Mr. Vincent indicated that the upper levels of the command chain would need incentives/goals for it to trickle down the chain and that those goals have not been set at the higher levels. He did mention that incentives are in place for family housing units where they are given an allocation for electricity use. If they use more, they have to pay for it and if they use less they can receive a rebate.

For use as a facility management tool, Mr. Vincent was enthusiastic. He described current efforts at collecting and using meter information from buildings at Fort Bliss. The US Army Corps of Engineers Metered Data Management System (MDMS) is an enterprise energy information system for the collection, analysis and display of energy data. According to Mr. Vincent, the current format is raw data (with uncorrected anomalous data points) printed out on paper. There is little practical use they can make of the data without expending a lot of resources.

Mr. Vincent indicated that the quality and ease of access of the 3M system data was ahead of what MDMS provides. With the 3M system he could easily examine buildings or sections of buildings over any period of time. More importantly, he could overlay energy use graphs to make comparisons between similar buildings over time. This type of comparative analysis was important to him. He was able to gain insights about electricity use that were not possible with the current systems at Fort Bliss.

One feature that would make the system even more useful would be an automated analysis to send email or text alerts when buildings were operating outside expected levels. If a building was above, they could then figure out why more electricity was being used and attempt to correct the situation (e.g., air conditioning malfunction). If a building was below, it might indicate that occupancy levels were reduced (as observed during the study) and the building could be put into a different mode of electricity use controls (e.g., raise temperature set-point to decrease air conditioning use). Currently, his department controls HVAC attributes in 235 buildings on base, but they do not get usage information to guide this control.

He would especially like to see such a system in larger buildings (e.g., barracks and other buildings with greater than 29,000 sq ft) where the most energy can be saved.

Mr. Vincent had the opinion that a 30 minute resolution would be acceptable, although 15 minutes would be better. He didn't think he needed the one minute resolution of the current system. He did indicate that being able to change resolution on an as needed basis would be a good feature.

He thought that installation costs (equipment plus installation) for smaller buildings could be $1,000 with the largest costing $8,000 (which would measure all circuits). Currently, it costs about $8,000 for a single reporting meter that only shows use for a whole building; even if the building is small. He thought $3,000 - $5,000 per building would be a reasonable range for costs. He thought it might take 0.25 FTE to support the system with many buildings covered.

He would have liked to do a more in-depth study of energy use and occupancy, looking at soldiers day to day behaviors with regard to electricity use. What happens to use over lunch time, or weekends, or holidays? They could predict when to reduce consumption, such as by reducing air conditioning or lighting in buildings.

He thought that a payback of less than 10 years would be acceptable for a system like this or perhaps a SIR of 1.2 or greater.

6.8.2. AMARG: Interview with Lt Col Andy Middione

Lt Col Middione was pleased with the information the system provided—it was very effective. He was especially impressed by the ability of the system to identify an inefficient air conditioning unit in the Command Building. He thought the system was innovative and couldn't come up with any specific recommendations for change, although he would want to use local networks instead of the cell phone plans due to their high cost. He thought a time resolution of 10-15 minutes would be plenty for his needs.

If he was able to retain the system he would experiment with before and after conditions with additions of energy efficiency modifications such as reflective paint, light film, lighting, etc. He could also diagnose situations with defective components or poor design. The system would be even more effective if there were more buildings covered such that similar buildings could be compared over time (e.g., being able to compare Command to Start). Two specific modifications he would have wanted to test would have been applying reflective ceramic coatings on buildings to compare before/after use, and doing some LED lighting upgrades to measure before/after impact.

For system cost, he cited a $50,000 system installation cost for a Boeing system in 13-15 buildings with maintenance at less than $3,000 per month. He thought a system like this would not need a required payback period. He though a 5-10 year payback would be good and 1-5 years would be optimal.

He didn't think the current civilian employees would change their behaviors without some type of incentives. No incentives are provided now and energy reduction is not encouraged. In fact, it is very difficult for civilians to suggest and implement changes with regard to energy savings because of the rules imposed by the Air Force Civil Engineer Center (AFCEC). These rules are also imposed on new buildings. From Lt Col Middione's perspective, AFCEC is incentivized to build

the cheapest buildings possible and don't take into account on-going maintenance/energy costs once they are built.

Lt Col Middione liked being able to break down electricity use within buildings. It is important to be able to separate air conditioning use from other use to have a good understanding of overall building electricity use. Having multiple MTUs in a building was important.

