Final Report: ESTCP Energy and Water Project EW-201241 Kinetic Super-Resolution Long-Wave Infrared (LWIR) Thermography Diagnostic for Building Envelopes

Scott AFB, IL, and Camp Lejeune, NC

January 30, 2015
Version 1.0

James P. Miller
U.S. Army ERDC-CERL
Champaign, IL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
25-03-2015	Final	January 2014 to March 2015

4. TITLE AND SUBTITLE
Kinetic Super-Resolution Long-Wave Infrared (LWIR) Thermography Diagnostic for Building Envelopes

5a. CONTRACT NUMBER
W9132T-14-C-0002

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James P. Miller, Navi Singh, Thomas Scaramellino

5d. PROJECT NUMBER
EW-201241

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
EW-201241

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
SERDP/ESTCP
4800 Mark Center Drive, Suite 17D08
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
SERDP/ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
EW-201241

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

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Each year, U.S Department of Defense buildings waste millions of dollars' in energy lost through leaks in building envelopes. Identifying the source of this wasted energy has historically been time consuming and prohibitively expensive for large-scale energy analysis. This work used an independently developed drive-by thermal imaging solution that can enable the Department of Defense (DoD) to achieve cost-effective energy efficiency at much greater scale than other commercially available techniques of measuring energy loss due to envelope inefficiencies from the built environment. A multi-sensor hardware device is attached to the roof of a customized vehicle to rapidly scan hundreds of buildings in a short period of time.
At Scott Air Force Base, the unit identified over 3,000 distinct building feature components (doors, windows, soffits, etc.) on buildings across the base. At U.S. Marine Corps Base Camp Lejeune, the unit identified over 2500 distinct building feature components identified across various buildings throughout the base. These features were categorized by type and surface temperature to provide an in-depth analysis of each building's envelope energy profile. This report includes an in-depth analysis of 30 buildings at each installation, recommends specific energy conservation measures (ECMs), and quantifies significant potential return on investment.

15. SUBJECT TERMS
Infrared Thermography, thermal imaging, building envelopes, energy conservation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			James P. Miller
Unclassified	Unclassified	Unclassified	SAR	359	19b. TELEPHONE NUMBER *(Include area code)* (217) 373-4566

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Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

Each year, millions of dollars' worth of energy leaks from the envelopes of DoD buildings due to missing or improperly installed insulation, cracks around doors and windows, thermal bridges in the wall system and many other deficiencies. Identifying the sources of this wasted energy has historically required manual thermal audits that are typically inconvenient, time consuming, and prohibitively expensive for large-scale energy analysis. At the same time, Federal agencies are under immense pressure to dramatically reduce the amount of energy consumed by their buildings.

A unique contractor-developed drive-by thermal imaging solution is available that can enable the Department of Defense (DoD) to achieve cost-effective energy efficiency at much greater scale than other commercially available techniques of measuring energy loss due to envelope inefficiencies from the built environment. This solution uses a multi-sensor hardware device mounted on the roof of a customized vehicle to rapidly scan hundreds of buildings in a short period of time. The gathered data are processed and analyzed at the contractor's (Essess, Boston, MA) headquarters to ascertain important building envelope information. This project demonstrated this technology by scanning U.S. Marine Corps Base Camp Lejeune, NC (ASHRAE Climate Zone 3) and Scott Air Force Base, IL (ASHRAE Climate Zone 4) to determine the amount of energy being lost at each installation due to energy inefficient building envelopes.

A primary objective of this work was to compare this drive-by thermal imaging process with the conventional thermal imaging process using a handheld infrared camera. The hypothesis was that the drive-by thermal imaging method is much faster, more accurate and more cost effective than traditional handheld thermal imaging methods. Table ES-1 summarizes a number of the most significant performance objectives and the results of this work. The results shown in Table ES-1 show that the drive-by method satisfied its performance objectives for Rapid Scanning and Rapid Analysis with over 100 buildings scanned per hour and the thermographic image data was analyzed at a rate of approximately 327 buildings per hour. This is at least an order of magnitude faster than could be achieved with handheld thermographic methods.

Table ES-1. Summary of performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Rapid scanning	Buildings scanned per hour	Number of Buildings scanned and required time	> 100 Buildings per hour	*Scott AFB:* • 327 buildings scanned at approx. 109 buildings scanned per hour *Camp Lejeune:* • 1,307 buildings and other objects (Objects being sheds and unmanned buildings) scanned at a rate of approx 110 objects per hour
Rapid analysis	Buildings per hour	Number of Buildings analyzed and required time	> 50 Buildings per hour	Approx. 327 buildings per hour for both Scott AFB and Camp Lejeune

Cost effectiveness	Cost ($) for square footage of building scanned and analyzed/reported.	Scanning, analysis and reporting costs for various numbers of Bldgs, similar costs for handheld methods	Cost below handheld methods for scanning 1million sq ft of building space or more, Simple payback = 10 years. (Since buildings can vary from a few hundred to several thousand square feet, total building square feet was used as a metric to measure the cost effectiveness of handheld versus mobile thermal imaging)	*Scott AFB:* Handheld thermography audits would have cost an estimated $920,000*. Essess costs for Scott AFB were approx. $200,000. *Camp Lejeune:* Handheld thermography audits would have cost an estimated $840,000 based on 4.2 million sq ft scanned. Essess costs for Camp Lejeune were approx. $200,000

The contractor team scanned at least six buildings at each installation using a FLIR i7 handheld thermal camera, The FLIR i-Series cameras are handheld thermal cameras specially designed for building diagnostics and commonly used in residential and commercial thermal audits). The scanned images for these cameras are 140x140 pixels with a 29 degree by 29 degree Field of View (FOV). The FLIR i7 camera uses a Spotmeter to detect the maximum and minimum temperatures within an image, isotherm above/below. The contractor found that each of the buildings scanned by this method required about 25 minutes of imaging work. Part of the extra effort involved in this method is the necessity to overlap building components in each frame. No effort was made to analyze the thermal image data from the handheld camera because it would have been a very time consuming effort since all of the images would need to be stitched together. Even then, the results would have been more uncertain since a good deal of analyst interpretation would be required.

The contractor team found that commercial energy audits that include envelope thermal imaging using handheld thermography typically cost around $1,000 for a 5,000 sq ft building and $10,000 for a 50,000 sq ft building (based on data from local thermal imaging auditors within 100 miles of Scott AFB and Green-Buildings.com). Based on the area of buildings scanned at Scott AFB (4.6 million ft^2) and Camp Lejeune (4.2 million ft^2) using the drive-by method, it would have cost approximately $920,000 and $840,000, respectively, using the handheld method.

By comparison, the KSR LWIR method uses an integrated system camera which captures 640x512 pixels per frame for a 45 degree x 37 degree Field of View. The temperature of each feature within the image is calculated and material emissivity is obtained by computer vision. Using the drive-by method, it took about 30 seconds to scan each of the six buildings in the set that were also scanned by the handheld method. Essess' costs to scan, analyze and report results for each installation was basically $200,000 regardless of actual square footage scanned. In this respect, the driveby thermal imaging was found to be more cost effective than handheld scanning methods.

At Scott Air Force Base, over 3,000 distinct building feature components (doors, windows, soffits, etc.) were identified on buildings across the base. These features were categorized by

type (e.g., brick wall, roof, window glass, window frame) and surface temperature to provide an in-depth analysis of each building's envelope energy profile. This report includes an in-depth analysis of 30 buildings with a breakdown of recommended energy conservation measures (ECMs) and the potential return on investment. This analysis showed over $300,000 in potential envelope-related savings per year that could be achieved by implementing various envelope-related ECMs. Over the lifetime of the measures, Scott AFB has the potential to save over $4 million by investing around $2 million with a simple payback period of roughly 7 years.

At U.S. Marine Corps Base Camp Lejeune, over 2500 distinct building feature components were identified across various buildings throughout the base. Similar to Scott Air Force Base, these features were categorized by type and surface temperature to provide an in-depth look at each building's envelope efficiency. This report also includes a detailed thermal analysis of 30 buildings from Camp Lejeune with a breakdown of the most notable leaks for each building and remediation recommendations. This quantified analysis showed that Camp Lejeune can save over $100,000 per year by implementing ECMs outlined in this report. The total investment would be less than $1 million, but would allow the base to save nearly $1.7 million over the lifetime of the measures with a simple payback period of less than 9 years. The analysis assumes a cost per kWh of $0.056 and cost per therm of $0.59 for both installations

Although both Scott AFB and Camp Lejeune have a positive return on investment (ROI), this research shows that Scott AFB has a higher potential savings threshold. This is partially due to the fact that Scott AFB is located in ASHRAE Climate Zone 4 while Camp Lejeune is in ASHRAE Climate Zone 3. Increasing ASHRAE climate zone numbers indicate colder climates. The long-term vision of this work is to help the DoD reach its goal of saving energy across all military installations by identifying the best candidate installations for energy-saving improvements to building envelopes, i.e., those with the highest potential savings. It would be possible to combine that priority list with information on optimal building stocks and portfolios of cost-effective improvements to equip the DoD to save millions of dollars in energy loss.

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ACKNOWLEDGEMENTS

Funding for this demonstration was provided under Military Interdepartmental Purchase Request (MIPR) No. W74RDV40212876 and MIPR No. W74RDV33512272 by the Environmental Security Technology Certification Program (ESTCP) under Energy and Water Project EW-201241, "Kinetic Super-Resolution Long-Wave Infrared (LWIR) Thermography Diagnostic for Building Envelopes." The work, including scanning of buildings at Camp Lejeune, NC, and Scott Air Force Base, IL, analysis of data and reporting of results was performed by Essess, Boston, MA, under U.S. Army ERDC-CERL contract W9132T-14-C-0002.

Various individuals and organizations participated in this demonstration and provided (review, guidance, information, access to facilities, and logistics) support that was valuable to the success of this project.

The following persons and organizations are gratefully acknowledged:

- The Essess team (Boston, MA), who performed this work under ERDC contract W9132T-14-C-0002, in particular, Mr. Navi Singh, Head of Solutions Delivery, and Mr. Tom Scaramellino, President & Chief Executive Officer, for their tireless efforts and "can do" attitude that helped them to overcome various technical and administrative hurdles to bring this project to a successful conclusion.
- Scott Air Force Base, IL, especially Elizabeth Toftemark for all of her help in scanning Scott AFB
- Marine Corps Base Camp Lejeune, NC, especially Thomas Burton of U.S. Marine Corps Base Camp Lejeune for all of his help in scanning Camp Lejeune
- Scott Clark of the ESTCP for his feedback and guidance throughout the project.

LIST OF ACRONYMS

AFB	Air Force Base
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BLCC	Building Life-Cycle Cost
C&P	Cost and Performance
COR	Contract Officer Representative
COTS	Commercial off-the-Shelf
DHW	Domestic Hot Water
DoD	U.S. Department of Defense
ECM	Energy Conservation Measure
EI	Engineering Instructions
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESTCP	Environmental Security Technology Certification Program
EW	Energy and Water
GB	gigabyte
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Positioning System
HASP	Health and Safety Plan
HDL	High Definition LIDAR
IMU	Inertial-Measuring-Unit
IPR	In Progress Review
IR	infrared
KSR LWIR	Kinetic Super-Resolution Long-Wave Infrared
LBL	Lawrence-Berkeley Laboratory
LEED	Leadership in Energy and Environmental Design
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
LWIR	Long-Wave Infrared
MIT	Massachusetts Institute of Technology
MOU	memorandum of understanding
NIBS	National Institute of Building Sciences
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
O&M	Operations and Maintenance
OPNAV	Office of the Chief of Naval Operations
OPNAVINST	Office of the Chief of Naval Operations Instruction
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PO	Performance Objective
QCLCD	Quality Controlled Local Climatological Database

ROS	Robot Operating System
SAG	Stakeholder Advisory Group
SCOW	Supply Chain Operations Wing
SLAM	Simultaneous Localization and Mapping
TAP	Thermal Analysis Program
TBD	To Be Determined
TI	Technical Instructions
TM	Army Technical Manual
UFGS	Unified Facilities Guide Specification
U.S.	United States
USA	United States of America
USACE	U.S. Army Corps of Engineers
USDOE	U.S. Department of Energy
USGBC	U.S. Green Building Council
USMC	U.S. Marine Corps

1.0 INTRODUCTION

According to the FY2012 Base Structure Report, the Department of Defense (DoD) has an existing inventory of 298,897 buildings comprising 2,300 million sq ft. These buildings represent almost every known facility type and range in age from recently constructed buildings to historic buildings more than 100 years old. The size and diversity of this building inventory makes it very difficult to identify and prioritize opportunities to improve building envelopes to reduce energy losses to the exterior ambient environment. It also makes it difficult to verify that building envelope repair/improvement projects have achieved their desired results.

This project demonstrated a capability to quickly diagnose the condition and thermal performance of building envelopes using Kinetic Super-Resolution Long-Wave Infrared (KSR LWIR) thermography to help DoD identify and implement opportunities to improve the thermal performance of its existing building inventory. The work was conducted at two DoD installations, Camp Lejeune, NC, and Scott Air Force Base, IL. It demonstrated a method of rapidly scanning and analyzing many facilities in a few hours, which proved to be far more efficient than current methods, which involve manual infrared thermographic scanning and analysis of facilities. This method produced an accurate and actionable assessment of the assessed installations' facilities that allowed Facilities Engineers to optimize use of their limited funds to repair or upgrade building envelopes to reduce installation energy consumption.

1.1 BACKGROUND

Many DoD installations are on a scale comparable to villages or small cities, with hundreds or thousands of facilities of various types and ages. Quality and condition of the building envelopes typically range from good to very poor. For most installations, there is significant opportunity to reduce installation energy consumption by identifying and prioritizing opportunities to improve the thermal performance of building envelopes.

Many installations have used infrared thermography as a tool to help identify buildings that have significant energy leakage through the building envelope and to pinpoint specific problems on existing building envelopes that might be good candidates for repair or improvement. USACE requires infrared scanning of newly constructed buildings prior to turnover to the customer. Unfortunately, although the current state of the handheld thermography technology produces reasonably good results, it is very time consuming to implement. Due to the number of facilities at most DoD installations, it would be a formidable task to scan more than a small fraction of the facilities. Post-scanning analysis is also very time intensive and very much dependent on the skill of the individuals operating the IR camera and interpreting the data. As a result, handheld infrared scanning and analysis methods are too time consuming, not cost-effective for large numbers of buildings, and may yield questionable results.

This technology demonstration enabled Facility Engineers to a cost-effectively perform and analyze scans of their installations to identify and prioritize candidate buildings that might benefit from building envelope repairs/improvements. The resulting data help the installations to improve the energy performance of their facilities, to reduce energy consumption and utility costs, and to meet mandated energy reduction goals.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objectives of this demonstration were to:

- *Validate*. This project validated a method of rapidly and cost effectively scanning and analyzing large numbers of building envelopes, quantifying energy losses, and prioritizing energy leaks for cost-effective repairs or improvements.
- *Provide Findings and Guidelines*. This project demonstrated a process by which Facilities Engineers can cost effectively evaluate large portions of their building stock to determine the overall condition of their building envelopes and identify opportunities to repair or improve the envelopes to reduce unnecessary energy losses and improve overall energy efficiency.
- *Accomplish Technology Transfer*: The Essess imaging rig was deployed based on a licensing model so there was (and will be) no turnover of hardware, software, or intellectual property to the Government. However, technology transfer will still occur through the Essess team, working with ESTCP and ERDC-CERL. Furthermore, it is anticipated that ERDC-CERL will publish an ERDC Technical Report and at least one article in the Society of American Military Engineers' (SAME's) *The Military Engineer*, or other publications with a military engineer audience.
- *Facilitate Acceptance*: This technology is currently marketed as a service to the utilities industry. Essess supports the energy conservation programs of utilities by performing drive-by scanning of large portions of their service areas. This can entail performing scans of tens of thousands of residential or commercial structures. The system software automatically analyzes the thermal imagery and provides a custom report for each building that recommends cost-effective measures to improve comfort, save energy and lower utility costs. In some cases, the utilities may offer the homeowners subsidies or incentives to motivate adoption of recommended measures. Essess may also perform follow-up scans several months after an initial scan to verify that homeowners actually made improvements for which they claimed a credit. In a similar fashion, this technology is a useful tool that can help military installation Facilities Engineers evaluate the effectiveness of building repair and renovation projects, and determine if the energy performance of new buildings complies with design requirements.

1.3 REGULATORY DRIVERS

Regulatory drivers that require Facilities Engineers to explore cost-effective means to improve facility energy performance are:

Executive Orders

EO 13423. 2007. *Strengthening Federal Environmental, Energy, and Transportation Management.* Per Principle #2 of the "Guiding Principles for Sustainable New Construction and Major Renovations," major renovation projects are required to reduce the facility's energy use by 20% below the facility's 2003 pre-renovation baseline.

EO 13514. 2009. *Federal Leadership in Environmental, Energy and Economic Performance*. This Executive Order mandates that all new construction, major renovations, or repairs/alterations of Federal buildings comply with the Implications of the Guiding Principles for existing buildings include:

- Building energy performance is to be optimized.
- At least 15% of existing agency buildings (above 5,000 gross sq ft) shall meet the Guiding Principles by Fiscal Year 2015 (FY15) and the agency shall make annual progress towards 100% compliance across its building inventory.
- Existing building systems shall be managed to reduce energy consumption.

Legislative Mandates

Energy Independence and Security Act of 2007 (EISA 2007) – Among other things, EISA 2007 requires that Federal agencies conduct and document an energy survey of 100% of its "covered facilities" every 4 years.

Federal Policy

Federal Leadership in High Performance and Sustainable Buildings. MOU 2006

DoD Policy

Strategic Sustainability Performance Plan, Energy Security. MOU with DOE

Service Policy

Army Policy

Current Army policy is that all installations are required to move towards net zero energy status. To meet this extremely ambitious goal, the energy performance of all Army buildings must be drastically improved.

Navy Policy

To achieve a 30% facility energy intensity reduction by 2015 in compliance with public laws and executive orders, per OPNAVINST 4100.5E (Jun 2012), Navy shore energy consumption per gross square foot (energy intensity) of reportable facilities as compared with the FY03 baseline shall be reduced by 50% by 2020 and 50% of Navy installations shall be net zero energy consumers by 2020.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

2.1.1 Description

Long-wave infrared (LWIR) cameras are regularly used in conjunction with building audits to identify thermal leaks in building envelopes. Referred to as "infrared thermography," the technology allows the observer to "see" heat escaping from (or entering) specific areas of buildings. Because objects emit LWIR radiation in levels that vary with their temperature, infrared thermography can help detect problems invisible to the naked eye, including missing, damaged, or improperly installed insulation within walls and roofs, thermal bridges, poor seals, etc. For example, most thermal bridges have a distinctive spatial signature that yields a thermal image with relatively uniform hot areas surrounded by relatively uniform cooler areas, separated by a very steep temperature gradient. This data, captured from the street, can be used to locate leaks and determine their extent and, after analysis, their probable underlying cause(s).

Essess is a hardware and software technology company that has developed drive-by thermal imaging capabilities that enable utility and government clients to identify energy waste in buildings at an unprecedented scale. In the context of utility projects, the thermal images can be leveraged to deliver the Thermal Analysis Program (TAP), an energy efficiency program that helps utilities meet mandated state energy efficiency goals by guiding building owners through the process of fixing sources of energy waste. For government and military projects, the thermal images enable the system to generate a complete analysis of energy waste across the entire building stock, empowering government and military clients to allocate energy efficiency investments and resources optimally and with greater confidence around the return on investment (ROI).

For military installations, Essess focuses on building envelope analysis and actionable recommendations based on envelope ECMs. A single thermal imaging rig can analyze thousands of buildings in 1 night depending on building density and other factors, enabling the system to deliver energy waste intelligence at an order of magnitude greater scale than current approaches. The patent-pending technology stems from cutting edge research conducted in the Field Intelligence Laboratory at the Massachusetts Institute of Technology (MIT).

The drive-by system uses specially equipped vehicles driving on streets and roadways to capture a 3D thermal video of the surrounding environment. The actual imaging system is a custom-designed multi-sensor rig integrated onto the top of the vehicle. As the vehicle drives, the imaging rig captures the scene on both sides of the car, enabling the system to image large geographic areas each night. The images are stored onboard the vehicle using a custom-built data recording system and then processed at Essess' headquarters in Boston, MA. Before analysis, the data are uploaded to the Amazon Web Services (AWS) servers housed in nondescript facilities. AWS data centers have industry leading security to ensure the data are protected by military grade perimeter control with state of the art intrusion detection systems.

In an IR thermal image, the brightness of an area indicates its relative energy loss. The brighter the area, the more energy is escaping. Common image patterns demonstrating substantial energy waste include bright yellow lines where siding meets the roof or a chimney, bright yellow or

orange auras near the foundation, and yellow auras or lines along window or door edges or around soffits. By contrast, a properly insulated building area will appear darker than the surroundings, most commonly blue or purple.

In the context of utilities, this technology has the capability to generate complete thermal scans of entire utility service territories in a matter of days or weeks. This kind of unprecedented territory-wide analysis would take months or even years using traditional audits, and would likely be prohibitively expensive. This improved thermal scan methodology not only achieves this scale of operation more efficiently and cost effectively, but also with improved accuracy and reliability. While certain information can only be obtained through an in-home audit, the drive-by thermal imaging system provides comparable intelligence at an order of magnitude lower cost. Similar results can be expected for buildings on large government installations. This kind of intelligence is invaluable in determining the buildings that follow-on auditors should survey and also as a pre-diagnostic to make the most use of the auditor's time on site.

2.1.2 Components of the System

The drive-by thermal imaging vehicles are equipped with the following components:

- Multi-spectral infrared imaging of structures, which includes:
  - long-wave infrared (LWIR) radiometric cameras
  - near infrared (NIR) high dynamic range cameras
  - NIR scene illumination for rural and poorly lit suburban regions
  - capture of thermal signatures of structures
  - discovery of building facades and background removal using computer vision and machine learning engines
  - camera housing offers 70 degree vertical field of view and full width horizontal field of view of structure due to vehicle motion.
- Automated building detection within property boundaries, which includes:
  - rotating laser array light detection and ranging (LIDAR) sensor captures ranging and reflectance even from large standoff distances
  - buildings are isolated from the scene using 3D LIDAR point clouds
  - ranging capability allows structures to be bounded within property lines and relevant locations
  - Mapping grade Global Positioning Systems (GPS) and support filtering algorithms ensure that location of structures and properties are highly accurate
  - Collected data used in simultaneous localization and mapping (SLAM), which allows the system to supplement the GPS data captured and more accurately correlate each image to the relevant building.
- Highly reliable onboard data capture and diagnostics system, which includes:
  - a system that performs over wide range of seasonal temperatures, down to at least -30 °C and up to above 40 °C.
  - a high mast that enables operation in a variety of regions, including short standoff distances with 3-4 story buildings
  - onboard data validation and recording software and hardware
  - real-time diagnostic and quality control provided by LTE cell network streaming to Essess headquarters.

Combined, these hardware and software capabilities constitute a highly effective way to capture heat loss and building envelope data via drive-by thermal imaging (Figure 1). Each camera captures data in a video format, meaning that the drive-by system generates hundreds of thousands of images comprising over 2 terabytes of data each night. The LIDAR sensors (Figure 2) enable the system to generate a 3D map of the physical environment and map buildings to parcels in a highly accurate manner. The proprietary hardware and software configuration enables the system to capture vast amounts of data and subsequently process that data in a very efficient and automated manner.

Figure 1. Specially equipped Essess scanning vehicle.

Figure 2. Contractor-developed scanning rig including GPS, long-wave infrared, near infrared and LIDAR instrumentation.

2.1.3 Comparison to Existing Technology

This technology is similar to handheld infrared scanning technology in that both methods use infrared photographic methods. Unlike handheld methods, which record still images, this process captures video infrared images. This method combines video data with GPS data, LIDAR data, and GIS data (e.g., building size, building age, envelope materials) to permit rapid data analysis, including quantification and prioritization of envelope energy leaks and an analysis of cost-effective methods of repair and improvement. Essess normally acquires GIS data from private companies. For military projects GIS data are acquired from the installation being scanned (billing was provided). Because this is a video process, it is capable of scanning many buildings in a short period of time. Handheld infrared imaging methods would require many work-hours to achieve the same results.

- *Future Potential for DoD*. This technology may prove to be a useful aid in operations and maintenance of facilities and in installation planning. Energy leaks identified using this technology can be analyzed and prioritized for the most effective use of O&M dollars. The installation's inefficient facilities can be identified and a cost associated with their condition can be used in prioritizing buildings for repair, major renovations or outright replacement.
- *Anecdotal Observations*. The heat map of thermal imaging data collected from Cambridge, MA (Figure 3) shows a distribution of blue (efficient building envelopes) and red (inefficient building envelopes) buildings. In certain cases buildings of similar vintage, square footage, location, and style have very different envelopes in terms of energy efficiency. This suggests that there are numerous instances where thermal imaging data may very well be the main differentiating factor in determining building envelope quality between two otherwise similar structures even for cases where only one side of the building is visible from the street.

Figure 3. Building envelope efficiency map of over 17,000 buildings in Cambridge, MA.

2.1.4 Energy Analysis Architecture

This unique hardware and software approach, known as the "Essess Energy Analysis Architecture," develops very specific remediation recommendations to increase building energy efficiency. It begins by combining scanning data with GIS data, property records (for residential buildings), and information on construction material properties, and produces building-specific energy reports and/or a region-wide energy analysis.

After the system scans a specific area, each building scanned must be matched with its corresponding address or geographical location (latitude and longitude). Once the building has been detected and correlated to the correct building number, the construction material library, a database containing information on the emissivity of various types of materials, is used to differentiate, for example, a building's window from a door. This phase is referred to as "building component detection." It allows the algorithms to identify windows, doors, and other features of the building. Once the building and the building components are detected, those data are used to build a model to automatically detect similar buildings and similar building components in comparable datasets. These data are combined with a Remediation Model to automatically detect the building components that may need attention, and with a Climate Model to determine the weather-related variables of the scanning data. The Building Model, the Remediation Model, and the Climate Model are then used to develop a Conductive Heat Transfer Model to identify conductive leaks, a Convective Heat Transfer Model to identify convective heat loss, and a Radiative Heat Transfer Model to identify thermal radiation heat loss. The Conductive, Convective, and Radiative Models provide heat loss data that can then be combined with fuel prices, and labor and materials costs in the Financial Model. This model quantifies the energy loss and the potential dollars that can be saved by preventing the identified heat loss. Correlating the potential savings to specific fixes (Remediation Recommendation Model), allows the system to recommend the energy efficiency remediations that have the best ROI. Figure 4 shows the Energy Analysis Architecture breakdown.

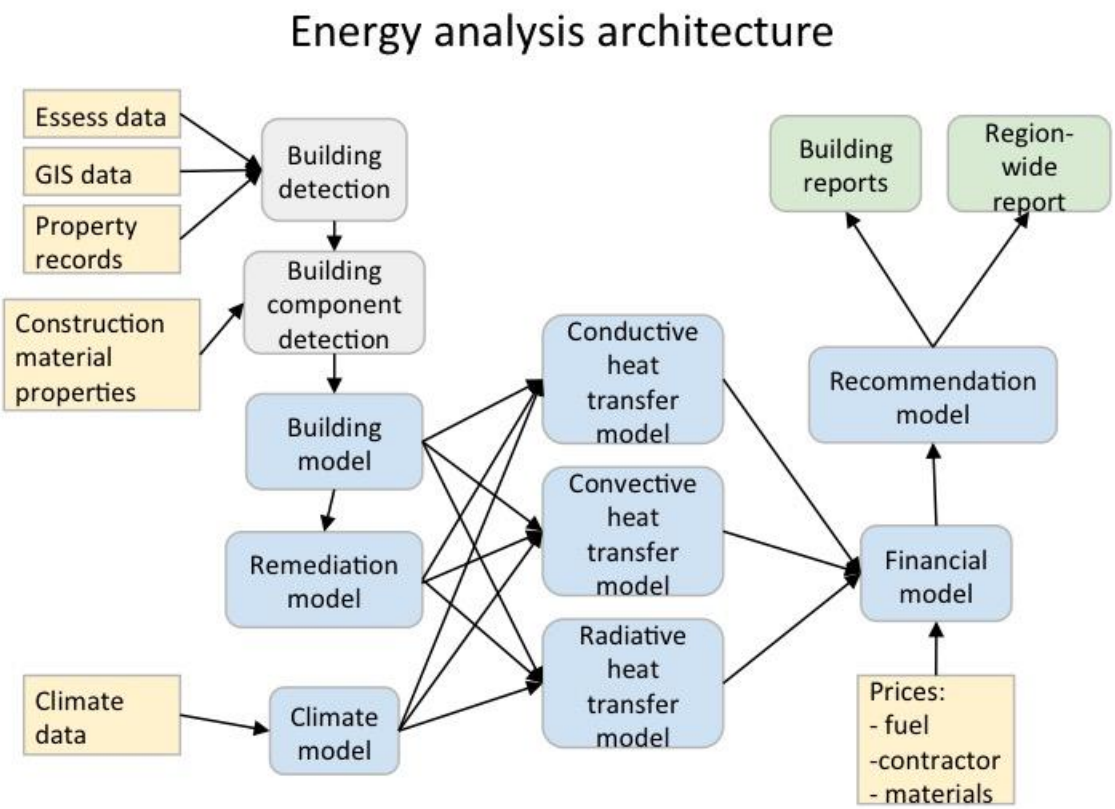

Figure 4. Schematic breakdown of the Essess Energy Analysis Architecture.

2.2 TECHNOLOGY DEVELOPMENT

Essess is unique in the thermal imaging space as it is the only company in the world with the ability to scan thousands of buildings using a proprietary hardware device comprised of multiple sensors and process and analyze that data in a completely automated way. The hardware, which is comprised of the physical sensors on top of the vehicle, and the software, which processes and analyzes the collected data, are both based on research conducted at the Field Intelligence Lab at the MIT. Sanjay Sarma, Professor of Mechanical Engineering, recruited leading scientists and thought leaders to study the viability of remote, high-throughput thermal imaging at scale and develop techniques for identifying and assessing energy waste on a large scale. The practical applications of high-throughput thermal imaging were researched and studied for multiple years before a prototype was built. The first imaging rig was tested in Cambridge, MA, and the data were analyzed to create a heat map overview of the city (Figure 3). The rapid scanning methodology and processing of imaging data were also demonstrated at Fort Drum, NY in February 2011.

After years of research and development and millions of dollars, Essess developed the current imaging rig, which uses cutting edge technology to gather terabytes of data on a nightly basis. The custom hardware is augmented by advanced software algorithms that process the data. The system overcomes the small-scale limitations of traditional infrared thermography, which uses

handheld cameras, and which must analyze each image manually, by using advanced machine learning and computer vision algorithms to scale up thermal imaging and processing.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Performance Advantages

This technology may improve energy efficiency by enabling Facilities Engineers to cost effectively scan and analyze most or all of the building envelopes on their installations to identify and prioritize the most significant energy leaks and to implement measures that repair or improve the building envelopes. With handheld thermography methods, it would be too costly and time consuming to perform infrared scans and analyze the data for large numbers of buildings.

2.3.2 Cost Advantages

For large sets of buildings, this technology should be much more cost-effective than traditional handheld methods of performing infrared thermography scanning and analysis of buildings. Handheld IR scanning methods are much more time consuming, resulting in significant added labor costs.

2.3.3 Performance Limitations

This technology is limited to scanning the street sides of buildings. As a result, for most buildings, four sides of the buildings will not be scanned. Two or three sides are typically scanned depending on the orientation of a building relative to the street. This technology is also limited by the requirement to have a ΔT between building interior and exterior ambient temperatures of at least 20 °F, so scanning must occur when nighttime temperatures are below 50 °F. This limits application of this technology to regions where there is at least 1 week of the year in which nighttime temperatures are below 50 °F. Most regions of the United States fall within this boundary condition. Adjustments are made for empty buildings or buildings where there is no internal heating and no way of knowing the internal temperature setpoint (further discussed in the Methodology Appendix D). This technology is somewhat hindered by trees, bushes and other obstructions that might partially obscure a clear view of a building's envelope from the street. However, the automated data processing pipeline developed by Essess to take the scanned data and prepare it for a report format, corrects for these kinds of obstructions in a number of ways that have been tested by Essess.

2.3.4 Cost Limitations

There is a lower limit of the number of buildings that can be cost effectively scanned and analyzed by this method. Below this limit, it is more cost-effective to identify and analyze building envelope energy leaks by another method. This demonstration sought to determine this cutoff point. As referenced in Table 2. *Performance Objectives*, the average cost for performing a handheld thermal audit on a 5,000 sq ft commercial building is approximately $1000. Considering Essess charges (approx.) $200,000 per installation, it is beneficial to perform an Essess scan for any installation that has at least 1 million sq ft in buildings (determined by

adding the individual square footage of each building scanned). For perspective, over 4.6 million sq ft of buildings were scanned at Scott Air Force Base.

