ERDC/CERL TR-17-2

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
INNOVATIVE SOLUTIONS for a safer, better world

Energy Conservation in Historic Buildings

David M. Underwood, Brett N. Garret, and Tapan C. Patel

November 2023

Fort Sill, OK, Bldgs. 750 (top) and 462 (bottom)

Construction Engineering Research Laboratory

ERDC/CERL TR-17-2
November 2023

Energy Conservation in Historic Buildings

David M. Underwood, Brett N. Garret, and Tapan C. Patel

U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
2902 Newmark Dr.
Champaign, IL 61824

Final Report

Prepared for Office of the Assistant Secretary of Defense for
Energy, Installations, and Environment (OASD[EI&E])

Under Department of Defense Legacy Resource Management Program, Project Number 15-777 “Identify Life Cycle Cost Benefits of Energy Efficiency in Historic Buildings”

Abstract

The work reviewed the Department of Defense (DoD) stock of buildings listed or determined eligible for listing in the National Register of Historic Places (NRHP) and developed recommended Energy Efficiency Measures (EEMs) for representative buildings. At Fort Sill, six buildings that represent commonly found buildings were selected to be studied for potential EEMs. Three historic buildings located at Fort Bliss were also included in the analysis. Computer models of each building's energy use were developed and used to estimate the potential energy savings, cost, and simple payback. The results were then extrapolated to the 15 U.S. climate zones. This report provides a list of EEMs that may be applicable to historic buildings and can be used as a general guide to determine their effectiveness in various climate zones.

Executive Summary

The work reviewed the Department of Defense (DoD) stock of buildings listed or determined eligible for listing in the National Register of Historic Places (NRHP) and developed recommended Energy Efficiency Measures (EEMs) for representative buildings. This report is intended for energy managers and cultural resources persons to use as a guide when evaluating historic facilities for EEMs that will reduce building energy consumption while maintaining the "historic" status.

Nine buildings were selected for this analysis (six at Ft. Sill, three at Ft. Bliss). Computer based energy models of each building's energy use were developed, and used to estimate the potential energy savings, cost, and simple payback ((Initial cost[$]/Savings[$] per year). The results were then extrapolated to 15 U.S. climate zones to estimate the effectiveness of various EEMs in those climate zones.

Table ES1 shows a summary of the simple payback of each of these measures, across various climate zones. In general, replacing mechanical equipment controls and reducing infiltration yielded the quickest payback. Replacing mechanical equipment, skylights and adding wall insulation show moderate savings. Roof/attic insulation, lighting retrofits, Photovoltaic (PV) panel retrofits and ground floor insulation had poor payback. Although lighting retrofits are typically cost effective, most facilities analyzed in this study were under-lit and/or already had efficient lighting fixtures (e.g. LED) installed. Over the last decade, most (if not all) installations have prioritized lighting retrofits and there are unlikely many opportunities left.

This report provides a list of EEMs that may be applicable to historic buildings and can be used as a general guide to determine their effectiveness in various climate zones.

ERDC/CERL TR-17-2

Table ES1: Average Simple Payback for Each Climate Zone and Improvement Type

Climate Zone vs. Improvement Type	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Decreasing Infiltration	2.1	0.9	1.3	0.8	1.5	1.7	0.7	1.1	1.2	0.5	0.7	0.5	0.5	0.4	0.4
Wall Insulation	12.9	11.7	14.8	10.4	12.3	24.2	12.2	11.6	13.6	12.3	11.9	14.4	10.9	13.6	17.3
Roof/Attic Insulation	55.1	50.9	35.0	46.5	38.8	95.0	31.6	33.6	43.9	33.8	30.7	28.9	23.8	22.3	12.8
Replacing Mech. Equipment	15.0	6.2	7.5	2.1	3.0	8.7	3.3	4.3	4.3	2.4	2.9	2.2	2.3	1.8	1.4
Replacing Mech. Equipment (controls)	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.2	0.2
Lighting Retrofit	15.1	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2
PV Panel Retrofit	25.5	27.8	21.6	25.7	21.0	24.0	28.2	20.9	34.2	29.1	23.5	29.7	28.1	29.1	40.3
Ground Floor Insulation	87.2	35.4	32.1	26.7	21.4	13.1	26.8	19.4	15.4	29.5	18.5	29.8	21.7	25.9	28.4
Skylighting	5.4	6.1	6.1	6.6	6.4	8.1	6.9	6.8	8.7	6.8	7.3	7.0	7.5	7.4	9.9

Legend: Very good (green) = 0 to 5 | Good (yellow) = 5 to 15 | Bad (red) = 15 +

Contents

Tables and Figures

Tables

Tables

Tables

Tables

Tables

Figures

Figures

Figures

Figures

Preface

This study was conducted for the Office of the Assistant Secretary of Defense for Energy, Installations, and Environment (OASD[EI&E]) under the Legacy Resource Management Program, Project 15-777, "Identify Life Cycle Cost Benefits of Energy Efficiency in Historic Buildings."

The work was performed by the Energy Branch (CFE) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). Thanks are owed to the Legacy program for funding this research. Special credit is bestowed upon Adam Smith and Megan Tooker, of the Cultural Resources group at ERDC-CERL, for their assistance in analyzing the types and number of historic buildings within DoD and the selection of buildings to model. Great appreciation is owed to the Fort Sill, OK, personnel who generously assisted with these tasks. At the time of publication, Gisselle Rodriguez was Acting Chief, CEERD-CFE; L. Michelle J. Hanson was Acting Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CZT was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel.

COL Bryan S. Green was Commander of ERDC, and Dr. Jeffery P. Holland was the Director. Program and technical guidance was provided by Michelle Volkema, DoD Deputy Federal Preservation Officer, OASD(EI&E).

1 Introduction

1.1 Background

The U.S. Department of Defense (DoD) is required by several executive orders (EO 13693 [2015], EO 13423 (White House, 2007), EO 13123 (White House, 1999)) and other laws and policies (Environmental Policy Act (EPACT) 2005, Energy Independence and Security Act (EISA) 2007 (White House, 2007), Army Directive 2014-02 [SA 2014]) to decrease energy consumption and increase the use of renewable energy throughout the building's lifecycle. Specifically, the Army is required by law to reduce overall facility energy use by 30% by 2015 and to eliminate fossil fuel use in new and renovated facilities by 2030.

An analysis of DoD's real property records shows that over 30% of DoD buildings are over 50 years old. By 2025, DoD real property more than 50 years old will increase to nearly 70% and will become eligible for National Register of Historic Places (NRHP) evaluation. However, the energy efficiency measures (EEMs) commonly implemented in buildings are often difficult or impossible to implement on historic buildings because they involve making changes to the buildings that violate the requirements of the National Historical Preservation Act (NHPA). For example, installation of solar panels on a roof commonly alters the building's historic appearance.

In such cases, energy efficiency studies must meet dual (and sometimes conflicting) requirements to enable historical buildings to conserve energy while preserving their historic and cultural nature and appearance. This work was undertaken to help military installations meet those requirements in historic buildings on DoD sites.

1.2 Objectives

The objective of this work aimed to assist military installations in meeting energy efficiency and NHPA requirements in onsite historic buildings by: (1) conducting an assessment of all factors influencing energy use in historic buildings, (2) analyzing the impact of EEMs on energy use, and (3) prioritizing and optimizing the utilization of combinations of EEMs in typical building types across various climate zones in the United States.

1.3 Approach

The study examined the DoD stock of buildings listed in the NRHP or deemed eligible for NRHP inclusion. To generate findings applicable to this extensive collection of diverse historic (or potentially historical) buildings, a representative set of similar historic buildings was selected for analysis. Computer models utilizing the eQUEST building energy simulation software tool were developed for the selected buildings.

The analysis evaluated selected EEMs for their potential to achieve energy and cost savings while ensuring compliance with the NHPA, which aims to preserve historical and archaeological sites throughout the United States of America by providing federal funding for preservation activities. The findings of these evaluations were extrapolated to similar buildings in different climate zones and then summarized, providing a guide on the utilization of various EEMs or combinations of EEMs commonly applicable to different types of historic buildings across diverse U.S. climate zones.

2 Energy Terms

2.1 Heating and cooling degree days

"Degree days" are essentially a simplified representation of outside air temperature data. They are widely used in the energy industry for calculations relating to the effect of outside air temperature on building energy consumption.

"Heating degree days," or "HDD," are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific "base temperature" (or "balance point"). They are used in calculations relating to the energy consumption required to heat buildings.

"Cooling Degree Days," or "CDD," are a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base temperature. They are used for calculations relating to the energy consumption required to cool buildings.

2.2 Climate zones

Climate zones represent geographical areas of the United States with various heating and cooling needs (Figure 1). These needs are measured in the number of Heating Degree Days and Cooling Degree Days an area has. There are eight different climate zones in the United States (Table 1). The eight climate zones are further divided based on the moisture of the area, for a total of 15 different zone divisions. The three divisions are A (moist), B (dry), and C (marine). Table 2 lists an example city for each of the 15 different zone divisions.

Figure 1. Climate zone map.

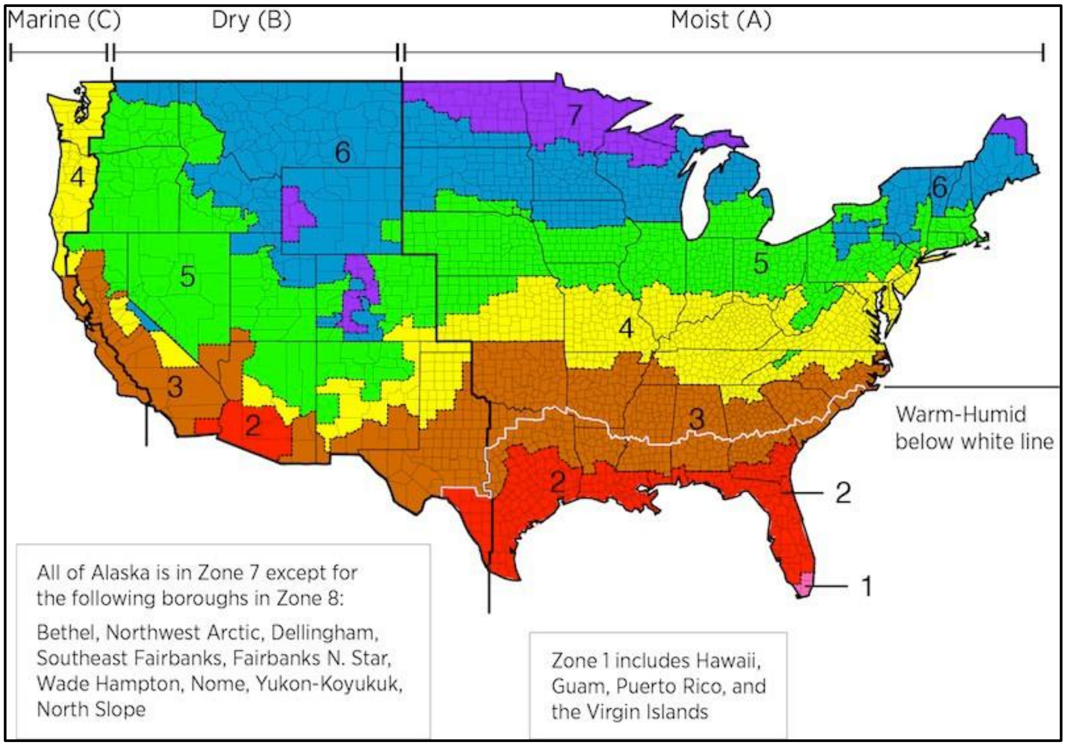


Table 1. Climate zone definitions.

Zone Number	Thermal Criteria	
	IP Units*	SI Units*
1	9000 < CDD50°F	5000 < CDD10°C
2	6300 < CDD50°F <=9000	3500 < CDD10°C <= 5000
3A and 3B	4500 < CDD50°F <= 6300 and HDD65°F <= 5400	2500 < CDD10°C <= 3500 and HDD18°C <= 3000
4A and 4B	CDD50°F <= 4500 and HDD65°F <= 5400	CDD10°C <= 2500 and HDD18°C <= 3000
3C	HDD65°F <= 3600	HDD18°C <= 2000
4C	3600 < HDD65°F <= 5400	2000 < HDD18°C <= 3000
5	5400 < HDD65°F <= 7200	3000 < HDD18°C <= 4000
6	7200 < HDD65°F <= 9000	4000 < HDD18°C <= 5000
7	9000 < HDD65°F <= 12600	5000 < HDD18°C <= 7000
8		

*IP = "inch-pound"; SI - Systeme Internationale
Source: http://www.energyvanguard.com/knowledge/us-climate-zones

Table 2. Example climate zone cities.

Climate Zone	Example City, State
1A	Miami, FL
2A	Houston, TX
2B	Phoenix, AZ
3A	Memphis, TN
3B	El Paso, TX
3C	San Francisco, CA
4A	Baltimore, MD
4B	Albuquerque, NM
4C	Seattle, WA
5A	Chicago, IL
5B	Colorado Springs, CO
6A	Burlington, VT
6B	Helena, MT
7A	Duluth, MN
8A	Fairbanks, AK

2.3 eQUEST – The Quick Energy Simulation Tool

2.3.1 Overview

The eQUEST building energy simulation tool (Hirsch 2010), which is based on DOE-2 (Hirsch 2016), has undergone decades of development. DOE-2 was originally developed by the Department of Energy. The eQUEST graphical interface allows users with limited simulation experience to quickly develop three-dimensional simulation models of a particular building design. These simulations incorporate building location, orientation, wall/roof construction, window properties, as well as Heating, Ventilating, and Air-Conditioning (HVAC) systems, daylighting, and various control strategies, along with the ability to evaluate design options for any single or combination of energy conservation measure(s).

2.3.2 Inputs

Initial input is done via the “wizard,” which is broken into a “Schematic Design Wizard” and a “Design Development Wizard.” The model’s complexity can begin with a simple box and single zone to the actual design, with the ability to import inputs from AutoCAD (*.dwg) files with complex occupancy schedules and rate schedules. Although the use of default values allows for quick development of building models, the use of too many default values without verification can produces unreliable results.

2.3.3 Outputs

The general outputs from eQUEST include annual energy consumption and associated costs for a particular building design. Included in the extensive output reports are:

- Summary of Inputs (schedules, building construction characteristics, summary of load components and peak loads)
- HVAC System Characteristics (input characteristics, system size, runtimes, capacity, and air/fluid flow)
- Hourly Reports from user-specified building components

2.4 Btus, therms, and MMBtus

A British Thermal Unit (Btu) is a unit of work, equivalent to the amount of work needed to raise the temperature of a pound of water by a single degree Fahrenheit. As it is not an Systeme Internationale (SI) unit, it is only commonly used in North America, where the energy content of fuels is often given in Btus. This measure is used to express the energy use of buildings in terms of Btu/year. This unit is most used when describing energy associated with heating. A therm is equivalent to 100,000 Btus. A MMBtu is 1,000,000 Btus.

2.5 Watts, kilowatts (kW), and kilowatt-hour (kWh)

A kilowatt is a unit of power used most to describe instantaneous electricity use. A kW is equivalent to 1,000 watts. A kWh is a unit of energy, which is the integrated power use over time. For example, if a device uses 10 kW of power for 1 hour, then 10kWh of energy has been consumed.

2.6 Footcandles and lumens

A footcandle (abbreviated fc, lm/ft^2, or sometimes ft-c) is a non-SI unit of illuminance or light intensity. The name “footcandle” conveys “the illuminance cast on a surface by a one-candle source 1 ft away.”

The unit is defined as the amount of illumination the inside surface of a 1-ft radius sphere would receive if there were a uniform point source of one candela in the exact center of the sphere. Alternatively, it can be defined as the illuminance on a 1-ft^2 surface of which there is a uniformly distributed flux of 1 lumen. Thus 1 footcandle is equal to 1 lumen/ft^2, or approximately 10.764 lux.

2.7 Economizer

There are a variety of “economizer” types and modes of operation. As its name implies, the function of the economizer is to “economize” or save on cooling costs. Economizers discussed in this report refer to the introduction of outside air into the building when its energy content is less that the return air from the building (i.e., “free cooling” using outside air rather than mechanical cooling”).

3 DoD Stock of Historic and Potentially Historic Buildings

The first phase of this project involved determining the types and number of historic buildings in DoD (Table 3). The purpose of this was to target the two most prevalent building types so the resulting Energy Conservation Measures (ECMs) would have the widest potential application. Table 3 lists the results of a query of the DoD Real Property Assets Database (RPAD). The query criteria were:

- Include Services (exclude Washington Headquarters Services [WHS])
- Include the United States and its Territories (exclude foreign assets)
- Include Federal assets (exclude Army Designated State Sites)
- Include Buildings and Structures (exclude Linear Structures and Land)
- Exclude assets with Interest Type of Lease
- Exclude Historic Status Code: Department of Natural Resources (DNR)
- Exclude Disposed Assets (Assets with a Disposal Completion Date)

For purposes of this report:

- The term "All Assets" is defined as all DoD real property assets regardless of/including all historic status code (HSC), i.e., historic and non- historic assets (including buildings and structures).
- The term "Historic Assets" is defined as real property assets eligible for listing or listed in the National Register of Historic Places (NRHP).

The data in Table 3 indicates that, of the four Service Branches, the Army has the most historic buildings. In fact, more than 50% of DoD's historic building inventory. Because of this, the Army historic building stock was investigated further. Data drawn from the "Real Property Summary Installation and Site Statistics for Fiscal Year 2016 Quarter 1" (also known as the "Army Green Book") indicate that there are 12 Army installations with more than 1000 historic facilities (Table 4).

Table 3. Historic assets in DoD.

Service Branch	All Assets	Historic Assets	All Assets 40-49 Years Old
Army	190,512	36,245	11,893
Navy	77,615	14,458	8,789
U.S. Marine Corps (USMC)	36,901	4,618	2,505
Air Force	71,784	5,465	6,587
DoD	376,812	60,786	29,774

Table 4 – Army Installations with over 1,000 historic facilities.

Installation	State	Number of Historic Facilities
Joint Base Lewis-McChord	Washington	3850
Letterkenny Army Depot	Pennsylvania	2838
McAlester Army Ammunition Plant	Oklahoma	2156
Fort Bragg	North Carolina	2084
Tooele Army Depot	Utah	1985
Fort Hood	Texas	1833
Pueblo Chemical Depot	Colorado	1546
Milan Army Ammunition Plant	Tennessee	1515
Anniston Army Depot	Alabama	1383
White Sands Missile Range	New Mexico	1174
Fort Bliss	Texas	1129
Blue Grass Army Depot	Kentucky	1030

While this count of "historic facilities" does not reflect the exact number of historic buildings (a facility can be something other than a building), it does reveal the relative number of historic buildings because most facilities are buildings. Section 3 provides more background information on this data.

3.1 Most prevalent building types

Based on the experiences of CERL's Cultural Resources Branch, the most common building types are (ordered by prevalence):

1. Barracks
2. Hangars
3. Administrative buildings

3.1.1 Barracks

While barracks is the number one building type, most barracks were built during the Cold War (1946-1975). Most of the pre-1946 barracks are now used as administrative buildings. This is a consequence of the space currently required per soldier, and the difficulty to modify these historic structures to meet modern barracks space requirements.

Any barracks built during the Cold War era fall under the DoD's *Program Comment for Cold War Ear Unaccompanied Personnel Housing*, which states that any changes and modifications to these buildings do not require any State Historic Preservation Officer (SHPO) consultation or have a need to meet any Federal preservation standards. Therefore, they are not of interest to this project and were not considered for modeling and analysis.

3.1.2 Hangars

Airfields typically boast a varying number of hangars, usually ranging from four to eight, regardless of whether these structures hold historical significance or not. There are also good examples at Pensacola (and Randolph) of these hangars being used as a Post Exchanges (PXs), Gymnasiums, and administrative buildings.

3.1.3 Administrative facilities

There are many different styles and ages of administrative facilities with a variety of historic statuses (eligible, individually eligible, and not eligible). Pre-1946 barracks are mostly used as administrative buildings now and are almost all are historic. A variety of construction materials were used (brick, stone, wood and concrete). The construction materials used also varied across the services. Most historic hospital buildings are also now used as administrative buildings as well.

3.1.4 Summary

This preliminary characterization of DoD buildings has revealed several general findings:

1. Old barracks (1946-1975) are unlikely to ever be designated as historic buildings.
2. Newer barracks (built after 1975) are not historic buildings due their age.
3. Nearly all pre-1946 barracks are historic buildings and are now administrative buildings.

Based on these findings, information was gathered from several candidate installations where the project team had previously done work. This analysis was done to analyze common types of historical buildings at military installations. Refer to section 3.1.4.5 for further reasoning.

3.1.4.1 Army

Fort Knox, KY, has buildings dating from the Interwar period (between WWI and WWII). The buildings here are mostly constructed out of brick and are multistoried. With 4,602 HDD and 1,421 CDD, the climate at Fort Knox has a good mix of heating and cooling needs.

Fort Leavenworth, KS, has some buildings dating from the pre-Civil War to Interwar periods. These historic buildings are constructed of a mixture of wood, brick, and stone. The team is familiar with approximately nine of these buildings. With 5,177 HDD, 1,590 CDD, the climate at Fort Leavenworth has a good mix of heating and cooling needs.

Fort Riley, KS, contains some buildings dating from the Civil War to the Interwar period, representing a mix of wood, brick, and stone construction. Fort Riley has 5,267 HDD and 1,843 CDD.

Fort Sill, OK, has some buildings dating from the Civil War to the Interwar period, representing a mix of wood, brick, and stone. Fort Sill has 3,523 HDD and 2,831 CDD.

Fort Benning, GA, has 2,643 HDD and 2,242 CDD.

Fort Bliss, TX, contains some buildings dating from the 1880s to the Interwar period, the majority of which are stucco over wood. Fort Bliss has 2,802 HDD and 2,568 CDD.

Fort Huachuca has some buildings dating from 1880 to the Interwar period, all of which are wood barracks from pre-1946 except for one remaining stucco (maybe over terracotta) building.

Fort Drum, NY, has no remaining pre-WWII barracks or administrative buildings.

3.1.4.2 Navy

Pensacola, FL, contains some buildings dating from WWI to the Interwar period, principally hangars and administrative buildings. (Pensacola took over a former Army fort and the barracks are now in Navy use.)

Jacksonville, FL, has buildings (hangars) dating from WWII.

The Norfolk, VA, Naval Base has buildings dating from the 1890s to the Interwar period, principally hangars and administrative buildings.

The Portsmouth, ME, Naval Shipyard has buildings dating from the 19th century, consisting of former industrial space now used as administrative offices.

The Norfolk, VA, Naval Shipyard has some buildings dating mostly from the 19th century, consisting of former industrial space now used as administrative offices.

Naval Base San Diego contains buildings (administrative buildings and hangars) dating from the Interwar period.

Analysis of the RPAD data shows the Navy did not have many pre-WWII barracks.

3.1.4.3 Marines

Quantico, VA, has buildings dating from the Interwar period. These include brick multistory barracks now used as administrative buildings and a few remaining hangars (the oldest of which is now a gymnasium).

Neither Camp Pendleton, CA, nor Camp Lejeune, NC, have any historic buildings.

Parris Island, SC, has buildings dating from the 1880s to WWI, most of which are old Navy industrial buildings now used as administrative buildings.

3.1.4.4 Air Force

Much of the historic infrastructure at Air Force installations consists of buildings that remain from former Army Airfields. The Cold War Air Force bases, built in 1950s, are mostly concrete block buildings.

Fort Sam Houston, TX, contains some buildings dating from the Civil War to the Interwar period. The Air Force base, which was formerly an Army installation, now contains a variety of wood and brick administrative buildings.

Francis E. Warren Air Force Base (AFB), WY, has buildings dating from the 1880s to the Interwar period. The Air Force base, which was formerly an Army installation, now contains brick administrative buildings.

Randolph AFB, TX contains buildings dating from the Interwar period. The Air Force base was formerly an Army Air Corps base.

Maxwell-Gunter AFB, AL has buildings dating from the Interwar period. The Air Force base was formerly an Army Air Corps base.

3.1.4.5 The Selection

Because of the large number of historic buildings in the Army and the project team's familiarity with Army installations, the selection process focused on Army installations. Another factor considered was the number and variety of building construction methods — because the types of EEMs possible depend on the construction method and materials used. The desirable factors considered include:

- active Army installation
- significant heating and cooling needs (based on climate)
- significant number of buildings designated as eligible for historic status
- non-unique facilities

Based on these factors, facilities such as warehouses and vehicle maintenance facilities were eliminated from consideration since they are rarely cooled. Also, while most installations have a historic church, they are used intermittently and are typically unique.

3.2 Selection of an Army installation

The next step in selecting the buildings to be studied was to identify Army installations that had the type of historic buildings of interest. The Headquarters Installation Information System (HQIIS) database was used to develop a list of potential sites to visit. This Army database includes a category code for the historical status of an item. Items not listed as buildings were eliminated from consideration. The list was further sorted to exclude buildings less than 5,000 ft^2 in size. Installations known to CERL's cultural resources people and were relatively close to CERL were searched and a table of prevalent building types was constructed (Table 5).

Table 5 – HQIIS database sorting results for six Midwest installations.