He would want the system to not rely on cell modems. It would be better to be hard wired into their local networks. Use of cell modems could be a security issue.

"It was a pleasure working with the 3M team. Both Phil and Peter were very knowledgeable. From our perspective this was a successful project. We gained baseline data that will be used on the Boeing project [another ESTCP Demonstration project taking place at Ft. Bliss], and we were able to justify the need for a new air conditioning system based on the data the system provided."

7. COST ASSESSMENT

The cost of the hardware, installation, communications and maintenance were tracked during the demonstration project.

7.1. Cost Model

A simple cost model for the 3M™ Energy Analyzer is shown in Tables 7 and 8. These represent the actual costs incurred as a part of the demonstration project. The cost elements were the same for Fort Bliss and AMARG, but the configuration of the buildings differed enough to yield slightly different costs per building. At Fort Bliss, there were more electrical circuits per building to measure which resulted in the need for more MTUs, CTs, and ECCs per building. Correspondingly, the electrical installation charges were also higher. It should be noted that no initial software costs or subscription fees are included in the cost model. 3M's intention was to use data generated in the demonstration to do value-based pricing of the service. Commercialization of the 3M™ Energy Analyzer has since been stopped.

Table 7. Cost Model of 3M™ Energy Analyzer – Fort Bliss

Cost Element	Data Tracked During the Demonstration	Cost / Unit	Number Required	Total Cost
Hardware capital costs	MTU	$162	84	$13,605
	Current Transformers	$15	252	$3,780
	Energy Control Center	$135	28	$3,779
	Communication Enclosure Type 3R	$168	14	$2,347
	Cradlepoint Cellular Gateway	$301	14	$4,214
	AP-Cell/LTE Antenna	$93	28	$2,607
	Cisco Switch	$58	14	$812
	Apple iPad wi-Fi, 3G + security enclosure	$649	10	$6,490
Installation costs	Labor & material required to install	$22,180	1	$22,180
Consumables	No consumables required			N/A
Facility operational costs	Annual cellular plan for modem	$300	14	$4,200
	Annual cellular plan for iPad	$804	14	$11,256
	Annual Microsoft Windows Azure plan	$3,756	0.5	$1,878
Maintenance	Defective hardware (labor)	$845	1	$845
Operator Training	Intuitive interface requires minimal training			N/A
Total Cost of Deployment	**Year 1**		**Site Total**	**$77,993**
Total Cost of Deployment	**Year 1**		**Per Barrack**	**$5,571**

Table 8. Cost Model of 3M™ Energy Analyzer – AMARG

Cost Element	Data Tracked During the Demonstration	Cost / Unit	Number Required	Total Cost
Hardware capital costs	MTU	$162	37	$5,993
	Current Transformers	$15	170	$2,550
	Energy Control Center	$135	13	$1,755
	Communication Enclosure Type 3R	$168	13	$2,180
	Cradlepoint Cellular Gateway	$301	13	$3,913
	AP-Cell/LTE Antenna	$93	26	$2,421
	Cisco Switch	$58	13	$754
	Apple iPad wi-Fi, 3G + security enclosure	$649	13	$8,437
Installation costs	Labor & material required to install	$13,050	1	$13,050
Consumables	No consumables required			N/A
Facility operational costs	Annual cellular plan for modem	$300	13	$3,900
	Annual cellular plan for iPad	$804	13	$10,452
	Annual Microsoft Windows Azure plan	$3,756	0.5	$1,878
Maintenance	Defective hardware (labor)			N/A
Operator Training	Intuitive interface requires minimal training			N/A
Total Cost of Deployment	**Year 1**		**Site Total**	**$54,905**
Total Cost of Deployment	**Year 1**		**Per Building**	**$3,922**

7.2. Cost Drivers

In addition to the 3M™ Energy Analyzer hardware platform costs, there are two key cost drivers that should be considered when selecting this type of technology for future implementations: network type and data security & privacy. The extra cost of cellular modems, antennas, and switches to implement a cellular network represented between 10 – 12% of the total Year 1 cost. Additionally, the on-going annual operating cost was an additional $1,100 per building. In a typical commercial installation, use of a wired or wireless local area network would be a more cost effective method of communication. However, none of the buildings used in this demonstration had either category 5 cabling installed near the breaker box or a local wireless network installed. Therefore, the costs to implement such networks would have to be considered.

