Strategies to Achieve Net Zero Energy:

The Fort Carson Energy Research Project

September 2014

Executive Summary

Background

Fort Carson is a historic, 72-year-old Army base in Colorado with major environmental accomplishments and ambitions. As a flagship in the Army's Net Zero Initiative, Fort Carson has set goals of net zero energy (NZE),[1] water and waste for the entire base by the year 2020. Fort Carson’s progress to date in meeting these goals includes the construction of over 70 LEED-certified green buildings on base. The base's sustainability goals dovetail with the objectives of the U.S. General Services Administration (GSA) Office of Federal High-Performance Green Buildings to improve understanding of how sustainable technologies and approaches can enhance building performance.

Figure 1 LEED-rated 4th Brigade Combat Team Brigade Battalion Headquarters, Fort Carson, Colorado

[1] For purposes of this report, an NZE building or installation is one that produces as much energy as it uses over the course of a year.

GSA partnered with Fort Carson, the U.S. Department of Energy and two National Laboratories to conduct the Fort Carson Energy Research Project from 2011 to 2013. The project goal was to identify the most lifecycle cost-effective strategies, on both the building and portfolio levels, to achieve NZE performance.

The project targeted six different Army building types and identified four areas of opportunity for the buildings to achieve energy efficiency breakthroughs. Three of the opportunities involved improving building systems and the fourth targeted the impact of building occupant behavior on energy performance. As a whole, this research project demonstrated effective ways to

What is Net Zero Energy?

- The most commonly used definition of an NZE building is: "for every unit of energy the building consumes over a year, it must generate a unit of energy."[2]
- Although not technically an NZE goal, the Energy Independence and Security Act of 2007 (EISA) requires that Federal buildings reduce fossil fuel-generated energy consumption by 100% by 2030.
- The Army defines a Net Zero Energy Installation (NZEI) as: "an installation that produces as much energy on-site as it uses, over the course of a year. To achieve this goal, installations must first implement aggressive conservation and efficiency efforts while benchmarking energy consumption to identify further opportunities. […] The balance of energy needs then are reduced and can be met by renewable energy projects."[3]

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[2] Whole Building Design Guide http://www.wbdg.org/resources/netzeroenergybuildings.php

[3] Army Vision for Net Zero, http://www.asaie.army.mil/Public/ES/netzero/docs/4Oct11_NET_ZERO_White_Paper.pdf

drive down building energy use and thereby save money and achieve ambitious energy and climate change goals.

The most effective approach to achieving NZE is to first reduce energy use to the greatest extent possible and then focus on renewable energy development for remaining energy needs. The project focused on the critical first step, aiming to identify energy reduction strategies with the highest return over the lifecycle of the buildings studied, including both building systems investments and occupant behavior change.

An NZE building is one that produces as much energy as it uses over the course of a year.

The National Renewable Energy Laboratory (NREL) led the building systems research, while the Pacific Northwest National Laboratory (PNNL) led the occupant behavior research. The research teams identified the following research questions to guide their work:

GSA Demonstration Projects

GSA's Office of Federal High-Performance Green Buildings conducts research to demonstrate how Federal buildings can improve their energy and environmental performance. More information on GSA demonstration projects, including reports from completed projects, is available at GSA's Building Research webpage: www.gsa.gov/buildingresearch.

Research Questions

1. How can thermal envelope construction be optimized for lifecycle energy savings?

2. How well are the daylighting and lighting systems performing now, and how can their performance be maximized?

3. What sets of efficiency solutions are available at optimal energy lifecycle cost for common retrofits?

4. Which occupant behaviors have the greatest potential to reduce energy use in buildings, and what approaches can motivate and maintain these behaviors?

This report documents the project teams' methods, findings and recommendations in pursuit of each of these research questions.

Key Research Findings

Thermal Envelope Optimization

The research incorporated actual performance and cost data into energy models to compare a variety of wall, roof and window envelope assemblies in five of the Fort Carson building types. NREL employed net present value analysis to determine the most cost-effective solutions over 30-year building lifecycles, compared to the building energy code baseline (ASHRAE Standard 90.1-2007). The lab also studied opportunities to save energy when troops are deployed, by zoning and partially shutting down unused building sections. We found that:

1. Envelope optimization in new buildings at Fort Carson can yield savings up to 25% over the code baseline with net present value up to $350,000 and simple payback as low as seven years.

2. Results vary widely by building type; e.g., envelope improvements are a key component of NZE design for buildings with large heating loads, but may be less helpful for buildings that are dominated by equipment loads.

3. Thermal zoning and ventilation setback when troops are deployed can yield energy savings up to 23%.

Daylighting and Lighting System Performance

To evaluate performance and identify opportunities for Fort Carson buildings to provide superior lighting with minimal energy use, NREL observed occupancy, lighting and daylighting patterns at four building types, modeled alternative solutions where appropriate, and translated lessons learned into recommendations for improvement. Findings include:

1. Fort Carson is using up to 50% less lighting energy than buildings meeting minimum energy code requirements.

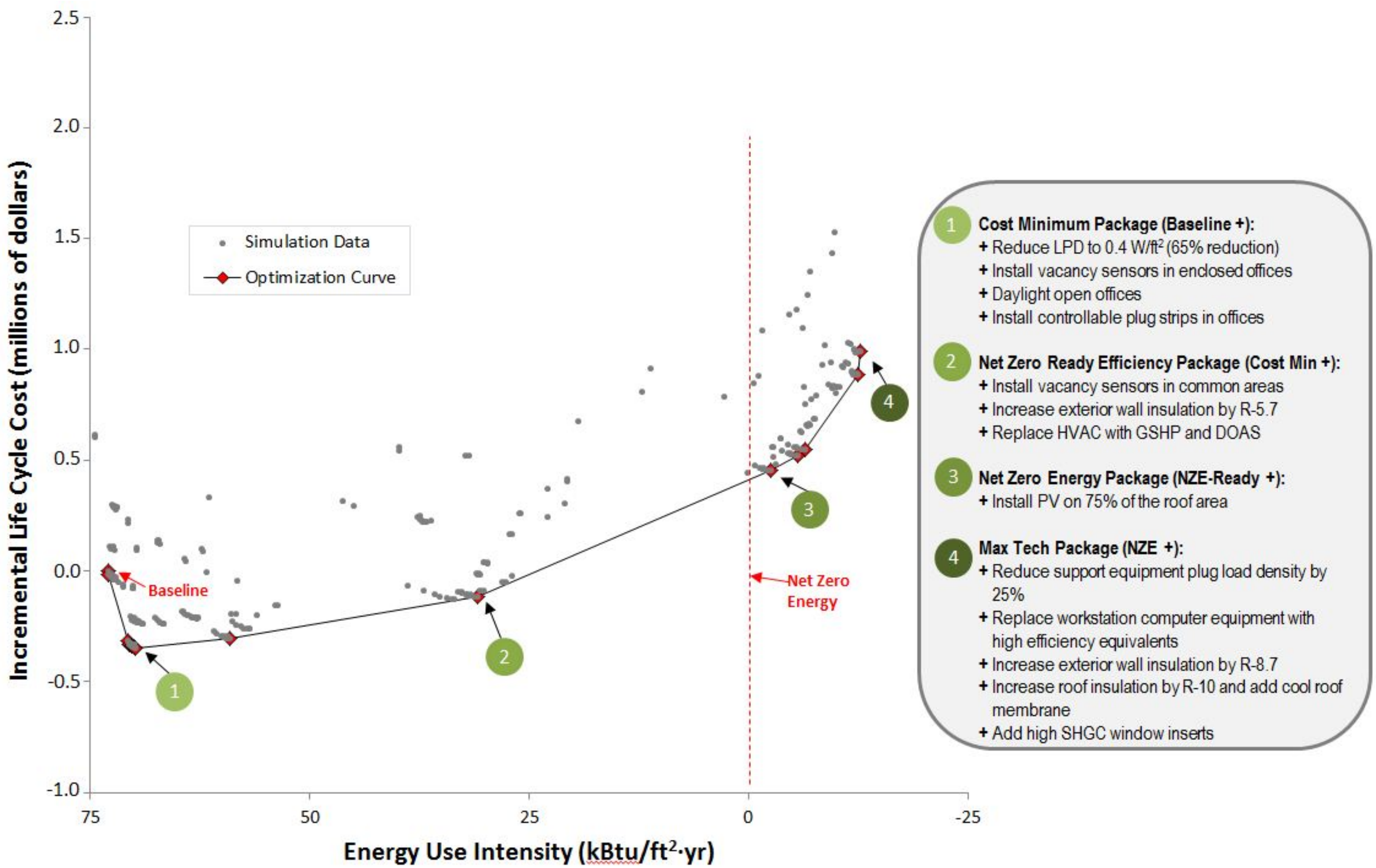
2. The base has further opportunities to optimize lighting quality and efficiency while reducing consumption to levels 90% lower than required by code.

Net Zero Retrofit Optimization

The research team used an office building on the base that had been renovated from a former barracks as the basis for a study to identify a lifecycle-cost-effective pathway to achieve energy reduction performance up to NZE for retrofit projects. NREL sought to demonstrate the feasibility of NZE retrofit planning primarily using open source on-line modeling tools. Findings include:

1. Fort Carson office building retrofits have a clear, low-risk investment path of bundled energy technology solutions from lowest life-cycle cost to NZE. (See output of the modeling exercise in Figure 2 below.)

2. Publicly available open source tools can be used to identify much of this roadmap of bundled energy technology solutions.



Note: DOAS – dedicated outdoor air system, GSHP – Ground source heat pump, HVAC – heating, ventilation, and air conditioning, kBtu/ft^2·yr – thousand British thermal units per square foot per year, LPD – Lighting Power Density, PV – Photovoltaic, SHGC – Solar heat gain coefficient, W/ft^2 – watts per square foot

Figure 2 Retrofit Optimization Results: Simulation Output

Occupant Behavior

PNNL gathered data on the energy-related behaviors of Fort Carson civilian and military building occupants through surveys, group interviews and energy metering. Based on these data, the research team designed a three month intervention at five buildings to test the potential of the Army's Building Energy Monitor (BEM) program to motivate occupants to employ energy-saving behaviors. The intervention tested a model of change that integrates policy ("Rules"), identification of people in specific roles as linchpins ("Roles") and a variety of behavior change methods ("Tools"). In contrast to the Rules, Roles and Tools approach, typical behavior change interventions focus on single behaviors and do not include the organizational context. Findings:

1. Occupants increased energy-saving behaviors as part of the intervention, leading to energy reductions of approximately 2% in one building. Success rates varied across the five buildings. (Results of the effort to increase nightly computer shutdowns shown in Figure 3 below.)

2. Having an engaged BEM with reinforcement from leadership helped drive behavior change.

3. Occupant behavior can be influenced as part of a well-structured effort that includes considering the institutional context, targeting specific and relevant behaviors, providing social reinforcement, measuring results and incorporating feedback.

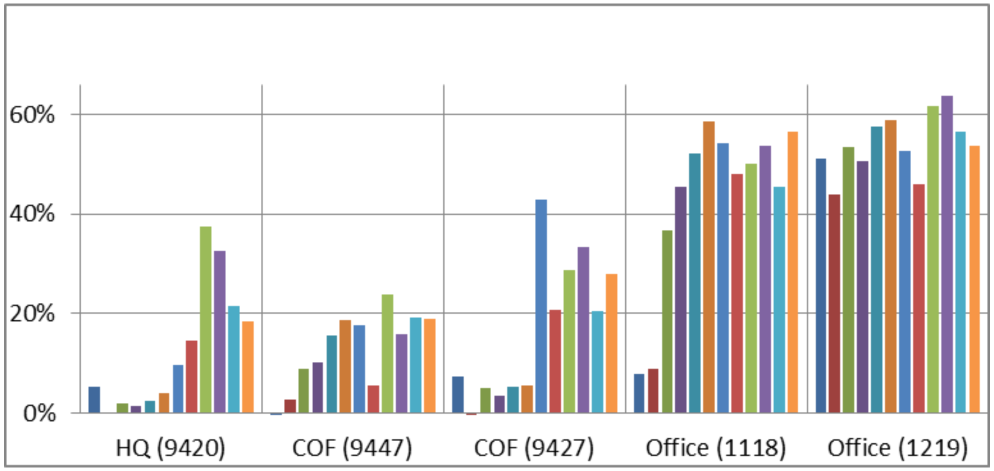


Figure 3 Percent of Computers Shut Down at Night during Research Intervention, by Building and Week

Recommendations Based on Research Findings

While the findings of this project are specific to the building types, systems, climate and population of Fort Carson, they also reveal lessons in integrating energy efficiency strategies applicable to other buildings:

- The building systems research conducted under this project demonstrated the value of taking a deep dive into how efficiently building systems (like lighting and envelope) are operating and identifying opportunities for improvements, up to NZE. Analyses that take lifecycle costs and benefits into account lay the groundwork for making the most rational decisions over the lifetime of a building.

- Best practices identified should be built into portfolio planning, standards, contract language and specifications. Solutions will need to be adapted to each individual building, at which point technologies and approaches can be bundled together to form the most lifecycle-cost-effective progression of investments.

- The behavioral research demonstrated opportunities to effectively engage building occupants in energy reduction. The research suggested the value of integrating building systems improvements with occupant engagement strategies, as both are needed to achieve NZE levels.

- Engaging occupants requires employing institutional approaches that integrate changes in policy and organizational roles with programs to influence specific occupant behaviors. Occupants need support to adopt energy-saving behaviors, and all relevant rules, roles and tools should be considered and adjusted to ensure that they receive such support. As a key example, local energy advocates need systems to monitor energy use and gain feedback from occupants while also informing occupants of energy use levels and how they can reduce them.

Attaining a high standard like NZE requires finding and using every tool in the toolbox. Yet even such an ambitious goal appears increasingly attainable as building professionals learn how to design and adapt building systems and work with occupants to make it happen.

Attaining a high standard like NZE requires finding and using every tool in the toolbox.

Table of Contents

List of Tables

List of Figures

Acknowledgements

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Thank you to all of these individuals, and those unintentionally omitted from the above list, for your hard work in taking this research project from concept to reality.

Chapter 1 The Role of Building Systems in Achieving Net Zero Energy: A Demonstration Project at Fort Carson

1.1. Background

For this demonstration project, the General Services Administration (GSA) funded the National Renewable Energy Laboratory (NREL) to support the measurement, evaluation, and analysis of the current stock of new Leadership in Energy and Environmental Design (LEED) Gold and Platinum buildings at Fort Carson to better understand and document the performance of energy efficiency technologies and strategies. The goal of this demonstration project was to generate best practices and case studies documenting how LEED Gold (and better) projects can achieve realized high performance. Technologies were selected based on the desire to focus on efficiency technologies that are the most passive and simple to install and use.

The purpose of this research project was to enable GSA to advance knowledge of green building planning, design,

Key Research Questions

- How can thermal envelope construction be optimized for lifecycle energy savings?
- How well are the daylighting and lighting systems performing now, and how can their performance be maximized?
- What sets of efficiency solutions are available at optimal energy lifecycle cost for common retrofits?

construction, and operation by:

- Analyzing Federal buildings and campuses whose planning, design, construction, and operation provide benchmark and performance data, to inform the development of planning, design and construction specifications and operating standards for the Federal real property inventory;

- Using Federal buildings and campuses as research learning laboratories and teaching tools to advance understanding of high-performance green building performance (emphasizing relationships among building diagnostics and human health, productivity, environmental impact, safety, security, and accessibility);

- Sharing lessons learned and best practices, guidance and tools drawn from project findings within the Federal community, as well as with the private real property community and selected green building industry sectors.

Specifically, NREL was tasked with answering three research questions:

1. How can thermal envelope construction be optimized for lifecycle energy savings?

1. How well are the daylighting and lighting systems performing now, and how can their performance be maximized?

2. What sets of efficiency solutions are available at optimal energy lifecycle cost for common retrofits?

Research findings and recommendations for each question are presented in the Recommendations section. Additional research performed in support of the overall Fort Carson LEED Demonstration Project is discussed in the Appendix D: Additional Project Support section. Our primary audience for this final report is Army projects as well as other Federal projects looking to reach the highest levels of Green Building certifications and net zero energy. Throughout the report, we discuss the application of research results to additional building types at Fort Carson, other Army bases in different climates, and the commercial buildings sector in general.

1.2. Thermal Envelope Optimization

Purpose

The purpose of this study was to answer the research question: “What is the optimal lifecycle thermal envelope system by space type?” The contribution that envelope improvements can make toward achieving net zero energy is highly dependent on the mix of end-use loads in the building, the physical characteristics of the building, and the climate.

Because of the diverse usage patterns in military buildings at Fort Carson and other bases, we assumed that the optimal envelope features may vary significantly based on several characteristics:

- Magnitude of internal heat gains (people and equipment)
- Timing of internal heat gains
- Heating and cooling set points
- Hours of operation
- Ventilation rates
- Surface area to volume ratio

Research Question

What is the optimal lifecycle thermal envelope system by space type?

This study investigated the most cost-effective envelope features for each of five major building types on the base, in order to determine the appropriateness of specifying a single set of envelope characteristics for all new Fort Carson buildings. Because we focused on a single subsystem, we did not determine the optimal envelope design needed to achieve Fort Carson's net zero energy goal. Whole-building optimization would be necessary for such an analysis, as described in the context of retrofit projects in Net Zero Retrofit Optimization.

Space Types

- Headquarters office building (HQ)
- Dining Facility (DFAC)
- Company Operations Facility (COF)
- Tank and Equipment Maintenance Facility (TEMF)
- Barracks

Methods

To answer this research question, we evaluated the performance of a variety of envelope components, including their impact on conductive heat gains and losses, air leakage, solar heat gains, daylighting, and thermal comfort. Space types included in the evaluation are those found in the following facilities for the newly constructed 4th Brigade LEED Gold facilities:

The methodology included the following steps:

1. Select a set of envelope characteristics spanning a range of performance from levels specified by standards from ASHRAE 90.1-2007 to Passivhaus.
2. Assess tested air barrier performance versus wall construction type.

3. Model each facility to determine the energy savings for each envelope improvement. Conditioned and semi-conditioned zones were analyzed separately.

4. Work with the U.S. Army Corps of Engineers (USACE) and the Design-Build teams to collect first cost information to include in the lifecycle assessments.

5. Perform lifecycle cost analysis of all measures to determine the optimal combinations for each building type.

Baseline Models

NREL obtained the USACE Construction Engineering Research Laboratory (CERL) models for five building types that will serve as the starting point for optimizing envelope design (USACE 2011). The ASHRAE 90.1-2007 models for the Colorado Springs climate location were used as the baseline for this study. Google Sketchup representations of the five buildings are shown in Figure 4 through Figure 8. Three of the models were developed by NREL (Dining Facility [DFAC], Company Operations Facility [COF], and Tactical Equipment Maintenance Facility [TEMF]), and the other two were developed by Big Ladder Software (Headquarters [HQ] and Barracks). Window-to-wall ratio (WWR) and skylight-to-roof ratio (SRR) are also provided for each building type.

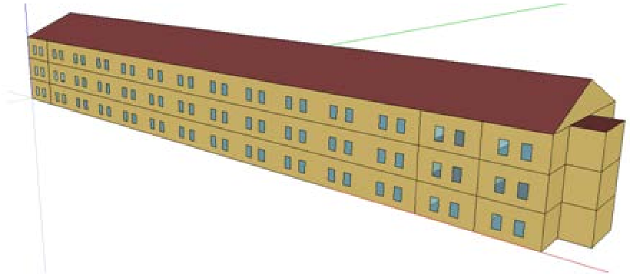


Figure 4 Barracks model (WWR=9%, SRR=0%)

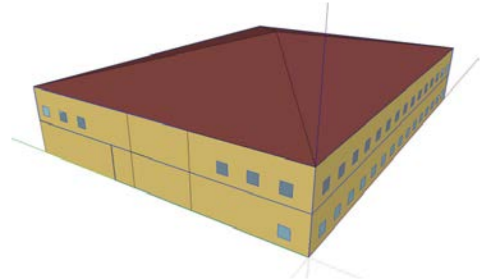


Figure 5 Brigade HQ model (WWR=7%, SRR=0%)

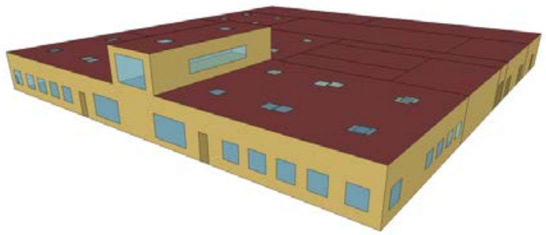


Figure 6 Dining Facility (DFAC) model (WWR=11%, SRR=0.6%)

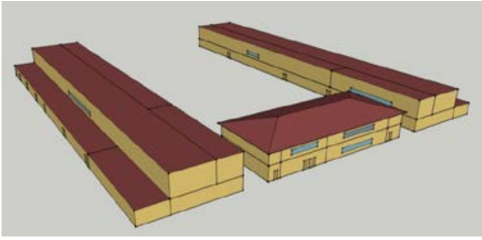


Figure 7 Company Operations Facility (COF) model (WWR=3%, SRR=0%)

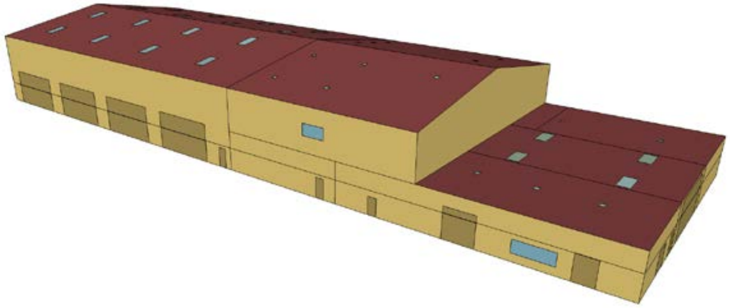


Figure 8 Tactical Equipment Maintenance Facility (TEMF) model (WWR=1%, SRR=3%)

NREL attempted to create OpenStudio models of the five building types using the EnergyPlus models developed for CERL, in order to utilize the same optimization capabilities used for the Net Zero Energy Retrofit task (See Net Zero Retrofit Optimization). Because the models were in a relatively old version of Energy Plus, and not all features of Energy Plus are supported by OpenStudio, there were a large number of conversion errors. We were unable to rectify these conversion issues in a reasonable amount of time, so we decided to proceed with a parametric optimization using EnergyPlus, along with run management features of OpenStudio.

NREL overcame some conversion issues while upgrading the five baseline models to the latest version of EnergyPlus. We also needed to prepare all baseline models for the parametric runs by making adjustments to assembly naming conventions, geometries, and material properties to ensure consistent application of the envelope measures in each building type.

We identified zone groupings in each of the five building types for which optimized envelope assemblies would be developed. Zones with similar heating and cooling set points were grouped together. In addition, zones that were likely to be vacant during troop deployments were identified, allowing the application of reduced ventilation rates, lower heating set points, and higher cooling set points.

The baseline models were used to examine the end-use breakdowns of energy use in each building type. These end-use breakdowns are shown in Figure 9 through Figure 13.

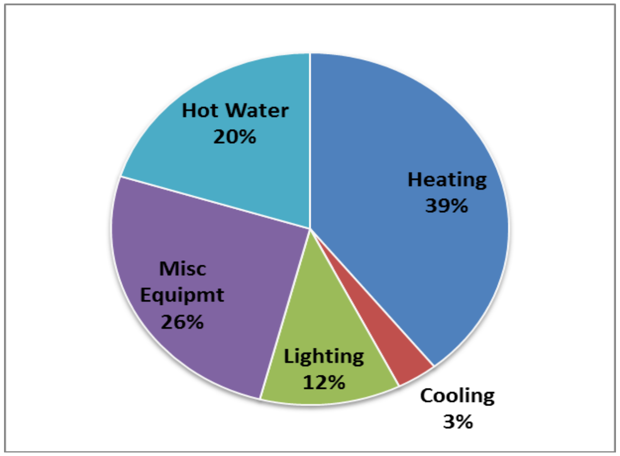


Figure 9 Barracks energy end-use breakdown

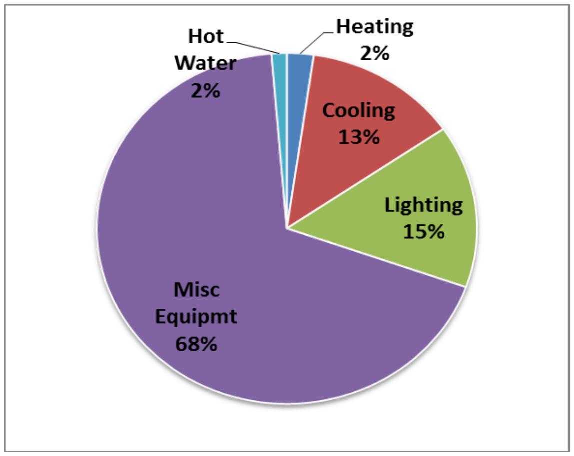


Figure 10 Brigade HQ energy end-use breakdown

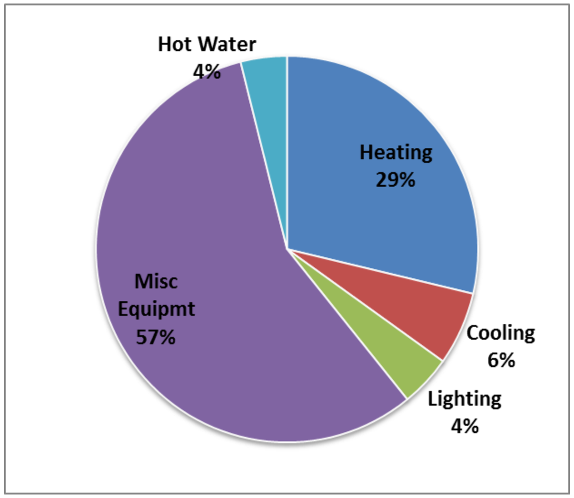


Figure 11 DFAC energy end-use breakdown

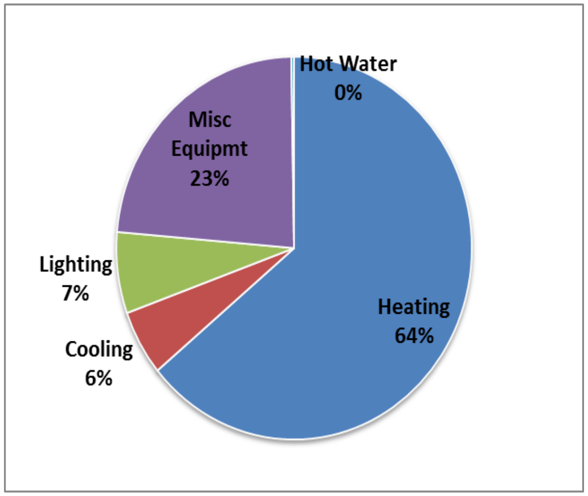


Figure 12 COF energy end-use breakdown

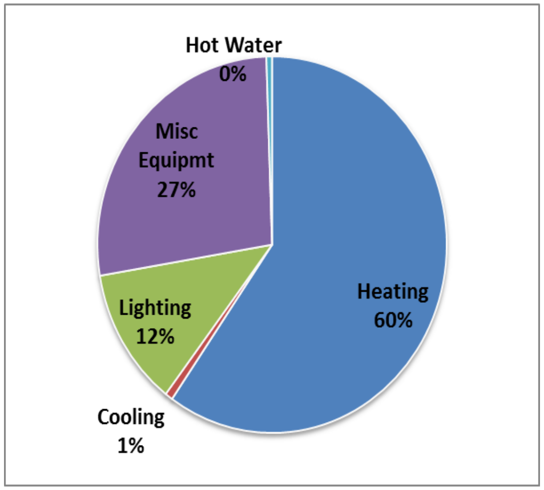


Figure 13 TEMF energy end-use breakdown

The Brigade HQ building model was dominated by equipment loads because a large data center was present.

Several important observations were made based on the end-use breakdowns of the five building types:

- The Brigade Headquarters building model was dominated by equipment loads because a large data center was present. As a result, the heating load calculated by the baseline model was very small, and the cooling load was relatively large. Expectations for significant energy savings resulting from added insulation and a tighter envelope should be tempered for buildings with such large internal heat gains.

- The DFAC model also had large internal heat gains due to cooking activities, but these loads occurred primarily during the day when meals are served. Greater opportunities exist for energy savings due to envelope improvements.

- The heating loads in the COF and TEMF models are relatively large, suggesting these building types are very good candidates for envelope upgrades. However, they also have large semi-conditioned spaces with lower heating set points, where envelope improvements may not be as cost-effective.

Measures Considered

Envelope components in the analysis included **wall construction, roof construction, window assemblies**, and **special interior zoning when troops are deployed**. We did not investigate basement or slab measures, which were deemed less likely to produce significant energy savings. We also did not study alternate building geometries or window placement, because the complexity of such analysis was outside the scope of this project. We also did not consider daylighting control measures such as clerestories or electrochromic windows, because those topics are addressed in the lighting optimization study (See Lighting System Performance).

Envelope analysis components included wall construction, roof construction, window assemblies, and special interior zoning when troops are deployed.

We performed a literature review to identify candidate envelope assemblies, including those analyzed in the draft report for the Military Construction (MILCON) Energy Efficiency and Sustainability Study of Five Army Buildings (USACE 2011). This report documented energy savings and cost projections for envelope types ranging from code minimum to Passivhaus levels. We noted a gap between insulation values for Passivhaus and what was referred to as the Army Whole Building Design Guide (WBDG), designated as Option 0 in the analysis. We decided to use the MILCON options for ASHRAE 189.1, WBDG, and Passivhaus, and fill in the gap with a few additional options. Recognizing that certain envelope design constraints are mission-critical (physical layout of zones, window blast/fire resistance, minimum view window area), we accepted the basic design features of the MILCON baseline models and focused on insulation levels, window coatings, and air sealing measures.

Specifications for the envelope measures were primarily taken from the MILCON study where available. Insulation levels for most of the additional wall and roof construction measures were interpolated between MILCON values. Precast concrete wall specifications were based on NREL experience with other projects. Infiltration values were obtained based on the recent USACE air barrier study conducted for buildings with various wall constructions at Fort Carson. Window properties were taken from the 2009 ASHRAE Handbook of Fundamentals. Thermostat setback and setup for the deployment zoning analysis was based on schedules for unconditioned spaces in the baseline models.

The final measure specifications used in the envelope optimization study are summarized in Table 1 through Table 4.

Table 1 Alternate wall constructions considered

Wall Efficiency Level	Wall Assembly	Wall Insulation R value*	Leakage rate cfm/ft^2 @ 0.3 in w.g.
ASHRAE 90.1-2007	2x4 Steel Framing, 2" EPS	13+7.5 ci	0.25
ASHRAE 189.1-2011	2x4 Steel Framing, 3" EPS	13+10 ci	0.25
Option 0	2x4 Steel Framing, 2" Polyiso	13+12.5 ci	0.25
Option 1	2x4 Steel Framing, 4" EPS	13+15 ci	0.25
Option 2	2x4 Steel Framing, 4" EPS, Tighter	13+15 ci	0.11
Option 3	Prefab Wall, Precast Concrete, 8" EPS	0+30 ci	0.05
Passivhaus	2x6 Steel Framing, 8" EPS, Tighter	19+30 ci	0.11

*Stated wall R-values are nominal, and do not include the effects of thermal short circuits, compression, or other impacts on installed R-value

Table 2 Alternate roof constructions considered

Roof Efficiency Level	Roof Assembly	Roof Insulation R value
ASHRAE 90.1-2007	IEAD, 4" Polyiso	20
ASHRAE 189.1-2011	IEAD, 5" Polyiso	25
Option 0	IEAD, 6" Polyiso	30
Option 1	IEAD, 8" Polyiso	40
Option 2	IEAD, 10" Polyiso	50
Passivhaus	IEAD, 11" Polyiso	55

Table 3 Alternate window assemblies considered

Window Efficiency Level	Window Assembly	Required Window U value	Required Window SHGC
ASHRAE 90.1-2007	Double, LowE, AlumNoBrk	0.55	0.40
ASHRAE 189.1-2011	Double, LowE, Bronze, AlumWBrk	0.45	0.35
Option 0	Double, LowE, AlumWBrk	0.42	0.39
Option 1	Double, LowE, Vinyl	--	--
Passivhaus	Triple, LowE, Vinyl	0.18	0.49

Table 4 Deployment status options

Unit Deployment Status	Heating Set Point (°F)	Cooling Set Point (°F)	Ventilation Rate (cfm)
Home Station	70	75	100%
Deployed	55	80	0

We considered the results of the Pacific Northwest National Laboratory (PNNL) interviews and surveys, which indicated that passive design measures, with minimal need for occupant intervention, were the most appropriate given the other important priorities of Army personnel. We originally planned to perform infrared imaging and other types of short-term envelope and thermal comfort testing to evaluate the envelope performance of existing buildings at Fort Carson, but resource constraints made this level of testing impractical.

We obtained peer reviews of our candidate envelope assemblies from the GSA team as well as a few members of the NREL Commercial Buildings Team and Mortenson Construction to verify the appropriateness of the measures for the building types under consideration. Several additional options were added based on these review comments.

Cost Inputs

Initial cost estimates for the envelope options were assembled from four sources. The primary cost estimates were provided by our partners at Mortenson Construction, who obtained quotes for most of the measures from their subcontractors. Alternate cost data sources were identified as a check for reasonableness, and to fill any gaps where Mortenson was unable to provide data. These alternate sources included the following:

- USACE air sealing cost data obtained from Fort Carson contractors

- Military Construction (MILCON) Energy Efficiency and Sustainability Study of Five Army Buildings (USACE 2011)
- Technical Support Document: Strategies for 50% Energy Savings in Large Office Buildings (Leach et al, 2010)
- RSMeans Building Construction Cost Data 2012 (R.S. Means, 2012)
- NREL's Opt-E-Plus cost library (NREL 2010)

The final incremental cost data used in the analysis are summarized in Table 5 through Table 7.

Table 5 Incremental wall construction costs

Wall Assembly	Incremental Cost ($/ft^2)
2x4 Steel Framing, 2" EPS	$-
2x4 Steel Framing, 3" EPS	$0.43
2x4 Steel Framing, 2" Polyiso	$0.95
2x4 Steel Framing, 4" EPS	$0.85
2x4 Steel Framing, 4" EPS, Tighter	$2.25
Prefab Wall, Precast Concrete, 8" EPS	$20.25
2x6 Steel Framing, 8" EPS, Tighter	$2.95

Table 6 Incremental roof construction costs

Roof Assembly	Incremental Cost ($/ft^2)
IEAD, 4" Polyiso	$-
IEAD, 5" Polyiso	$0.40
IEAD, 6" Polyiso	$0.80
IEAD, 8" Polyiso	$1.50
IEAD, 10" Polyiso	$2.20
IEAD, 11" Polyiso	$2.55

Table 7 Incremental window assembly costs

Window Assembly	Incremental Cost ($/ft^2)
Double, LowE, AlumNoBrk	$-
Double, LowE, Bronze, AlumWBrk	$4.80
Double, LowE, AlumWBrk	$1.80
Double,LowE, Vinyl	$5.00
Triple, LowE, Vinyl	$8.30

We did not attempt to estimate the cost of designing buildings where certain thermal zones can be isolated when troops are deployed. Modifications to the heating, ventilation, and air conditioning (HVAC) system would be necessary, along with additional interior walls and doors with a reasonable level of insulation and air tightness. This constitutes an uncommon set of features, and we were unable to locate relevant cost data. However, the potential energy savings justifies further research to evaluate cost-effectiveness.

Analysis Approach

NREL developed a Ruby script file that generated and ran EnergyPlus files for each envelope option in each of the five building types. The Ruby script utilized the run management features of OpenStudio to perform the modeling in an efficient manner, and allowed straightforward changes to the application of measures when necessary. EnergyPlus output data was loaded into a spreadsheet, which performed net present value (NPV) analysis of individual envelope construction types, as well as the optimal package for each building type. “Optimal” in this context refers to the option with the highest NPV among the choices that were considered.

Results and Lessons Learned

NREL performed net-present value analysis of all envelope options that were considered for the five building types, two of which included separate analysis of conditioned and semi-conditioned spaces (TEMFs and COFs). Optimal wall constructions, roof insulation levels, and window assemblies were identified based on maximum net present value in the corresponding building type over a **30-year project period using the standard 4% nominal discount factor** established by the U.S. Army. These optimal envelope features, along with their corresponding first cost and NPV, are summarized in Table 8 to Table 11. NREL also estimated the potential energy cost savings for designing the buildings with special zoning capability that would allow a significant temperature setback and reduction in ventilation for most of the building when troops are deployed, as shown in Table 11.

Table 8 Optimal wall constructions

Building Type	Wall Construction	Incremental First Cost	30 Year NPV vs. ASHRAE 90.1 2007
Barracks	2x4 Steel Framing, 4" EPS, Improved Air Barrier	$58,700	$90,100
HQ	2x4 Steel Framing, 2" EPS	$0	$0
DFAC	2x4 Steel Framing, 4" EPS	$7,670	$529
COF (Conditioned)	2x6 Steel Framing, 8" EPS, Improved Air Barrier	$60,000	$214,000
COF (Semi-conditioned)	2x4 Steel Framing, 4" EPS, Improved Air Barrier	$75,100	$128,000
TEMF (Conditioned)	2x4 Steel Framing, 4" EPS, Improved Air Barrier	$16,500	$30,600
TEMF (Semi-conditioned)	2x4 Steel Framing, 4" EPS, Improved Air Barrier	$30,700	$42,700

Table 9 Optimal roof constructions

Building Type	Roof Construction	Incremental First Cost	30 Year NPV vs. ASHRAE 90.1 2007
Barracks	Insulation Entirely Above Deck, 4" Polyisocyanurate	$0	$0
HQ	Insulation Entirely Above Deck, 4" Polyisocyanurate	$0	$0
DFAC	Insulation Entirely Above Deck, 4" Polyisocyanurate	$0	$0
COF (Conditioned)	Insulation Entirely Above Deck, 6" Polyisocyanurate	$18,300	$10,200
COF (Semi-conditioned)	Insulation Entirely Above Deck, 4" Polyisocyanurate	$0	$0
TEMF (Conditioned)	Insulation Entirely Above Deck, 4" Polyisocyanurate	$0	$0
TEMF (Semi-conditioned)	Insulation Entirely Above Deck, 4" Polyisocyanurate	$0	$0

Table 10 Optimal window assemblies

Building Type	Window Construction	Incremental First Cost	30 Year NPV vs. ASHRAE 90.1 2007
Barracks	Triple Pane, Low-E, Vinyl Frame	$20,900	$234
HQ	Double Pane, Low-E, Aluminum Frame without Thermal Break	$0	$0
DFAC	Double Pane, Low-E, Bronze Coating, Aluminum Frame with Thermal Break	$5,160	$4,200
COF	Triple Pane, Low-E, Vinyl Frame	$18,300	$1,810
TEMF	Double Pane, Low-E, Aluminum Frame without Thermal Break	$0	$0

Table 11 Impact of relaxed thermostat settings and reduced ventilation rates during troop deployments

Building Type	Annual Cost Savings	Annual Energy Savings
Barracks	$12,508	14%
HQ	$2,955	4%
DFAC	$7,799	4%
COF	$25,047	23%
TEMF	$5,254	12%

No single measure is optimal in all five building types.

The results of the individual measure analyses illustrated several important points:

- No single measure is optimal in all five building types.
- Using the assumed first cost estimates, roof improvements beyond code were generally not cost-effective.
- The optimal envelope constructions were the same for conditioned and unconditioned spaces in the TEMF, but slightly higher insulation was recommended for conditioned spaces in the COF.
- Interior zoning during troop deployment appears to be a very high impact measure in buildings with large heating loads (Barracks, COF, TEMF). It is important to note that the energy savings for this study does not include reductions in lighting and plug loads, which are assumed to occur whether or not special zoning is in place. This analysis only includes the effects of reduced ventilation and more relaxed thermostat settings.

The optimal wall, roof, and window designs for each building type were next combined into a single package, and re-analyzed to capture any interactive effects. The results for these optimal packages are summarized in Table 12.

Table 12 Energy savings of optimal envelope packages versus ASHRAE 90.1-2007

Building Type	Energy Savings	Incremental First Cost	Annual Energy Savings	30 Year NPV	Simple Payback
Barracks	15.8%	$79,700	$7,650	$83,000	10 yrs
HQ	0.0%	$0	$0	$0	N/A
DFAC	0.3%	$12,800	$601	$88	21 yrs
COF	24.8%	$168,000	$24,600	$353,000	7 yrs
TEMF	21.8%	$47,200	$5,660	$72,700	8 yrs

The results indicate that very large whole-building energy savings can be achieved cost-effectively for the COF, Barracks, and TEMF, by improving the envelope construction beyond code. However, no improvements were recommended for the HQ building beyond code. As mentioned earlier, the large data center in the HQ model produced such large internal heat gains, that very little supplemental heating was necessary. As a result, reducing heat losses through the thermal envelope was often counterproductive, increasing the cooling energy use more than it reduced heating energy. Large internal heat gains also resulted in minimal cost-effective improvements for the DFAC.

Recommendations

Whole-building energy savings up to 25% can be achieved in new buildings at Fort Carson with NPV over $300,000 and a simple payback as low as 7 years.

The results of the envelope study provide several important insights that should be considered for future new construction projects at Fort Carson:

- Whole-building energy savings up to 25% can be achieved in new buildings at Fort Carson with NPV over $300,000 and a simple payback as low as seven years.
- Improving air-tightness is generally higher impact than increasing insulation levels.
- Savings can be very significant for thermal zoning and ventilation setback when troops are deployed
- Designers should consider using envelope constructions adapted to the unique attributes and usage patterns of each building type. For example, buildings with smaller internal gains per square foot should be targeted for envelope improvements before buildings with relatively high internal gains. Also, semi-conditioned spaces may not benefit from envelope upgrades as much as fully conditioned spaces.

- Envelope improvements are an essential component of net zero energy design for buildings with large heating loads associated with the thermal envelope (infiltration, conduction) that must be met by the HVAC system, but should not be the primary focus for buildings that are dominated by internal gains from equipment.

There may be many non-economic reasons to select packages based on the energy efficiency goals of the Army.

There are a few limitations to the application of the envelope study results that should be noted:

- “Optimal” packages in the context of this study are based on the highest NPV relative to a code minimum building, using fuel costs that track with inflation. There may be many non-economic reasons to select packages that are not strictly optimal from an economic standpoint, based on the energy efficiency goals of the Army for a particular project. Societal impacts such as source energy, greenhouse gas emissions, and reduced dependence on limited fossil fuel sources, may be important considerations. Envelope improvements can also protect against unexpected increases in fuel prices, and can greatly improve the uniformity of temperatures in a building, creating a more comfortable work environment for occupants.

- Optimal envelope features may change if part of a larger package of improvements. For the most part, higher insulation levels and reduced air infiltration measures are independent of each other, and have no systems interactions. But many envelope improvements will be less cost-effective when bundled with HVAC efficiency improvements that reduce the amount of energy needed to meet envelope loads. At the same time, equipment downsizing may be possible when envelope loads are reduced, resulting in higher cost-effectiveness. Because these positive and negative interactive effects are common with energy efficiency projects, the optimal envelope design may depend on the efficiency of other building systems.

- Optimal envelope packages are likely to be dependent on building geometry. This study focused on representative building types at Fort Carson, but other building characteristics (e.g., surface area to volume ratios, window-to-wall ratio, solar exposure) could produce different results.

- NPVs of window enhancements are highly dependent on window orientation, heating/cooling loads, and daylighting controls.

- Cost data is highly variable, both over time and from site-to-site. It may be possible for Fort Carson to obtain materials at a lower cost than we assumed. If that is the case, more aggressive packages of envelope improvements may become optimal. Similarly, higher energy prices resulting from resource scarcity can also increase the economic value of investments in envelope improvements.

- This study was limited to the Colorado Springs area. As a result, the optimal packages may not apply to other Army bases in other locations. However, the key lessons learned are still relevant as general guiding principles.

- The analysis was performed in the context of new construction. The energy savings may be significantly higher for existing buildings with building envelopes that do not meet ASHRAE 90.1 requirements, or that experience performance degradation over time. However, envelope improvements are generally much more costly for existing buildings because installation costs are higher and incremental purchase costs cannot be used unless the envelope components are at the end of their useful life, or a major renovation is planned that requires replacement of major building envelope assemblies. As a result, the optimal envelope designs discussed in this section are relevant for very deep retrofits, but are unlikely to be cost-effective for more common energy-driven retrofit scenarios. A separate analysis should be performed in the context of retrofits.

1.3. Lighting System Performance

Purpose

While the Fort Carson Technology Evaluation project, in particular the Net Zero Retrofit Optimization research question, aims to address the path to net zero broadly, the purpose of this research question is to focus on the details of one system, lighting. **The questions answered through this work are:**

- To what level of energy efficiency are U.S. General Services Administration (GSA)/Fort Carson lighting systems performing currently and how does this compare to net zero building requirements?
- What components of the lighting systems do occupants generally accept or reject, and how can their lighting comfort be improved?
- Based on the previous two answers, what best practices can GSA and Army implement beyond current practice to make steps toward net zero energy?

Research Question

How well are the daylighting and lighting systems performing by space type?

Lighting systems typically use between **30%–40%** of a building's total energy consumption, making it an obvious focus area for net zero energy discussions. National Renewable Energy Laboratory's (NREL's) experience with net zero energy design and operation on its campus has shown that lighting systems in a net zero energy office facility should consume no more than 10% of the total building load, or closer to 6% when a data center or other equipment-heavy spaces are included. This translates to approximately 75% lighting energy use reduction versus an ASHRAE Standard 90.1-2007 baseline for new and retrofit buildings required to achieve net zero energy.

NREL's experience has also shown that the 75% building lighting energy savings can be broken down into savings expectations of 50% in non-daylit areas and as high as 90% in daylit spaces.[4] These numbers are used as lighting system goals in this research question because they have been proven to be achievable and because this level of efficiency is assumed for the Net Zero Retrofit Optimization lighting measures (See Net Zero Retrofit Optimization). The results of the retrofit optimization show that the electric lighting, daylighting, and general lighting control energy efficiency measures are necessary for cost-effective net zero energy design.

Lighting systems typically use between 30-40% of a building's total energy consumption, making it an obvious focus area for net zero energy discussions.

The approach for the lighting systems research question started with sampling the lighting energy use patterns of a subset of Fort Carson buildings for comparison to a 75% whole building lighting energy savings goal. Fort Carson presents a good litmus test for net zero energy, subsystem goal potential for a number of interconnected reasons. First, the Army has already implemented Leadership in Energy and Environmental Design (LEED) Silver and Gold certification on recent new construction and retrofit projects. The projects achieved Daylight and Views, and Optimize Energy Performance LEED credits, each of which imply that best practices for lighting efficiency were used. Second, Fort Carson is tracking toward net zero energy goals in design and operation and so the gap between current best practices for lighting efficiency in design and realized performance on this site are of particular interest to GSA and the Army. Lastly, comprehensive lighting strategies have been implemented and can therefore be observed for lessons learned. Comprehensive lighting strategies include:

[4] The results for the space types assessed in this study show an average code allowance of 4.9 kWh/sf/yr and a possible energy use intensity of approximately 0.9 kWh/sf/yr.

- *Electric lighting reductions* such as the retrofit from fluorescent to Light Emitting Diode (LED) lighting in Building 1219
- *Daylighting features* such as skylights in new Company Operations Facilities (COFs) and Tactical Equipment Maintenance Facilities (TEMFs), and tubular daylighting devices in the new Dining Facility (DFAC), with lighting controls to proportionately reduce electric lighting when daylight is present
- *Lighting controls* such as occupancy sensors in the open offices of the new Headquarters (HQ) building, and
- Occupant engagement activities such as “Please turn off the lights” stickers in Building 1219.

Each of these elements must be included in a building to see lighting energy savings as low as 75% versus a code baseline. The lighting research question intends to evaluate these best practices with respect to design, installation, and commissioning to glean insights into their effectiveness for energy savings and the potential for low-cost changes or tweaks to further the goal of net zero energy.

The approach for evaluating the Fort Carson lighting systems was to select a sample of buildings and space types, observe occupancy and lighting patterns in these areas, model alternative solutions where appropriate, and translate the lessons learned from the observations and modeling into recommendations for closing the net zero energy gap. The buildings sampled include new LEED construction—the Brigade Headquarters Facility (HQ, Building 9420), Company Operations Facilities (COFs, Building 9447 and 9486) and Tactical Equipment Maintenance Facilities (TEMF, Building 9487) buildings on Wilderness Road—and an old barracks renovated into an office—Building 1219. Spaces examined in these buildings included private offices, open offices, classrooms, community spaces, hallways, break rooms and high bay modules.

The following sections detail this process; the *Methods* section explains the sample building selection and monitoring plan, the *Research Results* section presents space-by-space observations and monitoring results, with an emphasis on comparing the effectiveness of different buildings' lighting strategies, and the *Daylighting and Lighting System* section synthesized the space-by-space results into broader observations that can be incorporated into future Fort Carson and GSA project requirements.

Methods

As a first step in the lighting system evaluation NREL visited Fort Carson to survey the variety of electric lighting, daylighting, and lighting control systems installed and select representative space types for further study. The visit revealed that the HQ, COF, and TEMF buildings on Wilderness Road house a variety of intentional daylighting features including skylights, clerestory glazing, and tubular daylighting devices. The electric lighting is primarily fluorescent, which is layered with "manual on, automatic off" control strategies to reduce load in response to occupancy and daylight. Subsystem monitoring results in Figure 10 show that the HQ building (office example) is using 15% of its energy on lighting, which indicates an aggressive lighting system design but possibly less so than needed for net zero energy operation.

The HQ building used 15% of its energy on lighting, which indicates an aggressive lighting system design but possibly less so than needed for net zero energy operation.

The older, renovated office Building 1219 offers contrast to the newer Wilderness Road buildings. Although retrofit with common best practice lighting strategies, the building takes a slightly different design approach. Instead of fluorescent sources, the building uses LED ambient lighting. The lighting controls are a mix of "manual on and automatic off," and "automatic on and automatic off" occupancy controls. A limited number of photosensors for automatic daylighting control are incorporated in conference rooms. The existing light switches and circuiting remain intact from the original building design. Subsystem monitoring results in Figure 77 show that Building 1219 is using approximately 22% of its energy on lighting. As with the HQ building, this suggests an aggressive lighting system design but not quite aggressive enough for net zero energy operation.

Since the Fort Carson new construction and retrofit buildings that were visited are on track for low energy lighting operation but show potential for improvement with respect to net zero energy goals (less than 10% building energy going to lighting), these building types were selected for study. Although the COF and TEMF prototypes show less lighting use than the HQ building, they were also selected for study due to their space type variety (e.g., offices, classrooms, and high bays). The DFAC was not visited or selected for further study, as its 4% building energy use for lighting shown in Figure 11 makes it the least lighting-dominated building of the available prototypes, due to its already well-implemented daylighting strategies and its high miscellaneous equipment loads.

Percentage of energy use attributed to the lighting systems gives an indication if the building is on the path toward net zero energy and if there is room for improvement, but does not provide much information on specific lighting system successes and failures. In addition to lighting energy use percentages aggregating the effects of electric lighting and control energy efficiency measures, they also need to be weighed against the energy use of other end-use systems such as miscellaneous equipment in each building.

In order to take a finer-grained look at Fort Carson lighting systems, NREL developed a monitoring plan to investigate the operation of specific ***electric lighting, daylighting, and lighting control*** strategies. This level of disaggregation required measuring electric lighting status (on or off), occupancy (occupant present or not), and illuminance (lighting quantity at the workplane in foot candles [fc]) for each space type. The monitoring plan details are given in the following sections, broken out by each lighting system component. The results of the monitoring are presented in the Research Results section.

Methodology

Electric Lighting Evaluation

A critical step in low-energy lighting system design is to reduce the installed lighting power density (LPD) for the times when electric lights must be used. In order to evaluate the current Fort Carson efforts with respect to net zero energy goals, NREL determined preliminary evaluation criteria:

- Installed lighting power efficiency measures should be 40% or more below code levels for low-bay spaces.
- To maintain occupant comfort, illuminance should adequately meet the task requirements (e.g., a minimum of 25 fc for general office/computer work) and should not create glare.
- The electric lighting should be compatible with lighting controls and other building systems.

The criteria were determined through a combination of literature review, experience, and sample calculations based on net zero energy building designs. While these criteria guided the creation of the test plan and served as a baseline for observations, they were only meant to be a starting point for the investigation. The criteria were refined and specified into best practices as the result of this research question where the need or potential for LPD reduction and/or improved lighting design strategies were observed.

A critical step in low-energy lighting system design is to reduce the installed lighting power density (LPD) for the times when electric lights must be used

In order to compare current Fort Carson conditions to the electric lighting criteria: LPD calculations for each space were performed; occupant comfort feedback provided by Pacific Northwest National Laboratory (PNNL) was reviewed; single-point-in-time illuminance measurements were taken. The following are specifics of the illuminance measurements.

- **Equipment type**: NIST calibrated Extech Instruments HD450 illuminance meter.
- **Equipment location**: Illuminance measurements were taken in representative locations including: perimeter offices in Buildings 1219, 9487, and 9420; high bay spaces in Buildings 9487 and 9486; daylight and non-daylight corridors; stairs; break rooms; restrooms; and conference rooms. Measurements were taken with and without electric lighting when daylight was present and the electric lights were manually controllable.

Daylighting Evaluation

In most climate zones, including Colorado Springs (where Fort Carson is located), daylighting is selected by optimization engines as a necessary building feature for net zero energy. The first step is to get the architectural elements of daylighting right. NREL determined evaluation criteria for a daylighting system are:

- Minimized fenestration-to-surface-area ratios such as 25%–35% for walls and 5% for roofs.
- Daylight sufficiency is targeted through the façade design, meaning that daylight should provide just the base level of light needed to perform most tasks in the space to prevent over-glazing of façades. A daylight sufficiency goal dovetails with the envelope recommendations given in Thermal Envelope Optimization. For most spaces, this means achieving 25 fc or less from daylight on a typical daylight condition, in the working zone.

- Maintained occupant comfort. For daylighting alone (without controls) the primary consideration is to mitigate glare potential. More specifically, this means preventing direct sun in occupants' field of view and maintaining a balance of daylight on the various surfaces in a given space.

- The daylighting should be compatible with lighting control and other building systems.

The criteria were determined through a combination of literature review and experience. While these goals guided the creation of the test plan and served as a baseline for observations, as with the Electric Lighting Evaluation Criteria, these criteria were refined and specified into best practices when the need or potential for envelope tweaks or different daylighting strategies were observed.

In order to compare current Fort Carson conditions to the daylighting criteria: fenestration-to-surface-area ratio calculations were performed; occupant comfort feedback provided by PNNL was reviewed; illuminance measurements were taken over a period of time that captured a variety of daylight conditions. The following are specifics of the illuminance measurements.

- **Equipment type**: Two LI-COR illuminance sensors and a Campbell Scientific data logger with battery power.

- **Equipment location**: The locations selected for placement of illuminance sensors was one representative COF high-bay space.

- **Measurement timeframe**: Sensors for the lighting research question were deployed in November 2012 through January 2013. Metering occurred for four to six months with interim data collection at one month after deployment to provide preliminary data for assessing existing and proposed lighting system strategies.

The daylight illuminance measurements were a lower priority than the occupancy and light switching data described in the following sections because daylighting models of key spaces were created using Radiance to provide a means for evaluating daylighting strategies. The illuminance measurements were primarily used for model validation and electric lighting control monitored data crosschecks but are not presented in the results or analysis of the Research Results section.