Installation	Administrative Buildings, General Purpose	General Instruction Building	Enlisted Unaccompanied Personnel Housing	Museum	Trainee Bks	Bn HQ* Bldg	HDD	CDD
Leavenworth	32	4	0	1	0	0	5177	1590
Knox	15	1	8	1	30	0	4602	1421
Sill	10	4	19	7	5	8	3523	2831
Benning	11	6	0	0	30	3	2643	2242
Riley	21	1	16	8	0	1	5267	1843
Bragg	14	0	12	2	0	11	2969	2127
Total	103	16	55	19	65	23		

*Battalion (Bn); Headquarters (HQ)

One further criterion sought was the existence of a significant heating and cooling season. This is indicated from historical weather data that are summarized in terms of HDD and CDD. Fort Sill was found to have the highest combined heating and cooling needs, a fair number of historic buildings, and a good mix of historic building types.

The real property database (HQIIS) was studied to narrow down a specific list of buildings to be studied. Some key building characteristics contained in the database include Building Type, Design Use, and Current Use. Unfortunately, nearly every item in every database listed the same code for both Design and Current use. It appears that when a building's Current Use is changed, the Design Use changed to the same value. Six main building types were found in Table 5. Three building types were found to be most prevalent: Administrative General Purpose, Unaccompanied Enlisted Personnel Housing, and Trainee Barracks. Trainee Barracks were prevalent at two of the installations, but virtually non-existent at the others. As expected from the experiences of CERL's Cultural Resources Branch, the Administrative General Purpose were prevalent at all the listed installations. The Unaccompanied Enlisted Personnel Housing were prevalent at most of the sites. The six building types were selected based on the available data and consultations with the sponsor.

4 Fort Sill and Buildings Modeled

Fort Sill remains the only active Army installation of all the forts on the South Plains built during the Indian Wars. There were several major construction periods at Fort Sill Military Reservation during the 20th century: the New Post construction period, ca. 1909-1911; the World War I mobilization construction period, ca.1917; the Academic area construction period, ca. 1933-1938; and the World War II mobilization construction period, 1939-1945. The last of these four construction phases, the World War II mobilization construction period, is addressed in this historic context. A vast amount of construction was carried out across the Nation from 1939 to 1945, defined by John S. Garner as the years of World War II mobilization construction (Garner 1993. Smith 1970). War-related construction included the completion of both the Command Facilities, “designed for use in the actual maintenance and operation of the Army, rather than for purposes of procurement,” and the Industrial Facilities, built to produce war materiel.

4.1 Building descriptions

4.1.1 Bldg. 441

Figure 2. Bldg. 441.

Table 6. Bldg. 441 details.

Parameter	Measure
Year Built	1870
Square Footage (ft^2)	10,614
# of Stories	1 + ½ basement
Original Use	
Current Use	Museum

Parameter	Measure
Envelope	
Roof	
Construction	Wood Frame (24 in o.c. est.), Shingles
Insulation type and thickness	None (est.)
Wall	
Construction	Stone (10 in.)
Insulation type/thickness/location	None
Floor/Basement	
Construction	Crawlspace/basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Single Pane, Wood Frame, Tint
Gross % of wall area (Overall)	10.2%
Occupancy	
Current Use	Museum
Hours	0700-1700 M-F
Average # of Occupants (if available)	Not Applicable (N/A)
HVAC	
Heating System	Air Source Heat Pumps
Cooling System	Air Source Heat Pumps
Domestic Hot Water System	Natural Gas Fired, 30 Gallon Tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	T8 with some T12, Exhibits are light emitting diode (LED) and incandescent
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

Bldg. 441 was originally built as a barracks for cavalry soldiers. At one point in time, the basement was used as a prison. Bldg. 441 is now a museum that has intermittent open hours but is occupied regularly from 8 a.m. to 5 p.m. by staff who care for the contents, set up displays, and perform the other tasks necessary to keep the museum running.

4.1.2 Bldg. 462

Figure 3. Bldg. 462.

Table 7. Bldg. 462 details.

Parameter	Measure
Year Built	1935
Square Footage ft^2	33,425
# of Stories	3 + basement
Original Use	
Current Use	Administrative
Envelope	
Roof	
Construction	Wood Frame (24 in o.c. est.), clay tiles
Insulation type and thickness	R-13 batt, no rad barrier
Wall	
Construction	Concrete masonry unit (12 in.)
Insulation type/thickness/location	None
Floor/Basement	
Construction	Basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Single Pane, Wood Frame, Clear Double Pane, Aluminum Frame, Clear Single Pane, Aluminum Frame, Clear
Gross % of wall area (Overall)	26.9%
Occupancy	
Current Use	Administrative

Parameter	Measure
Hours	0700-1700 M-F
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Hot Water Coils
Cooling System	Chilled Water Coils
Domestic Hot Water System	Natural Gas Fired, 191 Gallon Tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	Unknown
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

4.1.3 Bldg. 463

Figure 4. Bldg. 463.

Table 8. Bldg. 463 details.

Parameter	Measure
Year Built	1913
Square Footage ft^2	18,170
# of Stories	2 + basement
Original Use	
Current Use	Administrative
Envelope	

Parameter	Measure
Roof	
Construction	Wood Frame, Clay tiles
Insulation type and thickness	None
Wall	
Construction	Concrete Masonry Unit (12 inches)
Insulation type/thickness/location	Solid Grouted
Floor/Basement	
Construction	Crawlspace/basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Double Pane, Aluminum Frame, Clear Double Pane, Aluminum Frame, Tint
Gross % of wall area (Overall)	47.3%
Occupancy	
Current Use	Administrative
Hours	0800-1700 M-F
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Hot Water Coils and Boiler
Cooling System	Chilled Water Coils and Chiller
Domestic Hot Water System	Natural Gas Fired, 28 Gallon Tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	T8 with some T12, Exhibits are LED/INC*
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches
* Light Emitting Diode/Incandescent (LED/INC)	

4.1.4 Bldg. 750

Figure 5. Bldg. 750.

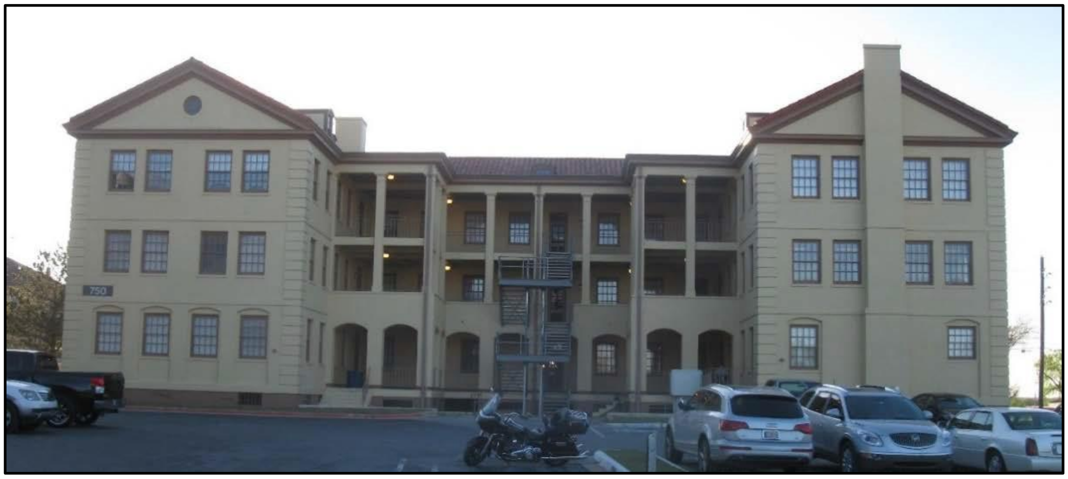


Table 9. Bldg. 750 details.

Parameter	Measure
Year Built	1934
Square Footage ft^2	38,480
# of Stories	3 + basement
Original Use	
Current Use	Administrative
Envelope	
Roof	
Construction	Wood Frame, Clay tile
Insulation type and thickness	None
Wall	
Construction	Concrete Masonry Unit (12 in. est.)
Insulation type/thickness/location	Solid Grouted
Floor/Basement	
Construction	Basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Single Pane, Wood Frame, Clear
Gross % of wall area (Overall)	36.4%
Occupancy	
Current Use	Administrative
Hours	0700-1700 M-F

Parameter	Measure
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Hot Water Coils
Cooling System	Chilled Water Coils
Domestic Hot Water System	Natural Gas Fired, 116 Gallon Tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	T8 with some T12, Exhibits are LED/INC
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

4.1.5 Bldg. 1803

Figure 6. Bldg. 1803.

Table 10. Bldg. 1803 details.

Parameter	Measure
Year Built	1939
Square Footage ft^2	8,076
# of Stories	2 + ½ basement
Original Use	Bakery
Current Use	Administrative
Envelope	
Roof	
Construction	Wood Frame, clay tiles
Insulation type and thickness	None
Wall	
Construction	Stone

Parameter	Measure
Insulation type/thickness/location	None
Floor/Basement	
Construction	Crawlspace
Insulation type/thickness/location	None (est.)
Windows	
Glazing/Frame/Features	Single Pane, Aluminum Frame
Gross % of wall area (Overall)	20.1%
Occupancy	
Current Use	Administrative
Hours	0800-1700 M-F
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Ground Source Heat Pumps
Cooling System	Ground Source Heat Pumps
Domestic Hot Water System	Natural Gas Fired, 17 Gallon Tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	T8 with some T12, Exhibits are LED/INC
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

Bldg. 1803 was originally built as a bakery (Rushing, 1997). Bldg. 1803 is now a general administrative building that operates from Monday through Friday, 0800 to 1700.

4.1.6 Bldg. 3419

Table 11. Bldg. 3419 details.

Parameter	Measure
Year Built	1954
Square Footage ft^2	37,735
# of Stories	3 + basement
Original Use	
Current Use	Administrative
Envelope	
Roof	
Construction	Concrete (4 in.)
Insulation type and thickness	None
Wall	
Construction	Concrete Masonry Unit (12 in. est.)
Insulation type/thickness/location	None
Parameter	Measure
Floor/Basement	
Construction	Basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Double Pane, Aluminum Frame, Clear
Gross % of wall area (Overall)	12.0%
Occupancy	
Current Use	Administrative
Hours	0700-1800 M-F
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Hot Water Coils
Cooling System	Chilled Water Coils
Domestic Hot Water System	Natural Gas Fired, 149 Gallon Tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	T8 with some T12, Exhibits are LED/INC
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

4.2 Approach to finding and evaluating ECMs

Researchers initiated the analysis by modeling the buildings in their current state, reviewing the modeled energy use, and comparing it to metered data in cases where reliable metered data was available. When metered data was accessible, researchers utilized Fiscal Year 2015 (FY15) data. For the energy modeling process, researchers employed eQUEST, which utilizes a 30-year average climate data. Upon comparing the 30-year weather data with FY15 weather data, researchers discovered that FY15 had 16% more CDD (a measure of required cooling) and 4% fewer HDD (a measure of required heating).

Unfortunately, several of the modeled buildings lacked metered data or possessed unreliable data. In such instances, researchers assessed the reasonableness of the results using a typical Energy Use Index (EUI). EUI represents a building's annual energy use per area of building envelope and varies based on factors such as building use and climate zone. To obtain average EUIs that closely matched the modeled buildings, researchers referred to a database of EUIs derived from the 2003 Commercial Buildings Energy Consumption Survey (CBECS). Parameters like age, current use, HDD, and CDD were taken into consideration to determine a typical EUI for each building type. The modeling results are summarized in Table 12.

Next, researchers evaluated the building models to identify retrofits that had already been implemented, affecting energy use and likely not applied to similar buildings. Retrofits suspected to have been unique to the modeled building were removed from the models. This approach ensured that potential energy-saving measures would not be disregarded for other buildings solely because they had already been implemented in the specific building under consideration.

On the other hand, retrofits that were likely to have been applied to most buildings were retained in the "Original State" model. For instance, many historic buildings were not initially equipped with air-conditioning, but if they currently serve as administrative buildings, they are more likely to have undergone retrofitting to include air-conditioning.

Thirdly, researchers integrated ECMs into the models and assessed them based on their potential energy and cost savings to identify the most economically viable options. Specifically, researchers only evaluated measures that could be realistically implemented on historic structures. For instance, researchers did not assess exterior insulation, as it may not be suitable for such buildings.

The fourth and final step in the modeling process involved evaluating the models for different climate zones. This step allowed researchers to consider the performance and suitability of the models under varying climatic conditions.

Throughout the evaluation process, utility rates reflecting the average DoD cost were utilized. The rates considered were $0.0939/kWh for electricity and $0.7780/therm for natural gas, as indicated in the DoD Energy Management Report of 2015.

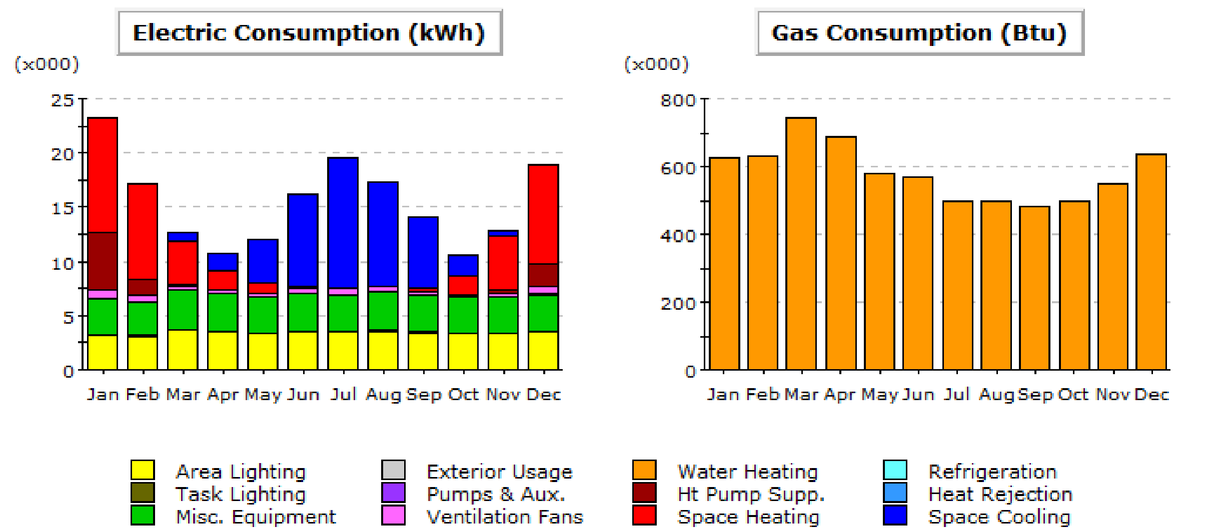
4.2.1 Bldg. 441 energy use – "as is"

An eQUEST model was created for the building in its current state and the building energy use was simulated. Figure 7 shows the results.

Table 12. EUI of various buildings – "as is."

Bldg	Current Use	ft²	Electric			Gas			Total MMBtu Billed	Total MMBtu Simulated	KBtu/ft² Billing	EUI Simulated KBtu/ft²	EUI Typical KBtu/ft²	EUI % Difference
			Billed (kWh)	Simulation (kWh)	Delta	Billed (MMBtu)	Simulation (MMBtu)	Delta						
441	Museum	10,614	215,826	188,070	13%		7	#DIV/0!	736	649	69	61	57	7%
462	Admin	33,425	960,451	493,720	49%	19,178	1,057	94%	22,455	2,742	672	82	81	1%
463	Admin	18,170	48,337	287,610	-495%		887	#DIV/0!	165	1,868	9	103	53	48%
750	Admin	38,480	143,347,745	688,580	100%	73	230	-213%	489,176	2,579	12712	67	81	-21%
1803	Admin (Contracting)	8,076	72,484	95,640	-32%	115	7	94%	363	334	45	41	47	-14%
3419	Battalion HQ (Barracks now Admin)	37,735	No data	367,880	#VALUE!		841	#DIV/0!	#VALUE!	2,097	#VALUE!	56	82	-48%

Figure 7. Bldg 441 "as is" annual energy use.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.00	0.01	0.88	1.61	4.08	8.47	11.94	9.54	6.48	1.93	0.46	0.01	45.41
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	10.59	8.69	4.02	1.80	0.90	0.10	-	0.03	0.29	1.82	4.98	9.21	42.23
HP Supp.	5.33	1.47	0.08	0.00	-	-	-	-	-	0.01	0.37	2.12	9.39
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.76	0.80	0.33	0.21	0.30	0.48	0.66	0.54	0.39	0.21	0.38	0.68	5.53
Pumps & Aux.	0.02	0.02	0.01	0.00	0.00	-	-	-	-	0.00	0.02	0.03	0.11
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	3.33	3.15	3.63	3.49	3.41	3.49	3.48	3.56	3.42	3.41	3.34	3.48	41.19
Task Lights	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.24
Area Lights	3.17	3.12	3.73	3.57	3.31	3.57	3.45	3.59	3.43	3.31	3.29	3.45	40.95
Total	23.22	17.08	12.70	10.71	12.01	16.14	19.55	17.27	14.02	10.51	12.86	18.99	188.07

Gas Consumption (Btu x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	624.9	631.6	743.7	689.7	580.3	570.0	497.6	496.4	482.0	496.6	548.5	633.9	6,995.2
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	624.9	631.6	743.7	689.7	580.3	570.0	497.6	496.4	482.0	496.6	548.5	633.9	6,995.2

The simulated annual energy use for Bldg. 441 is 188,070 kWh/year of electricity and 7 MMBtu/year of gas. With 10,614 ft^2 of envelope area, this equates to an EUI of 60 kBtu/ft^2/yr. According to the CBECS survey, the typical EUI for this building type in this climate is 57 kBtu/ft^2/yr. Seeing that the typical EUI is 57 kBtu/ft^2/yr and the simulation produces an EUI of 60 kBtu/ft^2/yr, this is a good correlation which indicates accuracy of the eQUEST model.

4.2.2 Bldg. 462 energy use – "as is"

The simulated annual energy use for Bldg. 462 is 493,720 kWh/year of electricity and 1,057.3 MMBtu/year of gas. With 33,425 ft^2 of envelope area, this equates to an EUI of 82 kBtu/ft^2/yr. According to the CBECS survey, the typical EUI for this building type in this climate is 81 kBtu/ft^2/yr. This is a good correlation and close enough to make the model feasible.

4.2.3 Bldg. 463 energy use – "as is"

The simulated annual energy use for Bldg. 463 is 287,610 kWh/year of electricity and 887 MMBtu/year of gas. With 18,170 ft^2 of envelope area, this equates to an EUI of 103 kBtu/ft^2/yr. According to the CBECS survey, the typical EUI for this building type in this climate is 53 kBtu/ft^2/yr, a significant difference. There are many reasons for this large difference. The building currently has virtually no insulation, a clay roof, and masonry walls. The cooling system energy usage is also relatively high at 1.3 kW/ton. So, while the modeled energy use was different than initially expected, it is believed to be an accurate model.

4.2.4 Bldg. 750 energy use – "as is"

The simulated annual energy use for Bldg. 750 is 688,580 kWh/year of electricity and 229.9 MMBtu/year of gas. With 38,480 ft^2 of envelope area, this equates to an EUI of 67 kBtu/ft^2/yr. According to the CBECS survey, the typical EUI for this building type in this climate is 81 kBtu/ft^2/yr. This can be partially explained by the upgraded HVAC system that is likely more efficient than the typical system in this building type. This is considered close enough to make the model feasible.

4.2.5 Bldg. 1803 energy use – "as is"

The simulated annual energy use for Bldg. 1803 is 95,640 kWh/year of electricity and 7.17 MMBtu/year of gas. With 8,076 ft^2 of envelope area, this equates to an EUI of 41 kBtu/ft^2/yr. According to the CBECS survey, the typical EUI for this building type in this climate is 47 kBtu/ft^2/yr. This is considered close enough to make the model feasible.

4.2.6 Bldg. 3419 energy use – "as is"

The simulated annual energy use for Bldg. 3419 is 367,880 kWh/year of electricity and 841.31 MMBtu/year of gas. With 37,735 ft^2 of envelope area, this equates to an EUI of 56 kBtu/ft^2/yr. According to the CBECS survey, the typical EUI for this building type in this climate is 82 kBtu/ft^2/yr. This is a 48% difference. The reason for this is that Bldg. 3419 has been recently renovated with many energy savings features. So, while the modeled energy use was different than initially expected, it is believed to be an accurate model.

4.3 The building model results – "Original State"

The buildings were then modeled to reflect the state that they would have been expected to be in for the original construction. The model left retrofits that would have had to have been done to maintain the building in a useful state. Retrofits that were done to save energy were removed from the model so that the effect could be evaluated to other buildings of the same type. The most significant changes made to return the buildings to their "original state" were:

- no scheduling of mechanical equipment to be on or off during specific hours, which can save energy throughout the day.
- no unoccupied setback of temperatures, which can heat/cool buildings depending on occupancy throughout the day, saving energy.
- less efficient heating and cooling equipment.

4.3.1 Bldg. 441 energy use – "Original State"

The simulated annual energy use for Bldg. 441 is 621,745 kWh/year of electricity and 42.4 MMBtu/year of gas. With 10,614 ft^2 of envelope area, this equates to an EUI of 204 kBtu/ft^2/yr.

4.3.2 Bldg. 462 energy use – "Original State"

The simulated annual energy use for Bldg. 462 is 959,081 kWh/year of electricity and 3,298.4 MMBtu/year of gas. With 33,425 ft^2 of envelope area, this equates to an EUI of 197 kBtu/ft^2/yr.

4.3.3 Bldg. 463 energy use – "Original State"

The simulated annual energy use for Bldg. 463 is 1,960,400 kWh/year of electricity and 4,937.3 MMBtu/year of gas. With 18,170 ft^2 of envelope area, this equates to an EUI of 640 kBtu/ft^2/yr.

4.3.4 Bldg. 750 energy use – "Original State"

The simulated annual energy use for Bldg. 750 is 1,442,616 kWh/year of electricity and 1,171 MMBtu/year of gas. With 38,480 ft^2 of envelope area, this equates to an EUI of 158 kBtu/ft^2/yr.

4.3.5 Bldg. 1803 energy use – "Original State"

The simulated annual energy use for Bldg. 1803 is 450,660 kWh/year of electricity and 2,765 MMBtu/year of gas. With 8,076 ft^2 of envelope area, this equates to an EUI of 533 kBtu/ft^2/yr.

4.3.6 Bldg. 3419 energy use – "Original State"

The simulated annual energy use for Bldg. 3419 is 1,127,300 kWh/year of electricity and 4,857.4 MMBtu/year of gas Table 13). With 37,735 ft^2 of envelope area, this equates to an EUI of 231 kBtu/ft^2/yr.

Table 13. Summary of "as is" and original energy use.

	As Is			Original State		
Building	Electric Use (kWh)	Gas Use (MMBtu)	EUI (kBtu/ft^2/yr)	Electric Use (kWh)	Gas Use (MMBtu)	EUI (kBtu/ft^2/yr)
441	188,070	7	61	621,745	42	204
462	493,720	1,057	82	959,081	3,298	197
463	287,610	887	103	1,960,400	4,937	640
750	688,580	230	67	1,442,616	1,171	158
1803	95,640	7	41	450,660	2,765	533
3419	367,880	841	56	1,127,300	4,857	231

4.4 Energy efficiency measures

When contemplating an energy conservation retrofit for a historic building, it is valuable to consult the report from the past Legacy Project 11-382 (Cherry/See/Reames Architects) titled "Design Guidelines for Implementing Energy Efficiency Strategies in Historic Properties." This report serves as a reliable reference for determining the appropriateness of potential retrofits. Initially, several measures were considered for all buildings. Subsequently, those measures that appeared practical for a specific building were simulated using the "Original" building model, which was modified to include the EEMs. The simulations allowed for the calculation of potential energy savings resulting from the implementation of the EEMs. It is important to note that the EEMs for the Fort Sill buildings were run independently, without considering interactions between the measures. Consequently, if multiple measures are performed simultaneously, the actual total savings might be lower than initially predicted. It is important to note that the specific EEMs for each building were selected based on the specific needs of that building.

For cost estimation, data from RS Means was used. Most of the costs were sourced from Commercial Renovation Cost Data 2014, with an annual increase rate of 3% (Keller):

- infiltration reduction
  - windows
  - doors
  - penetrations
- lighting fixture/lamp improvements
- lighting controls
- wall insulation
- roof/attic insulation
- replacement of mechanical equipment
- add storm windows
- add roof/ceiling insulation
- programmable thermostat
- duct and pipe insulation
- awning/shading
- PV cells
- solar hot water
- replace mechanical equipment controls
- PV panels

4.4.1 Bldg. 441 EEM Descriptions, implementation costs and savings by climate zone

The EEMs chosen for Bldg. 441 were:

- **Reduce Infiltration by weatherstripping windows and doors**. Air flow changed from 2.00 air changes per hour (ACH) to 1.00 ACH. The implementation cost was calculated from 66 windows that are 3.16 x 5.33 ft, two doors that are 6.5 x 7.1 ft, and six doors that are 6 x 3 ft for a total of 1,251 ft of weatherstripping, at a cost of $4.41/ft for a total of $5,517.
- **Wall Insulation**. Add 2 in. polystyrene (R-8) exterior board insulation to the exterior building walls, where previously there was no insulation. The cost of installing the insulation was estimated using RSMeans. At $1.62/ft^2 and a wall area of approximately 10,614 ft^2, the total estimated cost is $17,232.
- **Roof/Attic Insulation**. Add R-38 batt insulation plus radiant barrier

to the roof, where previously there was no insulation. The implementation cost was calculated from 10,614 sq. ft. of the building. The cost of the insulation was found to be $1.93/ft^2 in 2014, to which an escalation of 3% per year was added.