The second driver to be considered is data security & privacy. Should the DoD require the hosting of similar systems behind a DoD firewall the costs and resources necessary to maintain the system would be expected to increase.

7.3. Cost Analysis and Comparison

To illustrate the impact of cellular network costs on payback period, the simple payback - based on hypothetical energy reduction of 5% in a notional installation - was calculated for three different electrical rates.

7.3.1. Fort Bliss

Installed hardware cost of the 3M™ Analyzer System was assumed to be the same as in the demonstration, or $3,727 per barrack. The operational costs, which include the cloud service and maintenance, were assumed to be approximately $200 per barrack annually. Table 9 clearly illustrates the on-going cost of the cell network has the most significant impact on payback period, followed by the cost of electricity.

Table 9. Payback Period by Network Type – Fort Bliss

Electrical Rate $/kWh	Notional Barrack - Fort Bliss WITH Cell Network Simple Payback (Years)	Notional Barrack - Fort Bliss WITHOUT Cell Network Simple Payback (Years)
$0.05	∞	6.4
$0.08	∞	3.5
$0.14	4.8	1.9

7.3.2. AMARG

Installed hardware cost of the 3M™ Analyzer System was assumed to be the same as in the demonstration, or $2,613 per building. Fewer nodes were measured per building at AMRAG resulting in the need for fewer MTU's, CT's, and ECC's. The operational costs, which include the cloud service and maintenance, were assumed to be approximately $200 per building annually. Table 10 summarizes the theoretical payback periods both with and without cell network costs for varying electrical rates.

Table 10. Payback Period by Network Type - AMARG

Electrical Rate $/kWh	Notional Building - AMARG WITH Cell Network Simple Payback (Years)	Notional Building - AMARG WITHOUT Cell Network Simple Payback (Years)
$0.05	18.1	2.2
$0.08	3.2	1.3
$0.14	1.2	0.7

8. IMPLEMENTATION ISSUES

This section includes a discussion of the implementation issues in the areas of network communication, building selection, and chain of command engagement.

Network Communication

One technical issue which added significantly to the cost of initial implementation and on-going operational costs was the inability to run the system on local area networks due to security restrictions. It would have required about a year to gain approvals in order to tie into the local network. It would be possible to run the system entirely within a base intranet. The cell modem/service was also the least reliable aspect of the system.

In general, the approval protocols for installing these types of systems were not very clear at either base. In the end, it was an unexpected OPSEC review at AMARG which resulted in the shutdown of that system. 3M understood that base NEC granted all approvals, and that 3M's meetings with base NEC were sufficient. It is recommended that any similar ESTCP-funded projects in the future make certain that network communication expectations are confirmed during the initial proposal period.

Building Selection

As detailed in Section 6.0, at the time the barracks were selected for the study, 3M did not have access to real-time electrical data in any of the barracks at Fort Bliss. As a result, 3M did not have an appreciation for the level of variability that could be expected within and between the barracks. Furthermore, even moderate changes in occupancy levels had a considerable impact on data variability. Had 3M had visibility of the real-time electrical data during the initial proposal period, modifications could have been made to the proposed study design such as selecting a larger number of buildings, and randomizing that selection.

In future studies, it is recommended to use a larger number of buildings per group and to distribute buildings randomly into conditions. In this study, such a design may have resulted in a more randomized distribution of variability from occupancy levels, rather than concentrated in a barracks belonging to a single brigade.

Chain of Command Engagement

Even with a higher number of buildings and randomized group assignment, it is unlikely that significant behavioral changes would have occurred. No differences were observed even during periods of lower variability. It became clear that there was little incentive for the soldiers at Fort Bliss to change their behavior. They were not paying for electricity use, they are transient occupants of the barracks, there was not a wide range of control over power use, and there was no command chain influence applied. In the future, it will be critical to gain support and commitment from higher levels of the command chain during the planning stages of the study.

Ultimately, access to data alone is necessary, but not sufficient, to achieve significant energy reduction. The American Council for an Energy-Efficient Economy published a review of five successful workplace energy behavior programs.[vii] The five cases shared four common strategies

that contributed to a successful program: (1) setting the tone; (2) building a team; (3) employing communication tools; and (4) deploying key engagement techniques. Figure 21, taken directly from the ACEEE report, illustrates the important elements that fall beneath each of those strategies.