Lighting Control Evaluation

Lighting controls were the primary focus of the lighting research question since they represent a high potential for energy savings (an additional 50% beyond the 40% LPD reduction criterion) but also a high potential for implementation failure. Realizing energy savings after design is critical for net zero energy operation. NREL determined evaluation criteria for a daylighting system are:

- Electric lighting is on only:
  - during the time needed by the occupants.
  - in the location needed by the occupants.
  - to the quantity of light required by the occupant for the typical space task.
- The control interfaces are intuitive and engage occupants, and the control algorithms do not cause distraction or discomfort to the occupants.

Lighting controls were the primary focus since they represent a high potential for energy savings but also a high potential for implementation failure.

The criteria were determined from a passive design perspective used in NREL's net zero energy design and operation experience: electric lighting should only be turned on where and when needed. Again, these criteria were refined and specified into best practices as the result of this research question when the need or potential for control system design strategy changes, specification detail additions, or commissioning practice enhancements were observed.

In order to compare current Fort Carson conditions to the lighting control criteria, occupancy and light status (on/off) were logged to determine how closely the lighting load profile matches the occupancy profile, with respect to available daylight in each representative space. The following are specifics of the light status and occupancy measurements.

Equipment type: WattStopper IT-200 occupancy and light loggers.

Equipment location: The locations selected for placement of occupancy and light loggers were: Ten representative office spaces (five in Building 1219 and five perimeter offices in a representative COF); one representative COF high bay space; two representative HQ classrooms; two representative HQ open offices.

Measurement timeframe: All sensors for the lighting research question were deployed in November 2012 through January 2013. Metering occurred for four to six months with interim data collection at one month after deployment to provide preliminary data for assessing existing and proposed lighting control strategies.

The lighting control strategies were evaluated in tandem with appropriate daylighting and electric lighting control strategies. The analysis in the Research Results section primarily consists of using measured data to create occupancy profiles and use patterns for visual inspection, although a control module for Radiance also was used to determine the lighting control savings of improved daylight parameters. Occupant satisfaction was considered when comparing different buildings' control strategies.

NREL installed the monitoring equipment over the three-month period, and returned to the site intermittently during the test period to check equipment and take additional observation notes not recorded on the first site visit.

Research Results

The following sections summarize the observations from site visits and findings from the ongoing monitoring of Fort Carson lighting systems. The results are grouped by building type but refer to the electric lighting, daylighting, and lighting control criteria described in the previous section to qualitatively benchmark each building's performance. Typical spaces such as hallways, private offices, open offices, classrooms, and high-bay spaces are presented.

Results are presented by building and major spaces, including hallways, private offices, open offices, classrooms and high-bay spaces.

Office Retrofit (Building 1219)

The electric lighting and control system of Building 1219 was recently retrofitted as part of a larger building equipment transition toward LEED Silver performance. The new features include LED electric lighting fixtures and occupancy sensors in community spaces. The private offices line the outside of the building, with approximately two windows per office. A perspective of the north façade is shown in Figure 14.

Hallways

Figure 14 Image of Building 1219, North Façade

The hallways in Building 1219 create the central spine for the private offices and community spaces. While the hallways have little access to daylight, the LED electric lighting is reduced from 30 fc minimum horizontal illuminance, with all lights on, to 10 fc minimum, with every-other-fixture switched off as shown in Figure 17. A 10 fc minimum is still high with respect to the Illuminating Engineering Society of North America's (IESNA's) recommendation of 5 fc maintained for hallways.

While the maximum-to-minimum illuminance ratio of 7:1, distributed across the floor in the every-other-fixture scenario is higher than the IESNA recommendation of 2:1, occupants do not seem to mind since the lights were switched to this configuration during each site visit. Lighting fixture status was not measured in the hallways; it is not clear that the manual control of the lights in the hallway ensures that lights are completely off at night, when no occupants are present. The lessons learned from this space survey is that providing manual, every-other fixture control leads to lighting energy savings but the space design can be improved for occupant comfort and energy savings by reducing the installed power of each hallway fixture to achieve a more uniform 5 fc across the floor, and by providing automatic control to turn lights off at night.

Break Rooms

Each break room has access to daylight through a single window. During each site visit, the blinds were drawn shut in a majority of the rooms and the LED ambient lights were on. Based on spot checks, the ceiling-mounted occupancy sensors in each space do turn off the lights but the relatively high traffic in the areas and long timeout period (greater than ten minutes) keep the lights on much of the day as shown in Figure 15.

Figure 15 Images of Building 1219, Break Rooms

Spot measurements show the horizontal illuminance at counter level to be 70-100 fc, which is high compared to the IESNA recommendation of 30-50 fc. Restrooms are also overlit at 50-100 fc horizontal near the sink. This is likely due to the first-time implementation of LED fixtures where a one-for-one replacement can lead to over lighting in early operations (and possibly for the life of the LED fixture).

As with the hallway, a lesson learned from this space-type survey is that ambient lighting fixtures should be specified at a lower power output to maintain light uniformity but reduce illuminance and power density. Time of lighting use can be reduced by providing manual-on type occupancy, or vacancy, sensors so that the available daylight is used for basic kitchen tasks. Since glare is not a major occupant comfort concern in kitchen areas, the blinds can be removed, or specified to a lighter color to balance heat rejection and daylight admittance.

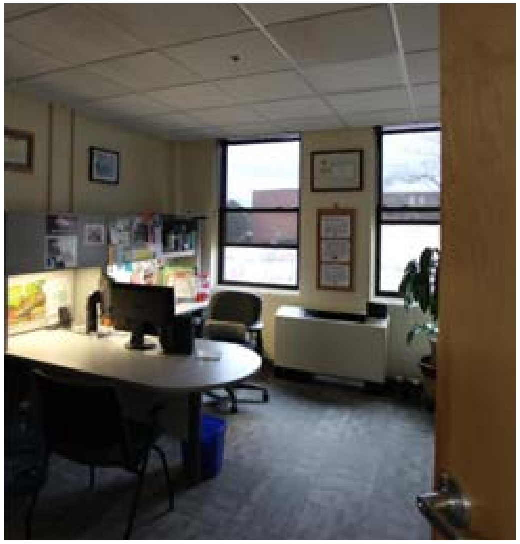


Figure 16 Image of Building 1219, Private Office

Figure 17 Image of Building 1219, First Floor Hallway

Private Offices

Figure 16 shows a typical private office in Building 1219 with the two overhead, ambient LED fixtures turned off and two linear fluorescent undercabinet fixtures turned on. The illuminance provided by each the ambient and task lights separately is approximately 50 fc. The private offices have a traditional on/off wall switch for the ambient lights. Each window has a full-length dark shade that is view preserving and lets in approximately 5% of the visible light that passes through the window.

Site visits revealed that most people do work with their ambient fixtures turned on—some people were noted as working with no electric lighting or only the task lights turned on as shown in Figure 16.

The following plots show the proportion of each hour that the office is occupied (in gray) and the proportion that the lights are turned on (in orange). This represents the typical lighting and occupancy schedule for the space type. If the lines were to overlap completely, this would imply that every time the space is occupied, the lights are on, and every time the space is unoccupied, the lights are off. Figure 18 shows a two-week light and occupancy pattern for private office 203. The office and dates are chosen to represent typical patterns during the data collection period. The data support a previous statement that at least some Building 1219 occupants work in their office without the ambient lights turned on (shown by the greater area under the gray, occupant line versus the orange, lighting line).

Hourly Lighting and Occupancy Schedules for 5/6/2013–5/20/2013, Private Office 203

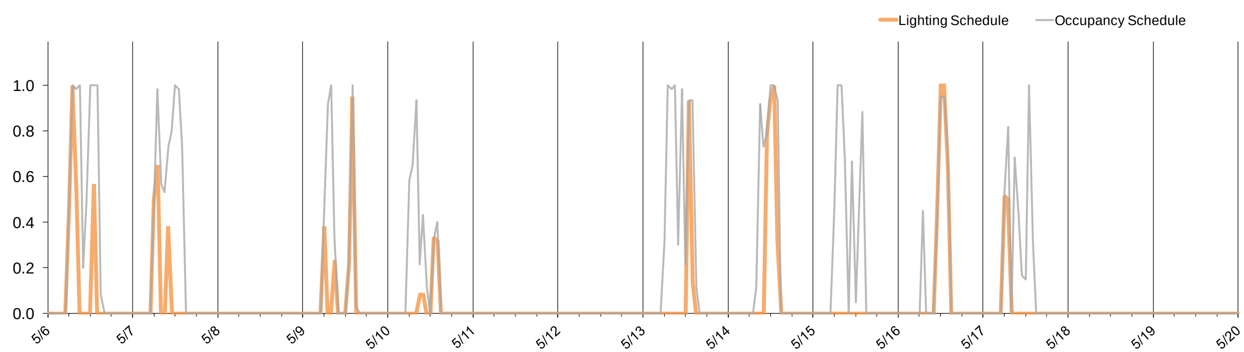


Figure 18 Measured Hourly Ambient Lighting and Occupancy Schedules for a Building 1219 Private Office

Figure 19 shows the private office lighting and occupancy schedules for the majority of the monitoring period. This display conceals some of the differences in lighting use and occupied hours but the general trend in each office can be seen: most occupants tend to use the lights when working but turn them off when they leave. Use of daylighting for working illuminance is not common. The three offices selected for display were those that had light loggers that were checked for accurate measurements during an interim site visit.

Hourly Lighting and Occupancy Schedules for 1/6/2013–5/19/2013, Private Offices 203, 208, and 216

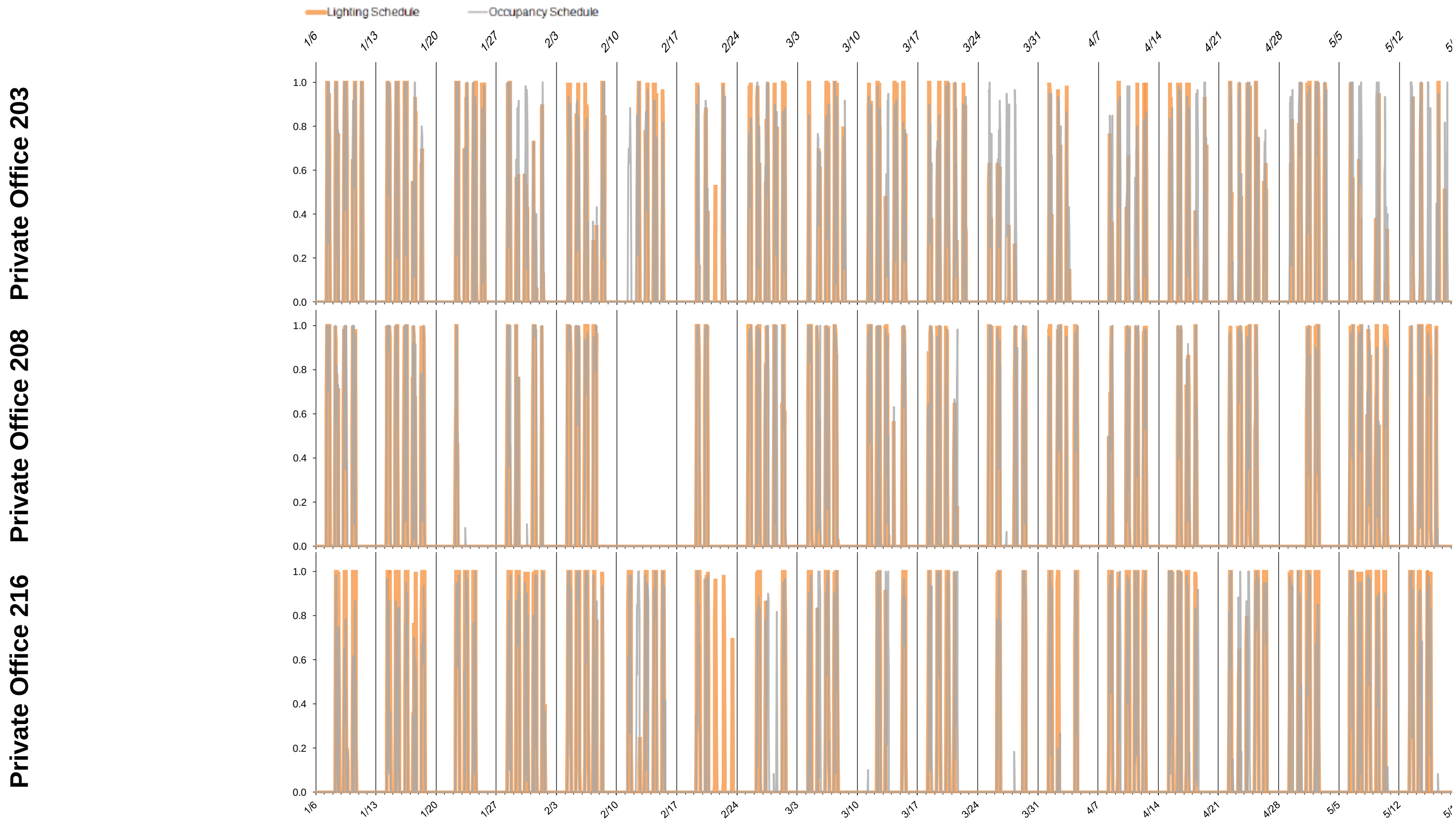


Figure 19 Measured Hourly Ambient Lighting and Occupancy Schedules for Building 1219 Private Offices

The charts show that the sensors are accurately measuring lighting and occupancy since the general patterns of lighting and occupancy track one another. It is possible that occupancy is not accurately tracked at all times since an occupant typing at the computer might not be detected by the WattStopper loggers. This potential inaccuracy in occupancy tracking does not affect energy saving numbers or light system recommendations.

Lessons learned from Building 1219 private office surveys are, again, that a one-for-one ambient lighting fixture replacement of LED for florescent should be evaluated for workplane illuminance rather than power equivalence. An ambient illuminance of 25 fc is sufficient for office tasks since task lighting is also provided. Designing to this illuminance will reduce the installed lighting power. Lighting energy, or time-of-use, can be reduced by engaging occupants to take advantage of the available daylight. Since occupants often forget to open blinds when they are involved in work, a passive strategy such as blinds that do not twist closed completely or shades that do not pull down completely will balance comfort/privacy and energy. Another consideration might be to move switches to the wall with the daylight feature. The data show that Building 1219 occupants are very successful at turning their lights off at night but there does not seem to be a culture or reminder for selecting daylight over electric lighting during the day. A daylighting analysis of a typical closed office is given in the Best Practices and Recommendations section, adding to the daylighting considerations discussed here.

Open Offices

The open offices in Building 1219 have high cubicle walls with a uniform pattern of ambient light fixtures set above, as shown in Figure 20.

The electric lighting is switched as one zone, leading to the noted conditions during site visits: (1) the perimeter electric lighting is on even when sufficient daylight is entering the windows as shown in Figure 21, and (2) makeshift solutions are used to alter the ambient illuminance for different occupant preferences as shown in Figure 22.

Figure 20 Image of Building 1219, Open Office

Figure 21 Image of Building 1219, Open Office Perimeter

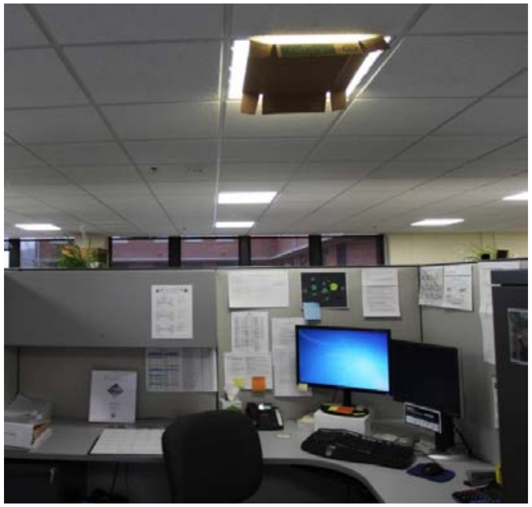


Figure 22 Image of Building 1219, Open Office Interior

The control system for the open office spaces consists of a ceiling-mounted occupancy sensor shown in Figure 23 and a wall switch shown in Figure 24. The occupant must turn on the wall switch for the occupancy sensor to trigger the ambient lights to go on. If the occupant forgets to turn off the switch then the occupancy sensor will do so, but in this case the lights will come back on automatically the next time someone enters the space. This is a typical occupancy sensor solution versus a "vacancy sensor" solution where the occupant must always choose to turn the lights on each time they enter a space.

Figure 23 Image of Building 1219, Open Office, Ceiling-Mounted Occupancy Sensor

Figure 24 Image of Building 1219, Open Office Manual Switch and Reminder Sticker

While the occupancy sensor solution is a cost-effective means to retrofit an open office with a traditional on/off switch, it often leads to unnecessary lighting-on time. As was shown for the private offices, the occupant training and awareness programs around turning lights off (e.g., light switch sticker in Figure 24) seems to be working since in monitored spaces, the lights are not left on once the occupant vacates the space for the day.

The lessons learned from the open office surveys are that finer-grained electric lighting zoning can reduce energy use due to daylighting and occupant preference, and lead to improved occupant comfort. Again, the ambient illuminance is high, at 50 fc, for an open office environment, which should provide closer to 25 fc without the added task lights.

New Company Operations Facility (COF, Building 9447)

Unlike Building 1219, Building 9447 is a new building that was designed and constructed initially for LEED Platinum certification. The building has private office and high-bay spaces, both of which are daylit using skylights and side lighting. The lighting control system has more automatic features as compared to Building 1219. The general strategy is that of true vacancy control where the occupant must turn on the lights on each entry to a space but the lights will turn off when no occupancy is detected. The front private office and rear high-bay modules are shown in Figure 25.

Figure 25 Image of Building 9447, Primary Façades

Private Offices

The private offices in Building 9447 each have two fluorescent troffers that provide 30–40 fc at the workplane. This illuminance is in line with IESNA recommendations for the space type.

The offices have prominent daylighting features. The perimeter windows are shaded by a louvered overhang and transom glass allows in borrowed daylight from the skylit hallway to the interior offices. These features can be seen in Figure 26. Note the difference between the overhang placement in the upper left versus upper right images. The upper right image is an interior view from the HQ building. The difference is the intent to divide the glass into daylight (upper) and vision (lower) glazing. While both solutions are helpful for reducing heat gain, neither is optimized for daylight quantity and quality.

Figure 26 Images of Building 9447, Private Office Components

The vacancy switch shown in the lower right corner is typical for the private offices. Figure 27 shows that the project documents specifically directed these switches to be programmed for vacancy operation, requiring the occupant to "opt-in" for electric light each time they enter the space.

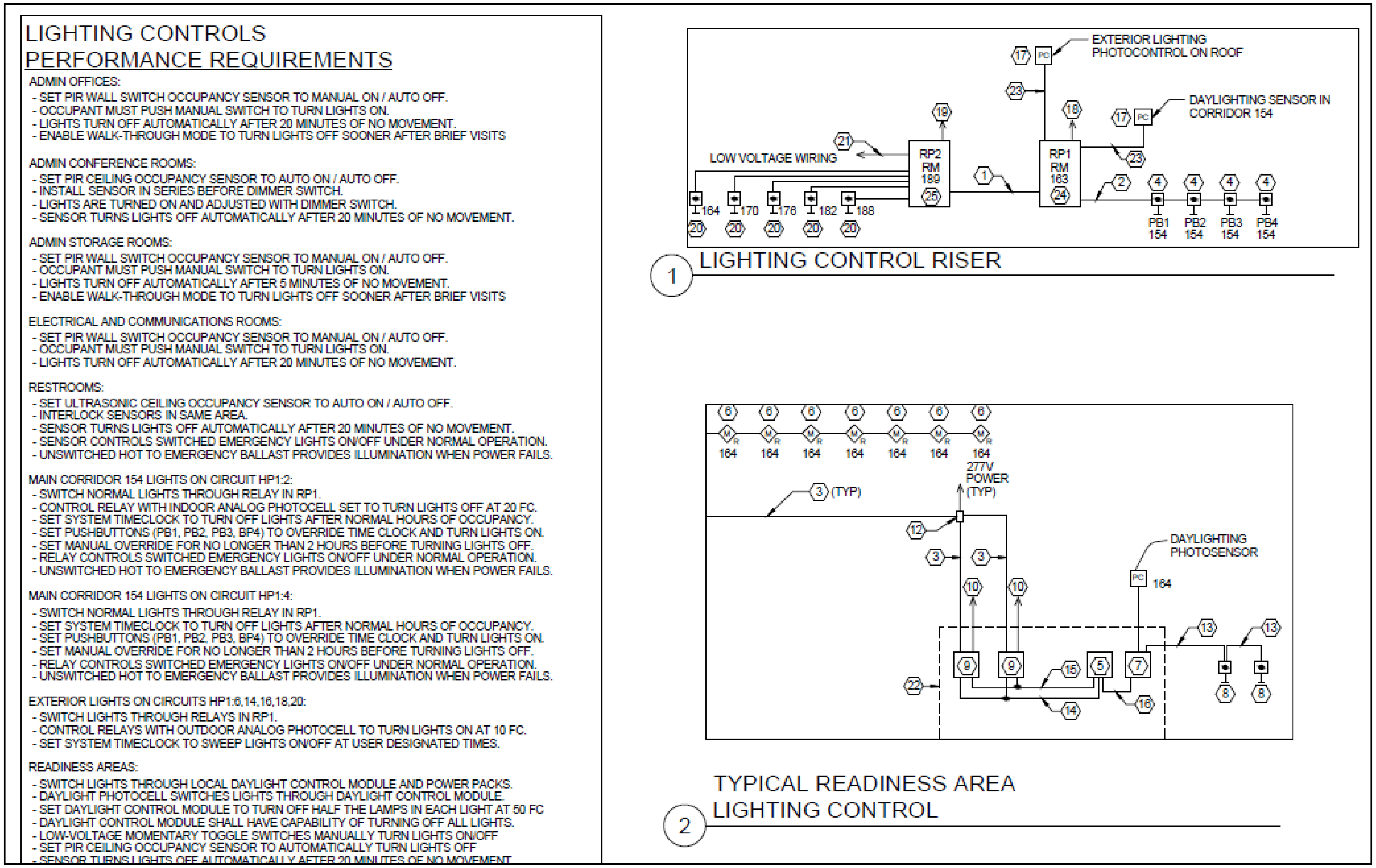


Figure 27 COF Lighting Sequence of Operations

Site visits showed that not all offices were set to vacancy control. It is not clear whether this was due to a lack of rigorous commissioning checks or after-occupancy changes. The switch settings are accessible by the occupant. Figure 28 shows that the vacancy specification is not meeting the net zero energy criteria of reducing electric lighting use while the space is occupied in response to daylight contribution. The electric lighting is on each time the space is occupied, regardless of daylight contribution (Office 101 is an interior office with transom glass facing the hallway).

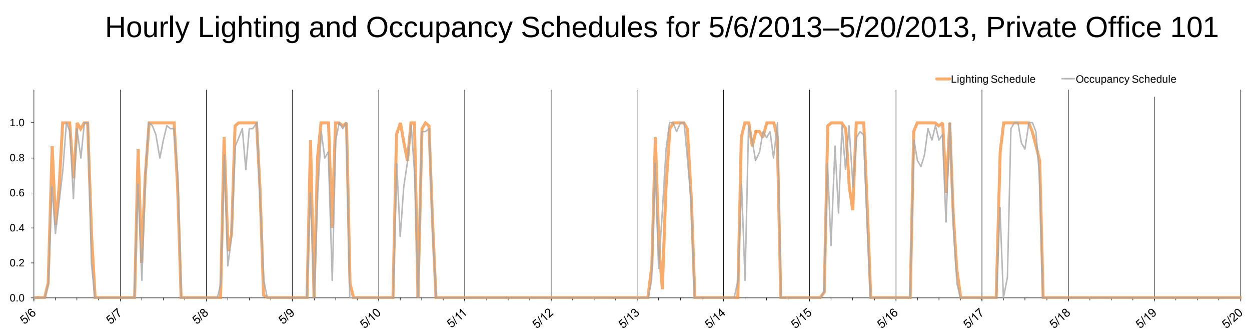


Figure 28 Measured Hourly Ambient Lighting and Occupancy Schedules for a Building 9447 Private Office

Hourly lighting and occupancy profiles for the monitoring period, shown in Figure 29 are meant to convey the high-level trend that ambient electric lighting is used when the spaces are occupied. Offices 101 and 106 are interior offices and office 119 is a perimeter office. Each office type has daylighting features yet the natural resource is not resulting in electric lighting energy savings. (The flat line from 2/2 to 4/14 is missing data. Although displayed, these flat values were not used for energy calculations).

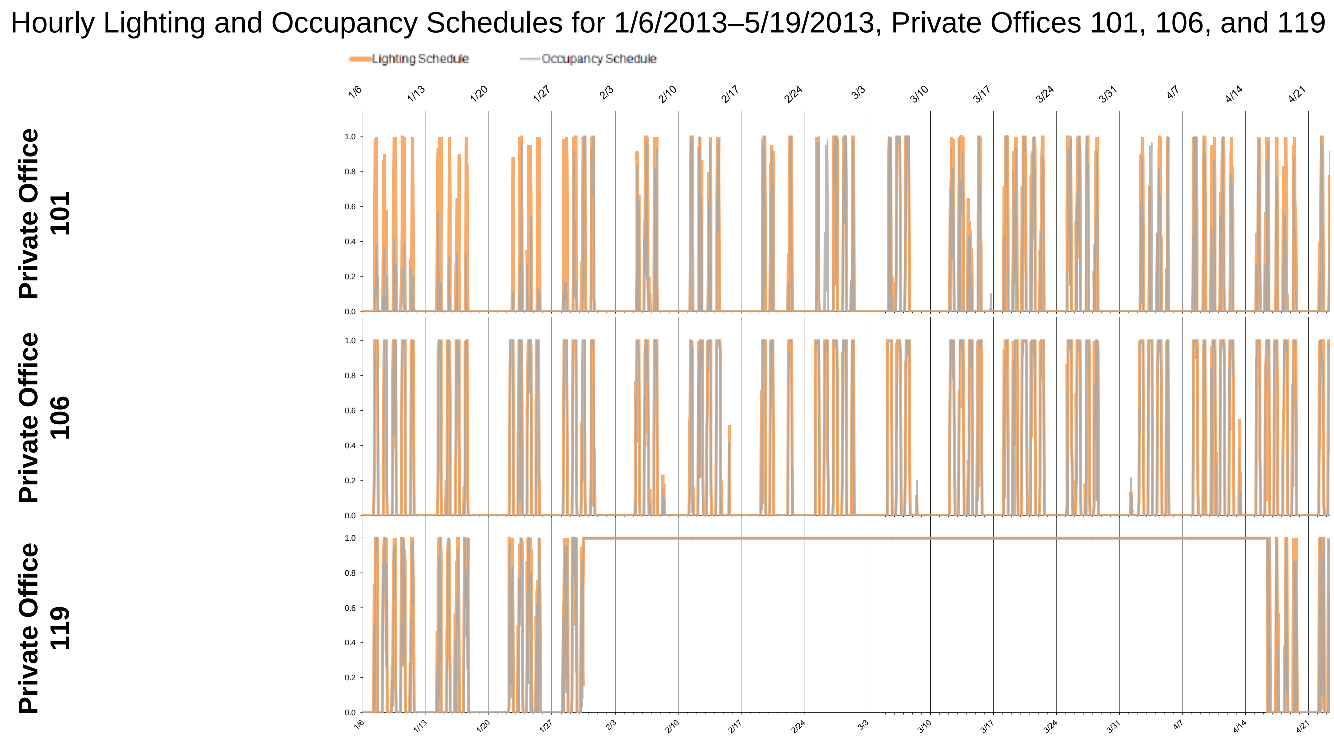


Figure 29 Measured Hourly Ambient Lighting and Occupancy Schedules for Building 9447 Private Offices

The plots show that the vacancy sensors are likely an energy saving feature since the lights are not left on at the end of the day. It is not clear from the lack of occupant switching, relative to Building 1219, that the lights would be turned off at night if the vacancy sensors were not installed.

The lessons learned from the COF private office survey are that the LEED requirements, particularly the Optimize Energy Performance credit, directed the design toward best practice electric lighting and lighting control features such as reduced LPD and vacancy lighting control. But the Daylight and Views credit, while apparent as a driver in the façade design, did not guide the result toward realized energy savings due to daylight since most office lights are on during the day when occupants are present.

High-Bay Modules

Figure 30 shows the skylights and vacancy sensor control system employed for a typical high-bay module. The daylighting system provides an average of 30 fc at the workplane for a mid-day, clear, Equinox sky condition. The electric lighting adds 30 fc to the workplane. The daylighting and electric lighting design are sufficient from a light quantity and quality perspective.

The lighting control system shown in Figure 30 looks different than the vacancy controls of the private office, although it functions in the same way. Ceiling-mounted occupancy sensors turn lights off if occupants forget—they are required to turn the lights on when they enter the space. The simple button interface (left image) does not seem to cause confusion based on observation of occupant interaction during the multiple site visits. The photocell (right) is mounted on the wall and switches the fluorescent troffers in two stages as daylight saturation reaches approximately 30 fc.

Figure 30 Images of Building 9447, High Bay Module Daylighting and Lighting Control Features

Figure 31 shows that the space is used without electric lighting (gray line only), substantiating the claim that the space meets the daylight sufficiency criteria for net zero energy. Conclusions regarding the lights being on when the space is unoccupied cannot be made since it was not possible to completely outfit the high-bay space with occupancy loggers. It is possible and likely that the space was occupied during most times that the lights are shown to be on.

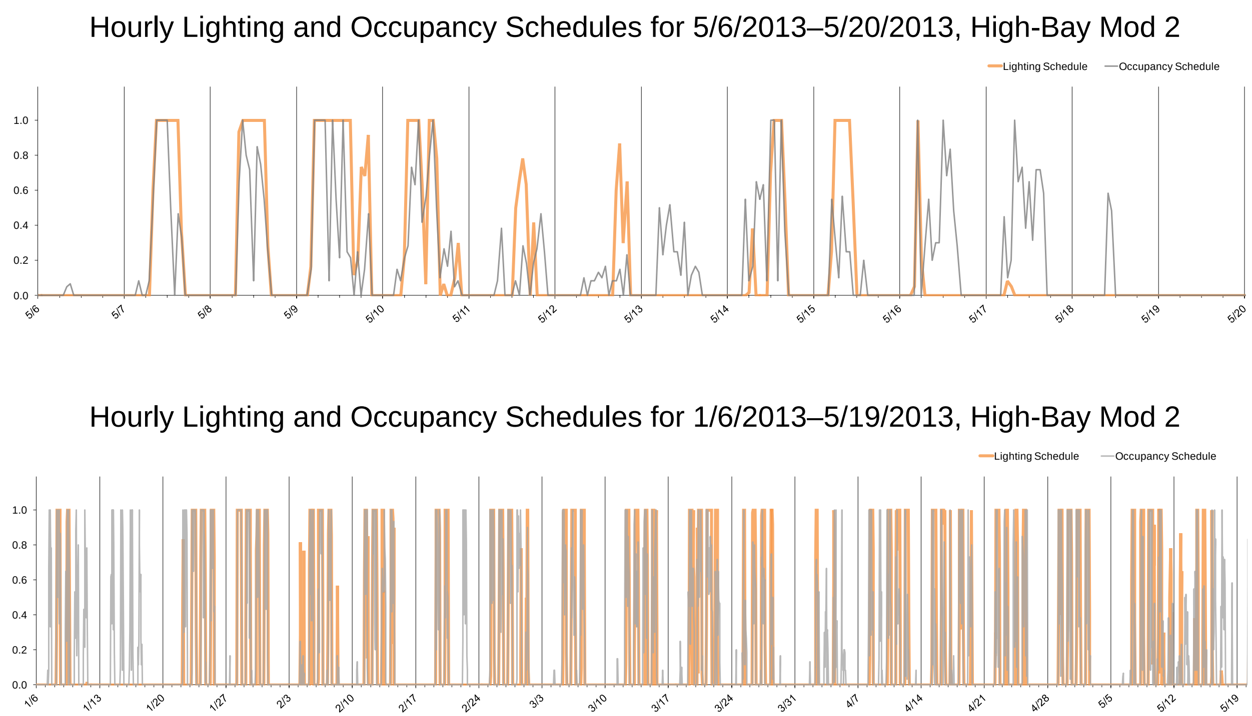


Figure 31 Measured Hourly Ambient Lighting and Occupancy Schedules for a Building 9447 High-Bay Module

New Brigade Headquarters Facility (Building 9420)

Like Building 9447, Building 9420 is a sustainably designed, newly constructed multi-use space. The primary space types in Building 9420 are private offices, open offices, and classrooms. The electric lighting is primarily fluorescent, with low lighting power densities and illuminance on par with IESNA recommendations. The lighting control system contains a mix of occupancy and vacancy sensors, classroom scene control (allowing one or more light fixtures in a space to be turned on/off/dimmed in groups to create different moods), and daylighting control.

Figure 32 Image of Building 9420, West Façade

Hallways

Figure 33 shows a mix of entry spaces and hallways. Each is lit with florescent fixtures. The images show an opportunity to take advantage of daylight or low illuminance requirements (5 fc for a hallway) to reduce the current lighting energy use.

Figure 33 Images of Building 9420, Shared Spaces

Open Offices

The open offices are similar to those of Building 1219 with high cubicle partition heights and a uniform grid of troffers for ambient lighting. The difference between the open office lighting scenarios is that some of those in Building 9420, shown at the top of Figure 34 are zoned so that the fixtures near the perimeter can be turned on automatically in response to daylight. This is not a universal design feature of the building, as shown by the lights on at the bottom of Figure 34. Opportunity exists for a more tightly integrated daylighting and lighting control system.

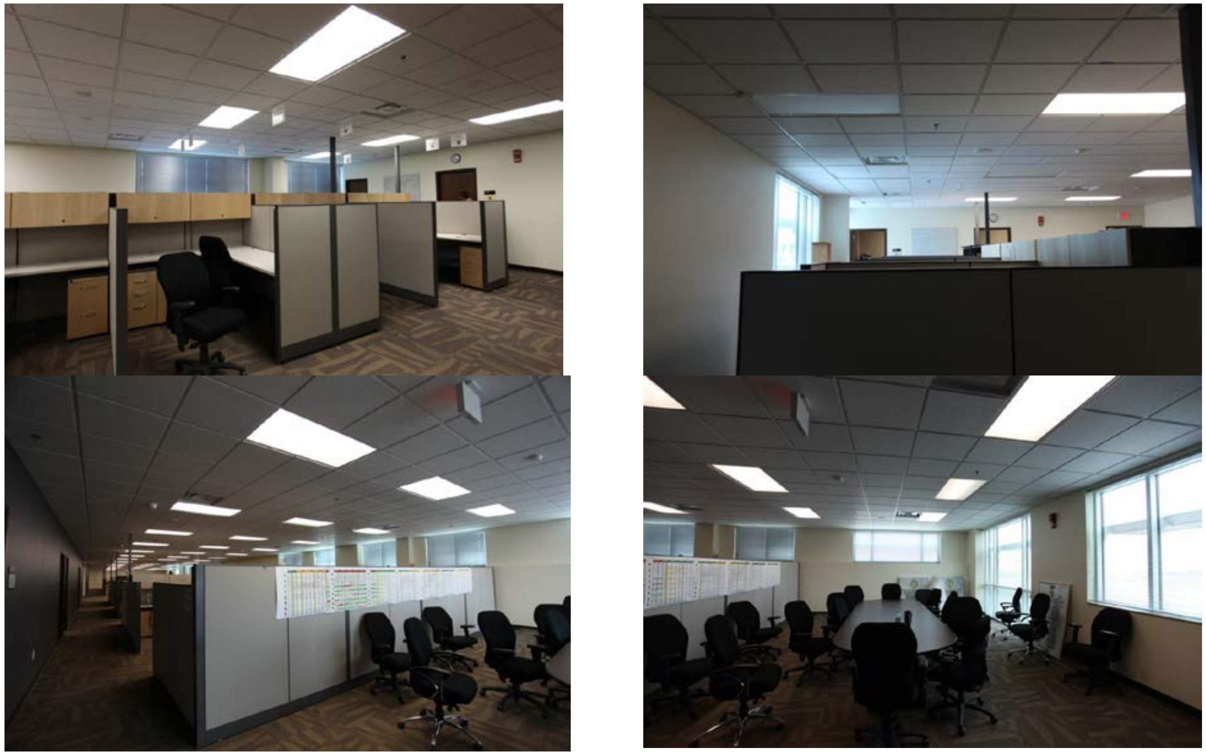
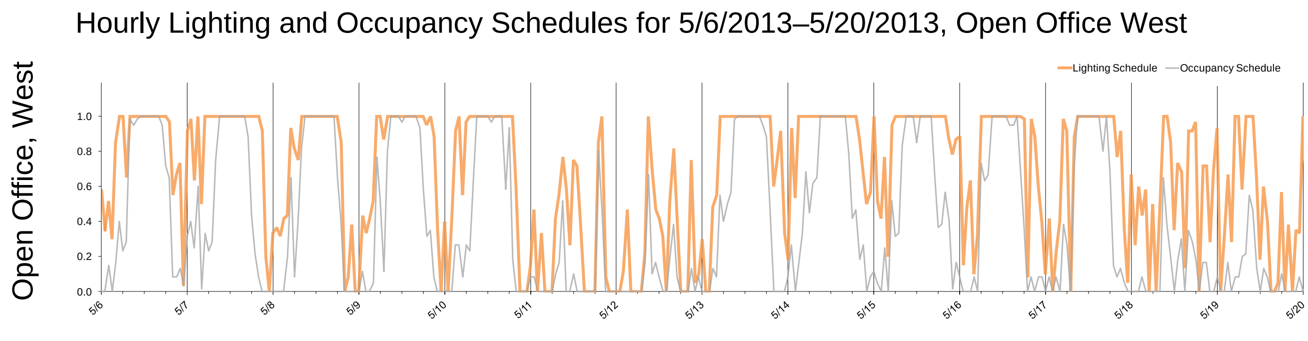


Figure 34 Images of Building 9420, Open Offices.

Figure 35 combined the lighting use of daylight controlled and non-daylight controlled electric lighting fixtures. The plots show that both the east and west offices have a heavy use of electric lights throughout the day and evening, and this trend does not differ between the west office that has perimeter windows and the east office that does not. While the afternoon and morning reduction of electric lighting is a good design result, allowed for by the ceiling-mounted vacancy sensors, there is opportunity to reduce electric lighting at night and to optimize the daylighting reduction for the space that contains windows.



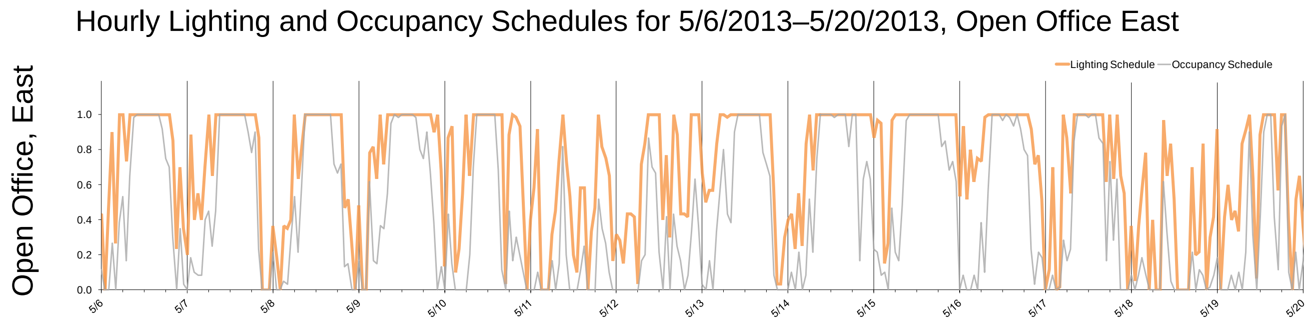


Figure 35 Measured Hourly Ambient Lighting and Occupancy Schedules for a Building 9447 High-Bay Module

Private Offices

Figure 36 shows the daylighting features of Building 9420's private offices. As noted in the private office discussion of Building 9447, the daylighting features do provide a view and opportunity for daylighting energy savings. But, the design solution does need to be optimized to prevent occupant overrides as shown in Figure 36 (center) and realized energy savings. A vacancy sensor is provided (bottom right), which is shown for comparison to the interface of Building 9447's vacancy sensors in Figure 26.

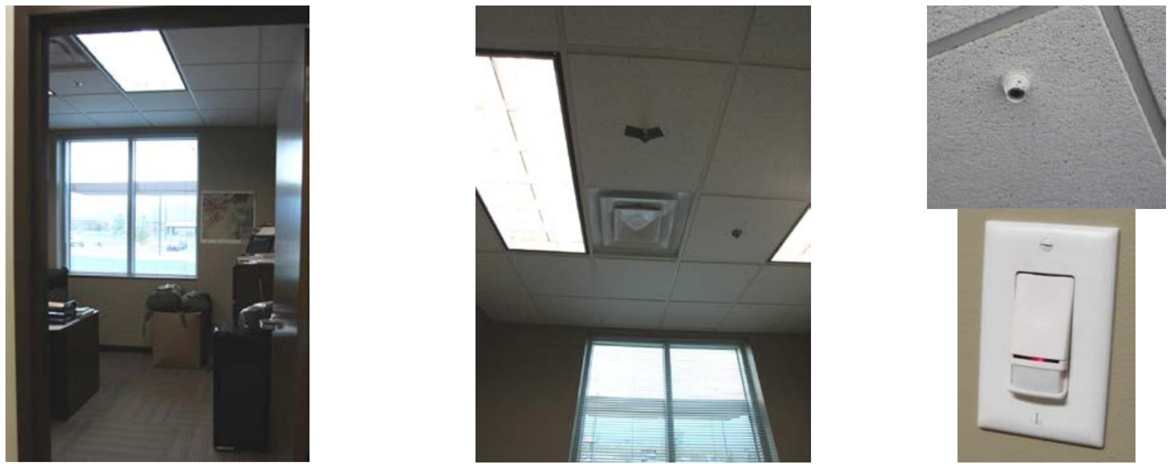


Figure 36 Images of Building 9420, Private Offices

Classrooms

Figure 37 shows a typical classroom lighting configuration in Building 9420. The electric lighting has three scenes for different teaching scenarios, which are manually controlled using the switches shown to the right. No occupancy or vacancy control exists.

Figure 37 Images of Building 9447, Classroom

The classrooms are not daylit, which is a wise energy choice (assuming not all spaces can have access to daylight) looking at the relatively low occupancy rate compared to other spaces in Building 9420. Figure 38 shows that the lights are often left on when the space is unoccupied so that the lighting energy use is twice the occupancy rate.

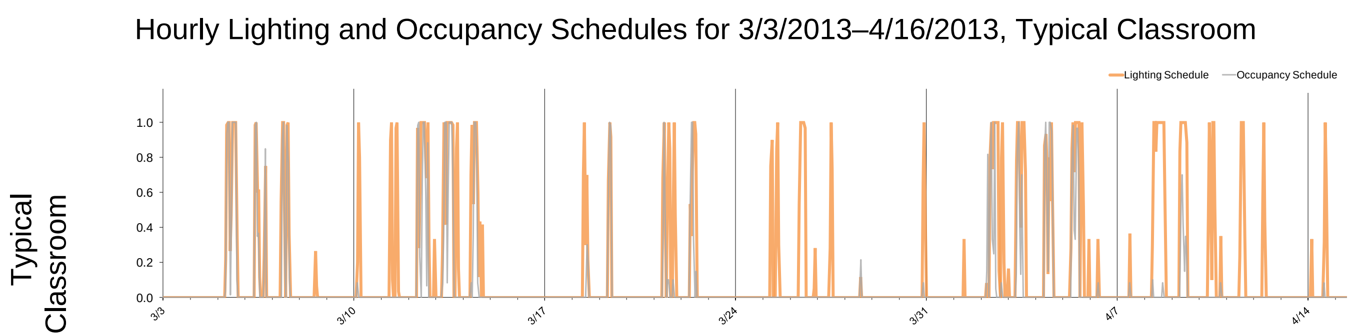


Figure 38 Measured Hourly Ambient Lighting and Occupancy Schedules for a Building 9420 Classroom

Figure 39 shows two of the additional control interfaces that were found in Wilderness Road building conference rooms. The occupancy and lighting patterns can be assumed to be similar to the Building 9420 classroom.

Figure 39 Images of Building 9447 and 9420, Conference Room Control Interfaces

Best Practices and Recommendations

The Army has made important steps toward realized energy savings by requiring LEED Silver and Gold certification in new construction and retrofits, and by incorporating net zero energy goals in recent new construction projects. The value of this lighting research question is in energy performance assurance: expanding on the currently used best practices to ensure that the design intent and predicted energy savings are being achieved in operation. Since LEED focuses on views and installed LPD, it is not always clear that even the most sustainably designed buildings, such as to LEED Platinum certification, show high performance in terms of occupant satisfaction and lighting energy use. This gap between intent and performance can widen at each stage of design and operations. The space surveys showed that Fort Carson's lighting systems are well designed, well implemented, and performing to most of the qualitative, net zero energy criteria outline in the Methods section. It is apparent that some gaps do exist though, in the energy performance and occupant acceptance needed to repeatedly produce and operate net zero energy buildings. The primary opportunities noted were:

- Retrofit space electric lighting can be reduced in power to achieve 25 fc.
- Retrofit space lighting control can all be vacancy type where occupants must manually turn lights on when they enter a space.
- All spaces' electric lighting zoning can be finer grained to take advantage of perimeter daylight and occupant preferences.
- All spaces' daylighting features can be more tightly integrated with occupant habits and electric lighting control to realize the predicted/expected daytime lighting energy savings.

Daylighting features can be more tightly integrated with occupant habits and electric lighting control to realize the predicted/expected energy savings.

These qualitative observations are evaluated in a more quantitative way in the following section, and then translated to best practices for Fort Carson and GSA.

Recommendations for Fort Carson

The recommendations for Fort Carson lighting systems are broken out by space type. Example analysis is shown to support recommendations made. The savings are extrapolated for building types to show potential energy savings for recommended solution sets.

Hallways

Reduce the installed LPD by targeting a 2:1 minimum-to-maximum uniformity ratio with a minimum of 5 fc between fixtures. Incorporate automatic control in all hallway spaces to either turn on/off with occupancy or sweep off at night. With automatic control, consideration must be given to the entry points and sensor or override switch location. A vestibule light should serve as an egress fixture to guide occupants entering the space to the sensor or switch that will turn the hallway lights on. Provide sequential pathways of light to ensure safety and comfort but do not continuously light all paths when occupants are not present.

Private and Open Offices

The electric lighting recommendation for the Fort Carson offices is to use LED ambient lighting fixtures but design to 25–30 fc. Currently, the Building 1219 office lighting power density is similar to that of other Wilderness Road office spaces but the illuminance is much higher. In other words, while Building 1219 is efficiently lit with LEDs, it appears overlit, providing further energy reduction opportunities. An LED fixture can be selected with lower light output, which will result in approximately proportionate reduction in electric lighting energy use.

A primary daylighting recommendation for all perimeter office spaces is to refine the daylight and vision glazing split. The overhang should sit above the vision glazing (<7.5 ft above the floor) and below the daylight glazing (>7.5 ft above the floor). The daylight glazing should be evaluated for glare potential with respect to the office furniture layout. If only brief periods of direct sun (<15 minutes) strike vertical surfaces in the space then consider leaving the daylight glazing without a glare treatment. Move the blinds or shades to the same elevation as the exterior overhang. If glare from the daylight glazing is deemed a potential problem, use daylight blinds, which are highly reflective and static, at the daylight glazing. The exterior shade and dropped blind configuration is shown in Figure 40.

Figure 40 Building 9420 open office section (left) with the blind head height at the top of the vision glazing (right)

Figure 41 Open Office Image (top left) and Radiance Renderings of base case blinds closed (top right), full blinds partially open (bottom left), and vision glazing blinds only (bottom right)

The workplane illuminance results for each scenario are shown in the following 4-ft by 4-ft grids. The typical grid represents a 40-ft by 36-ft partial floor plan of the space where the window wall is to the right of the grid.

Scenario	Annual Average Workplane Illuminance [fc]									
Blinds fixed :	1	1	1	1	1	1	2	2	2	2
	1	1	1	1	1	2	2	2	2	2
	1	1	1	1	1	2	2	2	2	3
	1	1	1	1	1	2	2	2	2	3
	1	1	1	1	2	2	2	2	3	3
	1	1	1	1	2	2	2	2	3	3
	1	1	1	1	2	2	2	2	3	3
	1	1	1	1	2	2	2	2	3	3
	1	1	1	1	1	2	2	2	3	3
Full blinds, ideal occupant :	6	6	7	7	8	9	10	10	10	10
	7	7	8	8	9	10	12	13	16	17
	6	7	8	9	10	11	13	16	19	23
	7	7	8	10	11	13	15	19	22	27
	7	8	9	10	11	14	17	20	25	30
	8	8	9	10	12	14	17	20	26	29
	8	8	9	10	12	14	17	20	26	30
	7	8	9	10	11	14	16	21	26	33
	7	8	9	10	11	13	16	19	24	28
Partial blinds, typical occupant :	11	11	11	11	11	12	13	12	12	11
	56	12	11	12	12	13	13	14	14	15
	57	12	12	12	13	14	15	16	17	17
	12	12	12	13	13	15	16	17	18	19
	57	12	12	13	14	15	17	18	20	22
	57	12	13	13	14	15	17	19	20	21
	12	12	12	13	14	15	17	19	21	22
	13	12	12	13	14	15	17	19	21	23
	12	12	12	12	13	14	16	18	20	21

(The window wall is on the right side of the page.)

The annual average light output for each office daylighting scenario is shown in Table 13. If the daylighting control system were ideally commissioned, the light output translates to annual energy use.

Table 13 Office Daylighting Alternatives, Light Output

Scenario	Annual Average Light Output
Blinds fixed	100%
Full blinds, ideal occupant	75%
Partial blinds, typical occupant	36%

In addition to the daylighting control tuning that would be needed to match the electric lighting use with the daylight resource as described in the previous table, additional control changes are conservatively estimated to reduce electric lighting use by 10%, based on case studies and the unnecessary on-time determined using the occupancy and light logging data. The control recommendations are to:

- Add bi-level control to all ambient light fixtures through multi-level ballast control or re-circuiting the fixtures. Change the control system to always turn on the lowest level of ambient lighting first, and require the occupant to use the control interface again to get the maximum ambient light output.

- Add a “walk-through” or security circuit to all open offices. This circuit should contain about 10% of the ambient lighting fixtures, or this can be the emergency or egress circuit depending on life safety system configuration. Add a control interface that allows the “walk-through” lights to be turned on for ten minutes with an automatic sweep off and label the switch for nighttime use.

Classrooms

The addition of occupancy sensors to the classrooms can ensure that lights turn off when the space is unoccupied, reducing the annual lighting energy use in half.

Community Spaces

Add daylighting control or re-commission daylighting control for fixtures near glazed entries, or glazed community spaces.

High Bay Modules

The high-bay modules are performing well. Skylight specification, placement, and size are adequate from a daylighting perspective. Electric lighting and lighting controls are performing well. No specific improvements are needed—the general strategies of the space type are included in the best practices.

Solution Sets

Using the solutions outlined in the previous sections paired with the energy savings potential calculated from the simulation results and the monitored data, space-by-space energy saving potential versus an ASHRAE 90.1 2007 baseline are given in Table 14, Table 15, and Table 16. Private offices, open offices, classrooms, and high bay spaces are selected for numerical analysis.

Table 14 gives the code-allowable LPD and assumed percentages of time lights are on (on-time) considering code requirements to turn lights off when occupants are not present. A 50% on-time is a conservative estimate for the energy savings calculations to follow since some of the spaces do not have automatic off mechanisms for nighttime reduction, such as the classrooms. The last row in the table translates the code allowances to energy use intensity values for comparison in the following tables.

Table 14 Solution Sets, ASHRAE 90.1 2007 Baseline

	Private Office	Open Office	Classrooms	High Bay
Code LPD [W/ft2]	1.1	1.1	1.4	0.9
Electric lighting on time [%]	50%	50%	50%	50%
Annual lighting energy use [kWh/sf/yr/space]	4.82	4.82	6.13	3.94

Table 15 shows the lighting power density and on-time for each space type. The LPD was derived from reflected ceiling and electrical plans, and the on-time was derived from the light logger data. The highlighted row shows the percent reduction of current Fort Carson lighting system energy use versus the code allowance shown in Table 14. The results reinforce the qualitative observations that Fort Carson buildings, and current GSA lighting best practices, rooted in LEED credits, are successful at producing real energy savings. Potential does exist, though, to become more aggressive in design and operation to realize the 75% lighting energy reduction goal for net zero energy readiness. The greatest potential exists in the open offices, which show the lowest LPD and lighting control reductions.

Table 15 Solution Sets, Current Lighting System Performance

	Private Office	Open Office	Classrooms	High Bay
LPD [W/ft2]	0.83	1.1	0.66	0.85
Electric lighting on time [%]	25%	33%	25%	15%
Annual lighting energy use [kWh/sf/yr/space]	1.83	3.18	1.45	1.12
Lighting energy savings versus code [%]	62%	34%	76%	72%

Table 16 takes the solutions described in the previous sections (listed in the first three shaded rows), and assigns LPD and light energy use reduction values that are known possible from NREL's experience operating net zero energy buildings, and substantiated through literature review and crosscheck calculations.

Table 16 Solution Sets, Potential Lighting System Performance

	Private Office	Open Office	Classrooms	High Bay
Electric lighting strategies	LED lighting to 30 fc	LED lighting to 30 fc	-	-
Daylighting strategies	Open daylight glazing	Open daylight glazing	-	-
Control strategies	Perimeter daylight control	Perimeter daylight control, "walk-through" and dual-level ambient fixture zoning	Occupancy sensors and dual-switching for ambient lighting	-
LPD [W/ft2]	0.5	0.66	0.66	0.85

	Private Office	Open Office	Classrooms	High Bay
Electric lighting on time [%]	15%	17%	13%	15%
Annual lighting energy use [kWh/sf/yr/space]	0.67	0.95	0.72	1.12
Lighting energy savings versus code [%]	86%	80%	88%	72%

These savings are possible with control system and daylighting element changes, and with an aggressive re-commissioning plan. A typical COF can see lighting energy savings of 75% with the measures outlined in this section; typical HQ building will see 80% lighting energy savings, extrapolating the space-by-space savings to the building footprint. The net zero energy criterion of 75% lighting energy savings versus an ASHRAE 90.1 2007 baseline can be achieved when the best practices given in the following section are considered early in the building planning and design process.

Best Practices for Federal buildings

> Translate a percent energy savings goal, such as 75% versus ASHRAE, to a lighting energy use intensity goal.

For the early planning and design, the lighting best practices determined through or corroborated by this project are:

Daylighting

- Place overhangs on south and west glazing. Do not put overhangs on north glazing.
- Position blinds at the vision glazing top mullion instead of at daylight glazing top mullion.
- Use daylight blinds instead of traditional blinds or shades to block glare from glazing higher than 7.5 ft above the floor.
- Use transom glass at the inner wall of most perimeter spaces. Even a small amount of light such as 5 fc is often sufficient for tasks such as printing, taking lunch out of the break room refrigerator, or picking something up from a desk.

Electric Lighting

- Fine tune design and delivered illuminance to 25–30 fc in all working spaces.
- Use a task-ambient lighting strategy with multiple layers of ambient lighting and multiple zones so that the low-illuminance occupant preference is the base case and others must “opt-in” for more light.

- Write or plan the emergency fixture specification to have an emergency relay instead of battery backup to create security or walk-though circuits and allow for daylighting control of all fixtures.
- Use low partition heights and light interior surface color to reflect light and create bright vertical surfaces for a bright feeling room at 30 fc.