- **Replace Mechanical Equipment Controls**. Change the building from an occupancy of 24 hours per day seven days a week to an occupancy of 0700-1700 Monday-Friday, and unoccupied Saturday-Sunday and on Holidays. Also change the temperature setpoints from occupied and unoccupied cooling and heating of 76 and 74 °F, to occupied cooling and heating of 78 and 68 °F and unoccupied cooling and heating of 85 and 55 °F, respectively. The HVAC system fans were set to operate 2 hours before open and 2 hours after close of the building. The fans were set to cycle at night with no Outside Air, to cycle on via Control Zones only, and to have the capability to operate in a continuous ON mode. When the fan's ON mode is set to continuous, the fan is run continuously during on periods, as opposed to only when heating or cooling is needed.

Six thermostats (one for each heat unit) can be used to achieve the above recommendations. A cost of $300 for the thermostat and 2 hours ($80/hr) of fixed labor is assumed for a total cost of $2760.

The model was then run for each EEM in each of the different climate zones using eQUEST. The results are listed in Tables 14-28 and shown in Figures 8-15.

Table 14. Bldg. 441, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	9,565	0	$898	$5,516.38	6.1
Wall Insulation	-914	0	-$86	$17,232	-200.8
Roof/Attic Insulation	10,234	0	$961	$27,429.44	28.5
Replace Mechanical Equipment Controls	319,071	-1	$29,953	$2,760	0.2
Total	337,956	-1	$31,726	$55,469.82	1.7

Table 15. Bldg. 441, savings and payback summary, **Climate Zone 2A (Houston, TX).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	28,936	0	$2,717	$5,516	2.0
Wall Insulation	30,304	0	$2,846	$17,232	6.1
Roof/Attic Insulation	13,127	0	$1,233	$27,429	22.3
Replace Mechanical Equipment Controls	304,643	-1	$28,598	$2,760	0.1
Total	377,010	-1	$35,393	52,938	1.5

Table 16. Bldg. 441, savings and payback summary, **Climate Zone 2B (Phoenix, AZ).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	19,407	0	$1,822	$5,516	3.0
Wall Insulation	18,799	0	$1,765	$17,232	9.8
Roof/Attic Insulation	15,076	0	$1,416	$27,429	19.4
Replace Mechanical Equipment Controls	276,966	-1	$25,999	$2,760	0.1
Total	330,248	-1	$31,003	52,938	1.7

Table 17. Bldg. 441, savings and payback summary, **Climate Zone 3A (Memphis, TN).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	33,763	0	$3,170	$5,516	1.7
Wall Insulation	39,153	0	$3,676	$17,232	4.7
Roof/Attic Insulation	14,391	0	$1,351	$27,429	20.3
Replace Mechanical Equipment Controls	308,351	-1	$28,946	$2,760	0.1
Total	395,658	-1	$37,145	52,938	1.4

Table 18. Bldg. 441, savings **and** payback summary, **Climate Zone 3B (El Paso, TX).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	20,356	0	$1,911	$5,516	2.9
Wall Insulation	22,540	0	$2,117	$17,232	8.1
Roof/Attic Insulation	15,246	0	$1,432	$27,429	19.2
Replace Mechanical Equipment Controls	271,602	-1	$25,496	$2,760	0.1
Total	329,744	-1	$30,955	52,938	1.7

Table 19. Bldg. 441, savings and payback summary, **Climate Zone 3C (San Francisco, CA).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	17,387	0	$1,633	$5,516	3.4
Wall Insulation	18,674	0	$1,753	$17,232	9.8
Roof/Attic Insulation	4,644	0	$436	$27,429	62.9
Replace Mechanical Equipment Controls	230,372	-1	$21,624	$2,760	0.1
Total	271,077	-1	$25,446	52,938	2.1

Table 20. Bldg. 441, savings **and** payback summary, **Climate Zone 4A (Baltimore, MD).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	38,851	0	$3,648	$5,516	1.5
Wall Insulation	46,040	0	$4,323	$17,232	4.0
Roof/Attic Insulation	18,075	0	$1,697	$27,429	16.2
Replace Mechanical Equipment Controls	319,336	-1	$29,978	$2,760	0.1
Total	422,302	-1	$39,646	52,938	1.3

Table 21. Bldg. 441, savings and payback summary, **Climate Zone 4B (Albuquerque, NM).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	25,903	0	$2,432	$5,516	2.3
Wall Insulation	34,426	0	$3,233	$17,232	5.3
Roof/Attic Insulation	21,181	0	$1,989	$27,429	13.8
Replace Mechanical Equipment Controls	312,257	-1	$29,313	$2,760	0.1
Total	393,767	-1	$36,967	52,938	1.4

Table 22. Bldg. 441, savings and payback summary, **Climate Zone 4C (Seattle, WA).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	28,971	0	$2,720	$5,516	2.0
Wall Insulation	36,954	0	$3,470	$17,232	5.0
Roof/Attic Insulation	16,039	0	$1,506	$27,429	18.2
Replace Mechanical Equipment Controls	281,353	-1	$26,411	$2,760	0.1
Total	363,317	-1	$34,108	52,938	1.6

Table 23. Bldg. 441, savings and payback summary, **Climate Zone 5A (Chicago, IL).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	48,056	0	$4,512	$5,516	1.2
Wall Insulation	61,384	0	$5,764	$17,232	3.0
Roof/Attic Insulation	23,065	0	$2,166	$27,429	12.7
Replace Mechanical Equipment Controls	357,152	-1	$33,529	$2,760	0.1
Total	489,657	-1	$45,971	52,938	1.2

Table 24. Bldg. 441, savings and **payback** summary, **Climate Zone 5B (Colorado Springs, CO).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	30,941	0	$2,905	$5,516	1.9
Wall Insulation	51,408	0	$4,827	$17,232	3.6
Roof/Attic Insulation	24,743	0	$2,323	$27,429	11.8
Replace Mechanical Equipment Controls	367,934	-1	$34,541	$2,760	0.1
Total	475,026	-1	$44,597	52,938	1.2

Table 25. Bldg. 441, savings and payback **summary**, **Climate Zone 6A (Burlington, VT).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	59,456	0	$5,583	$5,516	1.0
Wall Insulation	72,086	0	$6,769	$17,232	2.5
Roof/Attic Insulation	27,086	0	$2,543	$27,429	10.8
Replace Mechanical Equipment Controls	389,282	-1	$36,546	$2,760	0.1
Total	547,910	-1	$51,441	52,938	1.0

Table 26. Bldg. 441, savings and payback summary, **Climate Zone 6B (Helena, MT).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	49,461	0	$4,644	$5,516	1.2
Wall Insulation	67,896	0	$6,375	$17,232	2.7
Roof/Attic Insulation	29,256	0	$2,747	$27,429	10.0
Replace Mechanical Equipment Controls	385,012	-1	$36,145	$2,760	0.1
Total	531,625	-1	$49,912	52,938	1.1

Table 27. Bldg. 441, savings and payback summary, **Climate Zone 7A (Duluth, MN).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	72,028	0	$6,763	$5,516	0.8
Wall Insulation	96,047	0	$9,019	$17,232	1.9
Roof/Attic Insulation	37,469	0	$3,518	$27,429	7.8
Replace Mechanical Equipment Controls	449,935	-1	$42,241	$2,760	0.1
Total	655,479	-1	$61,542	52,938	0.9

Table 28. Bldg. 441, savings and payback summary, **Climate Zone 8A (Fairbanks, AK).**

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	112,783	0	$10,590	$5,516	0.5
Wall Insulation	134,468	0	$12,627	$17,232	1.4
Roof/Attic Insulation	61,208	0	$5,747	$27,429	4.8
Replace Mechanical Equipment Controls	579,040	-1	$54,364	$2,760	0.1
Total	887,499	-1	$83,328	52,938	0.6

Figure 8. Bldg. 441, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

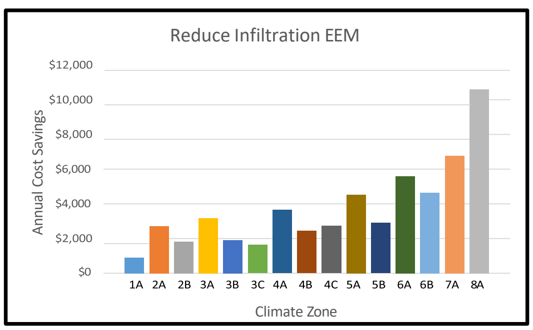


Figure 9. Bldg. 441, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

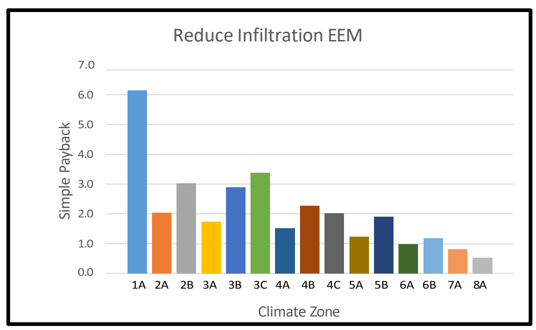


Figure 10. Bldg. 441, annual cost savings resulting from EEM "Wall Insulation," by climate zone.

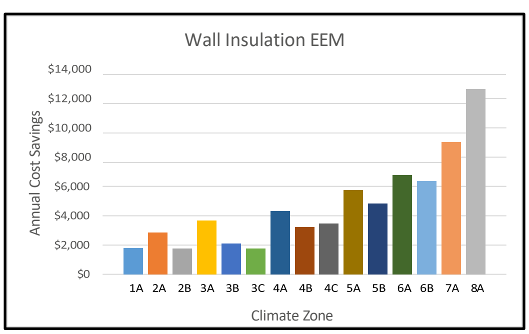


Figure 11. Bldg. 441, simple payback resulting from EEM "Wall Insulation," by climate zone.

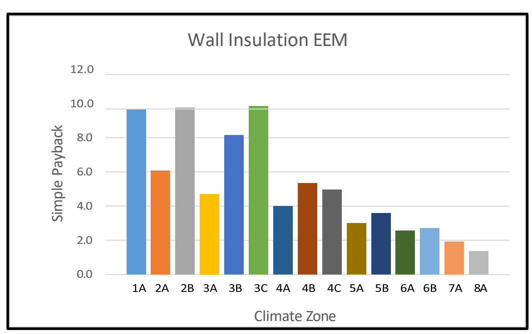


Figure 12. Bldg. 441, annual cost savings resulting from EEM “Roof/Attic Insulation,” by climate zone.

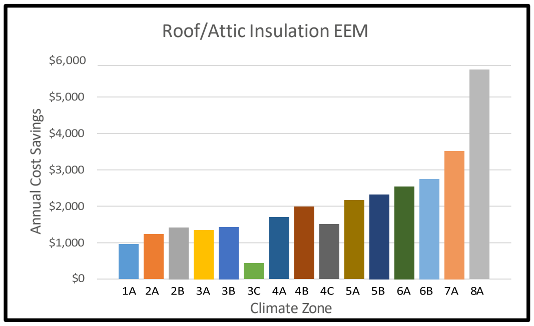


Figure 13. Bldg. 441, simple payback resulting from EEM “Roof/Attic Insulation,” by climate zone.

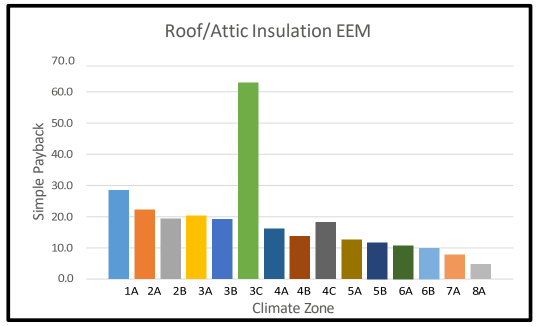


Figure 14. Bldg. 441, annual cost savings resulting from EEM “Replace Mechanical Equipment Controls EEM,” by climate zone.

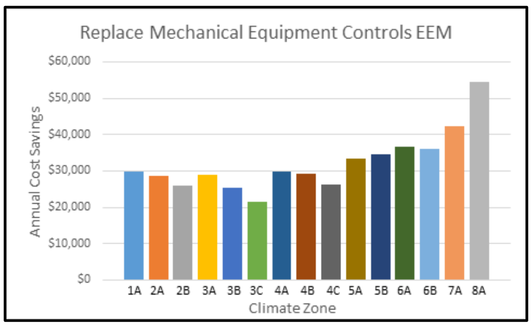
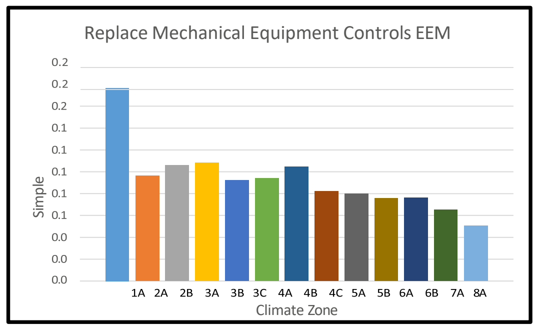


Figure 15. Bldg. 441, simple payback resulting from EEM “Replace Mechanical Equipment Controls EEM,” by climate zone.



4.4.2 Bldg. 462 EEM savings by climate zone

The EEMs chosen for Bldg. 462 were:

- **Reduce Infiltration**. Infiltration of the building was changed from 2.00 ACH to 1.00 ACH. The implementation cost was calculated from 48 windows that are 4 x 7 ft, 143 windows that are 3.33 x 4.17 ft, and 15 doors that are 3 x 6 ft for a total of 3381 ft of weatherstripping, at a cost of $4.41/ft.
- **Roof/Attic Insulation**. Add R-38 batt insulation plus radiant barrier to the roof, where previously there was no insulation. The cost of this insulation was estimated using RSMeans. The cost of the insulation was found to be $1.93/ft^2 in 2014, to which an escalation of 3% per year was added. With 8,076 ft^2 of roof/attic area, the estimated cost is $17,117.
- **Replace Mechanical Equipment**. Replace the building’s 88% efficiency boiler with a boiler that is 95% efficient. Using RSMeans, the costs to replace a 2,000 MBH boiler, is estimated at $29,900 for equipment and $7,475 for labor, summing to a total cost of $37,375.

- **Replace Mechanical Equipment Controls**. Change the building from an occupancy of 24 hours per day seven days a week to an occupancy of 0700-1700 Monday-Friday, and unoccupied Saturday-Sunday and on Holidays. It also changed the temperature setpoints from occupied and unoccupied cooling and heating of 74 and 72 °F, to occupied cooling and heating of 78 and 68 °F and unoccupied cooling and heating of 85 and 55 °F, respectively. The HVAC system fans were set to operate 2 hours before open and 2 hours after close of the building.
  A time clock for each air handling unit (AHU) and labor can be used to achieve the above recommendations. A cost of $3,900 for the time clock and $1,392 of fixed labor (based on previous experience) was assumed. For the three AHUs, this is a total cost of $15,876.
- **Lighting Controls.** Energy audits of this facility indicated a large number of open areas that had potential for savings via occupancy sensors. A cost of $0.95/ft² was used based on Zhang et al. (2013). With a facility area of 33,425 ft², the estimated cost is $31,754.

The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 29-43 and shown in Figures 16-25.

Table 29. Bldg. 462, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	35,677	45	$3,700	$14,910.21	4.0
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	1,669	0	$157	$17,117.41	109.2
Replacement of Mechanical Equipment	0	48	$373	$37,375	100.1
Replace Mechanical Equipment Controls	519,582	618	$53,597	$15,876	0.3
Total	569,285	711	$58,987	$117,032.37	2.0

Table 30. Bldg. 462, savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	56,341	457	$8,846	$14,910	1.7
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	1,331	6	$172	$17,117	99.7
Replacement of Mechanical Equipment	0	142	$1,105	$37,375	33.8
Replace Mechanical Equipment Controls	462,042	1,393	$54,223	$15,876	0.3
Total	532,071	1,998	$65,506	117,032	1.8

Table 31. Bldg. 462, savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	29,021	234	$4,546	$14,910	3.3
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	3,339	10	$391	$17,117	43.7
Replacement of Mechanical Equipment	0	104	$809	$37,375	46.2
Replace Mechanical Equipment Controls	445,698	1,102	$50,425	$15,876	0.3
Total	490,415	1,450	$57,331	117,032	2.0

Table 32. Bldg. 462, savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	74,264	808	$13,260	$14,910	1.1
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	1,146	9	$178	$17,117	96.4
Replacement of Mechanical Equipment	0	218	$1,696	$37,375	22.0
Replace Mechanical Equipment Controls	437,607	1,983	$56,519	$15,876	0.3
Total	525,374	3,018	$72,813	117,032	1.6

Table 33. Bldg. 462, savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	29,578	424	$6,076	$14,910	2.5
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	2,090	11	$282	$17,117	60.7
Replacement of Mechanical Equipment	0	159	$1,237	$37,375	30.2
Replace Mechanical Equipment Controls	389,094	1,544	$48,548	$15,876	0.3
Total	433,119	2,138	$57,304	117,032	2.0

Table 34. Bldg. 462, savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	26,781	628	$7,401	$14,910	2.0
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	574	12	$147	$17,117	116.2
Replacement of Mechanical Equipment	0	201	$1,564	$37,375	23.9
Replace Mechanical Equipment Controls	318,221	1,855	$44,313	$15,876	0.4
Total	357,933	2,696	$54,585	117,032	2.1

Table 35. Bldg. 462, savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	81,510	1,094	$16,165	$14,910	0.9
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	1,660	9.1	$227	$17,117	75.5
Replacement of Mechanical Equipment	0	309	$2,404	$37,375	15.5
Replace Mechanical Equipment Controls	414,817	2,613	$59,280	$15,876	0.3
Total	509,344	4,107	$79,780	117,032	1.5

Table 36. Bldg. 462, savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	34,966	631	$8,192	$14,910	1.8
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	1,261	9	$188	$17,117	90.8
Replacement of Mechanical Equipment	0	231	$1,797	$37,375	20.8
Replace Mechanical Equipment Controls	356,946	2,015	$49,194	$15,876	0.3
Total	405,530	2,886	$60,532	117,032	1.9

Table 37. Bldg. 462, savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	38,440	809	$9,904	$14,910	1.5
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	531	12	$143	$17,117	119.5
Replacement of Mechanical Equipment	0	274	$2,132	$37,375	17.5
Replace Mechanical Equipment Controls	330,218	2,233	$48,380	$15,876	0.3
Total	381,546	3,328	$61,719	117,032	1.9

Table 38. Bldg. 462, savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	141,630	1,801	$27,311	$14,910	0.5
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	465	10	$121	$17,117	140.9
Replacement of Mechanical Equipment	0	443	$3,447	$37,375	10.8
Replace Mechanical Equipment Controls	465,678	3,637	$72,023	$15,876	0.2
Total	620,130	5,891	$104,062	117,032	1.1

Table 39. Bldg. 462, savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	96,944	1,329	$19,443	$14,910	0.8
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	579	13	$156	$17,117	110.1
Replacement of Mechanical Equipment	0	368	$2,863	$37,375	13.1
Replace Mechanical Equipment Controls	402,490	3,150	$62,301	$15,876	0.3
Total	512,370	4,860	$85,922	117,032	1.4

Table 40. Bldg. 462, savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	143,854	1,950	$28,679	$14,910	0.5
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	354	13	$134	$17,117	127.4
Replacement of Mechanical Equipment	0	488	$3,797	$37,375	9.8
Replace Mechanical Equipment Controls	454,676	3,872	$72,818	$15,876	0.2
Total	611,241	6,323	$106,588	117,032	1.1

Table 41. Bldg. 462, savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	134,638	1,835	$26,919	$14,910	0.6
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	736	26	$271	$17,117	63.1
Replacement of Mechanical Equipment	0	473	$3,680	$37,375	10.2
Replace Mechanical Equipment Controls	439,507	3,797	$70,810	$15,876	0.2
Total	587,238	6,131	$102,841	117,032	1.1

Table 42. Bldg. 462, savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	160,431	2,286	$32,850	$14,910	0.5
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	153	12	$108	$17,117	158.9
Replacement of Mechanical Equipment	0	608	$4,730	$37,375	7.9
Replace Mechanical Equipment Controls	489,107	4,778	$83,100	$15,876	0.2
Total	662,048	7,684	$121,948	117,032	1.0

Table 43. Bldg. 462, savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	211,423	3,141	$44,290	$14,910	0.3
Lighting Controls	12,357		$1,160	$31,754	27.4
Roof/Attic Insulation	-1,040	32	$151	$17,117	113.1
Replacement of Mechanical Equipment	0	840	$6,535	$37,375	5.7
Replace Mechanical Equipment Controls	557,736	5,400	$94,383	$15,876	0.2
Total	780,476	9,413	$146,520	117,032	0.8

Figure 16. Bldg. 462, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

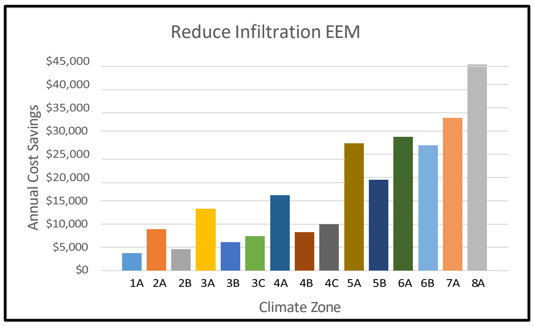


Figure 17. Bldg. 462, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

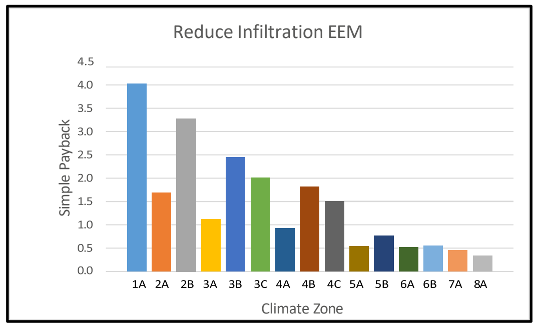


Figure 18. Bldg. 462, annual cost savings resulting from EEM "Lighting Controls," by climate zone.

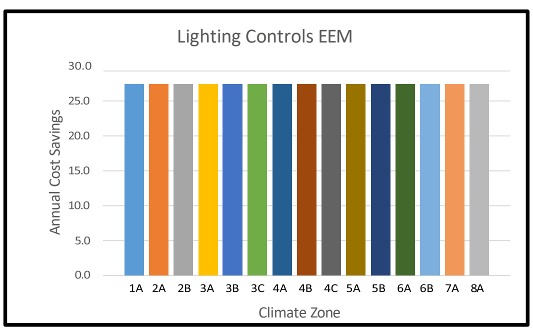


Figure 19. Bldg. 462, simple payback resulting from EEM "Lighting Controls," by climate zone.

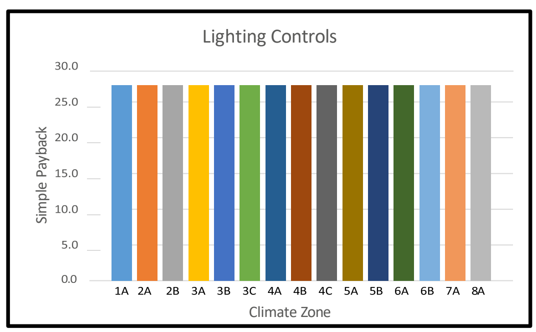


Figure 20. Bldg. 462, annual cost savings resulting from EEM “Roof/Attic Insulation,” by climate zone.

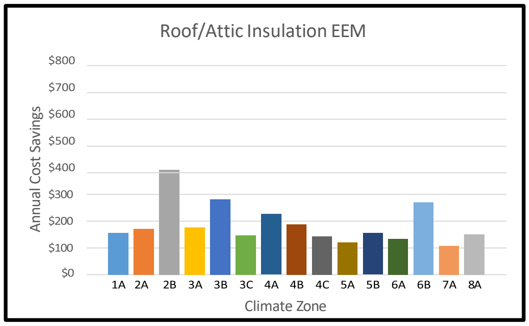


Figure 21. Bldg. 462, simple payback resulting from EEM “Roof/Attic Insulation,” by climate zone.

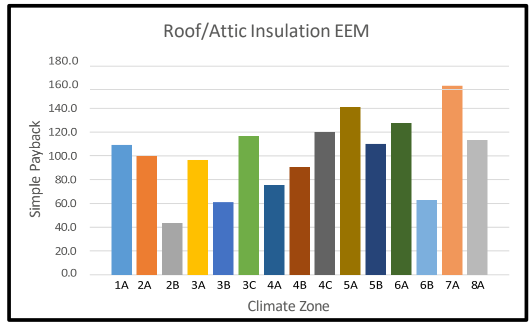


Figure 22. Bldg. 462, annual cost savings resulting from EEM “Replace Mechanical Equipment EEM,” by climate zone.

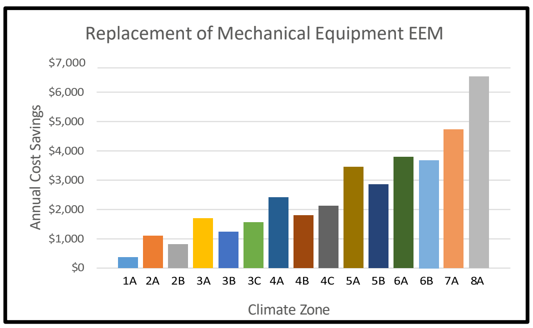


Figure 23. Bldg. 462, simple payback resulting from EEM “Replace Mechanical Equipment EEM,” by climate zone.