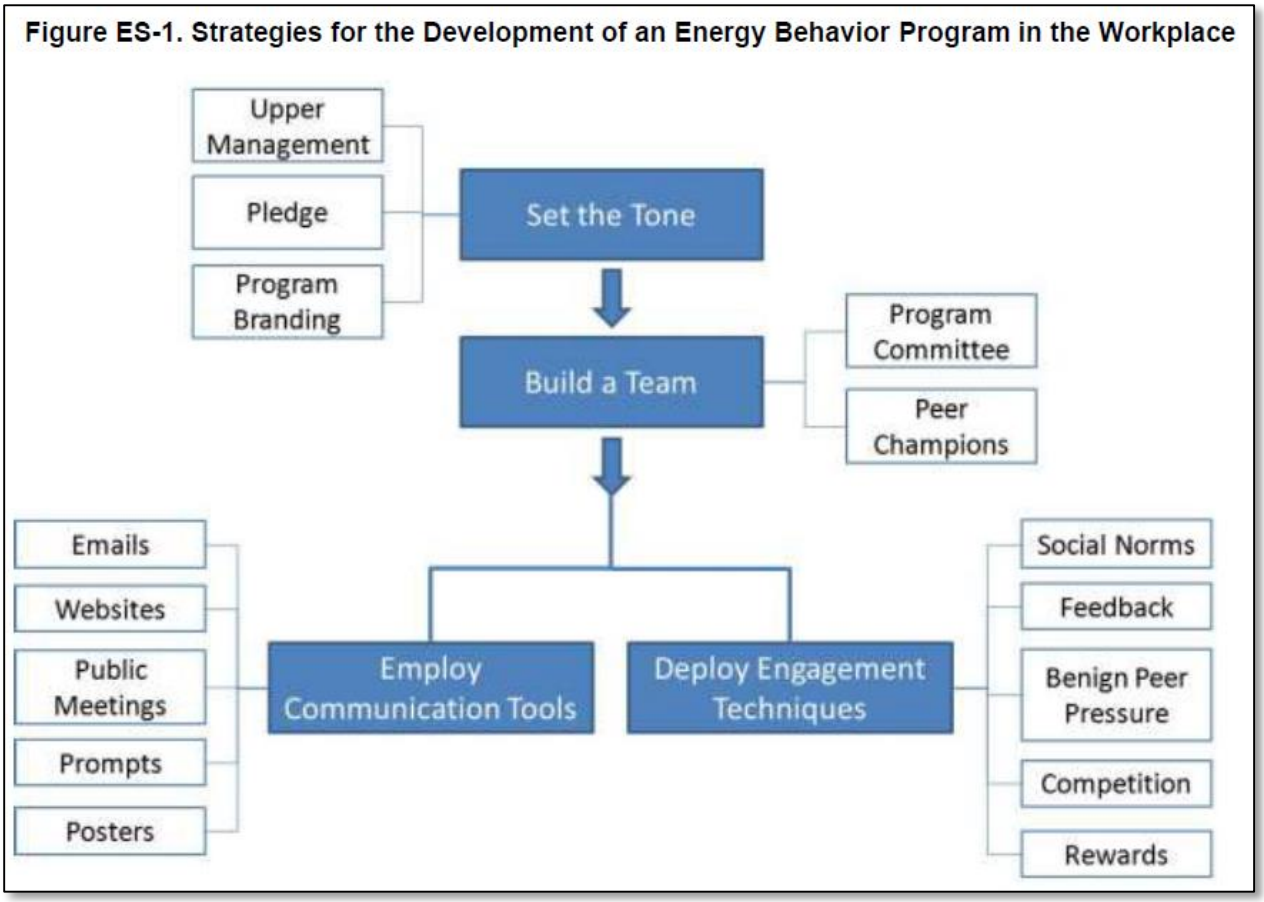

Figure 21. Strategies for the Development of an Energy Behavior Program – ACEEE

In the end, this demonstration did not employ all of the four basic strategies, and especially lacked full organizational commitment to set the tone at the top, and an accountable team of site resources comprised of both facilities managers and military personnel. To plan for success in future behavioral energy demonstrations, it is recommended that ESTCP require the demonstration to contain all four of these strategies.

Finally, ESCTP should consider conducting future studies at Officer Candidate Schools where the future leaders of our military are being trained to understand the energy security issues.