Lighting Control

- Use vacancy sensors in all locations so that occupants must choose to switch lights on even if they have left the space for just a few minutes.
- Consider dimming fixtures where appropriate to prevent the occupant distraction often caused by switching schemes.
- Consider using a central lighting control system that can be connected to other central control systems for continuity of operations across a campus and for ease of re-commissioning to maintain the designed energy savings.
- Use consistent and intuitive control interfaces across campuses so that transient occupants can easily learn and cannot disable commissioned systems
- Require that a detailed sequence of operations be produced by the lighting designer and electrical engineer, and require that this document be the basis of lighting commissioning.
- Translate a percent energy savings goal, such as 75% versus ASHRAE, to a lighting energy use intensity goal. Require that the lighting designer substantiate the design and that the commissioning agent verify that the goal is being met in early operations. This single step is the key to moving the discussion presented in this document to realized energy savings in operations.

The lighting system performance of Fort Carson is well designed and performing, **already nearing 50% annual lighting energy savings versus an ASHRAE 90.1 2007 baseline**. The broad-scoped investigation presented in this report allowed for investigation of the actual operational patterns of a high performance design. The results show that there are changes that can be made to the existing buildings' electric lighting, daylighting, and control systems that will allow for even deeper lighting energy savings than are currently being achieved. The realization of 75% energy savings versus code will require further space-by-space design analysis that accounts for system cost. Case studies such as NREL's Research Support Facility have shown this level of savings possible when best practices are considered early in design and validated in design and operations.

Fort Carson's lighting system performance is well designed and performing, already nearing 50% annual lighting energy savings.

1.4. Net Zero Retrofit Optimization

Purpose

The high level purpose of the net zero retrofit optimization was to demonstrate the feasibility of achieving net zero energy performance within the constraints of a retrofit construction project. Considerable analysis has been done on lifecycle cost-based integrated design for commercial new construction. However, retrofit projects have a number of unique constraints that limit the applicability of many new construction integrated design best practices. The Fort Carson net zero retrofit optimization was designed to characterize the aspects of retrofit projects that make them unique, and build a framework around that characterization that would allow retrofit project teams to accurately analyze retrofit efficiency packages from a lifecycle cost perspective.

Research Question

What set of efficiency solutions are available at the optimal energy cost lifecycle for common retrofits?

Building 1219—an office building that had been retrofitted from former barracks at Fort Carson—was used as the reference point for this analysis. Efficiency measure selection and design recommendations were tailored to the basic architectural characteristics of Building 1219 (size, shape, orientation, existing exterior constructions, etc.). By building the analysis around Building 1219, we ensured that outcomes from the retrofit analysis could be used to inform future Fort Carson renovations (particularly for the campus buildings similar to Building 1219).

We did not explicitly model the Building 1219 retrofit. The reference, or baseline, model for this analysis was designed to capture the fundamental characteristics of Building 1219 (geometry, space types, layout, use patterns, etc.), as well as the minimum performance requirements of ASHRAE Standard 90.1-2007. Accordingly, we did not incorporate any

Building 1219 retrofit strategies (Light Emitting Diode [LED] lighting, high efficiency boilers, etc.) into the baseline model that go beyond the minimum requirements of the ASHRAE Standard. However, we did use the Building 1219 retrofit strategies as a starting point for the development of a high efficiency retrofit package; many of the candidate efficiency measures for our optimization analysis align closely with measures currently implemented in Building 1219. In cases where candidate efficiency measures were modeled after implemented retrofit strategies, we detail that relationship and explain any recommended modifications.

> The Fort Carson net zero retrofit optimization was designed to analyze retrofit efficiency packages from a lifecycle cost perspective.

Methods

The following subsections detail the methodology used to construct and execute the Fort Carson net zero retrofit optimization. There are two key aspects to the methodology:

1. the design methodology used to select candidate efficiency measures; and
2. the simulation methodology used to evaluate the candidate efficiency measures and present the results of that analysis from a lifecycle cost perspective.

Design Methodology

Accounting for Retrofit Constraints

First and foremost, we limited our analysis to efficiency measures appropriate for a retrofit project. Retrofit projects are typically constrained in a number of ways, including:

1. **Footprint.** An existing building's basic shape and orientation are more or less fixed. Any serious modifications to shape and orientation would likely fall under the category of new construction. In a new construction scenario, a building's shape and orientation can be specified to maximize the benefits of many efficiency measures (passive solar design, daylighting, heating, ventilation, and air conditioning [HVAC] design, etc.). Accordingly, the potential benefit of certain efficiency measures may be limited in a retrofit scenario due to shape and orientation constraints.

2. **Exterior Constructions.** These include exterior wall constructions, roof constructions, and fenestration constructions, as well as fenestration placement. While it may be possible to completely replace existing exterior constructions in a retrofit scenario, it is much more likely that existing constructions would be modified (adding-on as opposed to replacing). Window construction replacement is relatively noninvasive and may make sense in certain scenarios (however, it will be much more expensive to replace windows in a retrofit scenario than in a new construction scenario, where there are no removal costs and window construction upgrades can be evaluated using incremental costs). Window size or placement modifications are much less likely (as they would require significant modification to the existing exterior wall constructions). Again, these constraints can affect the potential impact of a number of efficiency measures (e.g., daylighting).

Candidate Efficiency Measures

For our analysis, we designed candidate efficiency measures to account for these practical constraints. We also emphasized efficiency solutions that are simple and passive (require limited facility manager or occupant intervention, minimize long-term maintenance requirements, do not rely on complicated controls, etc.). We believe this to be good design practice in general, but even more important for retrofit scenarios, where retrofit technologies and strategies need to work within the framework established by the existing building design (construction, layout, systems, etc.). Many of the candidate efficiency strategies are modeled after strategies that were employed in the renovation of Building 1219. Candidate efficiency measures are described below. Measure costs properly account for the construction constraints (e.g., existing equipment removal and disposal) of a retrofit scenario. Much of our measure cost data came from equipment manufacturers, equipment distributors, or RS Means. Other costs were estimated by industry experts (HVAC) or National Renewable Energy Laboratory's (NREL's) in-house technology experts (lighting, plug loads). The detailed performance and cost assumptions that NREL used to develop candidate efficiency measures for modeling is provided in Appendix C.

Candidate efficiency measures were designed to account for practical constraints

1. **Lighting Power Density (LPD) Reduction.** Lighting equipment replacement is a proven retrofit measure. We considered two LPD reduction scenarios: (1) replacing existing fluorescent fixtures with 36W LED fixtures (corresponding to an LPD of 0.58 W/ft2); (2) replacing existing fluorescent fixtures with 24W LED fixtures and then supplementing the ambient fixture output with 6W LED workstation task lights (corresponding to an LPD of approximately 0.40 W/ft2). Building 1219 was retrofit with LED lighting technology, but with higher wattage fixtures and tighter grouping (resulting in an LPD of around 0.75 W/ft2).

2. **Improved Lighting Controls.** Upgrading lighting controls is also a common retrofit strategy, especially in cases where control upgrades are combined with the replacement of existing lighting equipment. We considered two lighting control improvements: (1) adding vacancy sensors to enclosed offices to turn off lights when spaces are unoccupied; (2) designing lighting (egress base lighting and vacancy sensor-controlled primary ambient lighting) in common areas to take advantage of the fact that the vast majority of tasks completed in those areas (corridors; open conference and printer areas between enclosed offices) require only low levels of light. The Building 1219 retrofit controls the lighting for open conference and printer areas using occupancy sensors. This strategy ensures that lights are off at night when the building is unoccupied but does not take advantage of the fact that most occupants do not need the full ambient lighting when passing through those spaces.

3. **Daylighting Open Offices.** Depending on building orientation, daylighting can also be a popular retrofit strategy (again, especially in cases where it is combined with other lighting retrofits). We considered daylighting for all open office areas (including large open conference rooms) with direct access to daylight through existing fenestration (all such spaces in Building 1219 meet this criterion). The impact of daylighting depends heavily on the commissioning process (verification of control strategies and tuning of set points contribute heavily to system performance); accordingly, commissioning makes up a substantial portion of our estimated cost for implementing daylighting. The Building 1219 retrofit utilizes dimming ballasts and photosensor-controlled daylighting in open conference rooms; however, its impact is limited by the design of the system (sensor placement, in particular).

4. **Plug Load Reduction and Controls.** Plug load reduction and controls are also very common retrofit measures (plug load equipment is typically purchased as new in retrofit scenarios). We considered three plug load reduction and control measures: (1) opting for controllable plug strips (which turn off automatically after 11 hours of use) over standard plug strips for all office workstations (this measure is equivalent to the office plug load control strategy currently utilized in Building 1219); (2) opting for high

efficiency computing equipment (mini desktops and high efficiency LED monitors) over standard efficiency equivalents; (3) reducing support equipment (printers, scanners, fax machines, elevators, etc.) plug load density by 25%. For the support equipment power reduction strategy, we conservatively assigned a whole-building budget of $50,000. In reality, however, there are many strategies that can be employed to make this a low- or no-cost measure (replacing multiple pieces of equipment with multi-function units; consolidating office support equipment [including eliminating redundant equipment at individual workstations]).

5. **Envelope Improvements.** We identified a set of envelope measures that work within the practical constraints imposed by the existing envelope of Building 1219 (prior to retrofit). As mentioned previously, many envelope improvements may not be practical in a retrofit scenario (from both cost and construction standpoints). Appropriate strategies are likely to be project dependent. However, our proposed strategies are built around conservative assumptions (existing exterior wall and roof constructions cannot be replaced; windows can be replaced but not resized or relocated). We considered four envelope improvement strategies: (1) adding exterior roof insulation and a white roof membrane (on top of the existing roof construction, as was done for the Building 1219 retrofit); (2) adding spray foam insulation to the interior side of exterior walls (which requires the exterior wall construction be finished with drywall on the interior side); (3) adding window insulation modules to the interior of existing window constructions to reduce heat transfer and infiltration; (4) replacing existing windows with electrochromic windows (a strategy that eliminates the need for window shades, which rely on occupant interaction to positively impact building energy consumption).

6. **HVAC Modification.** We considered a single, holistic, HVAC improvement: replacing the baseline HVAC system with ground source heat pumps (GSHPs) for conditioning and a dedicated outside air system (DOAS) for ventilation. This type of system can reduce long-term maintenance costs substantially. Additionally, decoupling conditioning equipment from ventilation equipment can result in substantial energy

savings. Key requirements for making this technology cost-effective are building load reduction and right-sizing of HVAC components. Higher capacity supplemental equipment (fluid cooler, boiler, etc.) may be required in very unbalanced climates (very hot or very cold).

7. **Renewable Generation.** As the goal of the analysis is to achieve net zero energy performance (on-building, as opposed to on-site or off-site, if possible), all building energy use not eliminated through efficiency improvements needs to be offset by renewable energy generation. For the purposes of this analysis, we assume that all renewable energy is generated by photovoltaic (PV) arrays. PV generation is a simple, passive strategy that can be applied successfully in most climates.

Simulation Methodology

The primary requirement of the simulation methodology for the Fort Carson net zero retrofit optimization was to make the overall analysis as replicable as possible. Accordingly, we utilized only publically available modeling tools (SketchUp [http://www.sketchup.com/] and the OpenStudio suite of modeling tools [http://openstudio.nrel.gov/]) to execute our analysis. We also prioritized tools (such as the Match Photo capability of SketchUp, which allows building geometry to be defined using a set of photos that map out the building exterior) that reduce the amount of existing information required to model a building. NREL has created a YouTube channel (http://www.youtube.com/user/NRELOpenStudio/) for OpenStudio that provides users with a wealth of up-to-date tutorial videos that cover all aspects of the OpenStudio tool suite (covering topics relevant to this analysis such as: creating geometry using Match Photo; modeling from imported plans and elevations; creating geometry with the OpenStudio plug-in for Sketchup; specifying model inputs using the OpenStudio application). The following steps define the simulation methodology that we applied to this analysis.

Only publically available modeling tools were used in the analysis.

1. **Create the Baseline Model.** The first step in the simulation process was to create a baseline energy model. As mentioned previously, we modeled Building 1219. To accurately capture the characteristics of Building 1219, as well as demonstrate the capabilities of SketchUp (Match Photo, in particular) and OpenStudio, we modeled Building 1219 through the following approach:

a. *Specify Exterior Geometry with Match Photo*. SketchUp has a capability known as Match Photo, which allows users to specify the geometry of a building solely using photos of the exterior of the building. During a site visit to Building 1219, we took a series of photos that fully captured the exterior wall geometry of Building 1219 and then used Match Photo to build the exterior geometry for the model of Building 1219. Match Photo is particularly useful for capturing elevations and exterior shading objects (trees, bushes, etc.); see Figure 42 for a visual of the Match Photo process.

Figure 42 Specify exterior geometry using Match Photo

b. *Adjust Geometry Using Building Floor Plans*. In this particular case, we had access to detailed floor plans for Building 1219. We took advantage of that resource by importing those plans into SketchUp and then using them as a reference point to make subtle adjustments to the geometry created using Match Photo (Figure 43). While using Match Photo does not require a user to have building floor plans, we were able to use them to improve the accuracy of the model geometry. In theory, we could have used the floor plans to specify the building outline and then used Match Photo only to specify relevant elevations, heights, and fenestration placement. However, one of our goals for this project was to demonstrate the capabilities of the simulation tools.

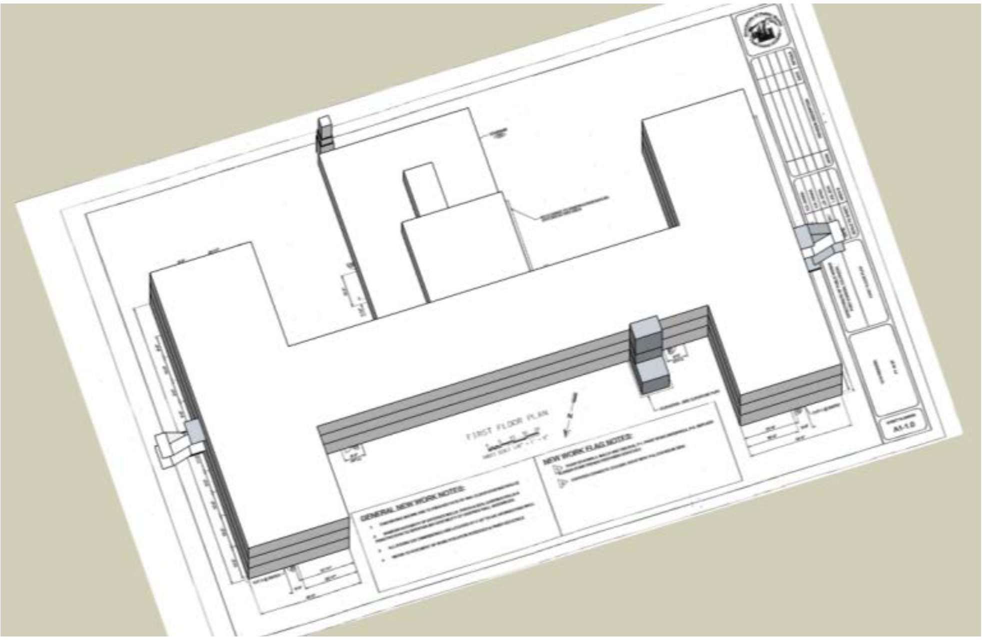


Figure 43 Adjust exterior geometry using building floor plans

c. *Specify Interior Geometry Using Building Floor Plans*. Next we specified Building 1219's interior geometry using the building floor plans (aligning the floor plan with the geometry for the appropriate floor and then tracing out interior zone boundaries onto the model geometry). This could be done without building plans (though likely requiring some estimation), but having the plans made the process much faster and more accurate; see Figure 44 for a visual.

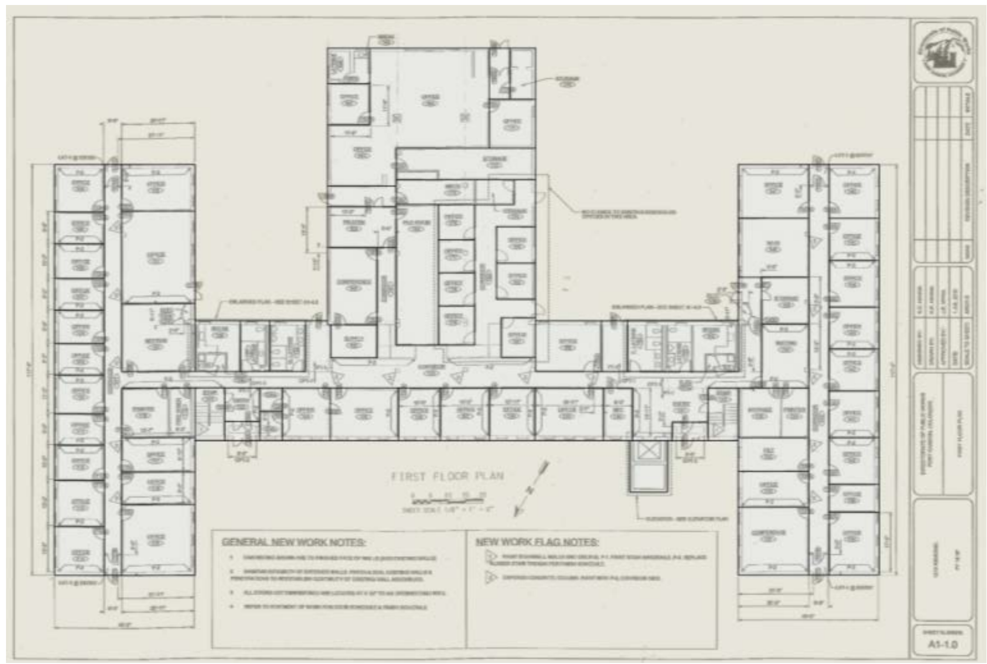


Figure 44 Specify interior geometry using building floor plans

d. *Use SketchUp Geometry As a Template for the Creation of An OpenStudio Model*. Once the SketchUp geometry was finalized, we used it as a template for the creation of OpenStudio spaces, the basic building blocks of an OpenStudio model. The OpenStudio plug-in for SketchUp allows users to create OpenStudio spaces by extruding SketchUp geometry into three dimensions (converting 2-D geometry to 3-D by specifying a height). Once spaces were created, we grouped them into logical thermal zones (e.g., combining two adjacent restroom spaces into a single thermal zone). We also converted the SketchUp geometry for overhangs, staircases, chimneys, trees, and shrubs into OpenStudio shading objects.

For this analysis, we did not lump together spaces (neither adjacent spaces of different types nor spaces of the same type distributed throughout the building); we modeled each space where it exists in the actual building. While this does add accuracy to the model, it also increases the complexity of the model as well as the time it takes to run. As mentioned previously, much of our workflow was determined by our goal of demonstrating simulation tool capabilities. For a typical analysis, we try to simplify models wherever possible (space lumping, simplified perimeter geometry, banded windows versus punched windows, etc.) to save analysis time.

e. *Use Building Operational Data to Specify Modeling Inputs*. After creating OpenStudio geometry, we used data collected during our Fort Carson site visit and through submetering to specify modeling inputs (internal gains, schedules, etc.). Where Building 1219 data were lacking, we specified building operational schedules according to typical schedules we have developed for past modeling efforts.

f. *Apply ASHRAE 90.1-2007 to Establish Baseline Performance*. Because we wanted to capture a baseline for building performance corresponding to code-minimum requirements, we applied ASHRAE Standard 90.1-2007 to the models to specify many other aspects of the energy model (HVAC system type, roof insulation, window properties, etc.). To ensure that our baseline model did not deviate too significantly from the characteristics of Building 1219, we bypassed 90.1 requirements in certain cases where they differed noticeably from Building 1219 characteristics (e.g., exterior walls, which are largely un-insulated in Building 1219).

2. **Write OpenStudio Measures.** The next step was to specify the inputs required to model our set of candidate efficiency measures and build those requirements into OpenStudio measures, which can be applied as perturbations to OpenStudio models to simulate the energy savings impacts of efficiency measures. OpenStudio measures are sets of programmatic instructions (such as an Excel macro) that make changes to an energy model to reflect their application. Measures can be written specifically for an individual model, or they may be more generic to work on a wide range of possible models; NREL has developed a guide to provide users with detailed instructions on how to write OpenStudio Energy Conservation Measures (http://openstudio.nrel.gov/openstudio-measure-writing-guide). We wrote OpenStudio measures for the majority of the efficiency strategies described in the Design Methodology section (and in more detail in Appendix C). Note that measures often need to be written with other measures in mind. Will a measure work correctly when applied in combination with other measures? This concept is important to remember when writing measures.

3. **Write EnergyPlus (IDF) Measures.** While the goal is to develop OpenStudio to the point that it supports all EnergyPlus modeling objects, that goal is not yet a reality. In certain cases, EnergyPlus objects do not have OpenStudio equivalents. To perturb those EnergyPlus objects for the application of an efficiency strategy, it is necessary to write IDF measures. IDF measures are very similar to OpenStudio measures; the only difference is that they are written to perturb EnergyPlus objects directly (as opposed to modifying OpenStudio objects that are later converted to EnergyPlus objects). Through necessity, we wrote IDF measures for efficiency strategies not currently supported by OpenStudio (ground source heat pumps, electrochromic windows, and PV generation). To clarify, the simulation workflow is as follows:

a. OpenStudio measures are applied to the OpenStudio model.

b. The OpenStudio model is converted to an EnergyPlus IDF file.

c. IDF measures are applied to the IDF file.

d. The IDF file is simulated using the EnergyPlus engine.

4. **Write a Script to Identify an Optimal Package of Retrofit Strategies.** There are multiple approaches to applying efficiency strategies to a baseline model. For this analysis we applied strategies using a sequential search algorithm, which mathematically optimizes a solution space according to primary and secondary objective functions. For our analysis, we chose incremental lifecycle cost and building energy use as the primary and secondary objective functions, respectively. What this means is that we used a mathematical algorithm to identify the package of efficiency solutions that results in the lowest lifecycle cost (which factors in first costs, energy cost savings, maintenance costs, replacement costs, analysis period, and discount rate) for a given level of building energy performance. The specifics of this approach are described in more detail in the Optimization Results section.

We wrote a Ruby script that used OpenStudio methods to assemble (through the application of our OpenStudio and IDF measures) optimized packages of efficiency strategies according to the output of the sequential search algorithm (with the objective functions described previously, as well as an analysis period of 20 years and a real discount rate of 2.3%). To analyze the cost-performance tradeoff associated with efficiency measure application, we assigned incremental costs (capital, maintenance, and replacement) to each measure (note that certain incremental costs, such as operations and maintenance (O&M) costs for LED lighting, were negative). To broaden the application of the analysis results, and for consistency throughout the Fort Carson project as a whole, energy models were simulated using national average utility rates. Figure 45 shows the final energy model, complete with exterior shading objects and PV panels covering 75% of the roof area, imported into its actual geographic location in Google Earth.

Currently, this type of optimization analysis can only be achieved through Ruby scripting and expert knowledge of the OpenStudio tool suite (users can develop the necessary understanding of OpenStudio at the sub-project, class, and method levels through exploration of the OpenStudio software development kit documentation [http://openstudio.nrel.gov/latest-c-sdk-documentation]). Recent releases of the OpenStudio tool suite have added user interface-based parametric analysis functionality through the Parametric Analysis Tool (PAT). While PAT does not currently support optimization analysis, it does allow users to apply and analyze specified combinations of OpenStudio measures; NREL has developed a series of tutorials to guide users through the PAT analysis process (http://openstudio.nrel.gov/parametric-analysis-tool-tutorials).

Results and Lessons Learned

The following subsections present the results of the net zero retrofit optimization and highlight key lessons learned throughout the process.

Optimization Results

The baseline model, specified to be minimally compliant with ASHRAE Standard 90.1-2007, was the starting point for the optimization. For this analysis, the baseline energy performance was approximately 73 kBtu/ft^2·yr, which is typical for an average office building. As a point of reference, Spectra Tech's analysis calculated baseline energy performance of 68 kBtu/ft^2·yr and retrofit performance (corresponding to the actual Building 1219 retrofit package) of 58 kBtu/ft^2·yr (corresponding to energy savings of approximately 15%).

To build lifecycle cost-optimized efficiency packages, candidate efficiency measures were applied as perturbations to the baseline models. The sequential search algorithm applies perturbations in groups we call iterations. During the first iteration, each measure is applied to the baseline and simulated independently. The algorithm then selects the mathematically optimal point for the given objective functions. For our analysis, the objective functions were incremental lifecycle cost (primary) and building energy use (secondary). Given these objective functions, the search algorithm searches for the lowest lifecycle cost package starting from the baseline model, and proceeding to packages with lower and lower energy use. Figure 46 shows the baseline point and the data points from the first iteration; the selected package from the first iteration was the baseline model perturbed with the common area lighting control measure.

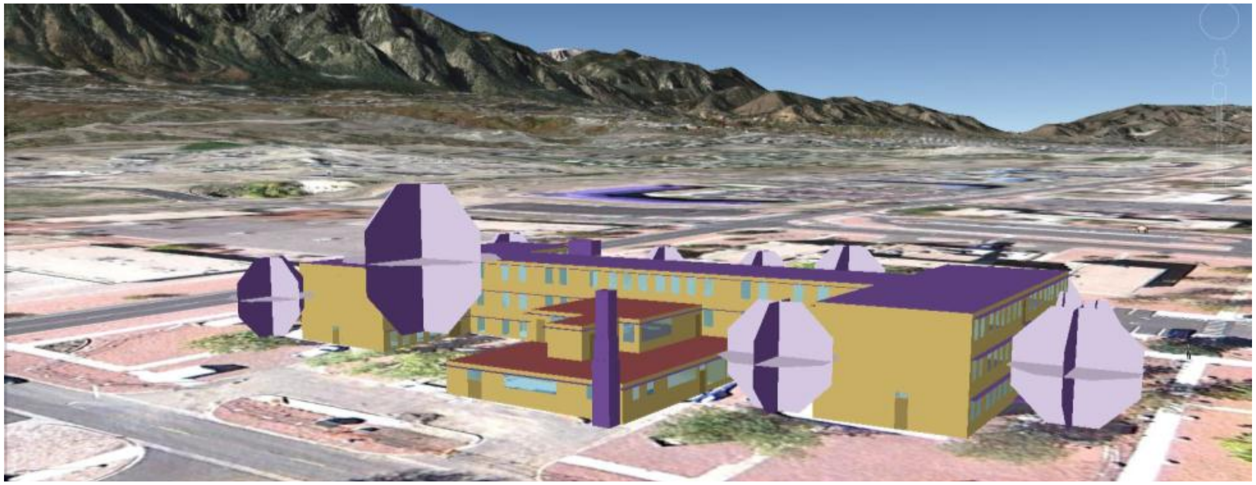


Figure 45 Final energy model in Google Earth with PV and shading objects

Once the most optimal package from the first iteration is selected, that package becomes the starting point for the second iteration. Once again, all packages that are single-measure perturbations of the iteration starting package are simulated (in this case, one of those perturbations would remove the measure selected in the first iteration, recreating the baseline; because that package would have already been simulated at the outset of the analysis, it would not be simulated again). After completion of the simulations for the second iteration, the search algorithm determines the most optimal package from within that group; that new optimal package then becomes the starting point for the next iteration. This process continues until the algorithm can no longer find a package with lower energy use (or lifecycle cost) than the selected package from the previous iteration. Figure 47 shows the results of the first four iterations of the Fort Carson net zero retrofit optimization; note that a plus sign indicates that the selected package is an addition to the previous package (as opposed to a subtraction, which occurs when a measure is removed).

Figure 46 shows the final results of the optimization, and describes a number of key packages:

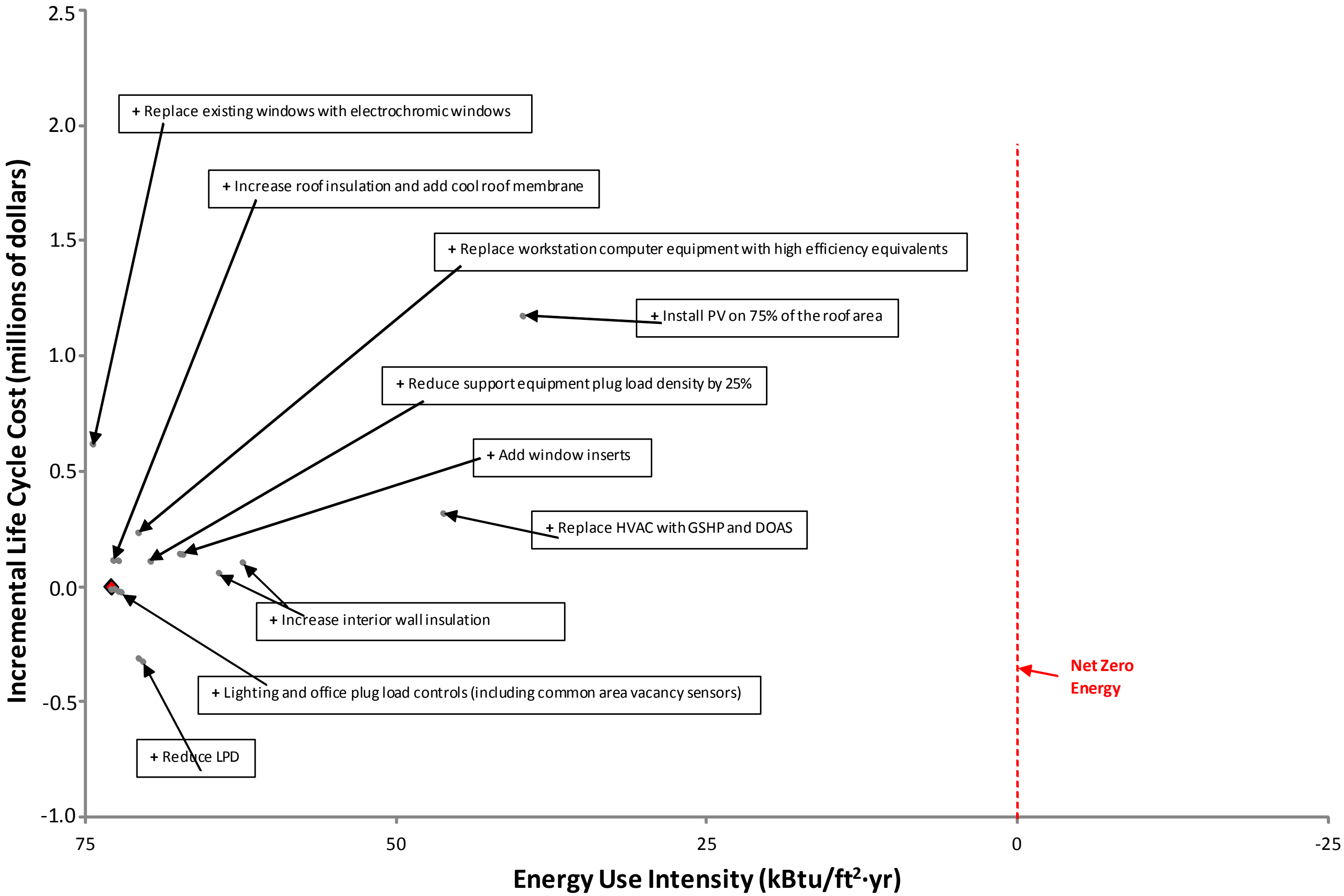


Figure 46 Baseline model and first iteration of perturbations

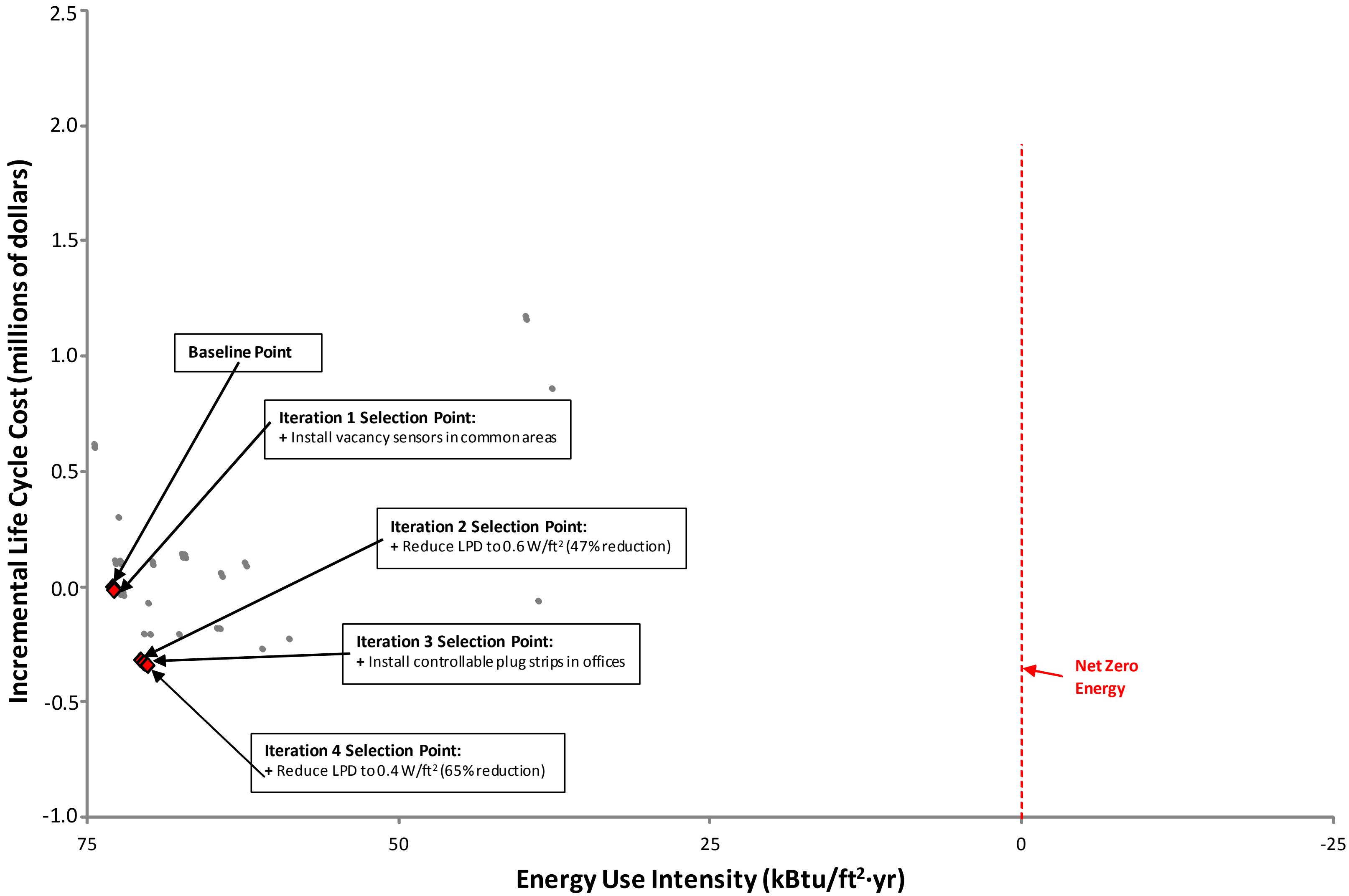


Figure 47 Results of first four iterations (with selected packages highlighted)

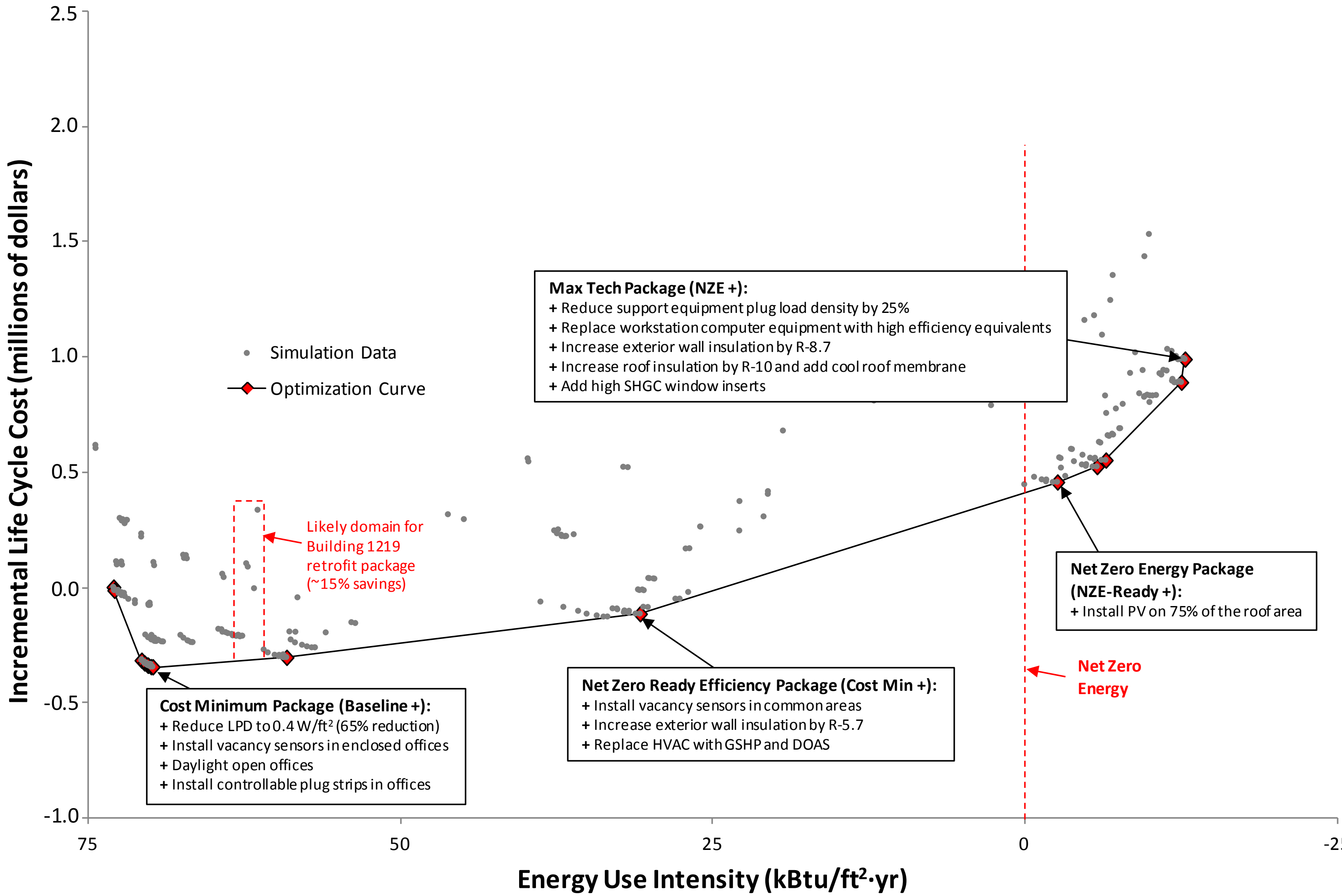


Figure 48 Final optimization results (with descriptions of notable packages)

1. **Cost Minimum Package.** This is the package with the lowest total lifecycle cost (in this case, the most negative incremental lifecycle cost). The cost minimum package results in the best return on investment for the given analysis period (20 years). Note, however, that the energy savings associated with the cost minimum package are quite small (less than 5%). There are many other packages that save considerably more energy and still represent cost-effective investments.

2. **Net Zero Ready Efficiency Package.** We define an efficiency package as being net zero ready when all efficiency measures that are more cost-effective (from a lifecycle cost perspective) than renewable generation have been applied. For this analysis, the net zero ready package resulted in 58% energy savings (corresponding to an energy use intensity [EUI] of 30.9 kBtu/ft2·yr, which is indicative of a high performance office building) at a net reduction in lifecycle cost when compared to the baseline model (indicating that this package is cost-effective for the given economic criteria). The net zero ready efficiency package contains the following key strategies:

a. GSHP with DOAS HVAC system.

b. LPD reduction (to 0.4 W/ft^2, a 65% reduction from baseline lighting levels).

c. Improved lighting controls (vacancy sensors in enclosed offices and common areas).

d. Daylighting of open office and conference spaces.

e. Controllable plug strips (which turn off automatically after 11 hours) for office workstations.

f. Increased exterior wall insulation (by R-5.7).

3. **Net Zero Energy Package.** The net zero energy package is achieved by adding renewable generation to the net zero ready package until net zero annual energy performance is achieved. In this case, net zero annual energy performance was achieved solely with on-building renewable generation (assuming photovoltaic [PV] panels could be installed on 75% of the existing roof area). Note that our analysis assumed direct purchase of the PV system, resulting in a net zero energy solution with a higher lifecycle cost than the baseline model. However, incentives or alternative financing strategies (e.g., power purchase agreements) could improve the economics of renewable generation.

4. **Max Tech Package.** This is the package that achieves the best possible energy performance, regardless of cost. For our analysis, the max tech package includes the most aggressive possible package of candidate efficiency measures and the maximum practical amount of on-building PV generation. The max tech package (without renewable generation) achieved an EUI of 20.7 kBtu/ft2·yr, which is comparable to that for NREL's Research Support Facility (not counting the energy use of the shared data center).

Lessons Learned

Throughout the Fort Carson net zero retrofit optimization analysis, we emphasized the importance of defining a process that is effective, straightforward, and replicable. Accordingly, we utilized only publically available modeling tools (SketchUp, the OpenStudio suite of modeling tools) and prioritized tools (Match Photo) that reduce the amount of existing information required to model a building. In this section, we highlight the key lessons learned in defining this process and applying it to a real building. Note that this was the first project for which we were able to utilize these simulation tools to this extent for a real building.

The net zero ready package resulted in 58% energy savings at a net reduction in lifecycle cost

1. **Balancing Model Fidelity with Available Time and Resources.** As mentioned previously, one of our goals for this project was to demonstrate the capabilities of the simulation tools. Accordingly, we modeled Building 1219 in great detail. An alternative approach would be to simplify the model in a number of key ways (lumping spaces together to reduce the number of thermal zones, replacing punched windows with banded windows, simplifying or eliminating shading objects, etc.). If done correctly, this can greatly reduce the time and effort needed to build and simulate the model without significantly impacting its accuracy. This is a well-known modeling tradeoff that is not unique to this analysis; however, it is worth mentioning from a replication standpoint.

2. **Using Match Photo.** For this analysis, we primarily used Match Photo to specify the exterior geometry of the model. Match Photo is a powerful tool that allows users to accurately capture the geometry of a building with nothing more than a camera. In cases where building plans may not be available, using Match Photo (and/or Google Earth, which in most cases could be used to establish a rough footprint of a building) to establish building geometry is likely to be the most effective approach. However, it is much simpler and faster to build a model from documented dimensions than to try to capture those dimensions using Match Photo. In cases where other building data is available, Match Photo should be used sparingly (ideally, only to capture dimensions that are otherwise undocumented).

3. **Using OpenStudio.** OpenStudio is a powerful suite of modeling tools. In the recent past, the OpenStudio development team has made great strides in making its capabilities user friendly (developing a software application [OpenStudio App] and resource database [Building Component Library] that allow users to build energy models through a download, drag, and drop approach, as well as a parametric analysis tool (PAT) that provides users with an interface through which they can apply and evaluate the results of efficiency strategies). That being said, there is still a significant scripting component to performing an energy modeling analysis using OpenStudio (especially when analysis needs to be tailored to a specific project); efficiency measure definition and sequential search optimization currently require scripting. When planning

to use the OpenStudio tools, it is important to take this into account and ensure that the proper project resources and expertise are available.

Recommendations

The following subsections detail NREL's recommendations, both to Fort Carson in particular and to GSA in general.

Fort Carson Recommendations

The retrofit analysis is most directly applicable to future retrofit of Fort Carson barracks buildings with the same basic characteristics as Building 1219; however, the recommended strategies should be applicable to office building retrofits in general. Applicability of recommended strategies to other Fort Carson building types (DFAC, TEMF, etc.) will depend on the extent to which those building types share characteristics with typical office buildings. While the exact packages that result in the lowest lifecycle costs at each level of energy performance will be somewhat building- and climate-specific (note that we only performed the optimization for Fort Carson, Colorado, not for any other locations), we believe that the majority of the proposed efficiency measures (especially the lighting and plug load measures, all of which are very common for office new construction and retrofit projects) should at least be considered in an office retrofit scenario. As we mentioned previously, we focused on proven measures that are simple and passive. By prioritizing efficiency strategies with a high probability of success (in particular, those for which success is not highly dependent on the behavior of facility personnel and/or building occupants), long-term, campus-wide return on retrofit investment can be maximized.

Note that many of the candidate efficiency strategies have already been incorporated to some extent in the Building 1219 retrofit, including:

- LED lighting

- Controllable plug strips for office workstations
- Zone level HVAC (fan coil units)
- High efficiency computer monitors
- Multifunction office support equipment
- Sensor-based lighting control, including daylighting
- Additional roof insulation and white roof membrane
- Renewable generation (solar water heating)

In that way, our recommendations build on the incorporation of efficiency into the Building 1219 retrofit to reach a higher tier of cost-effective retrofit performance. An integrated design approach to efficiency strategy selection (as embodied by our optimization analysis), as opposed to a like-for-like approach, is critical for maximizing energy performance in retrofit scenarios.

GSA Recommendations

A key focus of our analysis was to document the simulation process and highlight opportunities for replication across GSA and throughout the commercial building sector at large. Given the necessary expertise, NREL's analysis can be fully replicated. The simulation tools (SketchUp, OpenStudio) we used to execute our analysis are publically available. Additionally, much of the project workflow is aided by guided user interfaces that make the simulation tools more accessible and user friendly. Some aspects of the analysis required scripting capabilities and more detailed knowledge of the OpenStudio tool suite. However, some of those barriers can be mitigated through generalization. The Building Component Library (BCL) (https://bcl.nrel.gov/) provides many resources (OpenStudio measures, building constructions, operating schedules, etc.) that can help streamline project workflows and in some cases reduce the need for scripting. If generalized analysis will suffice, the required energy modeling expertise will be reduced (but certainly not eliminated). The more project-specific the analysis needs to be, the more in-depth knowledge of energy modeling, scripting, and the OpenStudio tool suite will be required.

Additionally, we believe the simple, passive efficiency strategies that we analyzed for the Building 1219 retrofit optimization, along with the integrated design approach that we applied to efficiency package selection, have wide applicability to office buildings across the commercial building sector. While the optimization package results are specific to Fort Carson and to Building 1219, we recommend considering the candidate efficiency strategies (especially the lighting and plug load strategies) for office retrofits throughout GSA's portfolio.

The simple, passive efficiency strategies identified in this retrofit optimization have wide applicability to office buildings across the commercial sector.

Chapter 2 The Role of Occupant Behavior in Achieving New Zero Energy: A Demonstration Project at Fort Carson

How occupants interact with their buildings needs to be a key consideration for all green building planning, design, operations and decision-making. Research on the performance of green buildings in recent years has placed greater emphasis on the need and opportunity to better understand the roles of occupants and the factors that shape their behavior, including default conditions, institutional frameworks, organizational culture, peer pressure and more. Understanding the relative impact of technology-based versus occupant behavior-based strategies—and combinations of the two—is a key to learning how to make high performing green buildings commonplace.

Research Question

Which occupant behaviors have the greatest potential to reduce energy use in buildings, and what approaches can motivate and maintain these behaviors?

These questions are especially critical in the Federal building context, where ambitious sustainability goals require pushing green building performance to exemplary levels. These goals include the requirement that all new Federal buildings be designed to achieve zero fossil fuel use by 2030 (Energy Independence and Security Act of 2007) and the Army's Net Zero Installation program, whereby Army installations work to make entire bases so resource efficient that they will use net zero energy, water or waste by 2020.

Fort Carson in Colorado Springs, Colorado, is one of only two Army bases currently pledged to achieve net zero energy, water and waste. Its ambitious goals, and over 70 Leadership in Energy and Environmental Design (LEED)-

rated green buildings, make it an ideal site for a demonstration project on how occupant behavior may be leveraged to help buildings achieve net zero energy performance.

This study, The Role of Occupant Behavior in Achieving Net Zero Energy: A Demonstration Project at Fort Carson, was sponsored by the U.S. General Services Administration's (GSA's) Office of Federal High-Performance Green Buildings (OFHPGB). The Office's mission is to facilitate the greening of the Federal building portfolio, by conducting applied research and demonstrations, developing standards, guidance and tools, and disseminating information. The Pacific Northwest National Laboratory (PNNL) partnered with GSA, the U.S. Department of Defense (DOD), and the U.S. Department of Energy (DOE) in conducting this demonstration project at five green buildings on the Fort Carson Army base.

The research focused on understanding the potential for institutional and behavioral change to enhance building performance. The research team identified specific occupant behaviors that had the potential to save energy in each building, defined strategies that might effectively support behavior change, and implemented a coordinated set of actions during a three-month intervention.

The intervention focused on changing two occupant behaviors with the potential to save energy

The intervention focused on changing two occupant behaviors that had the potential to save energy:

- shutting down computers at night in the participating buildings, and
- setting back thermostats 5–10 degrees at night during heating season in the two buildings with decentralized heating/cooling controls.

The behaviors were selected considering the specific context of each building, including the way occupants interacted with building features and estimates of the energy use impacts from changing different behaviors. Other behaviors (e.g., relying on natural light and task lighting instead of overhead lights) were also promoted but were not the focus of efforts to measure change and estimate energy savings.

The measure of success of this intervention was whether the groups targeted for behavior change modified their behavior as a result of it. The findings showed that many occupants changed their behavior during the study period, and differences in the degree of change by building helped point to factors that appeared to be most influential.

In the building showing the most dramatic change, just 8% of computers were shut down during the first week. This increased to 59% in week 6, which was the week of highest compliance based on computer network scans that verified whether assets were on or off. The maximum increase in computer shutdown compliance between the baseline week (week 1) and the week with the building's highest levels of compliance ranged from a 13% increase to 36% increase, indicating that occupants of all the participating buildings took some action as a result of the intervention. Self-reported changes in the post-intervention survey indicated that between 23% and 32% more occupants (for the two buildings participating in this measure) turned back temperature settings on their workspace heating units each night. These results were encouraging for a three-month intervention period.

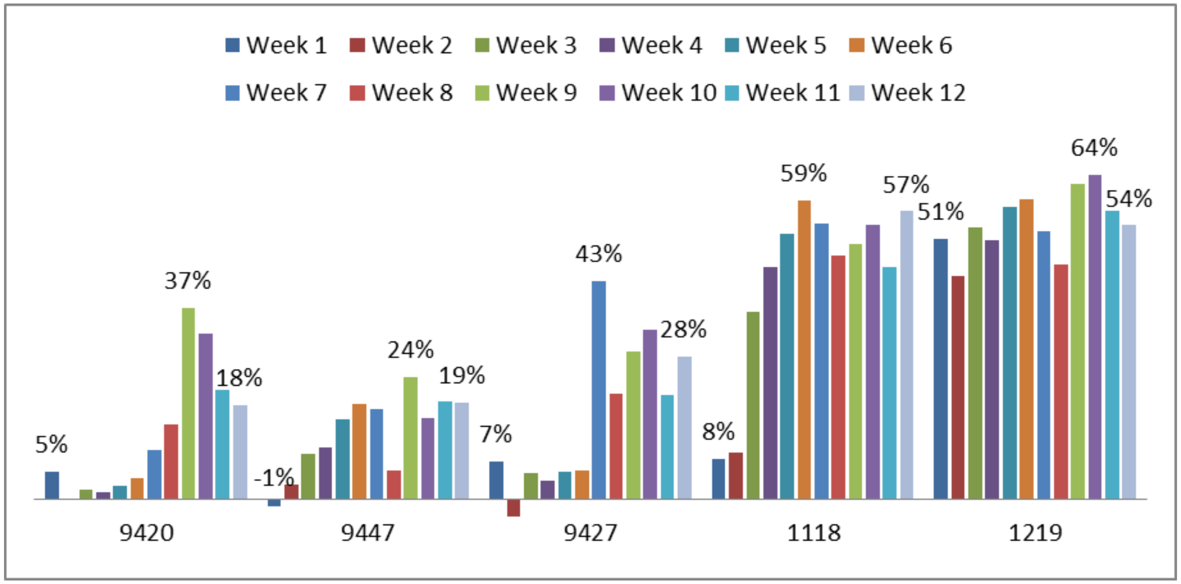


Figure 49 Percent of Computers Shut Down at Night by Building Number Based on Computer Network Scans (numbers represent compliance rates in first week, final week and the highest compliance week)

Changes in awareness and attitudes also suggest an overall positive reaction to the intervention. In surveys conducted prior to the intervention, most occupants initially reported having a high level of awareness and positive attitude about Fort Carson's net zero energy effort. However, fewer reported feeling a sense of personal responsibility to save energy in their building. This suggested that there may have been a disconnect between institutional goals such as achieving net zero energy use, and the beliefs of building occupants that they could contribute to achieving those goals through actions they take in their building.

Providing limited, specific, and locally relevant information during the intervention appeared to help occupants understand how they could take action and have an impact in their own building. In the building with the most dramatic changes in behavior, changes included increased proportions of respondents who agreed that they:

- have the skills to use energy saving technologies: from 65% to 90%,
- feel personally responsible for reducing energy in their building: from 64% to 89% and,
- believe reducing energy use in their building is important: from 76% to 92%.

This lends support to the idea that making conservation measures specific to the local context—and giving occupants the knowledge and ability to change—may help close the gap between big institutional objectives, like net zero energy, and small, individual actions.

Findings from this study support the idea that energy change efforts may be most effective if approached as "high touch" activity.

Findings from this study also support the idea that energy change efforts may be most effective if approached as a "high touch" activity through person-to-person communications. Specific factors that respondents said had the greatest influence on their energy conservation behavior were receiving:

- instruction from an immediate supervisor
- information on specific actions to take

- feedback on performance from a local advocate for energy conservation[5] and,
- a letter from leadership encouraging occupants to take the specific conservation measures.

The building showing the greatest improvement during the intervention was one with an engaged local advocate who regularly shared information and feedback with occupants and their managers and suggested changes in behavior when actions were not being followed. In the buildings with less engaged energy advocates, supervisors who talked with occupants were influential in changing poor computer shutdown compliance rates within a week's time.

Energy metering challenges and the dramatic occupancy changes in buildings occupied primarily by military personnel limited the research team's ability to draw conclusions about the actual energy savings. Analysis of whole-building metering data available for one building suggested that the combined results of shutting down computers and setting back thermostats at night would have saved an estimated 2% of total annual energy use in that building.

The actual range of potential savings could vary widely by building and depends on differences in opportunities for change. Even the 2% savings estimated from one building in this intervention—which required about two hours of effort each week on the part of a local advocate over a three-month period—may be meaningful in the context of a net zero energy target that requires squeezing out every potential percentage point of energy savings.

The building showing the greatest improvement during the intervention was one with an engaged local advocate

[5] Building Energy Monitors (BEMs) are local, building-specific energy conservation advocates.

As part of the baseline survey, this study also looked at occupant satisfaction with the features of their green buildings. Due to the transition of military personnel as part of their deployment cycle at the start of the study period, responses on satisfaction were primarily limited to civilians in two buildings. As a result, findings from the baseline analysis may not be generalizable to military personnel or buildings at Fort Carson or other bases. More than 80% of the respondents indicated they were generally satisfied with most personal workspace and buildings features. Eighty-three percent (83%) were satisfied with the overall building performance. Thermal comfort—often one of the greatest sources of occupant complaints—had satisfaction rates of 68%. This level of satisfaction is much higher than is typically found with building occupant surveys (e.g., 39% satisfaction in a study of 34,169 occupants in 215 buildings [Huizenga 2006]), and is likely due to the fact that most of the respondents were in buildings with direct occupant control over heating and cooling units.