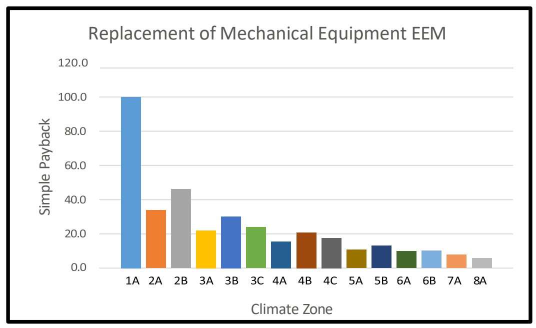


Figure 24. Bldg. 462, annual cost savings resulting from EEM “Replace Mechanical Equipment Controls EEM,” by climate zone.

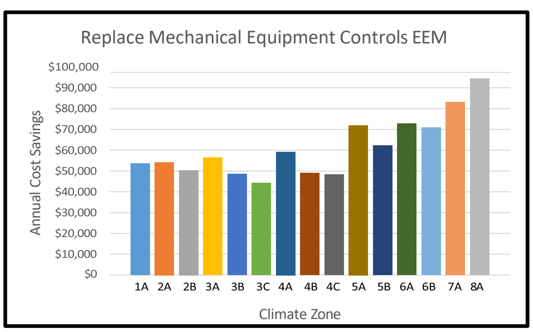
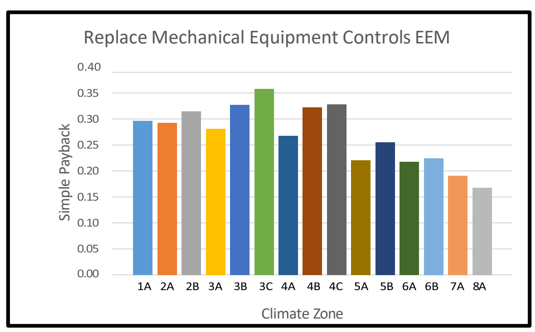


Figure 25. Bldg. 462, simple payback resulting from EEM “Replace Mechanical Equipment Controls EEM,” by climate zone.



4.4.3 Bldg. 463 EEM savings by climate zone

The EEMs chosen for Bldg. 463 were:

- **Reduce Infiltration**. Infiltration of the building was changed from 2.00 ACH to 1.00 ACH. The implementation cost was calculated from 355 windows that are 2.5 x 5.22 ft, five doors that are 4 x 6 ft, and one door that is 6 x 7 ft for a total of 5570.2 ft of weatherstripping. This came out at a cost of $4.41/ft.
- **Roof/Attic Insulation** Add R-38 batt insulation to the roof, where previously there was no insulation. The cost of the insulation was found to be $1.93/ft^2 in 2014, to which an escalation of 3% per year was added. With 9,085 ft^2 of roof/attic area, the estimated cost is $16,216.
- **Replacement of Mechanical Equipment**. Replace the building's 80% efficiency boiler with a boiler that is 95% efficient. Using RSMeans, the costs to replace a 1,000 MBH boiler is estimated at $20,100 for equipment and $5,025 for labor, summing to a total cost of $25,125.
- **Replace Mechanical Equipment Controls**. Change the building from an occupancy of 24 hours per day seven days a week to an occupancy of 0800-1700 Monday-Friday, and unoccupied Saturday-Sunday and on Holidays. It also changed the temperature setpoints from occupied and unoccupied cooling and heating of 74 and 72 °F, to occupied cooling and heating of 78 and 68 °F and unoccupied cooling and heating of 85 and 55 °F, respectively. The HVAC system fans were set to operate 2 hours before open and 2 hours after close of the building. The fans were set to cycle at night with minimum Outside Air, to use an economizer, and to cycle on via control zones.
  A time clock for each AHU, a controller for each Fan-Coil Unit (FCU) and associated labor can be used to achieve the above recommendations. A cost of $3,900 for the time clock and $1,392 of fixed labor (based on previous experience) was assumed. A cost of $172 for each controller, and $160 of fixed labor was assumed for the FCUs. For two AHUs and eight FCUs, this is a total cost of $13,240.
- **Lighting Controls.** Energy audits of this facility indicated a large number of open areas that had potential for savings via occupancy sensors. A cost of $0.95/ft^2 was used based on Zhang et al. (2013). With a facility area of 18,170 ft^2, the estimated cost is $25,892. The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 44-58 and shown in Figures 26-35.

Table 44. Bldg. 463, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	139,883	181	$14,546	$24,567.58	1.7
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	3,048	12	$380	$16,216.49	42.7
Replacement of Mechanical Equipment	0	98	$762	$25,125	33.0
Replace Mechanical Equipment Controls	564,067	544	$57,198	$13,240	0.2
Total	721944	835	$74,289	$105,041.32	1.4

Table 45. Bldg. 463, savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	356,316	943	$40,795	$24,568	0.6
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	1,698	5	$198	$16,216	81.8
Replacement of Mechanical Equipment	0	498	$3,874	$25,125	6.5
Replace Mechanical Equipment Controls	816,159	2,200	$93,753	$13,240	0.1
Total	1,189,119	3,646	$140,024	105041	0.8

Table 46. Bldg. 463, savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	208,197	523	$23,619	$24,568	1.0
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	4,541	12	$520	$16,216	31.2
Replacement of Mechanical Equipment	0	277	$2,155	$25,125	11.7
Replace Mechanical Equipment Controls	445,710	1,248	$51,562	$13,240	0.3
Total	673,394	2,060	$79,258	105041	1.3

Table 47. Bldg. 463, savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	347,496	1,181	$41,818	$24,568	0.6
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	1,465	8	$200	$16,216	81.2
Replacement of Mechanical Equipment	0	705	$5,485	$25,125	4.6
Replace Mechanical Equipment Controls	790,494	2,684	$95,109	$13,240	0.1
Total	1,154,401	4,578	$144,015	105041	0.7

Table 48. Bldg. 463, savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	165,083	618	$20,309	$24,568	1.2
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	2,782	12	$355	$16,216	45.7
Replacement of Mechanical Equipment	0	476	$3,703	$25,125	6.8
Replace Mechanical Equipment Controls	576,371	1,926	$69,106	$13,240	0.2
Total	759,182	3,032	$94,876	105041	1.1

Table 49. Bldg. 463, savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	175,894	878	$23,347	$24,568	1.1
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	899	13	$186	$16,216	87.4
Replacement of Mechanical Equipment	0	549	$4,271	$25,125	5.9
Replace Mechanical Equipment Controls	474,231	2,215	$61,763	$13,240	0.2
Total	665,970	3,655	$90,970	105041	1.2

Table 50. Bldg. 463, savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	360,217	1,379	$44,553	$24,568	0.6
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	1,005	11	$180	$16,216	90.1
Replacement of Mechanical Equipment	0	927	$7,212	$25,125	3.5
Replace Mechanical Equipment Controls	783,356	3,067	$97,418	$13,240	0.1
Total	1,159,524	5,384	$150,767	105041	0.7

Table 51. Bldg. 463, savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	286,390	1,139	$35,753	$24,568	0.7
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	1,808	11	$255	$16,216	63.5
Replacement of Mechanical Equipment	0	705	$5,485	$25,125	4.6
Replace Mechanical Equipment Controls	623,043	2,401	$77,184	$13,240	0.2
Total	926,187	4,256	$120,081	105041	0.9

Table 52. Bldg. 463, savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	226,708	1,122	$30,017	$24,568	0.8
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	818	14	$186	$16,216	87.3
Replacement of Mechanical Equipment	0	771	$5,998	$25,125	4.2
Replace Mechanical Equipment Controls	516,729	2,542	$68,298	$13,240	0.2
Total	759,201	4,449	$105,902	105041	1.0

Table 53. Bldg. 463, savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	521,576	2,054	$64,956	$24,568	0.4
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	789	13	$175	$16,216	92.5
Replacement of Mechanical Equipment	0	1,316	$10,238	$25,125	2.5
Replace Mechanical Equipment Controls	991,412	4,142	$125,318	$13,240	0.1
Total	1,528,723	7,525	$202,092	105041	0.5

Table 54. Bldg. 463, savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	393,220	1,600	$49,371	$24,568	0.5
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	986	16	$217	$16,216	74.7
Replacement of Mechanical Equipment	0	1,138	$8,854	$25,125	2.8
Replace Mechanical Equipment Controls	918,404	3,772	$115,584	$13,240	0.1
Total	1,327,556	6,526	$175,430	105041	0.6

Table 55. Bldg. 463, savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	530,760	2,189	$66,869	$24,568	0.4
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	598	17	$188	$16,216	86.1
Replacement of Mechanical Equipment	0	1,402	$10,908	$25,125	2.3
Replace Mechanical Equipment Controls	974,154	4,049	$122,974	$13,240	0.1
Total	1,520,458	7,657	$202,342	105041	0.5

Table 56. Bldg. 463, savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	514,332	2,122	$64,805	$24,568	0.4
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	1,297	33	$379	$16,216	42.8
Replacement of Mechanical Equipment	0	1,371	$10,666	$25,125	2.4
Replace Mechanical Equipment Controls	945,457	4,090	$120,599	$13,240	0.1
Total	1,476,032	7,616	$197,852	105041	0.5

Table 57. Bldg. 463, savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	647,976	2,618	$81,213	$24,568	0.3
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	484	17	$178	$16,216	91.3
Replacement of Mechanical Equipment	0	1,753	$13,638	$25,125	1.8
Replace Mechanical Equipment Controls	1,129,468	4,794	$143,354	$13,240	0.1
Total	1,792,874	9,182	$239,787	105041	0.4

Table 58. Bldg. 463, savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	810,770	3,561	$103,836	$24,568	0.2
Lighting Controls	14,946	0	$1,403	$25,892	18.4
Roof/Attic Insulation	-368	56	$401	$16,216	40.4
Replacement of Mechanical Equipment	0	2,205	$17,155	$25,125	1.5
Replace Mechanical Equipment Controls	1,284,219	5,314	$161,931	$13,240	0.1
Total	2,109,567	11,136	$284,726	105041	0.4

Figure 26. Bldg. 463, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

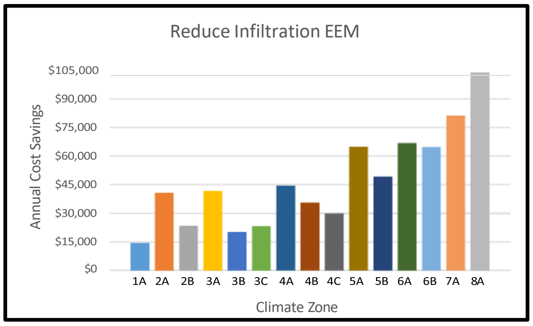


Figure 27. Bldg. 463, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

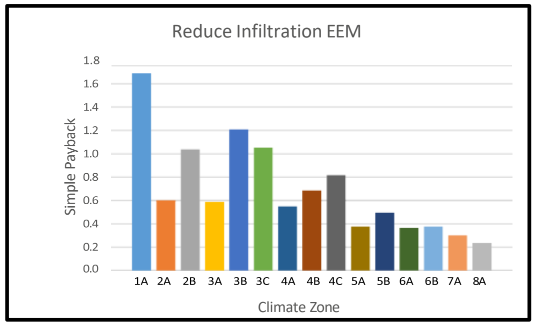


Figure 28. Bldg. 463, annual cost savings resulting from EEM "Lighting Controls," by climate zone.

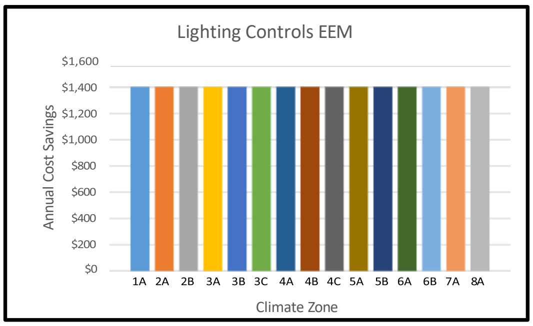


Figure 29. Bldg. 463, simple payback resulting from EEM "Lighting Controls," by climate zone.

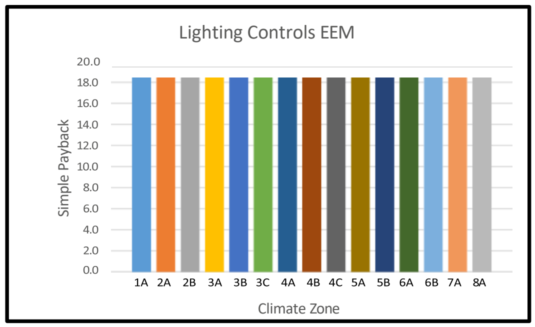


Figure 30. Bldg. 463, annual cost savings resulting from EEM "Roof/Attic Insulation," by climate zone.

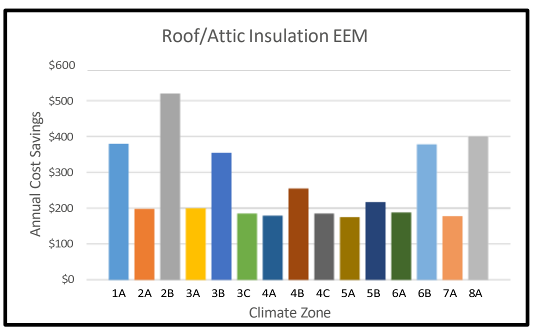


Figure 31. Bldg. 463, simple payback resulting from EEM "Roof/Attic Insulation," by climate zone.

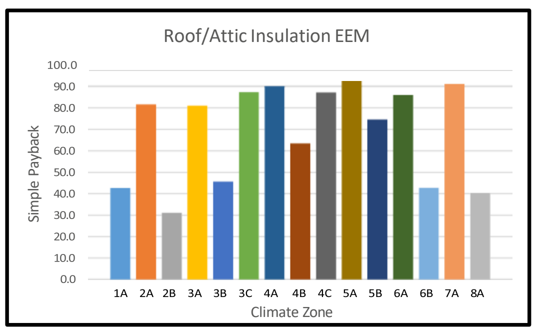


Figure 32. Bldg. 463, annual cost savings resulting from EEM "Replace Mechanical Equipment EEM," by climate zone.

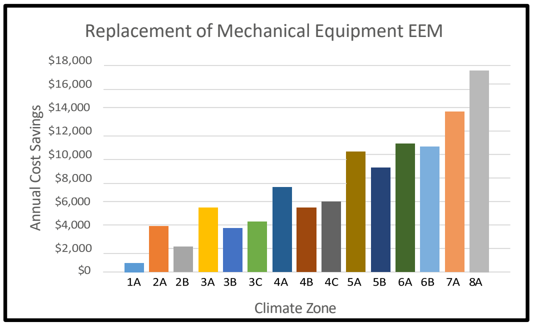


Figure 33. Bldg. 463, simple payback resulting from EEM "Replace Mechanical Equipment EEM," by climate zone.

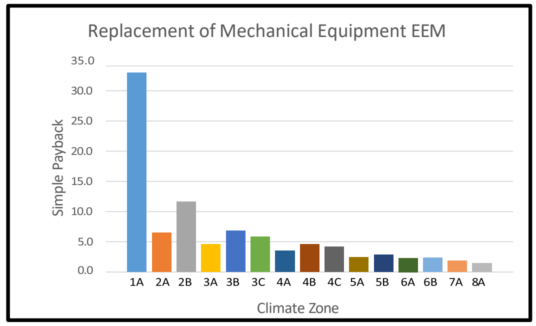


Figure 34. Bldg. 463, annual cost savings resulting from EEM "Replace Mechanical Equipment Controls EEM," by climate zone.

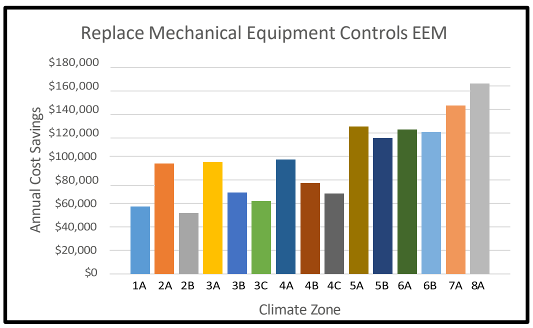
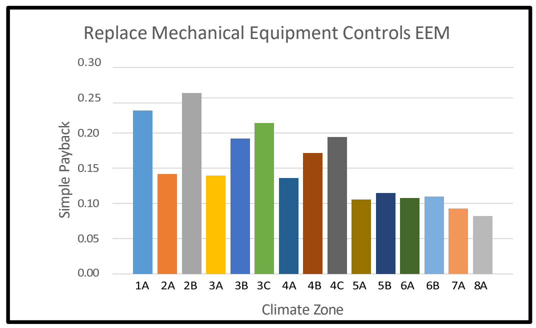


Figure 35. Bldg. 463, simple payback resulting from EEM "Replace Mechanical Equipment Controls EEM," by climate zone.



4.4.4 Bldg. 750 EEM savings by climate zone

The EEMs chosen for Bldg. 750 were:

- **Reduce Infiltration**. Infiltration of the building was changed from 2.00 ACH to 1.00 ACH. The implementation cost was calculated from 270 windows that are 4 x 6.3 ft, and seven doors that are 3 x 7 ft for a total of 5653 ft of weatherstripping. This came out at a cost of $4.41/ft.
- **Roof/Attic Insulation**. Add R-38 batt insulation to the roof, where previously there was no insulation. The cost of the insulation was found to be $1.93/ft^2 in 2014, to which an escalation of 3% per year was added. With 9,085 ft^2 of roof/attic area. The estimated cost is $16,216 for the improvements.
- **Replacement of Mechanical Equipment**. Replace the building's chiller, which has a coefficient of performance (COP) of 2.7, with a high efficiency chiller with a COP of 7. This replacement costs, on average, about $1,260/ton and varies by climate zone because the size of the chiller required. Size was estimated from the peak cooling load estimated by eQUEST.

- **Replace Mechanical Equipment Controls**. Changed the building from an occupancy of 24 hours per day seven days a week to an occupancy of 0700-1700 Monday-Friday, and unoccupied Saturday-Sunday and on Holidays. It also changed the temperature setpoints from occupied and unoccupied cooling and heating of 72 and 68 °F, to occupied cooling and heating of 78 and 68 °F and unoccupied cooling and heating of 85 and 55 °F, respectively. The HVAC system fans were set to operate 2 hours before open and 2 hours after close of the building. The fans were set to cycle at night with minimum Outside Air, to use an economizer, to cycle on via control zones, and to have the capability to operate in a continuous ON mode.

  A time clock for each AHU and a controller for each FCU and associated labor can be used to achieve the above recommendations. A cost of $3,900 for the time clock and $1,392 of fixed labor (based on previous experience) was assumed. A cost of $172 for each controller and $160 of fixed labor was assumed for the FCUs. For four AHUs and 20 FCUs, it is a total cost of $27,808.
- **Lighting Controls.** Energy audits of this facility indicated a large number of open areas that had potential for savings via occupancy sensors. A cost of $0.95/ft² was used based on Zhang et al. (2013). With a facility area of 38,480 ft², the estimated cost is $36,556.

The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 59-73 and shown in Figures 36-45.

Table 59. Bldg. 750, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	57,905	8	$5,500	$24,929.73	4.5
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	896	1	$92	$19,164.95	208.5
Replacement of Chiller	515,000	0	$48,359	$189,000	3.9
Replace Mechanical Equipment Controls	878,023	7	$82,501	$27,808	0.3
Total	1,491,409	16	$140,168	$297,458.68	2.1

Table 60. Bldg. 750, savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	32,194	171	$4,353	$24,930	5.7
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	646	7	$115	$19,165	166.5
Replacement of Chiller	399,000	0	$37,466	$189,000	5.0
Replace Mechanical Equipment Controls	766,299	148	$73,107	$27,808	0.4
Total	1,237,724	326	$118,759	297,459	2.5

Table 61. Bldg. 750, savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	21,218	115	$2,887	$24,930	8.6
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	824	7	$132	$19,165	145.4
Replacement of Chiller	424,000	0	$39,814	$189,000	4.7
Replace Mechanical Equipment Controls	754,321	89	$71,523	$27,808	0.4
Total	1,239,948	211	$118,073	297,459	2.5

Table 62. Bldg. 750, savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	28,847	335	$5,315	$24,930	4.7
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	556	12	$146	$19,165	131.7
Replacement of Chiller	327,000	0	$30,705	$163,800	5.3
Replace Mechanical Equipment Controls	701,499	355	$68,633	$27,808	0.4
Total	1,097,487	702	$108,516	272,259	2.5

Table 63. Bldg. 750, savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	16,687	224	$3,310	$24,930	7.5
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	703	12	$159	$19,165	120.3
Replacement of Chiller	312,000	0	$29,297	$163,800	5.6
Replace Mechanical Equipment Controls	708,737	268	$68,635	$27,808	0.4
Total	1,077,712	504	$105,118	272,259	2.6

Table 64. Bldg. 750, savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	3,100	285	$2,508	$24,930	9.9
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	122	14	$120	$19,165	159.2
Replacement of Chiller	181,000	0	$16,996	$163,800	9.6
Replace Mechanical Equipment Controls	581,913	204	$56,229	$27,808	0.5
Total	805,720	503	$79,570	272,259	3.4

Table 65. Bldg. 750, savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	16,066	539	$5,702	$24,930	4.4
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	403	14	$147	$19,165	130.6
Replacement of Chiller	247,000	0	$23,193	$163,800	7.1
Replace Mechanical Equipment Controls	614,415	620	$62,517	$27,808	0.4
Total	917,469	1,173	$95,276	272,259	2.9

Table 66. Bldg. 750, savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	6,831	396	$3,722	$24,930	6.7
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	646	15	$177	$19,165	108.1
Replacement of Chiller	253,000	0	$23,757	$126,000	5.3
Replace Mechanical Equipment Controls	639,793	470	$63,733	$27,808	0.4
Total	939,855	881	$95,107	234,459	2.5

Table 67. Bldg. 750, savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	-14,330	535	$2,817	$24,930	8.9
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	243	17	$155	$19,165	123.6
Replacement of Chiller	161,000	0	$15,118	$126,000	8.3
Replace Mechanical Equipment Controls	548,648	514	$55,517	$27,808	0.5
Total	735,146	1,066	$77,324	234,459	3.0

Table 68. Bldg. 750, savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	78,891	723	$13,033	$24,930	1.9
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	245	15	$140	$19,165	137.2
Replacement of Chiller	233,000	0	$21,879	$163,800	7.5
Replace Mechanical Equipment Controls	592,487	736	$61,361	$27,808	0.5
Total	944,208	1,474	$100,129	272,259	2.7

Table 69. Bldg. 750, savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	41,851	575	$8,403	$24,930	3.0
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	371	19	$183	$19,165	104.9
Replacement of Chiller	200,000	0	$18,780	$126,000	6.7
Replace Mechanical Equipment Controls	566,321	700	$58,624	$27,808	0.5
Total	848,128	1,294	$89,707	234,459	2.6

Table 70. Bldg. 750, savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	80,029	851	$14,136	$24,930	1.8
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	215	21	$184	$19,165	104.4
Replacement of Chiller	211,000	0	$19,813	$163,800	8.3
Replace Mechanical Equipment Controls	567,676	717	$58,883	$27,808	0.5
Total	898,505	1,589	$96,732	272,259	2.8

Table 71. Bldg. 750, savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	92,532	764	$14,633	$24,930	1.7
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	244	31	$264	$19,165	72.6
Replacement of Chiller	200,000	0	$18,780	$126,000	6.7
Replace Mechanical Equipment Controls	563,223	718	$58,473	$27,808	0.5
Total	895,584	1,513	$95,866	234,459	2.4

Table 72. Bldg. 750, savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	126,502	1,090	$20,359	$24,930	1.2
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	153	21	$178	$19,165	107.8
Replacement of Chiller	200,000	0	$18,780	$163,800	8.7
Replace Mechanical Equipment Controls	553,472	687	$57,316	$27,808	0.5
Total	919,712	1,798	$100,349	272,259	2.7

Table 73. Bldg. 750, savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	156,815	1,572	$26,955	$24,930	0.9
Lighting Controls	39,585		$3,717	$36,556	9.8
Roof/Attic Insulation	235	73	$590	$19,165	32.5
Replacement of Chiller	201,000	0	$18,874	$138,600	7.3
Replace Mechanical Equipment Controls	529,301	114	$50,588	$27,808	0.5
Total	926,936	1,759	$100,724	247,059	2.5

Figure 36. Bldg. 750, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

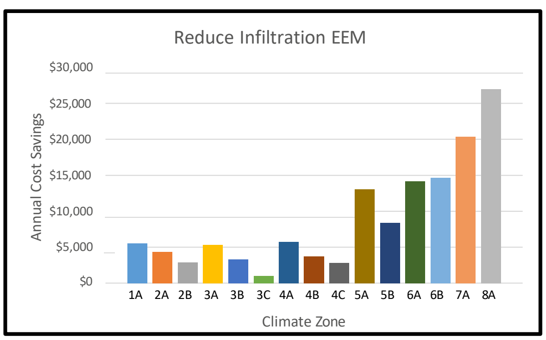


Figure 37. Bldg. 750, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

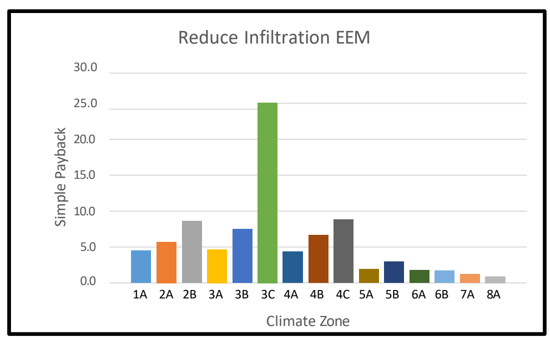


Figure 38. Bldg. 750, annual cost savings resulting from EEM "Lighting Controls," by climate zone.