It was also considered desirable to document the cost structure of this technology to help Facilities Engineers determine how the technology might fit within the constraints of their business process. For example, this technology is able to capture scan data on hundreds or thousands of buildings in a very short period of time such that very large installations could be scanned within a matter of days. The resulting marginal cost of scanning buildings is relatively inexpensive. However, the process of analyzing scan data to identify and prioritize energy leaks is more challenging and has a significantly higher marginal cost. Since both of these processes must be done together to provide the military base with actionable results, documenting the cost structure for these services will help Facilities Engineer determine how they might benefit from Essess thermal imaging.

2.3.5 Social Acceptance

There were no problems associated with social acceptance by installation staff. This technology had little or no impact on the activities or processes of the installations. On-site activities were conducted at night when very few installation operations were occurring. The only burden placed on installation personnel was the need for them to provide installation GIS data and energy data for analysis requirements. The GIS data were a necessary component of the scanning process as they allowed Essess to correlate the scanned image of a building with the building's exact geographical location. The energy data allowed Essess to calibrate the results of the thermal envelope analysis. They were also useful for evaluating non-envelope energy conservation measures (ECMs). Evaluations of non-envelope ECMs were not the focus of this demonstration project, but were provided as a "no-cost" additional service.

3.0 PERFORMANCE OBJECTIVES

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

Table 2. Summary of performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Rapid scanning	Buildings scanned per hour	Number of Buildings scanned and required time	> 100 Buildings per hour	*Scott AFB:* • Approx. 109 buildings per hour for a total of 327 buildings (Based on building density of Scott AFB, rig set-up and resting period. Total imaging time of 3hr0min with 52min of rig set-up, calibration, travel time, and resting period.) *Camp Lejeune:* • Approx. 110 buildings per hour scanned. • 1,307 buildings and other objects (e.g., sheds, lamps, and other unheated structures) were scanned. Total imaging time was 11hr54min after adjusting for various delays including inclement weather.
Rapid analysis	Buildings per hour	Number of Buildings analyzed and required time	> 50 Buildings per hour	Approx. 327 buildings per hour for both Scott AFB and Camp Lejeune (leaks identified as polygons and subsequently analyzed)
Actionable results	Building envelopes determined to be adequate (needing no improvements) or improvement projects scoped for envelopes having identified deficiencies	Number of envelopes deemed adequate and/or having projects scoped to correct identified deficiencies	For each installation, the envelopes of at least 25 of the 30 buildings selected for detailed analysis are deemed to be adequate or have projects identified to correct deficiencies	Scott AFB: • 392- Window Frames • 97- Door Frames • 686- Walls • 170 – Roofs • 241- Soffits See Chapter 6.0 (Performance Assessment) for more detail. Camp Lejeune: • 1,037 - Window Frames • 201 - Door Frames • 412 - Walls • 232 - Roofs • 329- Soffits See Chapter 6.0 (Performance Assessment) for more detail

Cost effectiveness	Cost ($) for square footage of building scanned and analyzed/reported.	Scanning, analysis and reporting costs for various numbers of Bldgs, similar costs for handheld methods	Cost below handheld methods for scanning 1million sq ft of building space or more, Simple payback = 10 years. (Since buildings can vary from a few hundred to several thousand square feet, total building square feet was used as a metric to measure the cost effectiveness of handheld versus mobile thermal imaging)	*Scott AFB:* Handheld thermography audits would have cost an estimated $920,000*. Essess costs for Scott AFB were approx. $200,000. *Camp Lejeune:* Handheld thermography audits would have cost an estimated $840,000 based on 4.2 million sq ft scanned. Essess costs for Camp Lejeune were approx. $200,000
Qualitative Performance Objectives				
Robust technique within defined range of operating conditions	High quality scanned imagery	Scan data quality under a range of environmental operating conditions	"High Confidence**" in results obtained within defined limits	Success: Within the defined range of operating conditions, the thermal imaging system is capable of capturing high quality data that can be analyzed for envelope issues.
Comparing the Fidelity and Usefulness of Imagery at Varying Scanning Distances	Measuring the image quality of data taken at varying distances starting at 20 yds and ending at 180 yds with 20 yd intervals	Thermal images taken by mobile imaging rig at 20 yd intervals from 20 to 180 yds	"High Confidence"** that the temperature data can be seen at extreme distances	The results show that infrared imaging is capable of capturing temperature data at 180 yds. However, the number of pixels in the frame limits the data quality.
Street-side scanning sufficient	Representativeness of street-side sample vs. 360-degree scan of building using handheld methods	Street-side drive-by scan results 360-degree handheld scan results	"High Confidence"** that results of street-side scans adequate for planning purposes	Street-side data is representative of sides not seen from the street
Ability to usefully scan Bldgs obscured by wall of trees and other obstructions	Data loss due to obstructions	Leaks obscured by obstructions	"High Confidence" that obstructions do not appreciably impact results	Line-of-sight between imaging system and building is required for data capture. The imaging rig is able to capture data when driving by a single tree or utility pole, but is unable to capture data when the when the building is completely blocked from the imaging rig (i.e., with a fence, multiple trees, etc.). This was previously tested while the technology was in research and development.

* Commercial energy audits that include envelope thermal imaging using handheld thermography can typically cost around $1,000 for a 5,000 sq ft. building and $10,000 for a 50,000 sq ft. building (based on data from thermal imaging auditors within 100 miles of Scott AFB and Green-Buildings.com). At Scott AFB, Essess imaged 4.6 million sq ft and 278 buildings. Unlike a typical auditor that charges per building, Essess' cost structure is on a per installation basis. This is due to the fact that the bulk of Essess' costs are front-loaded. Once the imaging rig is deployed to an area, there is only a marginal cost in imaging 1,000 buildings versus 100 buildings.

** "High Confidence" is a visual examination by an Essess scientist resulting in a determination that the data can be used for performing an analysis of the building envelope.

3.2 DESCRIPTION OF PERFORMANCE OBJECTIVES

A. Rapid Scanning:

- *Definition*. This Performance Objective measures how rapidly buildings can be scanned.
- *Purpose*. The purpose was to compare the speed of the demonstrated method of drive-by scanning to conventional handheld methods. In terms of speed, the drive-by method was orders of magnitude faster, which translates into an ability to scan more buildings and to minimize the scanning contractor's time on the installation and associated impact on installation personnel and operations. A detailed comparison of handheld versus drive-by scanning is provided later in this report.
- *Metric*. The metric is buildings scanned per hour.
- *Data*. Number of buildings scanned and duration of scanning operations.
- *Analytical Methodology*. A simple count of the number of buildings scanned and the elapsed time of the scanning activities.
- *Success Criteria*. Objective successfully met — Greater than 100 buildings scanned per hour.

B. Data Analysis:

- *Definition*. This Performance Objective measures how rapidly buildings can be analyzed.
- *Purpose*. The purpose was to determine whether the demonstrated method of automated data analysis could analyze 50 or more buildings per hour.
- *Metric*. The metric is buildings analyzed per hour.
- *Data*. Number of buildings analyzed and time required to analyze the scanned buildings.
- *Analytical Methodology*. A simple count of the number of buildings analyzed and the amount of time required to analyze these data.
- *Success Criteria*. Objective successfully met — greater than 50 buildings analyzed per hour.

C. Actionable Results:

- *Definition*. This PO measures the effectiveness of this process by validating the condition of building envelopes needing no repairs or upgrades and identifying projects to improve envelopes that are not deemed adequate.
- *Purpose*. This metric is intended to focus the demonstration on developing results that help Facilities Engineers determine whether or not the installation's stock of building envelopes are adequate and acceptable or, if not, by identifying projects to address identified deficiencies.
- *Metric*. Building envelopes determined to be adequate (needing no improvements) or improvement projects identified to bring the envelopes up to acceptable levels or performance.
- *Data*. Number of envelopes deemed adequate and/or having projects identified to bring the envelopes up to acceptable levels or performance.

- *Analytical Methodology.* This PO is based on a count of the number of buildings that are evaluated as having acceptable building envelopes and/or the number of buildings for which projects are identified to bring the envelopes up to acceptable levels of performance.
- *Success Criteria.* Objective successfully met — For each installation, the envelopes of at least 25 of the 30 buildings selected for detailed analysis are deemed to be adequate or to have projects identified to correct deficiencies.

D. Cost Effectiveness:

- *Definition*. This Performance Objective measures the economic value of this process to the Facility Engineer.
- *Purpose*. Facilities Engineers and installation managers will only be interested in this technology if they perceive it to produce economic value. Considering the cost of drive-by scanning and analysis, and the cost of implementation of identified mitigation measures, the energy savings must be sufficient to warrant the investment.
- *Metric*. Dollars (marginal cost) per building scanned, analyzed and reported. Simple payback ((Cost of scanning + cost of repair) / annual energy cost savings).
- *Data*. Marginal scanning, analysis and reporting costs for various numbers of buildings and comparable data for similar services using handheld thermography methods. Costs to execute repairs and estimated annual energy savings.
- *Analytical Methodology*. The methodology involves compiling the total costs of remediation of "feasible" fixes and the cost of conducting the drive-by scanning and the total anticipated energy cost savings. Feasible fixes are those with a payback of 15 years or less.
- *Success Criteria*. Objective successfully met — The costs of scanning, analysis, and reporting are below the same costs incurred using handheld thermography methods for scanning 1 million square feet of buildings. (The simple payback should be 10 years or less.)

E. Robust Technique Within Defined Range of Operating Conditions:

- *Definition*. This Performance Objective measures the quality of scanned imagery within the prescribed operating conditions of this methodology.
- *Purpose*. The objective is to define a range of environmental conditions within which acceptable results can be expected.
- *Metric*. A qualitative assessment of image quality based on resolution and size of scene captured under ideal imaging conditions (i.e., temperature difference of 20 °F and no precipitation).
- *Data*. Mobile scan data quality under a range of environmental operating conditions.
- *Analytical Methodology*. Perform scans within recommended environmental operating conditions and scans at conditions outside the recommended range and compare results.

- *Success Criteria*. "High Confidence" in results obtained within defined limits. ("High Confidence" is based on image resolution and limitations on motion blur. Specifically, for images taken in recommended environmental operating conditions, the resolution should produce images with a resolution of 640 x 512 without motion blur or color saturation. During the demonstration, this performance objective was successfully met by analyzing each image for motion blur.

F. Comparing the Fidelity and Usefulness of Imagery at Varying Scanning Distances:

- *Definition*. This Performance Objective measures the image quality of data taken at varying distances starting at 20 yds and ending at 180 yds with 20-yd intervals.
- *Purpose*. The objective is to test how distance affects temperature reading from a thermal image when using mobile imaging system.
- *Metric*. Measuring the image quality of data taken at varying distances starting at 20 yds and ending at 180 yds with 20-yd intervals.
- *Data*. Collect thermal images taken by mobile imaging rig at 20-yd intervals from 20 to 180 yds.
- *Analytical Methodology*. Perform scans with the mobile imaging rig at varying distances and compare results to determine the degradation in image quality as the distance is increased.
- *Success Criteria*. "High Confidence" that for results obtained at up to 180 yds, the imaging rig is capable of capturing useful temperature information. This performance was successfully met through a distance experiment conducted where the imaging rig was used to image a building from 20 yds all the way to 180 yds.

G. Sufficiency of Street-Side Only Scanning:

- *Definition*. This Performance Objective measures how well scanning of buildings from only the street side actually represents the overall condition of the building envelope.
- *Purpose*. The objective is to see how representative street-side only drive-by scanning is compared to 360-degree scanning. Since it will be impossible to drive all the way around many military buildings, it is useful to know how much one can depend on a scan on just the street side of the building.
- *Metric*. Representativeness of street-side sample vs. 360-degree scan.
- *Data*. Street-side drive-by scan results and 360-degree handheld scan results.
- *Analytical Methodology*. For a small subset of buildings, 360-degree drive-by scans were done, and those results were compared to the results of "street-side" only scans to estimate how much building information was lost by scanning the street side only.
- *Success Criteria*. "High Confidence" results from street-side scans adequate for planning purposes. This PO was based on number and size of leaks on the street-facing wall compared to those on other walls not normally observed from the street. This performance was successfully met by analyzing the results from buildings imaged from the street versus buildings imaged from all sides. The leak profile was consistent throughout the building envelope.

H. Ability to Usefully Scan Buildings Obscured by Trees and Other Obstructions:

- *Definition*. This Performance Objective measures how well the drive-by scanning process is able to accurately capture building envelope data for buildings that are obscured by trees, utility poles, and other obstructions.
- *Purpose*. Since many building facades will be partially obscured by utility poles, trees, shrubbery, and other obstructions, it is important to know how much value is lost due to such obstructions blocking a clear view of the building façade.
- *Metric*. The metric is the relative amount of data that are lost due to obstructions.
- *Data*. Lost data are measured in the number and severity of leaks obscured by obstructions.
- *Analytical Methodology*. Analysis involves a visual evaluation of energy leaks obscured by trees and other obstructions.
- *Success Criteria*. Objective successfully met — Success is judged in terms of "High Confidence" that obstructions do not noticeably impact results. This qualitative standard is based on the contractor's experience with off-site tests with obstructions in the line-of-sight of LWIR cameras. The conclusion of this experiment was that the imaging system must have line-of-sight between the imaging sensors and the building being imaged to capture any useful temperature information.

4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE SELECTION CRITERIA

4.1.1 Geographic Criteria

The mobile scanning technology is relevant to climate zones where the heating season ΔT (indoor to outdoor temperature) can be expected to be at least 20 °F during the building scanning period. As a result, this technology may not be applicable to certain regions within Climate Zones 1 and 2. This demonstration selected installations in Climate Zones 3, and 4, with the potential for Zone 5. Also, installations were chosen that had a large number of significant buildings from which to select. The technology is also capable of capturing data during cooling season as long as the ΔT (indoor to outdoor temperature) is 20 °F.

4.1.2 Facility Criteria

This demonstration worked with the installations to select buildings typical of modern installations. Buildings selected included command headquarters, dormitories, training facilities, admin facilities and similar large buildings. At each installation, a minimum of 250 buildings were scanned and a detailed analysis of 30 buildings, selected by the installation, was performed.

4.1.3 Facility Representativeness

The installations selected are very large and had a full range of facility types and buildings of various vintages. The buildings and building types at the selected installations were quite representative of buildings that would be found at other military installations.

4.2 FACILITY/SITE LOCATION AND OPERATIONS

4.2.1 Demonstration Site #1: Scott AFB, IL

Scott Air Force Base is the home of the 375th Air Mobility Wing and host to 30 tenant units including: U.S. Transportation Command, Air Mobility Command, 18th Air Force, the 618th Air and Space Operations Center (Tanker Airlift Control Center), the Military Surface Deployment and Distribution Command, 932nd Airlift Wing (Reserve), 126th Air Refueling Wing (Air National Guard), the Air Force Network Integration Center, the Defense Information Systems Agency and the Defense Information Technology Contracting Organization, and the 635th SCOW. Scott AFB has a broad range of facility types and a full spectrum of facility vintages from very old to very modern.

Scott Air Force Base is the home of the 375th Air Mobility Wing providing mission-ready Airmen and capabilities. Since the on-site activities associated with this demonstration were short term, there was little or no interaction between this project and normal military activities. Scott AFB is located approximately 20 miles east of St. Louis near Belleville and O'Fallon, IL (Figure 5).

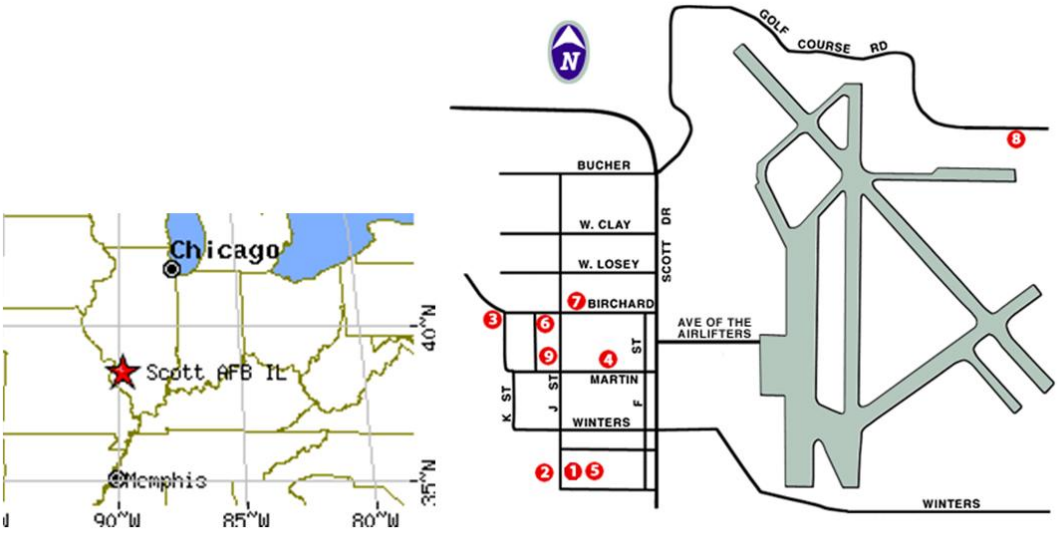

Figure 5. General location (left) and installation map (right) of Scott AFB.

4.2.2 Demonstration Site #2: Camp Lejeune, NC

Camp Lejeune is a 246-sq-mi U.S. Marine Corps training facility located along the Atlantic Coast in Jacksonville, NC (Figure 6). The main base is supplemented by five satellite facilities: Marine Corps Air Station New River, Camp Geiger, Stone Bay, Courthouse Bay, Camp Johnson, and the latest addition to the facility, the Greater Sandy Run Training Area.

Camp Lejeune is the largest Marine base on the East Coast. The base's 14 miles (23 km) of beaches make it a major area for amphibious assault training, and its location between two deep-water ports (Wilmington and Morehead City) allows for fast deployments. Since the on-site activities associated with this demonstration were very short term, there was little or no interaction between this project and normal military activities.

Figure 6. Location of Camp Lejeune, NC.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

5.1.1 Hypothesis

Compared to using traditional handheld thermography, the demonstrated drive-by thermal imaging technology gathers energy efficiency information from the building stock in a manner that is faster, more cost-effective, and easier to scale.

5.1.2 Independent Variable

The main independent variable being tested was the type of thermal scanning technique which was the KSR LWIR imaging and analysis process as compared to conventional thermal scanning using a handheld camera followed by processing of the handheld thermal imagery..

5.1.3 Dependent Variable(s)

Dependent variables measured included emissivity, building type, building square footage, and scene occlusion. Other variables tested during the demonstration process included:

- Scanning time (scanning time using a mobile imaging system versus scanning time using a handheld thermal camera to determine scalability in terms of time)
- The effects of resolution when scanning with the imaging rig versus scanning with a handheld camera to determine importance of image quality
- Scanned image quality from varying distances (specifically 20 meters, 50 meters, and 100 meters).

5.1.4 Controlled Variable(s)

Controlled variables included the pre-selection of building types of similar size and building materials for scanning and analysis by both the drive-by and the handheld methods. Both scanning methods were conducted simultaneously to ensure identical temperatures and weather conditions during scanning operations.

5.1.5 Test Design

The demonstration of the long-wave infrared (LWIR) imaging technology took place during February and March 2014. Multiple buildings were scanned at Camp Lejeune, NC and Scott Air Force Base, IL using the thermal imaging rig. Six buildings were scanned at each military installation using both the drive-by scanning rig and a traditional handheld thermal camera to set up the comparative analysis between the two methods of thermal data gathering. Note that the conventional handheld analysis was carried out under the same weather and temperature conditions as the mobile imaging scan to ensure that the data being captured was comparable. All attempts were made to tightly monitor the controlled variables for both the imaging rig and the handheld scans. The scanning process began 2 hours after sunset and concluded 30 minutes before sunrise on nights with temperatures below 50 °F. The imaging rig captured and recorded data on hard drives that were mailed back to Essess headquarters for processing. Images were

analyzed with respect to energy loss via infiltration, damaged building components, inadequate insulation, and thermal bridges. The imaging data was combined with GIS information, LIDAR data, and other building data. Note that thermal images taken with a handheld camera were not processed by automated methods, but were (necessarily) visually analyzed by a human auditor, which makes the process less efficient and more difficult to scale.

5.1.6 Test Phases

5.1.6.1 Phase 1

Tests were done to determine whether the mobile LWIR imaging could collect building envelope efficiency data faster than traditional handheld thermography without compromising the quality of the diagnostic data by customizing the imaging rig specifically for gathering data on a military installation. For example, a distortion map was created for NIR cameras, the NIR illuminator was adjusted for imaging buildings further back from the street than typical residential homes, the sweeping LIDAR was configured to compensate for poor street information, and the onboard GPS units were configured for optimal imaging in areas with low satellite access. The viewing angle for the entire hardware device was adjusted to optimally capture buildings larger than a typical residential home. A custom logistics dashboard was also created and tested to allow the logistics team to efficiently validate data being captured across the military base. The validation is important as it allows the driving team operating the vehicle to see the data being captured through the onboard monitor. A handheld thermal imaging camera was also used. The LWIR cameras converted camera output data from pixel values to temperatures. Other subtasks included optimizing imaging hardware based on potential building materials to be encountered on military installations; finalizing the logistics plan for the imaging team, coordinating base access and finalizing paperwork for clearance; and training Data Collection Technicians on using the onboard logistics dashboard.

5.1.6.2 Phase 2

The contractor drove to the specific military installations and scanned the installations using the imaging vehicle, and captured data using the handheld camera for a subset of the buildings scanned by the imaging vehicle. The contractor set up comparative tests to determine the quality of data collected from the mobile imaging process relative to the data collected from the conventional thermal imaging method. For example, a data quality test was conducted to determine the difference between gathering the street-view of a building versus capturing all sides with a manual camera. The captured data were verified through manual curation, and The contractor worked with on-base facilities managers at each base to access GIS and energy information. The contractor customized an analysis pipeline for post estimation and converting raw images to temperature images and data processing. The data were processed to match images to both vehicle GPS data and GPS data gathered from the military installations. After this, the captured data were correlated to building information obtained from the military installations. Further analysis was focused on building materials and correlated thermal inefficiencies to the areas imaged. The processing pipeline was configured to calculate energy scores for scanned buildings and determine the least efficient buildings. The results were published through an automated system that could be visualized using a front-end tool to manually verify building issues.

5.1.6.3 Phase 3

The contractor used the Drive-by Visualization Application to identify buildings that required further analysis and also provided the application to the installations to downselect a subset of 30 buildings for detailed analysis. The Drive-by Visualization Application was an online platform that displayed the thermal imaging video, a map of the base, and a list of the buildings selected for further analysis. The user then selected or unselected a particular building for analysis. The gathered data from the handheld scanner were analyzed to provide a detailed comparative analysis.

5.1.7 Fundamental Problem

Collecting useful building envelope energy efficiency data using traditional auditing methods is slow, costly, and difficult to scale. The demonstrated technology creates a new way to collect and analyze building envelope energy efficiency data, and augments (and in certain cases completely replaces) manual handheld audits of the building's envelope.

5.1.8 Demonstration Question

Can mobile thermal imaging collect building envelope energy efficiency data faster and more cost effectively than traditional handheld thermography without compromising the quality of diagnostic information being acquired?

5.2 BASELINE CHARACTERIZATION

5.2.1 Reference Conditions

The following data were collected for each military installation: building footprints (available for both Camp Lejeune and Scott AFB in the form of GIS polygons), parcel footprints (available for both Camp Lejeune and Scott AFB in the form of GIS polygons), address points, address metadata, energy consumption data (gas and electrical, only available for certain buildings for Camp Lejeune and Scott AFB) for multiple years for each metered building, building vintage (available for Scott AFB, but only partially available for Camp Lejeune buildings), and building size (available for Scott AFB, but only partially available for Camp Lejeune buildings).

Data collected by the imaging rig on scanning nights included: ambient temperature, ground temperature, sky temperature, and precipitation levels

Both Camp Lejeune and Scott AFB were able to provide GIS data. Energy data were not available for all buildings scanned at either military installation.

5.2.2 Baseline Collection Period

The data for Camp Lejeune were collected over the period of 10-14 February 2014. Scott AFB data were collected over the period of 28 February to 1 March 2014. For both installations, data were collected on nights where the temperature and weather conditions were conducive to thermal imaging. Handheld thermography images were captured on the same nights.

5.2.3 Existing Baseline Data

Given the nature of the technology and this demonstration, there was no baseline data for comparison purposes.

5.2.4 Baseline Estimation

The cost of conventional handheld infrared thermography was estimated based on the cost of equipment and the market rate of skilled labor to perform the analysis. Measurements of selected buildings were taken with handheld infrared cameras to create a baseline to compare with the results from the vehicle-mounted rig.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

5.3.1 System Design

The thermal imaging rig combines several commercial off-the-shelf (COTS) sensors with custom electronics, software and environmental housing to record data samples:

- Trimble A3000 DR+GPS
- Velodyne HDL-32e 3D LIDAR
- (4) FLIR A65 Thermal imaging cameras
- (2) Allied Vision Technologies Manta G-283B Camera
- SICK LMS111-10100 2D LIDAR.

The Trimble GPS along with the front facing SICK LIDAR were used to continuously estimate the position of the car during the scanning process. The Velodyne LIDAR was used for 3-D reconstruction of buildings and other structures. The Manta cameras were used with the computer vision system to detect near infrared features. Thermal measurements were made with the FLIR long-wave infrared cameras. The data produced by these systems were recorded to a mirrored set of hard drives, and were post-processed using computer vision, machine learning, and thermal analysis algorithms to generate actionable envelope intelligence.

5.3.2 System Layout

Figure 7 shows the multi-sensor imaging hardware. The GPS antenna maps the location of the car, the LIDAR creates a dense pointcloud to determine the 3-D landscape, the long-wave infrared (LWIR) cameras measure heat, the near infrared (NIR) cameras are able to detect building features similar to what someone might see through a night vision camera, and the NIR illuminator acts as a floodlight for the NIR camera.

Figure 8 shows a schematic outline of the proprietary Thermal Imaging System.

Figure 9 shows a snapshot of the user interface for the onboard data capture and diagnostic system interface that allows an imaging technician to validate the data as they are collected.

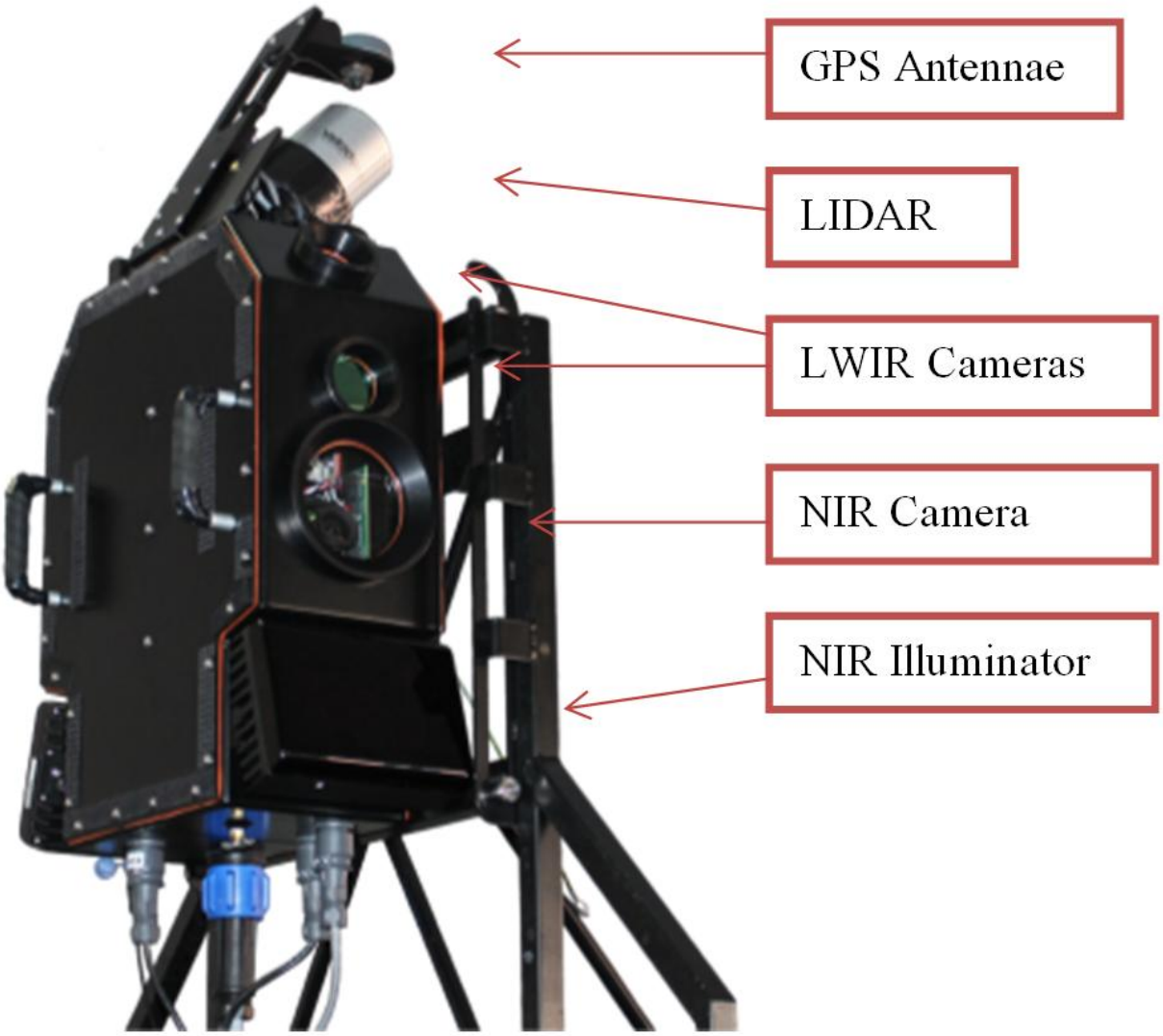

Figure 7. Essess' multi-sensor imaging hardware.

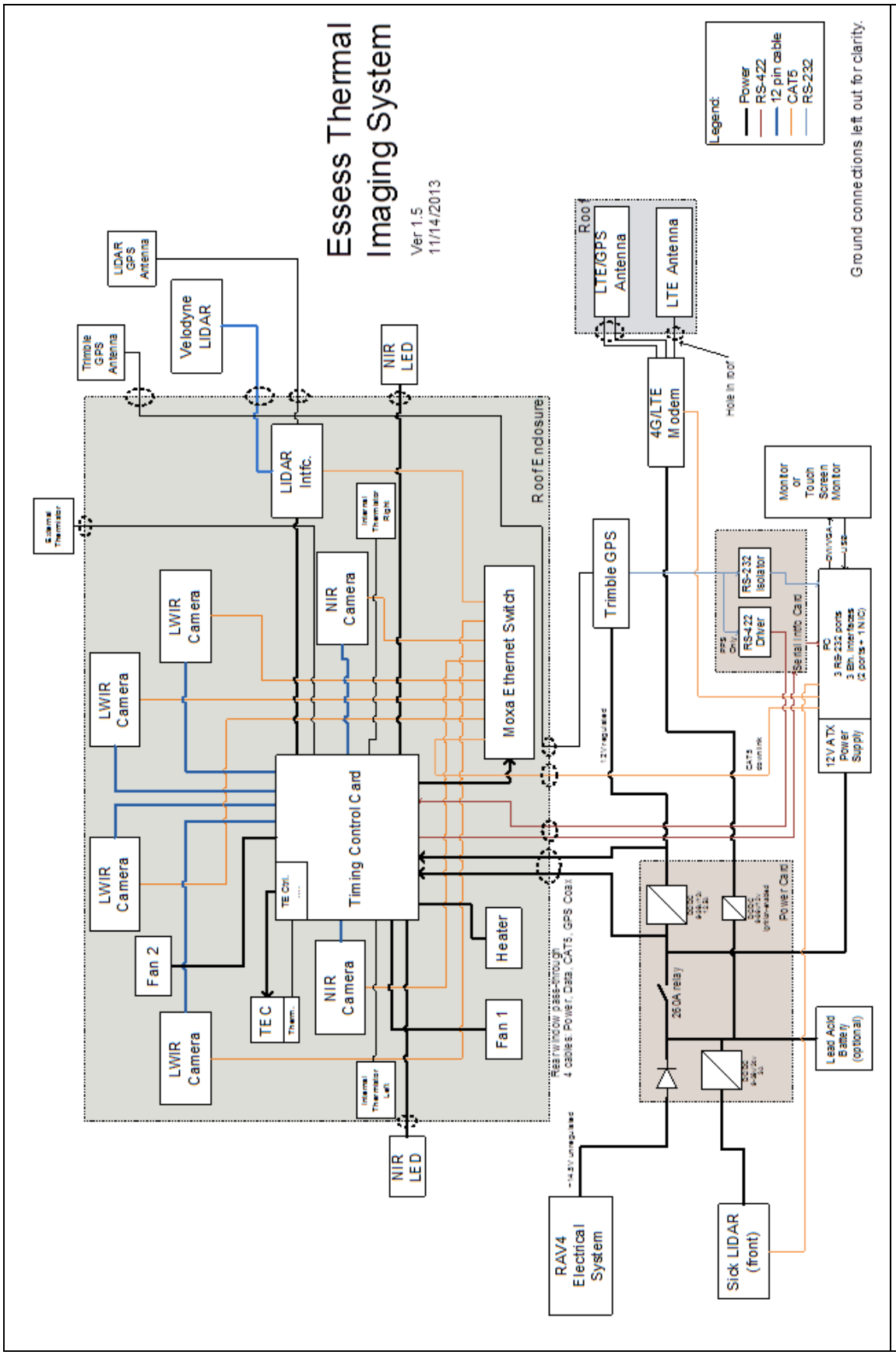

Figure 8. Schematic outline of the proprietary Essess Thermal Imaging System.