Our findings from this project have several implications for programs to help reach net zero energy goals through sustained institutional and behavioral change at Fort Carson and other Army installations. These include:

- Recognize that the institutional context must be understood to enable desired change in individual behavior.
- Make desired behaviors specific and locally relevant. Awareness of institutional goals is not enough to lead to local actions.
- Provide social reinforcement on a regular basis from known and trusted sources. An energy advocate can facilitate behavior change—if they are both required and equipped to maximize their effectiveness.
- Equip tenants with knowledge and resources to implement behavior change. That includes securing leadership support and ensuring accountability for follow-through.

Specific recommendations that may help Fort Carson and the Army strengthen its Building Energy Monitor (BEM) program and enable change at the local level include:

- Ensure that the BEMs, as local energy conservation advocates, are trained and have resources to facilitate energy behavior change in building occupants.

- Measure energy conservation behavior and outcomes in new and existing buildings.

- Provide regular information and feedback to building occupants on their performance.

Background

The GSA Office of Federal High-Performance Green Buildings is required under the Energy Security and Independence Act of 2007 (EISA 2007) to complete a demonstration project each year on green building features in federal buildings. The goal of these demonstration projects is to evaluate how green features, technologies, and approaches are working in practice (not just according to designed or modeled performance) to help make sure the Federal Government learns from its experiences in green building and applies those lessons to current and future programs.

About Fort Carson

Fort Carson is home of the 4th Infantry Division, the 10th Special Forces Group, the 71st Ordnance Group (EOD), the 4th Engineer Battalion, the 759th Military Police Battalion, the 10th Combat Support Hospital, the 43rd Sustainment Brigade, MEDDAC (Evans Army Community Hospital), the 13th Air Support Operations Squadron of the United States Air Force, and other support services. The post also hosts units of the Army Reserve, Navy Reserve, and the Colorado Army National Guard.

As of 2013, the population of Fort Carson totaled nearly 30,000 with 24,000 military and 5,700 civilian personnel. Fort Carson's footprint spans 215 square miles and includes about 900 buildings with nearly 13 million ft2 of heated space.

Fort Carson has a well-established sustainability program with a strong emphasis on energy conservation, efficiency, and renewable energy.

The 2012 demonstration project focused on the Fort Carson Army base in Colorado Springs, Colorado, and was conducted in collaboration with the DOD and the DOE. Fort Carson was chosen because of its goals to achieve zero net energy, water and waste and the presence of a strong, ongoing sustainability program with which to partner. The demonstration focused on five green buildings and involved two major activities:

- an evaluation of building performance and opportunities to optimize design in common types of military buildings, led by the National Renewable Energy Laboratory (NREL), and
- an evaluation of the way occupants interact with green buildings and opportunities to optimize their behavior to further reduce energy use, led by PNNL.

This report summarizes findings from the 18-month effort led by the PNNL to establish specific occupant behaviors that had the potential to save energy in the five green buildings, define strategies that might effectively support behavior change, implement a short-term change program, and evaluate its impacts. The five buildings studied as part of this demonstration included both typical administrative buildings and military support Company Operations Facilities (COFs) (occupied exclusively by military personnel) with combined office and high-bay storage areas for military equipment. Many of the military personnel moved into the buildings during the study period while the civilians remained in their designated buildings throughout the period.

Research

Behavior: Why it Matters

Interest in behavior change reflects a growing recognition that technology solutions alone will not achieve energy conservation goals. While organizations often emphasize investments in physical upgrades and new technologies, the full potential of these technologies often cannot be achieved without accompanying behavioral and institutional change (Lutzenhiser 1993; Earhardt-Martinez and Laitner 2010). Even when technology upgrades, such as occupancy sensors on lights, can reduce exclusive reliance on the need for behavior change for certain end-uses, budgets may constrain integration of technology upgrades into existing buildings, making human behavior the only means of conserving resources in some facilities. Furthermore, the practice of trying to design out the human element often has unforeseen consequences, such as creativity by building occupants to defeat or modify intended functionality (e.g., light sensors, thermostats). Occupant behavior can strongly influence building energy use. As shown by NREL in a study of zero energy homes[6] in the San Diego area, variation in utility consumption and cost across homes was considerable (a factor of 50) for homes with photovoltaics, with the primary difference being homeowner choices about energy-intensive equipment and amenities (Farhar and Coburn 2006). Some homes with zero-energy capability actually consumed *more* electricity than conventional designs.

A focus on behavioral interventions can be useful in defining and executing the transferable actions and lessons learned to help fully realize the “behavioral wedge” of a broader set of strategies that can help reduce energy use and stabilize greenhouse gas emissions. Considerable analysis in the past several years suggests that the behavioral wedge, which can include actions such as reducing plug loads or minimizing trips, and efficiency actions such as equipment replacement, can reduce energy consumption in the range of 10–30% (Gardner and Stern 2008; Dietz et al. 2009). Longer-term, understanding of behavior can help to reduce potential divergences between modeled and actual building energy performance, which is frequently observed in practice (Heschong Mahone 2012).

A focus on individual behavior is insufficient to affect enduring change.

[6] Zero energy homes combine energy-efficient construction and appliances with commercially available renewable energy systems, such as solar water heating and solar electricity, resulting in net zero energy consumption from the utility provider.

However, a focus on individual behavior is insufficient to affect enduring change. It is also necessary to change institutional behavioral patterns and thinking—this is essentially the infrastructure in which occupant behavior occurs (Moezzi and Janda 2013). *Institutional change* refers to a holistic systems approach to achieve change by integrating technology, policy, and *behavior change*. This means combining energy conservation cognizance and action into daily routines and ways of doing business, such as using natural light rather than electrical light in office settings, to ensuring that the purchase of energy efficient products is accepted practice. Behavior change is enabled by changes in institutional *roles* (who is responsible for what), *rules* (procedures and methods for doing things), and *tools* (specific energy reduction mechanisms, such as efficient equipment/appliances) (DOE 2013). To achieve aggressive energy conservation goals, it is increasingly important to develop integrated strategies that link mission, organizational policies, and behavioral change tactics to motivate and support new ways of interacting with the building environment (Moezzi and Janda, 2013).

State of Research on Behavior Change and Energy Reduction

There have been several, recent comprehensive reviews of research concerning behavior change in energy reduction (Heschong Mahone 2012; Moezzi and Janda 2013; Earhardt-Martinez and Laitner 2010) covering a wide range of factors (e.g., variability in energy usage, occupant engagement, and the behavioral/social potential for reducing consumption) and theoretical and empirical work over a 40-year period. The general conclusion from this work is that energy-behavior change can be demonstrated, but the impact and persistence of the change are the result of complex, interacting factors (Moezzi and Janda 2013). Long-term behavioral persistence, shown in several studies (Allcott 2010; Staats et al. 2004), suggests social factors, such as knowledge of continued participation in an energy program (Schwartz et al. 2013) and reinforcement through social learning (Staats et al. 2004), as contributing factors.

One recent review concerning behavior and organizational factors (Malone et al. 2013) synthesized the complex findings in this area into eight basic principles associated with behavior change and energy reduction:

Social Network and Communications Principle: Institutions and people change because they see or hear of others (e.g., individuals, groups, institutions) behaving differently.

Multiple Motivations Principle: Institutions and people almost always change their ways of doing things for more than one reason.

Leadership Principle: Institutions and people change because the workplace rules change and leadership communicates their commitment in a visible way.

Commitment Principle: Institutions and people change when they have made definite commitments to change, especially when those commitments relate to future conditions.

Information and Feedback Principle: Institutions and people change because they receive actionable information and feedback.

Infrastructure Principle: Institutions and people change because a changed infrastructure makes new behaviors easy and/or desirable.

Social Empowerment Principle: Institutions and people change when they feel they can reach desirable social goals.

Continuous Change Principle: Institutional change is an iterative process and takes time.

The eight principles described above delineate key enablers for change in complex organizations. However, they need to be considered in aggregate. There is no single approach that can work in isolation. Instead, behavioral change in an institution occurs when these principles are used together at various points in time.

There is a tendency to rely on awareness programs as the primary change strategy for changing behavior, but information and awareness alone are insufficient to change behavior. Multiple interacting strategies applied over an extended period have the best chance of changing institutional and behavioral patterns (Gardner and Stern 2002). The importance of focusing on behavioral and organizational factors is further emphasized by results showing that energy usage continues to rise over time, beyond the level simply accounted for by population increase (Shui et al. 2010). Technical efficiency alone may slow the rate of energy use, but by itself is insufficient to achieve performance goals associated with aggressive energy and carbon reduction policies such as net zero energy (Harris et al. 2008).

Figure 50 Army Net Zero Energy Hierarchy

An elaborated view of behavioral/institutional research is beginning to emerge, which focuses more on the complex interactions that engender and support energy consumption (Moezzi and Janda 2013). Simple views based on concepts such as habit or information deficits are giving way to an understanding that changing energy consumption needs to engage behavior and institutions at multiple levels, in multiple ways (Prins and Rayner 2007). There are precedents for this type of engagement in public health and recycling programs, wherein multiple communication methods, infrastructure modifications, incentives, etc., are applied over a broad range of actors: individuals at the consuming end, organizations, institutions and policies at the infrastructure end (Dietz and Stern 2002). Similarly, the view of energy consumption is changing from a focus on individuals—an "end of pipe" problem—to the interacting elements that require and support consumption, and the various interventions and policy levers that can be used to move toward energy reduction goals, including net zero (Heschong Mahone 2012; Moezzi and Janda 2013).

Relevance to Fort Carson and the Army

The importance of behavior-based energy reduction has several implications for the Army as a whole and Fort Carson, in particular, as a Net Zero Energy Installation.[7] First, energy use reduction is promoted as the most important element in moving toward net zero consumption (Figure 50). Although the Net Zero Initiative does not provide specific quantitative targets for each of these elements, reduction serves as the basis for the hierarchy of strategies. Implicit in this strategy are behavioral approaches that do not rely on new technology or generating capacity, but instead on reducing consumption. Thus, institutional and behaviorally based energy consumption represents a prime opportunity for demonstrating low/no-cost energy savings approaches that can reduce the need for additional technical efficiency measures or renewable generating capacity. This demonstration project aims to equip energy managers at Fort Carson and at other Army installations with practical lessons learned from a targeted effort to reduce energy use through institutional and behavioral change.

Prior research has shown that green building designs are subject to considerable variation in energy consumption, based on occupancy activities (Farhar and Coburn 2006). The Fort Carson demonstration project aims to provide further information concerning the interaction of green building features and occupant behavior on energy performance.

Finally, Fort Carson is projecting a 21% increase in building square footage by 2015, with accompanying increases in energy usage, but at a lower rate due to technical efficiencies (Anderson et al. 2012). By understanding how to limit

[7] A Net Zero Energy Installation is an installation that produces as much energy on-site as it uses, over the course of a year. To achieve this goal, installations must first implement aggressive conservation and efficiency efforts while benchmarking energy consumption to identify further opportunities. The next step is to utilize waste energy or to "re-purpose" energy, such as boiler stack exhaust. Co-generation recovers heat from the electricity generation process. The balance of energy needs then are reduced and can be met by renewable energy projects.

this demand through low or no-cost behavioral tactics, the need for additional generating capacity via renewables will be reduced. Net zero that is achieved simply by vastly increasing renewable generating capacity fails to address the core problem of overconsumption.

Research Questions and Objectives

The primary objectives of the behavior change demonstration project were to determine the extent to which green buildings at Fort Carson support the work performance, comfort, and well-being of occupants, and the extent to which occupants work with or against the green building design and operation features. This baseline understanding of occupant satisfaction and opportunities for improvement would inform potential behavioral interventions.

Which occupant behaviors have the greatest potential to reduce energy use?

Another important objective of this research was to help understand which occupant behaviors could have the greatest impact on building energy use and to test different interventions to determine optimal ways to modify those behaviors for maximum long-term energy reduction. This supports the overarching goal of the GSA-Fort Carson Demonstration Project, which is to enable the Federal Government to learn from its experiences in green building and apply lessons learned to current and future programs.

Buildings Selected for the Demonstration Project

The research questions were addressed in a study of five green buildings at Fort Carson, which are either certified by the LEED program or have some green building features. These included two administration buildings with predominantly civilian personnel, one administration building with military personnel, and two COFs, which are occupied by military personnel.

Table 17 summarizes key characteristics of each building and its occupants.

Table 17 Characteristics of Buildings in Fort Carson Demonstration Project

Building Number	Green Building Certification	Functions and Layout	Occupant Control of Building Features that Influence Energy Use	Type of Occupants	Approximate Number of Occupants
1118	None, but renovated in 2007 with several green features	Administration building with both private offices and shared work spaces	Office lighting is manual and most common areas have occupancy sensors; heating and cooling is decentralized; each office and common area has wall-mounted units that occupants control; office spaces and conference rooms have operable windows.	Predominantly civilians, few military personnel supporting installation operations	160
1219	LEED Silver Existing Building	Administration building with both private offices and shared work spaces	Office lighting is manual and most common areas have occupancy sensors; heating and cooling is decentralized; each office and common area has wall-mounted units that occupants control; office spaces and conference rooms have operable windows.	Civilians and contractors, most working for the Department of Public Works	130

Building Number	Green Building Certification	Functions and Layout	Occupant Control of Building Features that Influence Energy Use	Type of Occupants	Approximate Number of Occupants
9420	LEED Platinum New Construction	Brigade Headquarters/ administration building with private offices, open work spaces, classrooms, and data center	All lighting on occupancy sensors; heating and cooling controls are centralized (no occupant control); no operable windows.	Military personnel from 4th Brigade Combat Team / 4th Infantry Division (4/4BCT)	250
9427	LEED Gold New Construction	COF with private and shared offices and high-bay storage areas	All lighting on occupancy sensors; heating and cooling controls are centralized (no occupant control); no operable windows.	Military personnel from the 4/4 BCT	75
9447	LEED Gold New Construction	COF with private and shared offices and high-bay storage areas	All lighting on occupancy sensors; heating and cooling controls are centralized (no occupant control); no operable windows.	Military personnel from the 4/4 BCT	75

Methods

The methodology for the Fort Carson demonstration project is based on the DOE-Federal Energy Management Program (FEMP) guidance for implementing institutional and behavioral change (DOE 2013) (Figure 51). This section describes the steps in this process and illustrates how it was applied at Fort Carson as it may inform the design of other energy conservation behavior change programs. At Fort Carson, the entire process was implemented over an 18-month project period.

Determine Goal

The first step in the change process is to establish the desired outcomes from the change effort, or intervention, and time frame for realizing those outcomes.

At Fort Carson, the focus was on individual behavior changes[8] that might lead to energy conservation in five green buildings. The five buildings were selected for the analyses of both energy performance optimization opportunities by NREL and behavior change opportunities by PNNL, and were thought to represent typical building functions found on Army bases. The focus on energy conservation behavior was influenced by Fort Carson being a Net Zero Energy Installation with an interest in promoting well above average energy conservation, and synergies with NREL's work that involved energy submetering in select buildings.

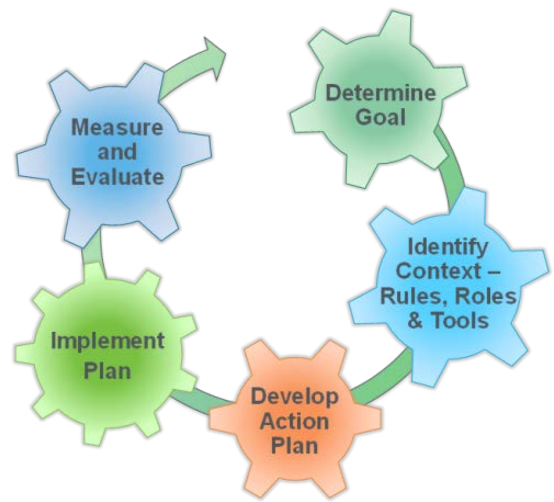


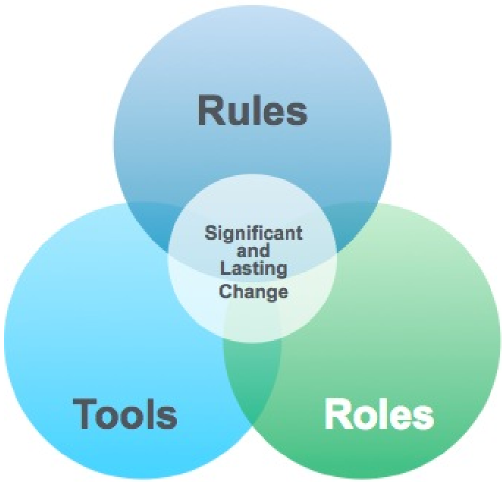
Figure 51 U.S. DOE FEMP Institutional Change Continuous Improvement Cycle

Identify Context – Rules, Roles and Tools

The next step is identifying the "rules, roles, and tools" (Malone et al. 2013) that shape the current context for energy conservation behavior, and understanding how they may influence success in driving toward the goal. This

[8] Broader institutional changes are important for long-term sustained change: however, the short implementation period for the intervention allowed for only limited implementation of institutional changes as they often take more time to carry out.

assessment ultimately shapes the design of the behavioral change intervention and is most critical to ensuring a successful outcome.



At Fort Carson, this phase of the process took about 40% of the time allocated for this project. A number of challenges with baseline data collection (e.g., getting survey responses, scheduling interviews during site visits), establishing metering connections, securing leadership support, and identifying personnel for key intervention support roles extended the "context assessment" and the subsequent intervention design period much longer than had been planned. Deployment of a large portion of the 4/4 BCT occurred between the time the buildings were selected for the project and data collection began, thereby reducing considerably the actual number of building occupants available to participate in the baseline assessment. Other issues related to installation of building energy use meters prevented the selection of replacement buildings with larger numbers of military occupants.

The rules, roles, and tools framework, as applied at Fort Carson, is described below:

- **Rules** –This involved identifying formal policies and procedures related to energy use in the five demonstration buildings, as well as informal rules that might affect how a policy is perceived and the extent to which it is implemented. The importance of understanding both formal and informal rules is illustrated by the way occupants manage their temperature set points in one of the Fort Carson buildings studied. For example, the existing temperature set-point policies at Fort Carson specify keeping thermostats at 70°F or below during heating season. However, practical thermostat and temperature calibration issues in one of the subject buildings meant that a thermostat setting of 75°F may have created a room temperature of only 68°F.

- **Roles** – Key individuals and groups who could make the most difference in achieving energy conservation goals were identified and engaged in the intervention design process. For this demonstration project, those roles included

  1. occupants
  2. Building Energy Monitors (BEMs)
  3. Fort Carson senior leadership
  4. computer network personnel

- BEMs are members of the building community that have been assigned responsibility for monitoring building operations for energy saving opportunities and reporting problems. The BEM program has been deployed Army-wide, although not all buildings have been assigned BEMs.

- **Tools –** The research team reviewed existing technologies, systems, and processes and developed new tools that could be used to support the energy use reduction goals and help people do their jobs more easily and consistently. For example, an existing Army-wide BEM program was leveraged to support occupant behavior change, but new tools including a floor-check form were developed to monitor key opportunities for improvement.

Several data collection methods were used to establish the context for developing the behavior change intervention approaches at Fort Carson:

- **Group and individual interviews** with a sample of civilian and military occupants from the five demonstration project buildings. Group interviews provided a basis for the design of a baseline survey. (Interview questions can be found in Appendix F.) Twenty-three individuals participated in the group interviews. Individual interviews were used to help clarify questions about operating conditions in the buildings (e.g., how well thermostat settings worked).

- **A baseline survey** of occupants on satisfaction, attitudes, and behaviors in the five buildings. (Survey questions are in Appendix G.) Fifty-four individuals completed the baseline survey, the vast majority of whom came from the two predominantly civilian buildings.
- **Observation** of occupant behavior and systems in place during site visits. All five buildings were visited at least once by the research team, which observed ancillary plug loads, thermostat settings, the types of lighting and shading available, and other factors. Observations were validated through follow-up interviews with Department of Public Works (DPW) and other personnel.
- **Partial submetering** of energy end-uses in one of the pilot buildings helped identify energy uses with the greatest potential for improvement in two similar administration buildings.[9]

Data collected through these methods was used to establish occupant behavior patterns related to energy use and which behaviors might be good candidates for change based on the need and opportunity for energy savings impact. Table 18 below illustrates how this methodology was used to identify target behaviors for the intervention.

[9] These data were not available prior to the intervention for any of the three military buildings. The lack of both submetering and baseline survey data limited the research team's ability to establish with any certainty what end-use reduction opportunities would have the greatest impact in the buildings occupied primarily by military personnel.

Table 18 Behavior Patterns that Affect Building Energy Performance, Basis for Change, and Priority

Behavior Patterns	How the Opportunity for Change was Identified	Relative Priority for Intervention
Plug Loads: Leave computers and monitors on at night and on weekends	• Focus-group feedback that computers were left on • Current policy requiring computers be left on at night • Interviews suggested most people follow this policy • Submetering data in Building 1219 indicated higher than expected nighttime plug loads • Two computers/monitors in Building 1219 were measured; neither went into sleep mode and each drew over 50 W in standby mode	High
HVAC[(a)]: Occupants do not regularly turn back heating units at night in heating season (Building 1219 and 1118 only)	• Interviews and survey suggested units not adjusted regularly • Energy use of wall-mounted heating units in different modes was measured; modeled savings assuming all units set back 10°F suggested potential ~3% reduction in energy use in Building 1219	High
HVAC: Use of thermostats, office heating units and other measures to control comfort versus less energy-intensive methods	• Survey suggests occupants in both Building 1219 and 1118 were inclined to use non-energy-intensive means of thermal comfort control (use shades, drink something cool/hot) • Measured energy use of wall-mounted heating/cooling units in Building 1219 suggested meaningful savings potential from setbacks	High
Lighting: Use of overhead lights when natural or task lighting may be sufficient	• Survey indicated occupants actively manage overhead lighting in two of the buildings, but interviews and observations suggested task lights not widely used • Metered comparison of task lighting (21 W) to LED ceiling lights (40 W) in Building 1219 suggested savings potential; Building 1118 has fluorescent ceiling lights so even greater savings potential	Medium
Lighting: Lights left on when rooms unoccupied	• Survey suggests many already turn lights off • Observation during site visit (most were off)	Low

Behavior Patterns	How the Opportunity for Change was Identified	Relative Priority for Intervention
Plug Loads: Use of desktop computers when laptops may meet business needs	• Survey results suggest 70/30 desktop/laptop ratio • Observed during site visit	Low
Plug Loads: Use of energy-intensive appliances in office spaces	• Interviews and survey results suggest policy against use of personal appliances effectively limits this • Only one building was observed to have much opportunity to remove appliances (Building 9420)	Low
Plug Loads: Use of personal printers	• Observation during site visit suggested limited opportunities in the military and civilian buildings • Interviews indicated most printers have been centralized but some opportunity for consolidation remains in Building 1118	Low
(a) HVAC = heating, ventilation, and air conditioning		

Based on the survey and focus group results, interviews, site visit observations, and energy use measurements, the intervention was designed to focus on two key behaviors:

- **shutting down computers at night, and**
- **setting back individual heating units at night (heating season only) in the two buildings with decentralized controls.**

Other behaviors were reinforced as part of the intervention, including turning off lights in unoccupied rooms and using task and natural lighting instead of overhead lighting when possible.

Develop Action Plan

After assessing the rules, roles, and tools, the research team developed an action plan to define the target actions that different audiences are expected to take and the strategies that will be implemented to achieve the program goals.

At Fort Carson, specific performance objectives were defined for each of the key roles in the intervention; these are summarized in Table 19.

Table 19 Performance Objectives for Groups Targeted through the Intervention

Occupants
Shut down computers at night
Set back wall-mounted heating units 5–10°F when leaving for the day or for extended periods during heating season (Buildings 1219 and 1118 only)
Turn off overhead lights when leaving an office or conference room
Use task and natural lighting instead of overhead lights when adequate
Use non-energy-intensive methods of managing thermal comfort including: • adjust window shades • drink something hot/cold • dress for the weather and wear layers (civilian occupants)
Use shared appliances in building, such as refrigerators and coffee makers. Limit use of nonessential appliances and space heaters (only applied to Building 9420)
Share energy saving ideas with BEMs and colleagues
Building Energy Monitors (BEMs)
Participate in BEM training
Conduct weekly floor checks with BEM checklist and share results with research team

Occupants
Communicate with occupants (in person and via email) about energy saving behavior performance and opportunities for improvement
Submit work orders for operational problems that could be affecting energy use
Leadership
Participate in start-up and mid-project status briefings
Make sure qualified BEMs are assigned to the five pilot buildings and resourced for the pilot
Demonstrate support for the intervention by sending a letter to occupants of the demonstration buildings
Make sure managers of BEMs encourage follow-through on job duties
Computer Network Personnel
Authorize policy exemption in the five demonstration buildings to allow nighttime computer shutdown
Measure compliance with computer shutdown via evening network sweeps

In the two primarily civilian administration buildings (Buildings 1219 and 1118), occupants of individual offices and shared workspaces had direct control of wall-mounted heating and cooling units. Occupants were asked to turn back the setting approximately 10°F before leaving their offices for the day. This measure was expected to have the greatest potential impact on energy use in these two buildings based on modeled estimates.[10]

Strategies to promote these energy saving behaviors were mapped to the eight principles of behavioral and institutional change discussed in the State of Research on Behavior Change and Energy Reduction section to make sure that most of the principles were being invoked through the intervention. The mapping is illustrated in Table 20.

[10] The HVAC controls in the three military buildings were centralized; therefore this measure did not apply to occupants of those buildings

Table 20 Behavioral and Institutional Change Principles and Examples of Planned Intervention Strategies

Behavioral and Institutional Change Principles	Fort Carson Intervention Strategies
Social Network & Communications	• Appoint locally recognized and respected member of the building community (the BEM) to advocate and monitor for energy conservation opportunities • Equip BEMs to send regular communications and engage occupants on *specific* actions they can take in their buildings • Provide information showing the actions undertaken by peers in neighboring buildings
Multiple Motivations	• Appeal to organizationally relevant topics in communications (security, cost-saving, and environmental interests) • Promote competition among buildings by comparing adoption rates for different occupant energy saving behaviors and actual building energy performance if data are available
Leadership	• Secure leadership commitment by briefing Garrison Commander and 4th Infantry Division Commander before the project start and again mid-intervention • Leadership sends letter to occupants conveying importance of their role in energy conservation and leadership commitment to conservation • Leadership asks BEM managers to provide for accountability and follow-through on BEM duties[(a)]
Commitment	• Did not employ
Information and Feedback	• BEM shares results of floor checks and computer shutdown performance with occupants • Energy coordinator shares monthly building energy use with BEMs[(a)]
Infrastructure	• Work with chief of the computer network services department to authorize policy exemption in five demonstration buildings allowing nighttime computer shutdown • Establish recommended responsibilities and qualifications of BEMs (see Appendix H) • Develop simple form to facilitate BEM floor checks • Provide training to BEMs on monitoring and promoting better energy management in their buildings
Social Empowerment	• BEMs ask occupants for energy conservation ideas

Behavioral and Institutional Change Principles	Fort Carson Intervention Strategies
Continuous Change	• Bring together BEMs to discuss lessons learned and modify tools or approach as necessary
(a) While these activities were part of the intervention design, they were not fully implemented due to different challenges encountered. For example, energy meter failures on some buildings limited distribution of building energy use reports.	

Once strategies were defined, a detailed action plan was created that laid out key activities, responsible parties, and a timeline for rolling out the intervention.

Implement Plan

Once the strategies for promoting change and action plans have been defined, implementation should occur in a way that suits the organizational context and the people and roles being targeted to change.

The intervention was limited to a 12-week period from March 4 through May 24 of 2013. Throughout the intervention period, the research team tracked BEM engagement, monitored occupant compliance via BEM floor check documentation (form is shown in Appendix I) and computer network scans, and drafted messages to be shared with occupants. An intervention period of six months would have enabled a more rigorous test of strategies and their impacts, including more institutional level changes that have the potential for greater impact than behavioral changes. However, the intervention launch was delayed several months primarily due to fluctuating occupancy in the military buildings,[11] delays in scheduling meetings with senior leadership support for the intervention, and challenges associated with data collection to establish baseline performance.

Implementation of change strategies should occur in a way that suits the organizational context and the people and roles being targeted.

Measure and Evaluate

The final step in the institutional change process—measurement and evaluation—is critical to establishing whether the actions implemented led to the desired energy savings.

A detailed evaluation plan was developed prior to the launch of the intervention at Fort Carson (Appendix J). The plan identified the specific behavioral change measures to be evaluated, who would collect the data, the timing and frequency of data collection, how the data would be recorded and shared with the research team, and the analytic methods that would be used to evaluate the effectiveness of the measure relative to the baseline performance.

The primary evaluation methods included the following:

- Evaluation of data by computer network personnel, who would scan all computer assets that could be shut down without security risk two times each day (at noon and again after work hours) and compare the ratio of computers that signaled they were on

[11] 4/4 BCT units were rotating between deployment and the reset/training phases of the Army Force Generation (ARFORGEN) cycle.

- Self-reported changes in behavior, captured via the post-intervention survey
- Post-intervention interviews with three of the five BEMs to understand what actions were implemented at the building level (two did not respond to the interview request)
- Reviewing weekly floor check forms completed by the BEM to gauge general compliance levels during the intervention (e.g., lights were observed to be off in 80% of unoccupied rooms)
- Analysis of whole-building and submetering data, as available.

While the research team initially planned to make direct comparisons of occupant responses to both the baseline survey and post-intervention survey, the low response rate to the baseline survey in three of the five buildings precluded this type of analysis. As a result, the post-intervention survey asked occupants to self-report whether they had changed specific behaviors during the previous three months and which factors most influenced any change in behavior.

Key Research Questions

1. How do occupants of green buildings interact with building features?
2. How do occupants of green buildings perceive their work environment?
3. What behaviors have the greatest potential to save energy?
4. What approaches are most effective at promoting energy saving behaviors in buildings?

Findings

This section summarizes findings in support of each key research question:

1. How do occupants of green buildings *interact* with building features?
2. How do occupants of green buildings *perceive* their work environment?
3. What *behaviors* have the greatest potential to save energy?
4. What *approaches* are most effective at promoting energy saving behaviors in buildings?

The first two questions are addressed in the Occupant Interaction and Satisfaction with Building Features section with findings from the baseline survey and supported by interviews, focus groups, and direct observation. The second two questions are addressed through the post-intervention survey and supporting methods.

Results from both surveys must be carefully interpreted in the context of which groups responded or did not respond. There were just 54 respondents to the baseline survey and 102 respondents to the post-intervention survey out of roughly 690 total occupants at the end of the intervention period.[12] A large majority of respondents to both surveys were civilians (roughly 80%) from Buildings 1118 and 1219. Because these two buildings had higher response rates to the post-intervention survey (24% and 35% respectively), they were the focus of the building-level analysis below.

[12] Because the three military-occupied buildings were still being filled with new military occupants at the time of the baseline survey, the total number of potential survey respondents at that time could not be established. The post-intervention occupancy levels are believed to be approximately 690, so 102 respondents represents a response rate of 15% across all buildings. When the buildings were selected to be part of the demonstration project, the buildings were expected to be fully occupied at the time the baseline survey was implemented.

As noted previously, many soldiers, who would eventually become occupants of the three military-occupied buildings throughout the intervention period, were just returning from deployment and on vacation at the time of the baseline survey. The fact that they may not have been engaged in the intervention from the beginning may have contributed to low numbers of post-intervention responses from military personnel.

More detail on the characteristics of respondents to the survey can be found in Appendix K.

Occupant Interaction and Satisfaction with Building Features

The baseline survey provided insights into the institutional context of how occupants used different green building features, their level of satisfaction with these features, and general awareness around energy use in buildings.

Building features that respondents to the baseline survey reported adjusting most often were window shades/blinds and overhead lights, followed by different mechanical heating and cooling controls (i.e., room air conditioning [AC] units, thermostats, and permanent heating/cooling units)[13] (Figure 52). The fact that adjusting heating and cooling units to affect comfort was only a “regular” behavior for 9–10% of

Research Questions

1. How do occupants of green buildings interact with building features?
2. How do occupants of green buildings perceive their work environment?

[13] In Buildings 1219 and 1118, “room AC unit” and “permanent heating/cooling unit” were likely interpreted to be the same thing as the wall-mounted units provided heating and cooling in offices. Temperature could be adjusted on both the heating/cooling fan unit and a thermostat on the wall.

occupants suggested an opportunity to save energy through a nighttime temperature setback intervention measure. Most workspaces were observed to have task lighting, while less than half of the respondents used desk or task lighting. Based on comments from interviewees, the design of the task lighting made it impractical to use.[14]

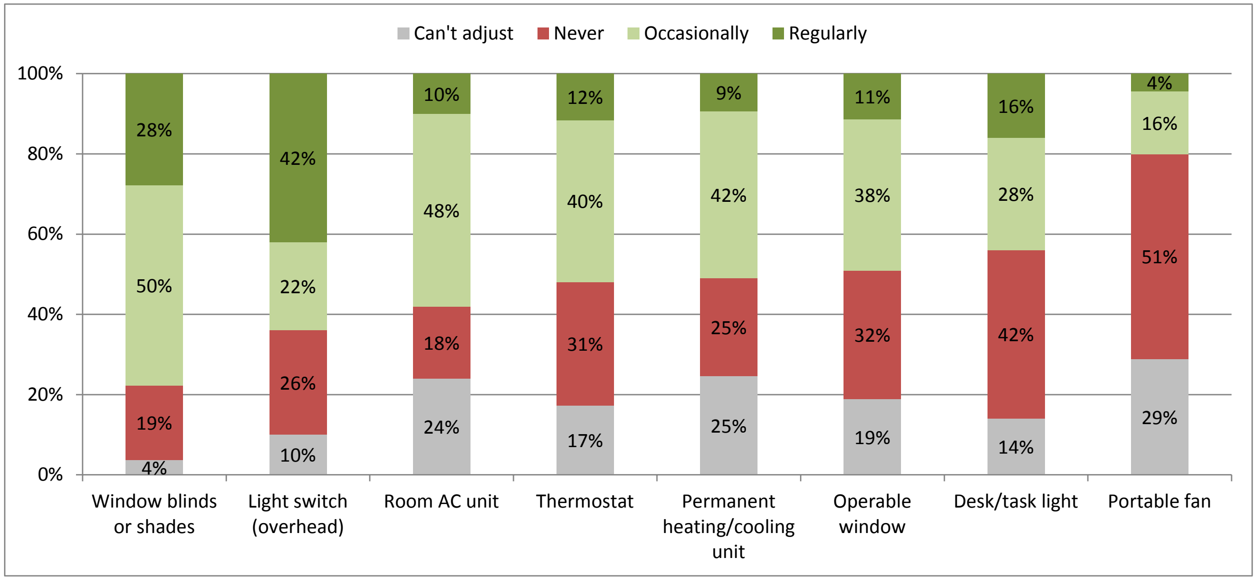


Figure 52 Frequency with Which Different Building Features are Adjusted by Occupants (baseline survey)

Only 52% of respondents to the baseline survey considered themselves informed on the energy saving features in their building (Figure 53), which suggested opportunity for improvement, perhaps by making information on how building features can help save energy more locally relevant.

[14] Task lighting in Buildings 1219 and 1118 was fluorescent lighting integrated into the back of the desk unit. To increase use of task lighting, the acquisition of adjustable LED desk lamps was considered but was not feasible as part of this intervention.

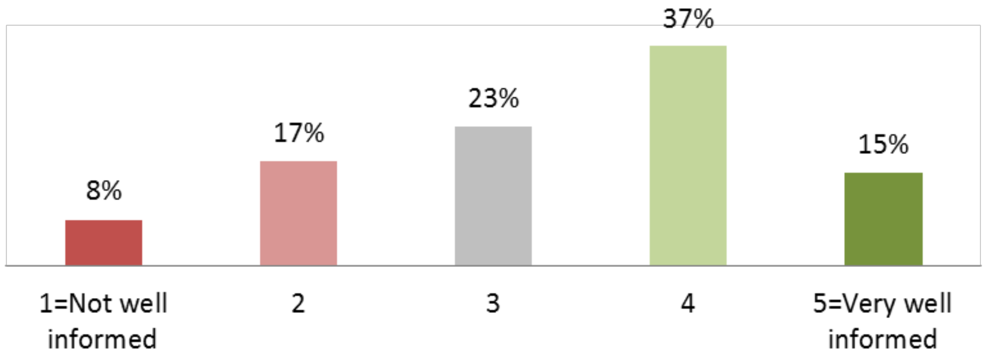


Figure 53 How Well Informed Occupants Feel About Energy Saving Features of their Building (baseline survey)

Baseline survey responses indicated that occupants are generally satisfied with most personal workspace and building features. More than 80% of the respondents were either satisfied with or indifferent to every feature but one: views of the outdoors, for which dissatisfaction was slightly higher (see Figure 54). Eighty-three percent (83%) of occupants were satisfied with the building overall. Even thermal comfort, which is often one of the greatest sources of occupant complaints, had satisfaction rates of 68%, which is much higher than typically found with building occupant surveys, and likely due to respondents having direct control over heating and cooling units. For comparison, a study which examined responses from 34,169 occupants in 215 buildings found that more occupants were dissatisfied (42%) with thermal comfort than satisfied (39%) (Huizenga 2006).

Adjusting heating and cooling units was only a regular behavior for 9–10% of occupants, thus suggesting an opportunity to save energy.

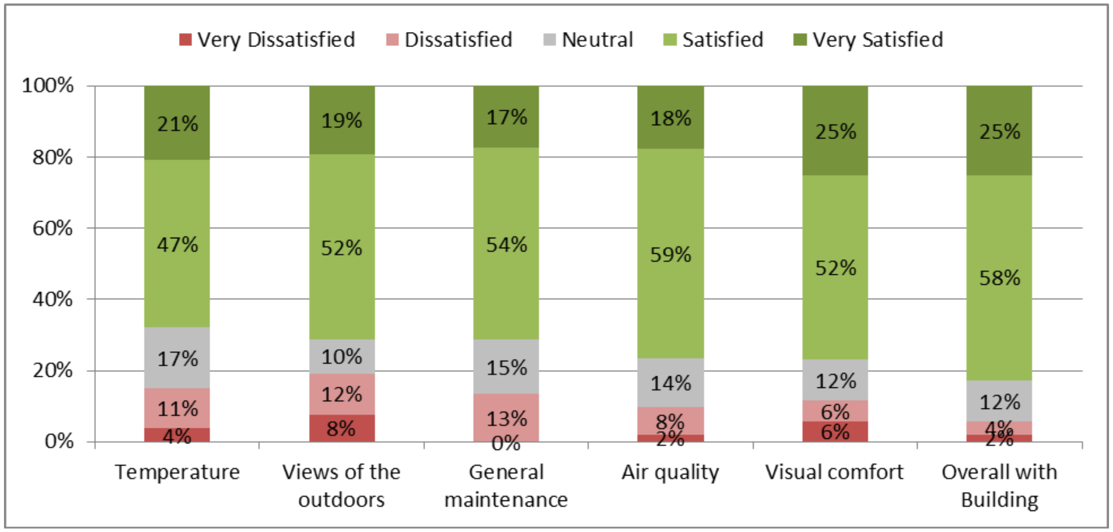


Figure 54 Occupant Satisfaction with Different Personal Workspace or Building Features (baseline survey)

Figure 55 below shows how satisfied occupants are with different building features in terms of how well they function to create a comfortable work environment.[15] Overall, occupants had the lowest levels of dissatisfaction plus highest levels of satisfaction with some of the features that let them control natural light in their workspaces (i.e., window blinds and roller shades). Waterless urinals were the exception to the generally high satisfaction ratings with 29% expressing dissatisfaction. During group interviews, complaints focused on odors emanating from the urinals.

[15] Respondents who did not have experience with each feature (about one-third of all) were excluded from this analysis.

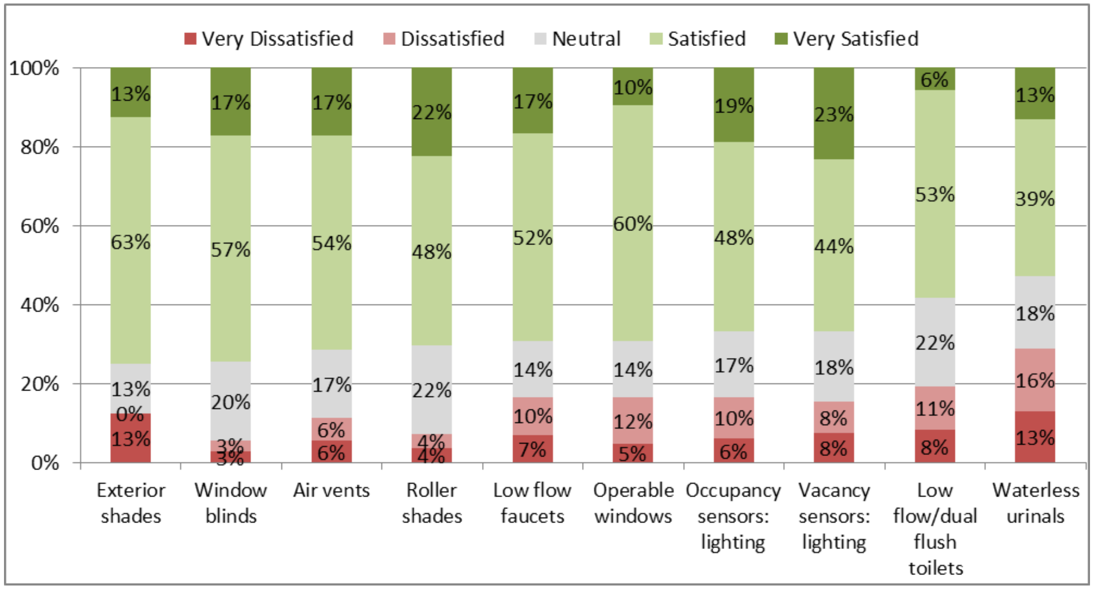


Figure 55 Satisfaction with How Well Different Building Features Function to Create a Comfortable Work Environment (baseline survey)

Changes in Behaviors and Attitudes

Behavior Changes

The measure of success of the intervention is whether the groups targeted for behavior change did in fact modify their behavior as a result of the intervention strategies, and whether any actions taken resulted in energy savings. As described below, the research team did find evidence that several of the intervention measures were effective.

Research Questions

3. What behaviors have the greatest potential to save energy?
4. What approaches are most effective at promoting energy saving behaviors in buildings?

In the post-intervention survey, occupants were asked how frequently they took each of the actions that were promoted as part of the intervention. Occupants were most likely to turn off their monitor and computer at night, followed by turning off lights when leaving a room. The action that occupants were least likely to take was “turning off overhead lights and using natural light or task lighting when adequate.” During interviews, some occupants of Buildings 1219 and 1118 commented that task lighting was difficult to use because it was attached to the back of the desk furniture and could not be moved to areas where tasks were performed. This may have contributed to comparatively fewer people taking this action. A comparatively high percentage of respondents (23%) also reported never or rarely setting back thermostats at night, which was one of the primary intervention measures (Figure 56).

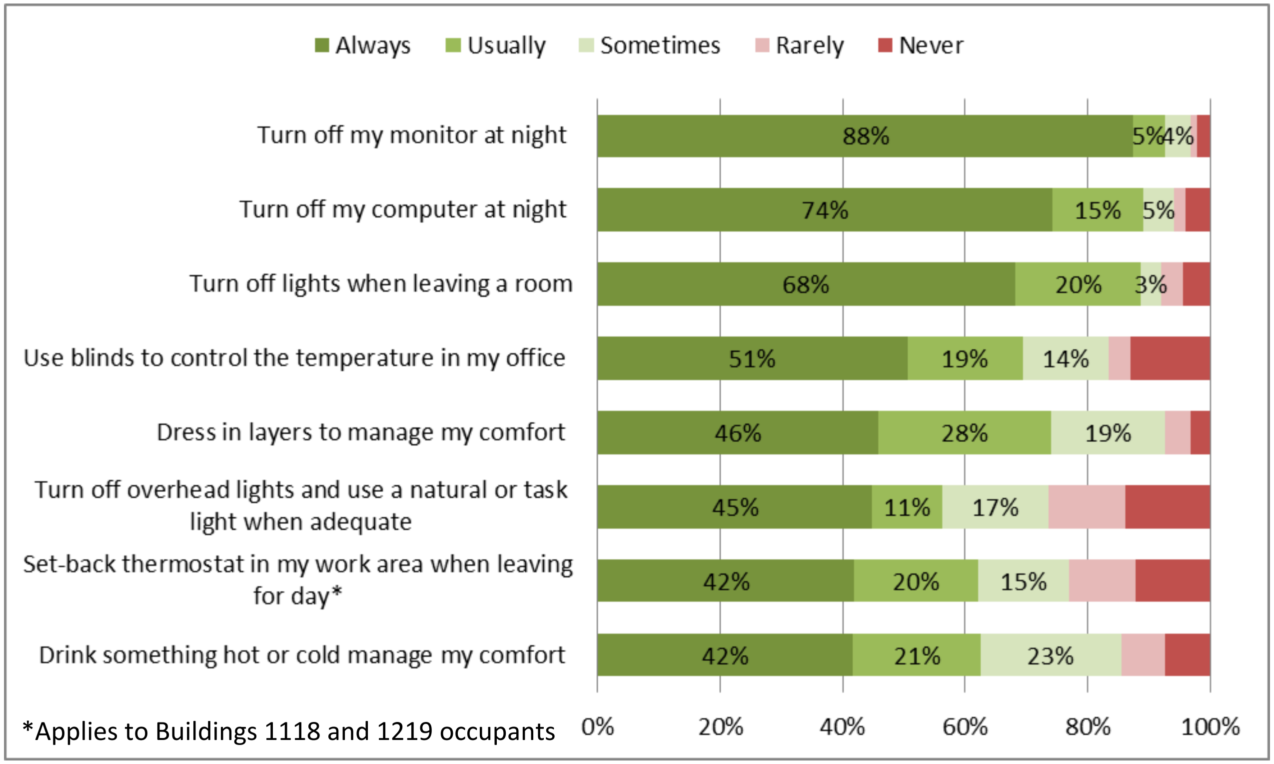


Figure 56 Frequency with Which Occupants Reported Taking Different Energy Saving Actions at Work (post-intervention survey)

To help gauge specific energy saving actions that were taken as a result of the intervention, occupants were also asked whether the frequency with which they took those actions had changed over the three-month demonstration period. As illustrated in Figure 57, there were reported increases in the frequency with which occupants took each of the actions being promoted to directly reduce building energy use. The greatest degree of change reported was for nighttime computer shutdown. Seventy-two percent (72%) of respondents reported shutting down their computers more at the end of the intervention period than at the start. This may be due to the relative ease of switching off a computer and because turning off computers typically only impacts the user whereas other energy reduction actions, such as setting back heating units, may affect others.

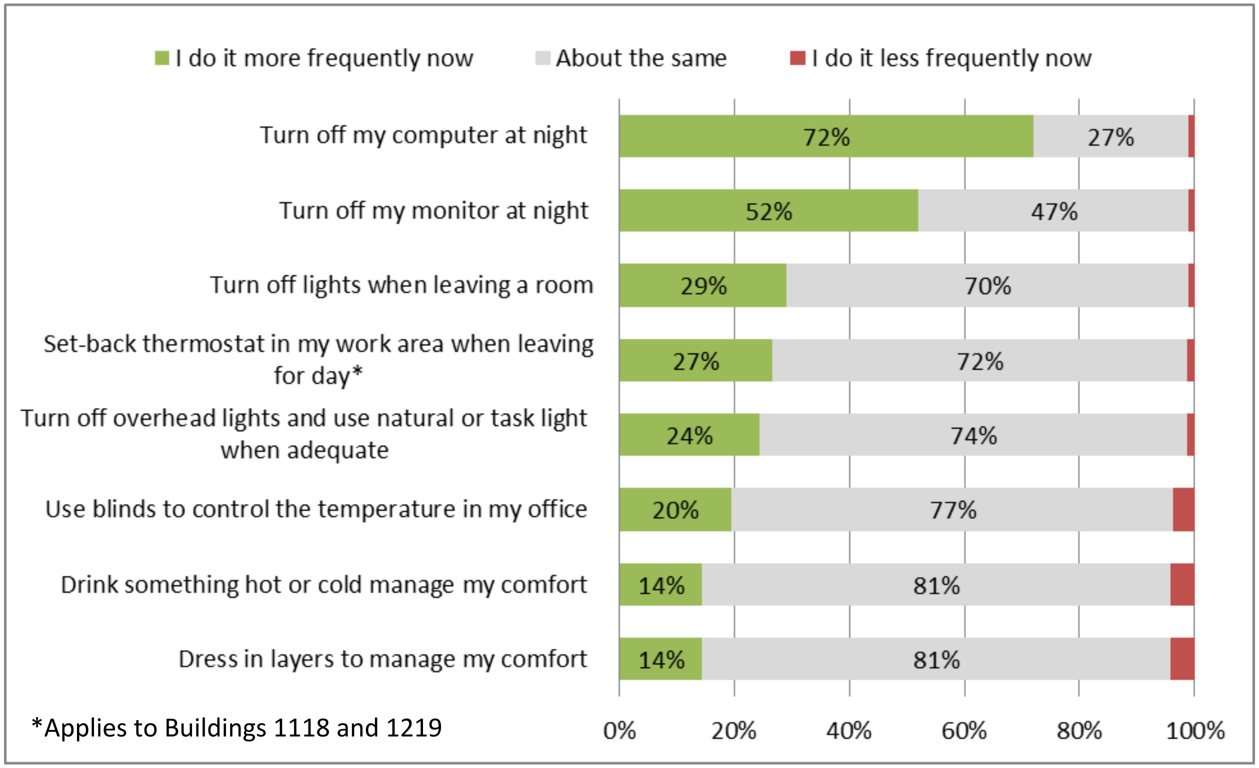


Figure 57 Change in Frequency with Which Occupants Took Different Actions during the Intervention (post-intervention survey)

It is also noteworthy that while 42% reported always setting back thermostats, 27% of respondents indicated they took that action more frequently at the end of the intervention period than they did at the beginning. There was some difference in reported changes in this behavior by building: 32% of Building 1118 respondents reported adjusting the thermostat more compared to 23% of 1219 occupants (see Figure 58).

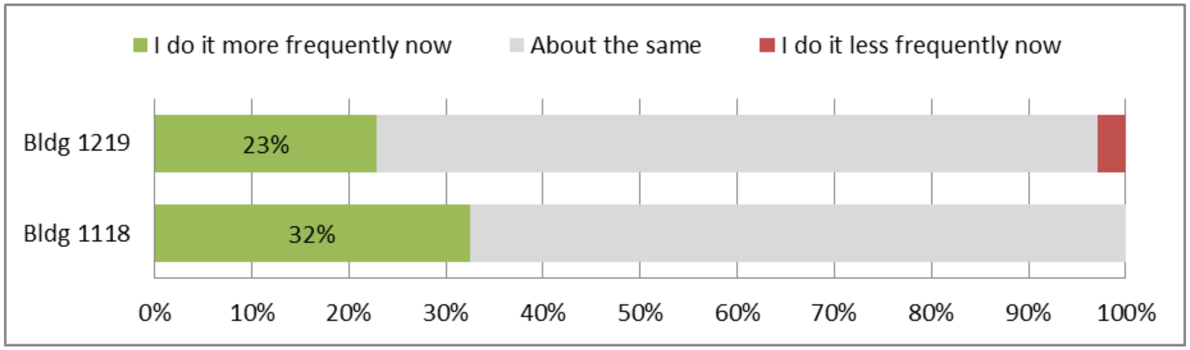


Figure 58 Frequency with Which Thermostats are Set Back in Work Area When Leaving for the Day at the End of the Intervention Compared to the Beginning (post-intervention survey)

Building 1118 respondents were just as likely as those in Building 1219 to turn off lights when leaving a room at the end of the intervention period. However, Building 1118 appears to have made the greatest change as a result of the intervention, with 33% reporting they turn off lights more frequently now than they did before, compared to 19% for the occupants of Building 1219.[16]

Weekly computer network scans provided a more comprehensive and accurate source of data on compliance with the nighttime computer shutdown measure by building. Because all network resources that were able to be shut down at

[16] There were too few respondents to the post-intervention survey from the military buildings to include in any building-to-building comparisons; therefore only survey responses from Buildings 1219 and 1118 are compared.

night were scanned, this is a more reliable estimate of compliance than self-reported compliance via the post-intervention survey. Four of the five buildings started with computer shutdown compliance rates of 8% or lower, which reinforced that this was not a typical behavior for most occupants. The exception was Building 1219, in which occupants were shutting down 51% of computer assets in Week 1 (see Figure 59). All five buildings improved from their starting point, although the timing of changes in behavior and degree of change observed by building varied. Buildings 1118 and 9447 showed improvement as early as Week 2. Two of the three military-occupied buildings notably did not show much change in behavior until midway through the intervention. Possible reasons for these differences are discussed below.

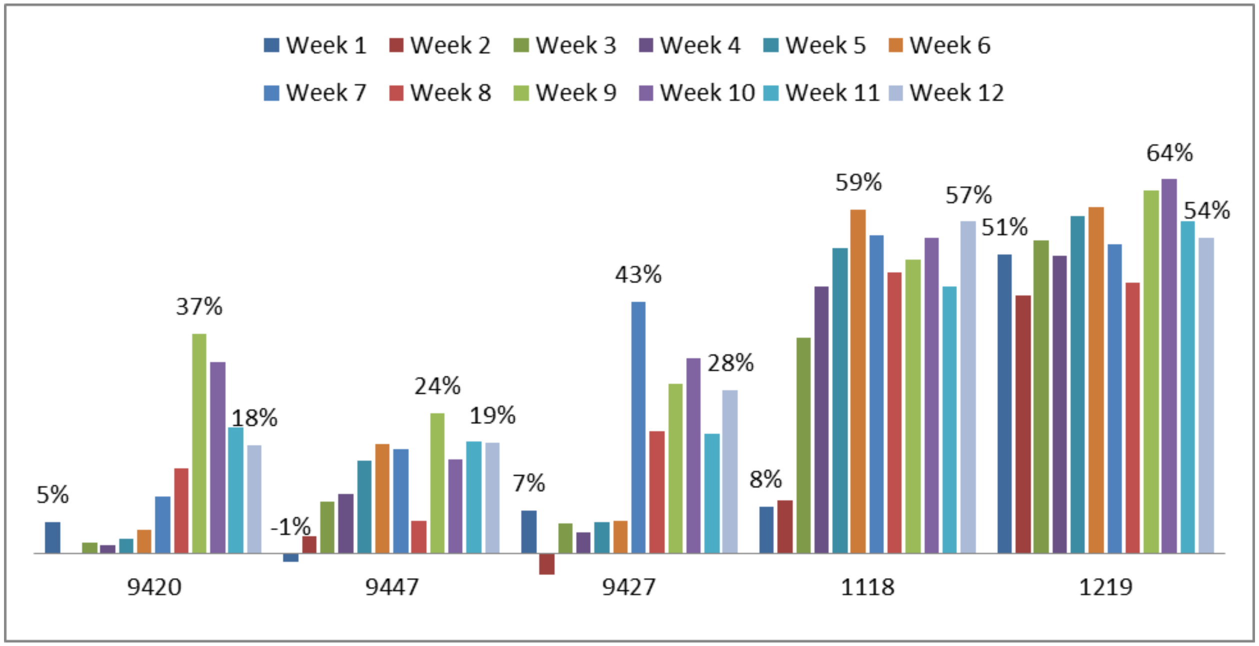


Figure 59 Percent of Computers Shut Down at Night by Building Based on Computer Network Scans (numbers represent first week, final week and highest compliance rates)

Figure 60 shows the difference in computer shutdown compliance rates between the first and last weeks of the intervention, which gives some indication of each building's ability to sustain the change; the difference between the first week and the peak week of compliance conveys the maximum change in behavior observed in each building. The level of improvement between Week 1 and Week 12 ranged from 3% in Building 1219 to 49% in Building 1118. The maximum change between Week 1 and the week of peak compliance in each building observed ranged from 13% in Building 1219 to 51% in Building 1118. While the military buildings had lower total compliance levels than Buildings 1219 and 1118, this figure shows that military buildings still showed a significant degree of change in a short period of time.