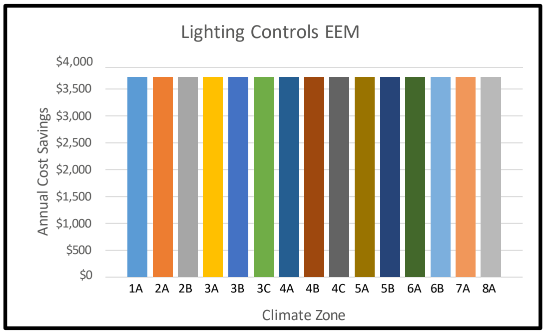


Figure 39. Bldg. 750, simple payback resulting from EEM "Lighting Controls," by climate zone.

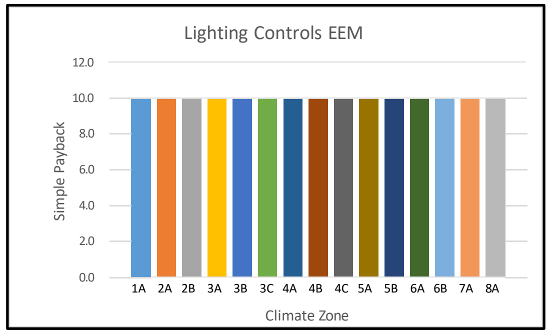


Figure 40. Bldg. 750, annual cost savings resulting from EEM "Roof/Attic Insulation," by climate zone.

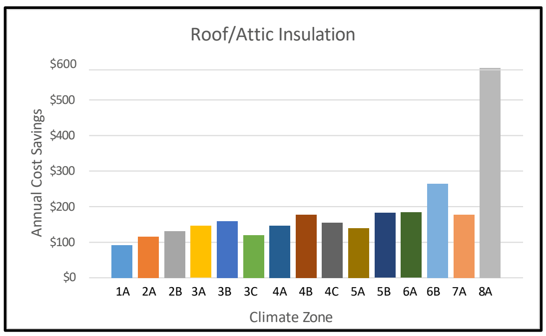


Figure 41. Bldg. 750, simple payback resulting from EEM "Roof/Attic Insulation," by climate zone.

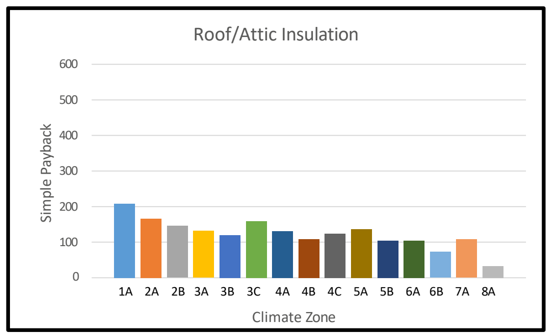


Figure 42. Bldg. 750, annual cost savings resulting from EEM "Replace Chiller EEM," by climate zone.

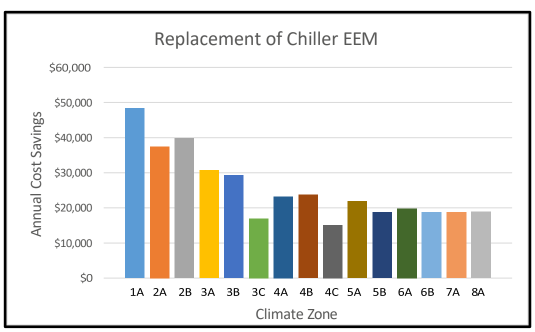


Figure 43. Bldg. 750, simple payback resulting from EEM "Replace Chiller EEM," by climate zone.

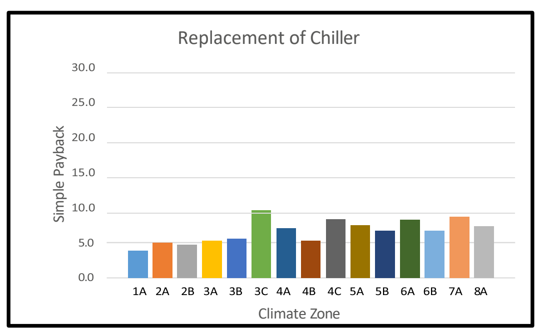


Figure 44. Bldg. 750, annual cost savings resulting from EEM "Replace Mechanical Equipment Controls EEM," by climate zone.

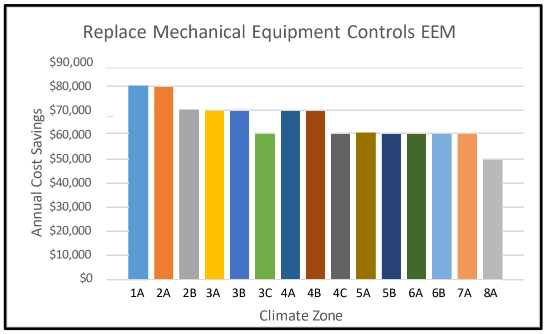
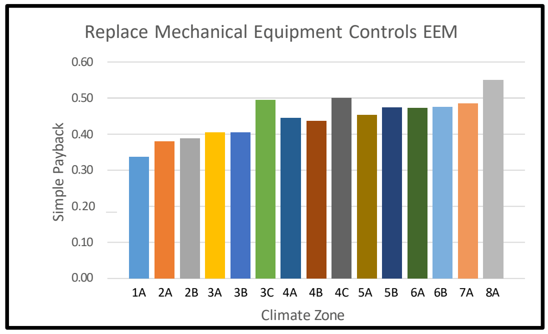


Figure 45. Bldg. 750, simple payback resulting from EEM "Replace Mechanical Equipment Controls EEM," by climate zone.

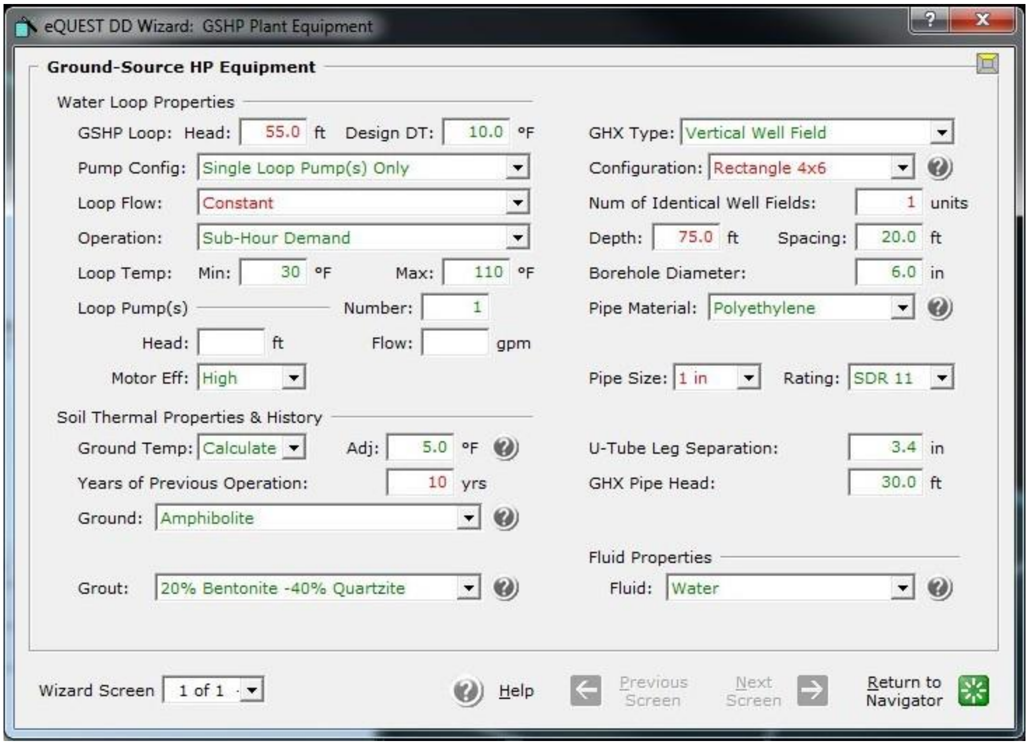


4.4.5 Bldg. 1803 EEM savings by climate zone

The EEMs chosen for Bldg. 1803 were:

- **Reduce Infiltration**. Infiltration of the building was changed from 2.00 ACH to 1.00 ACH. The implementation cost was calculated from 122 windows that are 3.3 x 3 ft, and eight doors that are 3 x 7 ft for a total of 1641.2 ft, at a cost of $4.41/ft.
- **Roof/Attic Insulation**. Add R-38 batt insulation to the roof, where previously there was no insulation. The cost of the insulation was found to be $1.93/ft^2 in 2014, to which an escalation of 3% per year was added. With 9,087 ft^2 of roof/attic area, the estimated cost is $19,165.
- **Replace Mechanical Equipment**. Replace the building's heating and cooling equipment. The original state building used chilled water coils as the cooling source, and hot water coils as the heating source. The hot water source was a hot water loop. The EEM set the cooling and heating source as a heat pump. The heat pump source is a ground loop. Figure 46 shows the system specifications. Using previous case studies and online estimates (Geothermal Genius 2009), the cost of installing six heat pumps with a total 205 MBH heating capacity and 22-ton cooling capacity is $90,562.

Figure 46. Heat pump specifications.



- **Replace Mechanical Equipment Controls**. Change the building from an occupancy of 24 hours per day seven days a week to an occupancy of 0800-1700 Monday-Friday, and unoccupied Saturday-Sunday and on Holidays. It also changed the temperature setpoints from occupied and unoccupied cooling and heating of 76 and 70 °F, to occupied cooling and heating of 78 and 68 °F and unoccupied cooling and heating of 85 and 55 °F, respectively. The HVAC system fans were set to operate 2 hours before open and 2 hours after close of the building. The fans were set to cycle at night with minimum Outside Air, to use an economizer, and to cycle on via control zones. A time clock for each AHU can be used to achieve the above recommendations. A cost of $3,900 for the time clock and $1,392 of fixed labor (based on previous experience) was assumed. For two AHUs, the cost is $10,584.
- **Lighting Controls.** Energy audits of this facility indicated a large number of open areas that had potential for savings via occupancy sensors. A cost of $0.95/ft^2 was used based on Zhang et al. (2013). With a facility area of 8,076 ft^2, the estimated cost is $7,672.

The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 74-88 and shown in Figures 47-56.

Table 74. Bldg. 1803, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	21,864	49	$2,434	$7,237.69	3.0
Lighting Controls	4,257	0	$400	$7,672	19.2
Roof/Attic Insulation	442	0	$42	$9,975.60	240.4
Replacement of Mechanical Equipment (Heat Pump)	111,921	309	$12,913	$90,563	7.0
Replace Mechanical Equipment Controls	133,394	249	$14,463	$10,584	0.7
Total	271,878	607	$30,252	$126,031.99	4.2

Table 75. Bldg. 463, savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	56,197	387	$8,288	$7,237.69	0.9
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	280	3	$50	$9,975.60	201.0
Replacement of Mechanical Equipment (Heat Pump)	183,158	751	$23,041	$90,562.50	3.9
Replace Mechanical Equipment Controls	187,681	1,131	$26,422	$10,584.00	0.4
Total	431,573	2,272	$58,201	126,032	2.2

Table 76. Bldg. 1803, savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	24,207	174	$3,627	$7,237.69	2.0
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	946	3	$112	$9,975.60	88.9
Replacement of Mechanical Equipment (Heat Pump)	126,696	946	$19,257	$90,562.50	4.7
Replace Mechanical Equipment Controls	128,085	626	$16,897	$10,584.00	0.6
Total	284,191	1,749	$40,293	126,032	3.1

Table 77. Bldg. 463, savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	48,269	424	$7,831	$7,237.69	0.9
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	276	4	$57	$9,975.60	174.9
Replacement of Mechanical Equipment (Heat Pump)	185,775	2,552	$37,299	$90,562.50	2.4
Replace Mechanical Equipment Controls	192,357	1,455	$29,382	$10,584.00	0.4
Total	430,934	4,435	$74,969	126,032	1.7

Table 78. Bldg. 1803, savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	39,226	352	$6,422	$7,237.69	1.1
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	564	5	$92	$9,975.60	108.6
Replacement of Mechanical Equipment (Heat Pump)	142,830	794	$19,589	$90,562.50	4.6
Replace Mechanical Equipment Controls	159,636	1,074	$23,346	$10,584.00	0.5
Total	346,513	2,225	$49,848	126,032	2.5

Table 79. Bldg. 1803, savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	14,296	264	$3,396	$7,237.69	2.1
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	193	5	$57	$9,975.60	174.9
Replacement of Mechanical Equipment (Heat Pump)	76,051	927	$14,353	$90,562.50	6.3
Replace Mechanical Equipment Controls	129,093	1,179	$21,294	$10,584.00	0.5
Total	223,890	2,375	$39,501	126,032	3.2

Table 80. Bldg. 1803, savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	38,238	436	$6,983	$7,237.69	1.0
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	239	4	$54	$9,975.60	186.2
Replacement of Mechanical Equipment (Heat Pump)	173,946	3,410	$42,863	$90,562.50	2.1
Replace Mechanical Equipment Controls	182,929	1,666	$30,139	$10,584.00	0.4
Total	399,609	5,516	$80,438	126,032	1.6

Table 81. Bldg. 1803, savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	41,190	460	$7,447	$7,237.69	1.0
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	359	4	$65	$9,975.60	153.9
Replacement of Mechanical Equipment (Heat Pump)	135,727	2,652	$33,377	$90,562.50	2.7
Replace Mechanical Equipment Controls	163,002	1,357	$25,863	$10,584.00	0.4
Total	344,535	4,473	$67,152	126,032	1.9

Table 82. Bldg. 1803, savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	27,380	410	$5,761	$7,237.69	1.3
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	222	5	$60	$9,975.60	167.0
Replacement of Mechanical Equipment (Heat Pump)	98,646	2,828	$31,265	$90,562.50	2.9
Replace Mechanical Equipment Controls	133,422	1,357	$23,086	$10,584.00	0.5
Total	263,927	4,600	$60,571	126,032	2.1

Table 83. Bldg. 1803, savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	67,264	780	$12,384	$7,237.69	0.6
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	214	5	$59	$9,975.60	169.1
Replacement of Mechanical Equipment (Heat Pump)	231,775	4,808	$59,170	$90,562.50	1.5
Replace Mechanical Equipment Controls	215,726	2,245	$37,723	$10,584.00	0.3
Total	519,236	7,838	$109,736	126,032	1.1

Table 84. Bldg. 1803, savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	29,353	415	$5,985	$7,237.69	1.2
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	215	4	$51	$9,975.60	194.4
Replacement of Mechanical Equipment (Heat Pump)	186,201	4,077	$49,203	$90,562.50	1.8
Replace Mechanical Equipment Controls	191,016	1,944	$33,061	$10,584.00	0.3
Total	411,042	6,440	$88,700	126,032	1.4

Table 85. Bldg. 1803, savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	63,089	793	$12,094	$7,237.69	0.6
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	156	6	$61	$9,975.60	162.7
Replacement of Mechanical Equipment (Heat Pump)	242,200	5,177	$63,020	$90,562.50	1.4
Replace Mechanical Equipment Controls	211,620	2,248	$37,361	$10,584.00	0.3
Total	521,322	8,224	$112,935	126,032	1.1

Table 86. Bldg. 1803, savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	63,662	795	$12,163	$7,237.69	0.6
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	315	11	$115	$9,975.60	86.6
Replacement of Mechanical Equipment (Heat Pump)	228,089	4,988	$60,224	$90,562.50	1.5
Replace Mechanical Equipment Controls	204,222	2,214	$36,401	$10,584.00	0.3
Total	500,545	8,008	$109,303	126,032	1.2

Table 87. Bldg. 1803, savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	72,439	951	$14,201	$7,237.69	0.5
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	66	5	$45	$9,975.60	221.2
Replacement of Mechanical Equipment (Heat Pump)	288,517	6,274	$75,903	$90,562.50	1.2
Replace Mechanical Equipment Controls	215,663	2,511	$39,786	$10,584.00	0.3
Total	580,942	9,741	$130,335	126,032	1.0

Table 88. Bldg. 1803, savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	103,542	1,384	$20,490	$7,237.69	0.4
Lighting Controls	4,257	0	$400	$7,672.20	19.2
Roof/Attic Insulation	-93	20	$147	$9,975.60	67.9
Replacement of Mechanical Equipment (Heat Pump)	367,420	7,732	$94,656	$90,562.50	1.0
Replace Mechanical Equipment Controls	243,328	2,753	$44,267	$10,584.00	0.2
Total	718,454	11,889	$159,959	126,032	0.8

Figure 47. Bldg. 1803, annual cost savings resulting from EEM “Reduce Infiltration,” by climate zone.

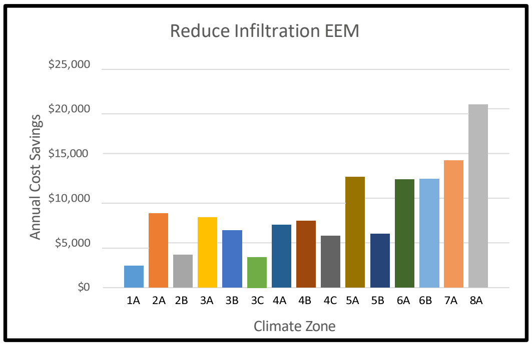


Figure 48. Bldg. 1803, simple payback resulting from EEM “Reduce Infiltration,” by climate zone.

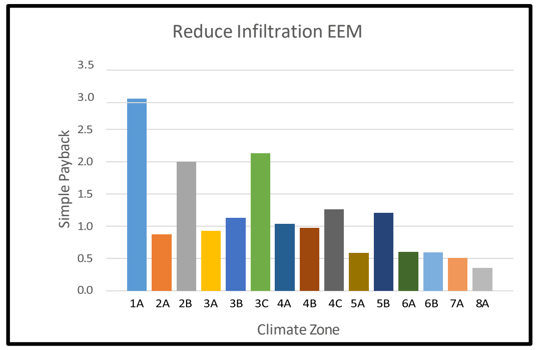


Figure 49. Bldg. 1803, annual cost savings resulting from EEM “Lighting Controls,” by climate zone.

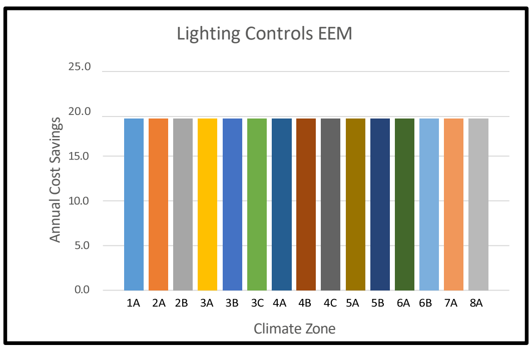


Figure 50. Bldg. 1803, simple payback resulting from EEM “Lighting Controls,” by climate zone.

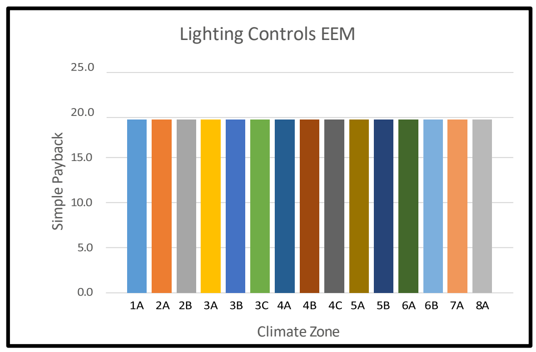


Figure 51. Bldg. 1803, annual cost savings resulting from EEM “Roof/Attic Insulation,” by climate zone.

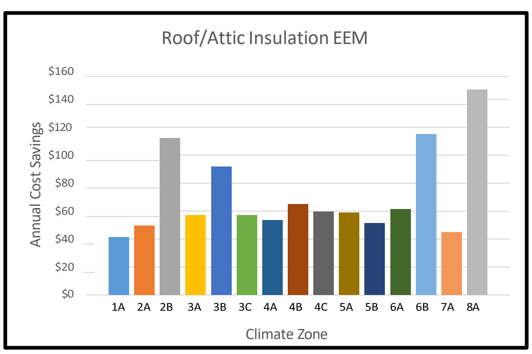


Figure 52. Bldg. 1803, simple payback resulting from EEM “Roof/Attic Insulation,” by climate zone.

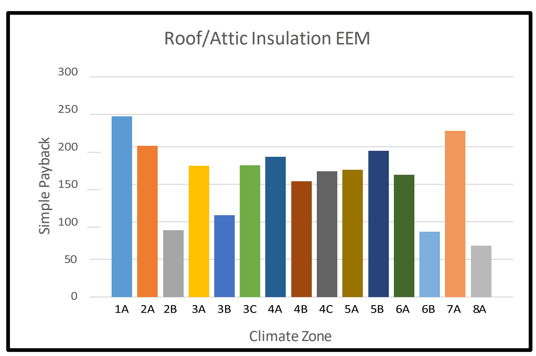


Figure 53. Bldg. 1803, annual cost savings resulting from EEM “Replace Mechanical Equipment EEM,” by climate zone.

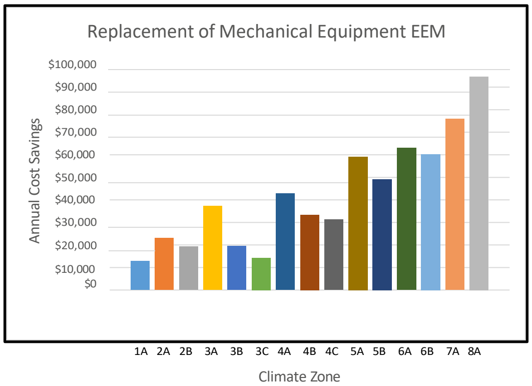


Figure 54. Bldg. 1803, simple payback resulting from EEM “Replace Mechanical Equipment EEM,” by climate zone.

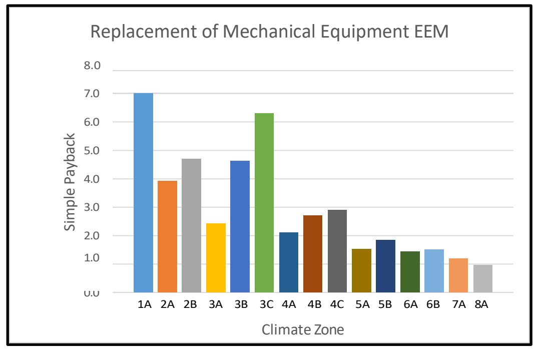


Figure 55. Bldg. 1803, annual cost savings resulting from EEM “Replace Mechanical Equipment Controls EEM,” by climate zone.

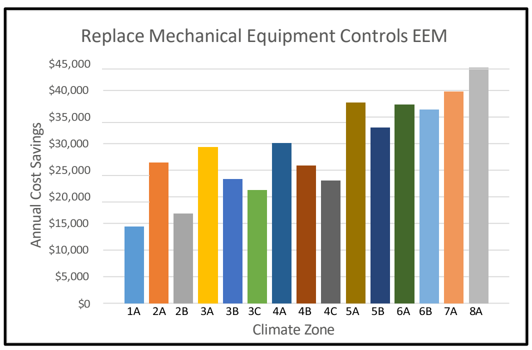
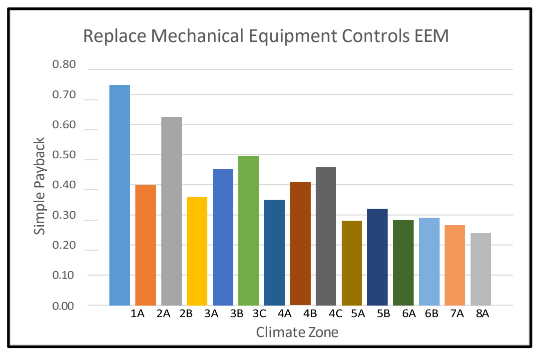


Figure 56. Bldg. 1803, simple payback resulting from EEM “Replace Mechanical Equipment Controls EEM,” by climate zone.



4.4.6 Bldg. 3419 EEM savings by climate zone

The EEMs chosen for Bldg. 3419 were:

- **Reduce Infiltration**. Infiltration of the building was changed from 2.00 ACH to 1.00 ACH. The implementation cost was calculated from an estimated 52 windows that are 3.33 x 6.5 ft, and four doors that are 6 x 7 ft for a total of 1098.32 ft. This came out at a cost of $4.41/ft.
- **Replacement of Mechanical Equipment**. Replaced the building’s 80% efficiency boiler with a boiler that is 95% efficient. Using RSMeans, the costs to replace a 2,000 MBH boiler are estimated at $29,900 for equipment and $7,475 for labor, summing to a total cost of $37,375.