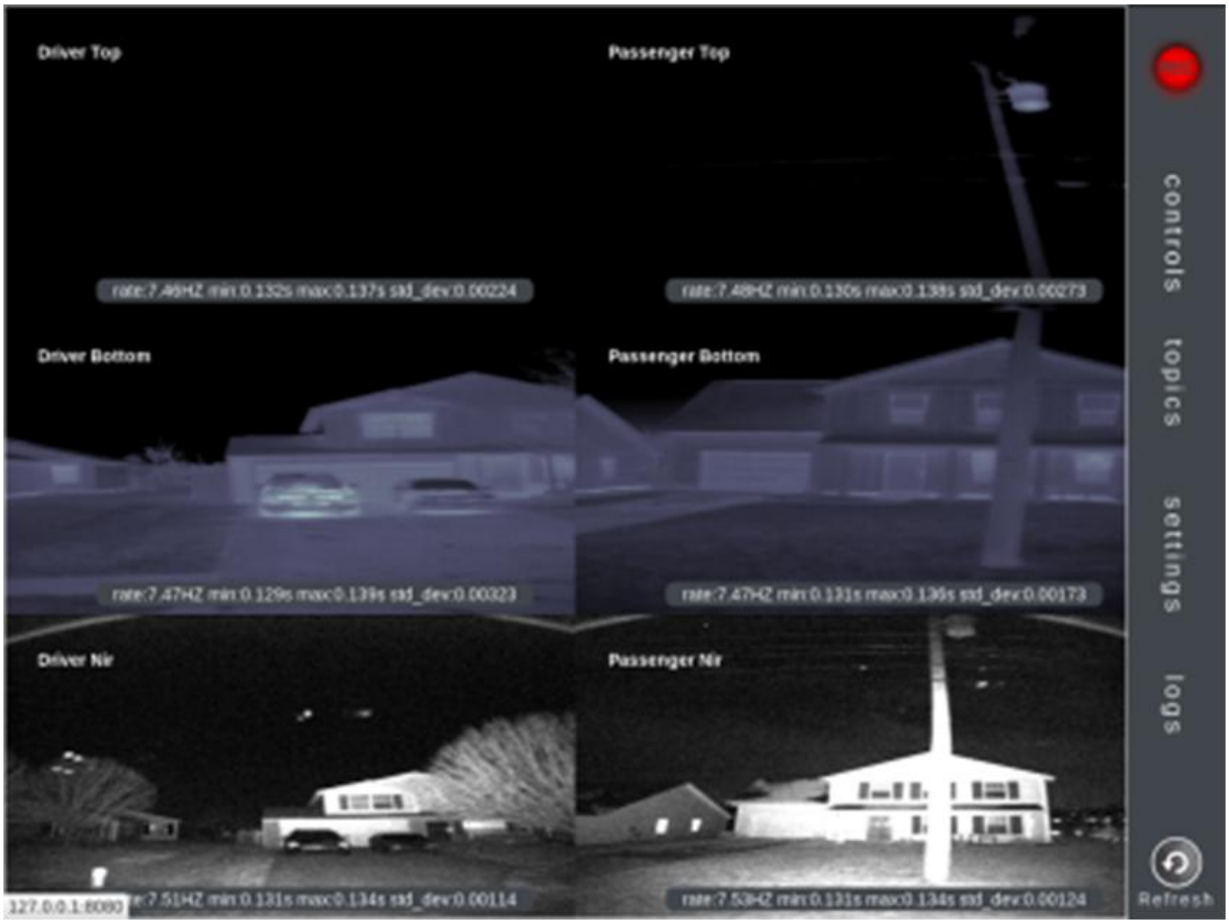

Figure 9. User interface for the onboard data capture and diagnostic system.

Figure 10 shows a very general overview of some of the key steps in the data processing pipeline, including:

- *High Speed Storage*. Each imaging vehicle captures several terabytes of data per night, which are stored in the Customized Vehicle Data Storage System.
- *File Expansion and Compression*. The compressed data are extracted from the hard drives to begin processing and analysis.
- *Vertical Stitching*. The vehicle is equipped with two LWIR cameras on each side of the imaging device and each camera captures a part of the scene as the vehicle passes by. To get a robust, vertical image of the scene, data streams from the two cameras are stitched together using proprietary algorithms.
- *Geo-location*. All of the data from the GPS units are analyzed and then combined with LIDAR information to adjust for any external noise or loss of satellite signal.
- *Building Matching*. Once the GPS data are processed and analyzed, they are matched up with the relevant thermal images for each building imaged.
- *Horizontal Panorama*. As the data are captured frame by frame, there may be tens or hundreds of individual images, each showing a small part of the entire scene. To get a seamless panorama of an entire building, the frames must be stitched together.

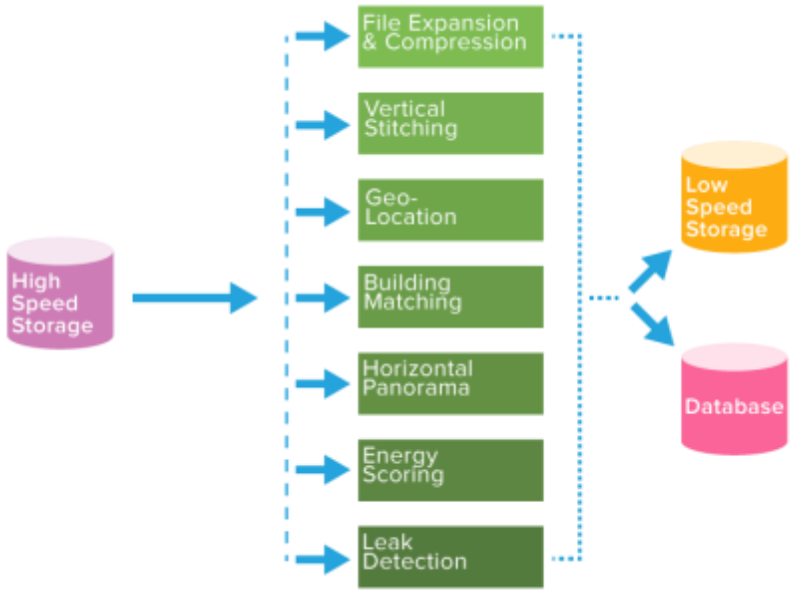

Figure 10. General overview of the Essess data processing pipeline.

- *Energy Scoring*. Once the images are extracted, vertically stitched, correlated with the relevant address, and horizontally grouped, they are analyzed to convert the thermal reading into an energy score. This energy score is relevant to each data set and allows for one building to be compared to a different building within the same data set.
- *Leak Detection*. The images are also analyzed for potential building envelope leaks.
- *Low Speed Storage*. All of the raw data are then placed in low speed storage.
- *Database*. The analyzed and processed data are stored in a database. Customers can then access this data using web applications layered on top of the database.

5.3.3 Heat Flux Calculation Methodology

5.3.3.1 Calculating Heat Flux

Heating energy losses (Figure 11) due to conduction through walls, roofs, windows, doors, and soffits were calculated by the equation:[1]

$$Q_{h,d} = A \cdot U \cdot (T_{in} - T_{out}) \quad (5\text{-}1)$$

where:

$Q_{h,d}$ = Total hourly rate of heat loss through surface in Btu/hr
U = Overall heat transfer coefficient of surface in Btu/hr-ft^2-°F
A = Net area of surface in ft^2
T_{in} = Inside temperature in °F
T_{out} = Outside temperature in °F.

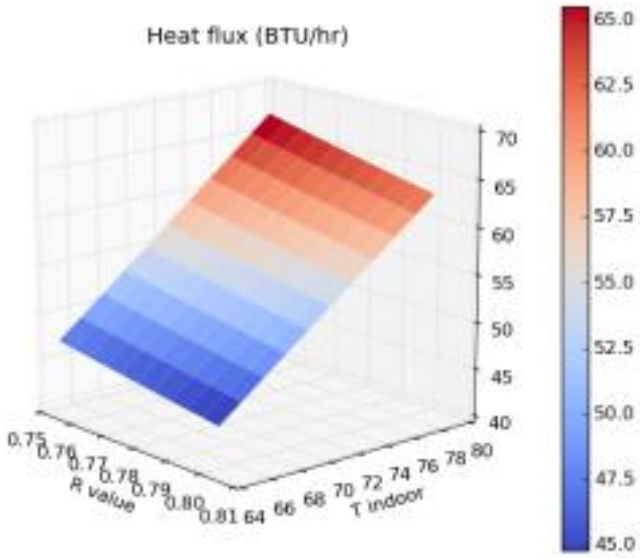

Figure 11. Heat flux (Btu/hr).

This analysis focused only on heat loss and assumed an indoor average thermostat (T_{in}) setting of 69 °F ± 4 °F (65 °F to 73 °F). This is slightly lower than the actual most likely thermostat setting to account for internal heat gain due to lighting, electronics, and machinery.

The hourly outdoor temperature (T_{out}) was obtained from the National Climate Data Center (NCDC) Quality Controlled Local Climatological Database (QCLCD).

The area of the surface was determined based on the relative size of polygons drawn on the building compared to door polygons (or synthetic door polygons when doors are not present). Doors were assumed to have an area of 20 sq ft, and were drawn individually so as not to conflate double doors with single doors.

The U value of elements of the building envelope were estimated based on their surface material, brightness, and the relationship between the indoor temperature, the surface temperature, and the outside air temperature. Specifically, calculations were done to determine the heat loss (radiative + conductive to the outdoor ambient air) of a material to the outside air assuming steady state for that heat flux and the estimated indoor temperature, then to determine the R value for that portion of the building surface. The approach taken is described in detail in the subsequent section.

The sensible heat loss from infiltration can be calculated as [2]:

$$Q_{h,i} = V_{cfm} \cdot \rho_{air} \cdot C_p \cdot (T_{in} - T_{out}) \cdot 60 \quad (5\text{-}2)$$

where:

$Q_{h,i}$ = sensible heating load from infiltration in Btu/hr
V_{cfm} = volumetric air flow rate in cubic feet per minute (CFM)
ρ_{air} = the density of the air in lb/ft³
C_p = specific heat capacity of air at constant pressure in Btu/lb°F.

The indoor and outdoor temperatures are the same as above. The density of air (ρ_{air}) is, on average, 0.074887 lb/ft^3. The specific heat capacity of air (C_p) is assumed to be 0.2403 Btu per (°F) (lbs).

The volumetric air flow rate per linear foot of door and window frame cracks was assumed to be 0.52 CFM on average for a pressure differential of 75 Pascals, with a standard deviation of 0.4 CFM and a minimum of 0.01 [3, 4, 5, 6]. At an average interior to exterior pressure differential of 10 Pascals, this translates into a mean CFM of 0.14, based on the functional relationship between air flow and pressure [3]:

$$Q = C(\Delta P)^{0.65} \quad (5\text{-}3)$$

The volumetric air flow rate of any given foot of leaks was estimated based on its relative emissivity compared to the mean of all observed windows and doors with the assumption that the distribution of leaks at both bases roughly matches that found in the literature [3,4,5]. Windows and doorframes were tagged separately from the window glass or door material, and the linear feet of cracks were estimated based on the dimensions of the frame relative to the door reference described previously. The mean emissive cracks were assigned an estimated value of 0.14 CFM; the 95th percentile of emissive cracks was assigned an estimated value of 0.36 CFM.

Total heating losses can be calculated as the sum of conductive and convective heating losses, adjusted based on the efficiency of the heating equipment. Assuming a natural gas space heating system with an average fuel use efficiency (f_{afue}) of 70% per the Illinois Technical Reference User Manual (TRM) default assumption for existing systems in commercial buildings [6], total heating losses (in therms per hour) were calculated as:

$$H_{therms} = \frac{Q_{h,d} + Q_{h,i}}{f_{afue}} \cdot \frac{1}{99{,}976} \quad (5\text{-}4)$$

Total cooling losses were estimated as the sum of conductive and convective cooling losses, with a typical Seasonal Energy Efficiency Ratio (SEER) of 10 Btu/watt-hour (f_{seer}) per the typical value of existing equipment in the TRM [6]:

$$C_{kwh} = \frac{Q_{c,d} + Q_{c,i}}{f_{seer}} \cdot \frac{1}{3{,}412} \quad (5\text{-}5)$$

Figure 12 shows an example of the results of this approach for a characteristic brick wall. For the time being, energy losses due to latent heat were excluded from this analysis. The analysis assumes a cost per kWh of $0.056 and cost per therm of $0.59.

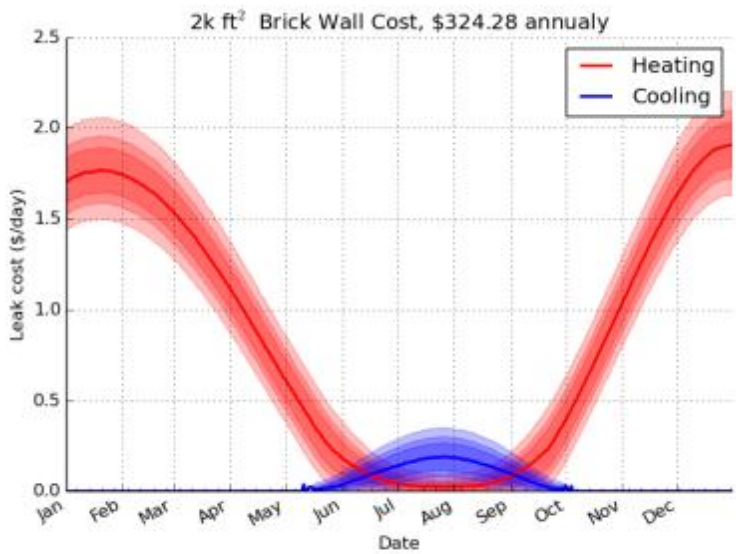

Figure 12. Brick wall cost.

5.3.3.2 Inferring R-Values

R-values were inferred by using a conservation of energy principle to assume that all energy leaving the surface of the material is matched by the energy flowing through the material. If the system is at steady state, the heat flowing through the material is equal to the heat leaving the material surface:

$$q_{through} = q_{exit} \quad (5\text{-}6)$$

Where $q_{through}$ is the heat flux through the material (inside the building to outside) and q_{exit} is the heat flux leaving the material and escaping into the atmosphere. The leaving heat flux can be split into two components: radiation (beaming photons) and conduction (warming up the film of outside air that touches the material).

$$q_{exit} = q_{rad} + q_{cond} \quad (5\text{-}7)$$

The radiation heat flux is:

$$q_{rad} = \epsilon\sigma A\left(T_{surf}^4 - T_{out}^4\right) \quad (5\text{-}8)$$

where epsilon (ϵ) is the emissivity of the gray body (a description of how shiny the material is), sigma (σ) is the Stefan-Boltzmann constant, area (A) is the material surface area, surface temp (T_{surf}) is the material's external surface temperature, and outdoor temp (T_{out}) is the ambient outdoor air temperature. Here it was assumed that most objects that are radiating back towards the building material were at approximately the ambient air temperature.

The exiting conductive heat flow is:

$$q_{cond} = hA\left(T_{surf} - T_{out}\right) \quad (5\text{-}9)$$

where h is the heat transfer coefficient of air.

This exiting heat flux is equal to the heat flux through the material:

$$q_{through} = \frac{(T_{in} - T_{out})A}{R} (5\text{-}10)$$

where R is the thermal resistance and indoor temp is the indoor air temperature.

Solving for the thermal resistance:

$$\hat{R} = \frac{A(T_{in} - T_{out})}{q_{through}} = \frac{A(T_{in} - T_{out})}{q_{exit}} \quad (5\text{-}11)$$

As mentioned previously, this method only produces an unbiased estimate of R-values in cases where the system is at a steady state. In practice, this will often not be the case due to residual solar heating of material surfaces and uncertainties in precision of measured surface temperatures and outdoor air temperatures. Failing to account for these will tend to result in a systemic underestimate of R-values, and concomitant overestimate of remediation potentials.

To effectively control for these uncertainties, the resulting R value estimates were normalized based on a prior distribution of assumed R-values in the literature [7, 8] for each component (Table 3).

Table 3. Current component R-values and new component R-values

	Current Component R-Values				New Component R-Values			
Component Name	**Min**	**Max**	**Mean**	**St Dev**	**Min**	**Max**	**Mean**	**St Dev**
Window – Glass	0.99	2.99	1.69	0.25	0.99	2.99	1.69	0.25
Door – Wood	1.85	3.7	2.17	0.5	1.85	3.7	2.17	0.5
Door – Metal	6	15	10	2.5	6	15	10	2.5
Door – Glass	1.8	5	2.5	0.5	1.8	5	2.5	0.5
Soffit	8	16	12	3	8	18	14	3
Exposed Foundation	6	14	10	2	6	14	10	2
Wall – Brick	8	16	12	3	8	18	14	3
Wall – Stone	6	12	8	2	6	14	10	2
Wall – Siding	6	12	8	2	6	14	10	2
Wall – Concrete	6	12	8	2	6	14	10	2
Roof	10	20	14	3	10	20	15	2.5
Wall – Thermal Bridge	4	12	8	2	8	18	14	3

Specifically, it was assumed that individual identified components on the base map to a distribution of current component R-values, such that the 10th percentile of brick walls on the base, would fit the 10th percentile of the normal distribution of current component brick wall R-values in the table.

This approach was conducted separately for areas with and without significant sunlight exposure on the evening of 28 February 28 2014 (e.g., south and southwest-facing surfaces between 120 and 300 degrees) [9]. This should help control for bias due to residual solar heating, as all surfaces observed around the same time with the same orientation will have similar biases. The relatively early cessation of direct sunlight also helps, as sunset occurred at 15:52. Figure 13 shows the angle and height of the sun relative to the horizon on February 28th for the Scott Air Force Base area:

An additional analysis was done to measure the effect of the imaging time on the surface temperature of buildings. Figure 14 shows the results for south-facing brick walls, which broadly indicate most other components observed. Given that the effect of time of observation on resulting surface temperatures is roughly equal in magnitude to the variation in surface temperature among buildings sampled, an explicit time-of-observation correction was warranted, using a simple ordinary least squares de-trending approach on each combination of building component and orientation to normalize for time of observation.

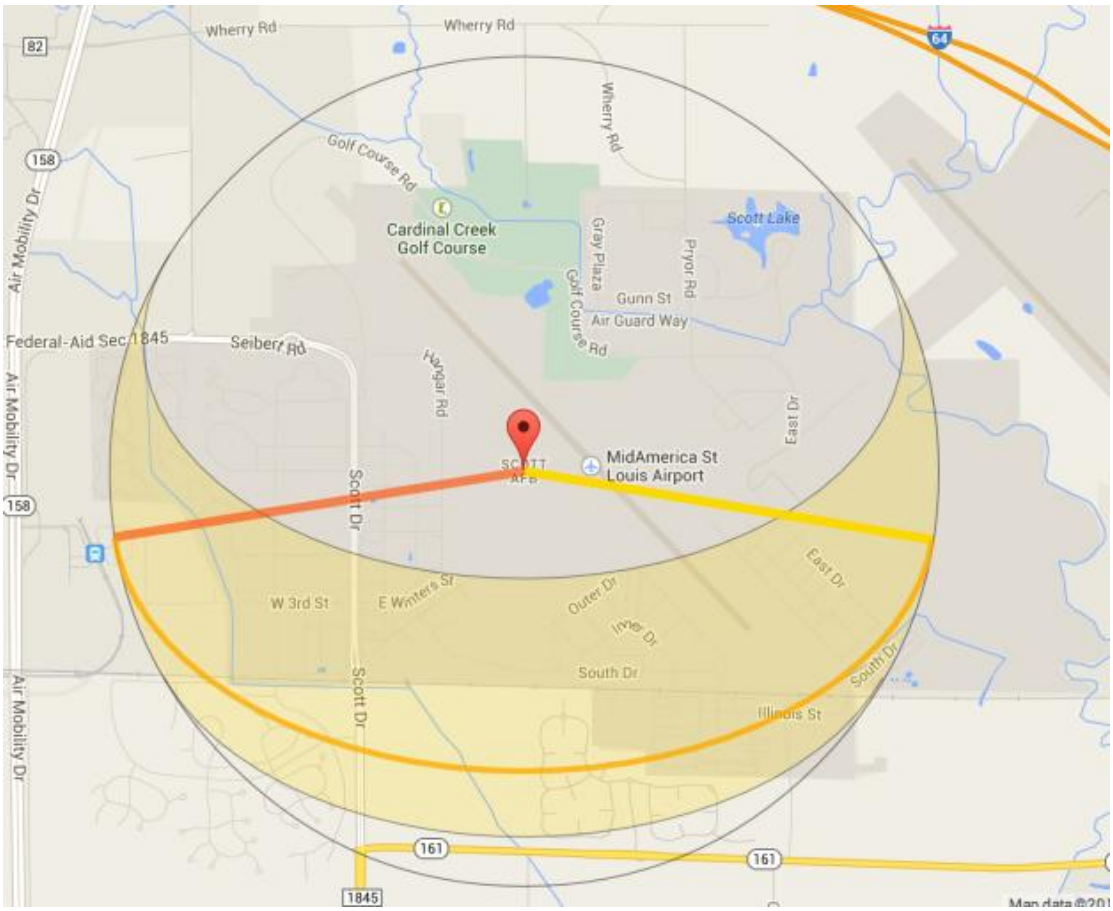

Figure 13. Angle and height of the Sun relative to the horizon on February 28 2014 for Scott AFB.

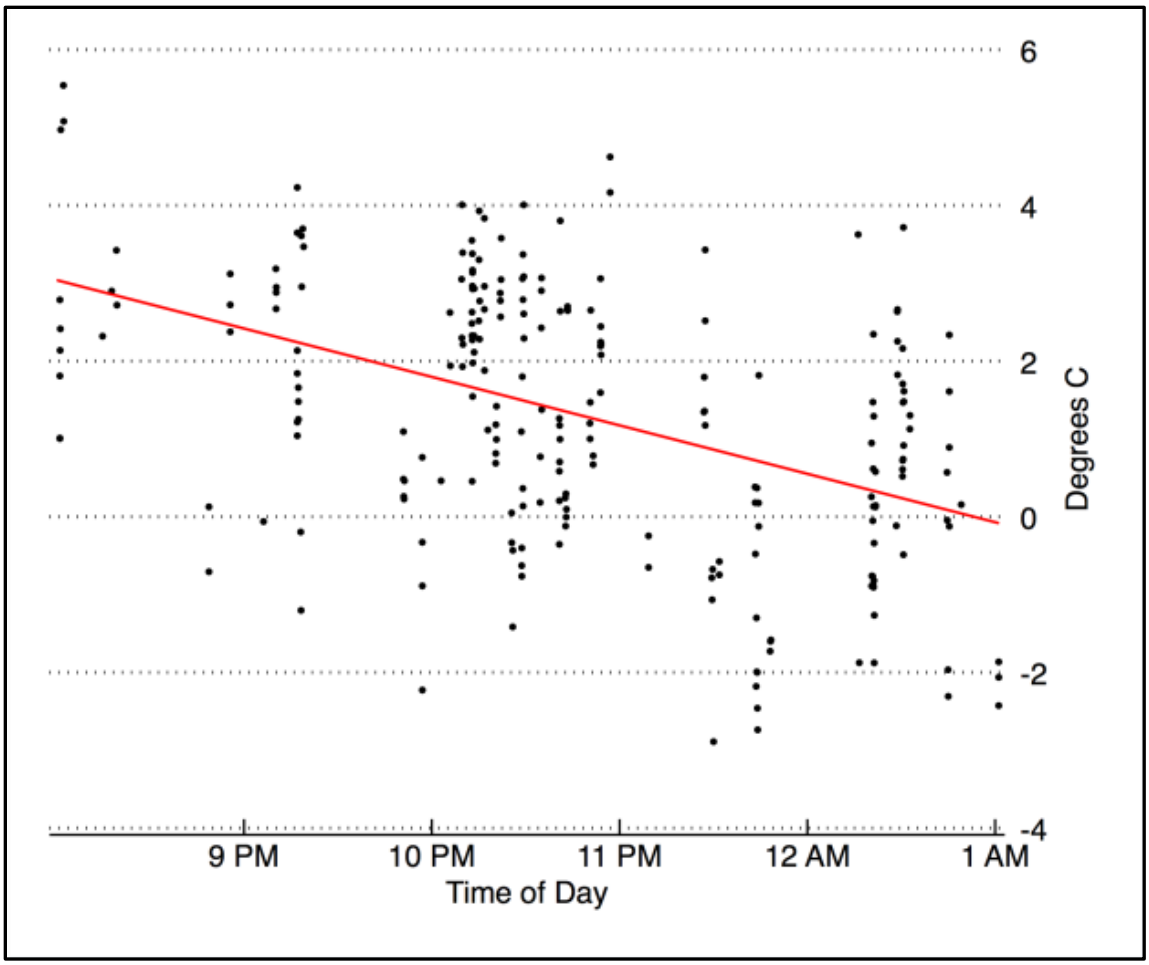

Figure 14. Building surface temperature values over time.

Additional factors that may introduce bias into the estimate included:

- *Unknown Material Types*. Currently, the process relies on human curators to tag the building component with the correct material type. If this type is wrong, then the model is no longer as accurate. This could be addressed by additional validation of component material types against aerial imaging, as well as review by base staff.
- *Imprecise Local Temperature*. Currently, ambient outdoor air temperatures are read from weather station logs, which are precise only to a single degree Fahrenheit. This introduces some error in the heat flow model, which is sensitive to temperature values. This could be addressed by incorporating data from the vehicle-mounted temperature sensor, or by readings from an on-base weather station.
- *Unknown Indoor Temperature*. Because it is impossible to read indoor temperature through the building surface, it must be estimated. In this work, indoor temperature was estimated using common temperature values that most people find comfortable, such as 65-73 °F in the winter and 70-78 °F in the summer. This could be addressed by receiving more information from facility managers regarding indoor summer and winter thermostat setpoints.
- *Uncertain Space Heating and Cooling Efficiencies*. There is a range of potential efficiencies of 60–95% for space heating and SEER ratings of 8 to 18. Lack of detailed information about

building-specific heating, ventilating, and air-conditioning (HVAC) equipment prevented these estimates from being further refined. Currently, mean estimates, of 70% AFUE for Scott and 85% AFUE for Lejeune, were used (as the upcoming replacement of the central steam plant will entail new space heating equipment installations). A cooling system SEER of 10 was used for both bases.

5.3.3.3 Temperature Data Analysis

To determine the potential savings of remediation measures over the cooling and heating seasons, assumed indoor temperatures were compared to typical outdoor temperatures based on average hourly data over the past 5 years from a National Weather Service weather station located in Belleville, IL. This was obtained via the NCDC's QCLCD [10]. Missing values were in-filled by adding an interpolated anomaly field to the average climatology of the missing hourly reading. Figure 15 shows the typical climate for Scott Air Force Base in the year 2013.

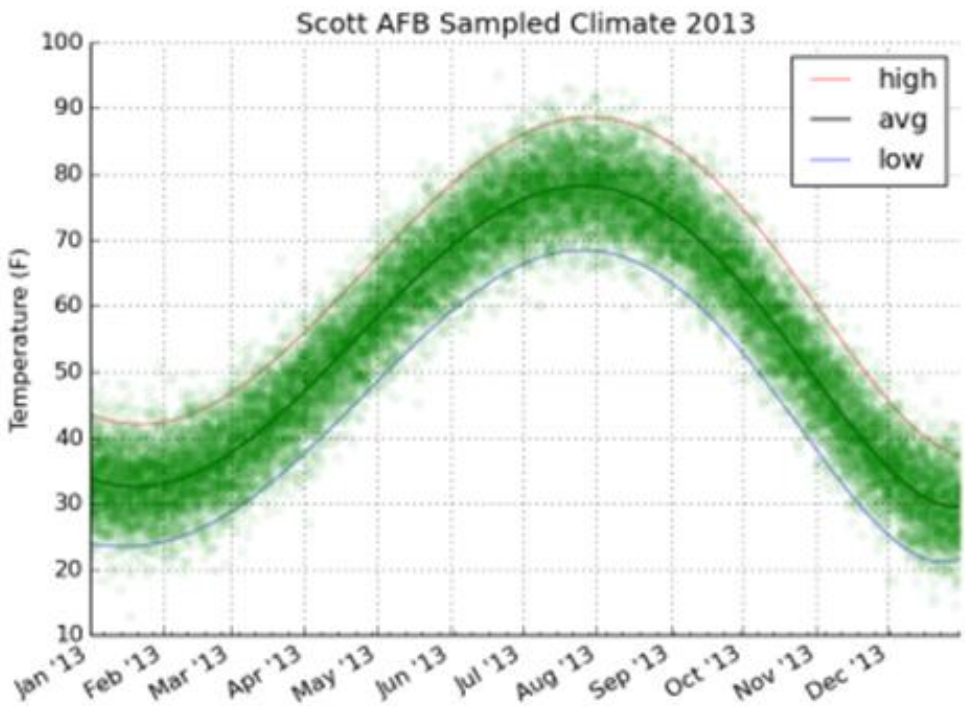

Figure 15. Scott AFB sample climate 2013.

5.3.4 System Integration

Although both handheld thermography and mobile thermal imaging use LWIR to determine energy loss, the imaging rig supplemented LWIR with NIR, LIDAR, GPS, and other sensors to gather better building diagnostic data. As a result, the final analysis can fully replace traditional handheld methods for gathering external building envelope data. This mobile thermal imaging technology allows the military to conduct baseline building envelope energy efficiency audits for hundreds of buildings in a matter of hours instead of months.

5.4 OPERATIONAL TESTING

5.4.1 Operational Testing of Cost and Performance

Data collection involved having an imaging rig drive to a given location and scan the area based on pre-defined, routing tracks. The imaging team waited until sunset to set up the system and then to begin imaging. This mitigated the effects of solar radiation and allowed the team to capture data at a period with the largest temperature difference (middle of the night). To ensure that the best data were captured, the contractor avoided imaging during any kind of precipitation events. Costs captured for driving the imaging rig included technician labor costs, cost of fuel for the imaging rig, and operating and maintenance costs.

5.4.1.1 Modeling and Simulation

All imaging data were logged onto the onboard data capture and diagnostics system. The onboard imaging technician was able to view the data as they were recorded to spot any problems in the data quality. Once the data were sent to Essess headquarters, they were processed and used for algorithmic testing. The algorithmic testing provided information on the cost, time, and image quality for mobile imaging versus traditional handheld thermography methods.

5.4.1.2 Timeline

Operational testing plan (Table 4) commenced in February 2014.

Table 4. Essess schedule of work.

	Task	2013	2014												2015	
		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2
1	Prepare plan for scanning Camp Lejeune Marine Corps base, NC and Scott Air Force Base, IL															
2	Scan Camp Lejeune Marine Corps base, NC and Scott Air Force Base, IL															
3	Process and Analyze Data from Camp Lejeune Marine Corps base, NC and Scott Air Force Base, IL															

5.4.1.3 Decommissioning

There was no need for decommissioning since this project involves a contracted service and a mobile scanning system.

5.4.2 Equipment Calibration and Data Quality Issues

The field engineer used an asymmetric circle calibration grid to optically calibrate the long-wave infrared cameras according to industry best practices (Figure 16) The thermal calibration was conducted using a black body radiation source at Essess headquarters.

Figure 16. LWIR camera calibration device.

The LIDAR was calibrated by its manufacturer, Velodyne, and qualitatively verified by the contractor. Sampling frequency was optimized based on the hardware limitations of the sensors and storage systems. The contracted Imaging Team allocated a specific imaging technician to resample a subset of the data to ensure that they were internally-consistent.

5.5 SAMPLING PROTOCOL

5.5.1 Data Description

Terabytes of thermal imaging, LIDAR and GPS data were collected at each base. For a subset of six of the buildings scanned by the drive-by method, data were collected using a handheld thermal camera to do a comparative analysis between handheld thermography and drive-by KSR LWIR scanning to determine the efficiency (amount of time taken to scan) and effectiveness (ability to identify energy leaks) of each method.

5.5.2 Data Storage and Backup

Data were written into 2 GB files to a mirrored disk array and checksums were generated and stored as metadata to ensure long-term data integrity. The data were physically uploaded to a

secure, private cloud system and physical hard drives were stored as back-ups at Essess' headquarters in Boston, MA.