9. REFERENCES

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10. APPENDICES

APPENDIX A: POINTS OF CONTACT

Table 11. Project Points of Contact

Name	Organization	Phone	E-mail	Role in Project
Megan Erickson	3M Renewable Energy Division 3M Center 235-2S-27 St. Paul, MN 55144	Phone: 651-733-7831 Fax: 651-737-3446	megan.erickson@mmm.com	Principal Investigator
Peter Eisenberg	3M Software, Electronics, and Mechanical Systems 3M Center 235-3F-08 St. Paul, MN 55144	Phone: 651-733-0624 Fax: 651-736-8258	peisenberg@mmm.com	Behavioral Scientist
Philip Savoie	3M Software, Electronics, and Mechanical Systems 3M Center 235-3F-08 St. Paul, MN 55144	Phone: 651-733-8017 Fax: 651-736-8258	psavoie@mmm.com	Project Manager
Ruth Charles	3M Government R&D Contracts 3M Center 224-2S-25 St. Paul, MN 55144	Phone: 651-736-7939 Fax: 651-736-4777	rpcharles@mmm.com	Contract Manager
LtCol Andy Middione	309 Aerospace Maintenance and Regeneration Group 4820 S. Wickenburg Ave, Bldg 7514 Davis-Monthan AFB, AZ 85707	Phone: 520-228-8396 Fax: 520-228-8513	andrew.middione@dm.af.mil	Energy Manager
Don Vincent	Fort Bliss DPW Bldg 777 / Rm 300 Ft. Bliss Garrison (IMCOM) 1733 Pleasonton Rd Fort Bliss, TX 79916-6812	Phone: 915-568-5172	donald.e.vincent.civ@mail.mil	Energy Engineer / Energy Manager

APPENDIX B: SYSTEM AVAILABILITY

Table 12. Fort Bliss System Availability

Building Name	MTU	Total Minutes Recorded	Missing Minutes	Smoothed Minutes	% Fully Available	Comments
20305	DP1A	264,960	-	376	99.9%	
	DP1B	264,960	-	367	99.9%	
	DP1C	264,960	-	370	99.9%	
	DP2A	264,960	-	358	99.9%	
	DP2B	264,960	-	384	99.9%	
	DP2C	264,960	-	364	99.9%	
20310	DP1A	264,960	-	252	99.9%	
	DP1B	264,960	-	279	99.9%	
	DP1C	264,960	-	237	99.9%	
	DP2A	264,960	-	286	99.9%	
	DP2A	264,960	-	256	99.9%	
	DP2C	264,960	-	276	99.9%	
20315	DP1A	264,960	-	379	99.9%	
	DP1B	264,960	-	344	99.9%	
	DP1C	264,960	-	380	99.9%	
	DP2A	264,960	-	348	99.9%	
	DP2B	264,960	-	325	99.9%	
	DP2C	264,960	-	348	99.9%	
20340	DP1A	264,960	-	226	99.9%	
	DP1B	264,960	-	261	99.9%	
	DP1C	264,960	-	268	99.9%	
	DP2A	264,960	-	255	99.9%	
	DP2B	264,960	-	251	99.9%	
	DP2C	264,960	-	272	99.9%	
20345	DP1A	264,960	-	250	99.9%	
	DP1B	264,960	-	211	99.9%	
	DP1C	264,960	-	235	99.9%	
	DP2A	264,960	-	222	99.9%	
	DP2B	264,960	-	236	99.9%	
	DP2C	264,960	-	220	99.9%	

20355	DP1A	264,960	-	307	99.9%	
	DP1B	264,960	-	265	99.9%	
	DP1C	264,960	-	306	99.9%	
	DP2A	264,960	-	330	99.9%	
	DP2B	264,960	-	326	99.9%	
	DP2C	264,960	-	332	99.9%	
20360	DP1A	264,960	-	260	99.9%	
	DP1B	264,960	-	254	99.9%	
	DP1C	264,960	-	290	99.9%	
	DP2A	264,960	-	273	99.9%	
	DP2B	264,960	-	283	99.9%	
	DP2C	264,960	-	290	99.9%	
21205	LP1	264,942	18	268	99.9%	
	PP1B	264,943	17	309	99.9%	
	PP1D	264,942	18	283	99.9%	
	PP1E	264,943	17	312	99.9%	
	PP1F	264,942	18	293	99.9%	
	PP2A	264,944	16	267	99.9%	
21206	LP1	264,960	-	264	99.9%	
	PP1B	264,960	-	6577	97.5%	ECC failure & replace
	PP1D	264,960	-	6600	97.5%	ECC failure & replace
	PP1E	264,960	-	6611	97.5%	ECC failure & replace
	PP1F	264,960	-	270	99.9%	
	PP2A	264,960	-	241	99.9%	
21208	LP1	223,897	41,063	237	84.4%	Cell modem failure & replace
	PP1B	223,899	41,061	242	84.4%	
	PP1D	223,899	41,061	216	84.4%	
	PP1E	223,898	41,062	231	84.4%	
	PP1F	223,898	41,062	233	84.4%	
	PP2A	223,898	41,062	238	84.4%	
21210	LP1	264,960	-	280	99.9%	
	PP1B	264,960	-	269	99.9%	
	PP1D	264,960	-	269	99.9%	
	PP1E	264,960	-	242	99.9%	
	PP1F	264,960	-	255	99.9%	
	PP2A	264,960	-	274	99.9%	