- **Replace Mechanical Equipment Controls**. Change the building from an occupancy of 24 hours per day seven days a week to an occupancy of 0700-1800 Monday-Friday, and unoccupied Saturday-Sunday and on Holidays. It also changed the temperature setpoints from occupied and unoccupied cooling and heating of 76 and 74 °F, to occupied cooling and heating of 78 and 68 °F and unoccupied cooling and heating of 85 and 55 °F, respectively. The HVAC system fans were set to operate 2 hours before open and 2 hours after close of the building. A time clock for each AHU can be used to achieve the above recommendations. A cost of $3,900 for the time clock and $1,392 of fixed labor (based on previous experience) was assumed. For five AHUs, the cost is $26,460.
- **Lighting Controls.** Energy audits of this facility indicated a large number of open areas that had potential for savings via occupancy sensors. A cost of $0.95/ft^2$ was used based on Zhang et al. (2013). With a facility area of 37,735 ft^2, the estimated cost is $35,848.
- **Install PV panels on Roof.** Building 3419 has a flat roof and is high enough so PV panels can be installed on the roof and not be seen from the ground. The System Advisory Model (SAM) program developed by the National Renewable Energy Laboratory (NREL) was used to determine the amount of electricity that could be produced. The cost of PV systems has dropped dramatically recently, and for a small commercial system is estimated to be $3,500/kW of capacity, the maximum instantaneous production (Barbose and Darghouth 2016). The roof is approximately 13,000 ft^2. Due to some obstructions such as exhaust vents and a setback requirement so that the panels are not easily seen from ground level is estimated that 70%, or roughly 9,000 ft^2, could have panels installed. It would have a maximum production capacity of 84kW. A typical PV panel has a capacity of 1 kW/107 ft^2. This translates into a total cost of $294K.

The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 89-103 and shown in Figures 57-66.

Table 89. Bldg. 3419, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	93,499	381	$11,744	$4,843.59	0.4
Lighting Controls	14,028	0	$1,317	$35,848.00	27.2
Replacement of Mechanical Equipment	82	348	$2,715	$25,125.00	9.3
PV Cells	122,841	0	$11,535	$294,000.00	25.5
Replace Mechanical Equipment Controls	503,185	1,049	$55,410	$26,460.00	0.5
Total	733,635	1,778	$82,721	$5,292.00	0.1

Table 90. Bldg. 3419, savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	188,794	1,264	$27,562	$4,844	0.2
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	71	564	$4,395	$25,125	5.7
PV Cells	112,468	0	$10,561	$294,000	27.8
Replace Mechanical Equipment Controls	451,867	1,285	$52,428	$26,460	0.5
Total	767,228	3,113	$96,262	386,277	4.0

Table 91. Bldg. 3419, savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	173,421	1,184	$25,496	$4,844	0.2
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	61	563	$4,386	$25,125	5.7
PV Cells	145,187	0	$13,633	$294,000	21.6
Replace Mechanical Equipment Controls	449,834	1,523	$54,088	$26,460	0.5
Total	782,531	3,270	$98,920	386,277	3.9

Table 92. Bldg. 3419, savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	217,750	1,801	$34,459	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	55	710	$5,529	$25,125	4.5
PV Cells	121,886	0	$11,445	$294,000	25.7
Replace Mechanical Equipment Controls	441,338	1,600	$53,890	$26,460	0.5
Total	795,057	4,111	$106,639	386,277	3.6

Table 93. Bldg. 3419, savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	101,975	1,003	$17,379	$4,844	0.3
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	41	536	$4,174	$25,125	6.0
PV Cells	148,976	0	$13,989	$294,000	21.0
Replace Mechanical Equipment Controls	352,514	1,234	$42,702	$26,460	0.6
Total	617,534	2,773	$79,560	386,277	4.9

Table 94. Bldg. 3419, savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	38,060	1,045	$11,704	$4,844	0.4
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	-25,310	592	$2,229	$25,125	11.3
PV Cells	130,581	0	$12,262	$294,000	24.0
Replace Mechanical Equipment Controls	267,781	1,240	$34,792	$26,460	0.8
Total	425,140	2,877	$62,304	386,277	6.2

Table 95. Bldg. 3419, savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	227,166	2,340	$39,536	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	41	876	$6,819	$25,125	3.7
PV Cells	111,082	0	$10,431	$294,000	28.2
Replace Mechanical Equipment Controls	418,263	1,963	$54,547	$26,460	0.5
Total	770,580	5,179	$112,650	386,277	3.4

Table 96. Bldg. 3419, savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	98,342	1,260	$19,037	$4,844	0.3
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	29	644	$5,013	$25,125	5.0
PV Cells	149,661	0	$14,053	$294,000	20.9
Replace Mechanical Equipment Controls	313,795	1,329	$39,805	$26,460	0.7
Total	575,855	3,233	$79,226	386,277	4.9

Table 97. Bldg. 3419, savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	66,053	1,386	$16,985	$4,844	0.3
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	17	711	$5,533	$25,125	4.5
PV Cells	91,500	0	$8,592	$294,000	34.2
Replace Mechanical Equipment Controls	262,232	1,294	$34,691	$26,460	0.8
Total	433,830	3,391	$67,119	386,277	5.8

Table 98. Bldg. 3419, savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	132,235	3,132	$36,784	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	29	1,130	$8,794	$25,125	2.9
PV Cells	107,490	0	$10,093	$294,000	29.1
Replace Mechanical Equipment Controls	370,310	2,428	$53,662	$26,460	0.5
Total	624,092	6,690	$110,650	386,277	3.5

Table 99. Bldg. 3419, savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	156,870	2,196	$31,815	$4,844	0.2
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	21	866	$6,739	$25,125	3.7
PV Cells	133,221	0	$12,509	$294,000	23.5
Replace Mechanical Equipment Controls	355,341	1,962	$48,631	$26,460	0.5
Total	659,481	5,024	$101,012	386,277	3.8

Table 100. Bldg. 3419, savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	158,839	3,441	$41,686	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	26	1,240	$9,650	$25,125	2.6
PV Cells	105,512	0	$9,908	$294,000	29.7
Replace Mechanical Equipment Controls	368,124	2,628	$55,013	$26,460	0.5
Total	646,529	7,309	$117,573	386,277	3.3

Table 101. Bldg. 3419, savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	127,873	3,194	$36,857	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	18	1,167	$9,081	$25,125	2.8
PV Cells	111,581	0	$10,477	$294,000	28.1
Replace Mechanical Equipment Controls	340,017	2,519	$51,525	$26,460	0.5
Total	593,517	6,880	$109,258	386,277	3.5

Table 102. Bldg. 3419, savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	23,246	4,029	$33,528	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	17	1,470	$11,438	$25,125	2.2
PV Cells	107,739	0	$10,117	$294,000	29.1
Replace Mechanical Equipment Controls	331,985	3,410	$57,703	$26,460	0.5
Total	477,015	8,909	$114,104	386,277	3.4

Table 103. Bldg. 3419, savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	8,115	6,353	$50,188	$4,844	0.1
Lighting Controls	14,028	0	$1,317	$35,848	27.2
Replacement of Mechanical Equipment	12	2,174	$16,915	$25,125	1.5
PV Cells	77,609	0	$7,287	$294,000	40.3
Replace Mechanical Equipment Controls	297,308	5,668	$72,014	$26,460	0.4
Total	397,072	14,195	$147,722	386,277	2.6

Figure 57. Bldg. 3419, annual cost savings resulting from EEM “Reduce Infiltration,” by climate zone.

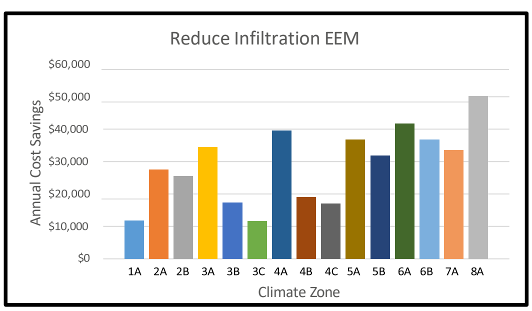


Figure 58. Bldg. 3419, simple payback resulting from EEM “Reduce Infiltration,” by climate zone.

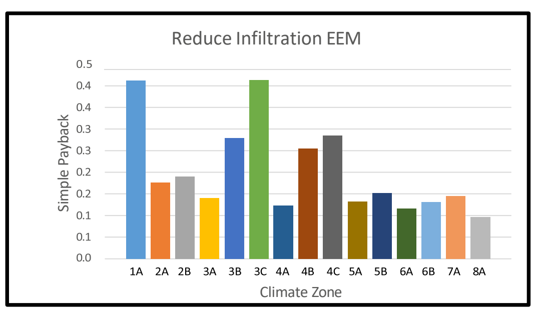


Figure 59. Bldg. 3419, annual cost savings resulting from EEM "Lighting Controls," by climate zone.

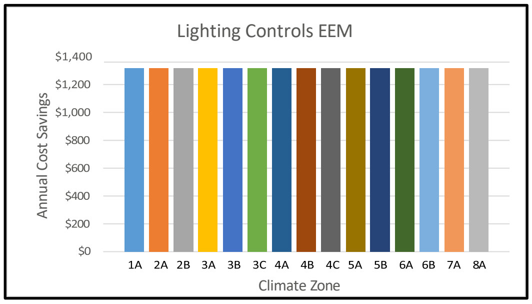


Figure 60. Bldg. 3419, simple payback resulting from EEM "Lighting Controls," by climate zone.

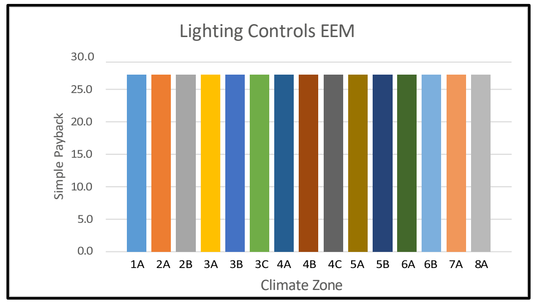


Figure 61. Bldg. 3419, annual cost savings resulting from EEM "PV Cells," by climate zone.

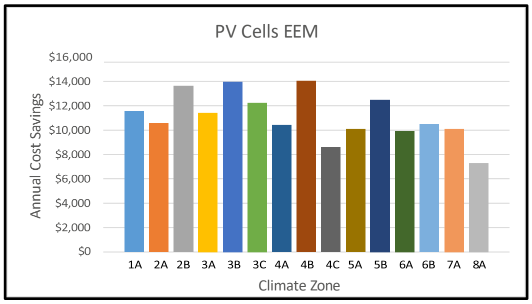


Figure 62. Bldg. 3419, simple payback resulting from EEM "PV Cells," by climate zone.

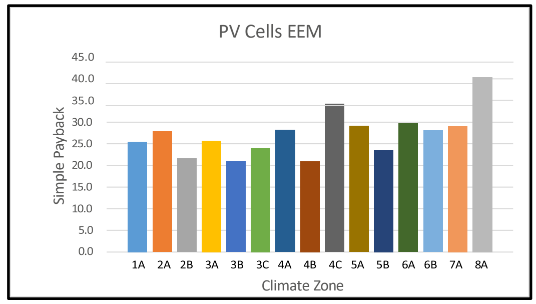


Figure 63. Bldg. 3419, annual cost savings resulting from EEM "Replace Mechanical Equipment EEM," by climate zone.

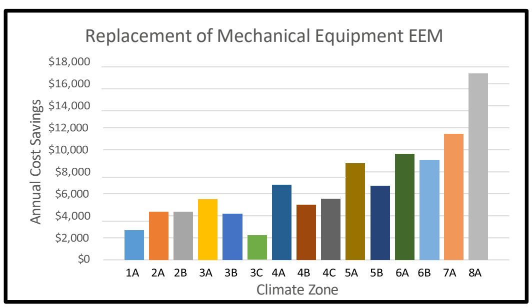


Figure 64. Bldg. 3419, simple payback resulting from EEM "Replace Mechanical Equipment EEM," by climate zone.

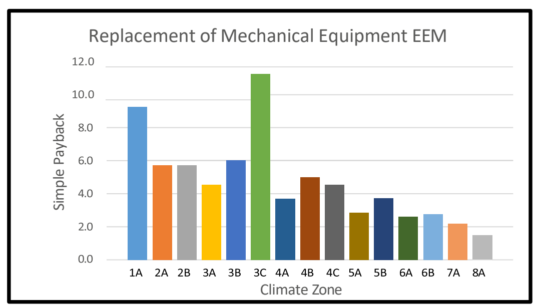


Figure 65. Bldg. 3419, annual cost savings resulting from EEM "Replace Mechanical Equipment Controls EEM," by climate zone.

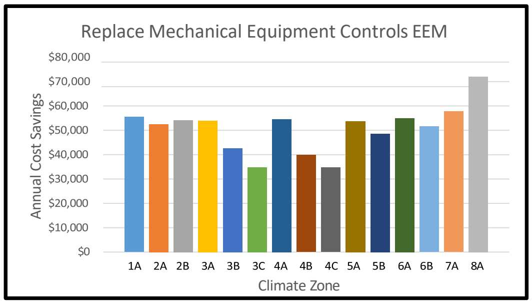
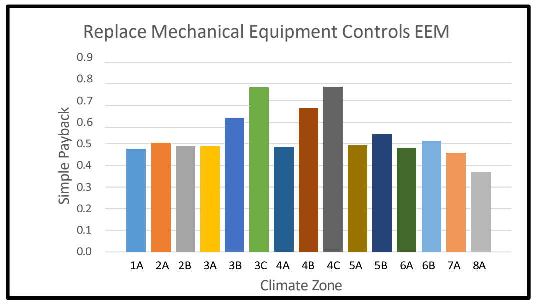


Figure 66. Bldg. 3419, simple payback resulting from EEM "Replace Mechanical Equipment Controls EEM," by climate zone.



5 Fort Bliss and Buildings Modeled

While this project was focused on the buildings at Fort Sill, three buildings that were modeled as part of a different study were revisited.

5.1 Buildings modeled

5.1.1 Bldg. 1

Figure 67. Bldg. 1, Fort Bliss.

Table 104. Fort Bliss, Bldg. 1 details.

Parameter	Measure
Year Built	1904
Square Footage ft^2	30,340
# of Stories	3 + basement
Original Use	
Current Use	Administrative
Envelope	
Roof	
Construction	Wood Frame, clay tiles
Insulation type and thickness	R-13 batt, no radiant barrier
Wall	
Construction	Triple brick masonry
Insulation type/thickness/location	None
Floor/Basement	

Parameter	Measure
Construction	Basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Single Pane, Wood Frame, Clear
Gross % of wall area (Overall)	15.9%
Occupancy	
Current Use	Administrative
Hours	0700-1800 M-Sa
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Forced Air
Cooling System	Direct Expansion (DX) Coils
Domestic Hot Water System	Natural gas fired, 39 gal tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	Various
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

5.1.2 Bldg. 115

Figure 68. Bldg. 115, Fort Bliss.

Table 105. Bldg. 115 Fort Bliss details.

Parameter	Measure
Year Built	1915
Square Footage ft^2	6,300
# of Stories	2 + ½ basement
Original Use	
Current Use	Administrative
Envelope	
Roof	
Construction	Wood Frame, clay tiles
Insulation type and thickness	None
Wall	
Construction	Concrete masonry unit (12 in.)
Insulation type/thickness/location	None
Floor/Basement	
Construction	Crawlspace/basement
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Single Pane, Wood Frame, Clear
Gross % of wall area (Overall)	15.9%
Occupancy	
Current Use	Administrative
Hours	24 hrs daily on 1st floor 0700-1700 on 2nd floor
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Air source heat pumps
Cooling System	Air source heat pumps
Domestic Hot Water System	Natural gas fired, 16 gal tank
HVAC Controls	DDC
Lighting and plug loads	
Primary Lighting Type/Fixture	Fluorescent T8
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

5.1.3 Bldg. 1103

Figure 69. Bldg. 1103, general purpose warehouse.

Table 106. Fort Bliss Bldg. 1103, details.

Parameter	Measure
Year Built	1921
Square Footage ft^2	16,000
# of Stories	1+
Original Use	
Current Use	Warehouse
Envelope	
Roof	
Construction	Wood Frame (24 in. o.c.), galvanized steel finish
Insulation type and thickness	R-11 batt, no radiant barrier
Wall	
Construction	Concrete masonry unit (12 in.)
Insulation type/thickness/location	None
Floor/Basement	
Construction	8 in. concrete floor 5 ft above grade
Insulation type/thickness/location	None
Windows	
Glazing/Frame/Features	Single Pane, Aluminum Frame, Clear Double Pane, Aluminum Frame, Tint
Gross % of wall area (Overall)	11.4%
Occupancy	

Parameter	Measure
Current Use	Warehouse
Hours	0800-1700 M-F
Average # of Occupants (if available)	N/A
HVAC	
Heating System	Forced Air
Cooling System	Evaporative Coolers
Domestic Hot Water System	Natural gas fired, 5 gal tank
HVAC Controls	Thermostat
Lighting and plug loads	
Primary Lighting Type/Fixture	Fluorescent T8
Lighting Usage	On during occupied/off during unoccupied hours
Lighting Controls	Switches

5.2 The building model results – "as is"

5.2.1 Original Use (Administrative -1) energy use – "as is"

The simulated annual energy use for Bldg. 1 is 335,800 kWh/year of electricity and 900.33 MMBtu/year of gas. With 30,340 ft^2 of envelope area, this equates to an EUI of 67 $kBtu/ft^2/yr$. The typical EUI for this building type (according to CBECS) in this climate is 87 $kBtu/ft^2/yr$.

5.2.2 Bldg. 115 (Administrative Building) energy use – "as is"

The simulated annual energy use for Bldg. 115 is 200,130 kWh/year of electricity and 7.41 MMBtu/year of gas. With 6,300 ft^2 of envelope area, this equates to an EUI of 110 $kBtu/ft^2/yr$. The typical EUI for this building type in this climate is 47 $kBtu/ft^2/yr$ (DOE 2011). This is only somewhat reliable due to representing only five total buildings. The most likely reason for the larger than usual energy use is the 24 hour per day occupancy for part of the building.

5.2.3 Bldg. 1103 (Warehouse) energy use – "as is"

The simulated annual energy use for Bldg. 1103 warehouse is 77,250 kWh/year of electricity and 1,163.1 MMBtu/year of gas. With 16,000 ft^2 of envelope area, this equates to an EUI of 89 $kBtu/ft^2/yr$. The typical EUI for this building type in this climate is 57 $kBtu/ft^2/yr$ (DOE 2011).

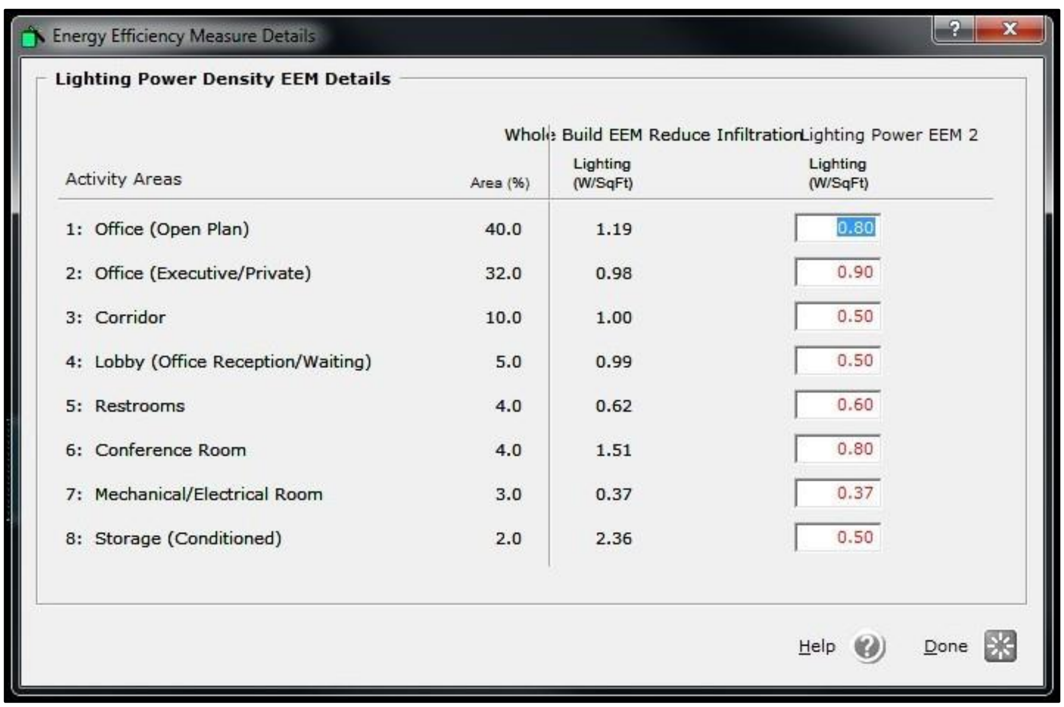
5.3 EEMs considered

5.3.1 Bldg. 1 EEM savings by climate zone

The EEMs chosen for Bldg. 1 were those with a simple payback of less than 30 years for the actual location of the building in El Paso, TX. These were:

- **Reduce Infiltration**. Building infiltration was changed from 2.00 ACH to 1.00 ACH.
- **High Efficiency Lighting**. The lighting power densities of the building were changed. Figure 70 shows the specifications.
- **Wall Insulation**. Three and a half inches of mineral/wool fiber fill insulation was added between the brick and gypsum board wall layers, where previously there was no insulation.
- **Night setback of thermostat temperatures**. The unoccupied cooling and heating setpoints were changed from 76 and 68 °F, to 80 and 60 °F, respectively.

Figure 70. Fort Bliss Bldg. 1, lighting details.



The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 107-121 and shown in Figures 71-79.

Table 107. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	38,338	34	$3,864	$16,406	4.2
High efficiency lighting	40,619	-2	$3,799	$52,807	13.9
Wall insulation	17,725	-3	$1,641	$13,723	8.4
Night setback of thermostat temperatures	22,182	11	$2,168	$446	0.2
Total	118,864	40	$11,473	$83,382	7.3

Table 108. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	29,232	282	$4,939	$16,406	3.3
High efficiency lighting	39,109	-24	$3,486	$52,807	15.1
Wall insulation	11,957	59	$1,582	$13,723	8.7
Night setback of thermostat temperatures	18,032	102	$2,487	$446	0.2
Total	98,330	419	$12,493	$83,382	6.7

Table 109. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	46,640	230	$6,169	$16,406	2.7
High efficiency lighting	38,932	-18	$3,516	$52,807	15.0
Wall insulation	17,145	25	$1,804	$13,723	7.6
Night setback of thermostat temperatures	23,625	90	$2,919	$446	0.2
Total	126,342	327	$14,408	$83,382	5.8

Table 110. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	23,856	506	$6,177	$16,406	2.7
High efficiency lighting	38,268	-45	$3,243	$52,807	16.3
Wall insulation	8,914	145	$1,965	$13,723	7.0
Night setback of thermostat temperatures	17,678	169	$2,975	$446	0.1
Total	88,716	774	$14,352	$83,382	5.8

Table 111. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	18,273	375	$4,633	$16,406	3.5
High efficiency lighting	37,180	-34	$3,227	$52,807	16.4
Wall insulation	8,348	74	$1,360	$13,723	10.1
Night setback of thermostat temperatures	17,463	141	$2,737	$446	0.2
Total	81,264	556	$11,956	$83,382	7.0

Table 112. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	7,535	618	$5,516	$16,406	3.0
High efficiency lighting	34,707	-71	$2,707	$52,807	19.5
Wall insulation	-7,155	125	$301	$13,723	45.6
Night setback of thermostat temperatures	19,512	265	$3,894	$446	0.1
Total	54,599	938	$12,424	$83,382	6.7

Table 113. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	15,644	758	$7,366	$16,406	2.2
High efficiency lighting	35,378	-63	$2,832	$52,807	18.6
Wall insulation	2,474	260	$2,255	$13,723	6.1
Night setback of thermostat temperatures	13,544	236	$3,108	$446	0.1
Total	67,039	1,191	$15,561	$83,382	5.4

Table 114. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	9,357	580	$5,391	$16,406	3.0
High efficiency lighting	35,602	-56	$2,907	$52,807	18.2
Wall insulation	-11	191	$1,485	$13,723	9.2
Night setback of thermostat temperatures	13,255	193	$2,746	$446	0.2
Total	58,203	908	$12,530	$83,382	6.7

Table 115. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	10,835	814	$7,350	$16,406	2.2
High efficiency lighting	33,718	-86	$2,497	$52,807	21.1
Wall insulation	-4,809	269	$1,641	$13,723	8.4
Night setback of thermostat temperatures	16,433	294	$3,830	$446	0.1
Total	56,176	1,291	$15,319	$83,382	5.4

Table 116. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	12,857	947	$8,575	$16,406	1.9
High efficiency lighting	34,748	-72	$2,703	$52,807	19.5
Wall insulation	735	353	$2,815	$13,723	4.9
Night setback of thermostat temperatures	12,646	278	$3,350	$446	0.1
Total	60,985	1,507	$17,451	$83,382	4.8

Table 117. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	7,618	802	$6,955	$16,406	2.4
High efficiency lighting	34,115	-74	$2,628	$52,807	20.1
Wall insulation	-3,522	315	$2,120	$13,723	6.5
Night setback of thermostat temperatures	13,358	266	$3,324	$446	0.1
Total	51,570	1,309	$15,026	$83,382	5.5

Table 118. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	13,058	1,133	$10,041	$16,406	1.6
High efficiency lighting	34,101	-82	$2,564	$52,807	20.6
Wall insulation	-1,016	407	$3,071	$13,723	4.5
Night setback of thermostat temperatures	12,749	311	$3,617	$446	0.1
Total	58,892	2,930	$28,325	$83,382	2.9

Table 119. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	9,151	1,012	$8,733	$16,406	1.9
High efficiency lighting	33,774	-83	$2,526	$52,807	20.9
Wall insulation	-2,221	398	$2,888	$13,723	4.8
Night setback of thermostat temperatures	13,444	297	$3,573	$446	0.1
Total	54,148	1,624	$17,719	$83,382	4.7

Table 120. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	9,300	1,361	$11,462	$16,406	1.4
High efficiency lighting	33,044	-91	$2,395	$52,807	22.1
Wall insulation	-2,776	535	$3,902	$13,723	3.5
Night setback of thermostat temperatures	12,121	364	$3,970	$446	0.1
Total	51,689	2,169	$21,728	$83,382	3.8

Table 121. Bldg. 1, Fort Bliss, savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	26,828	1,940	$17,612	$16,406	0.9
High efficiency lighting	30,156	-102	$2,038	$52,807	25.9
Wall insulation	2,432	727	$5,884	$13,723	2.3
Night setback of thermostat temperatures	8,739	380	$3,777	$446	0.1
Total	68,155	2,960	$29,429	$83,382	2.8

Figure 71. Bldg. 1, Fort Bliss, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

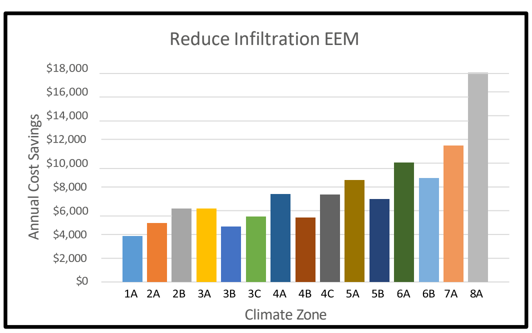


Figure 72. Bldg. 1, Fort Bliss, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

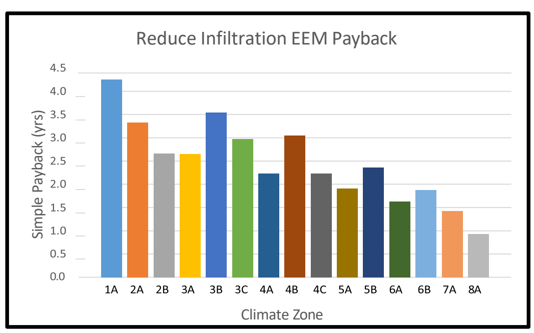


Figure 73. Bldg. 1, Fort Bliss, annual cost savings resulting from EEM "High Efficiency Lighting," by climate zone.