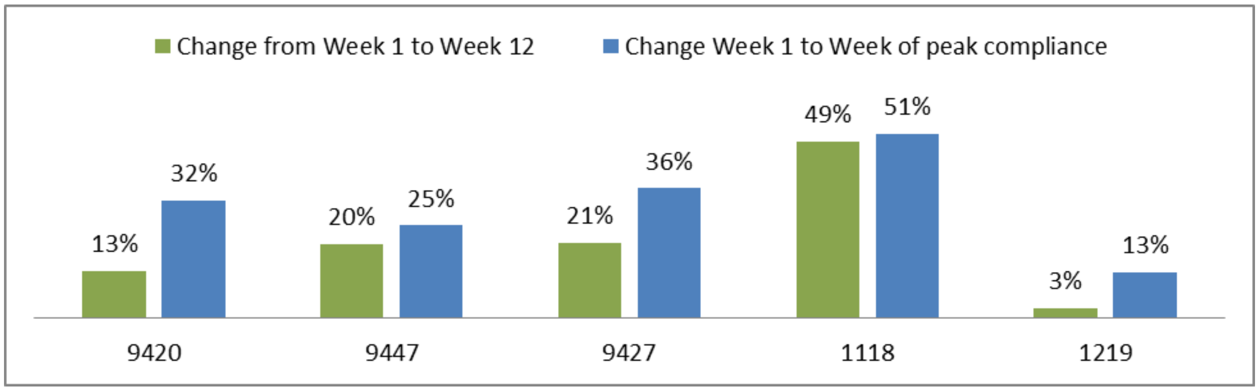


Figure 60 Change in Computer Shutdown Behavior by Building Based on Network Scans

Awareness and Attitude Changes

A comparison of baseline and post-intervention survey results showed high levels of awareness (near 90%) and favorable attitudes of Fort Carson's net zero energy goals across both surveys, with little change (Figure 61). Eighty percent (80%) of the baseline survey respondents believed they have the right skills to save energy. This percentage increased after the intervention. However, almost one-third (31%) of respondents were ambivalent or even disagreed that they felt responsible for reducing energy in their own building before the intervention. This suggested that there was some disconnect between having the ability to affect energy use and feeling responsible to do something about it in their building. The proportion of those ambivalent or in disagreement dropped slightly to 23% in the post-intervention survey.

Overall, the change in occupant responses reflected a positive reaction to the interventions. There were noticeable changes in three attitudes between the baseline and post-intervention surveys:

- The percentage of respondents who felt they had time to work on Fort Carson net zero energy efforts increased from 84% to 89%.
- The percentage of respondents who felt personally responsible for reducing energy use increased from 70% to 76%.
- The percentage of respondents who believed reducing energy use in their building was important increased from 49% to 58%.

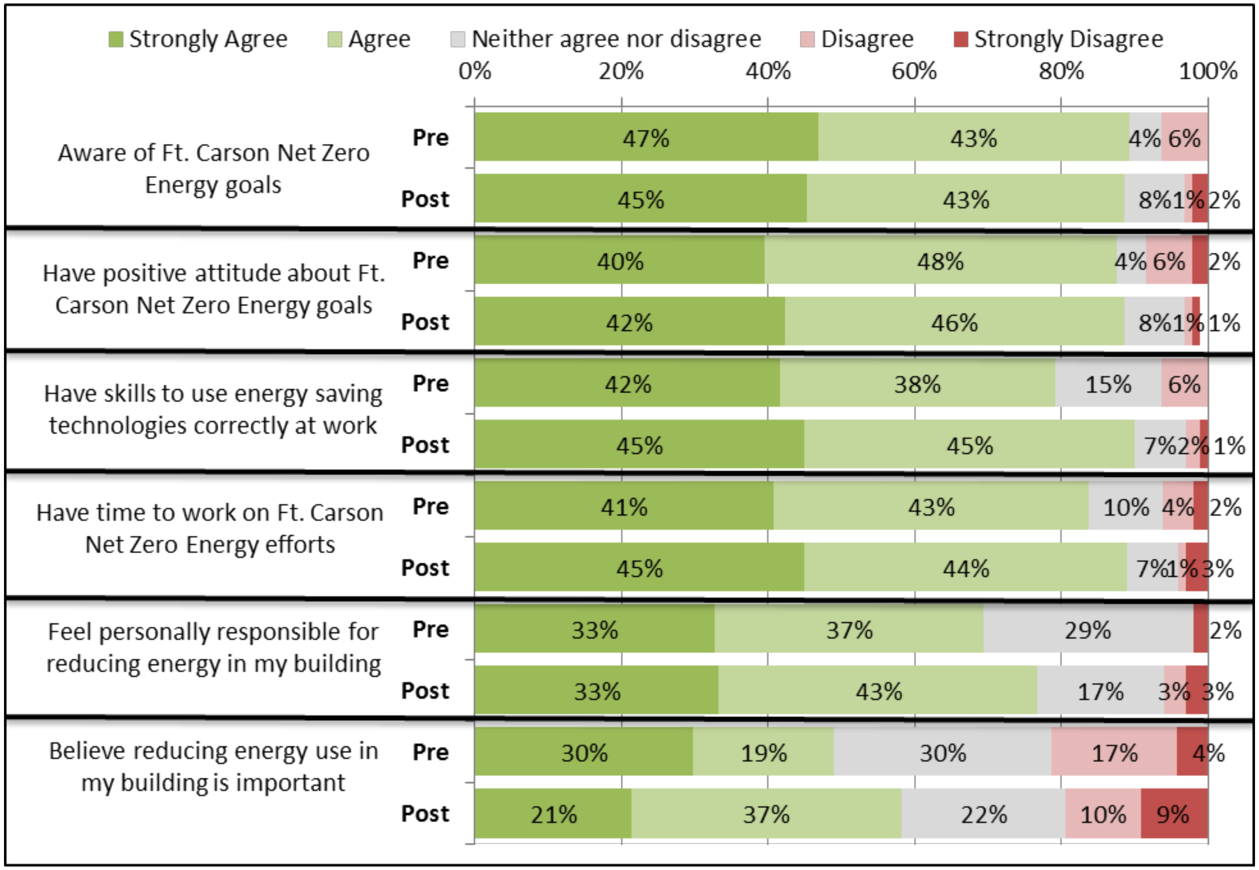


Figure 61 Change in Awareness and Attitudes about Energy Conservation in all Fort Carson Buildings (upper bar is baseline and lower bar is post-intervention)

The changes in awareness and attitudes varied by building due in part to differences in the way the intervention measures were implemented by building, as discussed in the Highest Impact Strategies for Behavior Change section. In Building 1118 (see Figure 62), there were marked differences in the proportion of respondents before and after the intervention who either agree or strongly agree that

- they *have the skills* to use energy saving technology at work, which increased from 65% to 90%
- they *feel personally responsible* for reducing energy in their building, which increased from 64% to 89%
- reducing energy use in their building is important, which increased from 76% to 92%
- they *have time* to work on Fort Carson net zero energy efforts, which increased from 41% to 67%.

Giving occupants *the skills* or ability to save energy in their local work environment was a key objective of many of the intervention strategies implemented. It appears that the intervention successfully drove at least some of that change. The change in proportion of occupants reporting they *had time* to work on net zero energy efforts might suggest that energy saving behaviors may be perceived as too much work until people learn there are easy behaviors involved.

Giving occupants *the skills* or ability to save energy in their local work environment was a key objective of many of the intervention strategies implemented

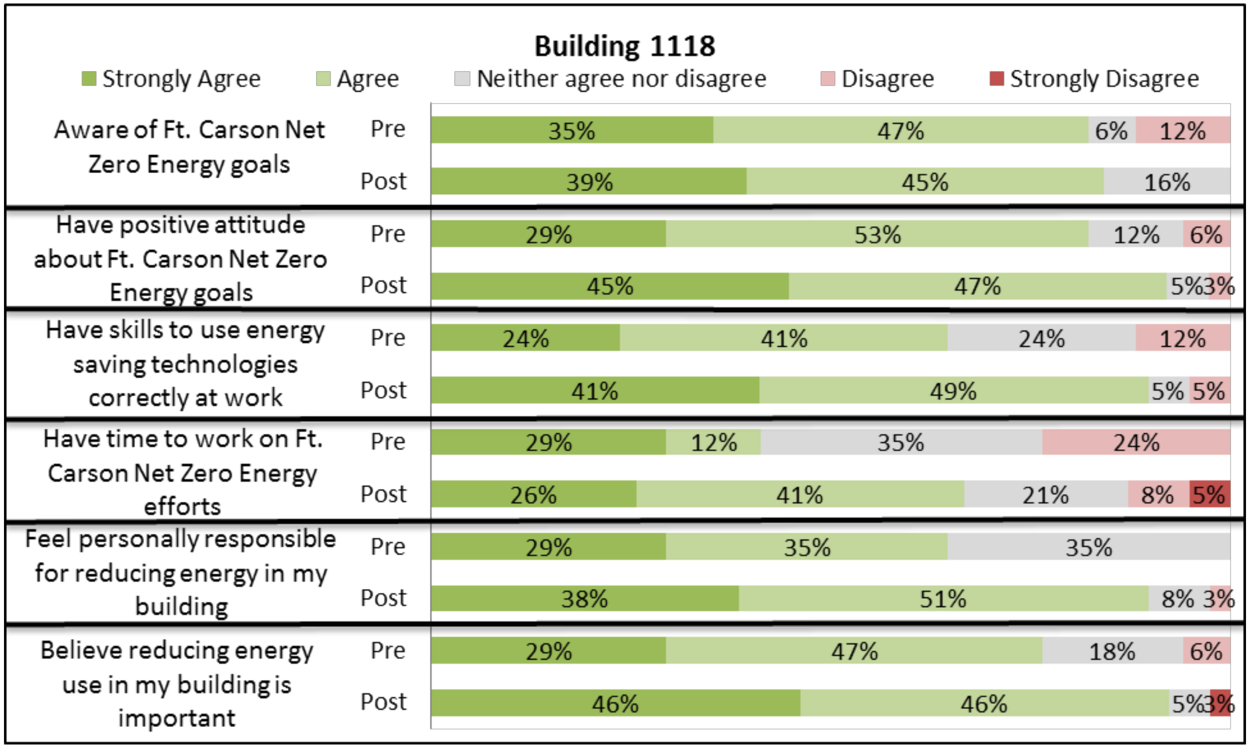


Figure 62 Changes in Awareness and Attitudes around Energy Conservation in Building 1118

One notable difference between Building 1219 and 1118 in energy conservation awareness and attitudes over the intervention period is the perception of time available to work on Fort Carson net zero energy efforts (see Figure 63). In fact there was a decrease (6%) in Building 1219 occupants who strongly agree that they have time to work on net zero energy and a notable increase (6%) in those who strongly disagree that they have time. Follow-up discussions with personnel suggest this could be the result of Building 1219 occupants—most of whom work in the Department of

Public Works—feeling they already do all they can as part of their daily job functions, and the fact that furloughs, rolled out during the intervention, squeezed their time even more.

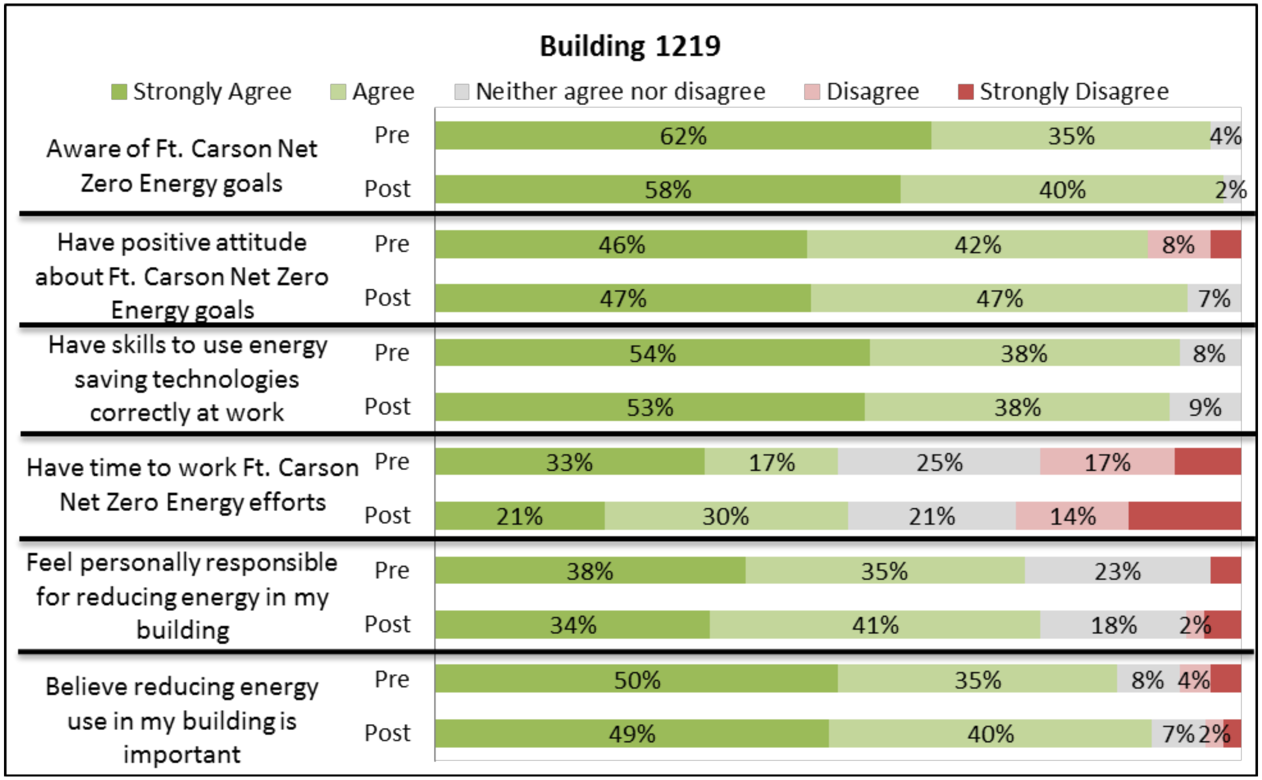


Figure 63 Changes in Awareness and Attitudes around Energy Conservation in Building 1219

Inadequate responses to either the pre- or post-intervention survey of Building 9420 occupants (just 13 out of 250 occupants) prevented comparison of their energy conservation awareness and attitudes. However, what we know about building occupancy patterns of military personnel may provide insights to their likely level of awareness and attitudes about net zero energy. Military personnel change assignments and physical locations regularly, unlike civilians who may work in the same location for many years. As a result, soldiers may not have the same level of personal connection—and therefore no perceived personal responsibility—to the locations in which they are temporarily assigned. This would likely make changing soldier attitudes more difficult and require different tactics from civilian occupants. As discussed in the following sections, the tactics for encouraging energy conservation behaviors in a military setting must take into account the transient nature of military occupants.

Highest Impact Strategies for Behavior Change

Responses to the post-intervention survey suggested that several factors had an influence on occupant behavior (see Figure 64).

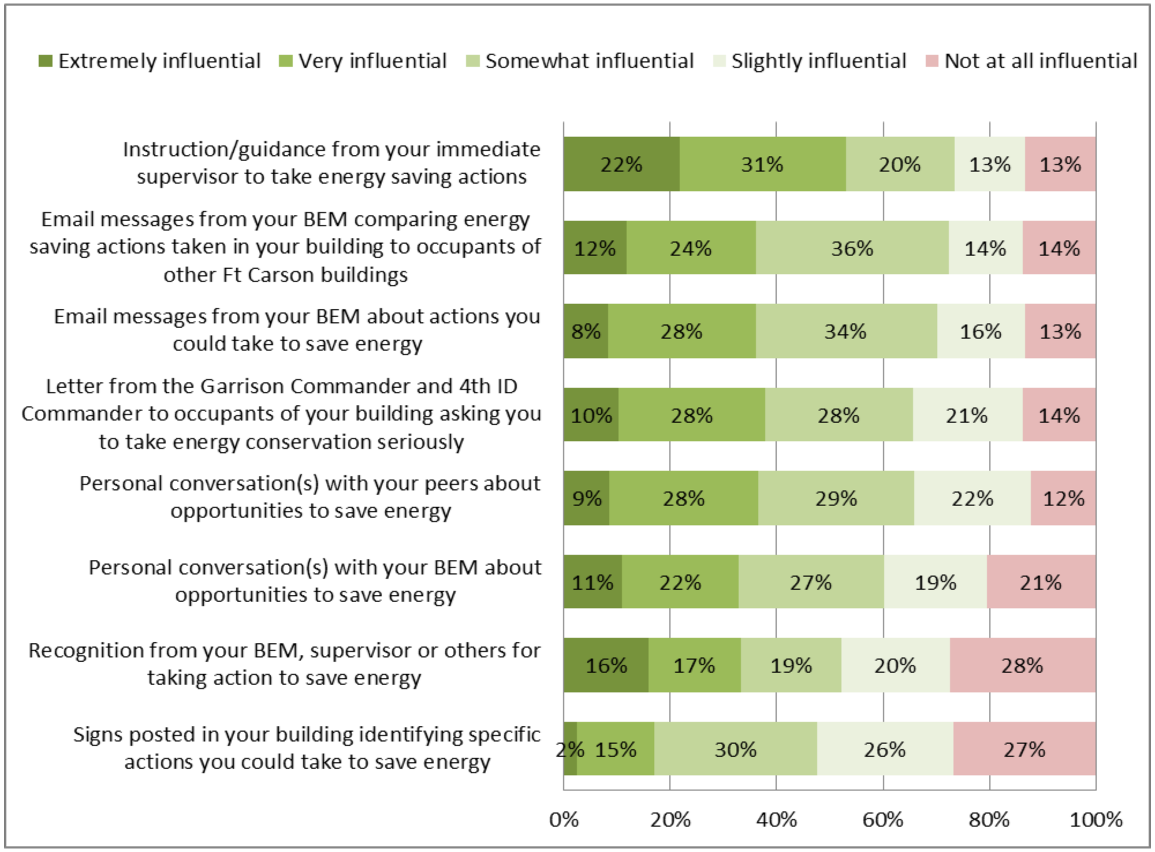


Figure 64 Extent to Which Factors Influenced Energy Use Behavior during the Intervention for all Buildings (post-intervention survey)

Factors identified by the greatest number of respondents as either extremely or very influential on energy use behavior were:

- **Instruction from immediate supervisors on energy conservation behaviors** – This action was considered to have the greatest impact among respondents in each of the three buildings that had sufficient data for comparison. Instruction on the conservation behaviors being promoted came in the form of the BEMs briefing group supervisors in civilian buildings and Executive Officers in charge of operations for each unit command in military buildings. The BEM of Building 1118, which showed the greatest improvement of all five buildings, also routed all email communications through group supervisors to help promote accountability. That 61% of respondents from that building considered instruction from a supervisor to be extremely or very influential suggests this can be a very effective strategy (Figure 65).

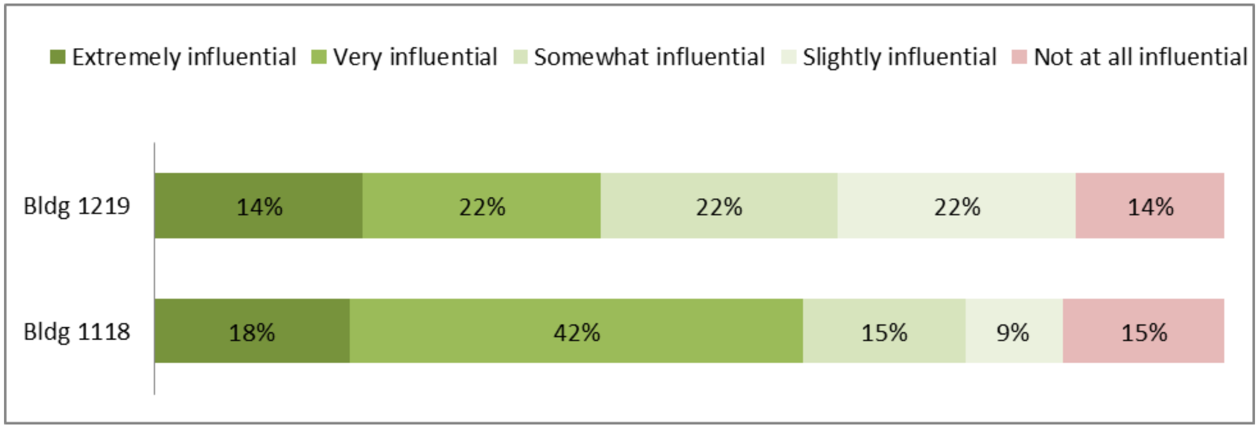


Figure 65 Influence of "Instruction or Guidance from Immediate Supervisor to Take Energy Saving Actions" in Civilian Administration Buildings (post-intervention survey)

- **Email messages from BEMs to occupants** – The four email messages sent from BEMs to occupants over the course of the intervention were considered extremely or very influential by 36% of respondents; another 50% found them somewhat or slightly influential, and just 14% indicated they had no impact on their behavior. The first email message provided only information on specific actions that occupants could take to improve building energy performance. The second email provided information on actions as well as a description of the results of floor checks (e.g., 70% of offices checked appeared to have lights off when unoccupied). The last two email messages also included a graph comparing nighttime computer shutdown compliance by building. (Email messages can be found in Appendix L). There was little difference of opinion on the effectiveness of messages that aimed to foster competition across buildings compared to those that just provided information on actions to taken. This may be because there was limited feedback provided during the short intervention period—just two email messages—or the feedback provided was limited to behaviors and not energy use impacts of those behaviors, due to limitations with metering.

- **Letter from senior leadership** – A letter from Fort Carson leadership (see Appendix AN) to occupants of the demonstration buildings was distributed by at least three BEMs during the first week of the intervention. It could not be confirmed whether the letter was distributed in the two military buildings. Thirty-eight percent (38%) of all respondents found this extremely or very influential.

- **Conversations with peers** – This is not a factor the research team directly managed as part of the intervention. However, the periodic email communications, posters, surveys, and the presence of an energy monitor in the building may have helped foster a dialogue that may not have occurred before the intervention. That this was extremely or very influential for 37% of all respondents—and more important than direct conversations with BEMs—reinforces the importance of the social networking principle to successful interventions. If communications can help to foster dialogue among occupants about energy conservation, this may be helpful. Differences between the two civilian buildings suggest that conversations with peers had greater influence in Building 1118 (see Figure 66). The BEM of that building did report talking with supervisors about opportunities for improvement when they were identified (e.g., when lights were consistently being left on during the lunch hour when no one was present), which may have been more likely to foster a dialogue than email alone.

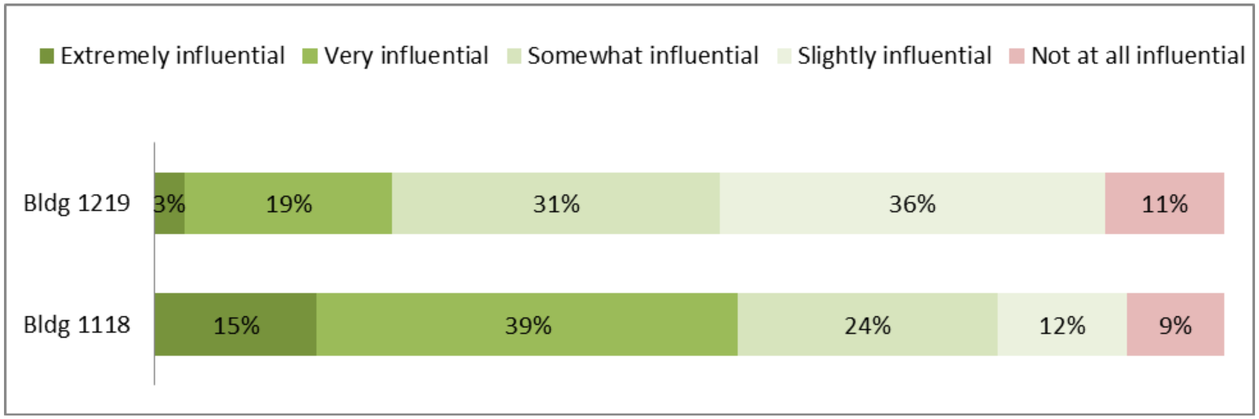


Figure 66 Influence of Personal Conversations with Peers about Opportunities to Save Energy

As illustrated in Figure 64, the least influential intervention factors were signs posted in buildings[17] and recognition from others.[18]

Comparing actions taken by BEMs in each building to observed weekly changes in computer shutdown compliance was used to help evaluate the effect of specific actions on behavior. Table 21 illustrates that three of the BEMs were fairly engaged while two did not appear to follow through on many of the BEM duties.

Based on this comparison, the BEM email messages to occupants and/or the letter from leadership appear to have had some immediate impact on computer shutdown behavior. Compliance rates in three buildings (Buildings 1118,

[17] This may be driven more by the fact that signs may not have been posted in all buildings.

[18] Post-intervention interviews with BEMs indicate that little direct recognition of occupant conservation efforts was provided.

1219, and 9447) showed increases in compliance in Week 2 and again in Week 3 after the BEMs of these three buildings sent the first two emails to occupants. Building 1118 peaked in Week 7 after the third email to occupants comparing nighttime shutdown compliance in all five buildings. The BEMs in two of the military buildings (Buildings 9420 and 9427) did not participate in the intervention after the initial training and it appears they did not distribute the email messages to occupants. There was no change in compliance rates in those two buildings during the first three weeks, probably because they had not received information on the desired changes in behavior.

Performance data validated that getting an occupant's supervisor engaged coincided with changes in behavior. The two military buildings with inactive BEMs did not begin showing much improvement until Week 7. This happened the week after the email comparing building computer shutdown compliance across buildings was sent out. During that week posters were finally placed throughout the military buildings and the energy conservation actions were discussed with Executive Officers during staff meetings. (The posters are shown in Appendix M). It appears that the data showing military buildings underperforming relative to the civilian buildings may have prompted BEMs or others to talk with Executive Officers and hang posters, which in turn led to an uptick in compliance. It also suggests that compliance and accountability become more relevant for military personnel once higher ranking personnel are also engaged. There was also some confusion about the policy requiring users to leave computers on at night among some of the military building occupants. Although the policy had been waived for the five pilot buildings and was supposed to have been communicated to building occupants, some had not received the message from someone they considered a trustworthy authority, and until that message was provided by supervisors or others in their chain of command, they continued in old behavior patterns.

Finally, the status briefing provided in Week 8 by the demonstration project research team to two senior leaders of military and garrison operations and the final BEM email to occupants that week also appeared to increase compliance rates. Three buildings showed peak compliance in the following two weeks. An action taken by the computer network personnel asking people to leave computers on over the weekend for updates may have had lingering effect, as compliance in the following week was lower. This may illustrate that three months does not provide sufficient time to allow people to form new energy use habits.

Table 21 Mapping of Actions Implemented by BEM for Each Building (shading indicates action was confirmed to have been implemented; if unknown, it was left blank)

Week	Intervention Activity	Actions Implemented by Building?					Computer Shutdown Impacts Observed?
		1219	1118	9420	9427	9447	
Pre-intervention	Participation in BEM training						
1	Letter from Leadership distributed						
	BEM sends Email #1 to occupants						
	Posters emailed to occupants						
	Floor checks completed						
2	Floor checks completed						Beginning of uptick: 9447, 1118, 1219
3	BEM sends Email #2 to occupants						
	Posters placed throughout building and emailed to occupants						
4	Floor checks completed						
5	BEM sends Email #3 to occupants						
	Floor checks completed						
6	BEM status check with project team						Peak week: 1118

Week	Intervention Activity	Actions Implemented by Building?					Computer Shutdown Impacts Observed?
		1219	1118	9420	9427	9447	
	Posters sent again to BEMs requesting they be hung, along with computer shutdown results by building						
	Floor checks completed						
7	Posters placed throughout military buildings						Peak week: 9427
	Other action: Republished Fragmentary Order directing computer shutdown						Beginning of higher compliance rates: 9420
	Other action: Leadership talked with Executive Officers about intervention action						
	Floor checks completed						
8	BEM sends Email #4 to occupants						
	Status briefing with Garrison and 4-4 leadership						
	Other action: Post-wide email sent notifying people that network personnel approve of computer shutdown						
	Floor checks completed						
9	Floor checks completed						Peak week: 9420, 9447
10	Floor checks completed						Peak week: 1219
11	Floor checks completed						

Week	Intervention Activity	Actions Implemented by Building?					Computer Shutdown Impacts Observed?
		1219	1118	9420	9427	9447	
	Other action: Computer network personnel emailed notice to leave computers on over weekend for upgrade						
12	Post-intervention survey distributed to occupants						Shutdown rates lower in 4 of 5 buildings
Other Actions / week not specified	BEM talked with occupants about specific energy saving actions						
	BEM emailed notice to remove private appliances (e.g., coffee makers)						

When occupants were asked an open-ended question regarding what other factors influenced how they managed energy, 57% of the comments related to personal interest and awareness (e.g., “I try my best to save energy not only at home but also at the office”) (see Figure 67). This seems to reinforce the idea that energy conservation at the office can depend a lot on the personal opinions and interests of individuals. Encouraging conservation behaviors at both work and home as part of such interventions may be important to help build this awareness. Others indicated that the support for the Army’s sustainable operation goals, for example to reduce costs and make Fort Carson a Net Zero Energy Installation, was also a driver.

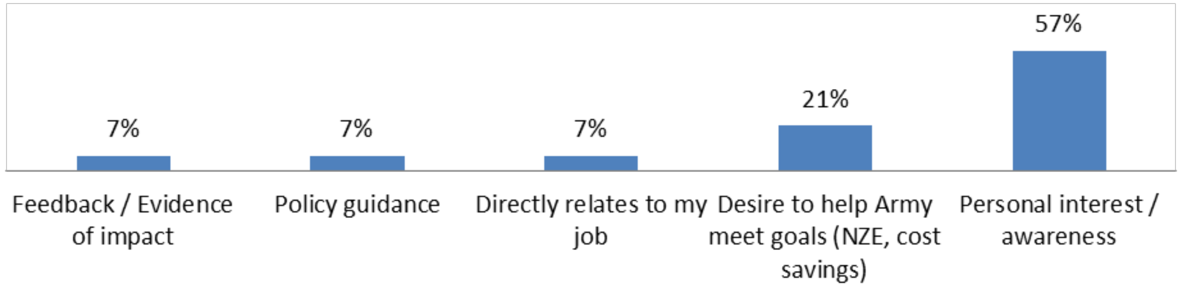


Figure 67 Other Factors that Influence the Way Occupants Manage Energy (grouped responses to open-ended question)

Estimated Energy Savings Impact Intervention

Energy Savings Potential

During the intervention design, estimates of potential energy savings were made for each of the measures to compare their impact if implemented by all building occupants. Data were not available to establish estimates for each building, so decisions to select the two targeted intervention behaviors were informed by limited measurements of equipment energy use and simulated to estimate the building-level impact.

For the computer shutdown measure, energy use measurements were taken for two typical computer models found at Fort Carson: a laptop and a desktop, plus monitors. The computers were estimated to draw approximately 3 watts (W) continuously if they went into sleep mode overnight and continued to draw over 50 W if they stayed in standby mode and continued to run overnight.[19] These values comport with manufacturer's estimated energy use for these models of computers and monitors.

The estimates of potential savings if all occupants shut down their computers at night are presented in Table 22 below, using Building 1118 energy use to illustrate the savings impact. The range of potential savings varies significantly based on whether computers go into sleep mode or not, but at a minimum are assumed to save 0.5% of electricity use and at most about 10% of electricity use in this particular building. It should be emphasized that the percent savings achieved depends on other electricity uses in the particular building being studied; therefore these estimates should not be assumed to be representative of potential savings levels in other buildings.

Table 22 Estimates of Savings Potential from Computer Shutdown Assuming 100% Compliance by Occupants of Building 1118

Percent of Occupants' Computers Assumed to Go into Standby Mode vs. Sleep Mode (%)	Total Electricity Savings in Building 1118 (%)	Total Energy Savings in Building 1118 (%)
100% stay in standby mode	10.2	4.0
75% standby / 25% sleep	7.6	2.9
50% standby / 50% sleep	5.4	2.1
25% standby / 75% sleep	2.9	1.1
100% go into sleep mode	0.5	0.2

[19] The computer energy management settings of all computers in the demonstration buildings could not be determined. While taking measurements at Fort Carson both computers stayed in standby mode overnight. The intervention measure was selected considering that at least some portion of computers were likely not going into sleep mode and for those that were in sleep mode, at least 3 W could be saved, which could be meaningful over a large number of users. This measure was not intended to be a substitute for using sleep mode settings.

The savings potential from heating-season temperature setbacks of 5–10°F on wall-mounted heating units was estimated based on measured operation of the fan coil units at different settings in Building 1219. The building-level impacts were simulated over a full year assuming a 10°F setback on both weeknights and weekends. The potential energy savings, assuming 100% of wall-mounted heating units were set back, were estimated to be approximately 3.1% of total building energy use for Building 1219 and were assumed to be similar for Building 1118. These would be primarily natural gas savings.

Whole-building savings potential of the other intervention measures, for which compliance would be more difficult to track, were not estimated at the building level, but their potential to save energy was verified before the measures were recommended as part of the intervention. For example, fluorescent task lighting that was built into the desk furniture was confirmed to have a lower wattage draw (about 18 W) compared to Light Emitting Diode (LED) ceiling lighting (40 W) in Building 1219 and overhead fluorescent lighting (about 90 W) in Building 1118.

Measurement Approach and Metering Challenges

To measure actual energy savings resulting from the intervention, the research team intended to use a combination of whole-building meter data, submetered data, and as necessary, modeled estimates of savings based on actual compliance with different measures. Whole-building metering has the potential to provide insight to energy impacts when comparing daytime and nighttime energy use patterns to a similar baseline period, but the effects of small changes in occupant behaviors can easily be overshadowed by system-level problems or efficiency measures implemented (e.g., changes in lighting levels). Submetered data can provide more accurate measures of behavior change impacts that can be directly traced to energy end-uses (e.g., lighting), but does not provide a complete picture of the building-level impact. Ideally, a building being studied would have

- reliable whole-building metered data for the entire intervention period and a baseline period,

- submetered data for a significant portion of loads that correspond with the intervention activities,
- relatively stable occupancy levels and building operating parameters across baseline and study periods, and
- observed changes in behavior that could be tracked in those buildings.

None of the buildings examined in this study had all of these measurement elements. Submetered data were available for a portion of Buildings 1219 and 9420, but readings from submeters in Building 1219 failed to be transmitted to the data management system for several weeks during the intervention, which limited the research team's ability to do much comparative analysis. Building 9420 did have functioning submeters but this was one of the buildings with limited BEM involvement, and as a result, occupants in this building were not believed to have changed behavior significantly. Even though up to one-third of computers were shut off in Building 9420 during one week, submetering of plug loads only included a few circuits and was not extensive enough to draw conclusions about impacts from this change. Furthermore, neither Building 1219 nor 9420 had functioning whole-building gas meters during the intervention. The meters were connected but were not tracking properly according to the Fort Carson energy program coordinator. The whole-building electric meter in Building 1219 also failed to record accurate interval data due to a server problem during the study period.

Whole-building metered data were available for Building 1118 for most of the intervention period. The meter was not recording during Weeks 1 and 2, but recorded data correctly for Weeks 3 through 12. Because this was also the building in which occupants made the most dramatic changes in behavior, this represented the best opportunity to identify real energy savings impacts that might be attributed to the intervention.

Estimated Savings Based on Actual Compliance in Building 1118

While it is difficult to discern the impact of individual energy conservation behaviors using only whole-building metered data, the research team was able to establish probable savings levels from the intervention by comparing weather-corrected energy use during most of the study period (mid-March through May 2013) with energy use in a previous baseline period (September to early November 2012).[20]

For the analysis of changes in electricity use, savings identified were believed to be the result of four measures:

- *Measure 1:* De-lamping of hallways (independent of intervention)[21]
- *Measure 2:* Nighttime and weekend computer shutdown (intervention measure)
- *Measure 3:* Nighttime setback of heating units[22] (intervention measure)
- *Measure 4:* Turning off overhead lights and using natural or task lighting (intervention measure)

Measures 1 and 2 were expected to have a larger contribution toward electricity savings than Measures 3 and 4. It was also difficult to approximate expected savings for Measures 3 and 4 because these behaviors were not tracked, unlike computer shutdown compliance. To verify that observed savings from the intervention measures were consistent with expectations, an estimate of savings from Measure 1 (yellow area in Figure 68) was subtracted from the overall observed savings, and then the remainder of the observed savings (green area in Figure 68), which should all be from intervention measures, was compared to the expected savings from Measure 2.

[20] The meter stopped providing readable data from early November through mid-March; therefore the most recent data available was used and weather-corrected to provide a basis for comparison.

[21] It was discovered after the intervention that several hallway lighting fixtures were de-lamped in Building 1118 during the first of week of the intervention, independent of this project. The research team isolated the impact of the de-lamping from intervention-driven electricity savings.

[22] Electricity was only affected by change in use of the fan; reduced heating loads are captured as gas savings.

Estimated savings from Measure 1 were created using information from the Fort Carson energy coordinator about the scale of the de-lamping effort (55 32-W fluorescent bulbs were removed for a total of 1.76 kW) and assumptions about lighting use in Building 1118 (i.e., 100% of hallway building lights were modeled to be “ON” from 6 a.m. to 5 p.m., with 10% of lights remaining “ON” after hours for emergency lighting).

Estimates for Measure 2 were bounded by the two scenarios in the dashed lines. Computer network sweeps suggest the intervention is responsible for an average of 86 additional computers being shut down each night in Building 1118, some of which were assumed to go into sleep mode. The exact percentage of computers expected to go into standby versus sleep mode could not be established (the two tested did not go into sleep mode), but it is assumed that some would. Two scenarios were considered to provide a possible range of impact: one assumed that 25% of computers would have stayed in standby mode and one assumed that 50% of computers would have stayed in standby mode. This range provides the basis for the two dashed-line estimates in Figure 68. Computers in sleep mode were assumed to draw 3 W of energy; when completely shut off, they save just 2.5 W of energy. Computers with monitors in standby mode are assumed to continue drawing 50 W overnight.

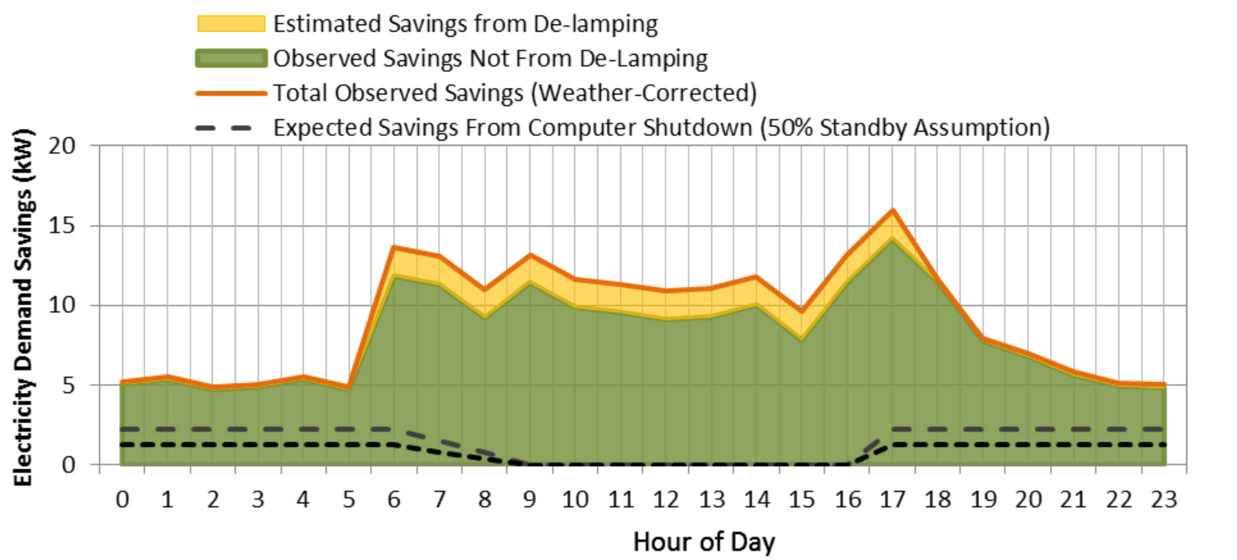


Figure 68 Hourly Comparison of Expected and Observed Weekday Electricity Savings in Building 1118

Total estimated and observed electricity savings, averaged across the entire study period, are listed below:

- **Total Observed Savings:** 12.56 kW (21.4% of raw baseline electricity consumption)
- **Estimated Measure 1 Savings (from calculation):** 0.74 kW (1.3% of raw baseline electricity consumption)
- **Estimated Measure 2 Savings (from calculation):** 0.89–1.64 kW (1.5%–2.8% of raw baseline electricity consumption)

- Remainder of observed savings, including "persistent savings"[23] from Measure 2, and effects from Measures 3 and 4: 10.18–10.93 kW (17.8%–19.2% of baseline electricity consumption)

The total observed electricity savings from the intervention should be higher than the expected savings from nighttime and weekend computer shutdown (Measure 2) alone. However, actual energy savings not attributable to the de-lamping are many times higher than the expected effect from the computer shutdown. Given that the other two measures were not expected to have as large an impact on electricity savings, the level of additional savings observed remains unexplained. It was considered that the longer and presumably brighter days in the spring (study period) may have contributed to more of the lights being turned off, however, nearby Denver, Colorado, has about 10% more average sunshine hours in the spring study period versus the fall baseline period (a monthly weighted average of 255 versus 281 hours). This may have contributed to a small increase in the manual use of lighting in the baseline period, but the difference in sunshine is not large enough to be considered a major factor in the observed drop in electricity consumption.

The analysis of gas savings in Building 1118 was used to estimate the impact of occupants turning back office heating units at night during the heating season. Models of occupied and unoccupied baseline operation generated from the measured baseline data were used to predict baseline building natural gas consumption at each hour during the study period for which there was valid metered data. The predicted baseline consumption for each hour used the study period's outdoor air temperatures. This weather-normalized version of the baseline data was compared with raw

[23] The computer shutdown savings estimates assume that people start arriving at work between 6 and 9 a.m. and leave between 4 and 5 p.m., but that all occupants are at work during the heart of the work day from 9 a.m. to 4 p.m. This is not necessarily true and may help to account for some of the unexplained savings during the work day. It is possible that some people may power down their computers one evening and not come in the following work day due to sickness, travel, or vacation. Thus their power-down computer savings would persist through at least the following work day, and perhaps longer.

average hourly natural gas consumption data during the study period. Figure 69 shows the hourly savings in the study period in percentage terms, for both weekdays and weekends. Most savings were achieved during heating, ventilation, and air conditioning (HVAC) setback hours, so this is believed to be the biggest contributor. According to the Fort Carson energy program coordinator, no other energy conservation measures that would affect gas usage were known to be implemented between the baseline and intervention study periods.

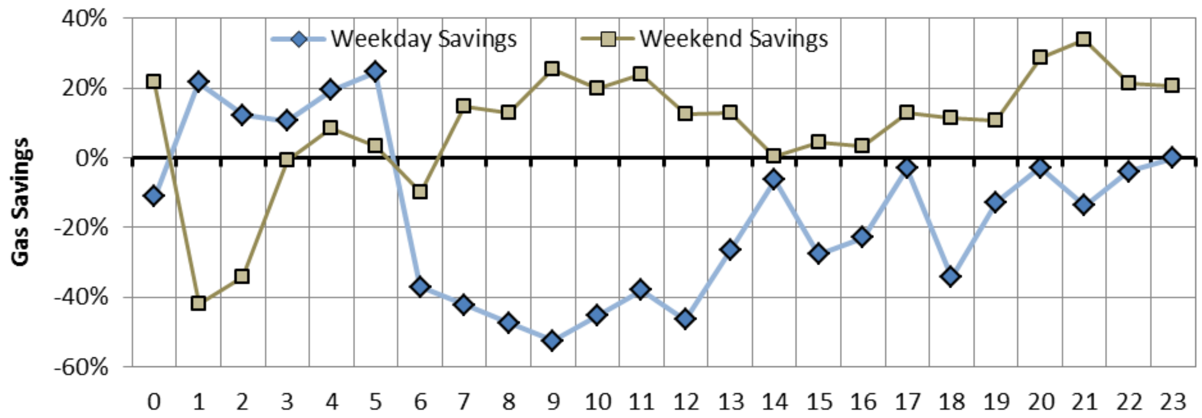


Figure 69 Hourly Natural Gas Savings Patterns in Building 1118

Overall, there was an average 4.8% decrease in natural gas consumption during all unoccupied hours when comparing the weather-corrected natural gas use in the baseline period to actual natural gas use during the study period. However, this was more than offset by an average 35.6% increase in consumption during occupied hours compared to the baseline period. There are two likely factors at play in the increased consumption during occupied hours. First, there was dramatically lower electricity consumption in the study period, and this may have contributed to generally higher demands for natural gas to compensate for lost internal heat gain. Second, lower nighttime setback may have contributed to a rebound effect in natural gas consumption when the building became occupied again. On its own, increased consumption during the rebound period would only be expected to be a fraction of the total amount saved in the overnight period. The total increase in gas consumption averaged across the entire study period was 12%, suggesting a fairly large increase in heating demand at comparable temperatures to account for the overall increase.

Assuming that the overall increase in natural gas consumption compared to the baseline period is due to an increase in heating demand, it is still likely that the natural gas consumption was lower in the study period than it would have been without the heating setback measure. There is unfortunately no way to empirically validate this assumption, given the change in internal loads from the baseline to the study period. An attempt at quantifying the expected savings from the heating-unit setback uses modeling results from NREL EnergyPlus simulations of the impact of a similar measure on other buildings on the Fort Carson base. NREL modeled two scenarios for Building 1219, which has a heating system similar to that in Building 1118: a first with full setback of heating units, plus keeping ventilation off at night (4.9% total building energy savings) and a second that only kept ventilation off at night (1.8% total building energy savings). In Building 1118, there is not an option to stop ventilation at night on the heating unit, so the research team made the assumption that the 1.8% savings modeled from the night ventilation reduction could be subtracted from the savings from the first scenario to estimate the impact of the full night setback alone. This methodology estimated a 3.1% annual building energy savings from a full setback alone. However, in Building 1118, only 32% of survey respondents indicated compliance with the setback measure. As a rough approximation of expected savings at Building 1118, we multiplied the 3.1% expected savings from full setback by 32% to arrive at an expected annual building energy savings of 1.0% for this measure as it was implemented.

2% of the building’s total energy savings were estimated to come from the computer shutdown and heating setback measures.

The total combined electricity and gas savings in Building 1118 between the baseline period and intervention period were estimated to be 8.9%, with 2% of the building’s total energy savings estimated to come from the computer shutdown and heating setback measures, and some portion of the remaining 6.3% of unaccounted-for savings potentially coming from occupant lighting control measures (see Figure 70).

To summarize, the observed savings in electricity were several times higher than what was expected and what could be accounted for from the observed energy measures that were implemented. We do not have an explanation for why the savings are so high. The high electricity savings coincided with higher natural gas demand in the heating season, which made it difficult to identify natural gas savings through measured natural gas consumption data. Nevertheless, based on the specifics of the implementation of the heating setback measure and modeling of its expected performance, we believe that there are some small natural gas savings compared to what would otherwise have been used.

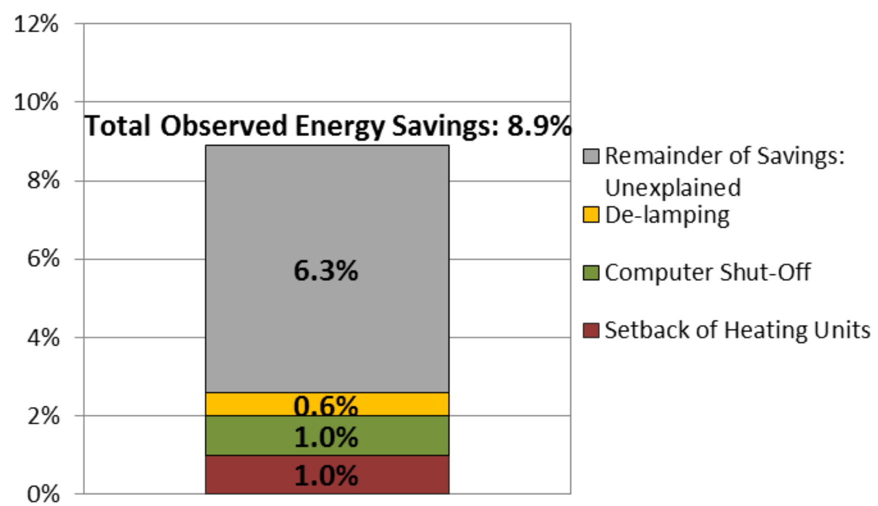


Figure 70 Total Observed Energy Savings in Building 1118 between Baseline and Intervention Period

Conclusions and Recommendations

This section presents the major conclusions and interpretations of the findings from the Fort Carson intervention study. There are three parts to this section: a summary of findings from our research, implications for deploying programmatic approaches to energy conservation and behavioral change, and specific recommendations for Fort Carson and the Army.

Summary of Findings

Through this study, the research team aimed to apply a focused, methodical approach to encouraging behavior change for energy conservation—leveraging guidance developed by DOE-FEMP on Institutional Change—and to gauge what impact such a program would have on actual behavior. This involved

- understanding the local context in which behavior change would occur to support energy conservation (i.e., the people with the potential to save energy, and the rules and tools that influence their behavior),
- defining behaviors with the greatest potential to save energy and leveraging proven strategies to promote change,
- implementing a coordinated program of activities over a three-month pilot period, and
- evaluating which behaviors changed, what supported the change, and what impact the change had on building energy use.

Findings from this study suggest that over a very short period of time the audiences targeted did change some behaviors that support energy conservation. Occupants in all five buildings in the demonstration project showed higher levels of compliance with the computer shutdown measure over their baseline levels, increasing from 13% to 51%

between Week 1 and the peak week of compliance in each building. Behaviors were most likely to change when there was an engaged advocate for energy conservation providing information on specific energy saving actions and feedback on performance at the building level, and also when people in leadership and supervisory positions reinforced the importance of taking these actions.

Occupants in all five buildings showed higher levels of compliance with the computer shutdown measure, increasing from 13% to 51%

Despite several challenges to getting reliable data to evaluate the impact of these behavioral changes, analysis of metered data from one of the buildings studied (Building 1118) suggests that the intervention contributed to a reduction in energy use of at least 2% after just three months. This is based on assumptions that approximately one-third of the occupants complied with the nighttime temperature setback measure and about half of the occupants of Building 1118 started shutting down their computers at night as a result of this behavior change program. Higher levels of compliance may have been achieved over a longer intervention program that would have allowed time for the team to adapt to different challenges that were encountered. To provide a sense of the maximum savings potential from applying two targeted behaviors—nighttime computer shutdown and temperature setbacks on heating units—in this particular building, if 100% of occupants had complied with these measures, energy savings may have ranged from 3% to 7%.[24] It is important to consider, however, that this is a single building with unique features and energy saving opportunities; the actual percentage of energy saved in other buildings could vary dramatically depending on the building's baseline.

[24] As noted above, actual energy savings would depend on the proportion of computers that went into sleep mode versus standby mode overnight.

Implications for Institutional and Behavioral Change Programs

The overall framework for conducting this study was to provide GSA with actionable guidance for implementing behavioral change to complement the operational and technical aspects of Federal green buildings. In general, following a methodical approach to behavior change as was laid out in the Methods section can be a useful mechanism for making sure that actions are defined around well-understood principles for behavior and institutional change. It is recognized that most organizations lack the resources to take advantage of every opportunity for institutional or behavioral change as a full-blown intervention. Fortunately, this research does not suggest that organizations must have dedicated teams of behavioral scientists at every building to foster change at the building level. It does suggest, however, that having an engaged, trained and resourced advocate at the building level can be effective. Many of the elements of an effective change program can likely be centralized in the organization and disseminated to a network of implementers on the ground. Implementation at the ground level does not necessarily require more than a few hours per week.

Findings from this demonstration project at Fort Carson lend support to the idea that behavior change efforts will be more successful if several key elements are in place, as discussed below.

Understand the institutional context in which behavior takes place

The existing social science literature and the findings from this study reinforce the importance of addressing the entire context in which individual behavior takes place in order to effectively foster change. While individual behavior is known to be important for the implementation of many energy reduction approaches, the numerous institutional factors that may inhibit action or reinforce inaction (e.g., policy of leaving computers on at night) are less frequently recognized. The harmonization of policies (rules), communications (tools), and communicators (roles) involves considerable coordination by change agents to make sure that the desired individual behavior (e.g., computers off at night) is enabled by appropriate policies, enabled through communications of those policies, and reinforced by trusted and authoritative communicators.

In this study, when the rules, roles, and tools were aligned and reinforced, higher rates of behavior change were observed. When they were not harmonized, behavior was less likely to change. The slower rates of change in computer shutdown behavior in the military buildings compared to the primarily civilian buildings, partially due to conflicting messages received by individuals about the exception to this policy, is a prime example of this. Although the policy requiring users to leave computers on had been waived for the five pilot buildings and the waiver was supposed to have been communicated to building occupants, occupants of some buildings had not received the message from a trustworthy authority and, until that message was provided, continued in old behavior patterns.

In this study, when the rules, roles, and tools were aligned and reinforced, higher rates of behavior change were observed.

Institutional and behavioral programs should work to identify and eliminate institutional barriers that may be problematic at many sites, and provide guidance to those promoting change at the local level to get rules, roles, and tools successfully aligned.

Make desired behaviors specific and relevant

There is a tendency in energy behavior-change research to utilize broad-based awareness programs coupled with generic lists of the top ten things you can do to save energy. While awareness is a necessary component of behavior change, relying on awareness campaigns alone may not result in much action for two reasons: (1) information and awareness alone tend to be insufficient for eliciting sustained behavior change, and (2) top ten type lists are so generic that their relevance to circumstances is not perceived by individuals, making implementation, let alone impact, unlikely.

In the work conducted for this report, we initially evaluated a large number of potential behaviors, and ultimately selected relatively few for implementation, and only promoted those that were relevant to specific buildings (e.g., thermostat setbacks were only promoted in buildings that were properly equipped). By narrowing the field of choices to those relevant to the occupants and making the desired parameters very specific (e.g., 5–10 degrees setback at night, computers off when leaving the office, using daylighting or task lighting instead of overhead lights when sufficient), the occupants were not overwhelmed with choices or required to interpret vague suggestions and determine their own implementation. Findings from the post-intervention survey suggested that intervention helped to close the gap between general awareness of the importance of energy conservation and specific actions that occupants could take in their building.

Intervention helped to close the gap between general awareness of the importance of energy conservation and specific actions that occupants could take in their building.

Programmatic approaches to behavioral change should reinforce the need for local implementers to identify a select set of high-impact behaviors that support energy conservation *in their building.* For example, propping doors open in the winter may be a problem for just a few buildings and may not be included in a list of generic behaviors that occupants are encouraged to change. But in the buildings where that behavior is occurring, it may save more energy than all other problematic behaviors combined. Such behaviors should be identified and targeted for change where they are relevant.

Provide social reinforcement through known and trusted sources on a regular basis

While difficult to demonstrate unambiguously, it was observed that individual behavior change tended to increase as a direct response to social reinforcement, such as communication from supervisors, BEMs, and/or peers. We base this conclusion on data showing a substantial increment in one of the desired behaviors (i.e., shutting down computers) immediately following communication and emphasis from supervisors or BEMs, and on survey responses suggesting that these interactions were the top reasons people changed their behavior. While it is not known whether such impacts would be observed over a longer period of time than this limited three-month demonstration, the result is compatible with other findings that energy reduction behaviors that are recognized and reinforced by significant persons within the local environment tend to be sustained.