5.5.3 Data Collection Diagram

The data collection approach was described in detail in Section 5.3 ("Design and Layout of System Components").

5.5.4 Schedule of Activities

Contract Award. The contract was awarded to Essess on 28 January 2014.

Kickoff Meeting. Kickoff meetings were conducted telephonically with Essess and with Energy Managers at the individual installations. A Kickoff telecon with Camp Lejeune was held Thursday, 6 February 2014 and with Scott AFB was held Friday, 7 February 2014.

Scanning – Camp Lejeune. Scanning activities at Camp Lejeune were conducted over the period of February 10-14. This work probably could have been accomplished over a period of 2 nights were it not for a large blizzard that caused the installation to be shut down for 2 days.

Scanning – Scott AFB. Scanning activities at Scott AFB were conducted over the evening of 28 February– 1 March 2014.

Essess Schedule of Work																
	Task	2013	2014												2015	
		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2
1	Prepare plan for scanning Camp Lejeune Marine Corps base, NC and Scott Air Force Base, IL															
2	Scan Camp Lejeune Marine Corps base, NC and Scott Air Force Base, IL															
3	Process and Analyze Data from Camp Lejeune Marine Corps base, NC and Scott Air Force Base, IL															

Figure 17. Management and Staffing Flow Chart.

5.5.5 Post-Processing Statistical Analysis

Several layers of testing and data quality measurement were used at each stage of processing, from initial data acquisition to final presentation of energy analysis results. When the data capture system started, it performed sensor integrity checks, ensuring that each sensor was communicating with the main computer and sending valid data. Throughout recording, the

system continued to monitor data quality, such as valid temperature ranges, image information content, GPS location, and LIDAR distance measurements. The system also monitored sensor connectivity, and raised errors if a sensor had stopped communicating. Any error or warning messages were immediately logged to a system diagnostics log and also displayed to the onboard display for the driver and navigator. At any time, a technician could log into the mobile system remotely and securely, view the images and other sensor data, and update the recording system software.

When the hard drives were imported into the secure data storage system, the import agent program ran a more rigorous data quality filter. This filter checked for data file integrity and file size, image size and information content, the frequency of each sensor message, the presence of each sensor data stream, and additional in-depth screens for GPS location noise, image pixel values, LIDAR distances and pointcloud sizes with scene distances, and thermistor readings. It also checked the data feed of sensor chamber operating conditions to make sure that the sensors were kept within specified operating temperatures. All sensor data passing these quality control checks were marked and queued for further analysis. There were few instances of unusable data caused by sudden onsets of precipitation while the team was still imaging. These data were limited and did not affect the overall analysis since the team paused the imaging until there was no precipitation.

During data processing and energy analysis, each stage of the processing pipeline passed its intermediate results through quality filters that checked for data validity, such as scene temperature readings, building metadata, GPS location consistency, raw energy flow estimates, and energy scores.

In addition to these data checks, the software behavior was tested several times a day in an automated testing environment. Each piece of processing code was built with unit tests, and integration tests checked the interaction of various software modules. The entire software infrastructure was built with continuous integration and continuous deployment, allowing for fast feedback and agile development.

Above the normal quality control process for this study, the contractor performed outlier detection in utility consumption data to detect outliers of energy usage per square foot of building area grouped by building type. Specifically, the contractor fit elliptic envelopes of data distributions using Mahalanobis distance. The Mahalanobis distance is a way of determining the "similarity" of a set of values from an unknown sample to a set of values measured from a collection of "known" samples. It measures the separation of two groups of objects. For more information please see: http://www.encyclopediaofmath.org/index.php/Mahalanobis_distance.

5.6 SAMPLING RESULTS

5.6.1 SCOTT AIR FORCE BASE, IL

The Kinetic Super-Resolution long-wave infrared integrated scanning team identified 3,263 distinct feature components on 146 different buildings on Scott Air Force Base out of a total of 328 buildings and other objects surveyed. These features were categorized by type (e.g., brick wall, roof, window glass, window frame) and surface temperature. Heat losses were calculated

based on the temperatures of the features, the times of observation, the orientations of the features, and the outdoor air temperature as described in Section 5.2 ("Baseline Characterization").

This analysis of Scott Air Force Base identified $304,393 in potential annual building envelope-related electricity and natural gas savings across all buildings on the base for remediation measures that have a payback period of 15 years or less (see Section 5.2 for detailed calculation methodology). These savings would require approximately $2,211,500 in capital expenditures for remediation. The recommended measures include retrofitting of walls, soffits, and roof insulation and sealing leaks around windows and doorframes. Total savings from these remediation measures could save Scott Air Force Base approximately $4,385,376 over the lifetime of the projects (15 years on average), and the measures would pay for themselves after 7.3 years. This is based on the assumption (based on field tests while the technology was being developed in the laboratory) that envelope-related issues and potential savings observed from the street were representative of the sides not visible from the street *on a per-building basis*, something generally true when examining buildings where all four sides are available. Note that, for the majority of buildings, at least 33% of the surface area of the building was scanned due to the fact that the imaging system typically views at least two sides of a building.

For areas visible from the street, this analysis showed $113,264 in potential annual building envelope-related savings across all building components imaged with a payback period of 15 years or less. These savings would cost approximately $824,985 in capital expenditures for remediation and a payback period of 7.3 years.

Figures 18 to 20 show spatial results of the analysis of conductive* leaks, convective† leaks, and all remediation measures.

The map shown in Figure 18 represents the average dollar loss per square foot of floor area from conductive leaks, e.g., leaks of energy through walls, roofs, and other surfaces due to poor insulation. Buildings highlighted in red are the most emissive, with the highest annual conductive heating and cooling losses per square foot of floor area.

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* Conductive heat loss involves heat being lost through the building's walls, thermal bridges or roof. If one side of a wall is at a higher temperature, then the heat will be transferred within the material to the other side which is at a lower temperature. This type of heat loss typically depends on three factors: the size of the building, local weather conditions, and the building envelope's capacity to resist heat loss.

† Convective leaks or convective heat loss refers to heat being lost through air leaks. For commercial heating, it is the process by which heat is lost by warm air leaking to the outside when a window or door is opened or cold air leaking into the building through cracks or openings in walls, windows, or doors.

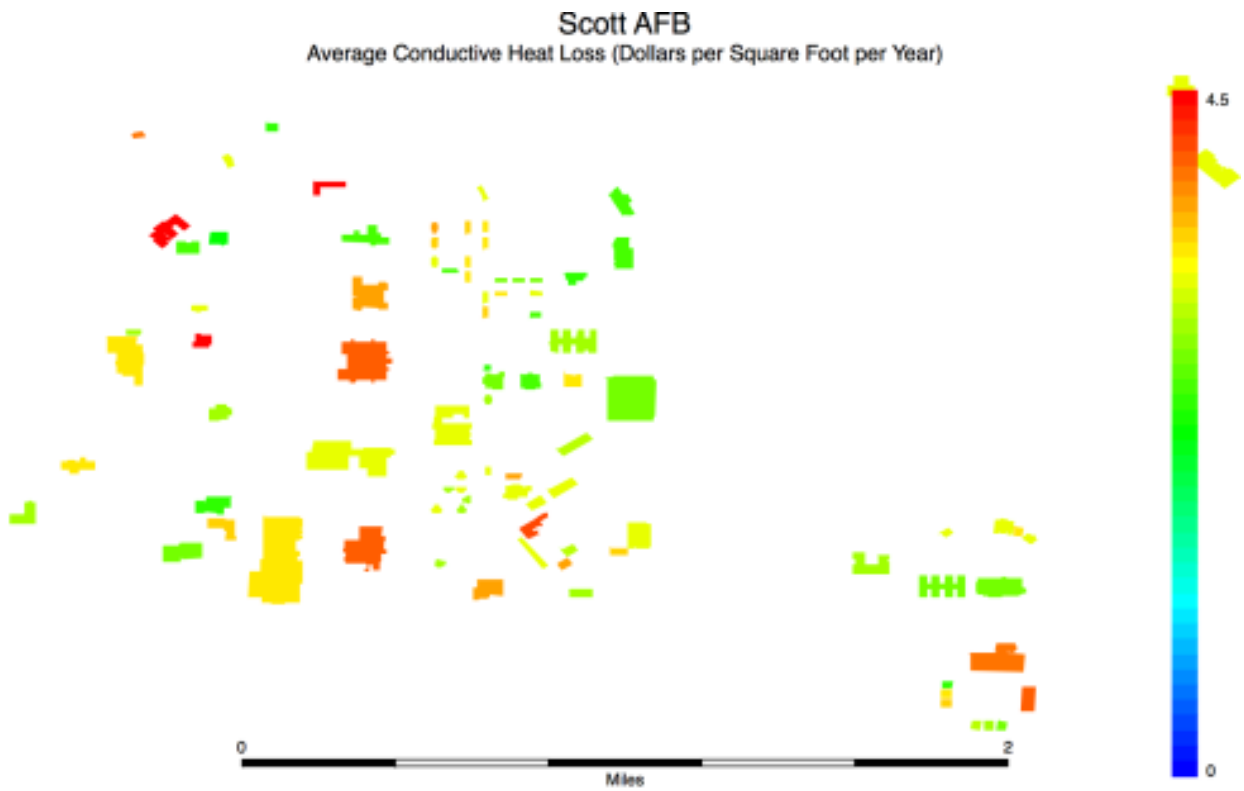

Figure 18. Average conductive heat loss for Scott AFB.

The heat loss map shown in Figure 19 represents the average dollar loss per square foot of floor area from convective leaks, e.g., leaks of energy through infiltration via cracks and gaps in door and window frames. Buildings highlighted in red are the most emissive, with the highest annual convective heating and cooling losses per square foot of floor area.

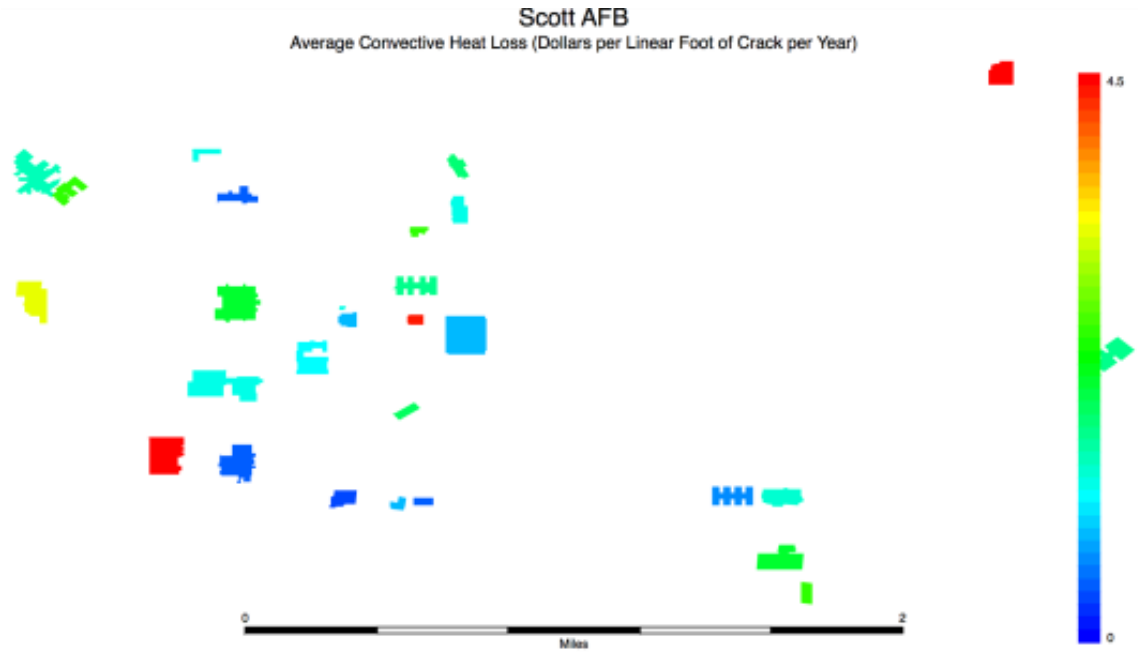

Figure 19. Average convective heat loss map for Scott AFB.

The above Payback Period for Envelope Measures map (Figure 20) shows the combined cost effectiveness of the remediation of conductive and convective leaks expressed as a payback period (in years). Buildings in blue have an attractive payback period, while buildings in red have a less attractive payback period.

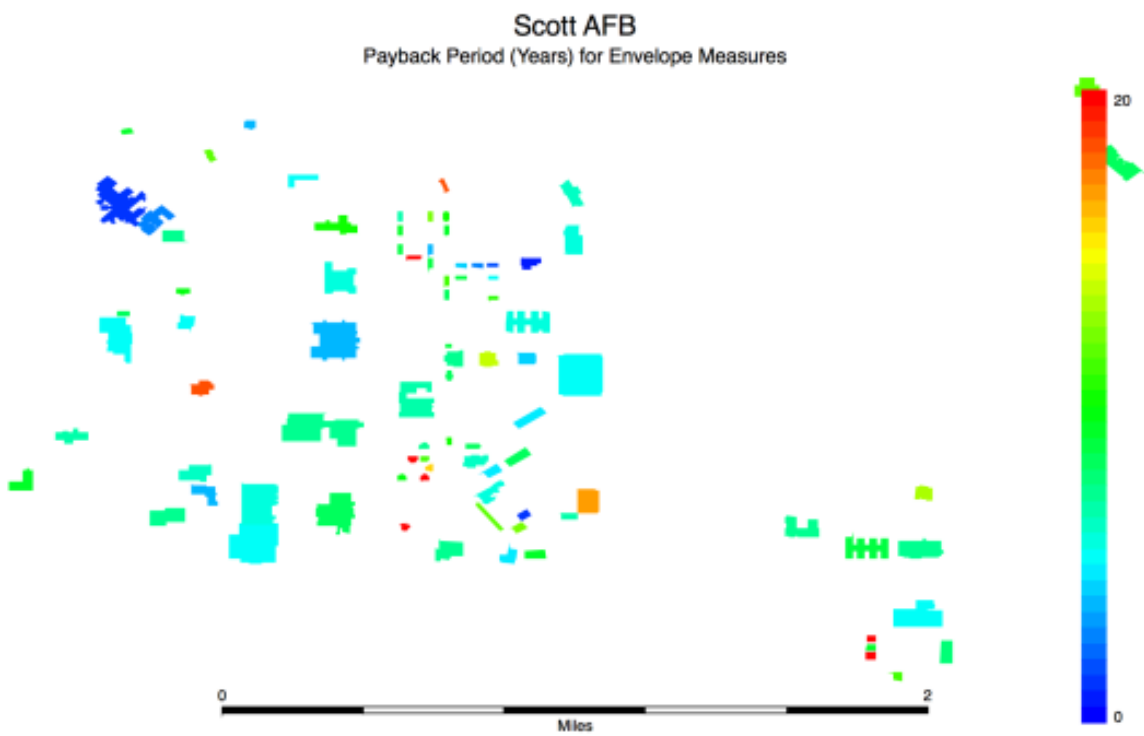

Figure 20. Payback period for envelope measures for Scott AFB.

5.6.2 MARINE CORPS BASE CAMP LEJEUNE, NC

The Kinetic Super-Resolution long-wave infrared integrated scanning team identified 2,883 distinct feature components on 147 different buildings on Camp Lejeune out of a total of 1,307 buildings and other objects surveyed. These features were categorized by type (e.g., brick wall, roof, window glass, window frame) and surface temperature. Heat losses were calculated based on the temperatures of the features, the times of observation, the orientations of the features, and the outdoor air temperatures as described in Section 5.2 ("Baseline Characterization").

This analysis of Camp Lejeune identified $113,085 in potential annual building envelope-related savings across all buildings on the base for remediation measures that have a payback period of 15 years or less. These savings would require approximately $996,669 in capital expenditures for remediation. The recommended measures include retrofitting of walls, soffits, and roof insulation and sealing leaks around windows and doorframes. Total savings from these remediation measures could save Camp Lejeune approximately $1,696,275 over the lifetime of the projects (15 years on average), and the measures would pay for themselves after 8.8 years. This is based on the assumption that envelope-related issues and potential savings observed from the street were representative of the sides not visible from the street *on a per-building basis*.

For areas visible from the street, this analysis showed $38,983 in potential annual building envelope-related savings across all building components imaged with a payback period of 15 years or less. These savings would cost approximately $333,256 in capital expenditures for remediation and a payback period of 8.5 years.

This section provides a spatial overview of results at Camp Lejeune. The second section provides a breakdown of heat loss costs and potential remediation savings by component. The third section describes specific envelope and non-envelope remediation measures in more detail. The fourth section provides a detailed analysis of 30 specific buildings on the base that have been determined to be high priority buildings. The 30 buildings were selected based on a visual and objective leak analysis, ROI potential, and Camp Lejeune's internal priorities. The fifth section discusses base-wide potential savings and costs. Chapter 6.0 (Performance Assessment) demonstrates the relative benefits of mobile imaging compared to traditional handheld alternatives. One building per base was selected for detailed analysis. An analysis for the remaining 29 buildings can be viewed in the appendix.

Figures 21 to 23 show the spatial results of this analysis of conductive leaks, convective leaks and all remediation measures are found in the following paragraphs.

The conductive heat loss map represents the average dollar loss per square foot from conductive leaks, e.g., leaks of energy through walls, roofs, and other surfaces due to poor insulation. Buildings highlighted in red are the most emissive, with the highest annual additional heating and cooling load per square foot.

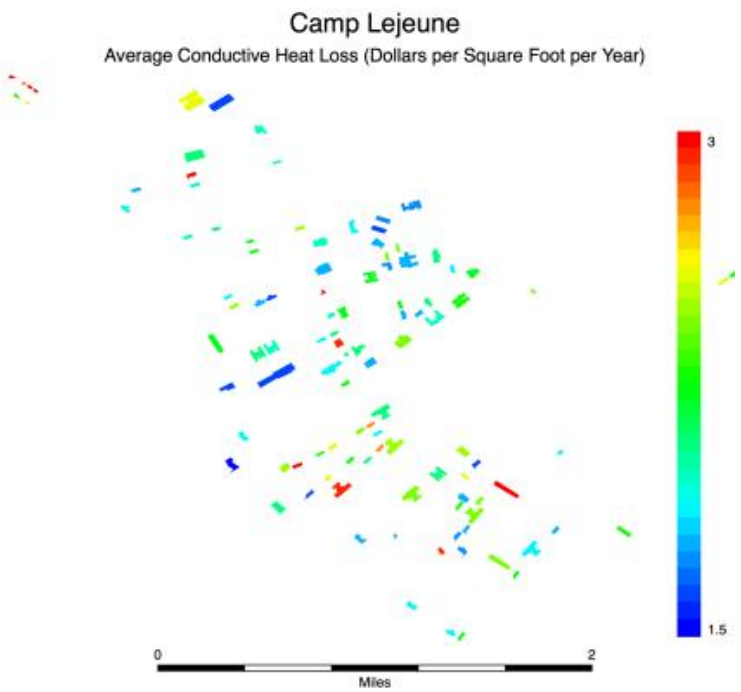

Figure 21. Average conductive heat loss map for Camp Lejeune.

The convective heat loss map shown in Figure 22 represents the average dollar loss per square foot from convective leaks, e.g., leaks of energy through infiltration via cracks and gaps in door and window frames. Buildings highlighted in red are the most emissive, with the highest annual additional heating and cooling load per square foot.

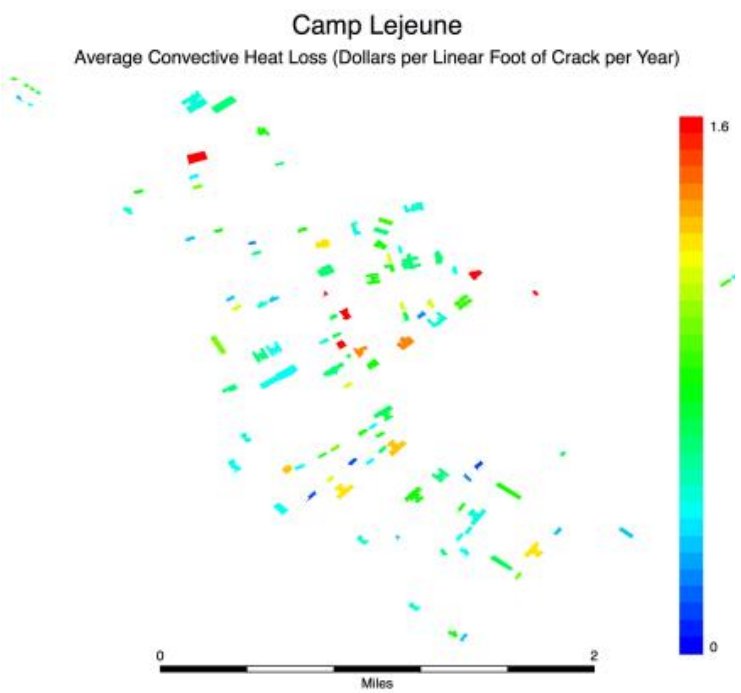

Figure 22. Average convective heat loss for Camp Lejeune, NC.

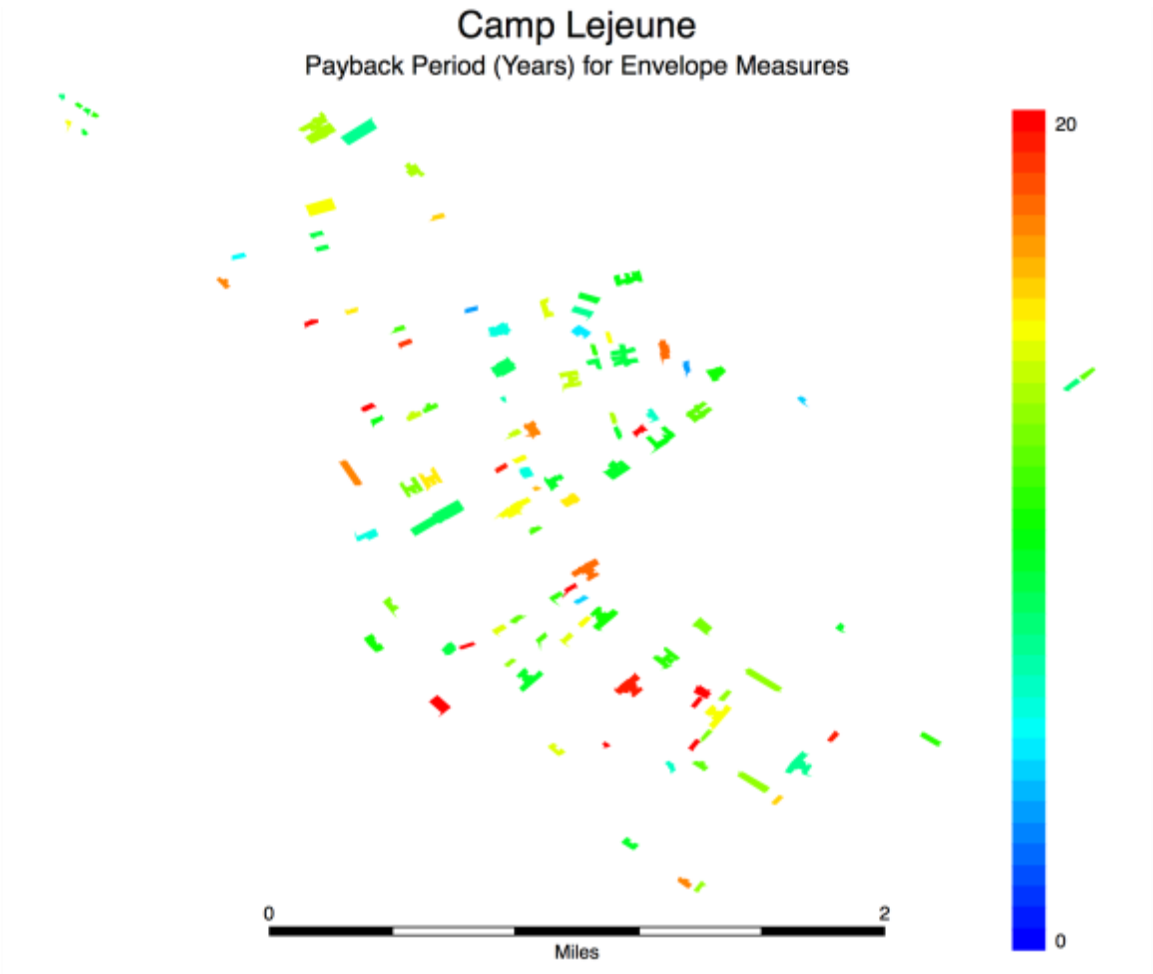

Figure 23. Payback period for envelope measures for Camp Lejeune, NC.

The above payback period map (Figure 23) shows the combined cost effectiveness of the remediation of conductive and convective leaks expressed as a payback period (in years). Buildings in blue have an attractive payback period, while buildings in red have a less attractive payback period.

5.6.3 RECOMMENDED ENVELOPE ECMs

A number of ECMs —both envelope and non-envelope measures— are recommended for specific buildings on each base. These were determined by a combination of thermal imaging, energy consumption analysis and disaggregation, and building characteristics.

Note that the non-envelope ECMs were not the focus of this demonstration project, but were provided as a "no-cost" extra service by the contractor. The non-envelope ECMs are based on common assumptions regarding internal building equipment and products that may require validation or modification via an on-site inspection.

When determining the optimal envelope ECMs to recommend for a given building, the relative cost effectiveness of each ECM is compared to other available options based on the specific heat

loss characteristics of the building in question. The method for calculating potential savings through envelope ECMs is characterized by a comparison of the heat flow across every hour of the year (for both cooling and heating) for an estimated current R value and a new post-remediation R value, incorporating hourly outdoor temperatures based on weather data. Air sealing-related ECMs involve a similar approach by comparing the difference between estimated current infiltration rates per linear foot of crack and post-remediation infiltration rates. Section 5.2 ("Baseline Characterization") describes the technical details of how these are calculated.

The specific envelope ECMs examined include:

- *Improve Wall Insulation*. This can encompass either patching up discrete insulation holes, or improving the overall insulation of a wall through the addition of blown or sheet insulation.
- *Improve Roof Insulation*. This can encompass either patching up discrete insulation holes, or improving the overall insulation of a roof/ceiling through the addition of blown or sheet insulation.
- *Improve Soffit Insulation*. Soffits are the junction between walls and roofs and are often poorly insulated. In many cases they can be accessed and have their insulation improved.
- *Improve Exposed Basement Wall Insulation*. When buildings have part of their basement wall exposed, they can often benefit from installing insulation on the portion exposed to the air.
- *Seal Window Frame Leaks*. This involves using caulk or weather-stripping to seal cracks in window frames that are letting air in or out of the building.
- *Seal Door Frame Leaks*. This also involves using weather-stripping (and in some cases caulk) to reduce the size of gaps around doorframes while not hindering the operation of the door.

Window and door replacement are not recommended because they are generally not cost effective, especially in military facilities, where security requirements can increase the cost of window and door installations.

6.0 PERFORMANCE ASSESSMENT

6.1 RELATIVE COST EFFECTIVENESS OF HANDHELD AND MOBILE IMAGING METHODS

6.1.1 Handheld Method

- Each building takes about 25 minutes of imaging work; necessary to overlap building components in each frame.
- Handheld unit is a FLIR i7 (The FLIR i-Series cameras are handheld thermal cameras specially designed for building diagnostics and commonly used in residential and commercial thermal audits).
- 140x140 pixels.
- 29 by 29 degree Field of View (FOV).
- Spotmeter, area with max/min. temperature, isotherm above/below.
- Scanning Cost: $920,000 for Scott AFB and $840,000 for Camp Lejeune. Based on the amount of building space imaged, the estimated cost is ~ $1,000 per 5,000 sq ft of floor space.

6.1.2 KSR LWIR Method

- Each building takes about 30 seconds to scan
- Mounted in integrated system camera
- 640x512 pixels
- 45x37 degree FOV
- Temperature calculated per feature
- Material emissivity obtained by computer vision
- Scanning Cost: Set cost at $200,000 per installation, regardless of square footage

The KSR LWIR approach provides a number of significant advantages over conventional handheld infrared thermography, both in terms of the speed and cost of imaging and the quality and utility of the images and analysis.

Handheld radiometric imaging instruments are standard equipment for energy efficiency measurements of building envelopes. The use cases for these imagers are low throughput, non-quantitative work. Data are stored on a low speed secure digital (SD) card. Image contrast is tuned for visual use. The center point of reported temperatures is what is outputted to the user. Resolution typically ranges from 80 x 80 pixels to 150 x 150 pixels. The FOV is 30 x 30 degrees.

The Kinetic Super-Resolution long-wave infrared integrated scanning system uses multiple radiometric thermal cameras. These devices are designed for high-throughput analytical and computer vision work. The devices are configurable through computer control and automation. Data flows from devices over a high speed local network to high speed redundant storage. Raw digital number information is stored for each image frame. Resolution per camera is 640 x 512 pixels. The field of view per camera is (FOV) 37 x 45 degrees while the total field of view is 37 x 80 degrees.

Images can be acquired at a much faster rate using the Essess sensor system. There is continuous acquisition without the need to frame the building. Each frame contains overlapping information. Further, the raw information allows temperature conversions to be done per individual region in the frames versus just one temperature point in the handheld instrument. The Essess system also provides near infrared images associated with each long-wave infrared image. These provide the ability to pick out features and textures that may not be easily visible in the long-wave infrared image, as the near infrared image is similar to a conventional photograph (Figure 24).

6.1.3 Example Performance in Scott Air Force Base Bldg 8 (PAX Terminal)

Handheld thermographic data acquisition of Bldg 8 was collected within minutes of capturing thermographic data for the same building using the KSR LWIR scanning system. Handheld data were collected on foot. Each frame was acquired by walking until the desired portion of the facade was in view. The image was acquired and stored to the SD card. The total time exceeded 30 minutes. Data capture using the vehicle scanning system took only about 30 seconds because, except for the driver operating the vehicle, no manual interactions were required (Figure 25).

Due to the nature of how the data are stored in handheld systems, the raw data are not stored along with the colored and contrasted temperature image. This means that it is more difficult to accurately determine the temperature fluctuation from one part of a building to the next. Without the temperature data, one solely depends on the color of the image. Furthermore, the emissivity of the material type must be set before the image can be acquired. Imaging multiple materials makes thermal calculations inaccurate. This makes it nearly impossible to use a handheld camera's data to accurately assess building facade temperature.

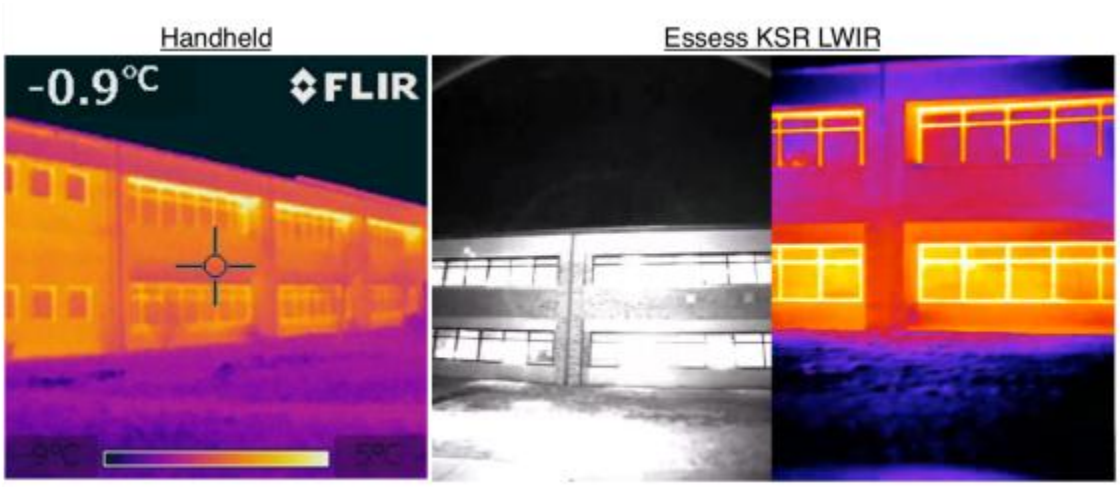

Figure 24. Handheld thermographic image (left) versus the KSR LWIR thermographic image (right) for Scott Air Force Base

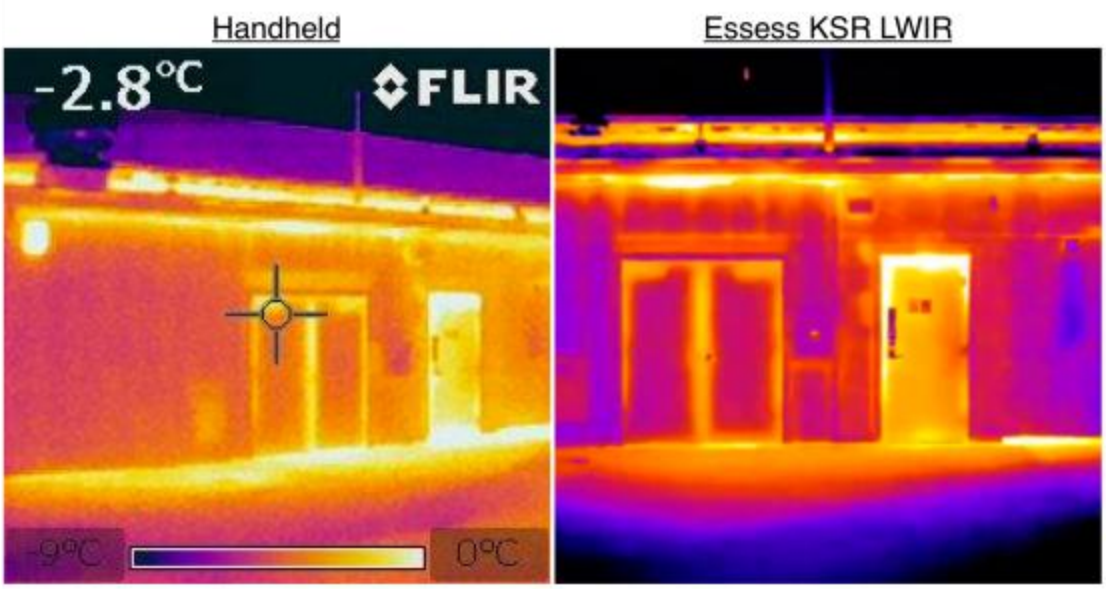

Figure 25. Handheld thermographic image versus the KSR LWIR thermographic image for Bldg 8, Scott AFB.