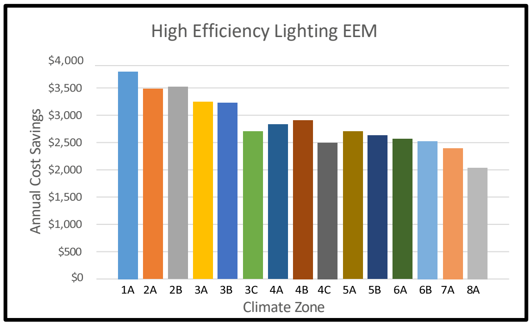


Figure 74. Bldg. 1, Fort Bliss, simple payback resulting from EEM "High Efficiency Lighting," by climate zone.

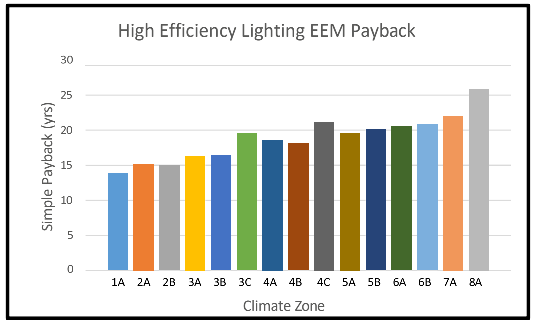


Figure 75. Bldg. 1, Fort Bliss, annual cost savings resulting from EEM "Wall Insulation," by climate zone.

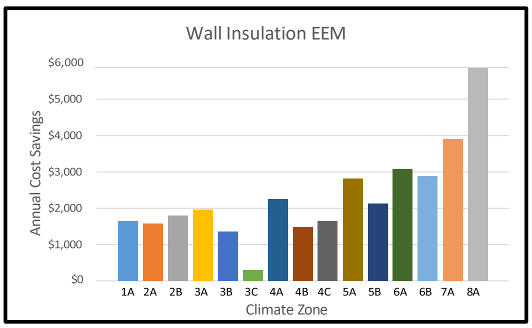


Figure 76. Bldg. 1, Fort Bliss, simple payback resulting from EEM "Wall Insulation," by climate zone.

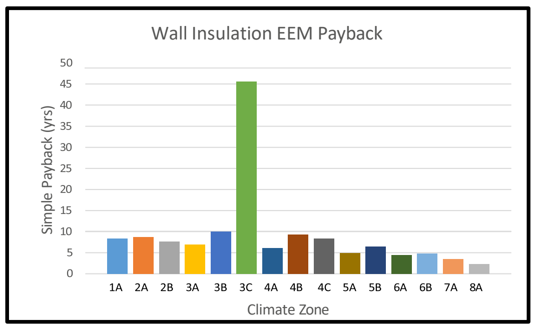


Figure 77. Bldg. 1, Fort Bliss, annual cost savings resulting from EEM "Night Setback of Thermostat Temperatures EEM," by climate zone.

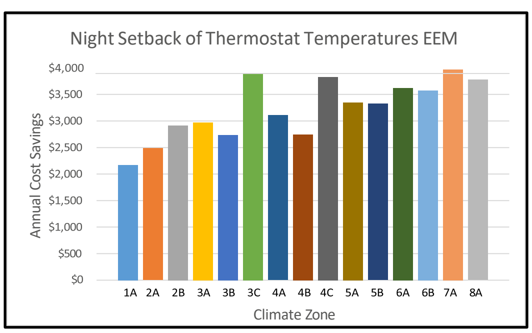


Figure 78. Bldg. 1, Fort Bliss, simple payback resulting from EEM "Night Setback of Thermostat Temperatures EEM," by climate zone.

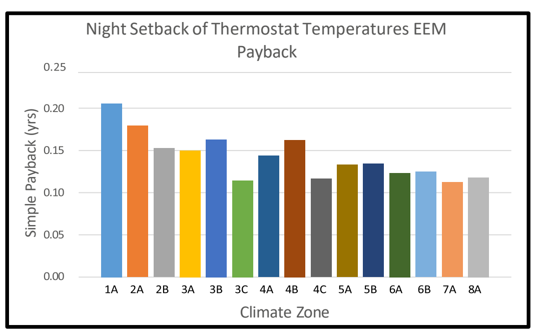
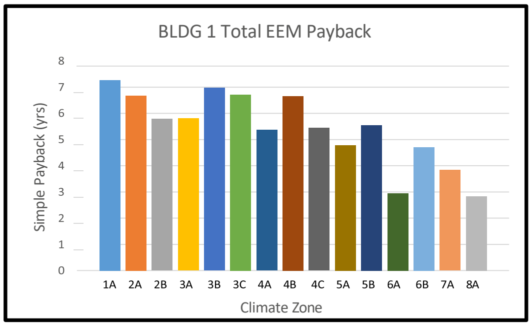


Figure 79. Bldg. 1, Fort Bliss, total EEM payback, by climate zone.

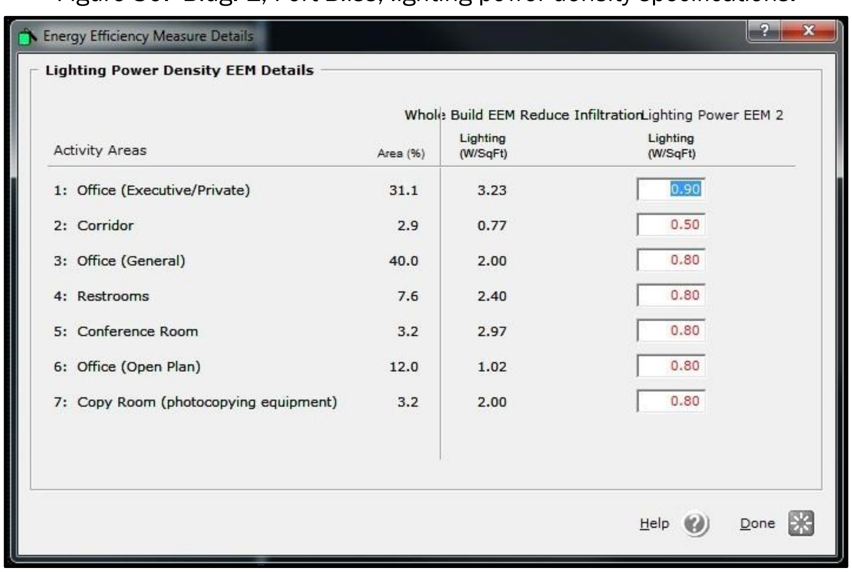


5.3.2 Bldg. 115 EEM savings by climate zone

The EEMs chosen for Bldg. 115 were those with a simple payback of under 30 years, for the actual location of the building in El Paso, TX. These were:

- **Reduce Infiltration**. The building infiltration was changed from 2.00 ACH to 1.00 ACH.
- **High Efficiency Lighting**. The lighting power densities of the building were changed. Figure 80 shows the specifications.
- **Night setback of thermostat temperatures**. The unoccupied cooling and heating setpoints were changed from 73 and 68 °F to 85 and 61 °F, respectively. The occupancy schedule was also changed, for the second floor, from 24 hours per day to 0700-1800 Monday-Friday and 0700-1300 Saturday, and unoccupied Sunday and Holidays.

Figure 80. Bldg. 1, Fort Bliss, lighting power density specifications.


Energy Efficiency Measure Details

Lighting Power Density EEM Details

Activity Areas	Area (%)	Whole Build EEM Reduce Infiltration Lighting (W/SqFt)	Lighting Power EEM 2 Lighting (W/SqFt)
1: Office (Executive/Private)	31.1	3.23	0.90
2: Corridor	2.9	0.77	0.50
3: Office (General)	40.0	2.00	0.80
4: Restrooms	7.6	2.40	0.80
5: Conference Room	3.2	2.97	0.80
6: Office (Open Plan)	12.0	1.02	0.80
7: Copy Room (photocopying equipment)	3.2	2.00	0.80

Help Done

The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 122-136 and shown in Figures 81-87.

Table 122. Bldg. 115 savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	12,376	0	$1,162	$11,181	9.6
High efficiency lighting	62,647	0	$5,883	$29,485	5.0
Night setback of thermostat temperatures	24,523	0	$2,303	$446	0.2
Total	99,546	0	$9,347	$41,112	4.4

Table 123. Bldg. 115 savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	13,537	0	$1,271	$11,181	8.8
High efficiency lighting	56,513	0	$5,307	$29,485	5.6
Night setback of thermostat temperatures	22,341	0	$2,098	$446	0.2
Total	92,391	0	$8,676	$41,112	4.7

Table 124. Bldg. 115 savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	14,151	0	$1,329	$11,181	8.4
High efficiency lighting	56,630	0	$5,318	$29,485	5.5
Night setback of thermostat temperatures	22,510	0	$2,114	$446	0.2
Total	93,290	0	$8,760	$41,112	4.7

Table 125. Bldg. 115 savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	14,437	0	$1,356	$11,181	8.2
High efficiency lighting	51,750	0	$4,859	$29,485	6.1
Night setback of thermostat temperatures	21,383	0	$2,008	$446	0.2
Total	87,571	0	$8,223	$41,112	5.0

Table 126. Bldg. 115 savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	9,528	0	$895	$11,181	12.5
High efficiency lighting	53,118	0	$4,988	$29,485	5.9
Night setback of thermostat temperatures	19,119	0	$1,795	$446	0.2
Total	81,765	0	$7,678	$41,112	5.4

Table 127. Bldg. 115 savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	6,573	0	$617	$11,181	18.1
High efficiency lighting	46,602	0	$4,376	$29,485	6.7
Night setback of thermostat temperatures	10,072	0	$946	$446	0.5
Total	63,247	0	$5,939	$41,112	6.9

Table 128. Bldg. 115 savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	18,815	0	$1,767	$11,181	6.3
High efficiency lighting	46,955	0	$4,409	$29,485	6.7
Night setback of thermostat temperatures	22,788	0	$2,140	$446	0.2
Total	88,559	0	$8,316	$41,112	4.9

Table 129. Bldg. 115 savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	11,929	0	$1,120	$11,181	10.0
High efficiency lighting	47,630	0	$4,472	$29,485	6.6
Night setback of thermostat temperatures	18,158	0	$1,705	$446	0.3
Total	77,717	0	$7,298	$41,112	5.6

Table 130. Bldg. 115 savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	12,433	0	$1,167	$11,181	9.6
High efficiency lighting	44,297	0	$4,159	$29,485	7.1
Night setback of thermostat temperatures	16,276	0	$1,528	$446	0.3
Total	73,007	0	$6,855	$41,112	6.0

Table 131. Bldg. 115 savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	29,316	0	$2,753	$11,181	4.1
High efficiency lighting	39,340	0	$3,694	$29,485	8.0
Night setback of thermostat temperatures	28,011	0	$2,630	$446	0.2
Total	96,667	0	$9,077	$41,112	4.5

Table 132. Bldg. 115 savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	19,172	0	$1,800	$11,181	6.2
High efficiency lighting	40,350	0	$3,789	$29,485	7.8
Night setback of thermostat temperatures	24,429	0	$2,294	$446	0.2
Total	83,950	0	$7,883	$41,112	5.2

Table 133. Bldg. 115 savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	35,403	0	$3,324	$11,181	3.4
High efficiency lighting	36,992	0	$3,474	$29,485	8.5
Night setback of thermostat temperatures	34,044	0	$3,197	$446	0.1
Total	106,439	0	$9,995	$41,112	4.1

Table 134. Bldg. 115 savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	30,197	0	$2,835	$11,181	3.9
High efficiency lighting	36,158	0	$3,395	$29,485	8.7
Night setback of thermostat temperatures	30,531	0	$2,867	$446	0.2
Total	96,886	0	$9,098	$41,112	4.5

Table 135. Bldg. 115 savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	46,141	0	$4,333	$11,181	2.6
High efficiency lighting	31,580	0	$2,965	$29,485	9.9
Night setback of thermostat temperatures	44,883	0	$4,215	$446	0.1
Total	122,604	0	$11,513	$41,112	3.6

Table 136. Bldg. 115 savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce infiltration	73,923	0	$6,941	$11,181	1.6
High efficiency lighting	25,841	0	$2,426	$29,485	12.2
Night setback of thermostat temperatures	71,538	0	$6,717	$446	0.1
Total	171,302	0	$16,085	$41,112	2.6

Figure 81. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

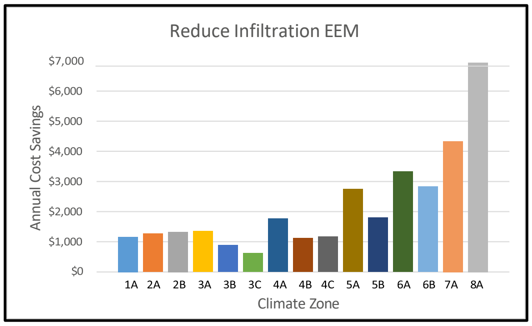


Figure 82. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

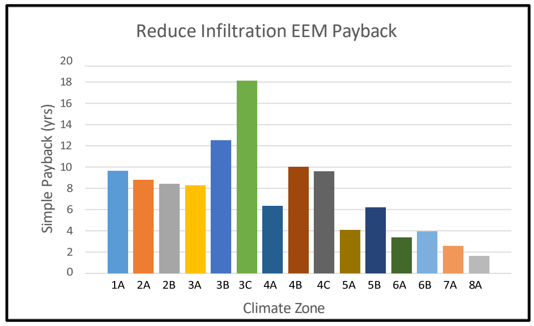


Figure 83. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "High Efficiency Lighting," by climate zone.

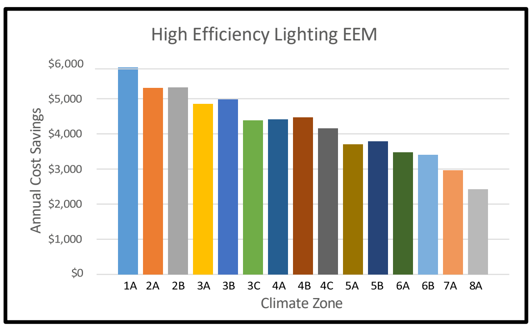


Figure 84. Bldg. 115, Fort Bliss, simple payback resulting from EEM "High Efficiency Lighting," by climate zone.

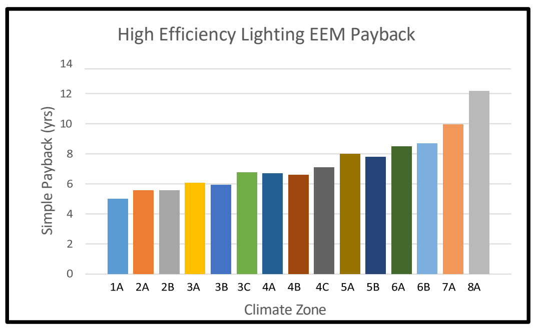


Figure 85. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Night Setback of Thermostat Temperatures EEM," by climate zone.

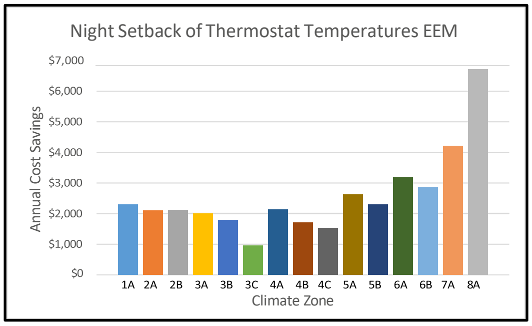


Figure 86. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Night Setback of Thermostat Temperatures EEM," by climate zone.

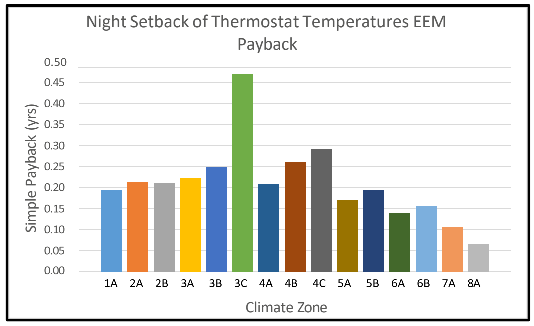
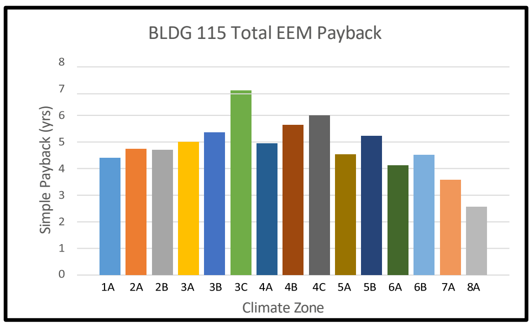


Figure 87. Bldg. 115, Fort Bliss, total EEM payback, by climate zone.



5.3.3 Bldg. 1103 EEM savings by climate zone

The EEMs chosen for Bldg. 1103 were those with a simple payback of under 30 years, for the actual location of the building in El Paso, TX. They were:

- **Reduce Infiltration**. The building infiltration was changed from 2.00 ACH to 1.00 ACH.
- **Use Condensing Furnaces**. The building's 65% efficiency boiler was replaced with a 90% efficiency boiler.
- **Wall Insulation**. R-13 wood furred interior insulation was added to the exterior building walls, where previously there was no insulation.
- **Ground Floor Insulation**. Three inches of polyurethane (R-18) exterior/cavity insulation was added to the ground floor, where previously there was no insulation. This can be done from underneath the floor since the building sits on pillars.
- **Use Sky Lighting**. The Daylighting option in eQUEST was enabled using the simplified method. One photo sensor was selected, and 100% of the building's lights were selected to use daylighting. The design light

level was set at 40 footcandles, and the control method was set to allow light produced by the light fixtures to be reduced by up to 30% to take advantage of natural daylight.

The model was then run in each of the different climate zones using eQUEST. The results are listed in Tables 137-151 and shown in Figures 88-98. Of note concerning the Sky Lighting ECM, reducing the power used for lighting produces a small penalty on the heating requirement since the (fewer) remaining lights produce correspondingly less heat.

Table 137. Bldg. 1103 savings and payback summary, Climate Zone 1A (Miami, FL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	-489	29	$180	$9,183	51.1
Use Condensing Furnaces	0	23	$179	$14,578	81.5
Wall Insulation	3,249	2	$321	$6,596	20.6
Ground Floor Insulation	3,653	37	$631	$55,002	87.2
Use Sky Lighting	8,882	-1	$826	$4,458	5.4
Total	15,295	89	$2,129	$89,817	42.2

Table 138. Bldg. 1103 savings and payback summary, Climate Zone 2A (Houston, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	-92	95	$730	$9,183	12.6
Use Condensing Furnaces	0	191	$1,486	$14,578	9.8
Wall Insulation	2,240	15	$327	$6,596	20.2
Ground Floor Insulation	3,267	160	$1,552	$55,002	35.4
Use Sky Lighting	8,487	-8	$735	$4,458	6.1
Total	13,902	453	$4,830	$89,817	18.6

Table 139. Bldg. 1103 savings and payback summary, Climate Zone 2B (Phoenix, AZ).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	547	126	$1,032	$9,183	8.9
Use Condensing Furnaces	0	158	$1,229	$14,578	11.9
Wall Insulation	1,700	11	$245	$6,596	26.9
Ground Floor Insulation	4,758	163	$1,715	$55,002	32.1
Use Sky Lighting	8,364	-7	$731	$4,458	6.1
Total	15,369	451	$4,952	$89,817	18.1

Table 140. Bldg. 1103 savings and payback summary, Climate Zone 3A (Memphis, TN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	69	117	$917	$9,183	10.0
Use Condensing Furnaces	0	337	$2,622	$14,578	5.6
Wall Insulation	1,697	23	$338	$6,596	19.5
Ground Floor Insulation	3,213	226	$2,060	$55,002	26.7
Use Sky Lighting	8,294	-13	$678	$4,458	6.6
Total	13,273	690	$6,615	$89,817	13.6

Table 141. Bldg. 1103 savings and payback summary, Climate Zone 3B (El Paso, TX).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	202	141	$1,116	$9,183	8.2
Use Condensing Furnaces	0	283	$2,202	$14,578	6.6
Wall Insulation	1,944	22	$354	$6,596	18.6
Ground Floor Insulation	5,036	270	$2,573	$55,002	21.4
Use Sky Lighting	8,417	-12	$697	$4,458	6.4
Total	15,598	705	$6,950	$89,817	12.9

Table 142. Bldg. 1103 savings and payback summary, Climate Zone 3C (San Francisco, CA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	1,343	333	$2,717	$9,183	3.4
Use Condensing Furnaces	0	488	$3,797	$14,578	3.8
Wall Insulation	-72	50	$382	$6,596	17.3
Ground Floor Insulation	2,687	509	$4,212	$55,002	13.1
Use Sky Lighting	7,819	-24	$547	$4,458	8.1
Total	11,777	1,354	$11,640	$89,817	7.7

Table 143. Bldg. 1103 savings and payback summary, Climate Zone 4A (Baltimore, MD).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	61	102	$799	$9,183	11.5
Use Condensing Furnaces	0	470	$3,657	$14,578	4.0
Wall Insulation	1,324	16	$249	$6,596	26.5
Ground Floor Insulation	2,790	230	$2,051	$55,002	26.8
Use Sky Lighting	8,060	-14	$648	$4,458	6.9
Total	12,235	803	$7,396	$89,817	12.1

Table 144. Bldg. 1103 savings and payback summary, Climate Zone 4B (Albuquerque, NM).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	179	114	$904	$9,183	10.2
Use Condensing Furnaces	0	430	$3,345	$14,578	4.4
Wall Insulation	1,542	23	$324	$6,596	20.4
Ground Floor Insulation	3,782	319	$2,837	$55,002	19.4
Use Sky Lighting	8,204	-15	$654	$4,458	6.8
Total	13,708	870	$8,056	$89,817	11.1

Table 145. Bldg. 1103 savings and payback summary, Climate Zone 4C (Seattle, WA).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	1,017	192	$1,589	$9,183	5.8
Use Condensing Furnaces	0	592	$4,606	$14,578	3.2
Wall Insulation	-4	31	$241	$6,596	27.4
Ground Floor Insulation	2,391	429	$3,562	$55,002	15.4
Use Sky Lighting	7,209	-21	$514	$4,458	8.7
Total	10,613	1,222	$10,504	$89,817	8.6

Table 146. Bldg. 1103 savings and payback summary, Climate Zone 5A (Chicago, IL).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	259	94	$756	$9,183	12.2
Use Condensing Furnaces	0	542	$4,217	$14,578	3.5
Wall Insulation	1,006	17	$227	$6,596	29.1
Ground Floor Insulation	2,681	207	$1,862	$55,002	29.5
Use Sky Lighting	8,011	-13	$651	$4,458	6.8
Total	11,957	847	$7,712	$89,817	11.6

Table 147. Bldg. 1103 savings and payback summary, Climate Zone 5B (Colorado Springs, CO).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	694	125	$1,038	$9,183	8.8
Use Condensing Furnaces	0	564	$4,388	$14,578	3.3
Wall Insulation	598	26	$258	$6,596	25.5
Ground Floor Insulation	2,740	349	$2,973	$55,002	18.5
Use Sky Lighting	7,982	-18	$609	$4,458	7.3
Total	12,015	1,046	$9,266	$89,817	9.7

Table 148. Bldg. 1103 savings and payback summary, Climate Zone 6A (Burlington, VT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	595	123	$1,013	$9,183	9.1
Use Condensing Furnaces	0	587	$4,567	$14,578	3.2
Wall Insulation	448	18	$182	$6,596	36.2
Ground Floor Insulation	2,280	210	$1,848	$55,002	29.8
Use Sky Lighting	7,892	-13	$640	$4,458	7.0
Total	11,215	924	$8,242	$89,817	10.9

Table 149. Bldg. 1103 savings and payback summary, Climate Zone 6B (Helena, MT).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	434	129	$1,044	$9,183	8.8
Use Condensing Furnaces	0	623	$4,847	$14,578	3.0
Wall Insulation	623	26	$261	$6,596	25.3
Ground Floor Insulation	2,497	296	$2,537	$55,002	21.7
Use Sky Lighting	7,716	-17	$592	$4,458	7.5
Total	11,270	1,057	$9,282	$89,817	9.7

Table 150. Bldg. 1103 savings and payback summary, Climate Zone 7A (Duluth, MN).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	622	117	$969	$9,183	9.5
Use Condensing Furnaces	0	699	$5,438	$14,578	2.7
Wall Insulation	160	22	$186	$6,596	35.4
Ground Floor Insulation	1,807	251	$2,122	$55,002	25.9
Use Sky Lighting	7,761	-16	$604	$4,458	7.4
Total	10,351	1,073	$9,320	$89,817	9.6

Table 151. Bldg. 1103 savings and payback summary, Climate Zone 8A (Fairbanks, AK).