This provides some indication that initiating, reinforcing, and maintaining energy reduction behaviors is likely to be best accomplished in a context where there are numerous interpersonal interactions to promote and recognize the desired behaviors. This suggests that institutional and behavioral change be approached more as a high touch activity, through person-to-person interaction, than as a high tech activity. The prevailing physical, technical, and economic approaches to energy reduction focus on technical efficiencies, feedback devices (such as dashboards), and relatively small financial savings. The high touch approach involves the general philosophy that people will change because they want to please others with whom they regularly interact (Gwande 2013, White 1983).

This reinforces the importance of having advocates for energy conservation at the local or building level.

This reinforces the importance of having advocates for energy conservation at the local or building level—people who can observe behaviors and engage in dialogue around them—in order to foster change. As the landlord for the civilian

Federal Government, GSA might encourage building tenants to identify energy conservation advocates in each building or complex of buildings who are recognized and trusted by their fellow occupants.

Equip tenants with knowledge and resources to implement behavior change

Energy advocates working at the building or site level can be instrumental in promoting change, but they need knowledge and access to resources to carry out their responsibilities efficiently. Based on our experience at Fort Carson, each of the BEMs required about two hours per week to carry out their duties. During the design and implementation phases, however, quite a bit of coordination was required on the part of the research team and personnel operating at the installation level in the energy and sustainability programs.

In GSA buildings, the tenant organizations can play a critical role in fostering energy conservation behavior if they are well equipped to do so. The types of resources made available to BEMs as part of the Fort Carson project (e.g., email messages to occupants, floor check forms, training materials) could be packaged by GSA or other agencies at a program level, and disseminated with guidance on how to adapt the resources for local use.

Based on the findings of this project, some general principles that should be considered for incorporation into the GSA support process for building tenancy and operation include:

- Work with the tenant organizations to help define the operating and social reinforcement process. This requires an understanding of the kinds of tasks occupants will perform, and general issues related to the organizational culture (e.g., autonomous, centrally controlled). Ideally this process can define a means for linking energy consumption to business processes and the individual worker and group behaviors that carry out those business processes. Knowledge of the small-group (e.g., 10–50 individuals) structure and process can be used to identify potential candidate individuals to adopt a role similar to the BEMs in the Fort Carson intervention.

- Leadership of the organization and work group levels need to be committed to the social reinforcement process for energy reduction, and demonstrate it through active participation and periodic acknowledgement.
- A responsible person at the building or work group level must be accountable, knowledgeable, and properly resourced to observe how energy is being used, identify opportunities for conservation, and engage occupants and others in resource conservation behaviors.
- Accountability requires that encouraging others to conserve energy is part of someone's job, not an add-on responsibility for an already overworked individual. While energy monitoring and social reinforcement imply dedicated time, our observations suggest that the commitment is not excessive—generally less than two hours per week for a properly supported individual.

The specific means by which GSA works with tenants to develop this type of socially based energy reduction through behavioral approaches will likely be a consulting process between various offices of the GSA, such as Federal High-Performance Green Buildings and the Public Building Service, and the tenant organizations and corresponding energy manager roles.

Recommendations to Fort Carson and the Army

The lessons learned from this behavioral change demonstration project in a small number of buildings provide insights that extend to other Fort Carson buildings and to the Army as a whole. The Army-wide BEM provides an excellent model to leverage and adapt for purposes of fostering a culture of energy awareness and promoting conservation behaviors at the local level. Findings from our research suggest that utilizing a BEM-like program can work to promote local behavior change. The Fort Carson BEM program can work to promote local behavior change. This program might be adapted based on lessons learned from this demonstration to more explicitly address the factors found to drive change. The BEM program was developed and rolled out Army-wide based on the premise that someone with a local presence who can observe local conditions will be much more successful than an unknown authority trying to manage building energy use. This research lends support to the idea an engaged BEM can be instrumental in supporting energy conservation at Fort Carson and potentially beyond.

At Fort Carson, a single energy program coordinator is responsible for over 900 buildings. While advocating for building-level behavior change still requires local, building-level engagement, much of the guidance and support for BEM program implementation can be managed centrally. Many of the recommendations below can be effectively supported at the Army headquarters and/or installation level and disseminated through the BEM network.

These recommendations include:

- **Revisit BEM qualifications and identify a qualified BEM for each building** – The BEM should be viewed as a specialized job function requiring specific skills in communications and outreach– not a requirement that can be met by assigning just anyone. As the local advocate for energy conservation, the BEM may be most effective if they: (1) have an interest in being the BEM, (2) personally engage in energy conservation and sustainability, (3) have some level of respect from the occupants (in buildings with military occupants, a fairly high-ranking officer may be the right person to get the attention of soldiers), and (4) are comfortable engaging building occupants in productive dialogues about ways to support energy goals. They should be an energy coach and aim to help occupants without being overly intrusive. Those who can and are willing to talk with occupants about energy conservation will be more likely to foster dialogue among occupants, which we have seen has an important influence on behavior change.

    - Even with a fully resourced program, as described below, identifying and training BEMs can be time consuming considering the number of buildings at Fort Carson and across the Army. One way to manage this would be to prioritize buildings for BEM identification based on their energy-use and energy-intensity profiles and occupancy levels if known (e.g., at least ten occupants). Another solution for buildings occupied by military personnel may be to require each company or unit to assign a BEM. This would work best if members of the unit were based in buildings in a common geographic area so that the BEM could visit them on a regular basis. While it may not be as effective as having a peer from the building observe behavior on a regular basis, the BEM would still be recognized and trusted by his or her peers in the unit.

- **Resource the position** – The BEM position does not require substantial time, once the BEM is familiar with their duties. However, it should not be assigned to people already 100% committed to other duties. Establish an expectation for a time commitment from the BEM to carry out their duties—perhaps two hours per week once the BEM has identified building-level conservation opportunities—and make sure that supervisors of the BEMs understand and support this time commitment.

- **Create accountability and incentive structures** – In addition to ensuring that BEMs have the time to carry out their duties, supervisors of BEMs must establish clear expectations for BEM duties and ensure they are completed. Because it is difficult for a single installation energy manager who may rarely visit the facility to effectively track several BEMs, it is important to involve the BEM's supervisor. The BEM's supervisor should work with the BEM to determine what energy use behaviors are problematic in their building, generate ideas for changing those behaviors, and what changes have been observed during floor checks. Good performance should be rewarded or recognized. For example, an installation-level program recognizing the "BEM of the month" could be implemented.

- **Provide BEMs ongoing training on behavior change** – While checking the physical elements of the building for possible impacts on energy performance (e.g., looking for good seals around windows and doors) BEM training must also explicitly address how humans influence building energy use. For example, BEMs should learn how to identify the energy saving behaviors that may be impacting energy use, as well as effective ways to change those behaviors, including how to effectively engage occupants and motivate change. Training should clearly convey to the BEM their role in the building as it relates to occupants, the building manager and others. The training should be continual. Bring BEMs together quarterly or twice a year to provide a refresher, roll out new resources, and allow BEMs to share successes and lessons learned.

- **Provide BEMs with a toolkit that can be adapted locally** – BEMs need a set of simple tools to effectively engage occupants and understand how the building and its occupants are performing. A lengthy handbook distributed on training day will likely not be reviewed again. Keep the toolkit fresh and distribute material to BEMs on a regular basis, perhaps monthly or quarterly. Training should focus on how to use the tools and how to make them locally relevant. Examples of some electronic resources that may help BEMs to be more effective include

  1. monthly building energy performance reports (one-page summary)
  2. a list of energy use behaviors that are commonly seen on installations, which BEMs could use for reference in identifying priority opportunities for improvement
  3. a floor-check template
  4. generic email messages or ideas for topics to address, which the BEM can tailor based on their building's characteristics and performance
  5. a short template for developing a "conservation behavior-change plan."

- **Make new occupant orientation *conversation* about *conservation* a requirement** – Military installations are in a constant state of flux with soldiers coming and going as they prepare for and return from deployment. This frequent turnover of personnel can affect the operating tempo of buildings and poses a challenge to fostering a culture of energy conservation that can be sustained over time. From the day a new occupant sets foot in a building, they begin to establish patterns and habits that will stick with them throughout their tenure in the building. A key function of the BEM should be to orient new occupants to the building in a way that is personal, brief, and timely. A five-minute conversation with a new occupant about their role in energy conservation behaviors will likely have much greater impact than referencing a building handbook with details that are superfluous to occupants. For example, for buildings with occupant control of heating/cooling units, the BEM might establish expectations for heating season setbacks and cooling season temperature increases, as appropriate.

- **Institutionalize measurement and feedback on performance** – Build measurement of building energy performance and the impact of specific behaviors at the end-use level into regular feedback to occupants. There are building meter connection and meter data management challenges that must be addressed to make this data readily accessible and some supporting analytics required to make the data informative. To the extent that these challenges can be addressed, people at the end-use level will benefit from seeing the impact of their actions (or failure to act) on energy use in their building. Also, if there are behaviors that may be worth promoting installation-wide (e.g., nighttime computer shutdown), it may be helpful to institutionalize a process for measuring compliance with such measures and making sure that the information is fed back to occupants through the BEMs.

Chapter 3 Findings and Recommendations

The Fort Carson Energy Research Project identified four areas of opportunity to advance buildings to net zero energy (NZE) levels of performance:

1. Thermal envelope optimization
2. Daylighting and lighting system performance
3. Net zero retrofit optimization
4. Occupant behavior

Areas of Opportunity

1. Thermal envelope optimization
2. Daylighting and lighting system performance
3. NZE retrofit optimization
4. Occupant behavior

The four studies in this project were designed based on several principles:

- Identifying strategies that provide optimal energy and cost savings across Fort Carson buildings' lifecycles, up to NZE performance levels;
- Emphasizing occupant needs and feedback; and
- Identifying where Fort Carson research results may be applicable to other military, government, and commercial buildings.

Findings by project follow.

Thermal Envelope Optimization

This study sought to identify:

- Which thermal envelope assemblies provide maximum energy and cost savings over the building lifecycle, and how much they can save compared to buildings that just meet the energy code; and
- Whether and to what extent Fort Carson would benefit from zoning off unused areas of buildings during military deployments and setting back HVAC controls within those areas.

NREL incorporated actual performance and cost data into existing Army Corps of Engineers energy models of five relevant building types to evaluate the performance of a variety of wall, roof and window constructions. The five Fort Carson building types included:

1. Headquarters (HQ: mostly office and training space),
2. Company Operations Facilities (COFs: a mix of office and storage space),
3. Dining Facilities (DFACs: cafeterias),
4. Tactical Equipment Maintenance Facilities (TEMFs: primarily service bays for large vehicles), and
5. Barracks (residential apartment buildings).

The research team used net-present value analysis to determine the most cost-effective solutions over 30-year building lifecycles, compared to the building code baseline (based on ASHRAE Standard 90.1-2007). The materials and components constituting the optimal packages are outlined in the report.

Finding 1: Envelope optimization in new buildings at Fort Carson can yield savings up to 25% over the code baseline with net present value up to $350,000 and simple payback as low as seven years.

Table 23 below estimates performance of the most energy-efficient envelope assemblies for each of the five building types studied:

Table 23 Lifecycle Energy and Cost Savings of Optimal Envelope Packages In Comparison to Building Code Baseline (ASHRAE 90.1-2007)

Building Type	Energy Savings	Incremental First Cost	Annual Energy Savings	30 Year NPV	Simple Payback
Barracks	15.8%	$79,655	$7,652	$82,951	10 yrs
HQ	0.0%	$0	$0	$0	N/A
DFAC	0.3%	$12,831	$601	$88	21 yrs
COF	24.8%	$168,065	$24,633	$353,403	7 yrs
TEMF	21.8%	$47,217	$5,657	$72,733	8 yrs

In fact, Fort Carson is already achieving envelope energy savings well above code levels. These findings indicate how to maximize those gains through the use of the most optimal envelope packages for each building type. (Discrepancies are discussed below.)

Finding 2: Results vary widely by building type: e.g., envelope improvements are a key component of NZE design for buildings with large heating loads, but may be less helpful for buildings that are dominated by equipment loads.

This study confirmed and quantified the value of using envelope packages that are adapted to the unique attributes and usage patterns of each building type.

First, the research team found the five building types to have very different heating requirements—a fact that drove many of the subsequent results. Whereas the COF and TEMF use 60–64% of their energy on heat, the DFAC and Barracks use 29–39%, and the HQ building only 2%. Both the HQ and DFAC generate much internal heat, from the data center and cooking equipment, respectively.

As shown in Table 23, the buildings with higher heating needs benefited most from envelope improvements beyond code, showing large, lifecycle cost-effective whole-building energy savings with significant net present value (NPV) and simple payback within 7–10 years. By contrast, for the buildings that generated more of their own internal heat, reducing heat losses through the thermal envelope was often counter-productive, increasing cooling energy requirements more than it reduced heating energy needs.

As another example of divergent findings among building types, semi-conditioned spaces (e.g., storage sections of the COFs and open bay areas of the TEMFs) did not appear to benefit from envelope upgrades as much as fully conditioned spaces.

Finding 3: Thermal zoning and ventilation setback when troops are deployed can yield energy savings up to 23%.

As shown in Table 24, zoning to shut off HVAC services to parts of buildings during troop deployment appeared to be a high energy and cost saving measure in buildings with large heating loads (Barracks, COF, TEMF). This was true even though the analysis conservatively included only the effects of reduced ventilation and relaxed thermostat settings, without estimating reductions in lighting and plug loads. Again, the impact in the low heating load HQ and DFAC buildings was more modest.

Table 24 Impact of Relaxed Thermostat Settings and Reduced Ventilation Rates During Troop Deployments

Building Type	Annual Cost Savings	Annual Energy Savings
Barracks	$12,508	14%
HQ	$2,955	4%
DFAC	$7,799	4%
COF	$25,047	23%
TEMF	$5,254	12%

While this analysis was specifically targeted at new construction of specific Fort Carson building types in the Colorado Springs climate zone, based on best available cost estimates, it may be replicated for other building types, climates and cost structures.

Daylighting and Lighting System Performance

This study sought to evaluate the performance of the lighting and daylighting systems in four Fort Carson building types, to determine their levels of efficiency, ability to meet occupant needs, and potential for improvement to NZE levels.

The research team's findings therefore include information on Fort Carson's current lighting and daylighting performance, and recommendations to enhance performance to levels sufficient to support the base's NZE installation goal.

Finding 1: Fort Carson is using up to 50% less lighting energy than code level buildings.

The space surveys showed that Fort Carson's lighting systems are well designed and implemented, and meet most of the research team's qualitative NZE criteria, including:

- façade design that brings in sufficient daylight,
- minimal glazing-to-surface-area ratios,
- reducing glare and maintaining occupants' visual comfort, and
- integrating daylighting with lighting controls and other building systems.

As a result, buildings studied at Fort Carson (including HQ, TEMF, COF, and office buildings) are using a lower percentage of their energy on lighting than comparable buildings designed to meet ASHRAE Standard 90.1-2007. While commercial buildings typically use 30–40% of their energy on lighting, the HQ building in the study is only using 15% of its energy on lighting, and the retrofitted office building only 22%. The lower lighting energy use in the study buildings is likely due to a number of practices, including:

- *Electric lighting reductions,* such as using more efficient fluorescent and Light Emitting Diode (LED) fixtures;
- *Daylighting features* including bringing in high daylight with diffusing apertures, clerestories, and skylights;
- *Lighting controls,* such as occupancy sensors (automatic on and off) and vacancy sensors (manual on, automatic off); and
- *Occupant engagement activities,* such as "Please turn off the lights" stickers.

Based on the research team's measurements, Fort Carson is generally successful at aligning lighting status with occupancy, i.e., lights are mostly off when spaces are unoccupied.

Finding 2: The base has further opportunities to optimize lighting quality and efficiency while reducing consumption to levels 90% lower than required by code.

While Fort Carson is doing an above average job on lighting and daylighting, the research team identified several areas for further improvement to boost performance to NZE levels. These include:

- Optimizing daylighting design features, such as louvered overhangs and transom glass, to maximize daylighting gains.

- Increasing application of blinds and controls to use daylight effectively.

- Reducing the unnecessarily high light levels to which fixtures are set, so that even high-efficiency LED lights can save more energy than they do currently.

- Replacing occupancy sensors (automatic on and off) with vacancy sensors (manual on, automatic off), i.e., making the off position the default until manually adjusted, to reduce the amount of time lights may be left on unnecessarily.

From a strategic perspective, based on NREL’s experience, lighting systems typically should consume no more than 10% of total building energy load to meet NZE targets. This translates to about 75% lighting energy use reduction from the code baseline (ASHRAE Standard 90.1-2007), which in turn breaks down into expectations of 50% savings in non-daylit areas and up to 90% in daylit spaces.

Following these expectations and NREL’s observations and measurements at Fort Carson, the research team proposed a comprehensive lighting strategy to work toward NZE goals:

- Set a 75% energy savings goal and translate that into a lighting energy use intensity goal. Require the lighting designer and commissioning agent to verify that essential steps toward the goal are being met.

- Set ambient light at minimum acceptable levels to meet occupant needs (e.g., 25–30 fc (269–323 lux) for working spaces, potentially lower for other space uses).

- Provide glare-free daylight in all spaces, as the baseline source of ambient light.

- Design exterior overhangs (for south and west sides) and blinds to carefully refine the split between the upper portions of windows used for daylighting and the lower portion used for views. Use transom glass at the inner wall of most perimeter spaces.
- Use low partition heights and light interior surface color to reflect light and create bright vertical surfaces.
- Design in layers of light to allow occupants additional choices, such as task lighting, to meet their individual needs.
- Engage occupants and design user-friendly control systems to meet their needs.
- Use vacancy sensors rather than occupancy sensors in most settings, so occupants need to “opt-in” for light beyond ambient levels.
- Zone electric light systems to tailor them to the space (e.g., to take advantage of perimeter daylight) and to occupant preferences.
- Consider a central lighting control system with consistent, intuitive controls to assist facility managers with continuity of operations, re-commissioning and ease of use.

Net Zero Retrofit Optimization

The net zero retrofit optimization study was designed to:

- Identify a lifecycle cost effective pathway to achieve energy reduction performance up to NZE for an office retrofit project, and

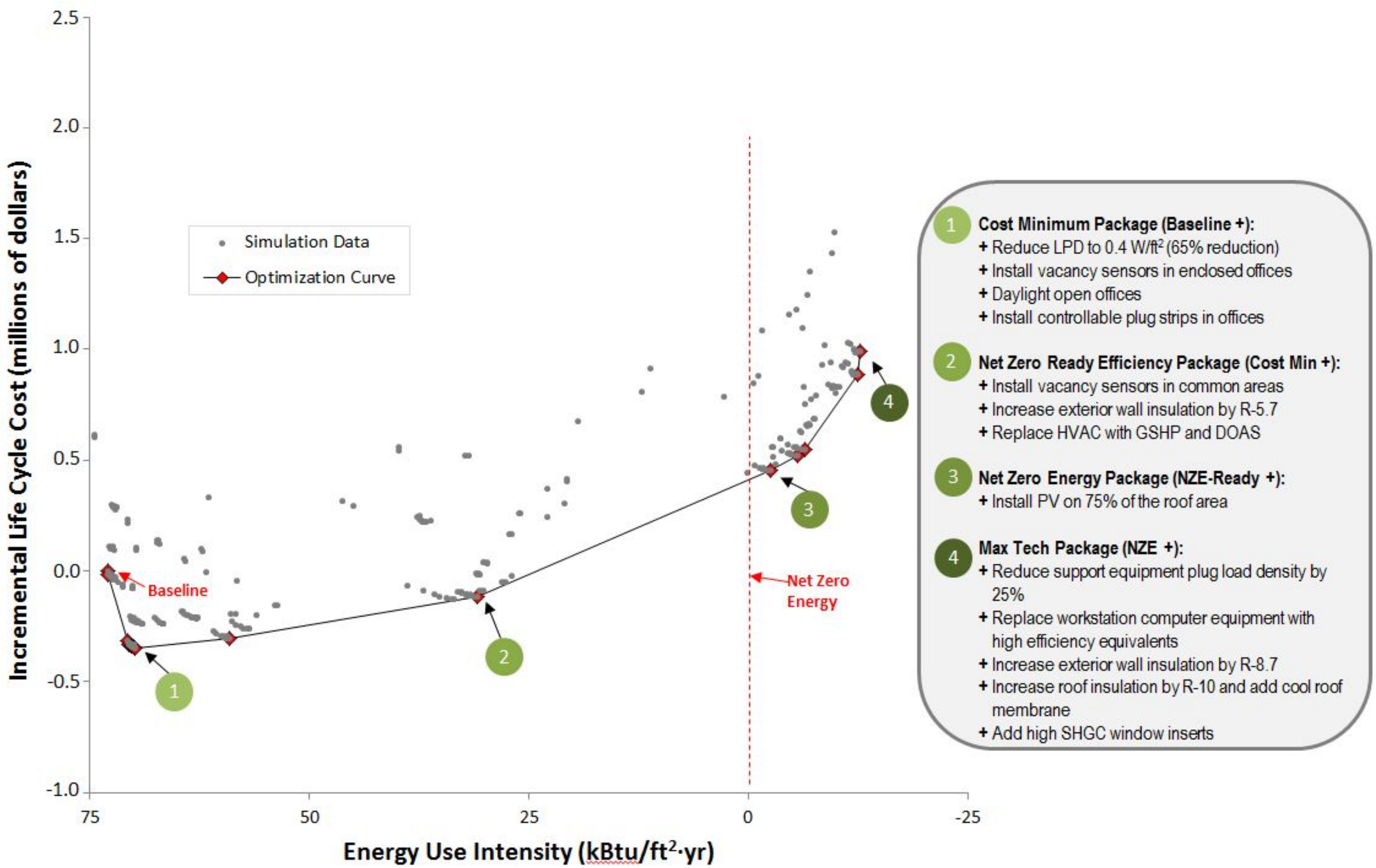
- Demonstrate the feasibility of using open source, on-line modeling tools for NZE energy retrofit planning.

NREL developed a list of best practices for energy retrofit and modeled them, based on energy savings and lifecycle costs, for an office building that had been renovated from a former barracks,. Lifecycle cost estimates factored in first costs, energy cost savings, maintenance costs, replacement costs and discount rate over a 20-year period.

This approach yielded findings regarding both the most beneficial combinations of methods and technologies to achieve cost-effective energy efficiency in a retrofit project ("technology bundles"), and the usefulness and replicability of the methodology and results.

Finding 1: Fort Carson office building retrofits have a clear, low-risk investment path of bundled energy technology solutions from lowest life-cycle cost to NZE

NREL's simulation created a roadmap (Figure 71) showing a logical progression for investments to be steadily ramped up, starting with the most lifecycle cost effective technology bundle on the bottom left, with the return on investment steadily decreasing as the line moves upward, toward the ultimate goal of NZE. Table 25 summarizes the impact of applying these approaches, as each bundle incrementally boosts energy savings.



Note: DOAS – dedicated outdoor air system, GSHP – Ground source heat pump, HVAC – heating, ventilation, and air conditioning, kBtu/ft2•yr – thousand British thermal units per square foot per year, LPD – Lighting Power Density, PV – Photovoltaic, SHGC – Solar heat gain coefficient, W/ft2 – watts per square foot

Figure 71 Retrofit Optimization Results: Energy Model Simulation Output

Table 25 Summary of Retrofit Optimization Results

Technology Packages	Energy Use Index (EUI/Net EUI: kBtu/ft^2 yr)	Net Energy Savings (%)	Incremental Total Lifecycle Cost (millions of $, over 20 years)
Baseline	73.0	NA	NA
Cost Min	69.9	4%	-0.3
NZE Ready	30.9	58%	-0.1
NZE	30.9/-2.5	103%	0.5
Max Tech	20.7/-12.7	117%	1.0

Bundled technology packages along this roadmap include:

- **Cost Minimum Package:** This technology bundle (including reducing lighting power density 65%, installing vacancy sensors in enclosed offices, daylighting open offices and using controllable power strips) represents the best investment dollar-for-dollar, though with modest energy savings (less than 5%).
- **Net Zero Ready Efficiency Package:** This package yields 58% additional energy savings, slashing the energy use index (EUI) to 31 kBtu/ft^2/yr and making the building “net zero ready,” i.e., including all efficiency measures more lifecycle-cost-effective than adding renewables. Efficiency measures include installing ground source heat pumps, dedicated outdoor air systems, vacancy sensors in common areas, and added exterior wall insulation.
- **Net Zero Energy Package:** This package adds renewable energy sources on top of the previous packages, to the point that NZE performance is attained.
- **Max Tech Package:** The most aggressive—though least cost-effective—efficiency package without renewables included. Measures include maximizing insulation levels and installing high efficiency equipment.

Finding 2: Publicly available open source tools can be used to identify much of this roadmap of bundled energy technology solutions.

The Fort Carson net zero retrofit optimization analysis was focused not simply on obtaining the simulation results but on defining an effective, straightforward, and replicable process for others to use. Accordingly, the research team utilized only publicly available modeling tools including OpenStudio (http://openstudio.nrel.gov), SketchUp (http://www.sketchup.com), and Match Photo (http://help.sketchup.com/en/article/94920). The process was found to be generally replicable, with a few tips and caveats:

- While OpenStudio continues to make progress in improving the scope and usability of its tools, they did not completely cover the needs of this research study. The definition of energy efficiency measures and sequential search optimization as part of this project's energy modeling analysis still required a significant computer scripting component. For projects in which more simplified models would be acceptable, this barrier can be mitigated by using default inputs rather than project-specific variables. NREL's Building Component Library (BCL) (https://bcl.nrel.gov) can be used as a source of such default components and measures. In fact, while this study involved modeling a building in great detail to demonstrate simulation tool capabilities, a user could save a great deal of time and effort by simplifying the model without significantly reducing its accuracy.

- This project used Match Photo to capture the geometry of a building with the use of photos. However, where other building data are available, a model can be constructed much more simply and quickly from documented dimensions.

Although this analysis was geared to one specific building retrofit project, this lifecycle based, integrated design approach to efficiency package selection may be applied more broadly.

Occupant Behavior

For the occupant behavior study, Pacific Northwest National Laboratory (PNNL) sought to:

- Better understand the energy-related behaviors of Fort Carson building occupants, and
- Apply that understanding to a research intervention, testing an evidence-based approach to spur occupants to increase energy-saving actions.

The research team gathered initial occupant data from surveys, group and individual interviews, site visits, and limited energy metering. Although a low survey response rate made it difficult to draw conclusions, the data did allow PNNL to identify two occupant behaviors to target for a behavioral research intervention: end-of-day computer shutdowns and thermostat setbacks.

The three-month intervention was carried out at five buildings (one Brigade HQ, 2 COFs, 2 office buildings), with the assistance of each buildings' Building Energy Monitor (BEM). BEMs are members of the Army building community who have been assigned responsibility to monitor building operations for energy saving opportunities and problems. The BEM program has been deployed Army-wide, although not all buildings have been assigned BEMs. Evaluating the potential of this program was a major focus of the intervention.

The intervention was designed and conducted based on a theoretical framework that identifies the rules, roles, and tools that shape the context for energy conservation behavior:[25]

- **Rules** include both formal and informal policies and procedures related to energy use, e.g., both required and traditional thermostat set points. In this project, occupants particularly needed clarification of rules about whether shutting down one's computer at the end of the day was encouraged or even permitted.
- **Roles** refer to individuals and groups with the most influence over energy use, including occupants, building managers and base commanders. For the intervention, BEMs played a key role in educating occupants on energy saving approaches, while leadership reinforced these messages by endorsing them from the top down.
- **Tools** are technologies, systems, and processes that can be used to support energy use reduction goals. In this project, researchers equipped BEMs with a suite of tools (floor check forms, posters, etc.) to enable them to play their role more effectively, while additional tools (computer scans, post-intervention surveys and interviews, metering, etc.) were used to evaluate results.

Finding 1: Occupants increased energy-saving behaviors as part of the intervention, leading to energy reductions of approximately 2% in one building. Success rates varied across the five buildings.

[25] Wolfe, A., Malone, E., Heerwagen, J. & Dion, J. (2014). *Behavioral Change and Building Performance: Strategies for Significant, Persistent, and Measurable Institutional Change.* Pacific Northwest National Laboratory. PNNL-23264. http://www.osti.gov/scitech/biblio/1132691

As shown in Figure 72, occupants of all five buildings participating in the behavioral intervention shut down a greater percentage of their computers at the end of the day, increasing on average from 13% to 51% of computers (measured from the first week of the intervention to the peak week of compliance for each building).

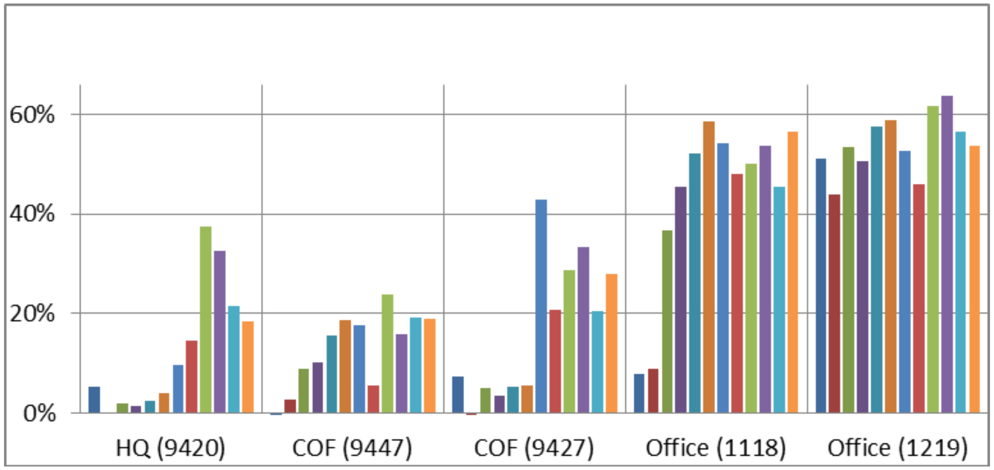


Figure 72 Percent of Computers Shut Down at Night by Building and Week Based on Computer Network Scans

This increase corresponded with post-intervention surveys showing 72% of civilian occupants reporting more frequently turning off their computers at night, and 52% more frequently shutting off their monitors. Over a quarter of respondents also reported more frequently turning off lights and setting back thermostats at the end of the day, though the research team had less data to confirm these behavior changes. (Survey results from military personnel were insufficient for analysis.)

Despite energy measurement challenges during this project, analysis of metered data from one of the office buildings studied suggests that the intervention contributed to a reduction in energy use of at least 2% after just three months. A longer intervention period may have allowed opportunities to achieve higher levels of compliance. If 100% of occupants had complied with these measures, energy savings are estimated to have ranged from 3% to 7%. While these savings may sound modest, in the context of a NZE goal, every increment of savings matters.

Finding 2: Having an engaged Building Energy Monitor (BEM), with reinforcement from leadership, helped drive behavior change.

The research team's findings suggest that a BEM-like program can work to promote energy-saving behavior change, if such a program includes certain features:

- **Revisit BEM qualifications and identify a qualified BEM for each building.** The BEM should be viewed as a specialized job function requiring specific communications skills. BEMs may be most effective if they: (1) have an interest in the position, (2) are personally committed to energy conservation and sustainability, (3) have some level of respect from the occupants (e.g., a fairly high-ranking officer in military buildings), and (4) are comfortable engaging building occupants in dialogue about energy. They should be energy coaches who aim to help occupants without being overly intrusive.

- **Create accountability and incentive structures.** In addition to ensuring that BEMs have the time to carry out their duties, supervisors of BEMs should establish clear expectations for BEM duties, ensure they are completed, and recognize and reward good performance. An expected time commitment—e.g., two hours per week once the BEM has identified building-level conservation opportunities—should be established and reinforced by supervisors.

- **Provide BEMs ongoing training on behavior change.** In addition to checking a building's physical features for possible impacts on energy performance, BEM training must also explicitly address how occupants impact energy use, and how best to influence these behaviors.

- **Provide BEMs with a toolkit that can be adapted locally.** BEMs need a set of simple, periodically updated tools to understand how the building and its occupants are performing, and to engage occupants effectively, such as:

  - Monthly building energy performance summaries,
  - A floor-check template,

  - A list of energy use behaviors commonly seen on installations,
  - A model conservation behavior-change plan, and
  - Templates for email messages and topics to address, which BEMs can tailor based on their buildings' characteristics and performance.

- **Make new occupant energy orientation a requirement.** New occupants should receive a personal, brief and timely building orientation. For example, for buildings with occupant control of heating/cooling units, the BEM might establish expectations for thermostat setbacks.

- **Regularly measure and provide feedback on performance.** BEMs should provide regular feedback to occupants on building energy performance and the impact of specific behaviors on energy use. This will require setting up energy meters and systems to make these data readily accessible and developing analytics to make the data informative.

Finding 3: Occupant behavior can be influenced as part of a well-structured effort that includes considering the institutional context, targeting specific and relevant behaviors, providing social reinforcement, measuring results, and incorporating feedback.

This study reinforced previous behavioral research findings in demonstrating both the challenges to and opportunities for influencing occupant energy behavior. As people have many competing demands on their time, simply getting their attention, much less their commitment, can be difficult in many environments. Occupant behavior change should not be the first or only strategy employed for energy reduction in buildings, but should be part of an integrated strategy that includes optimizing building systems and setting default conditions that favor energy conservation.

Figure 73 Office thermostat

Nevertheless, given that the human element will always be a factor in building operations, and that much energy behavior is habitual, influencing occupant energy habits can provide significant benefits.

Key lessons for employing occupant behavior strategies include:

- **Understand the institutional context in which behavior takes place.** While individual behavior is important for energy reduction, many institutional factors can reinforce or inhibit individual action. The harmonization of policies (rules), communicators (roles) and approaches (tools) involves considerable coordination by change agents to ensure that desired behaviors are enabled by appropriate policies, and communicated and reinforced by trusted authorities. Building energy programs should work to identify and eliminate institutional barriers and provide guidance and resources to building-level change agents to get rules, roles, and tools successfully aligned.

- **Make desired behaviors specific and relevant.** Energy programs often employ broad-based awareness programs coupled with generic lists of the "top ten things" occupants can do to save energy. While education and awareness are essential, simply providing information and calling attention to it are often insufficient to elicit sustained behavior change. The more tailored the advice is to one's specific circumstance, the more relevant it is likely to appear to its target audience.

- **Provide social reinforcement through known, trusted sources on a regular basis.** Institutional and behavioral change should be regarded as a *high touch* activity, reinforced through person-to-person interaction, rather than simply a *high tech* activity. This includes having advocates for energy conservation at the local or building level who can observe behavior and engage in dialogue with occupants. It also includes reinforcement from leadership figures.

- **Measure results and provide regular information and feedback on performance.** Achieving all of the goals outlined above requires an iterative process whereby occupants both give and receive feedback. Program success requires taking into account occupant concerns, ideas and levels of comfort and productivity. It also requires providing information on energy performance to occupants, energy advocates, building managers and leaders so that all can know where they stand and adjust behaviors and systems accordingly. Energy metering and submetering are important wherever practical to gauge progress and areas for improvement.

Recommendations Based on Research Findings

The Fort Carson Energy Research Project examined a series of strategies to help already above-average green buildings approach NZE levels—all within the constraints of an active military base. While the findings of this project are specific to the building types, systems, climate and population of Fort Carson, they also reveal lessons in integrating energy efficiency strategies applicable to other buildings:

- The building systems research conducted under this project demonstrated the value of taking a deep dive into how efficiently building systems (like lighting and envelope) are operating and identifying opportunities for improvements, up to NZE. Analyses that take lifecycle costs and benefits into account lay the groundwork for making the most rational decisions over the lifetime of a building.[26]

- Best practices identified should be built into portfolio planning, standards, contract language and specifications. Solutions will need to be adapted to each individual building, at which point technologies and approaches can be bundled together to form the most lifecycle-cost-effective progression of investments.

- The behavioral research demonstrated opportunities to effectively engage building occupants in energy reduction. The research suggested the value of integrating building systems improvements with occupant engagement strategies, as both are needed to achieve NZE levels.

[26] Note that it would not be accurate to simply add up the savings among the studies represented here, due to methodological variations and potential double-counting among them.

- Engaging occupants requires employing institutional approaches that integrate changes in policy and organizational roles with programs to influence specific occupant behaviors. Occupants need support to adopt energy-saving behaviors, and all relevant rules, roles and tools should be considered and adjusted to ensure that they receive such support. As a key example, local energy advocates need systems to monitor energy use and gain feedback from occupants while also informing occupants of energy use levels and how they can reduce them.

Attaining a high standard like NZE requires finding and using every tool in the toolbox. Yet even such an ambitious goal appears increasingly attainable as building professionals learn how to design and adapt building systems and work with occupants to make it happen.

Attaining a high standard like NZE requires finding and using every tool in the toolbox.

Acronyms and Abbreviations

AC: air conditioning

AEDG: Advanced Energy Design Guide

ARFORGEN: Army Force Generation

BCL: Building Component Library

BCT: Brigade Combat Team

BEM: Building Energy Monitor

CBP: Commercial Building Partnerships

CERL: USACE Construction Engineering Research Laboratory

cfm: cubic foot/feet per minute

ci/c.i.: continuous insulation

COF: Company Operations Facility

CT: current transformer

DFAC: Dining Facility

DOAS: dedicated outdoor air system

DOD: U.S. Department of Defense

DOE: U.S. Department of Energy

DPW: Directorate of Public Works. Department of Public Works

EISA: Energy Independence and Security Act of 2007

EOD: Explosive Ordnance Disposal

EPS: expanded polystyrene

ES&H: Environmental, Safety, and Health

ESPC: Energy Savings Performance Contract

EUI: Energy Use Intensity, Energy Use Index

fc: foot candle

FEMP: Federal Energy Management Program

ft: foot/feet

ft^2: square foot/feet

GSA: U.S. General Services Administration

GSHP: Ground source heat pump

IEAD: Insulation entirely above deck

HQ: Headquarters

hr: hour(s)

HVAC: heating, ventilation, and air conditioning

IDF: input data file

IESNA: Illuminating Engineering Society of North America in: inch(es)

J/kg·K: joule/kilogram/K

kBtu: Thousand British Thermal Units

kW: kilowatt(s)

lb: pound(s)

LED: Light Emitting Diode

LEED: Leadership in Energy and Environmental Design

LPD: Lighting Power Density

lx: lux

MDMS: Meter Data Management System

MEDDAC: Medical Department Activity

MILCON: Military Construction

MW: megawatt(s)

NEC: Network Enterprise Center

NIST: National Institute of Standards and Technology

NPV: net present value

NREL: National Renewable Energy Laboratory

NZE: net zero energy

NZEI: Net Zero Energy Installation

O&M: Operations and Maintenance

OFHPGB: Office of Federal High-Performance Green Buildings

PAT: Parametric Analysis Tool

PNNL: Pacific Northwest National Laboratory

PV: Photovoltaic

RSF: Research Support Facility

SHGC: Solar heat gain coefficient

TEMF: Tactical Equipment Maintenance Facility

TSD: Technical Support Document

USACE: U.S. Army Corps of Engineers

W: watt(s)

WBDG: Whole Building Design Guide

w.g.: water gauge

WWR: window-to-wall ratio

yr: year

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Appendix A Fort Carson Sustainability Program

Fort Carson has had an active Sustainability Program for two decades, and is one of only two bases in the nation committed to meet the Army's net zero energy, water, and waste goals by the year 2020.

Among the base's achievements is one of the largest collections of buildings certified under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system, over 70, ranging from Silver to Platinum, as of August 2014. Most of these buildings were newly constructed, as the base has increased in size by over 4 million ft^2 since 2008.

7 Elements of Fort Carson's Sustainability Program:

1. Energy and Water
2. Sustainable Procurement
3. Zero Waste
4. Sustainable Training Lands
5. Sustainable Transportation
6. Sustainable Development
7. Air Quality

Energy efficiency has been a major focus, and Fort Carson has succeeded in reducing energy use (in kBtu) per square foot (energy use intensity [EUI]) since 2003 by nearly 17%. Major efficiency projects have included replacing inefficient lighting in over 80 facilities, replacing aging boilers in over 30 facilities, and expanding the energy management control system to over 30 facilities. Smart meters are being installed and reporting to the Army Meter Data Management System, to improve identification of potential facility issues and raise energy awareness of facility managers and occupants.

Fort Carson also has made major progress in increasing on-site renewable energy resources. The base has a 2 megawatt (MW) solar electric (photovoltaic [PV]) array that was completed in 2007 under a power purchase agreement. Fort Carson has integrated over 1.2 MW of PV in new construction including a carport, three ground mounted systems and several rooftop systems, and an additional 1.7 MW of PV is planned under two current construction projects. Four facilities have been built with ground source heat pump systems, with over a dozen solar hot water systems installed. As a result of all of these efforts, on-site renewables account for about 3.5% of Fort Carson's current energy use.

Fort Carson has received assistance toward meeting its energy goals from the Department of Energy (DOE), National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL) and other organizations including in the form of energy assessments, microgrid design, performance metric development, technology demonstration projects and Energy Savings Performance Contract (ESPC) support.

Appendix B Lighting and Daylighting Glossary

Ambient lighting: General lighting in a space typically provided by uniformly spaced overhead light fixtures.

Bi (dual) -level control: Control of light source intensity at two discrete levels in addition to off. Typically, the discrete levels are 50% and 100%.

Clerestory glazing: Vertical glass portions of the building envelope that typically sit at least 9 ft above the finished floor.

Control interface: The components of the lighting control system with which occupants interact. Commonly, this includes wall-mounted on/off switches and slide dimmers.

Daylight blinds: Blinds that sit in the daylight glazing, that are static or operable, and serve to redirect direct sun into a space more deliberately than traditional blinds, while blocking glare from direct sun.

Daylight glazing: Vertical glass portions of the building envelope that sit above 7.5 ft on each floor.

Daylight quality: The distribution and color of daylight at a given point in time. Daylight quality metrics include uniformity and color temperature.

Daylight quantity: See Illuminance

Daylight sufficiency: The minimum daylight quantity needed for typical tasks in a space to be performed, without excess daylight.

Egress fixture (versus emergency): Egress pathway lighting, which is commonly about 10% of a space's lighting load placed near pathways that lead to exits for the space.

Electric lighting zones (switching, granularity): A zone encompasses the floor area lit by all the luminaires on a common controller.

Emergency lighting bypass relay: A relay that allows for emergency/egress fixtures to be powered by a backup power source in a normal power failure event while operating as a typical relay that can be controlled by the lighting control system at all other times.

Fenestration-to-surface-area: The ratio of glass to envelope area for a given plane, used as a daylighting and envelope design metric. Examples include window-to-wall area and skylight-to-floor area ratios.

Glare: The sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility. There are a variety of glare types such as disability glare, which is a type of glare that causes a loss of visibility from stray light being scattered within the eye, and discomfort glare, which is the sensation of annoyance or even pain induced by overly bright sources.

Illuminance: The average density of luminous flux incident on a horizontal (unless another orientation is specified) surface, measured in foot candles (fc) or lux (lx). One fc equals 10.76 lx.

Lighting control algorithms: The way in which the light in the space responds to input (typically daylight quantity). Types of algorithms include continuous dimming or switching, and are further defined by settings such as dimming rate and deadband (buffer to prevent rapid cycling of lights). The settings result in a combined electric light and daylight quantity at any given point in time.

Lighting power density (LPD): The maximum lighting power per unit area of a building classification of space function.

Lighting schedule (0-1): A normalized measure of the number of lights used in a space each hour. All lights on results in a value of 1 and all lights off results in a value of 0.

Maximum-to-minimum illuminance ratio: uniformity metric; the degree of variation of illuminance over a given plane. Greater uniformity means less variation of illuminance.

Occupancy and light loggers: Measurement devices independent of the lighting control system that detect and record a change in light level and occupancy in the space. These devices must be set up (located and sensitivity adjusted) for a given space so that the change in light level corresponds to a group of lights being on or off and for all occupancy within a zone to be detected. The output of this type of device can be used to create lighting and occupancy schedules for a space.

Occupancy schedule (0-1): A normalized measure of the number of occupants in a space each hour. A value of 1 is associated with the maximum expected occupancy and a value of 0 is given to an empty space.

Passive lighting control design, same as: Occupant engaged(?)-lowest level first, and must be selected

Photosensor: A device used to integrate an electric lighting system with a daylighting system so lights operate only when daylighting is insufficient. A photosensor consists of a photocell (light sensitive diode) and a controller or logic device that determines the status of the lights in response to daylight. Often these components are packaged together and mounted on the ceiling.

Reflectance: A measure of the ability of an object to reflect or absorb light, expressed as a unitless value between 0 and 1. A perfectly dark object has a reflectance of 0, and a perfectly white object has a reflectance of 1.

Sweep: A timed lighting control event that turns a group or all of a space's lights off at once. Often, a warning such as a quick cycle of the lights on and off will be given to occupants approximately ten minutes prior to the event.

Task lighting: A secondary layer of light, in addition to the ambient lighting, that is focused in a particular area of the space. Task lighting typically takes the form of a desk lamp.

Transmittance: A property of glazing that expresses the percentage of visible light that passes through it.

Transom glass: High glass, typically above 7.5 ft above the finished floor, set into an interior wall that allows an interior space to borrow daylight from a perimeter space.

Troffers: Rectangular, overhead light fixtures that are recessed into a regular ceiling grid.

Tubular daylighting devices: A specific type of toplighting, or lighting from the ceiling, that uses a highly reflective tube to transfer light from the roof to a lower ceiling plane.

Vacancy control (versus occupancy, typically mounted on the ceiling): A manual switch control setup that requires an occupant to manually turn lights on but will automatically turn lights off after preset duration without detected motion.

Vision glazing: Vertical glass portions of the building envelope that sit below 7.5 ft on each floor (often considered only above 2.5 ft)

"Walk through" circuits (or security circuits): A group of lighting fixtures that lights an often traversed pathway in a space, such as that used by nighttime security staff, that can be switched on and off independently of other fixtures in the space.

Workplane: The working surface, which is often typical desk height, 2.5 ft above the finished floor, but can also be the floor in hallways.

Contributing references: Rensselaer Polytechnic Institute Lighting Research Center, National Lighting Product Information Program; Energy Center of Wisconsin; ASHRAE

Appendix C Retrofit Efficiency Measure Detailed Assumptions

Lighting Measures:

1. Reduce Lighting Power Density (LPD)

- Apply to whole building (office lighting equipment will dominate the building; ignore the fact that not all spaces will be lit by the same type of fixture).

- **Baseline:** assume 1.1 W/ft^2 (according to ASHRAE 90.1-2007 limit for offices), provided by 2x2 fluorescent fixtures with four 17W lamps at a contractor cost of $131 per fixture ($187.14 per fixture assuming a contractor markdown of 30%). At 68W per fixture, each fixture should cover an area of 61.8 ft^2 to result in an LPD of 1.1 W/ft^2. Area normalized fixture cost for the baseline case is $3.03/ft^2 (see costing assumptions below for fixture spacing).

- Costing assumptions:

  i. Assume the same fixture spacing (one per 61.8 ft2) for all lighting scenarios. Base system costs purely on fixture costs unless otherwise noted (assume all other costs are the same regardless of lighting fixture).

  ii. All fixtures are assumed to be 2x2 (both fluorescent and Light Emitting Diode [LED]), for consistency.

  iii. Account for the incremental operations and maintenance (O&M) cost associated with installing LED fixtures rather than fluorescent fixtures (assume O&M costs are the same for both LED LPD reduction scenarios). Assume baseline fluorescent lamps would have a rated life of 30,000 hrs but an actual average life of 20,000 hrs; fluorescent lamp life is significantly affected by on/off cycling and many other sources estimate fluorescent lamp life at 10,000 hrs or even less. Assume LED lamps have a life of 70,000 hrs (the lamp for the fixture used to cost LED lighting for this measure is rated for 50,000 hrs to L80 [the industry standard for LED useful life is L70, indicating the lamps would last longer than 50,000 hrs]; other sources indicate that LED lamps can last to 100,000 hrs or more). Assume that fluorescent replacement bulbs cost $4 each ($16 per fixture, for this case [4 lamps per fixture]) and that it takes 15 minutes (0.25 hrs @ $70/hr [RS Means labor rate] = $17.50) to replace the lamps in each fixture (other sources estimate 30 minutes per lamp; our assumption is more in line with group re-lamping). Assume that fluorescent ballasts must be replaced every other re-lamping cycle at a cost of $115 per fixture ($45 for parts and $70 for labor [1 hr @ $70/hr]). Assume that fluorescent fixtures must be replaced every four re-lamping cycles at a cost of $187.14 per fixture and $140 for labor (2 hrs @ $70/hr) Assume that the cost of LED lamp replacement is half of the fixture cost (assuming an average fixture cost for the two LPD reduction strategies of $315.29 results in a per fixture re-lamping cost of $157.64) and that this cost covers fixture replacement as well (in reality, some LED fixtures will require full fixture replacement for re-lamping whereas others will allow for the replacement of individual LED modules , at a significantly reduced cost; our assumption is meant to represent an average case). Assuming that LED lamp replacement takes 1 hour, labor for re-lamping would be $70/fixture (the same as that for ballast replacement, based on the assumption that it would require more work than simple fluorescent tube replacement). These assumptions result in per fixture O&M costs of $8.64/1000 hrs and $3.25/1000 hrs for fluorescent and LED lighting fixtures, respectively. Assuming 4,560.4 lighting hrs per year (neglecting any schedule changes or daylighting strategies that may be applied during the optimization) and 61.8 ft2 per fixture, this results in annual O&M costs of $0.64/ft2·yr and $0.24/ft2·yr for fluorescent and LED lighting fixtures, respectively.

- **LPD Reduction 1:** reduce fixture wattage from 68W to 36W (2x2 LED fixture), resulting in an LPD of 0.58 W/ft^2 (47% reduction).

i. Contractor cost is $240 per fixture ($324.86 per fixture assuming a contractor markdown of 30%). Area normalized fixture cost is $5.26/ft2 (incremental cost above baseline is $2.23/ft2).

ii. Assume lighting design is required for this low LPD scenario (primarily for fixture selection). Lighting design costs are taken from a Whole Foods Commercial Building Partnership (CBP) project, for which the lighting design fee was $10k. Assume the fee is flat and not area dependent. Also assume that some minimal lighting design (provided by the fixture manufacturer and/or the project lighting contractor) is required for the baseline scenario, at 25% of the cost of expert lighting design (the Whole Foods case). So the incremental cost for lighting design is $7,500 for the building (Building 1219 has a floor area of $49,000 ft2, resulting in an area normalized lighting design cost of $0.15/ft2).

iii. Combining the incremental fixture cost ($2.23/ft2) and the incremental lighting design cost ($0.15/ft2), the total incremental cost for this measure is $2.38/ft2.

- **LPD Reduction 2:** reduce fixture wattage from 68W to 24W (2x2 LED fixture), resulting in an overhead lighting LPD of 0.39 W/ft^2 (a 65% reduction). Assume that task lights will need to be added at the workstations due to the lower lighting levels. According to estimates made from the Building 1219 floor plan, the average floor area per enclosed office workstation is 166.7 ft^2. That increases to 244.8 ft^2 per open office workstation.

i. Task light data for the Research Support Facility (RSF) was used as a reference point. Assume that each task light has 6W of lighting power and costs $225. The LPD added to the enclosed office and open office space types should be 0.04 W/ft^2 (at $1.35/ft^2) and 0.02 W/ft^2 (at $0.92/ft^2). So an LPD of 0.43 W/ft^2 (61% reduction) should be applied to enclosed offices, an LPD of 0.41 W/ft^2 (63% reduction) should be applied to open offices, and a 65% LPD reduction should be applied to all other spaces.

ii. Contractor cost is $214 per fixture ($305.71 per fixture assuming a contractor markdown of 30%). Area normalized fixture cost is $4.95/ft^2 (incremental cost above baseline is $1.92/ft^2)

iii. Again assume an incremental lighting design cost of \$7,500 (\$0.15/ft^2) is required for this scenario. Assume that the lighting design expertise and effort is the same for both LPD reduction strategies, and that the different in LPD is a matter of personal preference on the part of the building owner.

iv. Combining the incremental fixture cost (\$1.92/ft^2), the incremental task light cost (\$1.35/ft^2 for enclosed offices, \$0.92/ft^2 for open offices, and \$0 for all other space types), and the incremental lighting design cost (\$0.15/ft^2), the total incremental cost for this measure is \$3.42/ft^2 for enclosed offices, \$2.99/ft^2 for open offices, and \$2.07/ft^2 for all other space types.

2. Add Vacancy Sensors to Enclosed Offices

- Apply only to enclosed offices.

- Model during unoccupied hours using an adjustment to the night schedule (reduce night time LPD fraction from 0.2 to 0.05). Model during occupied hours using on/off daylighting control with a daylight threshold of 300 lux; basically, assume that occupants will turn the light on if the daylight level decreases below 300 lux, but would otherwise leave the light off.

- Base incremental costs for this measure on the cost required to add network control functionality to the lighting system. Assume that Building 1219 has the most basic of lighting control systems in the baseline scenario (\$0.12/ft^2 for basic lighting timer control for a 50 zone system, according to RS Means). Use the RSF lighting control system as a reference case for the cost of advanced lighting control. The RSF cost for lighting controls is \$0.98/ft^2. The RSF lighting system is more complex than most commercial lighting systems; assume a 25% cost premium is associated with that additional level of complexity, resulting in a typical advanced lighting control cost of \$0.74/ft^2. Thus, the incremental lighting control cost for this measure is \$0.62/ft^2.

- Because 90.1-2007 requires occupancy sensors for enclosed offices, assume that the costs associated with occupancy sensors and vacancy sensors cancel out.

3. Light Common Areas with a Combination of Egress Lighting and Vacancy-Sensor Controlled Primary Lighting

    - Apply this measure to the following space types: Common and Corridor.

    - Assume an egress lighting level of 0.1 W/ft^2. Base the incremental cost of egress lighting on the cost of the additional wiring that would be required to control it separately from the rest of the overhead lighting. According to RS Means, this cost amounts to \$0.20/ft^2.

    - Incremental cost for adding vacancy sensors is again assumed to be the cost associated with adding advanced lighting control capabilities, \$0.62/ft^2.

    - This measure will be modeled with a schedule modification. The modification will be different for corridors and common areas. RSF data indicate that, for spaces where lights may or may not be turned on depending on the task being performed (break room, printer room, etc.), the average fraction of installed lighting power that is used during occupancy is 30% (or, more simply, that, during occupancy, the lights are turned on 30% of the time and off 70% of the time). Assume the average power of the "off state" during occupied hours is 0.1 W/ft^2 (9% of the installed lighting power). Accordingly, the average power fraction of the corridor lighting system during occupancy is 0.36 (assuming 30% "on" and 70% "off"). The baseline lighting fraction at max occupancy is 0.9; 0.36 is 40% of that value. To model this measure for corridors, the existing lighting schedule fractions will be multiplied by 40% during occupied hours. For common areas, which are used as meeting rooms, assume (conservatively) that the lights are turned on 50% of the time. Accordingly, the average power fraction of the common space lighting systems during occupancy is 0.55. The baseline lighting fraction at max occupancy is 0.9; 0.55 is 61% of that value. To model this measure for common spaces, the existing lighting schedule fractions will be multiplied by 61% during occupied hours. For both corridors and common spaces, the lighting fraction schedules will be set to 0.05 during unoccupied hours (assuming vacancy sensors keep lights totally off, but assuming conservatively that all spaces have some minimum usage throughout the night to account for security, random occupancy, etc.).