Capturing continuous, video format handheld data acquisition is hampered by multiple factors. Framing shots is the limiting factor in throughput of imaging the entire building. The secondary factor in limiting throughput is the storage media (20 MB/second), which is approximately 12-20 times slower than Essess' data collection system storage rate.

6.1.4 Example Performance in Camp Lejeune Bldg 235 (Bus Station)

The resolution and FOV of the handheld unit is not nearly as good as the cameras employed in the vehicle scanning system (Figure 26). The resolution is 15 times higher in the cameras used on the Essess scanning system. The FOV of the scanning system is higher. Due to multiple overlapping features and high acquisition speed, the effective FOV is exceedingly high.

Figure 26. Handheld thermographic image versus Essess KSR LWIR thermographic image for Bldg 235, Camp Lejeune, NC.

6.1.5 Summary

After a one-to-one comparison of handheld imaging against the vehicle scanning system, it is clear that the mobile imaging system is capable of collecting thermal imaging data in a far more scalable and efficient manner than traditional handheld thermography. Furthermore, the Essess imaging rig is equipped with multiple sensors including near infrared cameras and LIDAR, which, when combined with LWIR, allows significantly more information gathering than would be possible using traditional thermography. This includes building façade data and building orientation. The automated data processing system also allows an efficient and accurate analysis of each image, which contributes to detailed, accurate reporting. This type of quantitative analysis is not possible using the handheld system as it is impossible to accurately quantify how much energy is leaking out of one area of a building versus another area. In terms of speed, resolution, and FOV, Essess' scanning system exceeded the handheld unit by a significant margin.

6.2 COMPARISON OF THE FIDELITY AND USEFULNESS OF IMAGERY AT VARYING SCANNING DISTANCES

Essess scanned six buildings with each building being imaged from different distances starting at 20 yards and ending at 180 yards. The resulting data showed that there is very little difference in the measured building temperature for the entire building from 20 yards versus 180 yards (± 0.16 °F). Figure 27 shows that the first pass occurred at approximately 20 yards from the building with each succeeding pass being approximately 20 yards further from the building.

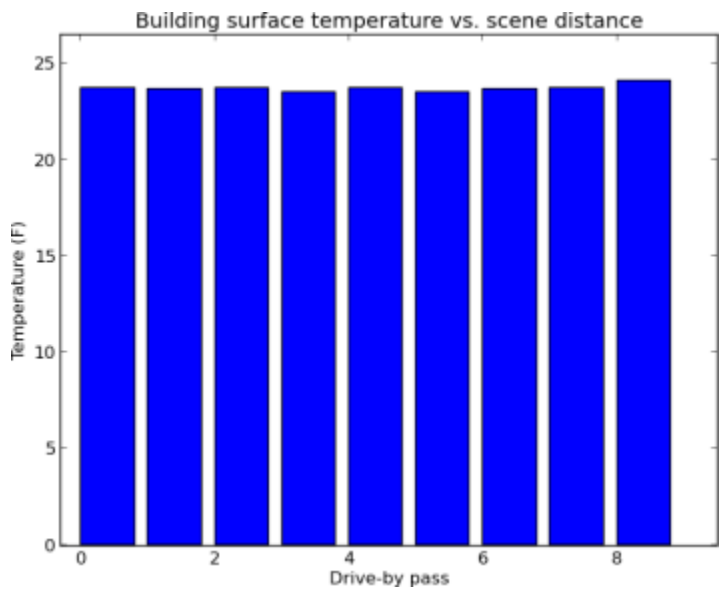

Figure 27. Building surface temperature vs. scene distance: Temp = 23.7 ± 0.16 °F.

Although the distance between the cameras and the building appears to have very little effect on the system's ability to measure building surface temperatures, building feature recognition becomes more difficult as you increase the distance from which the building is scanned. Individual building leaks also become gradually less visible as the distance is increased (as seen in the images below).

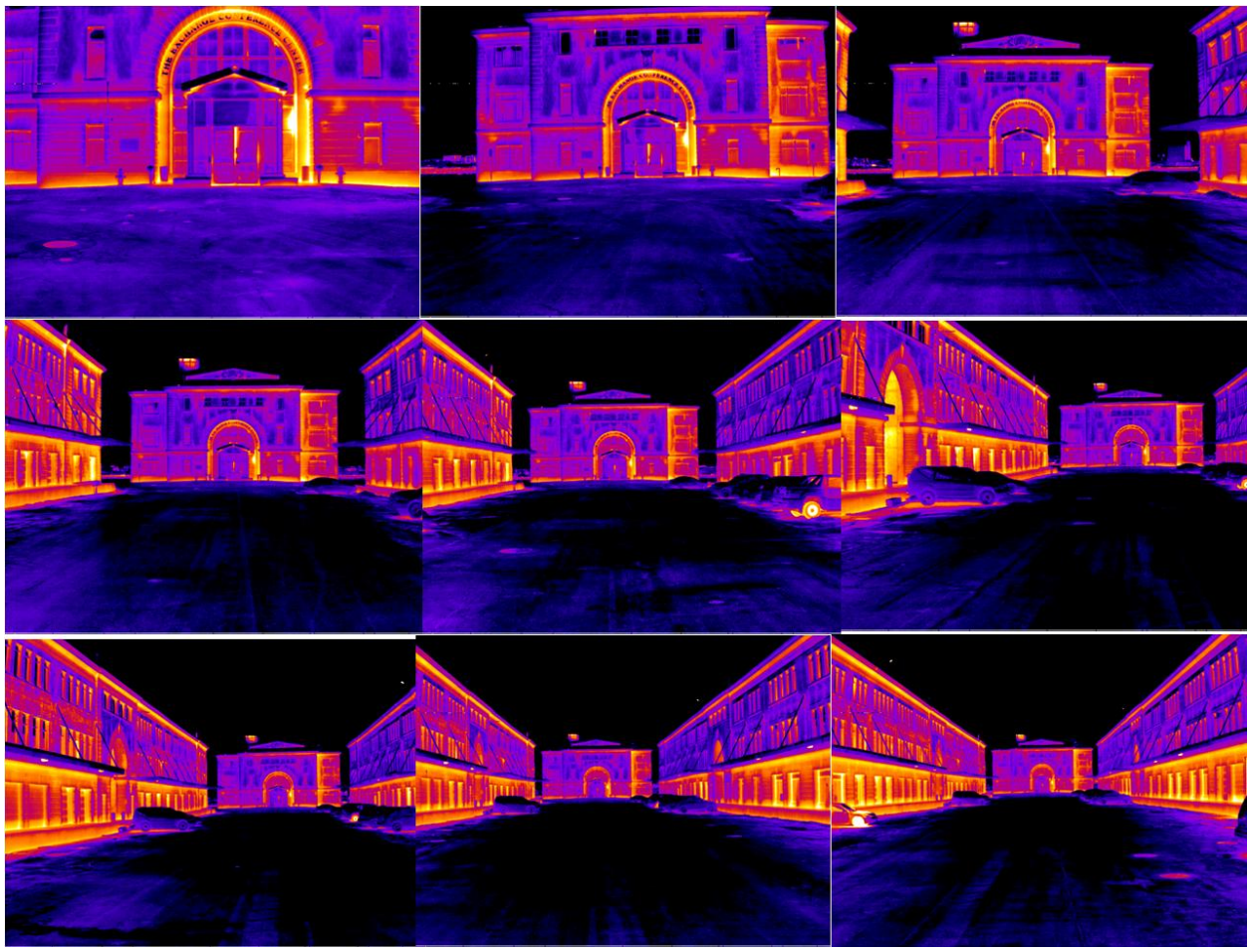

Figure 28. Essess LWIR distance test (from left to right) Row 1: 20 yards, 40 yards, 60 yards; Row 2: 80 yards, 100 yards, 120 yards; Row 3: 140 yards, 160 yards, 180 yards

6.3 ACTIONABLE RESULTS

6.3.1 Scott AFB, IL

6.3.1.1 Detailed Analysis for Bldg 1961, Scott Air Force Base, IL

Name: USTRANSCOMM Annex
Use Type: Office
Square Footage: 80,284
Avg. Daily Electric Use: 5,694 kWh
Avg. Daily Gas Use: 63.7 therms
Electricity Score: 60th Percentile
Gas Score: 50th Percentile
Annual Cooling Load: 614,284 kWh
Annual Heating Load: 18,071 therms

The electricity and gas scores above compare the building to similarly sized buildings of the same type on an energy use per square foot basis. An energy score at the 100th percentile

represents the highest energy use per square foot relative to similar buildings, while a score at the 0th percentile represents the lowest. The annual cooling and heating loads are calculated by regressing natural gas bills and electric bills against degree days for each billing period to disaggregate the heating and cooling components of building energy use.

Bldg 1961 has a gas usage of 28,960 Btu per square foot per year and electricity usage of 25.9 kWh per square foot per year.

Bldg 1961 serves as an interesting example of how energy use per square foot is not always a good predictor of leakiness or remediation potential. The building is perhaps the most obviously incompletely insulated building on the base, with numerous large hot spots scattered all over the exterior. However, its gas score only puts it in the 50th percentile, meaning that about half the buildings of a similar square footage have higher gas usage per square foot. The electricity use is a similarly middling 60th percentile.

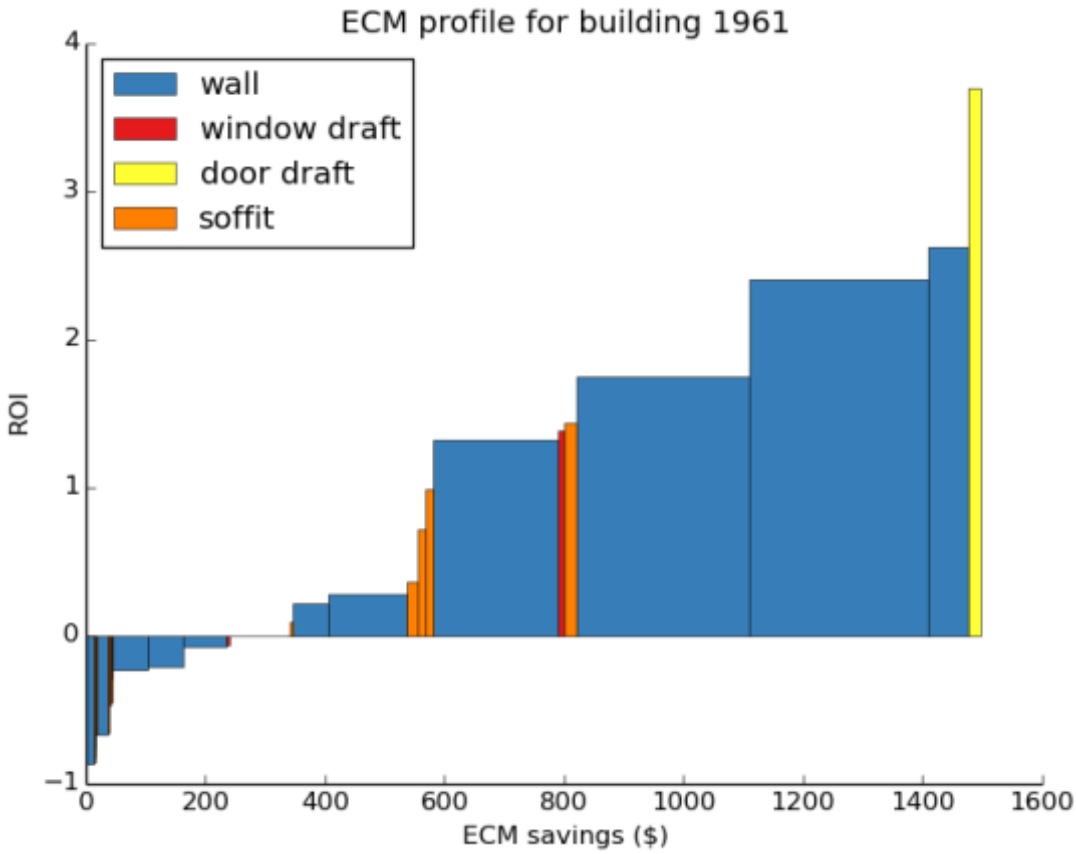

Figure 29. ECM profile for Bldg 1961, Scott AFB.

Figure 29 shows an abatement curve for all identified remediation measures for Bldg 1961, Scott AFB. Each bar represents a distinct remediation. The width of the bars represents the savings potential, while the height represents the economic viability (represented by ROI). The height of

each bar shows how many dollars of savings may be expected for every $1 spent on that particular remediation measure.

Table 5 lists the recommended envelope ECMs for Bldg 1961.

Table 5. Envelope ECMs, Bldg 1961, Scott Air Force Base.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	714	1721	1055	6818	6.5
Improve Soffit Insulation	47	114	70	612	8.8
Seal Door Frame Leaks	14	34	21	66	3.2
Seal Window Frame Leaks	7	17	10	66	6.3

Annual potential remediation savings for this building are $1,156 and simple payback is 6.5 years for this package of envelope-related ECMs.

6.3.1.2 Notable Leaks

There is a sizable patch of poorly insulated wall on the second story of the building around timestamp 42:55. The soffit also appears to be highly emissive (Figure 30).

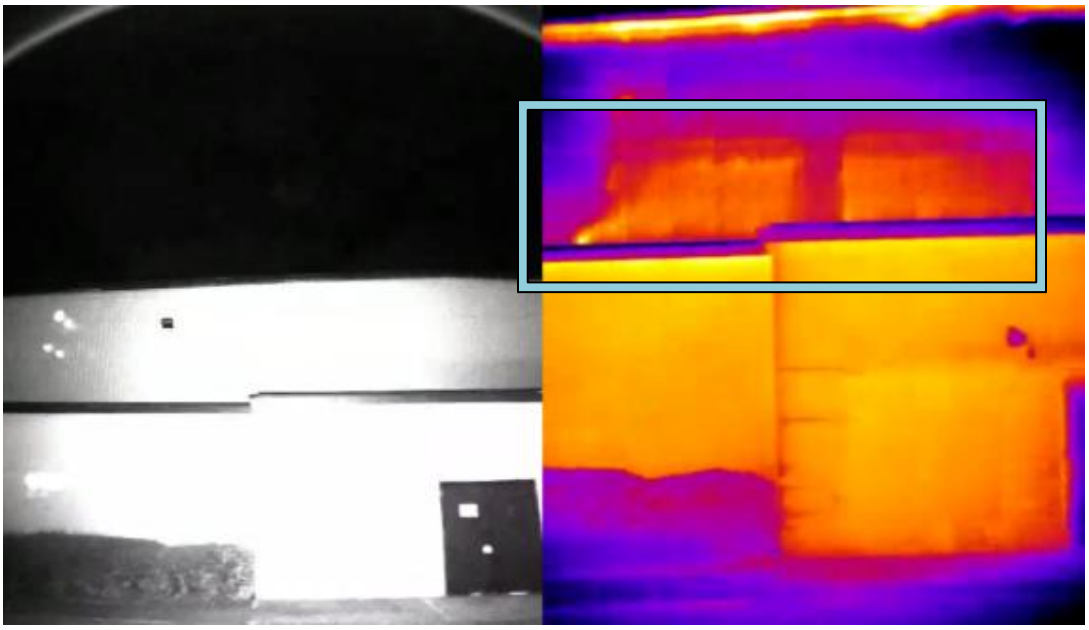

Figure 30. Poorly insulated wall for Bldg 1961, Scott AFB.

There is a sizable patch of poorly insulated wall on the second story of the building around timestamp 42:55 (Figure 31). The soffit also appears to be highly emissive.

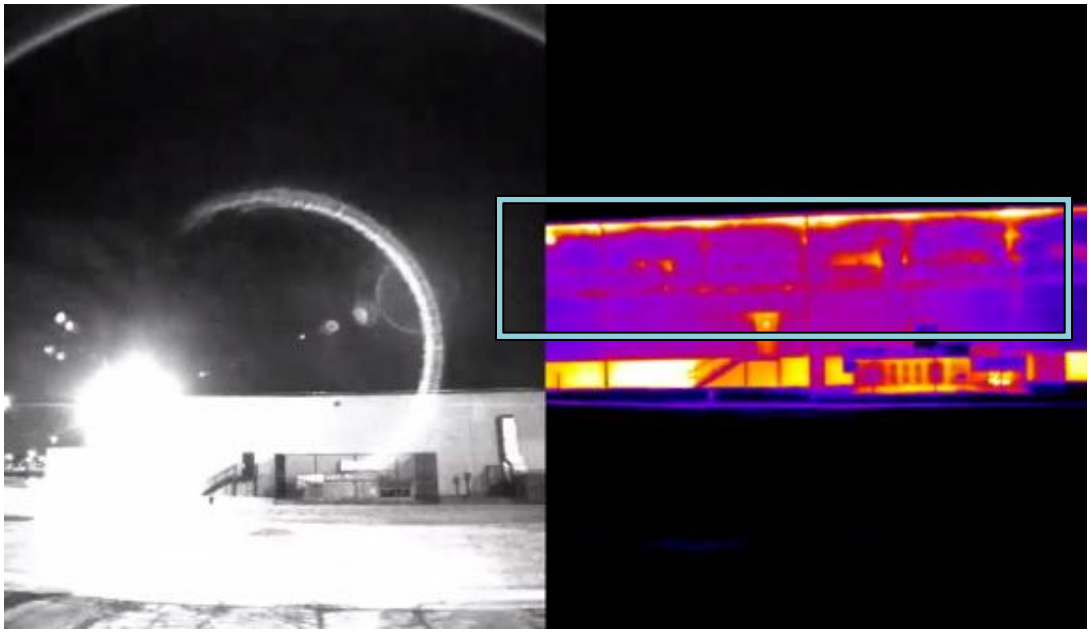

Figure 31. Various wall insulation gaps for Bldg 1961, Scott AFB.

There are numerous wall insulation gaps around the back of the building around timestamp 43:11, as well as a leaky soffit (Figure 32).

Figure 32. Rearview of Bldg 1961, Scott AFB.

The back of the building around timestamp 43:31 is particularly emissive, with large amounts of heat leaking out. The wall has insulation issues (Figure 33).

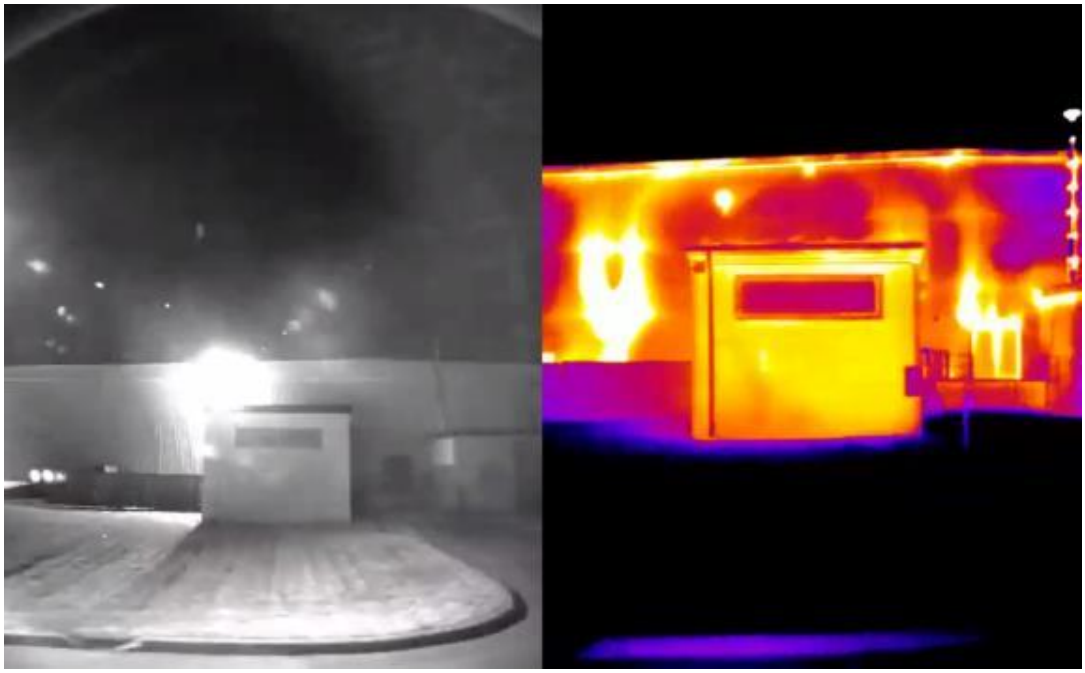

Figure 33. Large wall leaks for Bldg 1961, Scott AFB.

Similar large leaks are seen on the wall at timestamp 43:32. The "patchy appearance" indicates inconsistent insulation throughout the wall. The double doors to the right of the image may also have notable convective leaks around the frame.

6.3.1.3 Portfolio Strategy Analysis for Scott Air Force Base, IL

The analysis of Scott Air Force Base thermal imaging data resulted in an estimated $304,393 in potential annual building envelope-related savings across all buildings on the base for remediation measures that have a payback period of 15 years or less. These savings would require approximately $2,211,500 in capital expenditures for remediation. The recommended measures include retrofitting of walls, soffits, and roof insulation and sealing leaks around windows and doorframes. Total savings from these remediation measures could save Scott Air Force Base approximately $4,385,376 over the lifetime of the projects (15 years on average), and the measures would pay for themselves after 7.3 years. The recommended savings are the subset of those with a payback period of 15 years or less, while annual savings reflect all measures with positive savings independent of the remediation costs.

These base-level savings are estimated by multiplying the calculated savings for each building by the percent of the building imaged, assuming that the portions of the building not imaged are similar in characteristics (R-values, infiltration) to the portion imaged. The area of the buildings captured in the street-view thermal images identified $113,264 in savings from discrete building component leaks, at a cost of $824,985 and with a payback period of 7.3 years. The total savings over the lifetime of the envelope remediation projects identified in the thermal images was $1,612,845.

Additionally, Essess arrived at a rough estimate of about $928,330 of potential annual energy cost savings from non-envelope remediation measures. This rough estimate of cost savings was

arrived at by making assumptions about the buildings' occupancies, square footages, vintages, apparent conditions and the technologies that might be currently installed in the buildings. No effort was made to perform a walk-through audit of the Scott Air Force Base facilities. Based on these assumptions, the contractor estimateda cost of $7,691,294 to upgrade these buildings with more energy efficient technologies for an estimated total payback of 8.3 years. These savings were assumed to come primarily through the replacement of existing T8 fluorescent lamps and ballasts with high performance T8 lamps and through the use of occupancy sensors to control lighting. The number of lighting fixtures and savings potential is estimated based on the square footage and type of building. The relative paucity of building-specific information prevents a more detailed assessment of non-envelope savings options. Identification and validation of the expected energy cost savings and the cost of implementation of specific non-envelope ECMs would require further investigation through other energy auditing techniques.

Table 6 lists the potential savings and payback period for each category of envelope-related remediations for all imaged buildings at Scott AFB. Table 7 provides similar information for each category of non-envelope-related remediations for all imaged buildings at the installation.

Table 6. All recommended envelope-related remediations, Scott AFB.

Measure	Potential Savings	Payback Period
Door Frame Leaks	$3,376	2.2
Window Frame Leaks	$8,507	3.2
Basement Wall Insulation	$2,281	7.6
Wall Insulation	$93,905	7.7
Soffit Insulation	$2,582	9.6
Roof Insulation	$2,614	11.0

Table 7. All recommended non-envelope remediations, Scott AFB.

Measure	Potential Savings	Payback Period
Occupancy Sensors	$254,396	1.0
Low Flow Showerheads	$1,213	1.7
Light Emitting Diode (LED) Exit Signs	$67,442	2.2
Compact Fluorescent Lamps (CFLs)	$5,200	2.6
Programmable Thermostats	$3,724	2.7
Boiler Tune-ups	$8,028	4.0
EnergyStar Vending Machines	$10,446	4.3
Smartstrip Controls	$587	5.9
Fluorescent Lights	$567,294	12.6

Of all envelope remediation options examined, air sealing of doors and window frames tend to be the most cost-effective, with a typical payback period of 2.2 years for door frames and 3.2 years for window frames. For non-envelope measures, occupancy sensors and low flow showerheads (for residential buildings) have the lowest payback period, at 1 and 1.7 years respectively. The tables above show both estimated base-wide potential savings for identified components and the payback period for all measures considered.

A significant portion of envelope-related remediation savings comes from improving wall insulation. This is to be expected, as walls comprise the majority of the surface area of most buildings on the base. Wall insulation retrofits can be cost-effective for the more emissive surfaces, and the thermal imaging data can help provide an essential pre-assessment to determine the surfaces to target for improvements.

The total savings available at each different payback period may be examined by reviewing the cumulative savings across all measures by payback period (Figure 34).

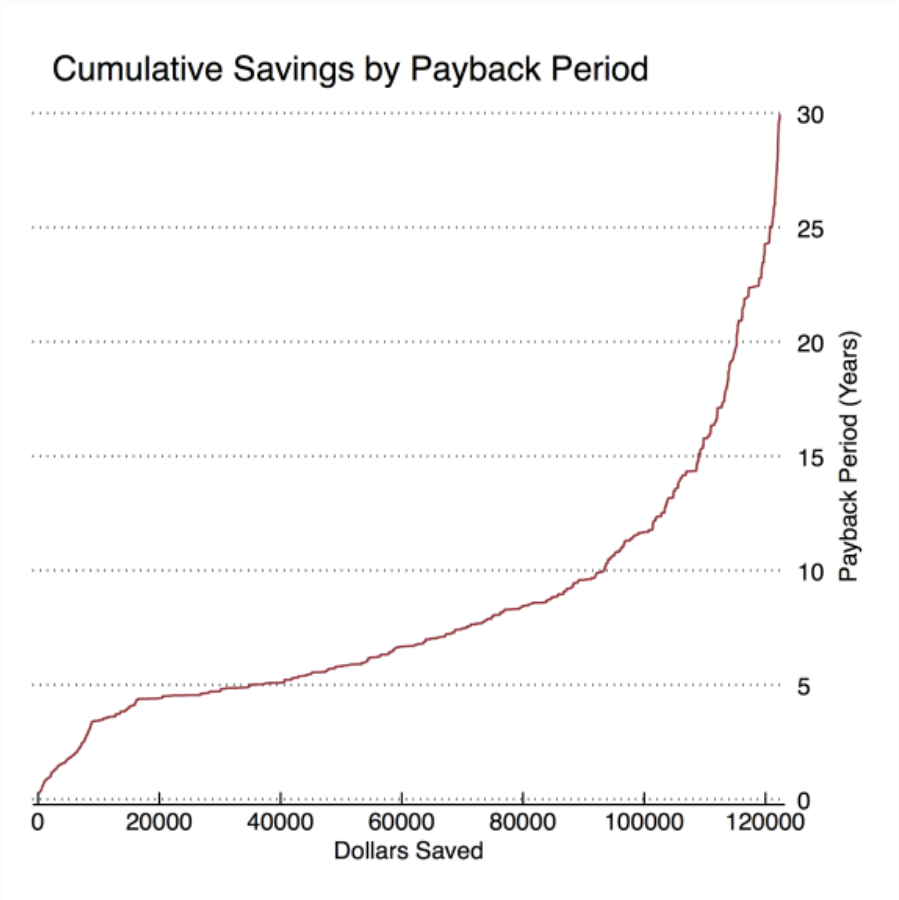

Figure 34. Dollars saved versus payback period (years).

Calculated potential annual savings resulting from envelope-related remediation of imaged surfaces were $35,000 with a payback period of less than 5 years, over $93,000 in savings with a payback of less than 10 years, and over $113,000 in savings with a payback of less than 15 years.

6.3.1.4 Recommendations for Scott Air Force Base, IL

Table 8 lists the high-impact cost-effective remediation measures that base planners should target first. These are primarily wall insulation-related measures for the buildings identified as the most emissive.

Table 8. Immediately actionable remediations for Scott Air Force Base

Label No.	Bldg No.	Action	Material	Init R Value	New R Value	Savings ($)	Cost ($)	Payback (yrs)
1	1600	Improve Wall Insulation	Brick	8.1	13.7	2509	11427	4.6
2	533	Improve Wall Insulation	Brick	8.1	13.6	1835	8337	4.5
3	1600	Improve Wall Insulation	Brick	8.4	13.6	1733	8706	5.0
4	1575	Improve Wall Insulation	Brick	8.4	13.6	1511	7694	5.1
5	1575	Improve Wall Insulation	Brick	8.0	13.7	1436	6327	4.4
6	1575	Improve Wall Insulation	Brick	8.3	13.7	1382	6721	4.9
7	40	Improve Wall Insulation	Brick	8.9	13.6	1362	8041	5.9
8	533	Improve Wall Insulation	Brick	8.2	13.6	1338	6306	4.7
9	1989	Improve Wall Insulation	Brick	8.6	13.6	1043	5628	5.4
10	1456	Improve Wall Insulation	Siding	6.9	10.0	1022	5340	5.2
11	1600	Improve Wall Insulation	Brick	8.3	13.6	865	4195	4.8
12	56	Improve Wall Insulation	Brick	8.8	13.6	732	4257	5.8
13	61	Improve Wall Insulation	Brick	8.8	13.5	650	3804	5.9
14	1644	Improve Wall Insulation	Concrete	6.1	10.0	627	2264	3.6
15	1989	Improve Wall Insulation	Brick	8.7	13.5	622	3559	5.7
16	1989	Improve Wall Insulation	Brick	8.4	13.6	586	2975	5.1
17	3296	Improve Wall Insulation	Brick	8.1	13.7	555	2519	4.5
18	5000	Improve Wall Insulation	Brick	8.7	13.7	552	3070	5.6
19	5022	Seal Window Frame Leak	Roof	10.0	15.0	227	66	0.3
20	1989	Improve Roof Insulation	Soffit	8.4	13.7	227	1642	7.2
21	1575	Improve Soffit Insulation	D Frame	N/A	N/A	147	775	5.3
22	1650	Seal Door Frame Leak	W Frame	N/A	N/A	117	66	0.6
23	1530	Seal Window Frame Leak	Soffit	8.6	13.7	113	66	0.6
24	1987	Improve Soffit Insulation	W Frame	N/A	N/A	94	538	5.7
25	10	Seal Window Frame Leak	W Frame	N/A	N/A	82	66	0.8
26	8	Seal Door Frame Leak	D Frame	N/A	N/A	73	66	0.9
27	1650	Seal Door Frame Leak	D Frame	N/A	N/A	70	66	0.9
28	1600	Seal Window Frame Leak	W Frame	N/A	N/A	68	66	1.0
29	3189	Seal Door Frame Leak	D Frame	N/A	N/A	67	66	1.0
30	5000	Improve Soffit Insulation	Soffit	8.7	13.6	51	299	5.9

These 30 measures would collectively save an estimated $21,696 per year at a cost of $104,953 with a payback period of 4.8 years. Note that Table 7 outlines the labor and material costs for implementing the listed ECMs and does not include the cost to identify these ECM opportunities. Essess' thermal imaging, data processing, data analysis and reporting costs of roughly $200,000 per military installation must also be factored into an economic analysis.

Figure 35 to 41 show the specific location of all 30 immediately actionable recommendations. Note that only the primary feature (e.g., the brick wall) is analyzed in the images. Obstructions like trees or flagpoles and unrelated features such as garage doors or windows are excluded.