EEM	Electrical Savings (kWh/yr)	Thermal Savings (Mil. Btu/yr)	Annual Cost Savings	Implementation Costs	Payback Period (yrs)
Reduce Infiltration	558	119	$978	$9,183	9.4
Use Condensing Furnaces	0	759	$5,905	$14,578	2.5
Wall Insulation	48	17	$137	$6,596	48.2
Ground Floor Insulation	1,396	232	$1,936	$55,002	28.4
Use Sky Lighting	6,031	-15	$450	$4,458	9.9
Total	8,034	1,113	$9,414	$89,817	9.5

Figure 88. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Reduce Infiltration," by climate zone.

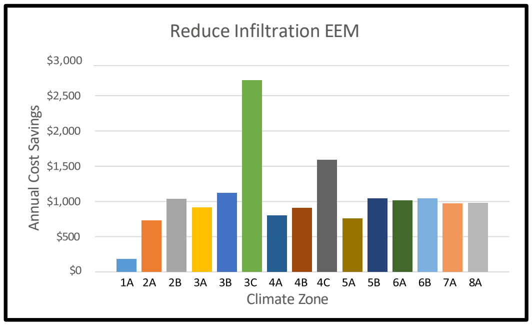


Figure 89. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Reduce Infiltration," by climate zone.

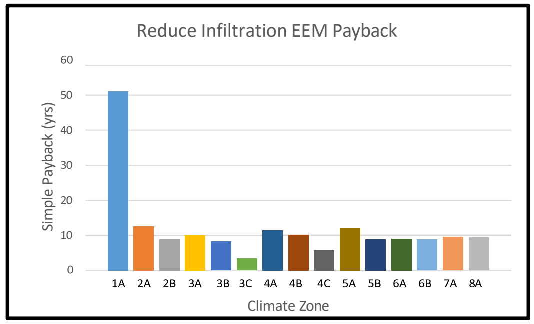


Figure 90. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Use Condensing Furnaces," by climate zone.

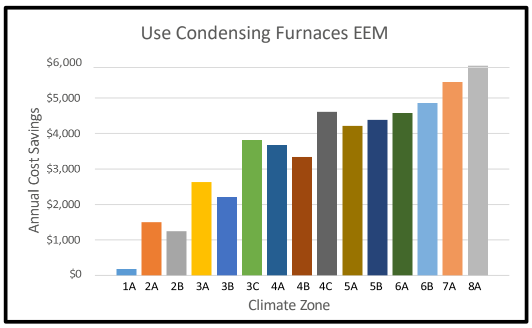


Figure 91. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Use Condensing Furnaces," by climate zone.

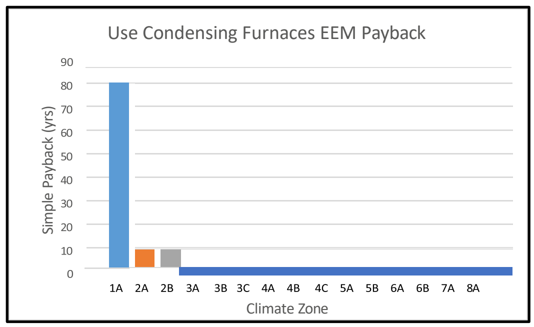


Figure 92. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Wall Insulation EEM," by climate zone.

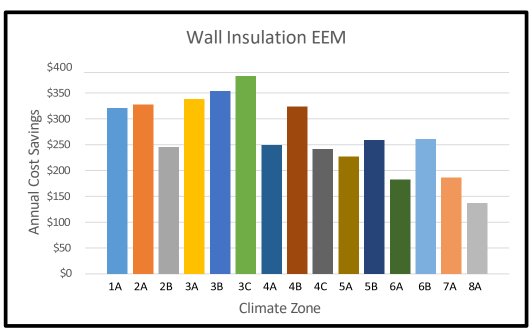


Figure 93. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Wall Insulation EEM," by climate zone.

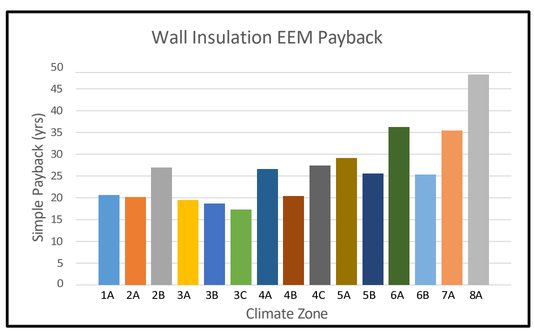


Figure 94. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Ground Floor Insulation EEM," by climate zone.

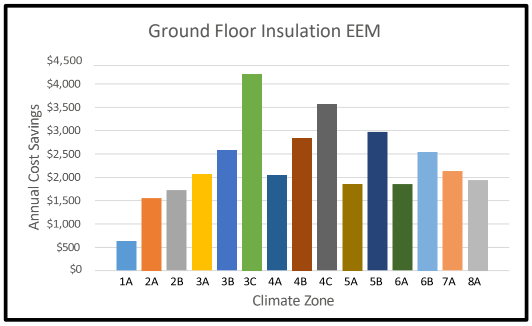


Figure 95. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Ground Floor Insulation EEM," by climate zone.

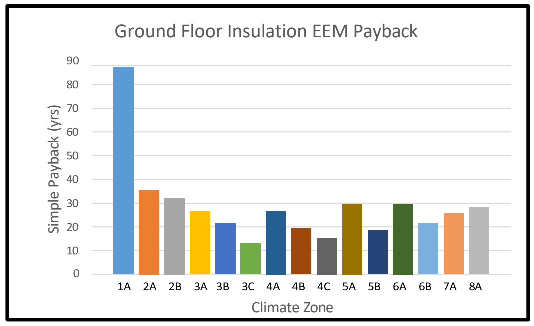


Figure 96. Bldg. 115, Fort Bliss, annual cost savings resulting from EEM "Use Skylighting EEM," by climate zone.

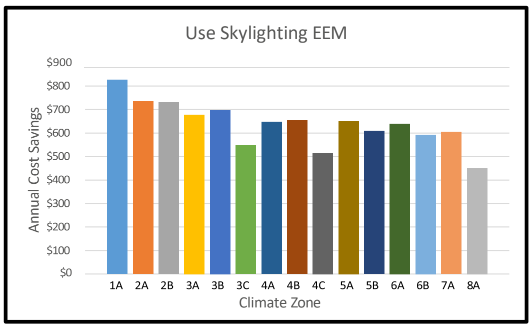


Figure 97. Bldg. 115, Fort Bliss, simple payback resulting from EEM "Use Skylighting EEM," by climate zone.

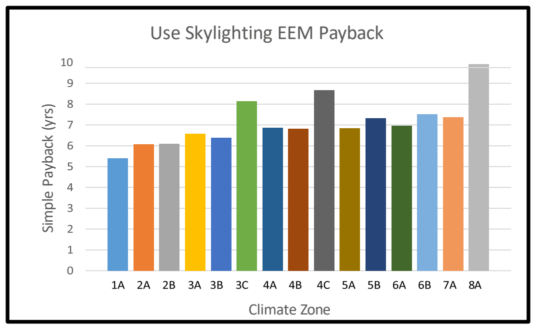
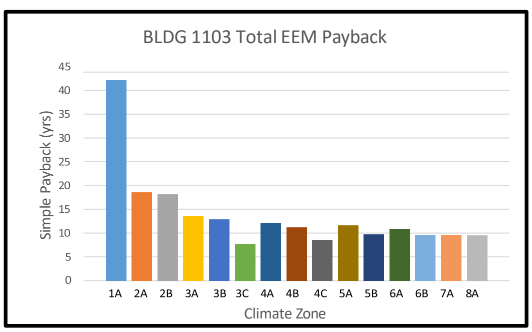


Figure 98. Bldg. 115, Fort Bliss, total EEM payback.



6 Historic Building Energy Savings Spreadsheet Tool

An Excel spreadsheet was developed to compile the results. It contains calculations of energy and cost savings. The utility costs used in calculations (natural gas and electricity) are a DoD average. These quantities can be easily changed if needed to recalculate the dollar savings for a particular location. The tool and the eQUEST models are available at the same Internet location as this report.

7 Summary and Conclusions

This study assessed the inventory of historic (or eligible candidates) buildings and developed recommended EEMs. At Fort Sill, six buildings that represent commonly found buildings were selected to be studied for potential EEMs. Three historic buildings located at Fort Bliss were also included in the analysis. Computer models of each building's energy use were developed and used to estimate the potential energy savings, cost, and simple payback. The results were then extrapolated to the 15 U.S. climate zones. This report provides a list of EEMs that may be applicable to historic buildings and can be used as a general guide to determine their effectiveness in various climate zones.

Key findings are summarized below and in Tables 152-160:

- In milder climates, most EEMs yield lower savings and result in higher payback.
- **Replacement of mechanical equipment controls** (to enable set-point and schedule changes) is by far the most cost-effective energy saving measure, with an average simple payback of less than 2 months for all buildings in all climate zones. The costs assumed were the minimum needed to allow setpoint and schedule changes. In many cases, it could be desirable to make changes to controls, such as installing Direct Digital Controls (DDC) for all equipment.
- **Reduction of infiltration** is also very effective, with a payback of less than 5 years in all but 8% of the climate zone building combinations.
- Improvement of **wall insulation** on the inside of exterior walls is also very cost effective, with a simple payback of less than 5 years in nine of the 15 zones, most of which were in the colder zones.
- Although **lighting retrofits** typically yield very good paybacks, they did not produce favorable results in most of the modeled buildings for two reasons: (1) The lighting density in these buildings was very low, and no areas were over-lit (2) Most buildings had already been retrofitted with energy-efficient lighting.
- The study found improvements in **roof/attic insulation** generally result in poor savings. Only Bldg. 441 had a simple payback of less than 15 years, and only five (cooler) climate zones had a simple payback of less than 30 years.
- **Replacement of mechanical equipment** generally yield good payback. As expected, replacing chillers in warm climates and boilers in cold climates also yield good paybacks.
- The use of **Renewable Energy** can be feasible in two buildings (3419 and 1803). Wind turbines could be a viable option but would ultimately distract from the historic scenery of the area. PV panels could instead be installed on the roof of Bldg. 3419 in combination with additional water heating panels to maintain the historical nature of the buildings. However, there was not enough demand for hot water in this administrative building to justify this measure. PV

has potential energy savings on Bldg. 3419, but the payback is relatively long at 21 to 40 years. In Bldg. 1803, the replacement of conventional boiler/chiller systems with ground source heat pumps have a good payback (1 to 7 years) depending on climate zone it is located in. Note that although ground source heat pumps have a good payback in colder climate zones, it may not be practical and is highly dependent on specific manufacturers and the equipment's operating bounds.
- Improvement of **ground floor insulation** is generally not recommended due to poor paybacks.

Bldgs. 441, 462, 463, 750, 1803, and 3419 are located at Fort Sill, OK.

Bldgs. 1, 115, and 1103 are located at Fort Bliss, TX.

The nomenclature used to identify the buildings is as follows: Original Use (Current Use – Building #).

Table 152. Simple payback resulting from decreasing infiltration.

Bldg. \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Barracks (Museum-441)	6.1	2.0	3.0	1.7	2.9	3.4	1.5	2.3	2.0	1.2	1.9	1.0	1.2	0.8	0.5
Unknown (Admin-462)	4.0	1.7	3.3	1.1	2.5	2.0	0.9	1.8	1.5	0.5	0.8	0.5	0.6	0.5	0.3
Unknown (Admin-463)	1.7	0.6	1.0	0.6	1.2	1.1	0.6	0.7	0.8	0.4	0.5	0.4	0.4	0.3	0.2
Unknown (Admin-750)	4.5	5.7	8.6	4.7	7.5	25.1	4.4	6.7	8.9	1.9	3.0	1.8	1.7	1.2	0.9
Bakery (Admin-1803)	3.0	0.9	2.0	0.9	1.1	2.1	1.0	1.0	1.3	0.6	1.2	0.6	0.6	0.5	0.4
Unknown (Battalion HQ-3419)	0.4	0.2	0.2	0.1	0.3	0.4	0.1	0.3	0.3	0.1	0.2	0.1	0.1	0.1	0.1

Table 153. Simple payback resulting from improving wall insulation.

Bldg. \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Barracks (Museum-441)	9.7	6.1	9.8	4.7	8.1	9.8	4.0	5.3	5.0	3.0	3.6	2.5	2.7	1.9	1.4
Unknown (Admin-1)	8.4	8.7	7.6	7.0	10.1	45.6	6.1	9.2	8.4	4.9	6.5	4.5	4.8	3.5	2.3
Unknown (Admin-1103)	20.6	20.2	26.9	19.5	18.6	17.3	26.5	20.4	27.4	29.1	25.5	36.2	25.3	35.4	48.2

Table 154. Simple payback resulting from improving roof/attic insulation.

Bldg. \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Barracks (Museum-441)	28.5	22.3	19.4	20.3	19.2	62.9	16.2	13.8	18.2	12.7	11.8	10.8	10.0	7.8	4.8
Unknown (Admin-462)	109.2	99.7	43.7	96.4	60.7	116.2	75.5	90.8	119.5	140.9	110.1	127.4	63.1	158.9	113.1
Unknown (Admin-463)	42.7	81.8	31.2	81.2	45.7	87.4	90.1	63.5	87.3	92.5	74.7	86.1	42.8	91.3	40.4
Unknown (Admin-750)	208.5	166.5	145.4	131.7	120.3	159.2	130.6	108.1	123.6	137.2	104.9	104.4	72.6	107.8	32.5
Bakery (Admin-1803)	240.4	201.0	88.9	174.9	19.2	174.9	186.2	153.9	167.0	169.1	194.4	162.7	86.6	221.2	67.9

Legend: Very good (green) = 0 to 5 | Good (yellow) = 5 to 15 | Bad (red) = 15 +

Table 155. Simple payback resulting from replacing mechanical equipment.

Building \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Unknown (Admin-462)	100.1	33.8	46.2	22.0	30.2	23.9	15.5	20.8	17.5	10.8	13.1	9.8	10.2	7.9	5.7
Unknown (Admin-463)	33.0	6.5	11.7	4.6	6.8	5.9	3.5	4.6	4.2	2.5	2.8	2.3	2.4	1.8	1.5
Unknown (Admin-750)	1614.7	44.2	76.9	19.7	32.0	30.2	10.4	14.9	11.6	7.1	8.8	5.7	6.3	4.2	2.7
Bakery (Admin-1803)	7.0	3.9	4.7	2.4	4.6	6.3	2.1	2.7	2.9	1.5	1.8	1.4	1.5	1.2	1.0
Unknown (Battalion HQ-3419)	0.5	0.5	0.5	0.5	0.6	0.8	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.5	0.1
Unknown (Admin – 1103)	81.5	9.8	11.9	5.6	5.6	6.6	3.8	4.0	4.4	3.2	3.5	3.3	3.2	3.0	2.7

Table 156. Simple payback resulting from replacing mechanical equipment controls

Building \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Barracks (Museum-441)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Unknown (Admin-462)	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.2
Unknown (Admin-463)	0.2	0.1	0.3	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Unknown (Admin-750)	0.3	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Unknown (Admin-1803)	0.7	0.4	0.6	0.4	0.5	0.5	0.4	0.4	0.5	0.3	0.3	0.3	0.3	0.3	0.2
Original Use (Battalion HQ-3419)	0.5	0.5	0.5	0.5	0.6	0.8	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.5	0.1
Unknown (Admin – 1)	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Unknown (Admin – 115)	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.3	0.3	0.2	0.2	0.1	0.2	0.1	0.1

Legend: Very good (green) = 0 to 5 | Good (yellow) = 5 to 15 | Bad (red) = 15 +

Table 157. Simple payback resulting from lighting retrofits.

Building \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Unknown (Admin-462)	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4
Unknown (Admin-463)	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Unknown (Admin-750)	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Bakery (Admin-1803)	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
Original Use (Battalion HQ-3419)	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2
Unknown (Admin – 1)	13.9	15.1	15.0	16.3	16.4	19.5	18.6	18.2	21.1	19.5	20.1	20.6	20.9	22.1	25.9
Unknown (Admin – 115)	5.0	5.6	5.5	6.1	5.9	6.7	6.7	6.6	7.1	8.0	7.8	8.5	8.7	9.9	12.2

Table 158. Simple payback resulting from PV panels retrofit.

Zone /Building	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Unknown (Battalion HQ-3419)	25.5	27.8	21.6	25.7	21.0	24.0	28.2	20.9	34.2	29.1	23.5	29.7	28.1	29.1	40.3

Table 159. Simple payback resulting from improving ground floor insulation.

Building \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Unknown (Admin – 1103)	87.2	35.4	32.1	26.7	21.4	13.1	26.8	19.4	15.4	29.5	18.5	29.8	21.7	25.9	28.4

Table 160. Simple payback resulting from the use of skylighting.

Building \ Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Unknown (Admin – 1103)	5.4	6.1	6.1	6.6	6.4	8.1	6.9	6.8	8.7	6.8	7.3	7.0	7.5	7.4	9.9

Legend: Very good (green) = 0 to 5 | Good (yellow) = 5 to 15 | Bad (red) = 15 +

References

Barbose, Galen, and Naim Darghouth. 2016. *Tracking the Sum IX: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States*. Berkeley, CA: Lawrence Berkley National Laboratory (LBNL), https://eetd.lbl.gov/sites/all/files/tracking_the_sun_ix_report.pdf

Cherry/See/Reams Architects. "Design Guidelines for Implementing Energy Efficiency Strategies in Historic Properties." DOD Environment, Safety & Occupational Health Network and Information Exchange (DENIX), 20 Sept. 2013, www.denix.osd.mil/legacy/denix-files/sites/33/2022/01/Design-Guidelines-for-DoD-Historic-Buildings-and-Districts-Fact-Sheet-2008-Legacy-07-382.pdf.

Department of Energy. "Buildings Energy Data Book." Buildings Technologies Office, Department of Energy, 2011.

Energy Independence and Security Act of 2007 (EISA). Public Law 110-140. 110th Congress, https://www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm

Energy Policy Act (EPACT). 2005. Public Law 109–58—Aug. 8, 2005, http://energy.gov/sites/prod/files/2013/10/f3/epact_2005.pdf

Geothermal Genius. 2009. By the numbers - Real results of a home geothermal installation. *geothermal: HEAT AND COOL WITH DIRT not oil*. Web page, http://www.geothermalgenius.org/thinking-of-buying/geothermal-installation-by-the-numbers-in-pennsylvania.html

Hirsch, James A. 2010. *eQUEST: The Quick Energy Simulation Tool*. Web page. Camarillo, CA: James J. Hirsch & Associates, http://www.doe2.com/equest/

NA. 2016. *Welcome to DOE2.com: The Home of DOE-2 Based Building Energy Use and Cost Analysis Software*. Web page. Camarillo, CA: James J. Hirsch & Associates, http://www.doe2.com/

Keller, Scott. Commercial Renovation Costs with RS Means Data. RSMeans Data from Gordian, Construction Publishers & Consultants, 2014.

Rushing, William P., Kane, Kimberly L. 1997 *Fort Still Military Reservation Historic Context: World War II Era Concurrent Camp/Officer Training School, 1939-1945,* https://apps.dtic.mil/sti/pdfs/ADA331692.pdf

Secretary of the Army (SA). 2014. *Net Zero Installations Policy*. Army Directive 2014-02. Washington, DC: SA, http://www.asaie.army.mil/Public/ES/doc/Army%20Directive%202014-02%20(NZ%20Policy).pdf

Sin, Jennifer, Tina Chui, Rosemarie E. Woodbury, Adam D. Smith, and Sunny E. Adams. *Application of Renewable Energy Sources at Fort Bragg; A Guide to Applying Renewable Energy Sources on Historic Buildings*. ERDC/CERL SR-12-2. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).

Underwood, David M., Alexander M. Zhivov, Richard J. Liesen, William J. Stein, Alfred Woody, Sunny Adams, Chad Grosshart, Halley Fitzpatrick, Georg Zielke, and

Michael DiPaolo. 2011. *Energy Assessment of Historical Buildings at Fort Bliss, TX*. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).

White House, The. 2015. *Planning for Federal Sustainability in the Next Decade*. Executive Order EO 13693. Washington, DC: The White House, Office of the Press Secretary, https://www.whitehouse.gov/the-press-office/2015/03/19/executive-order-planning-federal-sustainability-next-decade

———. 2007. *Strengthening Federal Environmental, Energy, and Transportation Management*. EO 13423. Washington, DC: The White House, Office of the Press Secretary, https://energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/Req-EO13423envtlmgmt.pdf

NA. 1999. *Greening the Government through Efficient Energy Management*. Executive Order EO 13123. Washington, DC: The White House, Office of the Press Secretary, https://ceq.doe.gov/nepa/regs/eos/eo13123.html

Zhang, J., G. Liu, R. G. Lutes, and M. R. Brambley. 2013. *Energy Savings for Occupancy - Based Control (OBC) of Variable - Air - Volume (VAV) Systems*. PNNL-22072. Richland, WA: Pacific Northwest National Laboratory (PNNL), http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22072.pdf

Acronyms and Abbreviations

Term	Definition
ACH	air changes per hour
AFB	Air Force Base
AHU	Air Handling Unit
ANSI	American National Standards Institute
Bn	Battalion
Btu	British Thermal Unit
CBECS	Commercial Buildings Energy Consumption Survey
CDD	Total Cooling Degree Days
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
COP	Coefficient of Performance
DDC	Direct Digital Control
DNR	Department of Natural Resources
DoD	U.S. Department of Defense
DX	Direct Expansion
ECM	Energy Conservation Measure
EEM	Energy Efficiency Measure
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order
EPACT	Energy Policy Act
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
EUI	Energy Use Intensity
FCU	Fan-Coil Unit
FY	Fiscal Year
HDD	Heating Degree Day
NHPA	National Historical Preservation Act
HQ	Headquarters
HQIIS	(Army) Headquarters Installation Information System
HSC	Historic Status Code
HVAC	Heating, Ventilating, and Air-Conditioning
IP	Inch –Pound
LBNL	Lawrence Berkeley National Laboratory
LED/INC	Light Emitting Diode/Incandescent
MBH	1000 Btu/hr
MMBtu	million Btu
N/A	Not Applicable
NREL	National Renewable Energy Laboratory

Term	Definition
NRHP	National Register of Historic Places
NSN	National Supply Number
OASD(EI&E)	Office of the Assistant Secretary of Defense, Energy, Installations, and Environment
OBC	Occupancy-Based Control
OMB	Office of Management and Budget
PNNL	Pacific Northwest National Laboratory
PO	Post Office
PV	Photovoltaic
PX	Post Exchange
RPAD	(DoD) Real Property Assets Database
SA	Secretary of the Army
SAM	System Advisory Model
SAR	Same As Report
SF	Standard Form
SHPO	State Historic Preservation Office
SI	Systeme Internationale
SP	Static Pressure
USMC	US Marine Corps
VAV	Variable Air Volume
WHS	Washington Headquarters Services
WWI	World War I
WWII	World War II

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)
11/5/2023

2. REPORT TYPE
Final

3. DATES COVERED (From - To)

4. TITLE AND SUBTITLE
Energy Conservation in Historic Buildings

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT
Legacy Resource Management Program

6. AUTHOR(S)
David M. Underwood, Brett N. Garret, and Tapan C. Patel

5d. PROJECT NUMBER
15-777

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005,
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL TR-17-2

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Assistant Secretary of Defense for Energy, Installations, and Environment (OASD[EI&E])
3400 Defense Pentagon, Room 3B856A
Washington, DC 20301-3400

10. SPONSOR/MONITOR'S ACRONYM(S)
OASD(EI&E)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This study assessed the inventory of historic (or eligible candidates) buildings and developed recommended Energy Efficiency Measures (EEMs). At Fort Sill, six buildings that represent commonly found buildings were selected to be studied for potential EEMs Three historic buildings located at Fort Bliss were also included in the analysis. Computer models of each building's energy use were developed and used to estimate the potential energy savings, cost, and simple payback. The results were then extrapolated to the 15 U.S. climate zones. This report provides a list of EEMs that may be applicable to historic buildings and can be used as a general guide to determine their effectiveness in various climate zones.

15. SUBJECT TERMS
Energy consumption--Cost effectiveness, Historic buildings, Historic preservation Buildings--Repair and reconstruction, Military bases

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	SAR	125	