21220	LP1	264,960	-	279	99.9%	
	PP1B	264,960	-	268	99.9%	
	PP1D	264,960	-	232	99.9%	
	PP1E	264,960	-	245	99.9%	
	PP1F	264,960	-	265	99.9%	
	PP2A	264,960	-	265	99.9%	
21222	LP1	264,960	-	293	99.9%	
	PP1B	264,960	-	265	99.9%	
	PP1D	264,960	-	275	99.9%	
	PP1E	264,960	-	275	99.9%	
	PP1F	264,960	-	295	99.9%	
	PP2A	264,960	-	285	99.9%	
21223	LP1	264,960	-	877	99.7%	
	PP1B	264,960	-	882	99.7%	
	PP1D	264,960	-	912	99.7%	
	PP1E	264,960	-	910	99.7%	
	PP1F	264,945	15	903	99.7%	
	PP2A	264,945	15	909	99.7%	
	Total	**22,010,135**	**246,505**	**46,268**	**98.7%**	**Fully Met Objective**
	Excl. Cell Failures	***20,666,746***	***134***	***44,871***	***99.8%***	

Table 13. AMARG System Availability

Building Name	MTU	Total Minutes Recorded	Missing Minutes	Smoothed Minutes	% Fully Available	Comments
7328	AC	264,960	-	623	99.8%	
	Main 1200A (3) CTs	264,960	-	629	99.8%	
	Panel H2	264,960	-	629	99.8%	
	Auto Transfer Switch	264,960	-	623	99.8%	
7391	Chiller	149,142	115,818	5,683	54.1%	Cell modem and EEC failure & replacement
	Main 800A	149,151	115,809	5,538	54.2%	
	Panel L3N-101	149,167	115,793	5,752	54.1%	
	Main1200A	149,166	115,794	5,102	54.4%	
7401	AC 200A	244,568	20,392	310	92.2%	Cell modem failure & replacement
	Main 600A (2) CTs	244,568	20,392	325	92.2%	
7408	Main 600A (2) CTs	264,960	-	664	99.7%	
	Cooler Panel HA	264,960	-	676	99.7%	
	AC	264,960	-	672	99.7%	
7431	Main 600A (2) CTs	264,944	16	632	99.8%	
	Cooler	264,944	16	599	99.8%	
	HP/AH/RAF (3) CTs	264,960	-	648	99.8%	
7439	AC	264,960	-	585	99.8%	
	Main 600A (2) CTs	264,960	-	597	99.8%	
7441	CT Cabinet (2) CTs	264,960	-	612	99.8%	
	Cooler	264,960	-	585	99.8%	
	Gutter (2) CTs	264,960	-	611	99.8%	
7506	Condensing Unit (2) CTs	264,960	-	603	99.8%	
	Main 800A (2) CTs	264,960	-	608	99.8%	
7507	HVAC SW	264,960	-	583	99.8%	
	HVAC SE	264,960	-	603	99.8%	
	Main	264,960	-	601	99.8%	
	HVAC North	264,960	-	599	99.8%	
7513	Main 200A	264,960	-	9,335	96.5%	Erratic cell signal
	AC	264,960	-	10,278	96.1%	
7514	AC	264,960	-	630	99.8%	
	Main1	264,960	-	626	99.8%	
	Main2	264,960	-	605	99.8%	