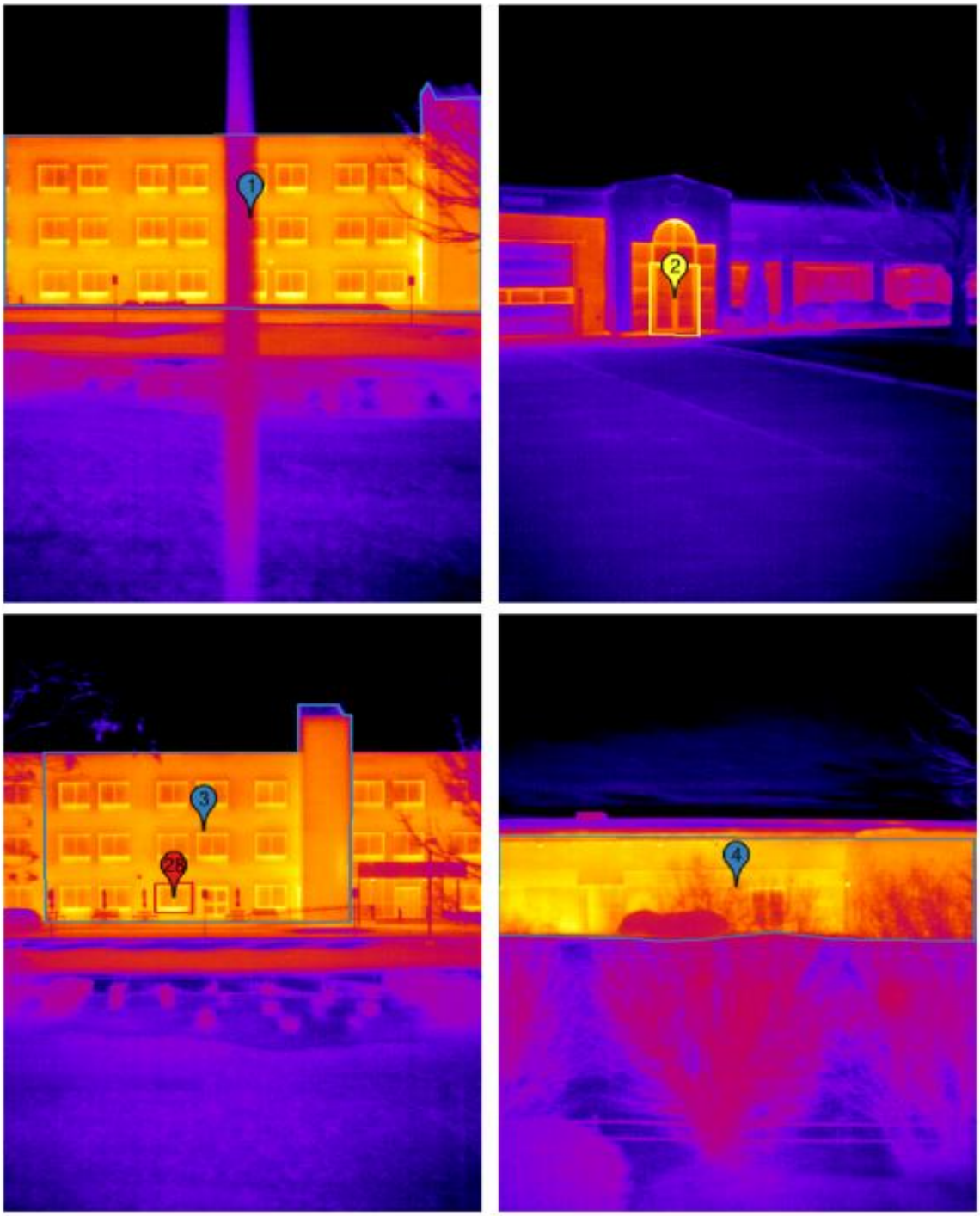

Figure 35. Scott AFB Bldgs 1600 (upper left), 533 (upper right), 1600 (lower left), and 1575 (lower right).

Figure 36. Scott AFB Bldgs 1575 (upper left), 1575 (upper right), 40 (lower left), and 533 (lower right).

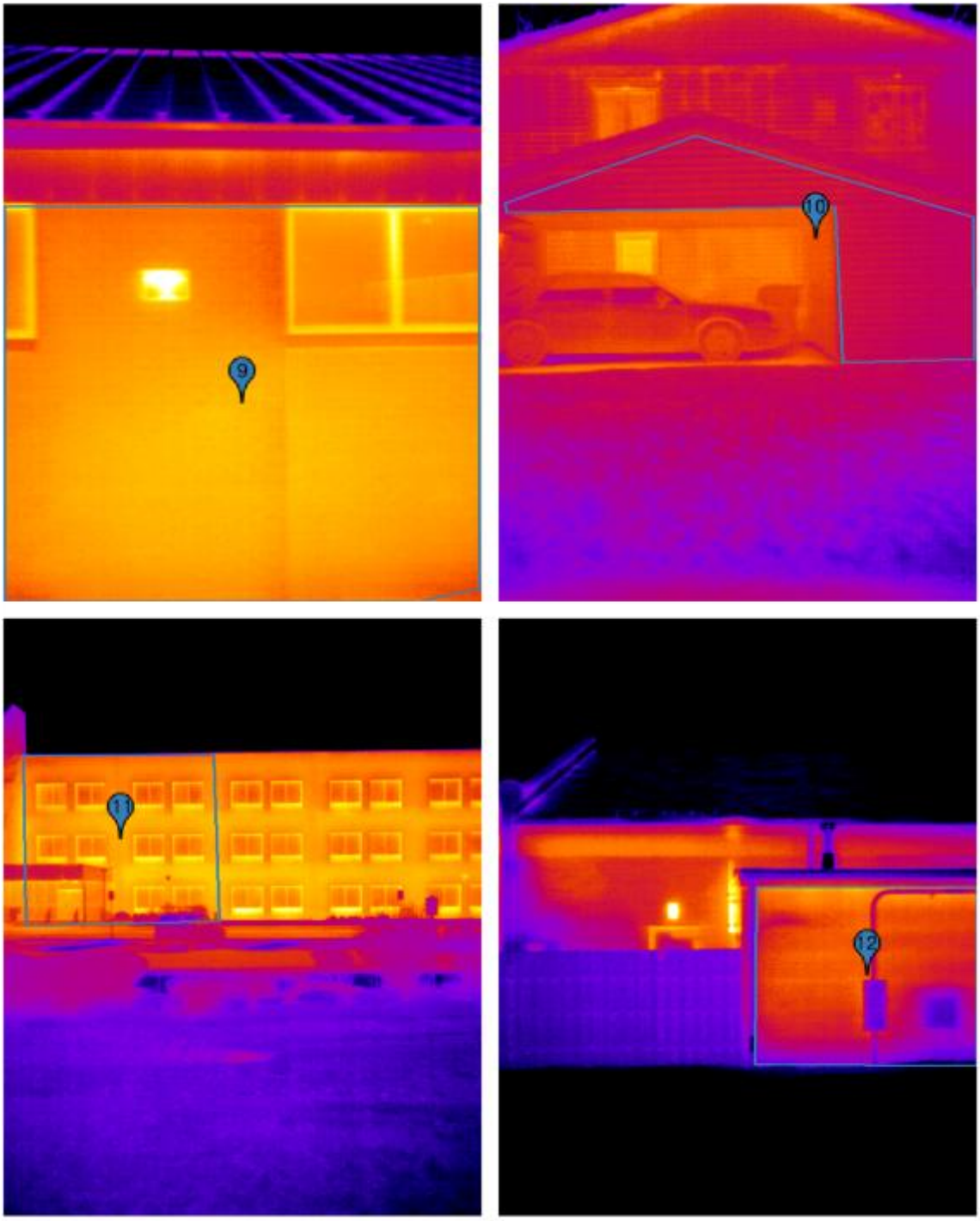

Figure 37. Scott AFB Bldgs 1989 (upper left), 1456 (upper right), 1600 (lower left), and 56 (lower right).

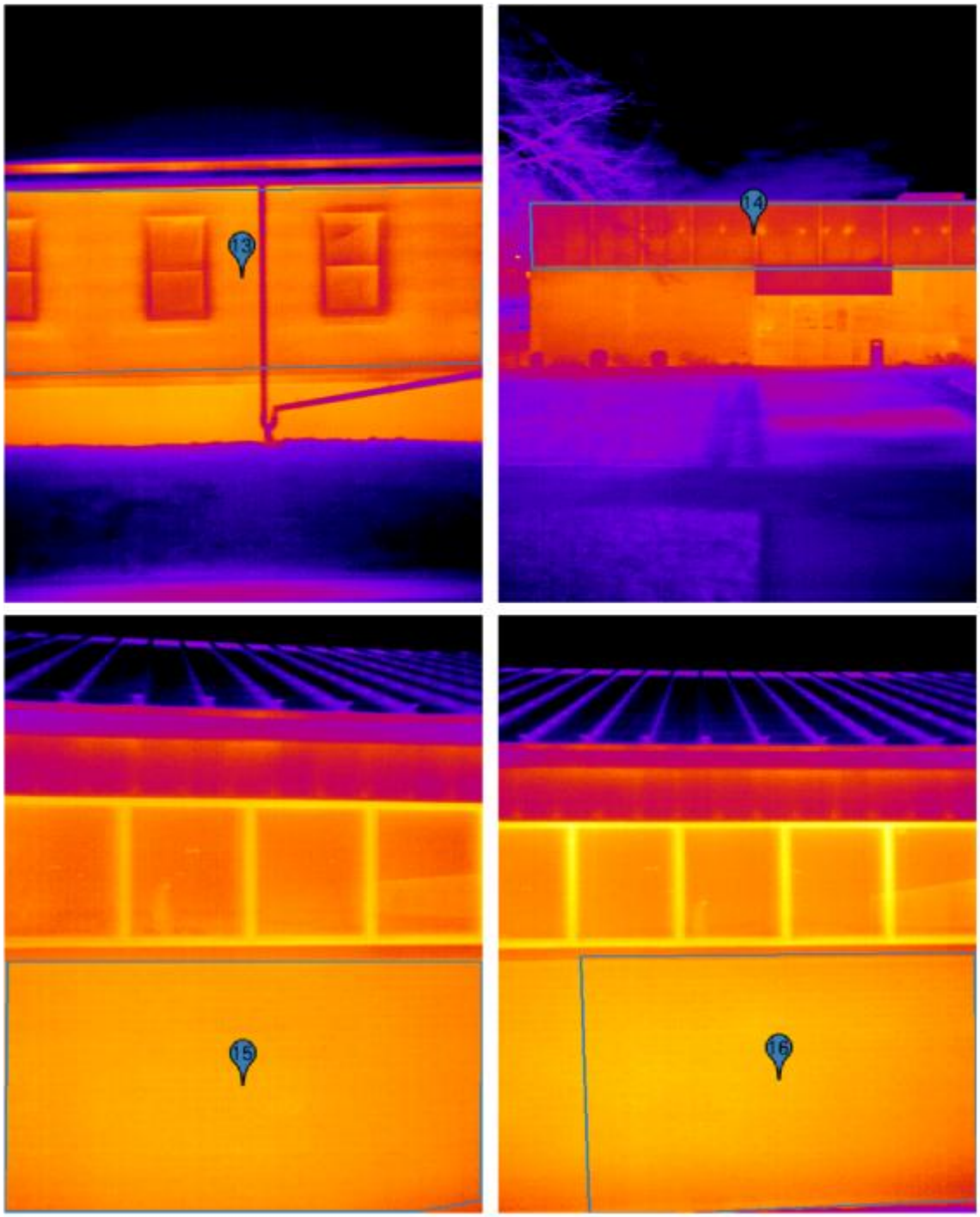

Figure 38. Scott AFB Bldgs 61 (upper left), 1644 (upper right), 1989 (lower left), and 1989 (lower right).

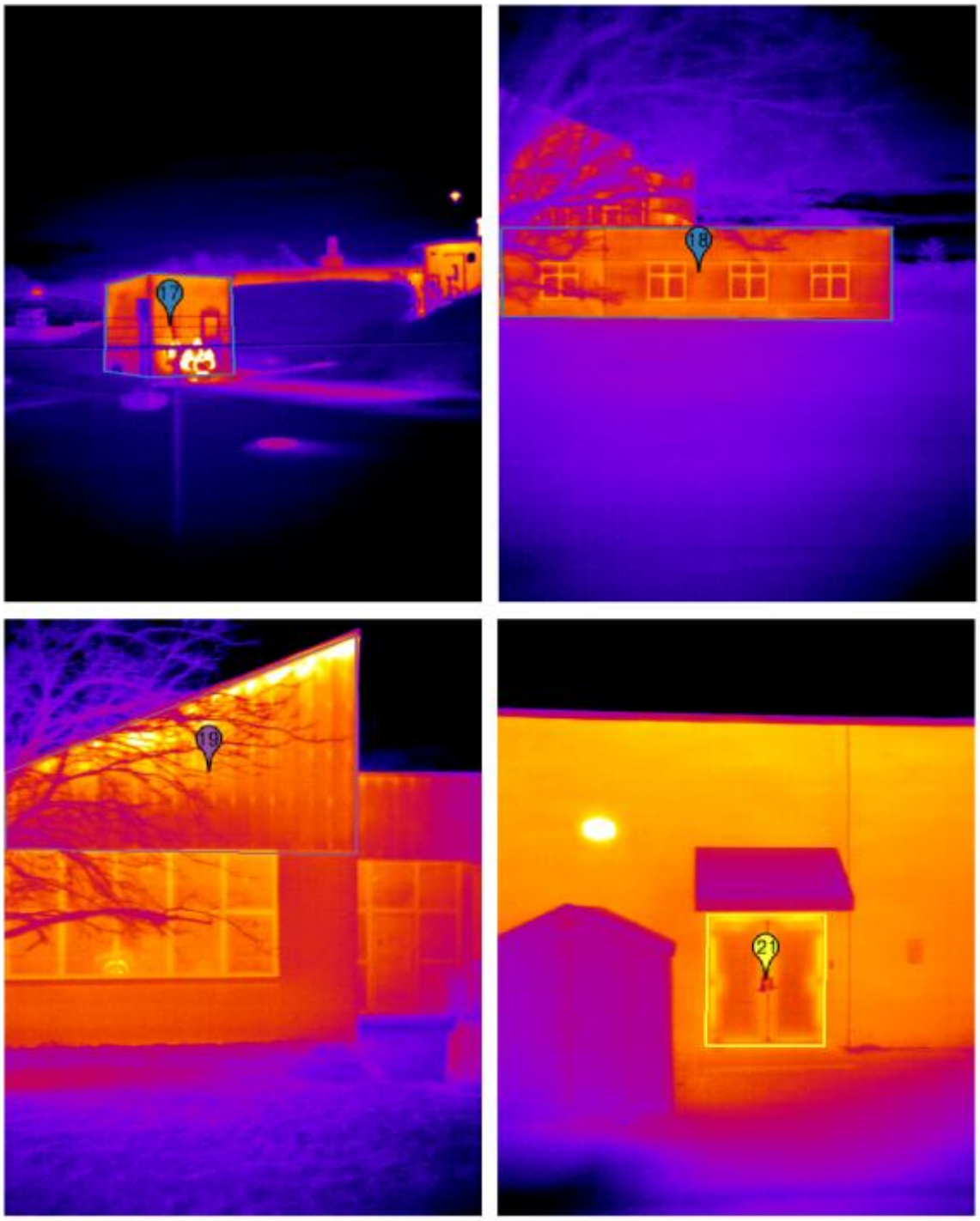

Figure 39. Scott AFB Bldgs 3296 (upper left), 5000 (upper right), 5022 (lower left), and 1575 (lower right).

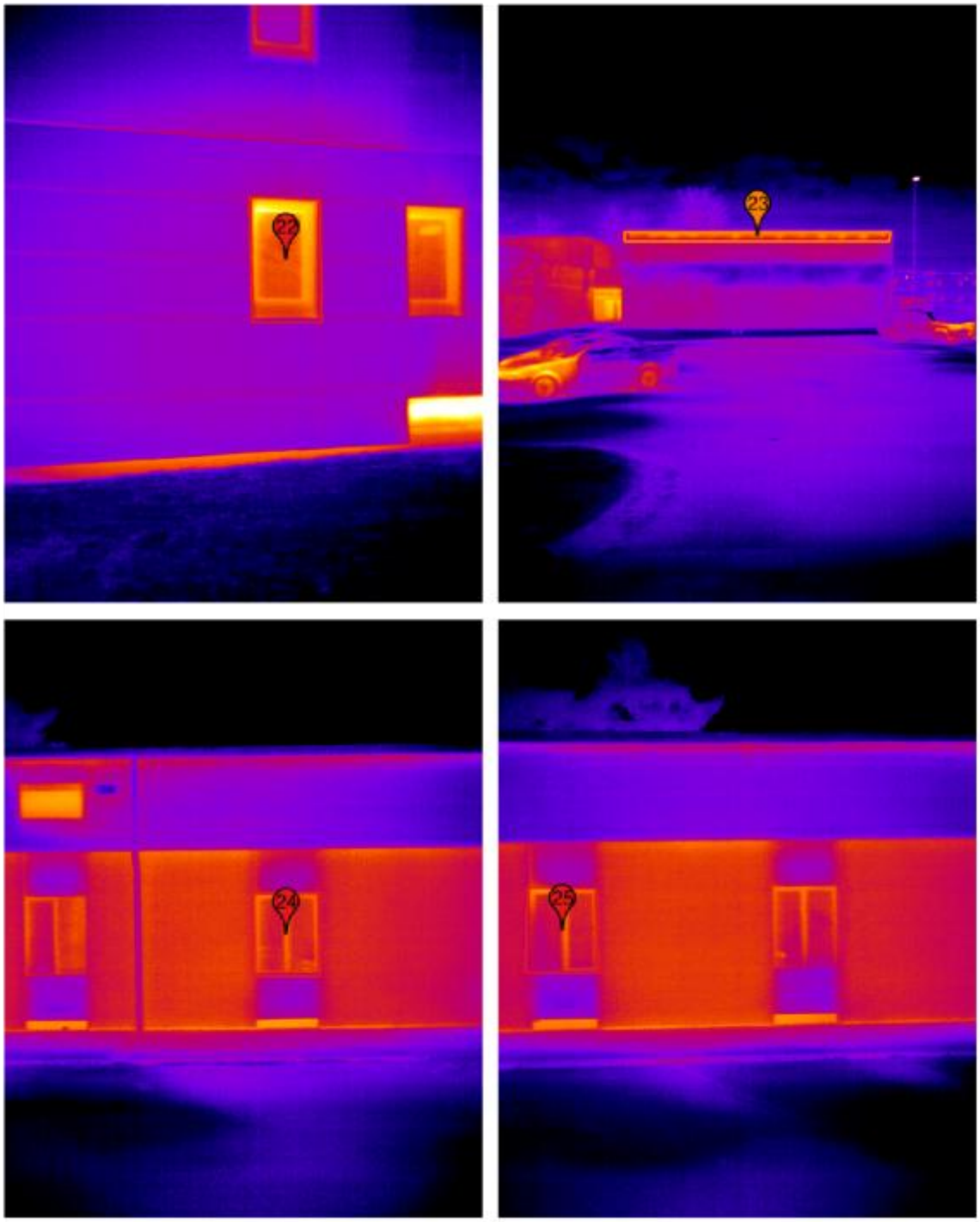

Figure 40. Scott AFB Bldgs 1650 (upper left), 1530 (upper right), 1987 (lower left), and 10 (lower right).

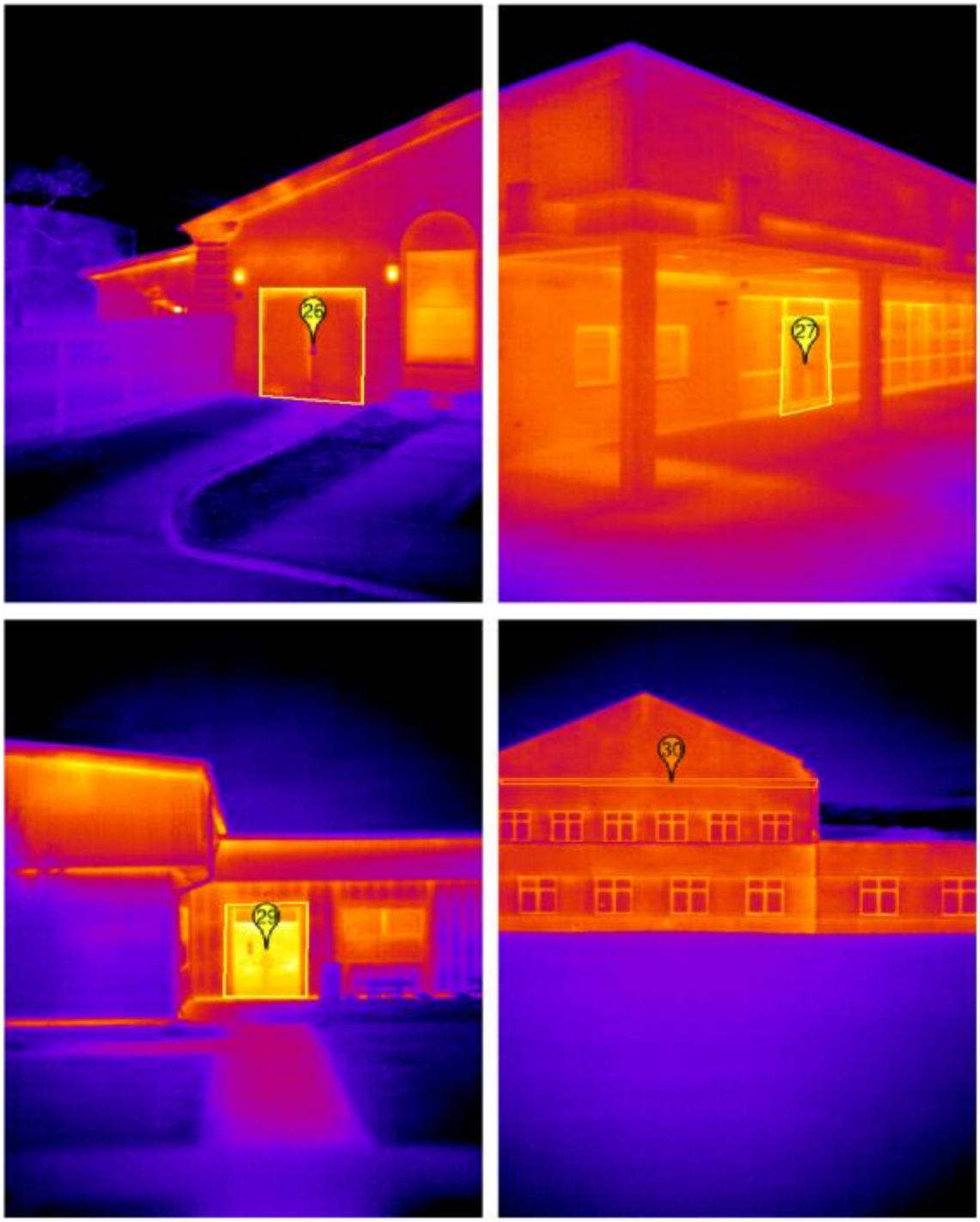

Figure 41. Scott AFB Bldgs 8 (upper left), 1650 (upper right), 3189 (lower left), and 5000 (lower right).

6.3.2 Marine Corps Base Camp Lejeune, NC

6.3.2.1 Detailed Analysis for Bldg 1, Marine Corps Base Camp Lejeune, NC

Name: Base Headquarters
Use Type: Office
Square Footage: 36,832
Average Daily Electric Use: 2,166 kWh
Electricity Score: 80th Percentile`

Bldg 1 (Figures 42 and 43) has an electricity usage of 21.5 kWh per square foot per year.

Figure 42. Aerial view of Bldg 1, Camp Lejeune.

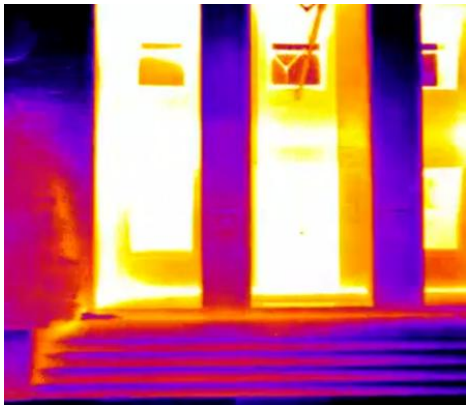

Figure 43. Thermal image of Bldg 1, Camp Lejeune.

The electricity and gas scores above compare the building to similarly sized buildings of the same type on an energy use per square foot basis. An energy score at the 100th percentile represents the highest energy use per square foot relative to similar buildings, while a score at the 0th percentile represents the lowest. The annual cooling and heating loads are calculated by regressing natural gas bills and electric bills (when available) against degree days for each billing period to disaggregate the heating and cooling components of building energy use.

Figure 44 shows an abatement curve for all identified remediation measures for the building in question. Each bar represents a distinct remediation. The width of the bars represents the savings potential, while the height represents the economic viability (represented by ROI). The height of each bar shows how many dollars of savings may be expected for every $1 spent on the remediation measure.

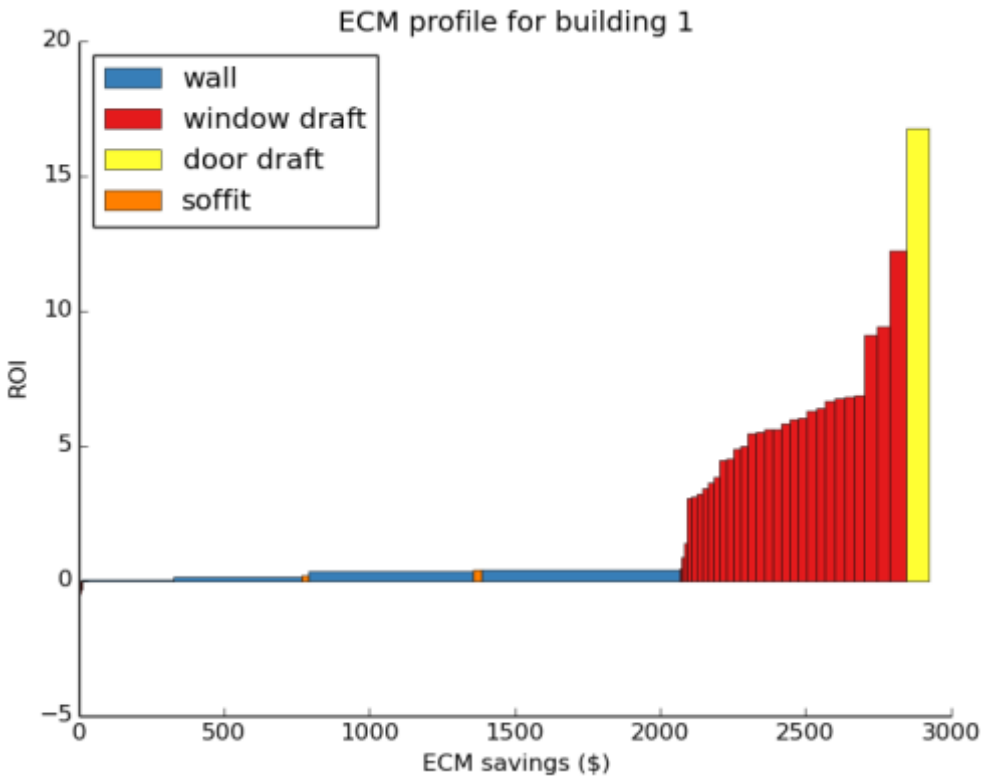

Figure 44. ECM savings for Bldg 1, Camp Lejeune, NC.

Table 9 lists the recommended envelope ECMs.

Table 9. Envelope ECMs, Bldg 1, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	3161	3096	2003	24240	12.1
Seal Window Frame Leaks	1244	1218	788	2069	2.6
Seal Door Frame Leaks	120	118	76	65	0.8
Improve Soffit Insulation	79	77	50	583	11.7

Annual potential remediation savings for this building are $2,918 for a simple payback of 9.2 years for this package of envelope-related ECMs.

The brick wall at timestamp 323:17 in the online Drive-by Application is highly emissive. There are some insulation holes around the middle of the wall (Figure 45), and the overall surface appears poorly insulated compared to other walls on the base (Figure 46).

The wall at timestamp 323:22 is also highly emissive, and has some apparent insulation holes near the middle of the wall. The soffit is also fairly emissive, and the window frames in the upper left are potentially leaky.

6.3.2.2 Notable Leaks

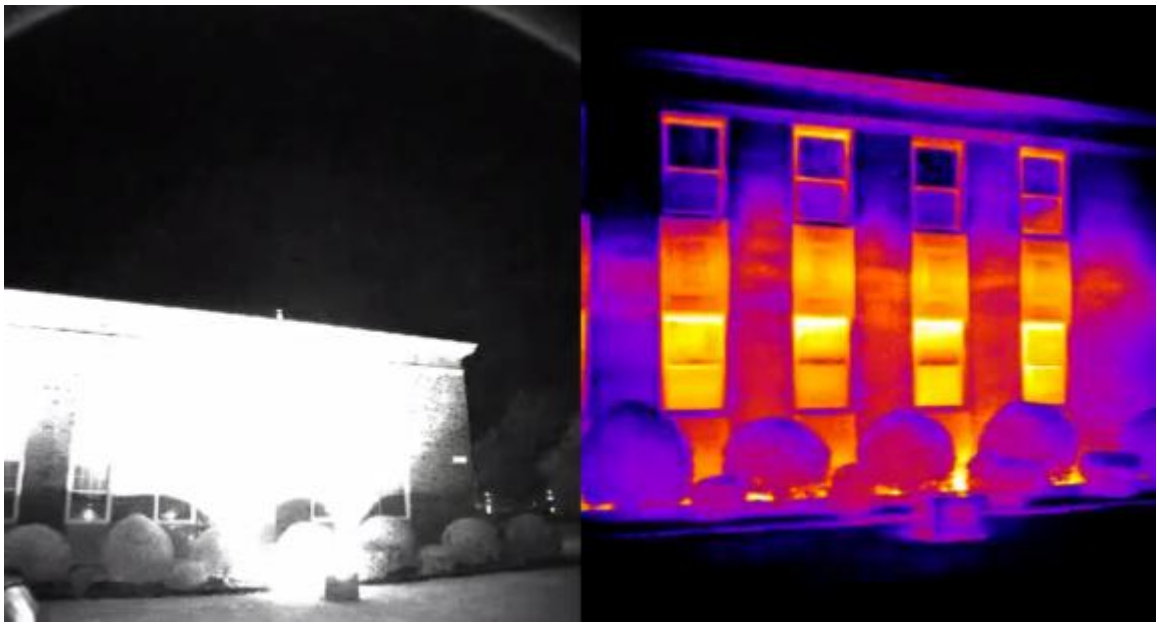

Figure 45. Insulation holes in Bldg 1, Camp Lejeune, NC.

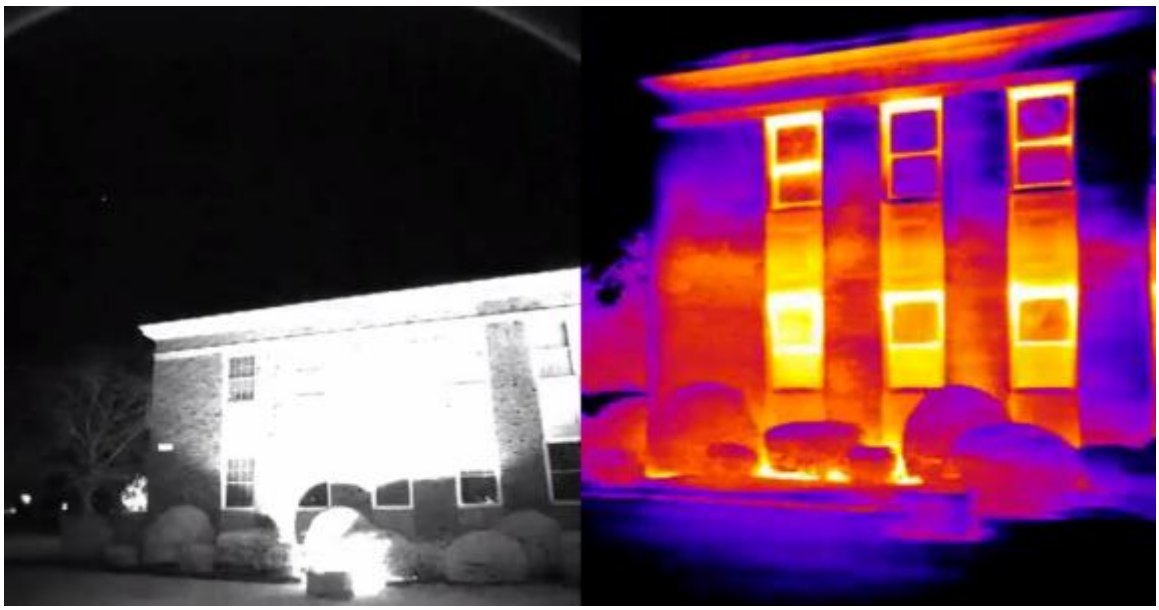

Figure 46. Additional wall insulation holes in Bldg 1, Camp Lejeune, NC.