- Total incremental measure cost is $0.82/ft^2

4. Daylight Open Offices

- Apply this measure only to open office space types (all open office spaces in Building 1219 have access to daylight).
- Assume a daylighting set point of 300 lux and continuous dimming. Assume continuous dimming down to 0% power.
- Assume daylighting can be facilitated with dimming ballasts, photosensors, and the necessary wiring and controls; assume no light louvers or other such equipment is needed.
- Assume a $10 fixture up-charge (conservative), resulting in a cost increase of $0.16/ft^2 to the lighting system.
- Approximate the rest of the cost for the daylighting system using the cost to commission and control it. It took a commissioning agent two weeks to commission the daylighting system for the RSF. Assuming 80 hours of total labor at $100/hr, this resulted in a cost of $8,000. Assume that the daylighting commissioning cost is largely fixed (not very floor area dependent). The total cost of the RSF lighting system was $2.2 million. Typical commissioning costs for an entire lighting system are on the order of 1%, or roughly $22,000 for the case of the RSF. This points to the fact that daylighting commissioning made up 36% of the lighting system commissioning cost, which seems reasonable. For Building 1219, the $8,000 daylighting commissioning cost can be area normalized to $0.16/ft^2
- Assume the cost of adding daylight control is the same as the cost of adding advanced lighting control, $0.62/ft^2
- Total incremental measure cost is $0.94/ft^2.

Plug Load Measures:

1. 11 Hour Plug Strip

- Apply this measure to Open Offices and Enclosed Offices.

- It is possible that this measure could be applied to equipment printer rooms (and common rooms, where such spaces double as printer rooms), break rooms, and meeting rooms, but it is unclear exactly how this would work. Would it be reasonable to have to activate the power strip in a printer room before it could be printed to each morning? Could a fax machine be turned completely off at any given time? What kitchen equipment could be plugged into the power strip and what fraction of the load would that make up? Obviously, a refrigerator could not. For a microwave, it might be possible, but the clock would be reset each morning. For simplicity, assume for now that the measure is applied only to office spaces.

- Currently plug load equipment share the same schedule. In reality, plug load schedules differ by space type. Network Enterprise Center (NEC) plug loads should be on an always on schedule. Printer rooms, common rooms, and break rooms should be on the modified Large Office TSD schedule (set to 30% of the peak daytime value [power fraction of 0.27] at night, to match Building 1219 measured data).

- Assume that current Building 1219 measured data for enclosed and open office plug loads reflect the benefits of installing the 11 hour controllable plug strips. Measured data indicate that such loads are reduced to 30% of the peak daytime value at night. Assume that such loads would be reduced to only 50% of the peak daytime value at night for the baseline case (with standard plug strips). To model this measure, create a modified version of the current baseline plug load schedule (increasing the night time plug load fraction from 30% to 50% of the peak daytime value [corresponding to a power fraction of 0.45]) and apply that schedule to the enclosed and open office space types. Then apply the measure only to the plug load schedules for those space types. This measure should not be applied to discrete plug loads, regardless of the spaces in which they are located.

- Assume that the incremental cost of the measure is \$20 per plug strip (assuming \$10 for a standard plug strip and \$30 for the 11 hour controllable version). Assuming 166.7 ft^2 per enclosed office workstation and 244.8 ft^2 per open office workstation, this amounts to an area normalized incremental cost of \$0.12/ft^2 for enclosed offices, and \$0.08/ft^2 for open offices.

2. High Efficiency Computer Equipment

   - Apply this measure to open offices and enclosed offices.
   - For the baseline case, assume 100W per desktop computer (at \$450 each) and 37.5W per monitor (totaling 75 W per workstation and \$340, assuming two monitors per workstation at \$170 each). This amounts to 175W and \$790 per workstation: 1.13 W/ft^2 for enclosed offices and 0.71 W/ft^2 for open offices.
   - For the low energy case, assume 16.7W per mini desktop (at \$829 each) and 16.5W per monitor (totaling 33 W per workstation and \$580, assuming two monitors per workstation at \$290 each). This amounts to 50W and \$1409 per workstation: 0.30 W/ft^2 for enclosed offices and 0.20 W/ft^2 for open offices (71.4% reduction in each case); at an incremental cost of \$3.71/ft^2 for enclosed offices and \$2.53/ft^2 for open offices.

Envelope Measures:

1. Add Roof Insulation and Replace Roof Membrane

   - Apply measure to entire roof.
   - Add insulation layer and membrane layer to the top of the existing roof construction.

- Baseline roof construction has R-20 c.i. The Advanced Energy Design Guide (AEDG) recommendation for climate zone 5 is R-30 c.i. We will model two instances of roof insulation addition: one at R-25 c.i. and one at R-30 c.i. For each case, polyisocyanurate materials of the appropriate thicknesses will be added to the baseline model, for access by the OS measure. A roof membrane material will also be added to the model (with cool roof surface properties), to be used by both instances of the roof insulation measure.

- Costs assume that the insulation and new membrane can be added to the top of the existing construction. RS Means cost for placing new membrane over existing: $482.22/100 ft^2 ($4.82/ft^2).

- Assume that the cost of insulation needs to be added. Cost to install 2” of perlite insulation is $1.70/$ft^2$ (RS Means Assemblies Costs for the same insulation are $1.51/$ft^2$; accordingly, apply 170/151 cost adjustment multiplier to RS Means Assemblies Costs for polyisocyanurate insulation). The adjusted cost for R-5 c.i. insulation is $1.00/$ft^2$; the adjusted cost for R-10 c.i. is $1.12. Accordingly, the cost of the insulation layers that need to be added to the baseline roof to hit R-25 c.i. and R-30 c.i. are $1.00/$ft^2$ and $1.12/$ft^2$, respectively.

- Total cost for improving the roof insulation from R-20 c.i. to R-25 c.i. and R-30 c.i. is $5.82/$ft^2$ and $5.94/$ft^2$, respectively.

- Assume no improvement in infiltration occurs with application of this measure.

2. Add Spray Foam Insulation on Interior of Exterior Wall Constructions

    - Apply to all exterior wall constructions.

    - Add an insulation layer (insulation and steel studs in parallel) and a gypsum board layer to the inside of the existing exterior wall construction.

- Baseline exterior wall construction has R-11.4 c.i. (replace existing baseline construction, which is incorrect, with the 90.1-2007 construction for Climate Zone 4B). The AEDG recommendation for climate zone 5 is R-13.3 c.i. We will model two instances of exterior wall insulation addition: one that assumes that a 1-5/8" metal stud framed wall is filled with polyurethane spray foam (R-4.8 per inch [the average value reported in a Building Green reference], at a density of 48.1 kg/m^3 and a specific heat of 1465.4 J/kg·K [0.35 Btu/lb·°F]); and one that assumes that a 3-5/8" metal stud framed wall is filled with polyurethane spray foam. In both cases the interior surface is finished with 5/8" gypsum board. For the stud spacing, 24" O.C. is assumed. The basic wall construction costs are \$2.15/ft^2 and \$2.25/ft^2 for the 1-5/8" and 3-5/8" cases, respectively. The effective insulating properties of the added constructions were calculated according to Example 5 on p. 27.5 of the 2009 ASHRAE Fundamentals handbook. R-values for each construction were calculated according to both the parallel-flow and isothermal planes methods and then averaged (the handbook indicates that the true value is bounded by the parallel-flow and isothermal planes methods). The resultant effective R-values were R-5.74 (R-5.18 for the insulating layer) and R-8.67 (R-8.11 for the insulating layer) for the 1-5/8" and 3-5/8" cases, respectively.

- Assuming an 8" area fraction for the steel stud material and a steel density of 7,833 kg/m^3, the resultant density of the overall insulating (combined steel and insulation) layer is 670.9 kg/m^3. Assuming a steel specific heat of 502.4 J/kg·K (0.12 Btu/lb·°F), the resultant specific heat of the overall insulating layer is 565.2 J/kg·K (0.14 Btu/lb·°F). Set the absorption properties to those of the insulation (use polyisocyanurate as a proxy for the spray foam).

- To model this measure, three materials will be added to the baseline model for access by the OS measure: (1) a 5/8" gypsum board material, (2) a 1-5/8" steel stud and insulation layer, and (3) a 3-5/8" steel stud and insulation layer.

- A local spray foam installer priced filling a 3-1/2" wall at \$1.10/board ft (assume 0.92 board ft per ft^2 of wall area, according to the area fraction assumption for the steel studs, resulting in a cost of \$3.67/ft^2 for filling a 3-

5/8" wall). RS Means data indicates that filling a 1-5/8" wall would cost roughly half as much as filling a 3-5/8" wall, or $1.83/ft^2.

- The total cost for this measure is $3.98/ft^2 of exterior wall area for the 1-5/8" case, and $5.92/ft^2 of exterior wall area for the 3-5/8" case.
- Assume that this measure reduces building infiltration by 25%. Assume baseline infiltration rates are in line with those for pre- and post-1980 construction from the reference building model set.

3. Add Window Inserts to Reduce Heat Transfer and Infiltration

- Apply this measure to all exterior window constructions.
- Windows are modeled using Simple Glazing Systems. To apply measure, replace baseline Simple Glazing System.
- Make sure that baseline Simple Glazing System construction meets the 90.1-2007 minimum requirements.
- Two instances of the measure will be modeled: a high solar gain instance and a low solar gain instance. Product data was taken from the iWindow web page (for the iWindow 5; iWindow 7 was not considered due to its thickness). First, both the low solar gain and high solar gain constructions (iWindow 5, 0.5" air gap) described on the web page (where the baseline window construction was ¼" single pane clear glazing) were recreated (properties were matched) in EnergyPlus. Then, the single pane, clear construction was replaced with the 90.1-2007 baseline glazing construction for Climate Zone 5B and new properties were calculated. The resultant properties are as follows: U-0.876, SHGC-0.270, and VLT-0.388 for the low solar heat gain case; U-0.850, SHGC-0.240, and VLT-0.347 for the low solar heat gain case.

- Measure cost is the cost of purchasing and installing the window inserts; the manufacturer estimates the total installed cost for the iWindow 5 product at $30/ft^2 of window area.

- Assume that this measure reduces building infiltration by 25%. Assume baseline infiltration rates are in line with those for pre- and post-1980 construction from the reference building model set.

4. Replace Windows with Electrochromic Windows

- Apply this measure to all exterior windows (this measure and the window insert measure are mutually exclusive; this measure cannot be combined with the window insert measure).

- Modeling this measure requires the addition of two EnergyPlus objects per existing glazing surface: (1) a WindowProperty:ShadingControl object, where Shading Type = SwitchableGlazing, ConstructionWithShadingName is the name of the glazing construction "dark" state, and ShadingControlType = OnIfHighSolarOnWindow; (2) a Simple Glazing System construction that defines the "dark" state for the electrochromic window. The default window construction should reflect the properties of the "light" state for the electrochromic window. For simplicity, assume that the "light" state corresponds to the properties of the baseline glazing construction (U-0.55, SHGC-0.4, and VT-0.508).

- The "dark" state has the following properties: U-0.55, SHGC-0.097, and VT-0.0335.

- To apply this measure, all windows will have to be replaced. According to RS Means, the average replacement cost for a 3 ft x 5 ft window in a three-story building is $71.12/ft^2 of window area. SAGE estimates that electrochromic windows cost $27/ft^2 ($35/ft^2 for the window construction plus $2/ft^2 for additional installation requirements less $10/ft^2 for eliminating the need for window shades) more than typical double pane glazing systems. Accordingly, the total cost associated with this measure is $98.12/ft^2.

- Assume that this measure reduces building infiltration by 25%. Assume baseline infiltration rates are in line with those for pre- and post-1980 construction from the reference building model set.

Heating, Ventilation, and Air Conditioning (HVAC) Measure:

1. Replace Baseline HVAC System with ground source heat pump (GSHP) and dedicated outdoor air system (DOAS) High Efficiency System

- Apply this measure to the entire building using a ruby script that specifies IDF substitutions (this will NOT be an OS measure).
- Ensure that low energy HVAC schedules are applicable.
- Assume that the baseline four pipe fan coil system costs approximately $25/ft^2, and that the system cost is completely independent of system size.
- GSHP with DOAS systems typically cost $25/ft^2, including approximately $5/ft^2 for well drilling. Assume that $20/ft^2 is fixed (not sizing dependent) and that the well drilling cost scales with system size.
- The peak cooling load measured for the RSF is approximately 80 kW. Assuming a safety factor of 1.2, and a COP of 7.8, this amounts to an installed cooling capacity of 748.8 kW, or 212.9 tons. Given that the RSF has a floor area of 225,000 ft^2, this results in a sizing metric of 1,057 ft^2/ton of cooling capacity. Assuming well drilling costs approximately $5/ft^2 for a building at this efficiency level, we calculate a capacity-normalized drilling cost of $5,284/ton.
- Assume 500 ft^2/ton of cooling capacity for the baseline case (typical efficiency). For Building 1219 (49,000 ft^2) this would result in an installed cooling capacity of 98 tons. Cost for a GSHP and DOAS system of this capacity would be $30.57/ft^2

- Assume 1,000 ft^2/ton of cooling capacity for a high efficiency case (compare to 1,057 ton/ft^2 for the RSF and even more for the RSFII). For Building 1219 (49,000 ft^2) this would result in an installed cooling capacity of 49 tons. Cost for a GSHP and DOAS system of this capacity would be \$25.28/ft^2, or roughly the cost of the baseline four pipe fan coil system. Note that a system capacity of 49 tons would amount to approximately a 39% reduction in system size for Building 1219 (currently equipped with 80 tons of cooling capacity).

- A lifecycle cost analysis by the Oregon Institute of Technology (for National Renewable Energy Laboratory [NREL]) indicates that the annual maintenance cost of a (peak load) 22 ton GSHP system is \$1,899. Assuming a sizing safety factor of 1.2, the annual O&M cost would be \$71.93/ton of cooling. The same analysis indicates that annual maintenance for a similarly sized baseline system (packaged rooftop units with DX cooling and gas furnace heating) would be \$4,476, or \$169.55/ton of cooling (a factor of roughly 2.4 larger than that for the GSHP system). The building floor area for this scenario is 14,632 ft^2, such that the area normalized O&M costs are \$0.13/ft^2 for the GSHP system and \$0.31/ft^2 for the packaged rooftop unit system. Other sources indicate that the O&M costs for a GSHP system are likely to range from \$0.06/ft^2 to \$0.11/ft^2, and that those for conventional systems can be three times as much. Assume that the O&M costs for the GSHP system are \$0.11/ft^2 and that the O&M costs for the baseline system are \$0.26/ft^2 (matching the ratio of O&M costs between the packaged rooftop unit system and the GSHP system from the Oregon study)

Appendix D Additional Project Support Provided by NREL

NREL provided additional support to Fort Carson beyond the three specific research questions addressed in the report. These focused on a general characterization of the performance of LEED rated Fort Carson buildings, and support for designing and evaluating the behavioral interventions developed by Pacific Northwest National Laboratory (PNNL). Highlights of these efforts are discussed in the following sections, and in Appendix E.

Electrical Submetering

NREL worked with Mazzetti and Panoramic Power to define a test set of low cost instrumentation that would be installed at Fort Carson to monitor electricity use over time. This instrumentation package included a novel wireless current transformer (CT) design that could collect circuit level electricity usage, and could be easily installed and uninstalled by an electrician (Figure 74). Panoramic Power programmed the system, collected and processed the raw data, and performed diagnostics and troubleshooting. A cellular modem was installed near each electrical panel to transmit data without needing access to the secure network at Fort Carson. Data collected by the Panoramic Power system were made available to the project

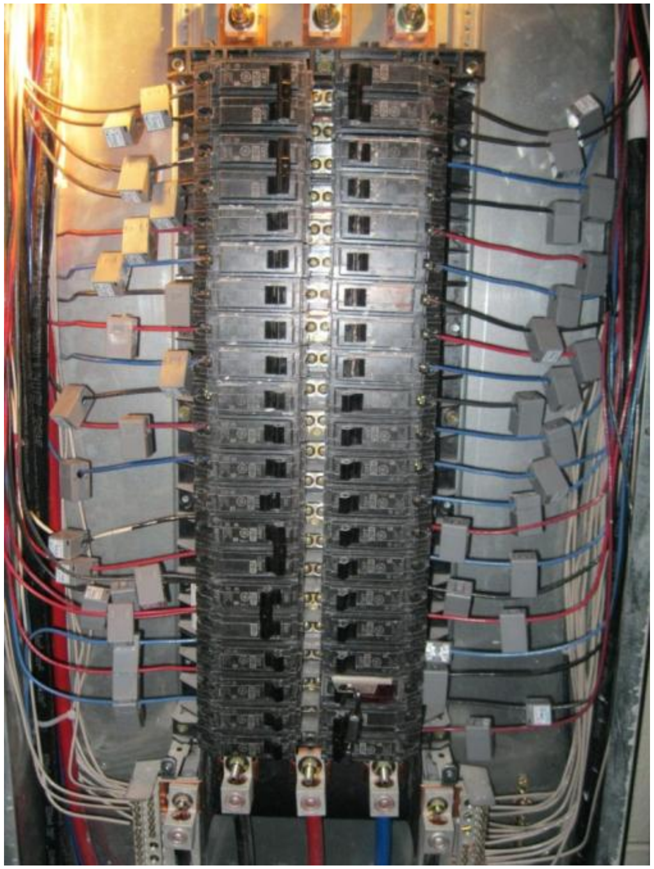


Figure 74 Wireless current sensors installed in an electrical panel in Building 1219

team through an energy dashboard (see Figure 75).

A test report summarizing key results from the monitoring effort is included in Appendix E.

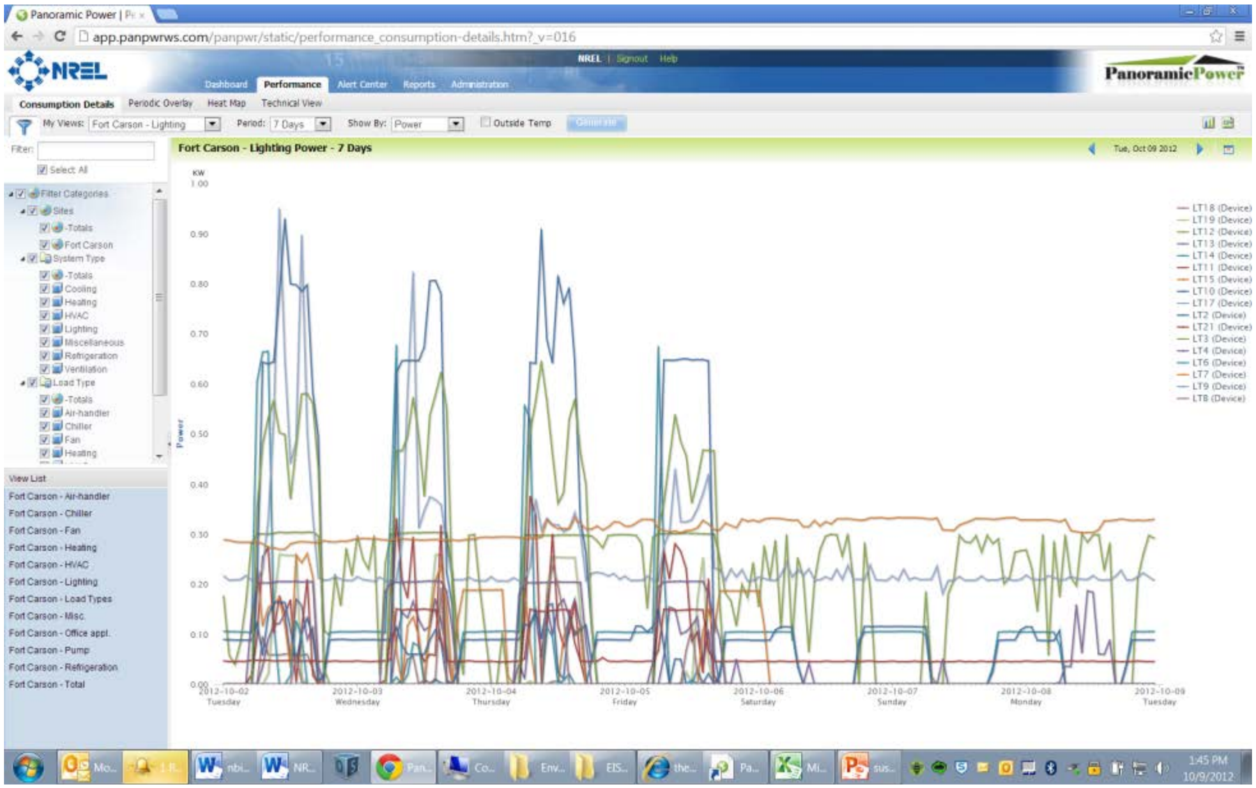


Figure 75 Energy dashboard reporting real-time electricity use in Building 1219

NREL also downloaded electricity and gas data from the Meter Data Management System (MDMS) system for several buildings. These data were used to evaluate the overall performance of LEED-rated buildings at Fort Carson, and to support model validation efforts. Because the MDMS was in the process of being populated during the course of this project, energy data were not available for all buildings, including the Directorate of Public Works (DPW) headquarters (Building 1219).

Highlights and lessons learned from the electrical submetering activities are summarized below:

- Members of the NREL project team met with DPW electrical and mechanical designers to gather information about the design of Building 1219. DPW staff members were extremely helpful, providing access to mechanical rooms and panel boxes, allowing us to take photographs of both inside and outside spaces when possible. They also gave us insights into the design of the systems in Building 1219, and discussed their experiences (positive and negative) with the building since the project was completed. The information collected proved helpful to NREL for addressing all three research questions.

- NREL and representatives of the DPW discussed the details of the electrical submetering plan, which included monitoring of Buildings 1219 (barracks retrofit to a LEED certified office building) and 9420 (new LEED certified Brigade Headquarters), and reached a verbal agreement on a few changes. Once those changes were made, the plan was agreed to by both parties.

- NREL placed an order for wireless current transformers to be used for detailed submetering of Building 1219, and spot metering of electrical circuits in other buildings as needed in support of this project. We purchased enough instrumentation to monitor 246 lines (~200 circuits) in six locations. The sensors and supporting equipment could have been easily moved to other locations if necessary. The total cost was $26,580, including design, programming, and data collection, hosting, and analysis services. This equipment is owned by GSA and can be redeployed for other projects.

- NREL provided Mazzetti (the supplier of the instrumentation package) with details of the submetering plan, including the list of specific circuits that will be monitored in Building 1219, and their voltage and current ratings. Mazzetti selected appropriate sensors and other necessary equipment, and ordered all materials from their supplier, Panoramic Power.

- NREL met with the Chief Engineer for Fort Carson, reviewed the test plan, discussed logistics, double checked the spaces served by each panel, and locked in a test date. We also visited Building 9420, and decided that the level of occupancy was too low to provide meaningful energy data. The full project team deliberated the alternatives, including testing a different building, but decided to proceed with Building 9420 on the assumption that it will be reoccupied sooner rather than later. Subsequently, Building 9420 was gradually reoccupied between December 2012 and the end of the monitoring period.

- NREL hired a certified electrician to install the current transformers on key circuits in Building 1219. The Directorate of Public Works had earlier informed NREL that submetering support would be outside the scope of their existing contract with the electrician, and NREL would have to bear the cost. NREL Environmental, Safety, and Health (ES&H) mandated safety precautions beyond those required by the U.S. Army, adding significant cost and time delays.

- On August 14–15, NREL and its subcontractors installed submetering equipment in four electrical panels in Building 1219. Two electricians from Berwick Electric installed the sensors on the evening of August 14. Alan Davis of DPW assisted NREL throughout the process, including making arrangements for the power to be turned off and the building to be evacuated. NREL and DPW worked together to identify some of the end-uses on each circuit being monitored. Unfortunately, most of the circuits in Building 1219 were mislabeled in the electrical panel, and only about 25% of the circuits could be correctly identified in the time available.

- NREL and Mazzetti provided the project team with a demonstration of the energy dashboard, which allowed anyone on the team to view and download real-time electrical data for Building 1219.

- NREL worked with Mazzetti to use the minute-by-minute data from the energy dashboard to deduce the physical end-uses being monitored based on how energy use responded to weather, time-of-day, and other variables. The correct loads on most of the circuits were identified through this process.

- NREL discovered that whole-building electricity and gas data was unavailable for Building 1219 through the MDMS at the time when the evaluation of LEED buildings was performed. There was an electric meter near the main distribution panel, but it had not yet been connected.

- Alan Davis of DPW at Fort Carson provided whole-building electrical measurements for Building 1219. This data set was very valuable because Building 1219 was not in the MDMS, and it was not practical to install current sensors to monitor whole-building performance.

- On December 5, NREL and its subcontractors (Berwick Electric and Mazzetti) installed approximately 100 current sensors in six electrical panels in Building 9420, focusing on panel-level power draws, HVAC systems, and a representative sample of plug loads and lighting. A follow-up trip was necessary on December 11 to install the cell modems. Shortly thereafter, the real-time data for Building 9420 was made available through the Panoramic Power Energy Dashboard.

Support for PNNL Behavioral Interventions

Throughout the project, NREL supported PNNL's behavioral intervention study. Results of the modeling and field testing performed by NREL as part of the behavioral study are discussed and interpreted in PNNL's final report. The following types of support were provided:

- NREL analyzed submetered electrical data to help identify areas where behavioral interventions could be very impactful, including interior and exterior lighting loads, plug loads, fan coil operation, and the server room.

Recommendations were discussed with PNNL, and helped guide the behavioral interventions that were implemented.

- NREL studied the lighting system designs in several building types (including HQ, COF, and TEMF), and discussed possible interventions to reduce lighting loads with PNNL.

- NREL modeled the potential energy savings for various behavioral interventions related to fan-coil operation in Building 1219.

- NREL's field test engineer made six site visits to Fort Carson (November 1, 8, 15, 21, 26, and 27), installing a variety of short-term submetering equipment to track performance parameters before and after behavioral interventions, including lighting operation, light levels, temperatures, fan-coil operation, and occupancy. In addition spot measurements were made for a sampling of computers, task lights, and fan-coils under various operating conditions.

- NREL processed the submetered electrical data before and after behavioral interventions to help determine the magnitude of energy savings. This was especially challenging in Building 9420, where occupancy levels continued to grow throughout the interventions.

Appendix E Electrical Submetering Results (October 15, 2012)

Overview

Energy use data was collected at Fort Carson from a number of sources:

- The Meter Data Management System (MDMS) provides real-time electricity and gas usage data for a number of buildings at Fort Carson, including Buildings 9420, 1118, and several Leadership in Energy and Environmental Design (LEED) buildings. However, it did not include Building 1219.
- Several weeks of whole-building electricity data for Building 1219 were measured and provided by Alan Davis of the Directorate of Public Works (DPW).
- A Panoramic Power submetering system is measuring about 70 electrical circuits in Building 1219, including most of the heating, ventilation, and air conditioning (HVAC) equipment and a representative sample of lighting and plug load circuits.

Whole-Building Data for Building 1219

The whole-building power draw for Building 1219 during a month long monitoring period is shown in Figure 76. Actual electricity use compared to the LEED analysis is shown in Table 26. The end-use breakdown of energy use in Building 1219 (extrapolated based on floor area represented by submetered circuits) is shown in Figure 77.

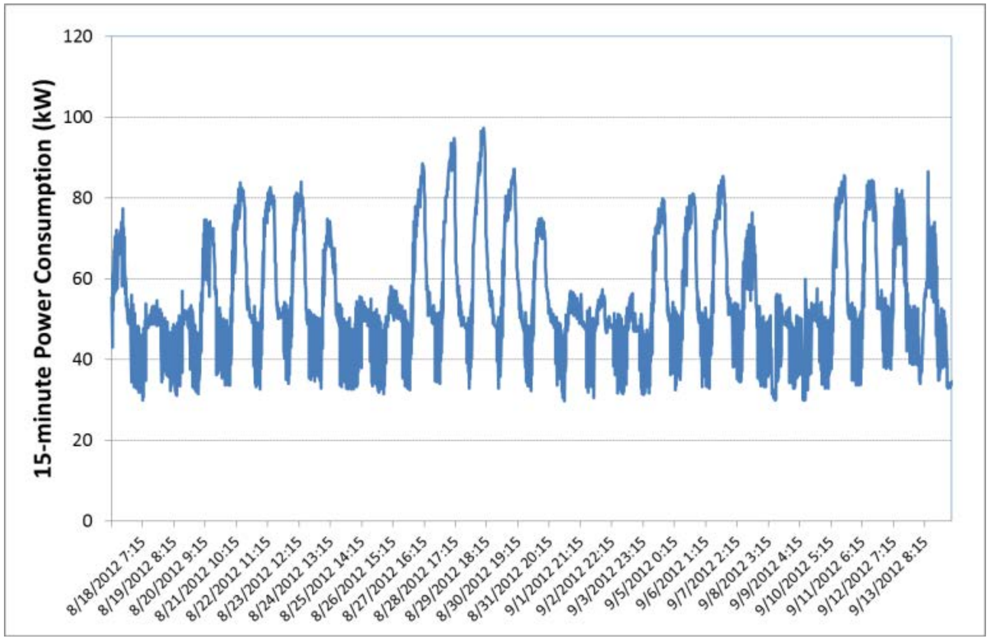


Figure 76 15-minute power draws for Building 1219

Table 26 Actual versus predicted electricity use in Building 1219

Building 1219 Electricity Use	Predicted based on LEED Modeling	Measured during Test Period
Annual EUI	17.9 kWh/ft^2	13.5 kWh/ft^2
Peak Demand	161 kW*, 88 kW**	97 kW

* Assumes peaks for individual end-uses are coincident. Annual whole-building peak would be less, but is not provided in the SpectraTech report.

** Sum of lighting and plug load peaks, which are likely to occur simultaneously.

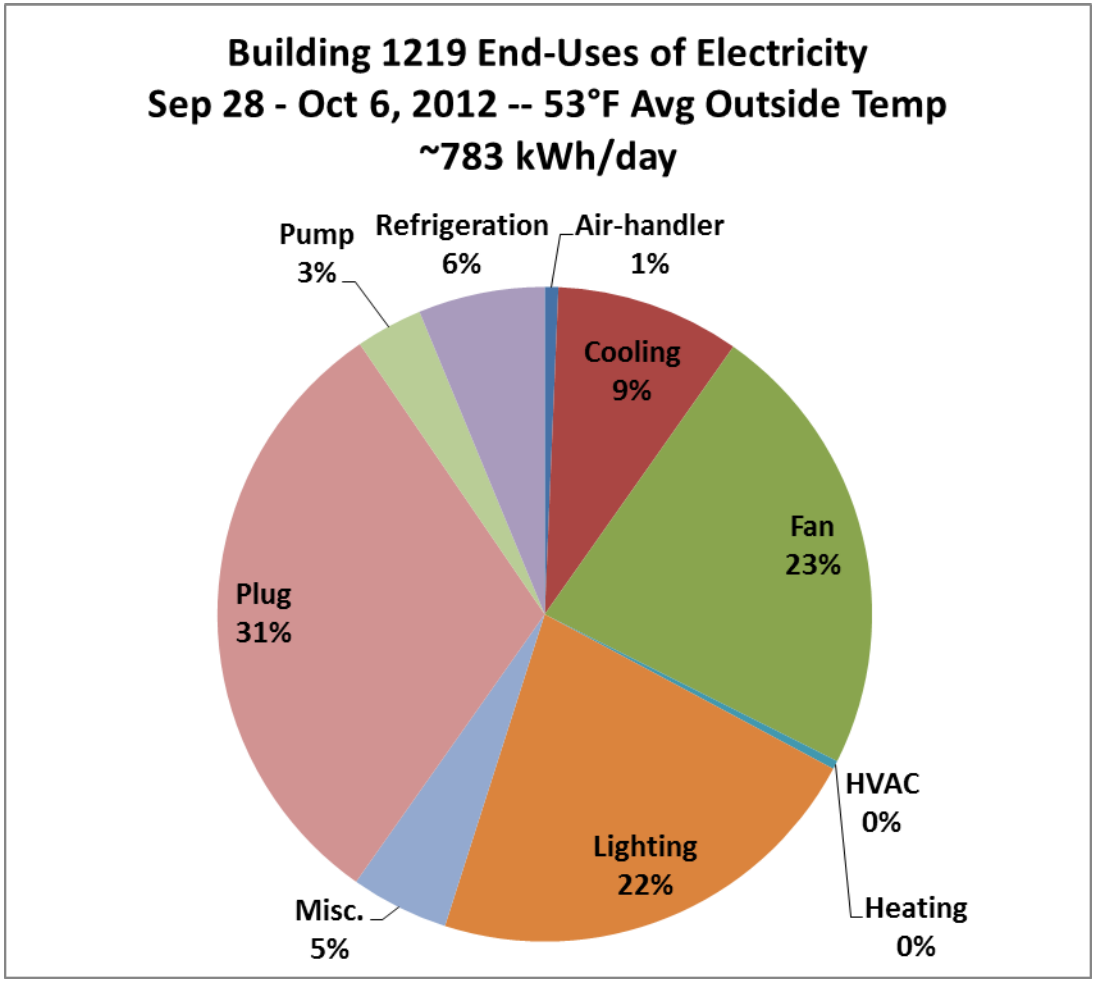


Figure 77 End-use energy consumption for Building 1219

The following observations can be made based on the whole-building electricity measurements:

- The overall electrical end-use intensity is lower than projections made by SpectraTech for LEED certification. The building appears to be performing well. The monitoring period was during the summer when there was a significant amount of cooling energy required. It is likely that the average power is less during the winter months (because heating energy is primarily gas), and the annual average electricity use may be significantly less than the measured data indicate.

- The peak demand appears to be less than predicted, but no definitive conclusion can be made. The SpectraTech report only provided end-use peaks, which would not occur at the same time in an annual simulation. However, the sum of lighting and plug loads (which are probably close to additive) was projected to be 88 kW, so the actual peak of 97 kW is likely to be much less than the projected combined total peak from all end-uses in the model if cooling is considered. Another source of uncertainty is the short monitoring period of one month, which may not accurately capture the actual peak power draw over the course of a year.

- There is a very large base electrical load of about 30–35 kW at night and throughout the weekends. It is likely that there are many power draws that unnecessarily run continuously, but whole-building data is not sufficient to identify what these draws might be.

- It is difficult to infer the impact of weather from the data because conditions were very similar each day, but cooling energy probably makes up most of the increase in power on weekend afternoons, which was about 20 kW. Predicted peak cooling energy based on the SpectraTech report was 37 kW. The weather conditions during the monitoring period were fairly normal for late summer in Colorado Springs, with highs around 85°F and lows around 50°F.

- Fan coils, lighting, and plug loads are approximately the same size, and represent most of the energy use in Building 1219 during a mild week in autumn.

Submetered Data for Building 1219

A typical week of end-use power consumption for the subset of circuits monitored in Building 1219 are shown in Figure 78. Outside temperature is also shown in the graph, indicating warmer days at the beginning of the week and a couple colder days at the end.

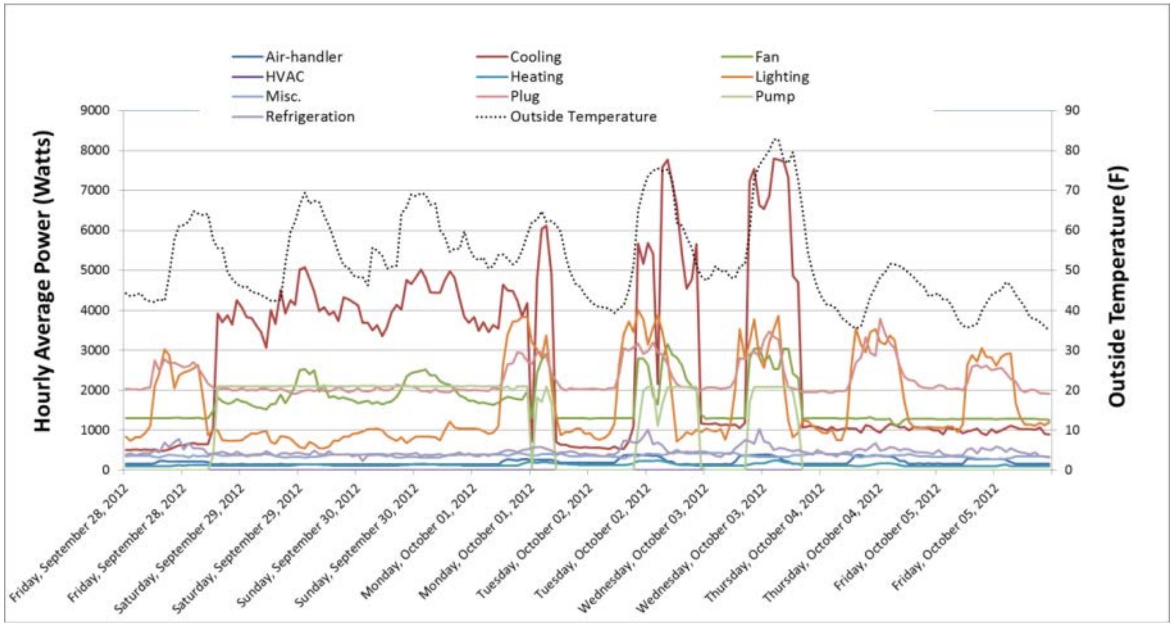


Figure 78 Hourly average power draws by end use for Building 1219

A few interesting conclusions can be drawn from the end-use level data:

- Cooling energy (not including fan-coils) behaves fairly predictably, peaking during the warmest temperatures. However, the cooling energy over the weekend is probably higher than necessary, and a larger setback may be appropriate. There is also a significant base load during cold weather, presumably related to standby energy or chilled water pump operation. A seasonal shutdown of the system during the winter should reduce this base load.

- There is virtually no baseboard heating energy during the period shown. It does not appear there are any excessively high set points for these units, which are located in stairwells and foyers, and should be set at 55F. Natural gas energy for the boilers is currently not available, so we do not know if there was any other space heating energy needed during the colder stretch at the end of the week.

- Fan-coil energy is relatively constant throughout the period shown in the graph. There may be some use of the “unoccupied” buttons on the fan-coil units, but this feature does not appear to have significant impact on fan energy. Most of the savings for this feature probably shows up in heating and cooling energy because of reduced ventilation load and temperature setbacks.

- The lighting profile appears reasonable for the building. It drops to about 30% of its peak during off hours, which is likely more than just security lighting, exterior lighting, and people working after hours. Most lights are turned off when not needed, but some improvement is probably achievable.

- The base load for plug loads is larger than the increase during working hours. Depending on the source of the base load, there may be significant opportunities for load reduction. The base load may result from computers being left on overnight and during weekends, or the circuits may include a few non-plug loads such as fan coils, pumps, refrigerators, or other equipment that would be expected to have more constant power draws. Further analysis is provided later in this report.

- There is a large amount of pumping energy during warmer (and likely sunnier) days, which is associated with the solar water heating system. Our understanding is that there is often excessive heat collected by the system, which must be rejected at night. The result is nearly continuous operation for days at a time. The mechanical designer is aware of the problem, and is looking for a solution. It is possible that disabling the system altogether would reduce overall energy use, but it is difficult to quantify the impact on gas heating energy without further analysis.

- Other end-uses are relatively small, and do not appear out of the ordinary.

More detailed plug load data for a few key circuits during the same week-long monitoring period are shown in Figure 79.

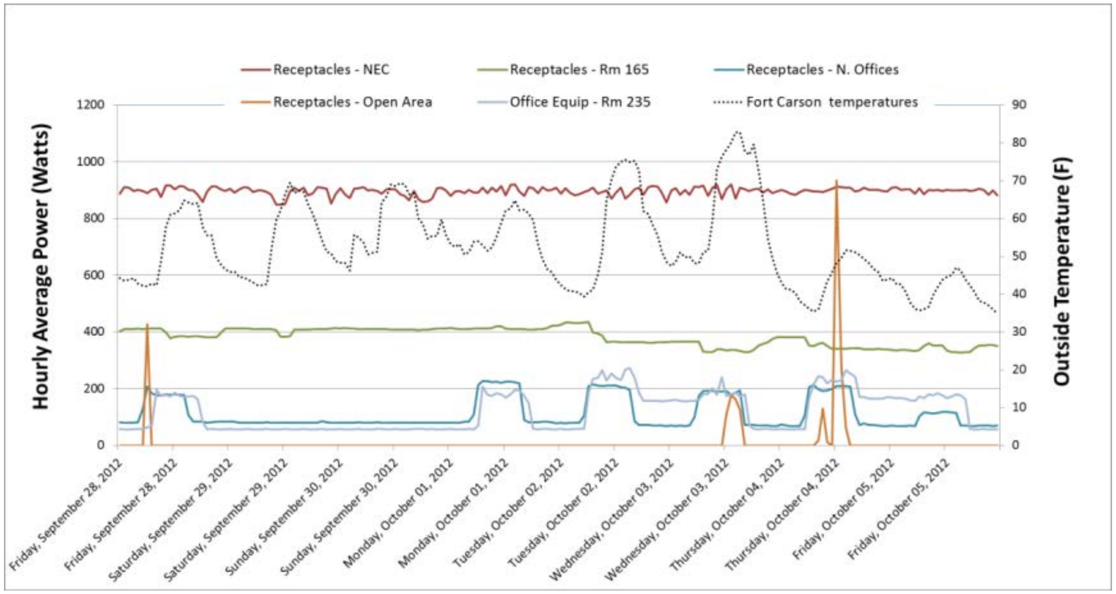


Figure 79 Hourly average power draws for several plug loads in Building 1219

The following conclusions can be drawn from the data:

- A large fraction of the base load for plug loads is associated with the NEC computer equipment on the first floor, which operates 24 hours/day. This equipment made an audible racket that could be heard outside the locked door on the first floor, but it is not clear how much it could be turned off during off hours. Our understanding is that it is high priority networking equipment and servers.

- The load for most receptacles drops about 70% during off hours, consistent with computers entering standby mode. Two such profiles are shown in the graph, but there are several others that show the same pattern. This base load could be reduced further if computers were turned off, but it may not have an energy impact as large as expected.

- The south wing of office space (Rm 165) has a relatively large, constant load. The constant load is inconsistent with diverse plug loads, so we would theorize that this circuit is a mislabeled fan-coil circuit. We will investigate on a future trip to the site.

- The open area has an unusual profile that is nearly always zero except for a few high use hours scattered at random times in the test period. It is possible this is the result of a malfunctioning sensor. Or possibly there may be occasional high intensity cleaning or maintenance equipment plugged into receptacles in that zone. Because the overall energy use is small, it is probably not worth pursuing further.

Lighting energy for several representative circuits is shown in F.

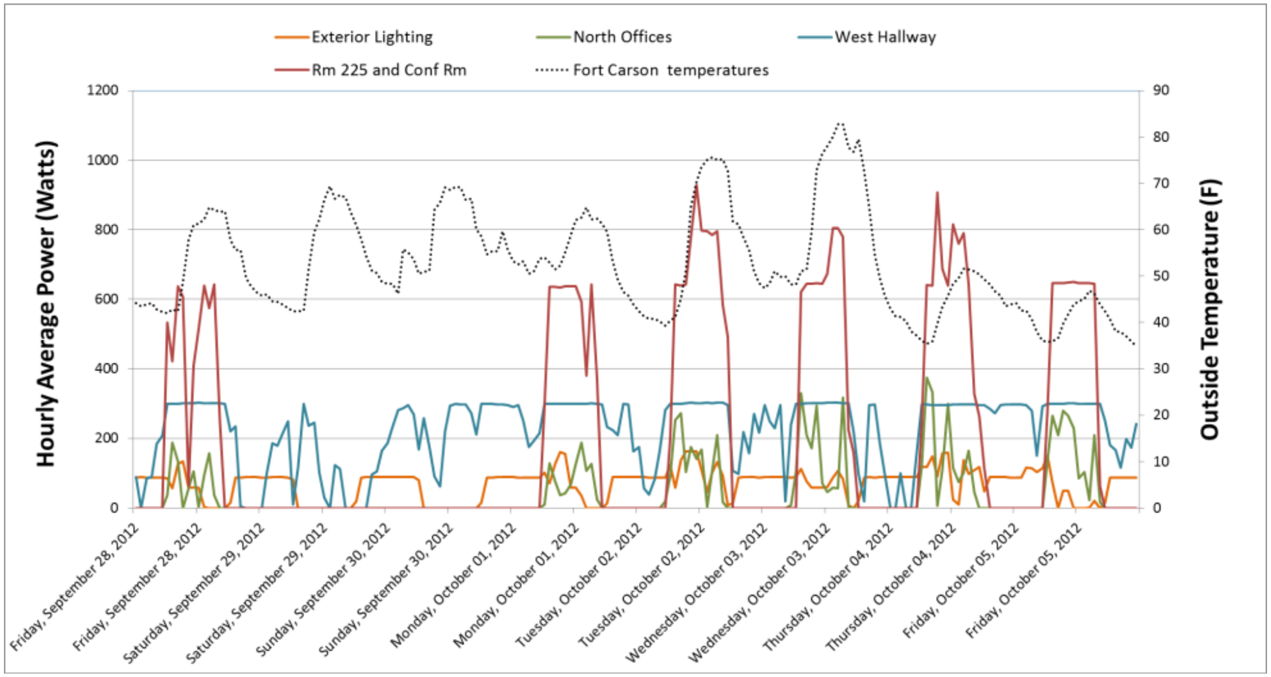


Figure 80 Hourly average power draws for a sample of lighting circuits in Building 1219

The following key observations can be made about the data:

- Office lighting is consistently turned off at night and over the weekends. It appears that most occupants are conscientious about lighting in their own workspace, or the occupancy sensors are working well.
- Lighting in the cubicle spaces and conference room are also off at night, though they are consistently on during the daytime. Better daylighting and controls would reduce the need for lights in these areas during the daytime.

- Exterior lights are occasionally on during the daytime, for reasons that are unclear. It appears there is effective timer control over the weekend, but perhaps the controls are overridden during the work week. Further investigation is required to understand the operation of these lights.

- West hallway lighting is very erratic, even on weekends. It appears that the occupancy sensors are not working well. East hallway lighting, though not shown in the graph, is generally off all night.

MDMS Data for Other Buildings

Electricity and gas data (when available) was downloaded from the MDMS site for three additional Brigade Headquarters (HQ) buildings: 1118 (standard barracks retrofit), 2132 (LEED Gold), and 9420 (LEED Platinum). The data are summarized in Figure 81 through Figure 83, and Table 27.

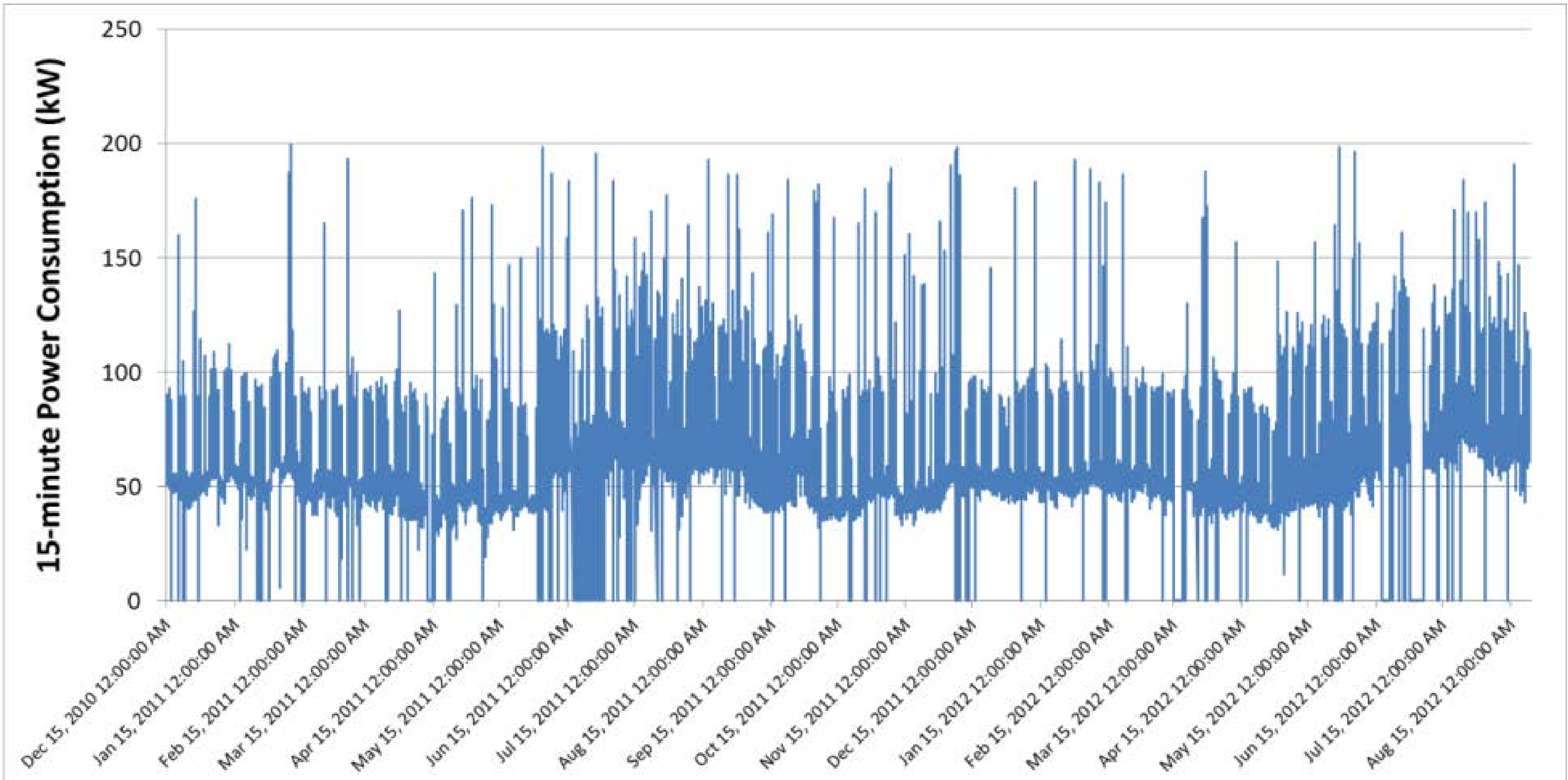


Figure 81 15-minute power draws for Building 1118

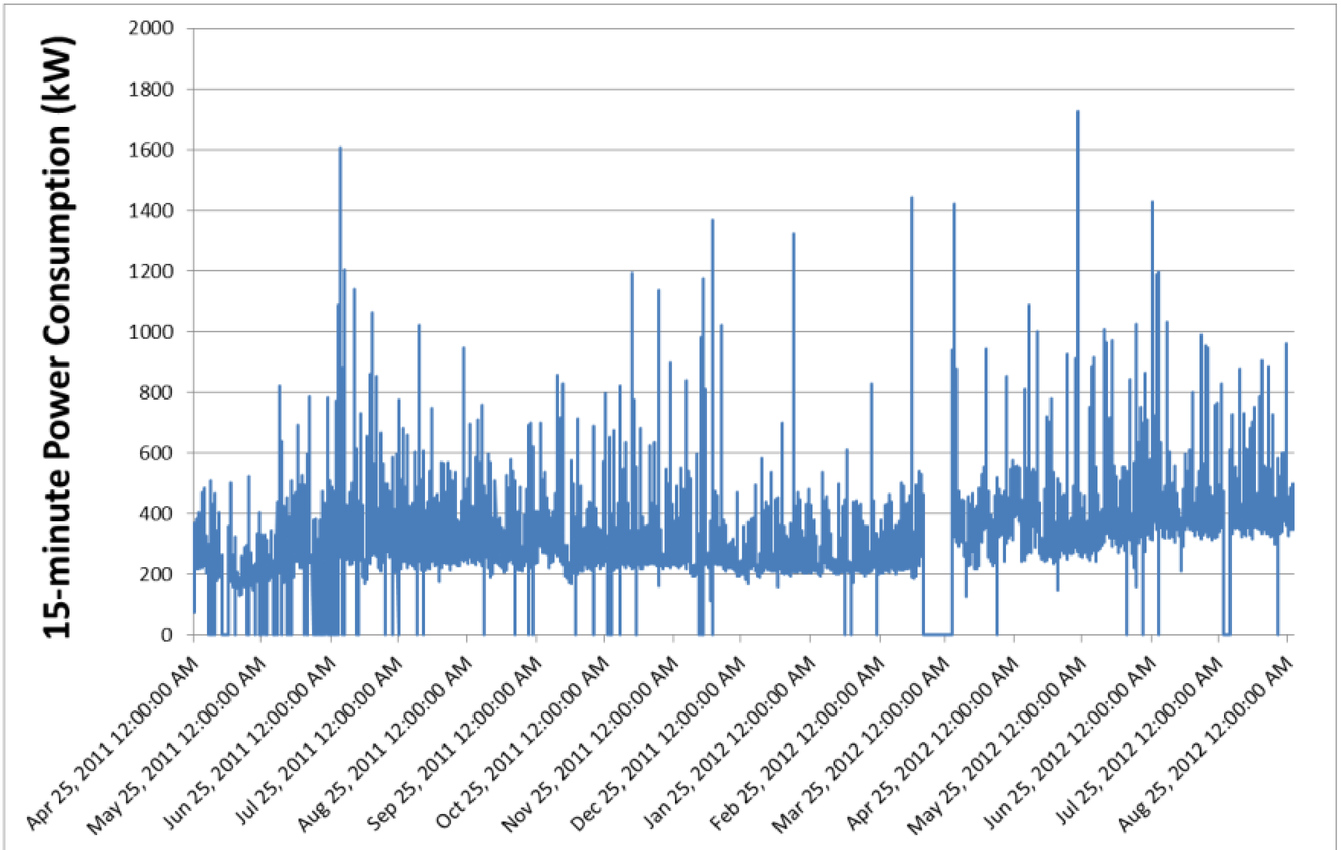


Figure 82 15-minute power draws for Building 2132

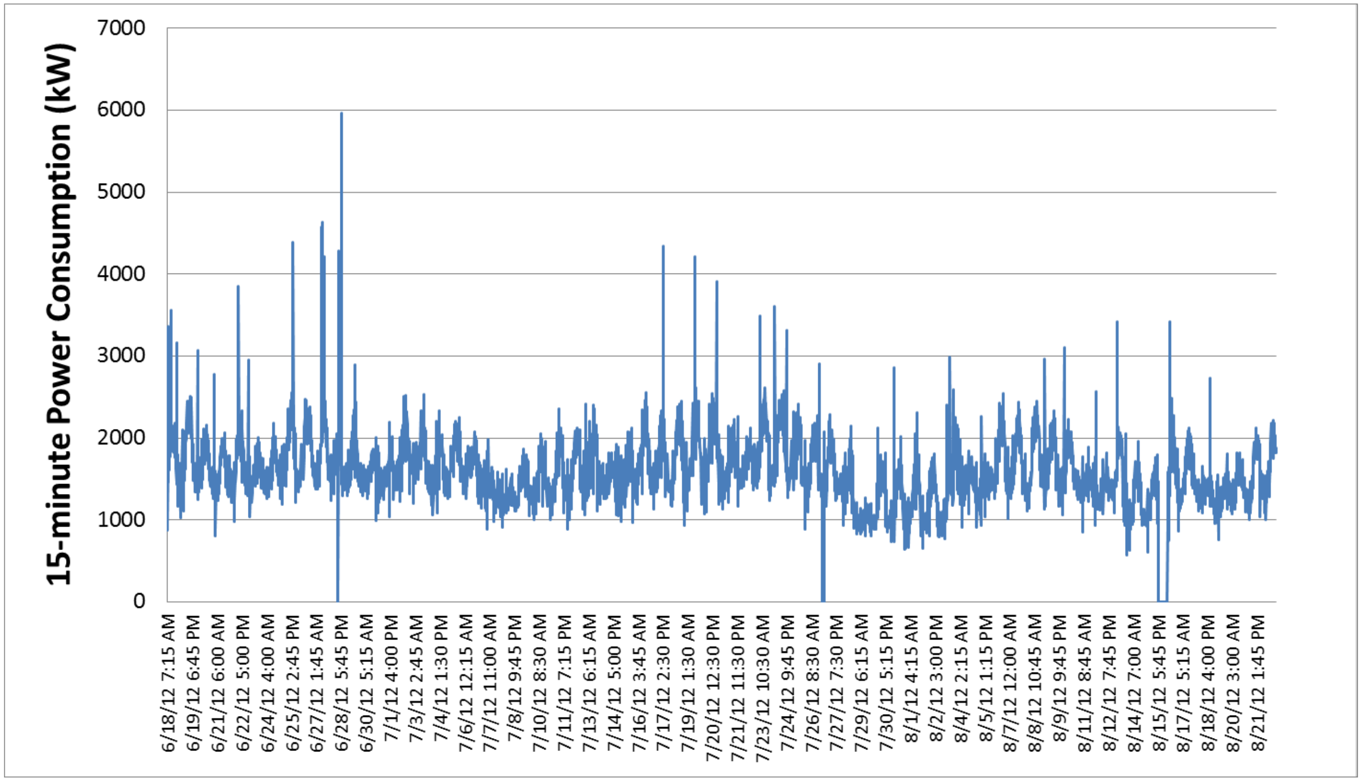


Figure 83 15-minute power draws for Building 9420

Table 27 Energy Use Intensity (EUI) for three LEED HQ buildings in MDMS

Building #	Annual Electricity EUI Measured during Test Period	Annual Gas EUI Measured during Test Period
1118	15.1 kWh/ft^2	31.5 kBtu/ft^2
2132	24.6 kWh/ft^2	N/A
9420	99.2 kWh/ft^2	0.1 kBtu/ft^2

The following observations can be made based on the whole-building electricity and gas measurements from MDMS:

- The MDMS data sets often have gaps, where communication with a meter was lost for one or more scheduled readings. As a result, there are some very high and low energy use values that must be smoothed out by using hourly running totals. This issue does not affect the total end-use intensities, but does affect the 15-minute profiles. The data will be more thoroughly processed in the final documentation.
- The electricity use pattern for Building 1118 is very similar to Building 1219, except the annual electricity use is about 12% higher. There is a similar electrical base load of 50 kW, which is significantly higher than the base load of 35 kW found in Building 1219.
- The electricity use for Building 2132 is much higher than would be expected for a LEED building. In fact, the electricity intensity is twice that of Building 1118, which is not LEED certified. A base load power draw of over 200 kW is present throughout the year.
- The electricity use for Building 9420 appears to be extraordinarily high for a LEED platinum building, especially considering that the troops are deployed and the building is 90% vacant. In fact, the electricity is so high that it is difficult to believe the data in the MDMS is correct. The large hourly and daily fluctuations are more consistent with a building that is occupied. A subsequent visit to Building 9420 on a very hot day in June 2013

revealed that the fully occupied electricity use was about 677 kW, much lower than the MDMS data indicated when the building was unoccupied (~2000 kW at mid-day).