7432	Main 800A (2) CTs 2	207,418	57,542	2,889	**77.2%**	Initial problem with wiring of power to communication unit
	Main 800A (2) CTs	197,949	67,011	328	**74.6%**	
	Micro Turbine 250A	207,418	57,542	2,421	**77.4%**	
7433	Main 600A (2) CTs	257,605	7,355	851	**96.9%**	Employees shutting off breaker
	Total	**8,845,080**	**693,480**	**63,655**	**92.1%**	
	Excl. Cell Failures	***7,759,318***	***189,482***	***40,945***	**97.6%**	

APPENDIX C: SOFTWARE INTERFACE EXAMPLES

Figure 22. Example Leaderboard - Points Per Week for Last 5 Weeks - Barack 20305

Figure 23. Example Leaderboard – Weather Display

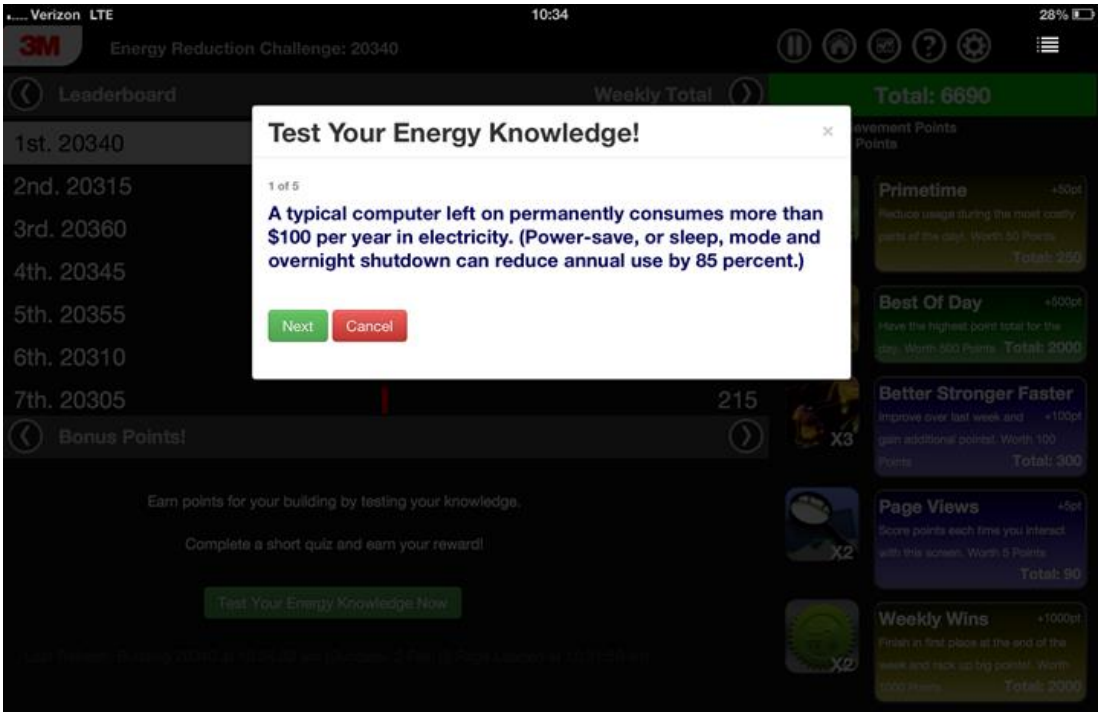

Figure 24. Example "Tip" Screen

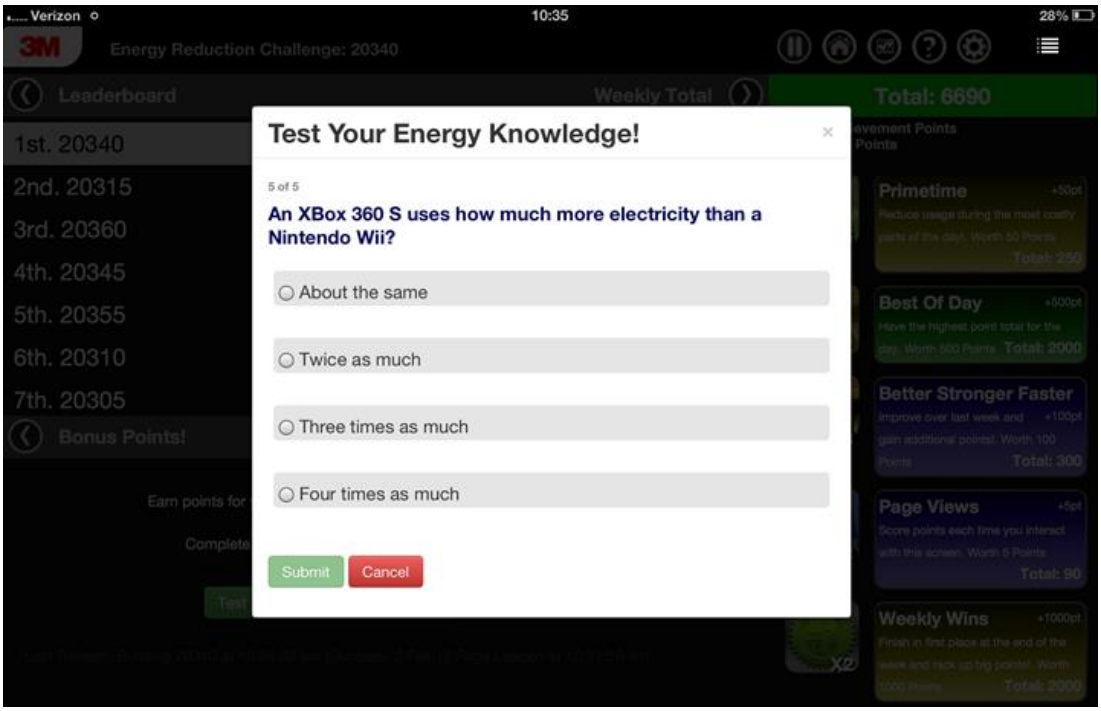

Figure 25. Example "Quiz" Screen – Multiple Choice

Figure 26. Example Achievement Summary – Barracks 20305

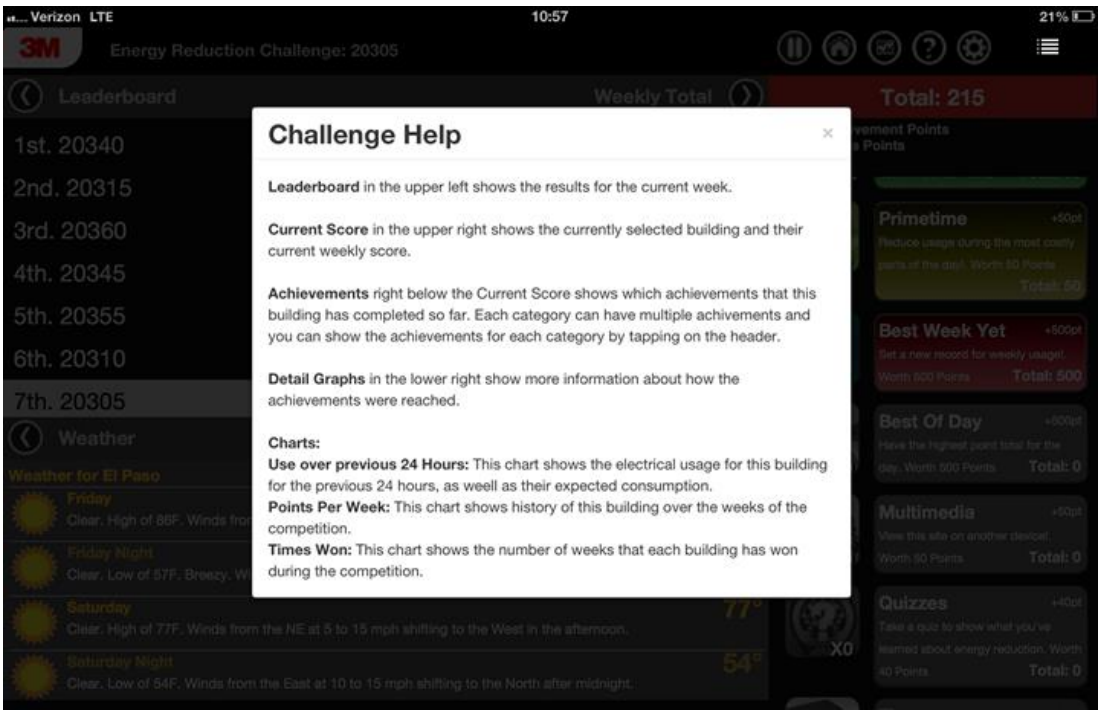

Figure 27. Example Help Screen

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