6.3.2.3 Portfolio Strategy Analysis for Marine Corps Base Camp Lejeune, NC

The analysis of Camp Lejeune thermal imaging data estimates $113,085 in potential annual building envelope-related savings across all buildings on the base for remediation measures that have a payback period of 15 years or less. These savings would require approximately $996,669 in capital expenditures for remediation. The recommended measures include retrofitting of walls, soffits, and roof insulation and sealing leaks around windows and doorframes. Total savings from

these remediation measures could save the military approximately $1,696,275 over the lifetime of the projects (15 years on average), and the measures would pay for themselves after 8.8 years.

These base-level savings are estimated by dividing the calculated savings for each building by the percent of the building imaged, assuming that the portions of the building not imaged are similar in characteristics (R-values, infiltration) to the portion imaged. The area of the buildings captured in the thermal images from the street identified $38,983 in savings from discrete building component leaks, at a cost of $333,256 and with a payback period of 8.5 years. The total savings over the lifetime of the envelope remediation projects identified in the thermal images was $584,749.

Additionally, as at Scott Air Force Base, Essess arrived at a rough estimate of approximately $373,201 of potential annual energy cost savings at Camp Lejeune from non-envelope remediation measures. This rough estimate of cost savings was arrived at by making assumptions about the buildings' occupancies, square footages, vintages, apparent conditions and the technologies that might be currently installed in the buildings. No effort was made to perform a walk-through audit of the Camp Lejeune facilities. Again, based on these assumptions, the contractor estimated a cost of $2,448,407 to upgrade these buildings with more energy efficient technologies for an estimated total payback of 6.6 years. These savings were assumed to come primarily through the replacement of existing T8 fluorescent lamps and ballasts with high performance T8 lamps and through the use of occupancy sensors to control lighting. The number of lighting fixtures and savings potential is estimated based on the square footage and type of building. The relative paucity of building-specific information prevents a more detailed assessment of non-envelope savings options. Identification and validation of the expected energy cost savings and the cost of implementation of specific non-envelope ECMs would require further investigation through other energy auditing techniques.

Table 10 lists the potential savings and payback period for each category of remediations for all imaged buildings on Camp Lejeune, NC.

Table 10. All recommended remediations, Camp Lejeune, NC.

Measure	Potential Savings	Payback Period
Seal Door Frame Leaks	$2,695	3.7
Seal Window Frame Leaks	$7,081	5.1
Basement Wall Insulation	$1,262	9.6
Improve Wall Insulation	$26,395	9.7
Improve Soffit Insulation	$952	10.7
Improve Roof Insulation	$598	14.0
Occupancy Sensors	$105,440	0.7
Low Flow Showerhead	$552	1.7
LED Exit Signs	$30,874	2.2
Replace Incandescent Bulbs with CFLs	$943	2.6
Smartstrips	$267	5.9
Efficient Fluorescent Lights	$235,126	9.8

Of all envelope remediation options examined, air sealing of doors and window frames tend to be the most cost-effective, with a typical payback period of 3.7 years for door frames and 5.1 years for window frames. For non-envelope measures, occupancy sensors and low flow showerheads (for barracks facilities and fitness centers) have the lowest payback period, at 0.7 and 1.7 years respectively. The table below shows both estimated base-wide potential savings for identified components and the payback period for all measures considered.

A significant portion of envelope-related remediation savings comes from improving wall insulation. This is to be expected, as walls comprise the majority of the surface area of most buildings on the base. Wall insulation retrofits can be cost-effective for the more emissive surfaces, and the thermal imaging data can help provide an essential pre-assessment to determine the surfaces to target for improvements.

The total savings available at each different payback period may be examined by reviewing the cumulative savings across all measures by payback period (Figure 47).

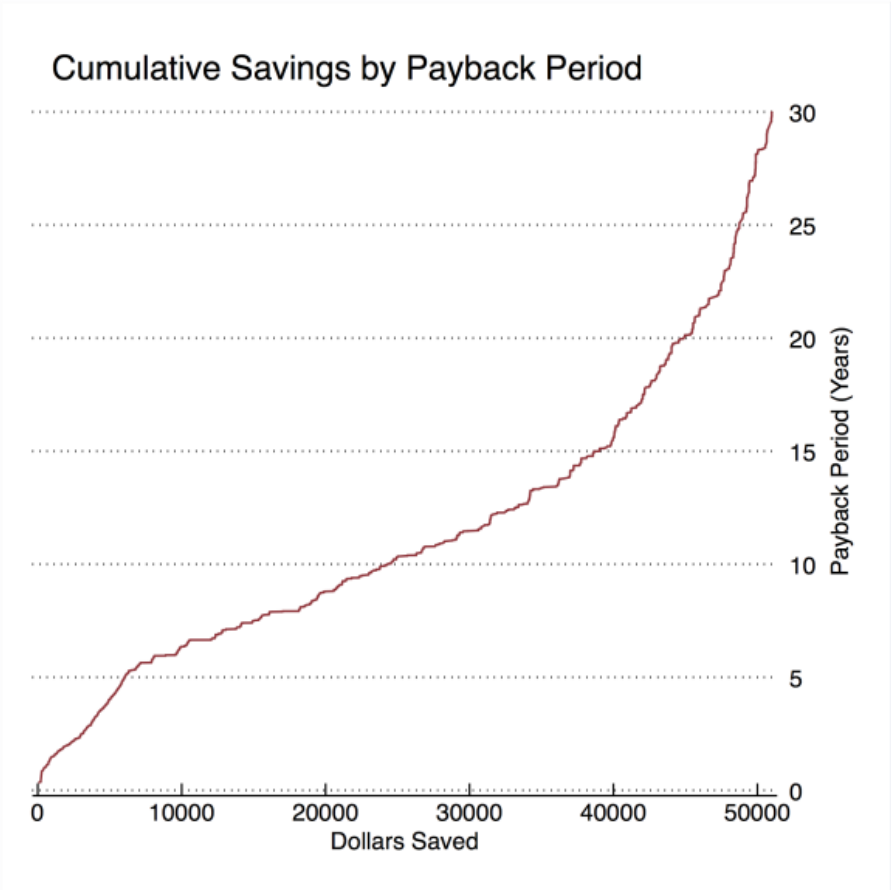

Figure 47. Cumulative savings by payback period.

There are potential annual envelope-related remediation savings from imaged surfaces with a payback period of less than 5 years, over $24,000 in savings with a payback of less than 10 years, and over $39,000 in savings with a payback of less than 15 years.

6.3.2.4 Recommendations for Marine Corps Base Camp Lejeune, NC

Table 11 lists the high-impact cost-effective remediation measures that base planners should target first. These are primarily wall insulation-related measures for the buildings identified as the most emissive.

Table 11. Immediately actionable remediations for Camp Lejeune, NC.

Label No.	Bldg No.	Action	Material	Init R Value	New R Value	Savings ($)	Cost ($)	Payback (yrs)
1	2600	Improve Wall Insulation	Brick	8.5	13.6	1101	8727	7.9
2	895	Improve Wall Insulation	Brick	9.9	13.7	888	11929	13.4
3	HP210	Improve Wall Insulation	Brick	8.1	13.6	714	5094	7.1
4	8	Improve Wall Insulation	Brick	9.5	13.7	715	8219	11.5
5	1	Improve Wall Insulation	Brick	9.3	13.6	681	7345	10.8
6	401	Improve Wall Insulation	Brick	9.2	13.6	592	6155	10.4
7	1	Improve Wall Insulation	Brick	9.4	13.7	568	6272	11.1
8	HP104	Improve Wall Insulation	Brick	9.0	13.6	486	4568	9.4
9	62	Improve Wall Insulation	Brick	10.4	13.6	327	5542	16.9
10	407	Improve Wall Insulation	Brick	9.3	13.6	331	3480	10.5
11	20	Improve Wall Insulation	Brick	10.1	13.6	317	4756	15.0
12	1	Seal Door Frame Leaks	D Frame	N/A	N/A	76	65	0.8
13	1826	Improve Wall Insulation	Siding	8.4	10.0	518	11315	21.9
14	2905	Improve Wall Insulation	Siding	7.9	10.0	352	5211	14.8
15	2603	Improve Wall Insulation	Brick	9.7	13.6	360	4470	12.4
16	8	Improve Wall Insulation	Brick	10.5	13.6	262	4666	17.8
17	18	Improve Wall Insulation	Brick	10.8	13.7	244	4832	19.8
18	424	Improve Wall Insulation	Brick	8.3	13.6	243	1833	7.5
19	430	Improve Wall Insulation	Brick	9.6	13.5	240	2936	12.2
20	8	Improve Wall Insulation	Brick	9.6	13.6	242	2837	11.7
21	408	Improve Wall Insulation	Brick	9.4	13.6	214	2369	11.1
22	2917	Improve Wall Insulation	Siding	7.8	10.0	273	3762	13.8
23	2913	Improve Wall Insulation	Siding	7.9	10.0	388	5569	14.4
24	235	Improve Wall Insulation	Brick	8.5	13.6	229	1860	8.1
25	217	Improve Wall Insulation	Brick	10.3	13.7	211	3203	15.2
26	2903	Improve Wall Insulation	Siding	7.7	10.1	498	6119	12.3
27	2600	Improve Wall Insulation	Brick	9.8	13.7	257	3253	12.7
28	408	Improve Wall Insulation	Brick	10.1	13.7	184	2608	14.2
29	2600	Improve Soffit Insulation	Soffit	8.9	13.6	58	571	9.9
30	2613	Improve Roof Insulation	Roof	10.8	15.0	336	4942	14.7

These 30 measures would collectively save an estimated $11,904 per year at a cost of $144,508 with a payback period of 12.1 years. Note that Table 10 outlines the labor and material costs for implementing the listed ECMs and does not include the cost to identify these ECM opportunities. Essess' thermal imaging, data processing, data analysis and reporting costs of roughly $200,000 per military installation must also be factored into an economic analysis.

Figure 48 to 55 show the specific location of all 30 immediately actionable recommendations. Note that only the primary features (e.g., the brick walls) are analyzed in the images.

Obstructions like trees or flagpoles as well as unrelated features like garage doors or windows are excluded.

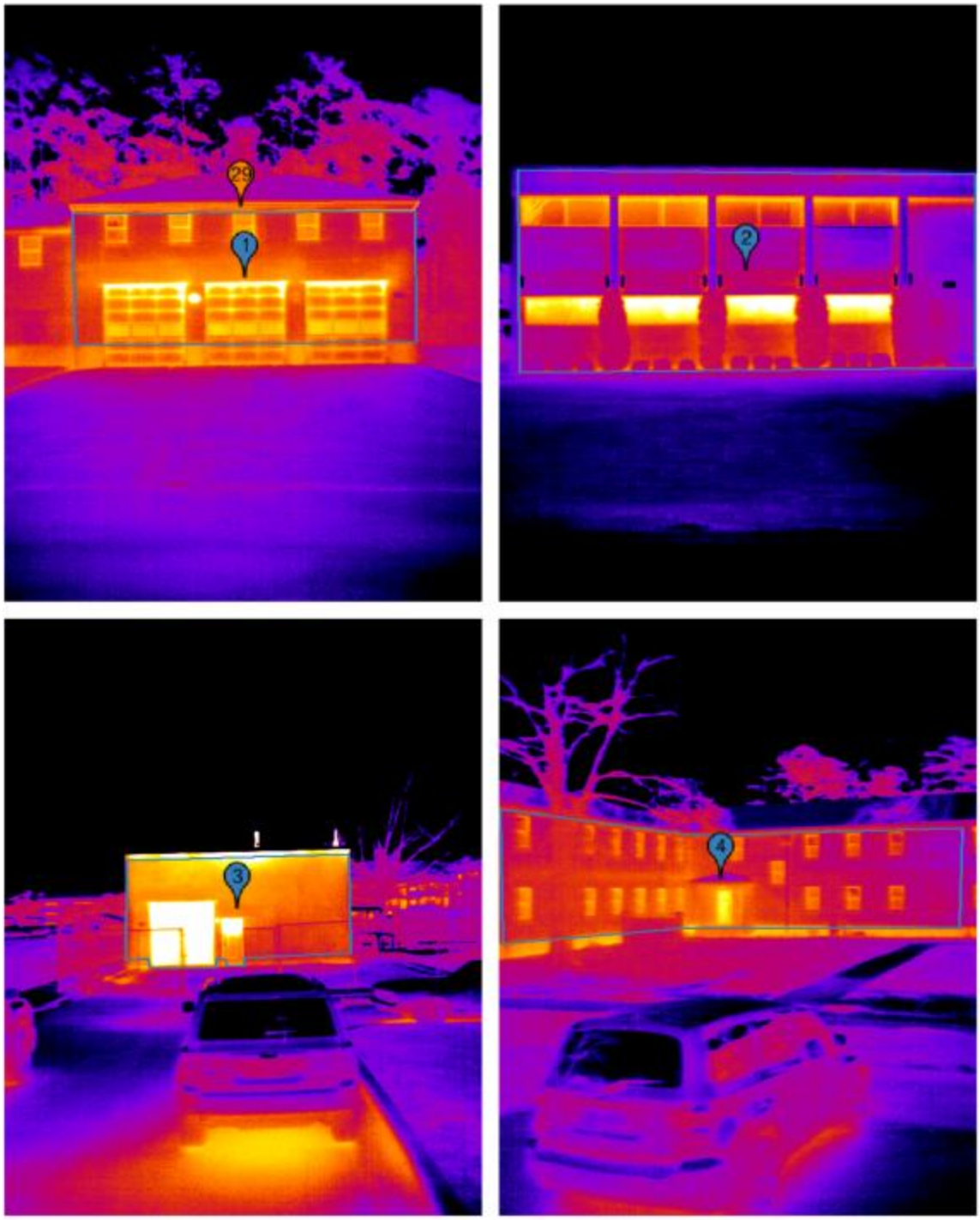

Figure 48. Camp Lejeune Bldgs 2600 (upper left), 895 (upper right), HP210 (lower left) and 8 (lower right).

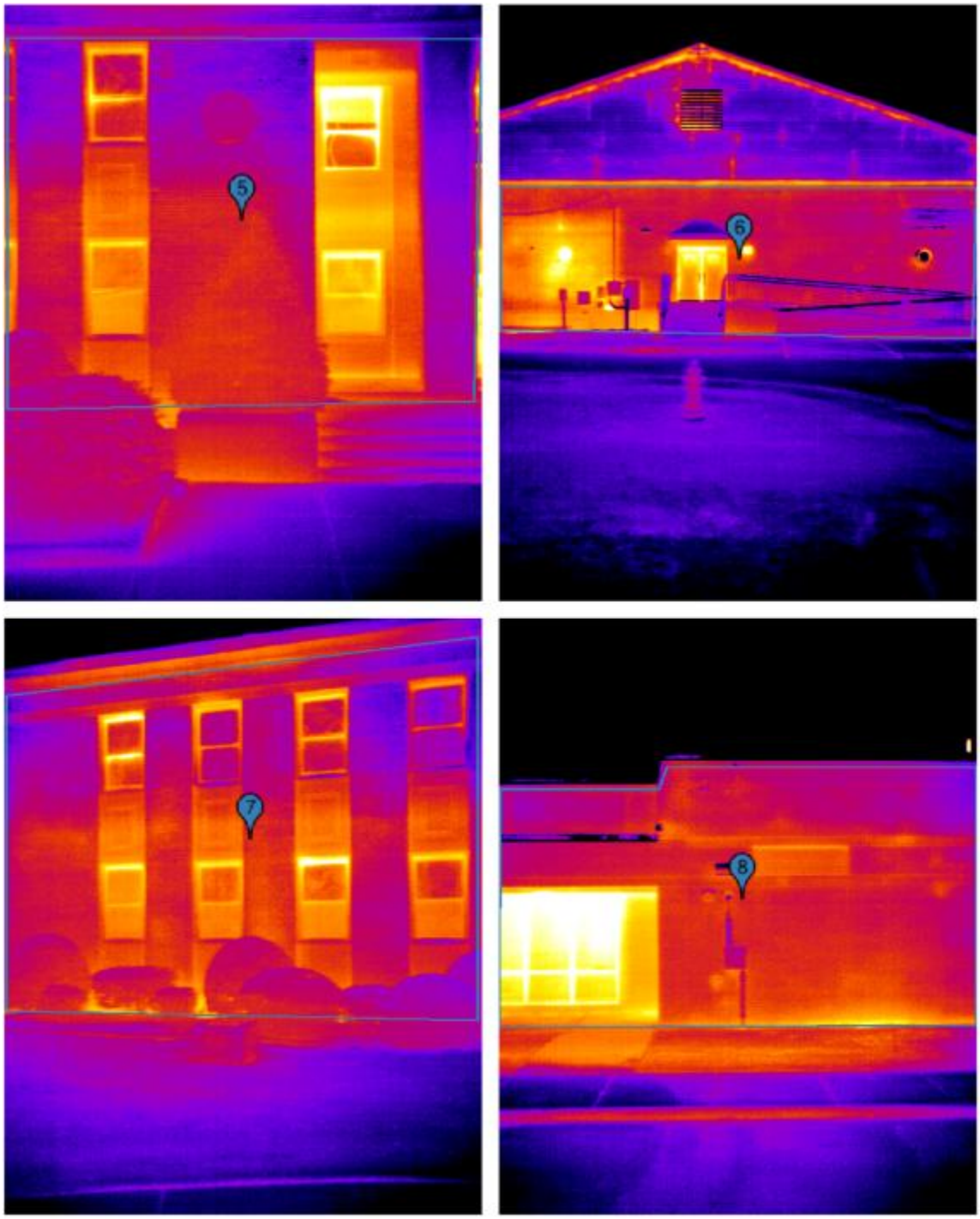

Figure 49. Camp Lejeune Bldgs 1 (upper left), 401 (upper right), 1 (lower left) and HP104 (lower right).

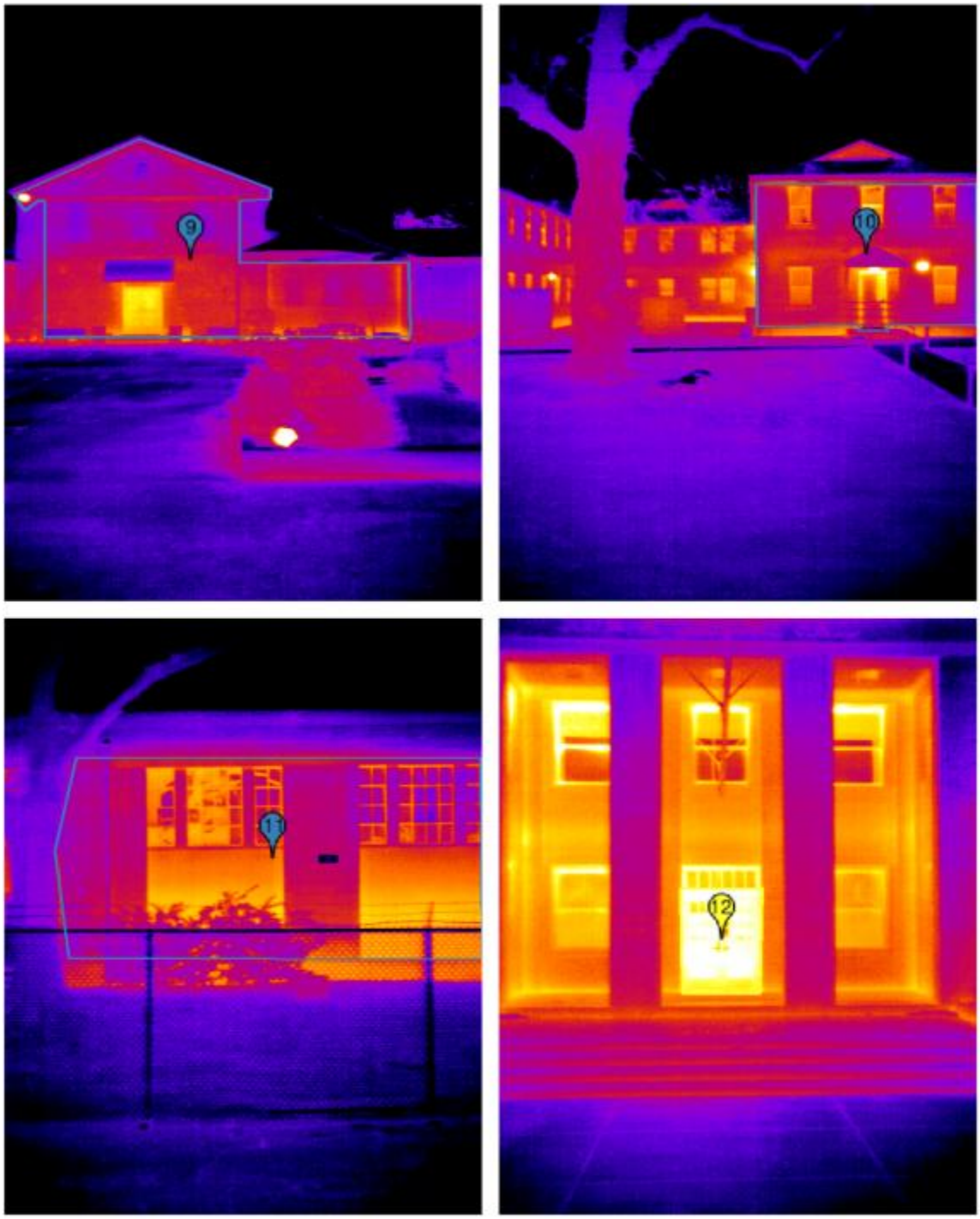

Figure 50. Camp Lejeune Bldgs 62 (upper left), 407 (upper right), 20 (lower left) and 1 (lower right).

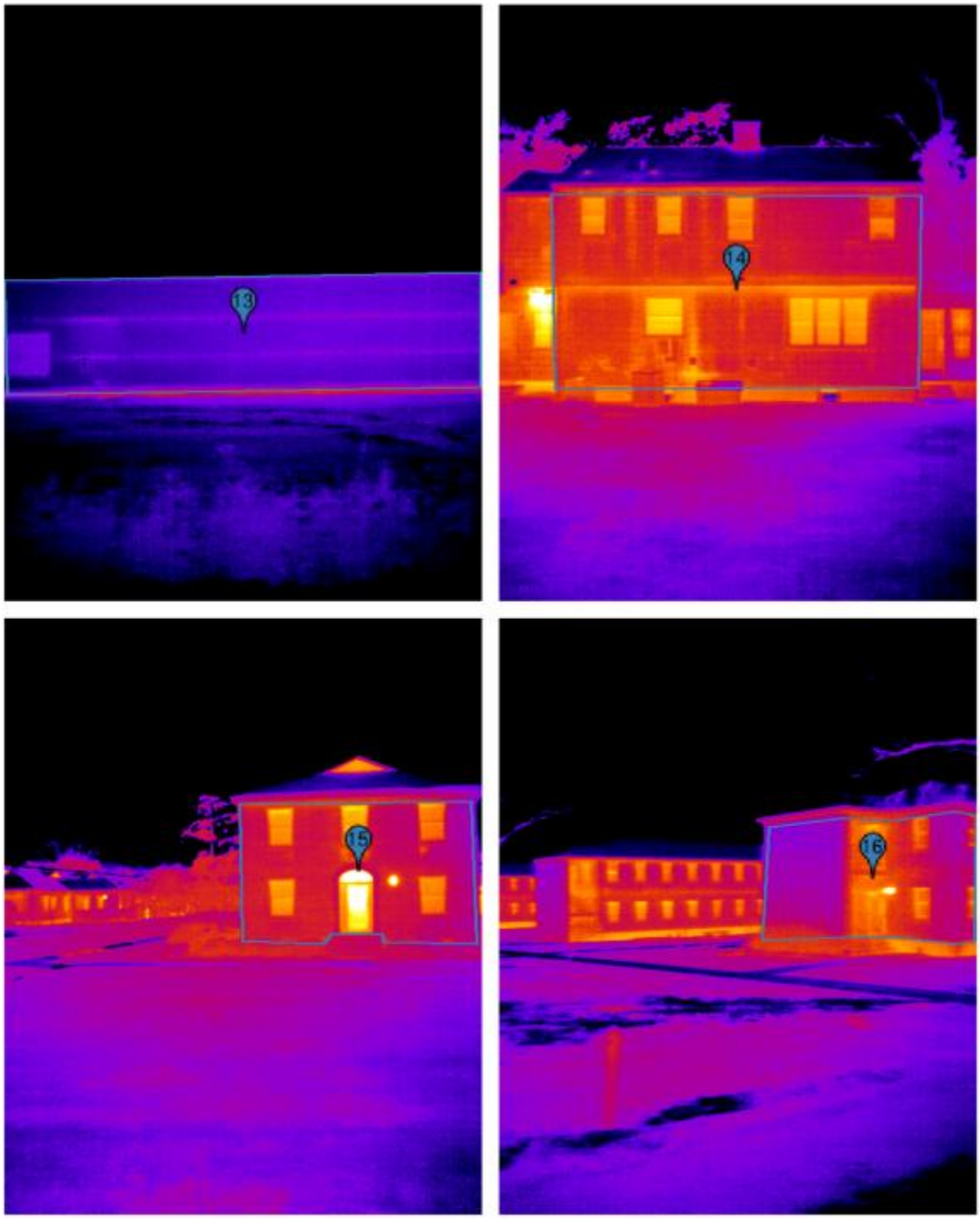

Figure 51. Camp Lejeune Bldgs 1826 (upper left), 2905 (upper right), 2603 (lower left), and 8 (lower right).

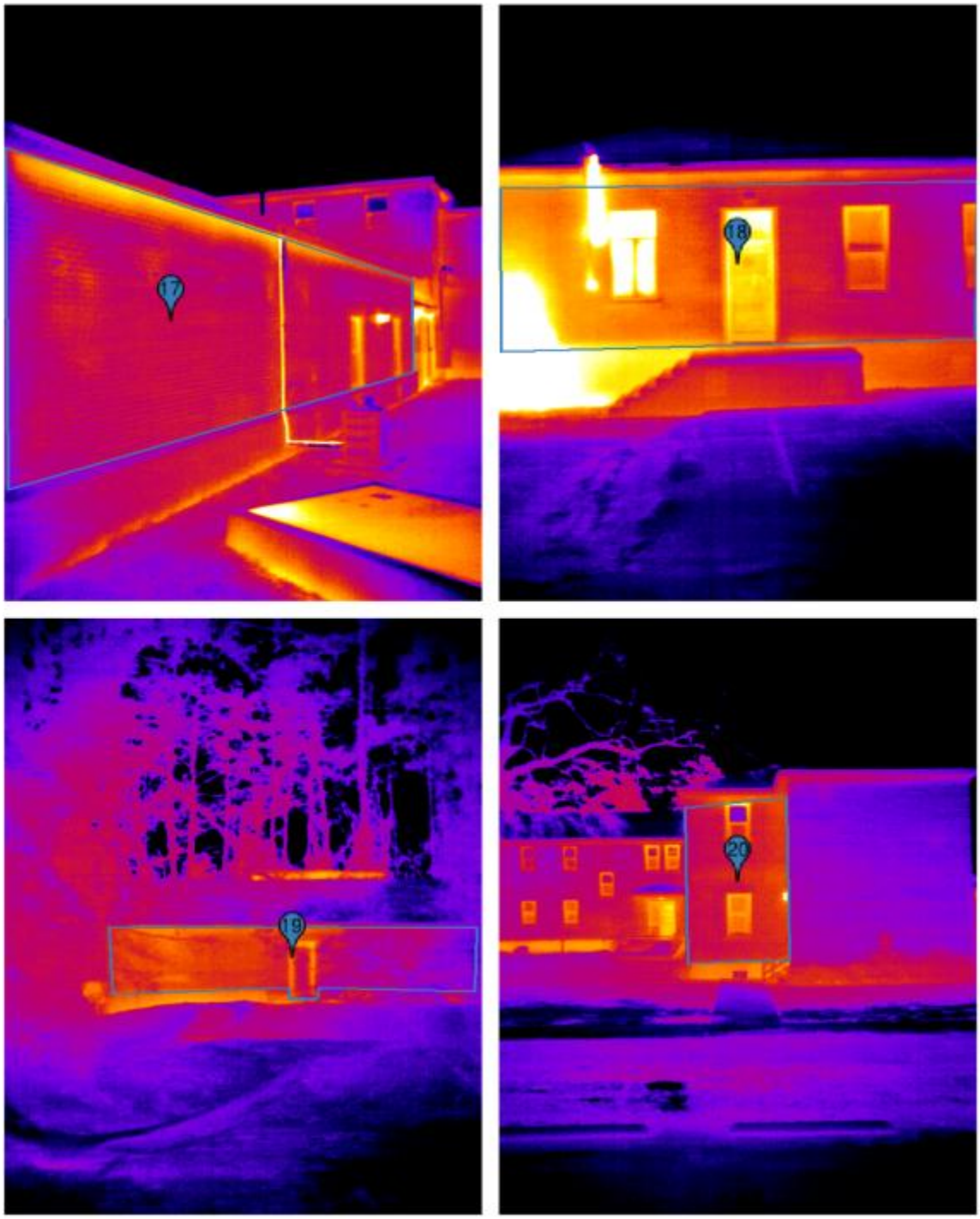

Figure 52. Camp Lejeune Bldgs 18 (upper left), 424 (upper right), 430 (lower left) and 8 (lower right).

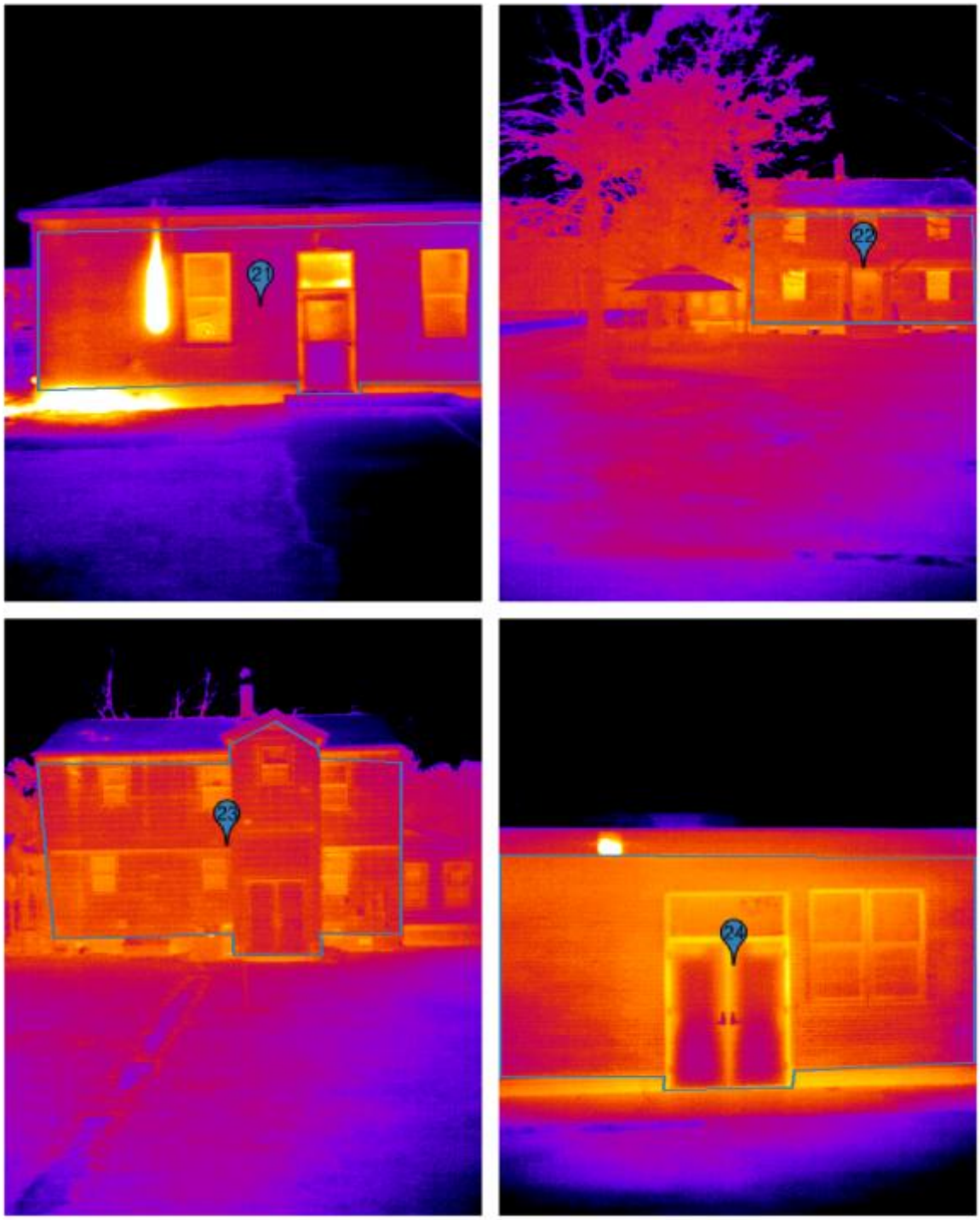

Figure 53. Camp Lejeune Bldgs 408 (upper left), 2917 (upper right), 2913 (lower left), and 235 (lower right).