- The gas usage for Building 9420 is extremely low, but the monitoring period only covered the summer months. There was probably very little gas appliance and hot water use because the building was largely empty. In addition, the large electricity use could explain the lack of space heating energy. However, an empty building in Colorado Springs with almost no heating energy throughout the summer is fairly surprising, and could be an additional error in the MDMS.

Appendix F Group Interview Questions

1. What is your overall impression of [your building]?

    a) How does [your building] compare with other buildings you have worked in at Fort Carson? Elsewhere?

2. What do you know about the sustainable design and operation features in [your building]? (For example, occupancy sensors control lights; day lighting)

3. What instructions, training, or assistance did you receive on how to use [your building's] design and operations features?

    a) When did the instructions, etc., occur? (before you moved into the building? If after you moved in, how long after?)

    b) How useful were the instructions, etc.? How could they be improved?

    c) If instructions, training, etc. were not provided, how long did it take to learn how to use the building's design and operation features?

4. How do the design and operation features of [your building] support the work you do?

    a) Do any of the features make it more difficult to do your work? How? [examples]

5. How have the sustainable design and operation features in this building affected how you do your work, equip your workspace, or dress for work—e.g., converse more/less with other people in your unit; change where you

place your laptop on your desk to get the best light/eliminate glare; use position of window blinds to regulate temperature or light; wear more clothing layers to deal with building temperatures; no change; etc.?

6. How does working in a Leadership in Energy and Environmental Design (LEED)-certified or LEED renovated building affect how you feel about your work, workspace, or Fort Carson?

   a) Do the sustainable design and operation features matter to you? How?

   b) Has working in a LEED-certified or renovated building changed your energy use in other, non-LEED buildings on post? Off post (e.g., at home, in public buildings, in public restrooms, etc.)?

7. From what you have observed in [your building], what do you think are the most effective measures being taken to help cut energy use? (For example, occupancy sensors control lights; temperature controls)

   a) What could be improved?

8. Are there any energy saving efforts, policies, or programs in [your building] to supplement or complement the building design and operation features (e.g., waste reduction efforts; minimizing nonessential lighting; evening floor sweeps to turn off lights; etc.)?

   a) How well are the efforts, policies or programs working (participation/interest, feedback on energy savings)?

9. What else could be done to sustain energy savings over time? (incentives, education, competition?)

10. How would you describe the culture within [your building] (e.g., what about the values, norms, work habits/preferences, etc., distinguishes the people in [your building] from the people in other buildings)?

a) Which, if any, of the sustainability design and operation features in [your building] best fit or match the culture (e.g., how much does having greater, less or no control over building features [e.g., lighting, temperature, privacy] matter)?

b) Has the culture affected how people are reacting to or using the design and operation features?

11. Would specific feedback about energy use help you reduce your energy use? (For example, “Your floor/business unit/group used this amount of electricity last month and this month the amount increased 3%.”)

a) What feedback would you like to receive?

b) What time period should it cover?

c) How often would you want it delivered to you?

d) Is it better to have it in a place you can “go” see it when you need it? (Website, dashboard, large screens at entrance etc.)

Appendix G Baseline Survey Questions

Energy Use at Fort Carson, CO

Q1.1 This section requests a little information about you that will be used to better understand your experiences with your building, workspaces, and energy use.

Q1.2 How would you describe the work you do?

- ❍ Administrative support
- ❍ Technical
- ❍ Professional
- ❍ Managerial/supervisory
- ❍ Driver
- ❍ Vehicle Maintenance
- ❍ Other (please describe) ____________________

Q1.3 Are you:

- ❍ Male
- ❍ Female

Q1.4 What is your age?

______ Years

Q1.5 What building do you usually work in?

- ❍ 1118 (Garrison Command HQ)
- ❍ 1219 (DPW)

- 9420 (4-4 BCT HQ)
- 9427 (COF)
- 9447 (COF)
- Other (please describe) ____________________

Q1.6 What is your position at Fort Carson?

- Soldier-Officer
- Soldier-Enlisted
- Civilian-Manager
- Civilian-Non-Manager
- Contractor

Q1.7 Military personnel: What unit are you assigned to?

Q1.8 Civilian personnel: What organization do you work for?

Q1.9 Where do you live?

- On-post Barracks
- On-post Housing
- Off post

Q1.10 How long have you worked at Fort Carson?

______ Years

______ Months

Q1.11 Do you anticipate leaving Fort Carson within the next two years?

- Yes
- No
- Don't know

Q1.12 If yes, check all that apply:

- ❍ Permanent change of station (PCS)
- ❍ Leave military service
- ❍ Change jobs
- ❍ Follow family member/spouse moving
- ❍ Other (please describe) ____________________

Q2.1 This section asks about the physical features and environment of your workspace and your satisfaction or discomfort with them.

Q2.2 Do you have a permanent workspace on post?

- ❍ Yes
- ❍ No

Q2.3 How long have you been working at your present workspace?

______ Years ______ Months

Q2.4 In a typical week, how many hours do you spend in your workspace?

______ Hours

Q2.5 Which of the following best describes your personal workspace or the type of space you usually work in at Fort Carson?

- ❍ Enclosed office, private
- ❍ Enclosed office, shared with other people
- ❍ Cubicles with high partitions (about 5 ft or more high)
- ❍ Cubicles with low partitions (lower than 5 ft high)
- ❍ Workspace in open office with no partitions (just desks)
- ❍ Other (please describe) ____________________

Q2.6 Where is your workspace located?

- ❍ Basement
- ❍ 1st floor
- ❍ 2nd floor
- ❍ 3rd floor
- ❍ 4th floor
- ❍ 5th floor

Q2.7 Are you near a window (within 15 ft)?

- ❍ Yes
- ❍ No

Q2.8 Are you near heating/cooling vents (within 15 ft)?

- ❍ Yes
- ❍ No

Q2.9 Which of the following electronics, including personally owned, are in your personal workspace? Check all that apply.

- ❍ laptop
- ❍ desktop computer
- ❍ desk phone
- ❍ coffee maker
- ❍ fan
- ❍ space heater
- ❍ radio
- ❍ Smart phone docking station
- ❍ personal desk lamp

- ❍ electric clock
- ❍ other (please describe) ____________________

Q2.10 How often do you recharge your cell/smart phone, iPod, or other personal portable electronic communications equipment at work?

- ❍ Daily
- ❍ Occasionally
- ❍ Never
- ❍ N/A (Not Applicable)

Q2.11 Which of the following building features do you adjust in your workspace? Check all that apply.

	How often?			
	Regularly	Occasionally	Never	Can't adjust
Window blinds or shades	❍	❍	❍	❍
Operable window	❍	❍	❍	❍
Thermostat	❍	❍	❍	❍
Permanent heating/cooling unit (e.g., wall-mounted unit)	❍	❍	❍	❍
Room air-conditioning unit	❍	❍	❍	❍
Portable fan	❍	❍	❍	❍
Ceiling fan	❍	❍	❍	❍
Air vent in wall or ceiling	❍	❍	❍	❍
Floor vent	❍	❍	❍	❍
Light switch (overhead lights)	❍	❍	❍	❍
Light dimmer (overhead lights)	❍	❍	❍	❍
Desk (task) light	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍

Q2.12 For each building feature listed below, please indicate how satisfied you are with how well that feature functions to create a comfortable work environment:

	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	I have no experience with this feature	N/A
Air vents	❍	❍	❍	❍	❍	❍	❍
Automatic daylight controls	❍	❍	❍	❍	❍	❍	❍
Occupancy sensors for lighting (auto on, auto off)	❍	❍	❍	❍	❍	❍	❍
Vacancy sensors for lighting (manual on, auto off)	❍	❍	❍	❍	❍	❍	❍
Window blinds	❍	❍	❍	❍	❍	❍	❍
Roller shades	❍	❍	❍	❍	❍	❍	❍
Exterior shades	❍	❍	❍	❍	❍	❍	❍
Low-flow faucets	❍	❍	❍	❍	❍	❍	❍
Waterless urinals	❍	❍	❍	❍	❍	❍	❍
Low-flow or dual flush toilets (for liquid and solid waste)	❍	❍	❍	❍	❍	❍	❍
Operable windows (open/close)	❍	❍	❍	❍	❍	❍	❍

Q2.13 How satisfied are you with each of the following personal workspace or building features?

	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	N/A (Not Applicable)
Temperature of your workspace	❍	❍	❍	❍	❍	❍
Air quality	❍	❍	❍	❍	❍	❍
Visual comfort (amount of electric or daylight available, glare, reflections, contrast)	❍	❍	❍	❍	❍	❍
Views of the outdoors from your workspace	❍	❍	❍	❍	❍	❍
General maintenance of the building	❍	❍	❍	❍	❍	❍

Q2.14 Please indicate why you are dissatisfied with the temperature of your workspace by checking all the reasons that apply:

- ❍ Too hot much of the time
- ❍ Too hot in the summer
- ❍ Too hot in the winter
- ❍ Too cold much of the time
- ❍ Too cold in the summer
- ❍ Too cold in the winter
- ❍ Other (please describe) ____________________

Q2.15 Please indicate why you are dissatisfied with air quality by checking all the reasons that apply:

- ❍ Stuffy/stale air
- ❍ Cleanliness
- ❍ Odors
- ❍ Other (please describe) ____________________

Q2.16 Please indicate why you are dissatisfied with visual comfort by checking all the reasons that apply:

- ❍ Not enough daylight most of the day
- ❍ Too much daylight most of the day
- ❍ Not enough overhead light in my workspace
- ❍ Too much overhead light in my workspace
- ❍ Not enough overhead light in the office overall
- ❍ Too much overhead light in the office overall
- ❍ Electric lighting is unattractive
- ❍ No task lighting
- ❍ Reflections in/glare on the computer screen

- ❍ Daylight glare from windows
- ❍ Other (please describe) ____________________

Q2.17 Please indicate why you are dissatisfied with the general maintenance of the building by checking all the reasons that apply:

- ❍ Dust visible on surfaces
- ❍ Spills/stains
- ❍ Dirty floors
- ❍ Trash cans not emptied overnight
- ❍ Trash cans get too full during the day
- ❍ Odors coming from trash cans
- ❍ Other (please describe) ____________________

Q2.18 Are you ever too warm at work?

- ❍ Yes
- ❍ No

Q2.19 People cope with thermal discomfort in many ways. For each of the actions below, please check whether you use it when you are <u>too warm</u> and if so, rate the extent to which the action affects your comfort.

How much does this increase your comfort?						
	None	Little	Some	A lot	Very much	N/A (Not Applicable)
Adjust a thermostat	❍	❍	❍	❍	❍	❍
Use a personal fan	❍	❍	❍	❍	❍	❍
Open or close the window shades	❍	❍	❍	❍	❍	❍
Drink something cool	❍	❍	❍	❍	❍	❍
Open or close a door or window	❍	❍	❍	❍	❍	❍
Complain to your manager or superior officer	❍	❍	❍	❍	❍	❍

How much does this increase your comfort?						
	None	Little	Some	A lot	Very much	N/A (Not Applicable)
Complain to the building manager	❍	❍	❍	❍	❍	❍
Talk with others in your group about the problem	❍	❍	❍	❍	❍	❍
Change location temporarily	❍	❍	❍	❍	❍	❍
Change location permanently	❍	❍	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍	❍	❍

Q2.20 Are you ever too cold at work?

- ❍ Yes
- ❍ No

Q2.21 For each of the actions below, please check whether you use it when you are <u>too cold</u> and if so, rate the extent to which the action affects your comfort.

How much does this increase your comfort?						
	None	**Little**	**Some**	**A lot**	**Very much**	**N/A (Not Applicable)**
Adjust a thermostat	❍	❍	❍	❍	❍	❍
Use a personal fan	❍	❍	❍	❍	❍	❍
Use a personal space heater	❍	❍	❍	❍	❍	❍
Open or close the window shades	❍	❍	❍	❍	❍	❍
Drink something hot	❍	❍	❍	❍	❍	❍
Open or close a door or window	❍	❍	❍	❍	❍	❍
Complain to your manager or superior officer	❍	❍	❍	❍	❍	❍

How much does this increase your comfort?						
	None	**Little**	**Some**	**A lot**	**Very much**	**N/A (Not Applicable)**
Complain to the building manager	❍	❍	❍	❍	❍	❍
Talk with others in your group about the problem	❍	❍	❍	❍	❍	❍
Change location temporarily	❍	❍	❍	❍	❍	❍
Change location permanently	❍	❍	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍	❍	❍

Q2.22 Do you ever experience discomfort from glare or sunlight from windows?

❍ Yes

❍ No

Q2.23 For each of the actions below, please check whether you use it when you experience lighting discomfort from glare or sunlight from windows and if so, rate the extent to which the action affects your comfort.

How much does this increase your comfort?						
	None	**Little**	**Some**	**A lot**	**Very much**	**N/A (Not Applicable)**
Close the window shades/blinds	❍	❍	❍	❍	❍	❍
Complain to your manager or superior officer	❍	❍	❍	❍	❍	❍
Complain to the building manager	❍	❍	❍	❍	❍	❍
Talk with others in your group about the problem	❍	❍	❍	❍	❍	❍
Change position in your workspace	❍	❍	❍	❍	❍	❍
Change location	❍	❍	❍	❍	❍	❍

temporarily						
Change location permanently	❍	❍	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍	❍	❍

Q2.24 Do you ever experience discomfort from too much or not enough light from ceiling lights?

❍ Yes

❍ No

Q2.25 For each of the actions below, please check whether you use it when you experience lighting discomfort from <u>glare or too much/not enough light from ceiling</u>, and if so, rate the extent to which the action affects your comfort.

	How much does this increase your comfort?					
	None	**Little**	**Some**	**A lot**	**Very much**	**N/A (Not Applicable)**
Turn ceiling lights off	❍	❍	❍	❍	❍	❍
Use a desk (task) lamp	❍	❍	❍	❍	❍	❍
Complain to your manager or superior officer	❍	❍	❍	❍	❍	❍
Complain to the building manager	❍	❍	❍	❍	❍	❍
Talk with others in your group about the problem	❍	❍	❍	❍	❍	❍
Change position in your workspace	❍	❍	❍	❍	❍	❍
Change location temporarily	❍	❍	❍	❍	❍	❍
Change location permanently	❍	❍	❍	❍	❍	❍
Cover up lighting sensor	❍	❍	❍	❍	❍	❍
Remove or alter light fixture above your workspace	❍	❍	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍	❍	❍

Q2.26 Do you ever experience discomfort with air quality (e.g., stuffiness, odors)?

- ❍ Yes
- ❍ No

Q2.27 For each of the actions below, please check whether you use it when you experience discomfort with air quality (e.g., stuffiness, odors) and if so, rate the extent to which the action affects your comfort.

	How much does this increase your comfort?					
	None	**Little**	**Some**	**A lot**	**Very much**	**N/A (Not Applicable)**
Use a personal fan	❍	❍	❍	❍	❍	❍
Open a window	❍	❍	❍	❍	❍	❍
Open a door to the outdoors	❍	❍	❍	❍	❍	❍
Open a door to a corridor	❍	❍	❍	❍	❍	❍
Step outside	❍	❍	❍	❍	❍	❍
Complain to your manager or superior officer	❍	❍	❍	❍	❍	❍
Complain to the building manager	❍	❍	❍	❍	❍	❍
Talk with others in your group about the problem	❍	❍	❍	❍	❍	❍
Change location temporarily	❍	❍	❍	❍	❍	❍
Change location permanently	❍	❍	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍	❍	❍

Q2.28 All things considered, how satisfied are you with your personal workspace?

- ❍ Very Dissatisfied
- ❍ Dissatisfied
- ❍ Neutral
- ❍ Satisfied
- ❍ Very Satisfied

Q2.29 All things considered, how satisfied are you with the building overall?

- ❍ Very Dissatisfied
- ❍ Dissatisfied
- ❍ Neutral
- ❍ Satisfied
- ❍ Very Satisfied

Q2.30 To what extent does the quality of your building's interior environment influence your ability to work effectively?

1	2	3	4	5
❍ Strongly interferes with my work	❍	❍	❍	❍ Strongly enhances my work

Q3.1 The following questions ask about energy efficiency and energy use in your building. If you do not work in a permanent location, please answer about the building where you work most frequently.

Q3.2 Considering energy use, in your opinion how efficiently is this building performing?

1	2	3	4	5
❍ Not at all energy efficient	❍	❍	❍	❍ Very energy efficient

Q3.3 How well informed do you feel about using the energy saving design features in your building?

1	2	3	4	5
❍	❍	❍	❍	❍
Not well informed				Very well informed

Q3.4 What do you do differently at <u>work</u> as a result of information or training you have received about sustainable behaviors and practices at Fort Carson?

Q3.5 What do you differently at <u>home</u> as a result of information or training you have received about sustainable behaviors and practices at Fort Carson?

Q3.6 Should energy reduction be a top priority at Fort Carson at this time?

- ❍ Yes
- ❍ No
- ❍ Do not know

Q3.7 For each of the following features or technologies in your building, please indicate how much experience you have with them and how much training/education you have received to operate them.

	Experience With						Training Received					
	None	A little	Some	Considerable	A great deal	N/A	None	A little	Some	Considerable	A great deal	N/A
Automatic day-lighting controls	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Programmable temperature controls	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Automatic window-darkening technologies	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Automatic window controls (to open/close)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

	Experience With						Training Received					
	None	A little	Some	Considerable	A great deal	N/A	None	A little	Some	Considerable	A great deal	N/A
Vacancy sensors (manual on; automatic off)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Occupancy sensors (automatic on; automatic off)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Green roofs (rooftop garden)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Other (please describe)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q4.1 This section asks about your engagement with and perceptions about Fort Carson's sustainability and net zero energy efforts.

Q4.2 I am aware that Fort Carson is an Army Net Zero Installation.

- ❍ Yes
- ❍ No
- ❍ Do not know

Q4.3 What actions do you take to support net zero and sustainability? (Ex: telework, car/van pool, ride a bike to work, walk to meetings, buy things made with recycled materials, buy local or organic food)

Q4.4 Where do you get information about sustainability initiatives or policy at Fort Carson? Check all that apply.

- ❍ Do not access or receive information about sustainability initiatives or policy at Fort Carson
- ❍ Fort Carson Facebook page
- ❍ Fort Carson website
- ❍ Email
- ❍ Notices posted in my building
- ❍ Fort Carson Mountaineer

- ❍ Fort Carson Annual Sustainability Report
- ❍ My manager/supervisor/commanding officer
- ❍ Department/Unit meetings
- ❍ My colleagues and/or coworkers
- ❍ Fort Carson policy letters
- ❍ Other (please describe) ____________________

Q4.5 My chain of command considers Fort Carson's net zero energy goals important.

- ❍ Strongly Disagree
- ❍ Disagree
- ❍ Neither Agree nor Disagree
- ❍ Agree
- ❍ Strongly Agree
- ❍ Do not know
- ❍ N/A (Not Applicable)

Q4.6 For each of the statements below about your personal views, rate the extent to which you agree or disagree.

	Strongly Disagree	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**	**Don't Know**
I am aware of Fort Carson's net zero energy goals.	❍	❍	❍	❍	❍	❍
I have a positive attitude about Fort Carson's net zero energy goals.	❍	❍	❍	❍	❍	❍
I have the skills and abilities to use energy saving technologies correctly at work.	❍	❍	❍	❍	❍	❍

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Don't Know
I have time available to work on Fort Carson's net zero energy efforts.	❍	❍	❍	❍	❍	❍
I feel personally responsible for reducing energy use in my building/ department/unit.	❍	❍	❍	❍	❍	❍
I believe reducing the amount of energy used in my building is important.	❍	❍	❍	❍	❍	❍

Q4.7 For each of the statements below about your group/unit, rate the extent to which you agree or disagree.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Don't Know
My group/unit is aware of Fort Carson's net zero energy goals.	❍	❍	❍	❍	❍	❍
My group/unit has a positive attitude about Fort Carson's net zero energy goals.	❍	❍	❍	❍	❍	❍
My group/unit has the skills and abilities to use energy saving technologies correctly at work.	❍	❍	❍	❍	❍	❍
My group/unit has sufficient time available to work on Fort Carson's net zero energy efforts.	❍	❍	❍	❍	❍	❍
My group/unit feels responsible for reducing energy use in my building/ department/ unit.	❍	❍	❍	❍	❍	❍

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Don't Know
My group/unit believes reducing the amount of energy used in my building is important.	❍	❍	❍	❍	❍	❍
My group/unit thinks I should use less energy in our building.	❍	❍	❍	❍	❍	❍

Q4.8 For each of the statements below about your group/unit, rate the extent to which you agree or disagree.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Do Not Know
My group/unit has clear, measurable energy reduction goals.	❍	❍	❍	❍	❍	❍
My group/unit has the resources it needs to reach its energy reduction goals.	❍	❍	❍	❍	❍	❍
My group/unit has the appropriate mix of skills and abilities to reach its energy reduction goals.	❍	❍	❍	❍	❍	❍

Q4.9 For each of the statements below about your manager/superior officer, rate the extent to which you agree or disagree.

	Strongly Disagree	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**	**Do Not Know**
My manager/superior officer has a positive attitude about Fort Carson's net zero energy goals.	❍	❍	❍	❍	❍	❍
My manager/superior officer takes energy reduction seriously.	❍	❍	❍	❍	❍	❍
My manager/superior officer leads by personal example to reduce energy use.	❍	❍	❍	❍	❍	❍
My manager/superior officer aligns the department's resources and processes to support Fort Carson's net zero energy goals.	❍	❍	❍	❍	❍	❍
My manager/superior officer expects me to use less energy in my building.	❍	❍	❍	❍	❍	❍

Q4.10 There has been too much emphasis on sustainability at Fort Carson.

- ❍ Strongly Disagree
- ❍ Disagree
- ❍ Neither Agree nor Disagree
- ❍ Agree
- ❍ Strongly Agree
- ❍ Do not know

Q4.11 How easy/difficult is it to reduce energy use in your building?

1	2	3	4	5	6	7
❍	❍	❍	❍	❍	❍	❍
Very difficult						Very easy

Q4.12 What is available to facilitate energy reduction at Fort Carson?

Q4.13 What are the obstacles or challenges to reducing energy use at Fort Carson?

Q5.1 The following questions ask about the support, challenges and opportunities at Fort Carson for performing specific energy use/saving behaviors.

Q5.2 How would you describe your approach to reducing energy in your building? Check all that apply.

- ❍ Follow policies/practices
- ❍ I do what I am told to do
- ❍ I act as role model for others
- ❍ I have accepted/taken on a formal lead role in the group/department/floor
- ❍ Other (please describe) ____________________

Q5.3 What information do you receive or have access to about the amount of energy used in your building?

Q5.4 Have you or any members in your group been recognized by your management or chain of command for reducing energy use?

- ❍ Yes
- ❍ No
- ❍ Don't know
- ❍ N/A (Not Applicable)

Q5.5 How important to you/them was it to be recognized?

1	2	3	4	5
❍ Not at all	❍	❍	❍	❍ To a very great extent

Q6.1 The following questions ask about your attitudes and beliefs about reducing energy use in your building.

Q6.2 In general, how would people in your group/unit react if they saw energy wasting behaviors (lights on in unoccupied spaces, computers on all the time, equipment left on at night)?

Q6.3 The following questions ask about your attitudes and beliefs about reducing energy use in your building.

	Definitely False	Probably False	Neither True nor False	Probably True	Definitely True
Most of the people I know at Fort Carson try to reduce energy use in their buildings.	❍	❍	❍	❍	❍
I am confident that if I wanted to I could reduce how much energy I use in my building.	❍	❍	❍	❍	❍
Others expect me to use less energy in my building.	❍	❍	❍	❍	❍

Q6.4 I will make an effort to use less energy in my building.

1	2	3	4	5
❍ Definitely will	❍	❍	❍	❍ Definitely will not

Q6.5 What would motivate you to use less energy in your building?

Appendix H Building Energy Monitor (BEM) Roles and Responsibilities

What will the BEM do?

The BEM's primary responsibility is to help the Installation Energy Manager achieve an energy efficient installation while maintaining the mission and quality of life. Team efforts are important in achieving this goal. Some of the BEM responsibilities are listed below:

- serving as the building point of contact for energy and water resource matters
- performing floor checks for problems with building systems that could affect energy use (e.g., heating, cooling, and lighting systems) and for occupant compliance with energy saving guidance (e.g., computer shut down)
- initiating work orders for problems identified with building systems and making sure repairs are followed up on in a timely manner
- monitoring building energy performance by reviewing monthly energy use data, as available
- recommending energy saving changes to your building's operating procedures
- working with occupants on behavior change for energy savings, including implementing specific actions and communicating results.

These responsibilities are covered in more detail in the BEM Handbook and training package.

BEMs supporting the building energy use behavior change intervention in the five pilot buildings will conduct regular building/office checks to make sure that computers, monitors and lights are turned off when offices are left for the day, and that individual office thermostats are set back to a predetermined level below the comfort zone. For buildings with central thermostats, the BEM will work with the facility manager to experiment with lower winter heating settings to determine impact on occupant comfort, as well as nighttime setbacks. Individual building checklists will be provided for this purpose.

The BEM will also act as a “social facilitator” of behaviors that can reduce energy use, by engaging occupants in discussion about the program on a casual basis, complimenting them when they have performed the desired behavior, providing reminders when appropriate, and addressing any problems that may occur. The BEM will also send weekly email messages to building occupants conveying the status of behavior changes, such as what percentage of occupants turned off their computers.

How often will the BEM do the periodic checks?

It is recommended that floor checks be performed at least once per week. The more frequently the office checks are performed, the more accurate the data will be.

Who does the BEM report to?

The BEM will report to their direct supervisor in the building for which they are responsible, and will provide the checklists and any other communication to the Repair & Utility section of the Directorate of Public Works (DPW).

Desirable characteristics of a BEM

A person taking on the BEM role should have the following characteristics:

- a fundamental interest and commitment to sustainability, energy efficiency and conservation
- familiarity with building energy and water systems is desirable, but can be obtained through training.
- comfortable engaging building occupants in productive dialogues about ways they can support Fort Carson's net zero energy goals. The BEM should be an "energy coach" and aim to help occupants without being overly intrusive.
- have some level of technical respect from the occupants.
- must be able to dedicate two hours per week on average to these responsibilities.

Appendix I Building Energy Monitor (BEM) Floor Check Form

Building Energy Monitor (BEM) Checklist for Buildings 1219 and 1118

Date:	Building:		Number of Occupants:	BEM:
Please record estimated percentages and action codes for each floor. Common space includes open office areas, conference rooms, etc.				
Floor	% Thermostat set back	% Monitors off	% Overhead Lights off in unoccupied offices	% Task lights or natural light used instead of overhead
1 – Office space				
1 – Common space				
2 – Office space				
2 – Common space				
3 – Office space				
3 – Common space				
Other observed energy saving practices (note locations)				
Other observed energy wasting practices (note locations)				
Occupant reports (note type, location)				
Physical problems observed (e.g., lighting sensors not working, water leaks, window seals broken, etc.). Note location.				

NO = notified occupant **WO** = called in work order **CA** = took

Instructions for BEM Checklist for Buildings 1219 and 1118

The BEM checklist is used to record your observations of energy saving or energy wasting practices seen during your periodic building walkthroughs, either during end of day or during daily operation. Capturing these practices will require both: e.g., making sure that computer monitors are off after people go home is best done through an end-of-day walkthrough, as is making sure that lights are off, although you can also observe this during the day to determine whether people are leaving lights on in unoccupied offices. Common spaces include conference rooms, open office areas, kitchens, and other space used by multiple occupants.

Because your buildings are fairly large with many private office and common spaces, the best way to use the checklist is to estimate percentages of energy saving or energy wasting practices by making selective observations on each floor during a walkthrough at the end of the day. For example, you might walk through the first floor, and check the thermostats in ten offices. If the thermostats are set back in eight of the ten offices, you would enter “80%” in the appropriate cell on the checklist. A similar procedure would be applied to computer monitors. Note that while computers should also be shut down at night, it will be the network checks (NECs) responsibility to monitor this and share results with the BEMs.

Other observations can be made on a casual basis during the hours that offices are occupied, such as the number or percentage of occupants you see using task lighting or natural light rather than overhead lighting, or the percentage of unoccupied spaces with lights on or off. Practices such as closing window coverings to reduce heat from sunlight can be noted in the rows at the bottom of the form.

In addition to observing occupant behavior, you should include any physical aspects of the building that may require attention, such as sensors that are not functioning properly, plumbing issues, and poor window or door seals.

For any problems observed, please note any action you have taken, such as notifying occupants or calling in work orders, by using the action codes at the bottom of the form. We do not expect you to capture all energy saving and energy wasting practices; our goal is to get a general sense of the degree to which these things are done.

Floor checks should be completed twice per week. However, if you believe it would be helpful to track certain energy saving behaviors more frequently (e.g., those that occupants are not complying with very well), you may want to do more frequent checks temporarily.

Please email or fax completed checklist each week to: Scott Clark, Energy Program Coordinator, scott.b.clark.ctr@mail.mil or Fax: 719-xxx-xxxx

Appendix J Intervention Evaluation Plan

Measure	Who Collects Data	Frequency and Timing	How Documented and Shared with Research Team	Analytic Methods
Computer nighttime shutdown compliance	Computer network personnel Pacific Northwest National Laboratory (PNNL)	Pre-intervention: one week of network scans During intervention: daily scans during first month; once weekly for remaining two months Post-intervention survey	Computer network personnel ping computer assets in five buildings mid-day and after work hours on same day and compare response rate. Weekly compliance rates (# of computers off/all computers) by building sent to PNNL. Post-intervention survey asks users whether behavior changed as result of the intervention.	Compare pre-intervention and post-intervention compliance ratios by building. Assume savings per computer of 3 W (sleep mode) to 50 W (running) depending on standby settings. Use post-intervention survey to establish change in frequency of shutdowns.
Temperature is set back on wall-mounted heating units	Building Energy Monitor (BEM) PNNL	Weekly floor checks during intervention (as feasible with offices that are not locked) Post-intervention survey	BEM emails floor check to PNNL each week, documenting number of units set back Survey asks users whether behavior changed as result of the intervention measures and how frequently.	Establish the percent of occupants who indicated changing behavior from survey responses. Use modeled estimate of energy savings, which range from 1.5–3.4% for full compliance depending on system. Adjust based on proportion indicating a change in behavior. Or, use building metered data as available.
Lights turned off in unoccupied office and conference rooms	BEM PNNL	Weekly floor checks during intervention Post-intervention survey	BEM emails floor check to PNNL each week, documenting instances of rooms with lights left on. Survey asks occupants whether behavior changed as result of the intervention measures.	Compare pre-intervention and post-intervention compliance using survey data. Will not quantify energy savings.

Measure	Who Collects Data	Frequency and Timing	How Documented and Shared with Research Team	Analytic Methods
Use task and natural lighting instead of overhead light when adequate	BEM PNNL	Weekly floor checks during intervention Post-intervention survey	BEM emails checklists to PNNL each week, documenting percent of occupants using of task or natural instead of overhead lights. Survey asks occupants whether behavior changed in past three months.	Compare pre- and post-intervention survey responses, as feasible. Establish the percent of occupants who indicated changing behavior. Will not quantify energy savings.
Use non-energy-intensive methods of managing comfort including, e.g., adjusting window shades	PNNL	Post-intervention survey	Survey asks in post-intervention survey whether they employed each behavior more now than before the intervention.	Compare pre- and post-intervention survey responses to same question as feasible. Establish the percentage of occupants who indicated changing behavior. Will not quantify energy savings.
Energy saving ideas submitted by occupants	BEM	During intervention Written, verbal correspondence with occupants	BEM emails floor check form to PNNL each week documenting number and nature of ideas submitted.	N/A
Impact of posters and other direct communications on occupant behavior	PNNL	Post-intervention survey	Survey asks occupants whether they received the communication and asks them to rate the extent to which the referenced communication influenced their behavior.	
Impact of BEM correspondence (emails) to occupants on occupant behavior	PNNL	Post-intervention survey	Survey asks occupants whether they received the specific communication and asks them to rate the extent to which the referenced communication influenced their behavior.	

Measure	Who Collects Data	Frequency and Timing	How Documented and Shared with Research Team	Analytic Methods
Impact of communications from Fort Carson Leadership on occupant behavior	PNNL	Post-intervention survey	Survey asks occupants whether they saw the specific communication and asks them to rate the extent to which the referenced communication influenced their behavior.	
BEM follow-through and feedback on role	PNNL	Post-intervention interviews with BEMs	Floor checks submitted, Fort Carson Energy Manager follow-up with BEMs, end of project debrief interview	N/A

Appendix K Characteristics of Survey Respondents

There were 54 respondents to the baseline survey and 102 respondents to the post-intervention survey out of approximately 690 occupants at the time of the post-intervention survey period. The three military buildings had not been fully occupied at the time of the baseline survey, which is believed to have contributed to the lower number of responses. Because the exact number of occupants in these buildings could not be established, the response rate for these buildings is not known.

An estimated 24% of Building 1118 occupants and 35% of Building 1219 occupants responded to the post-intervention survey, which made findings from of these two buildings more useful for building-level analysis. The post-intervention survey respondents from Building 9420 represent only 6% of all occupants in that building, but responses were still analyzed to provide some perspective on military occupants. The two military COFs (Buildings 9427 and 9447) also had an insufficient number of responses to the post-intervention survey for any building-level analysis.

As illustrated in Figure 84, the majority (89%) of the respondents to the baseline survey were from the two predominantly civilian administrative buildings. In the post-intervention survey, occupants of these two buildings represented 82% of respondents.

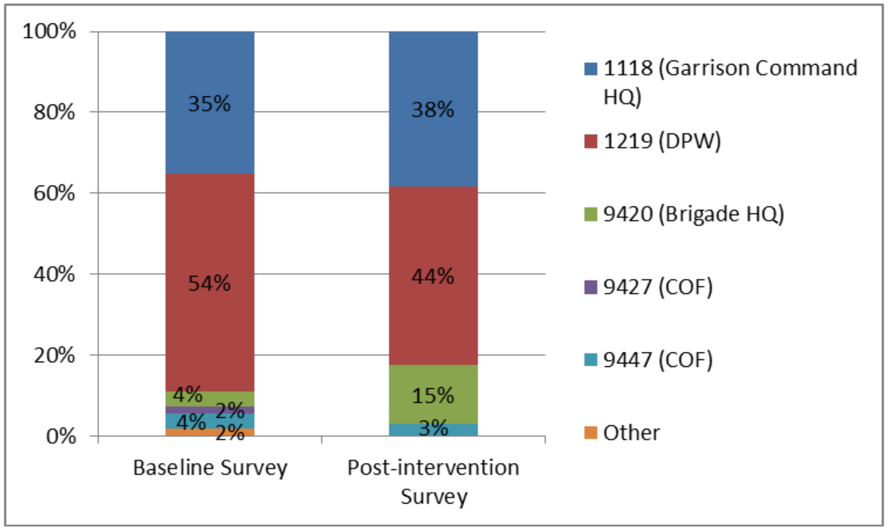


Figure 84 Percent of Total Respondents to Baseline and Post-Intervention Surveys by Building

Respondents to both surveys represented a fairly balanced mix of job functions (see Figure 85).

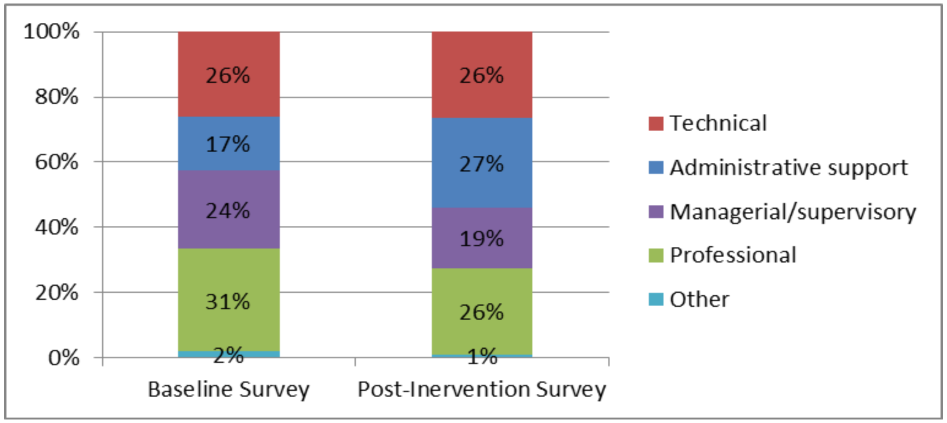


Figure 85 Percent of Respondents to Baseline and Post-Intervention Surveys by Job Function

The vast majority of respondents to both surveys were civilians. Just 17% of respondents to the baseline survey and 24% of all respondents to the post-intervention survey held military positions (see Figure 86).

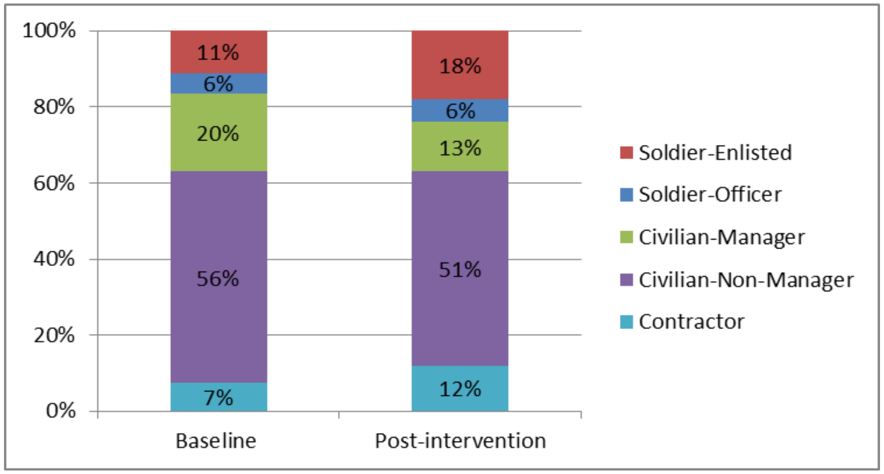


Figure 86 Percent of Total Respondents to Baseline and Post-Intervention Surveys by Position

In the baseline survey, the majority of civilian respondents reported having worked at Fort Carson ten years on average, but because the buildings were all new or recently renovated, they reported being in their current workspaces for about two years on average.

The largest proportion of respondents to both surveys reported working in enclosed private office spaces. In the post-intervention survey, 26% were in partitioned cubicles of some sort (Figure 87).

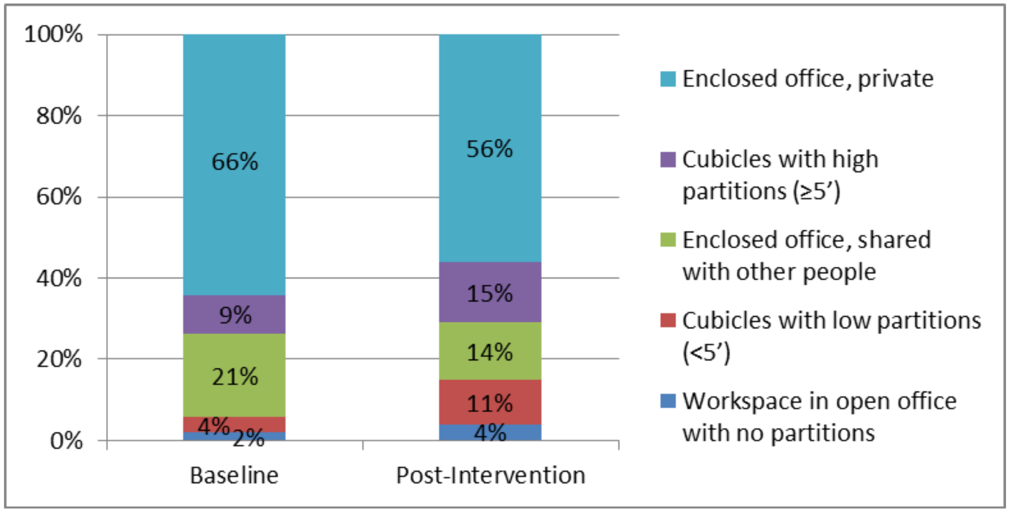


Figure 87 Percent of Total Respondents to Baseline and Post-Intervention Surveys by Type of Workspace

Appendix L Email Messages from Building Energy Monitors (BEMs)

Week 1 Email

Dear Building [XXXX] Occupants,

This note is to introduce myself, [INSERT NAME], as your Building Energy Monitor (BEM). As a BEM, I support Fort Carson's energy conservation program by inspecting our building and by working with you—the occupants of [Building #XXX]—to find ways to save energy.

Energy conservation is a growing priority at Fort Carson as our budgets tighten. Did you know that the energy utility bills cost [insert $ from training slides] per year for our building? As you saw from the email sent by [the Garrison Commander or General Commanding of the 4th Infantry Division] this week, our leaders are committed to reducing these costs, as well as the impact energy use has on our mission readiness and the environment.

How can you help? Start with five simple things:

1. Shut down your computers every night. This is approved by the NEC as a pilot.

[For Buildings 1219 and 1118] Turn back your wall-mounted heating units 5–10 degrees each night.

[For Buildings 9420, 9427, 9447] Use shared appliances and eliminate personal refrigerators, printers, scanners, and space heaters in your workspace.

Find ways to manage your comfort without increasing energy use. For example, use your window shades, drink something hot or cold, and dress in layers.

Turn off overhead lights when leaving an office or conference room.

Use task lights or natural light instead of overhead lights when possible.

Over the next three months, we will be monitoring energy use in our building and tracking how well our occupants follow through with these five actions. The NEC will support this effort by scanning the network each week for computers that are left on at night. I will share feedback with you every few weeks on our performance and any lessons learned. I also encourage you to let me know of energy issues that you are aware of and suggest ideas for energy conservation.

We all want to make sure Fort Carson achieves its energy objectives—I will appreciate your help in making this happen.

Sincerely,

[BEM Name]

[Building]

Week 3 Email

Dear Occupants of Buildings 1219 and 1118:

We are now entering the third week of the three-month period of engaging occupants to help Fort Carson achieve its energy reduction goals. We appreciate all you are doing to help with this effort.

Congratulations to the occupants of Building 1219, which leads the pack in turning off computers during off-hours. Network checks from the NEC indicate that computers in Building 1219 were shut down 46% of the time during the first two-week period; computers in Building 1118 were shut down just 13% of the time during this period.

We also saw from floor checks that overhead lights were off in nearly 100% of the unoccupied offices checked in Building 1118, and in some cases overhead lights are being shut off when task or natural light is adequate. In Building 1219, overhead lights were off in just 20–50% of unoccupied offices checked.

Finally, thermostats were set back in nearly 100% of the workspaces checked in Building 1118. In Building 1219, just 5% of the work spaces checked had turned back thermostats at night.

This is a great start, but there is obviously some room for improvement. Please consider setting up “reminders to self” for turning off computers and setting back thermostats when you leave at night; we know this is not something you may be accustomed to doing in the past, but this action does make a difference, and we encourage you to make it a habit. Continue to work with us, your Building Energy Monitors (BEMs), on creative approaches to reducing energy usage.

We will be providing an update on progress again in two weeks. Can you help us improve our energy reducing actions before then?

Thank you,

[BEM Name]

[Building]

Dear Occupants of Buildings 9420, 9427, and 9447,

We are now entering the third week of the three-month period of engaging occupants to help Fort Carson achieve its energy reduction goals. We appreciate all you are doing to help with this effort.

During floor checks, we observed that occupants of the BBHQ (Building 9420) are turning off overhead lights in unoccupied offices, including overriding lighting sensors when leaving. An estimated 80% of unoccupied offices had lights off, while just 30% of unoccupied shared spaces had lights off.

NEC network checks showed computers were shut down by occupants of these three buildings just 2–4% of the time during this first two-week period. For comparison, occupants of Building 1219 shut down their computers 46% of the time during the same period. Computer monitors were shut off in the evenings about 10% of time in the BBHQ.

This is a good start with lighting, but there is obviously some room for improvement. Please consider setting up “reminders to self” for turning off computers, monitors, and lights when you leave at night; we know this is not something you may be accustomed to doing in the past, but this action does make a difference, and we encourage you to make it a habit. Continue to work with us, your Building Energy Monitors (BEMs), on creative approaches to reducing energy usage.

We will be providing an update on progress again in two weeks. Can you help us improve our energy reducing actions before then?

Thank you,

[BEM Name]

[Building]

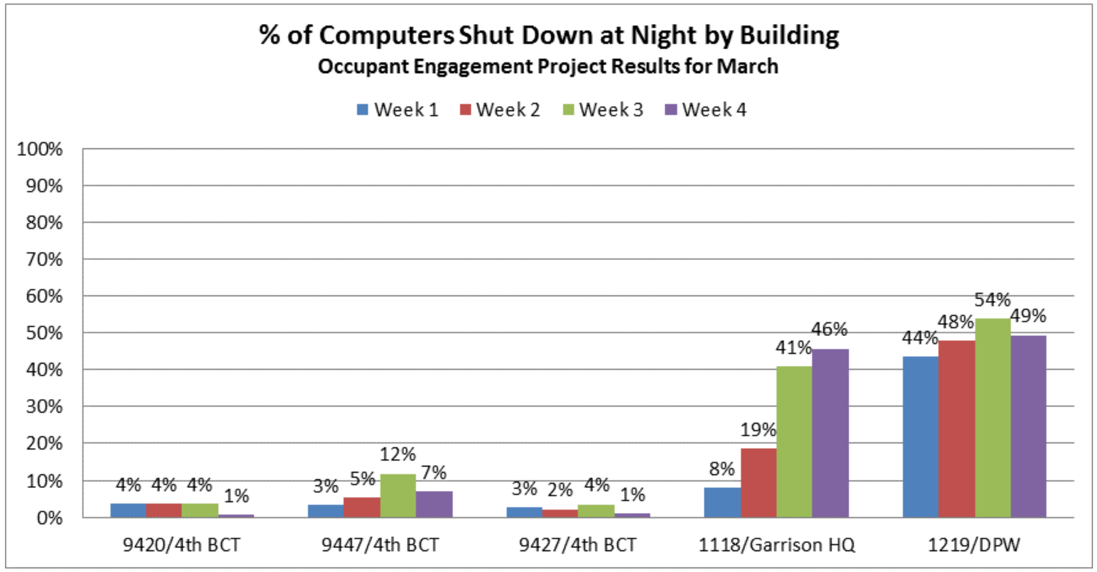
Week 5 Email

Dear Occupants of Buildings 9420, 9427, 9447, 1219, and 1118:

We are now in the fifth week of the 12-week effort of engaging building occupants to help Fort Carson achieve its energy reduction goals.

Congratulations to the occupants of Building 1118, which has shown the greatest improvement in turning off computers during off-hours! Occupants of Building 1118 shut down their computers 46% of the time during the last week of March, up from 8% during the first week of March—way to go!! They are catching up with Building 1219 occupants who are shutting down computers 49% of the time on average. But please do not stop there: another 50% savings could be reached if the rest of the occupants turned off their machines.

The three buildings in the 4th Brigade Combat Team (BCT) are lagging behind. Occupants of two of the 4th BCT buildings have not increased computer shutdown behavior at all. Occupants of Building 9447 showed a slight improvement. We would like to understand what the barriers to change might be here and would appreciate your input and ideas. Surely the occupants of these buildings can catch up to—and maybe exceed—the levels of Buildings 1118 and 1219.



Shutting down your computer at night is approved by the NEC is one simple thing you can do each day. But there are other ways you can help Fort Carson save energy, save money, and make a difference:

1. Turn off overhead lights when leaving an office or conference room.
2. Use task lights and natural light instead of overhead lighting.
3. Turn back heating units 5–10 degrees at the end of the day, if you have a wall-mounted heating unit in your work space.
4. Use window shades and dress in layers to help control your comfort.
5. Use shared refrigerators and coffee makers. Unplug private nonessential appliances and space heaters.

Make energy conservation a habit; consider setting up “reminders to self” for turning off computers, monitors, and lights you leave at night. As your Building Energy Monitors (BEMs), we thank you for your efforts and encourage you to share your creative approaches to reducing energy use at Fort Carson.

Thank you,

[BEM Name]

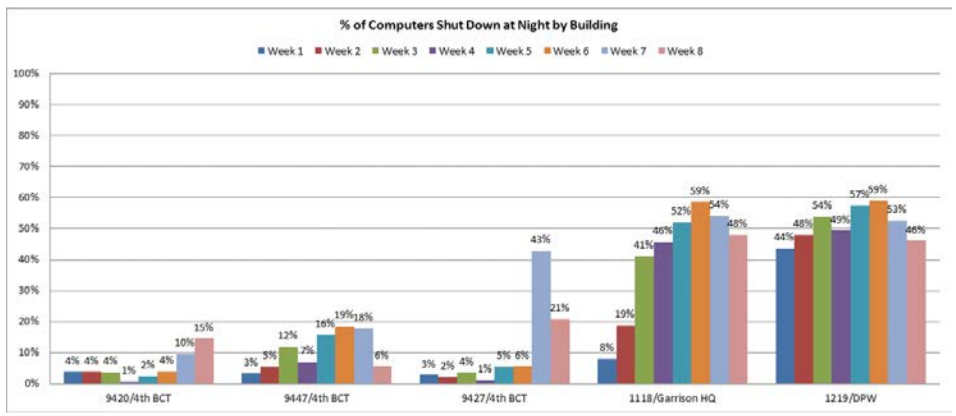
[Building]

Week 8 Email

Dear Occupants of Buildings 9420, 9427, 9447, 1219, and 1118:

We have just four weeks left in the pilot project to test how much energy building occupants can help save in Fort Carson buildings!

Efforts to shut down computers at night are taking hold in all five buildings. Occupants of the three 4th BCT buildings have shown a recent improvement with 21% of computers being shut down last week in Building 9447. The Garrison Headquarters (HQ) and Directorate of Public Works (DPW) buildings had the highest compliance rates a few weeks ago, reaching 59%, but both have lost ground in April.



Based on floor checks by the Building Energy Monitors (BEMs), most of you are turning off overhead lights when leaving a room, but we still have opportunities to save more. Ask yourself if you have enough natural light or task lighting to do your job and turn off the overhead lights if so.

Remember, you can do a few simple things in your building every day to have an impact:

- Turn off your computers and monitors at night
- Turn off overhead lights when leaving an office or conference room
- Use task lights and natural light instead of overhead lighting
- Use window shades and dress in layers to help control your comfort
- Use shared refrigerators and coffee makers and unplug private nonessential appliances
- During the heating season, turn back heating units 5–10 degrees at the end of the day if you have a wall-mounted heating unit in your work space

As your BEMs, thank you again for your efforts! Please do not hesitate to contact us with suggestions.

[BEM Name]

[Building]

Appendix M Customized Posters for Civilian and Military Buildings

Building 1118 Poster

Building 1219 Poster

Buildings 9420, 9427, and 9447 Poster

Appendix N Letter from Fort Carson Leadership to Building Occupants

Dear Occupants of Building XXXX,

We are writing to request your support of an effort to help save energy in Fort Carson buildings. Because of our strong commitment to net zero energy at Fort Carson, we were invited to collaborate with the General Services Administration on a project to examine your role in reducing building energy use. Your building is one of five at Fort Carson participating in this project.

Energy stewardship is not ancillary to our mission; it is essential to forging readiness. We firmly believe that it enhances our ability to project power, operate in the austere environments, and protect our forces. Our dependence on energy to support our operations has greatly increased, as has the cost of energy. Yet our budgets have tightened dramatically and will continue to do so. If we do not adapt to the reduced availability of energy resources, our ability to project force, sustain our daily operations, and ensure training readiness will be severely impaired.

Energy stewardship must start right here at home, with you. As part of this project on energy saving behavior, I would like you to do six simple things to become better energy stewards in your buildings:

- Shut down your computers and monitors each night. NEC is working to ensure we can do this without security risk during this project.
- Turn back heating units when leaving at night. *(send to Buildings 1219 and 1118 only)*
- Use non-energy-intensive ways to manage your comfort (e.g., drinking something warm).

- Turn off lights when leaving an office or conference room.
- Maximize use of task lights and natural light and turn off overhead lights as much as possible.
- Eliminate personal refrigerators, space heaters, coffee pots, and other small appliances that only service one or two persons. Use those provided for you in common spaces.

Your Building Energy Monitor (BEM), XXX XXX, will play an important role in this effort to help Fort Carson personnel become leaders in energy stewardship. I have asked your BEMs to observe and track how many of these energy saving practices actually occur and communicate with you on a regular basis about your building's performance. I will be tracking this as well and will follow up in three months to share with you what we have learned from this project.

Please support your BEM and help your co-workers to become better energy stewards support by sharing energy saving ideas that you have.

Thank you for helping Fort Carson to achieve to our net zero energy goals.

Colonel David Grosso	Major General Joseph Anderson
Garrison Commander	Commanding General 4th Infantry Division