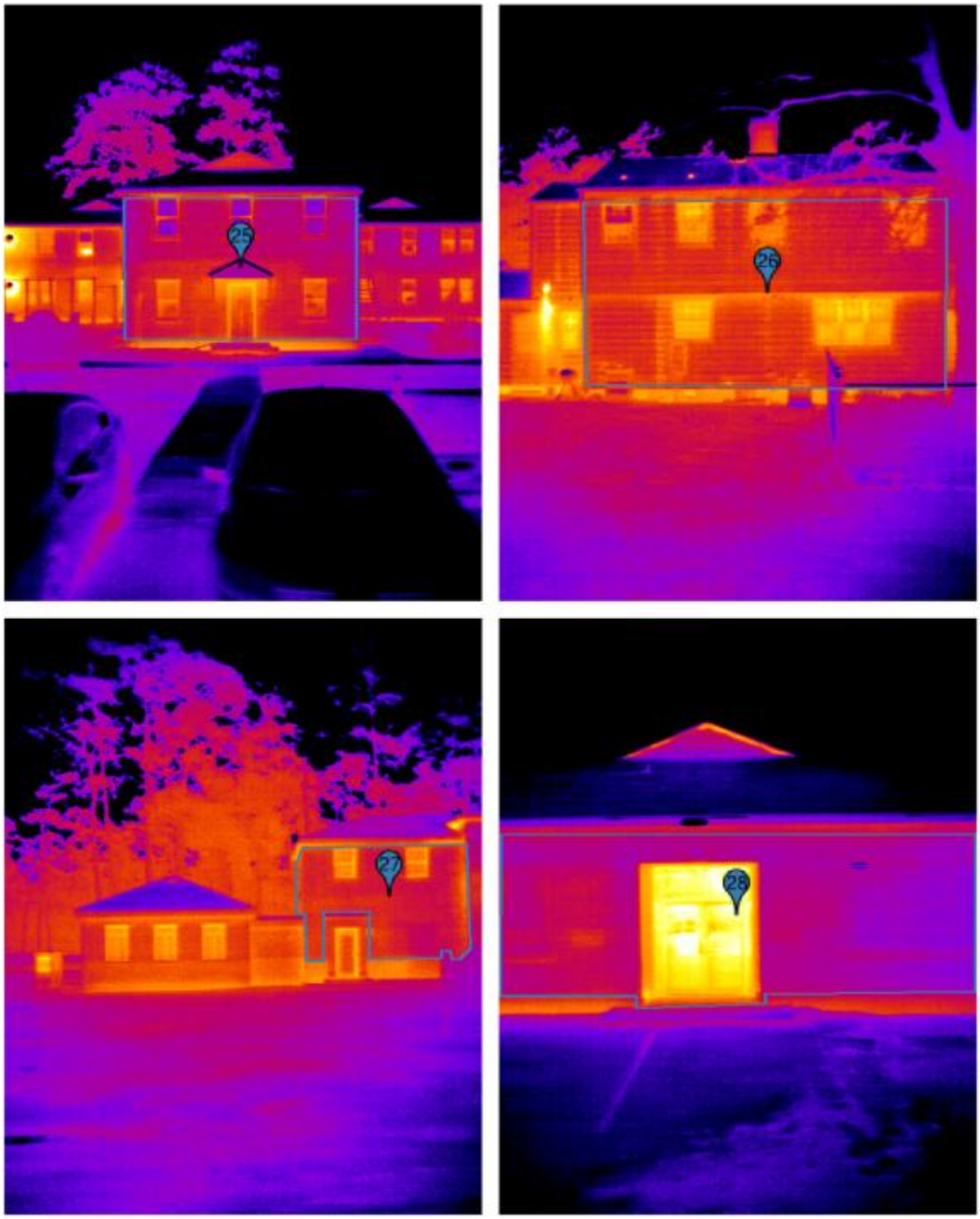

Figure 54. Camp Lejeune Bldgs 217 (upper left), 2903 (upper right), 2600 (lower left), and 408 (lower right).

Figure 55. Camp Lejeune Bldg 2613.

7.0 COST ASSESSMENT

The total cost for scanning, analyzing and producing a report for Camp Lejeune and Scott AFB was $404,577. For the purposes of this demonstration (and to adhere to the guidelines set forth in the Broad Agency Announcement) both installations were treated as a single project and the costs were broken up by phases rather than a per-building cost. Figure 56 shows the itemized cost breakdown.

Essess, Inc.
Budget Summary

	Phase One(1)	Phase Two(2)	Phase Three(3)	Total Phases One thru Three
Direct Labor	$33,392	$44,144	$30,008	$107,544
Fringe Benefits	$2,109	$2,732	$1,707	$6,547
Equipment Costs	$0	$0	$0	$0
Expendable Supplies	$0	$0	$0	$0
Travel	$0	$9,781	$0	$9,781
Subcontracts	$38,400	$72,000	$48,000	$158,400
Other Direct Costs	$0	$0	$0	$0
Indirect Costs	$29,821	$39,376	$26,641	$95,837
	$103,721	$168,032	$106,356	$378,109
Operating Margin (7%)				$26,468
Total Budget				$404,577

Notes:

1) See "1. Phase One Budget" for details
2) See "2. Phase Two Budget" for details
3) See "3. Phase Three Budget" for details
4) See "4. Phase Four Budget" for details
5) See "5. Phase Five Budget" for details
6) See "6. Phase Six Budget" for details

Figure 56. Essess cost summary for scanning, analysis and reporting for Camp Lejeune, NC and Scott AFB, IL.

7.1 COST MODEL

The subtasks accomplished in each phase are outlined in detail in Section 5.1.6 ("Test Phases," p 21). For all three phases, the majority of the costs were for direct labor and contracting Subject Matter Experts for computer vision aided data processing using commercial thermography and energy modeling. Phase 1 costs related to the customization of the imaging hardware and creating logistics software for the driving team to navigate while imaging. To capture data in the most efficient manner, the driving team was guided by an onboard navigation system with route guidance based on the installations' street network. This must be created for each base, as complete road network information for military installations is rarely publicly available. For Camp Lejeune and Scott AFB the Phase 1 costs were $103,721 (Figure 56).

Phase 2 costs were related to data capture and analysis. Essess drove the imaging vehicle to Camp Lejeune and Scott Air Force Base and captured thermal, NIR, LIDAR, and GPS data.

Once the data were sent to Essess headquarters, it was processed (the raw data were converted into temperature images and the temperature images were correlated to the correct GPS coordinates based on vehicle GPS and military provided GIS information). After the data were processed, the second part of Phase 2 analyzed the processed data to detect building thermal inefficiencies and leaks in the building envelope. The contractor also built an online Drive-by Application to enable Energy Managers at Camp Lejeune and at Scott Air Force Base to select buildings for further analysis. The total cost for Phase 2 was $168,032.

Phase 3 consisted of aggregating the mobile thermal imaging results, analyzing the handheld thermography data, and preparing this report. The total cost for Phase 3 was $106,356.

Table 12 lists "model" costs for a single military installation. Essess could image hundreds of bases in a single winter while maintaining the same cost structure making the technology significantly more scalable.

Table 12. Cost model for imaging a military installation.

Cost Element (for single military installation)	Estimated Costs
Phase 1: Hardware Customization and Logistics Software Optimization	$51,861
Phase 2: Data Capture, processing and Analysis	$81,567
Phase 3: Aggregating analyzed data in a report format	$50,744

7.2 COST DRIVERS

There are no major cost drivers for this technology as it is applicable to military bases across various ASHRAE Climate Zones. The technology is efficient and scalable, which allows Essess to image bases significantly larger than Scott Air Force Base without increasing the cost structure. However, unlike a typical auditor that charges per building, Essess' cost structure is on a per installation basis. This is due to the fact that the bulk of Essess' costs are front-loaded. Once the imaging rig is deployed to an area, there is only a marginal cost in imaging 100 buildings versus 1,000 buildings.

7.3 COST ANALYSIS AND COMPARISON

Essess' thermal imaging, data processing, data analysis and reporting costs are roughly $200,000 per military installation. As described in the Section 7.1 ("Cost Model," p 79), the operational implementation of the technology requires significant customization to the hardware rig and to the logistics, processing and analysis software. The data in Chapter 6.0 ("Performance Assessment") provide a detailed description of each remediation recommendation for Camp Lejeune and Scott AFB and also provides the life-cycle costs for each remediation. The end result is valuable energy efficiency data and remediation recommendations.

Traditionally, the only way to get envelope efficiency information for each building was to use a handheld thermal camera on each building. However, handheld thermography is relatively very inefficient and also requires a human to interpret each image whereas Essess has the ability to automatically analyze thousands of thermal images. Furthermore, commercial energy audits that include envelope thermal imaging using handheld thermography typically cost around $1,000 for a 5,000 sq ft building and $10,000 for a 50,000 sq ft building (based on data from local thermal

imaging auditors within 100 miles of Scott AFB and Green-Buildings.com). Essess imaged 4.6 million sq ft of building space at Scott AFB and 4.2 million sq ft at Camp Lejeune. Essess imaged, processed and analyzed data and developed reports for both military installations for $404,577. Based on the costs above, having the same amount of building space analyzed with a handheld camera would cost approximately $1,760,000 ($920,000 for Scott AFB and $840,000 for Camp Lejeune). That is $1,355,423 more than Essess' mobile imaging costs.

8.0 IMPLEMENTATION ISSUES

The Essess imaging rig is proprietary technology that was deployed based on a licensing model so there was (and will be) no turnover of hardware, software, or intellectual property to the Government. However, technology transfer will still occur through the Essess team, working with ESTCP and ERDC-CERL. Furthermore, it is anticipated that ERDC-CERL will publish an ERDC Technical Report and at least one article in the Society of American Military Engineers' (SAME's) The Military Engineer, or other publications with a military engineer audience.

This technology is limited to scanning the street sides of buildings. As a result, for most buildings, four sides of the buildings will not be scanned. Two or three sides are typically scanned depending on the orientation of a building relative to the street. This technology is also limited by the requirement to have a ΔT between building interior and exterior ambient temperatures of at least 20 °F, so scanning must occur when nighttime temperatures are below 50 °F. This limits application of this technology to regions where there is at least 1 week of the year in which nighttime temperatures are below 50 °F. Most regions of the United States fall within this boundary condition. Adjustments are made for empty buildings or buildings where there is no internal heating and no way of knowing the internal temperature setpoint (further discussed in the Methodology Appendix D). This technology is somewhat hindered by trees, bushes and other obstructions that might partially obscure a clear view of a building's envelope from the street. However, the automated data processing pipeline developed by Essess to take the scanned data and prepare it for a report format, corrects for these kinds of obstructions in a number of ways that have been tested by Essess.

9.0 REFERENCES

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APPENDICES

APPENDIX A: HEALTH AND SAFETY PLAN (HASP)

Since this work requires a vehicle to drive around the installations at low speeds, the Health and Safety Plan mostly entails obeying installation traffic rules. Since the scanning vehicle will be operating at very low speeds, drivers should be careful to avoid blocking faster traffic on higher speed installation roadways. Vehicle lighting systems must be maintained in good working order. The driver(s) must take care to signal all turns and to park outside of the lane of traffic when stopping is necessary.

APPENDIX B: POINTS OF CONTACT

Point of Contact	Organization	Phone & E-mail	Role in Project
James Miller	U.S. Army ERDC-CERL	(217) 373-4566, james.p.miller@usace.army.mil	Principal Investigator, COR
Navi Singh	Essess	(857) 445-4135 Navi@essess.com	Team Leader
Elizabeth Toftemark	Scott AFB, Base Civil Engineer	(618) 256-5534 elizabeth.toftemark@us.af.mil	Deputy of Operations Engineering
Thomas Burton	USMC, Camp Lejeune, Facilities Engineers	910-451-0784 thomas.h.burton@usmc.mil	Energy Manager

APPENDIX C: SCOTT AIR FORCE BASE, IL

This appendix examines specific components found in buildings around the base, including window frames, door frames, window glass, brick walls, other walls, and soffits (generally speaking, where the wall meets the roof). These components are examined in detail, as they are all readily remediable through air sealing and insulation improvements.

C.1 Building Window Frames

Window frames were differentiated from window glass in the 30 buildings on the base analyzed in detail to separate out energy loss due to conduction (e.g., poorly insulated single pane windows [Figure C-1]) and convection (leaks through cracks around window frames). The study tagged 511 discrete window frames. The measure of leakage is expressed in cubic feet per minute per linear foot of crack. Figure C-2 shows the frequency distribution of estimated leakages across the base. Section 5.2 ("Baseline Characterization") discusses the methodology for calculating these values.

Both heating and cooling losses can be calculated once the leakage rate is estimated. Figure C-3 shows the potential remediation savings for each surveyed window. The majority of windows have a savings potential below $25 per year, with a long tail of potentially very leaky window frames. The leakiest window frames have annual savings potentials through air sealing remediation of nearly $100 per year. Over 90% of the savings potential comes via reduced space heating fuel use; cooling contributes relatively little to the estimate of potential convective leak savings, especially since latent heat associated with cooling is not explicitly analyzed.

The leakiest window frames identified on the base were in Bldgs 5022, 8, 1600, 1530, 10, and 1900.

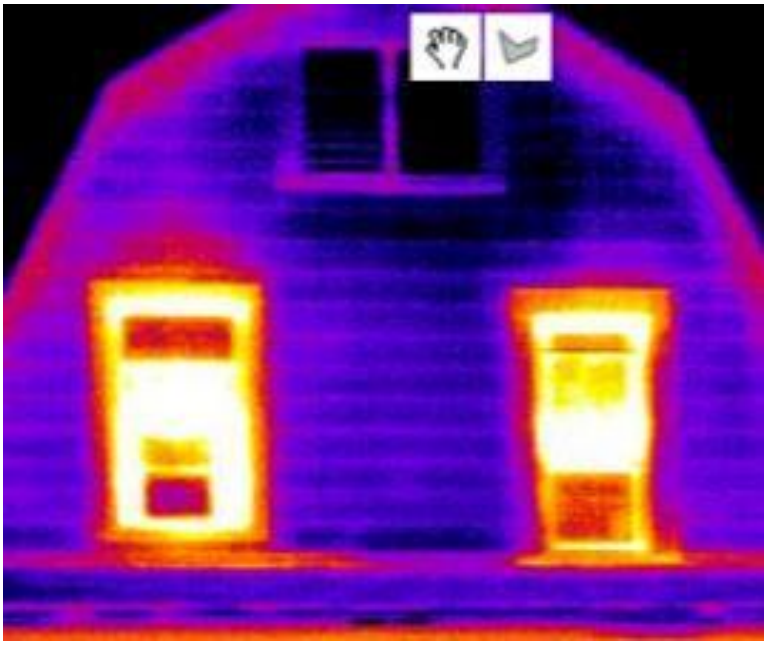

Figure C-1. Thermal image of typical window glass thermal leaks, Scott AFB.

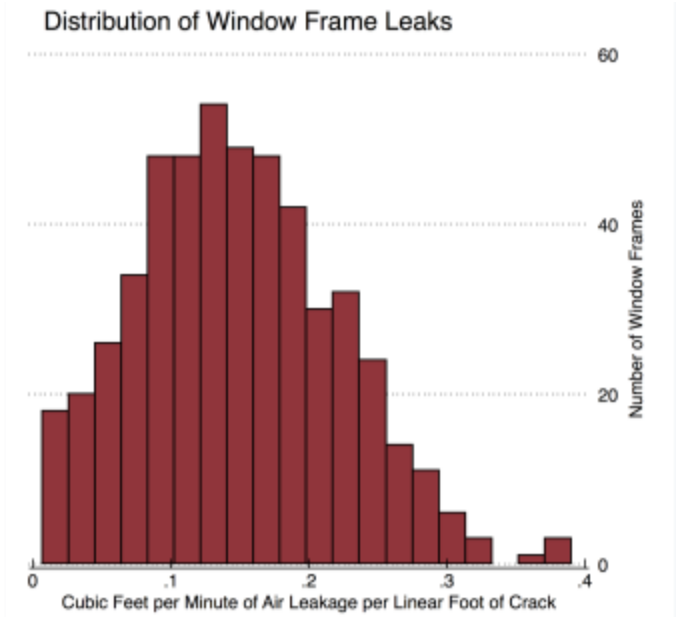

Figure C-2. Distribution of window frame leaks, Scott AFB.

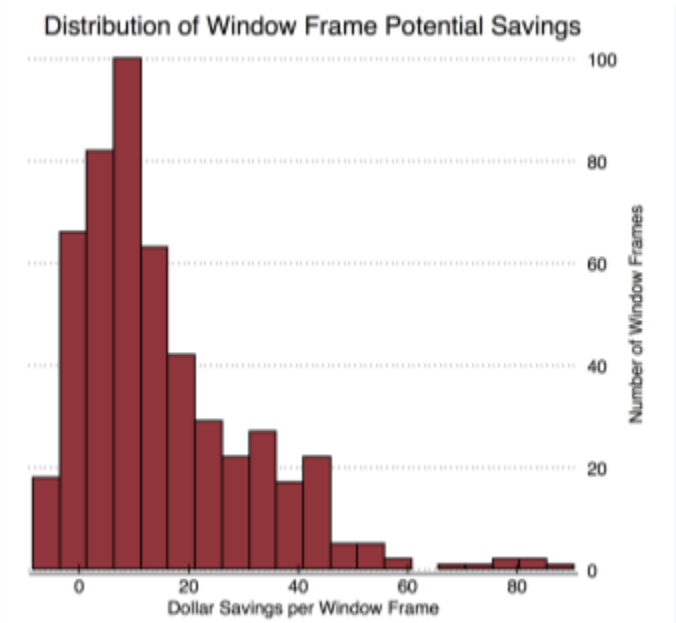

Figure C-3. Distribution of window frame potential annual energy cost savings, Scott AFB.

C.2 Building Door Frames

Building door frame leakage is estimated through process similar to that used to estimate window frame leakage, by isolating the frame polygon from the door polygon and measuring the emissivity relative to other doors on the base (Figure C-4). One hundred forty distinct door frames were identified in the 30-building detailed analysis, with a range of leakage from effectively nothing to at or above 0.4 CFM per linear crack foot (Figure C-5).

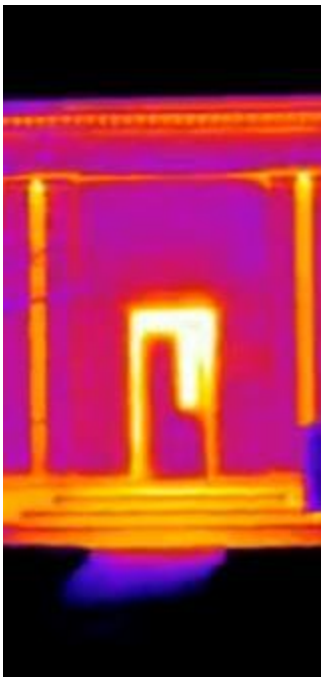

Figure C-4. Thermal image of typical door thermal energy leaks, Scott AFB.

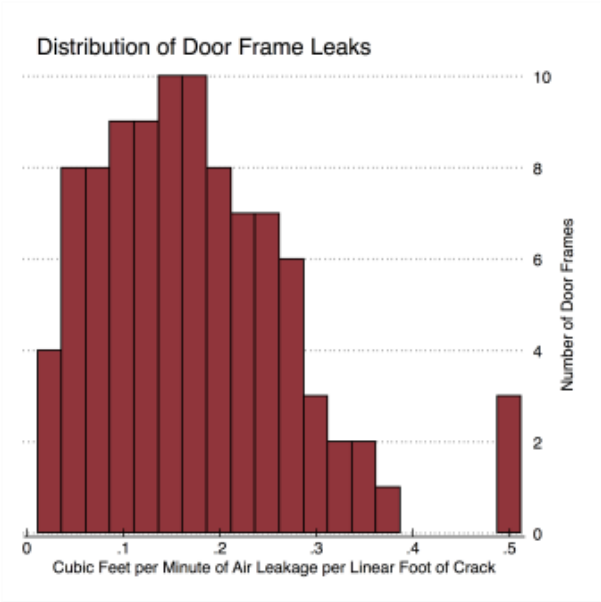

Figure C-5. Distribution of door frame air leaks, Scott AFB.

Figure C-6 shows a distribution of potential annual savings from remediation of door frame leaks, which are estimated to range from $0 to greater than $100 per year per door frame for some extreme cases. The average savings potential is about $40 per door. Remediation through the use of weather-strips and similar measures should be cost-effective for most doors surveyed on the base.

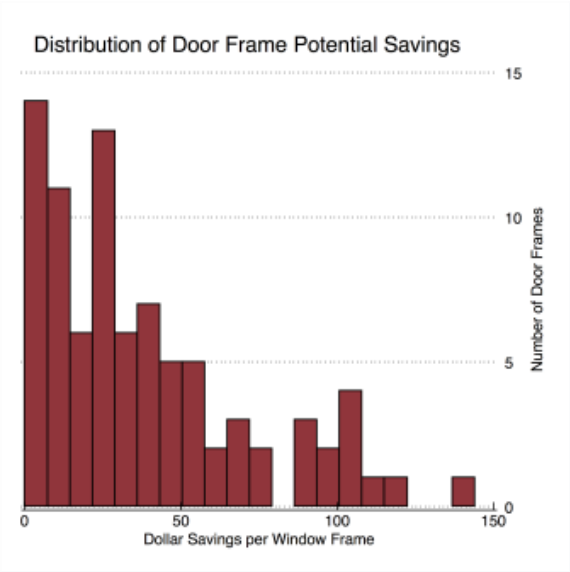

Figure C-6. Distribution of door frame potential annual energy cost savings, Scott AFB.

The leakiest door frames identified on the base were in Bldgs 1650, 470, 3189, 1600, 460, and 4010.

C.3 Walls

Walls on the base were categorized as either of brick, vinyl siding, or concrete. Three hundred 88 distinct brick wall polygons, 221 vinyl or other siding walls, and 77 concrete walls were identified. Costs associated with wall polygons were estimated based on their time-normalized surface temperatures (Figure C-7) and inferred R-values, as described in Section 5.2 ("Baseline Characterization"). Estimated annual heating and cooling costs from wall polygons range from $2.15/sq ft to $5.75/sq ft (Figure C-8). Brick walls in general had lower estimated costs per square foot (~$3) than did siding or concrete walls (~$4).

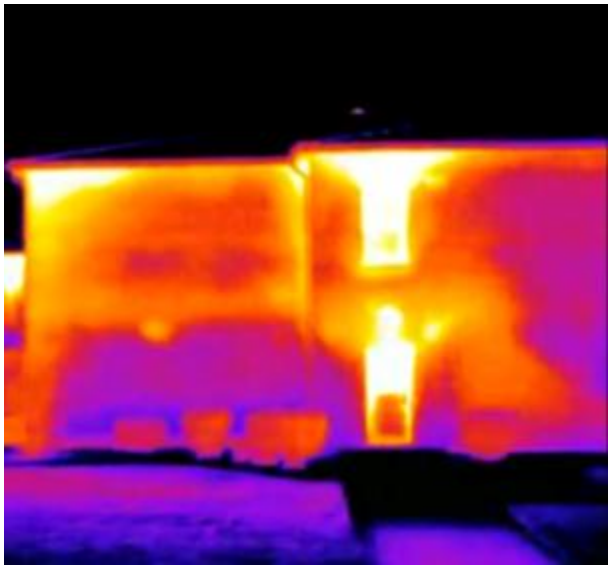

Figure C-7. Thermal image of a typical leaky wall, Scott AFB.

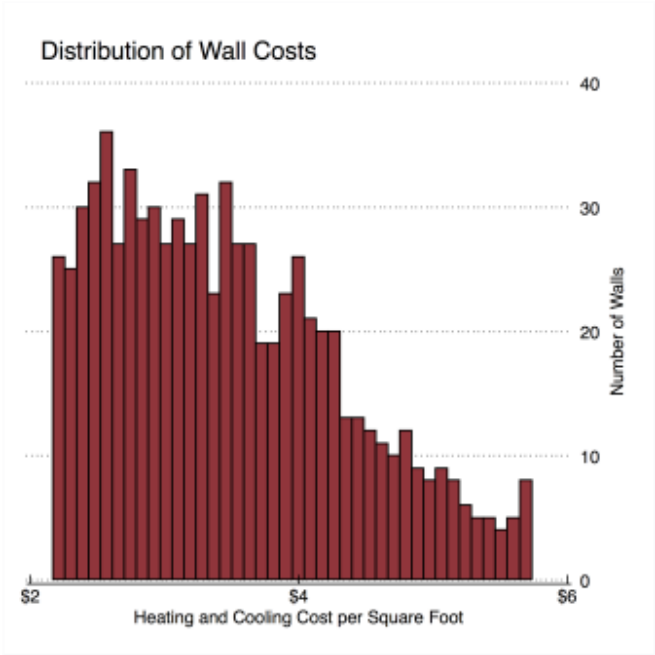

Figure C-8. Distribution of annual heating and cooling costs per square foot of wall, Scott AFB.

Potential remediation savings for walls were estimated by running the heat flow model on estimated current R-values and post-remediation R-values. Savings range from zero (or negative savings in a few cases of very well insulated walls) up to slightly over $2/sq ft (Figure C-9). At an average installation and labor cost of around $7/sq ft of wall area, walls with particularly high energy leakage are cost-effective to remediate.

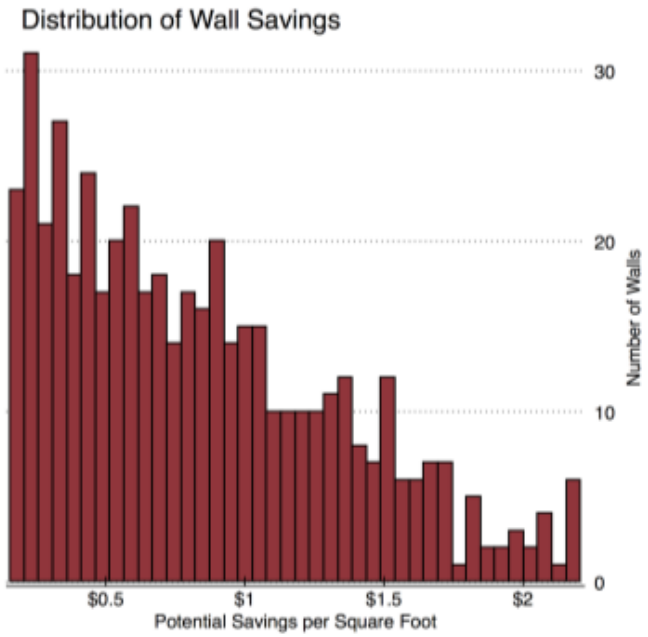

Figure C-9. Potential wall annual energy cost savings per square foot, Scott AFB.

Of the 777 wall polygons identified, 563 would have positive savings through improved insulation. Of these, approximately 335 would have a payback period of less than 15 years. The average savings associated with improving wall insulation for these 335 cases was around $1.08/sq ft of wall area. The most emissive walls identified on the base were in Bldgs 5029, 1456, 5713, 528, 3689, and 8040.

C.4 Roofs

Roof heat loss is calculated similarly to wall heat loss, by looking at time-normalized surface temperatures (Figure C-10). The system identified 211 distinct roof polygons. (Note that a single roof will usually have more than one polygon identified, as the maximum size of a polygon is dictated by the FOV of the camera in a single image frame.) The estimated heating and cooling cost associated with these roofs ranged from $1.75 to $3.44/sq ft of roof area (Figure C-11).

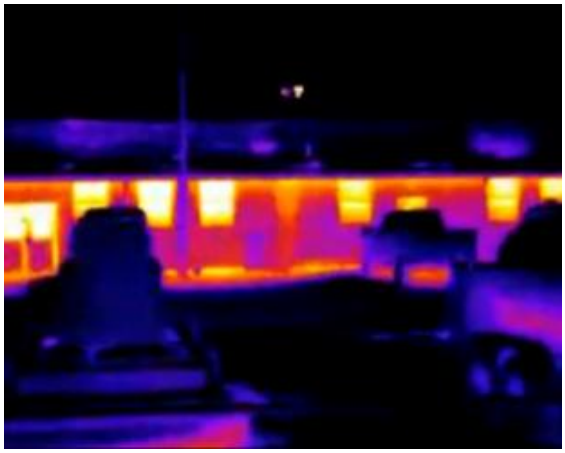

Figure C-10. Example of a thermally leaky roof, Scott AFB.

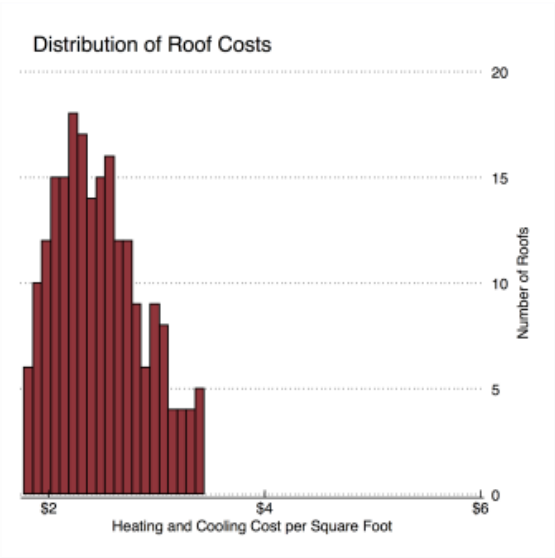

Figure C-11. Distribution of roof annual heating and cooling costs per square foot, Scott AFB.

One hundred nineteen identified roof polygons had positive remediation savings, with 38 having paybacks of less than 15 years. The average savings associated with improving roof insulation for these 38 cases was around $0.78/sq ft. The most emissive roofs identified on the base were on Bldgs 1635, 1640, 5713, 1512, 861, and 1441. Figure C-12 shows a distribution of potential roof annual heating and cooling savings associated with remediating roof energy leaks.

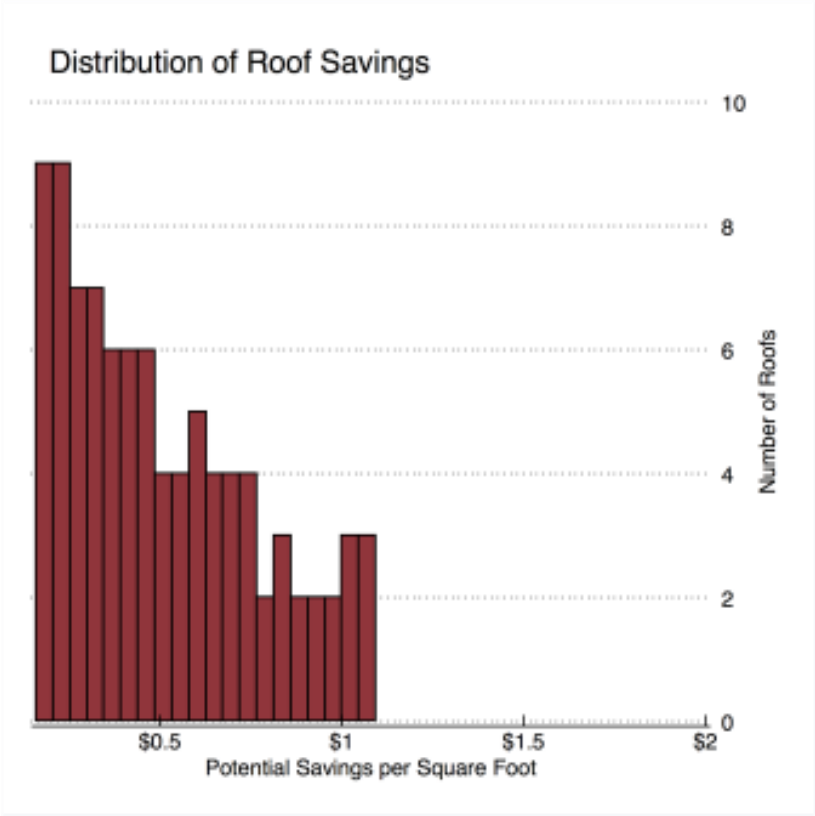

Figure C-12. Distribution of roof annual heating and cooling cost savings per square foot, Scott AFB.

C.5 Soffits

Soffits are areas where the wall meets the roof and are often spots where insulation is poor and air leaks are more common (Figure C-13). The system identified 282 total soffit polygons on buildings in the base. Their R-values were estimated based on surface temperatures similar to the calculation for walls and roofs. The average annual heating and cooling costs resulting from soffit energy leakage range from $2.15 to $4.30/sq ft (Figure C-14).

Of the 194 soffit polygons that had positive remediation savings, 96 had paybacks of less than 15 years. The average savings associated with improving soffit insulation for these 96 cases was around $0.99/sq ft. Figure C-15 shows a distribution of potential annual heating and cooling savings due to soffit improvements. The most emissive soffits identified on the base were on Bldgs 1650, 1987, 5000, 624, 755, and 60.

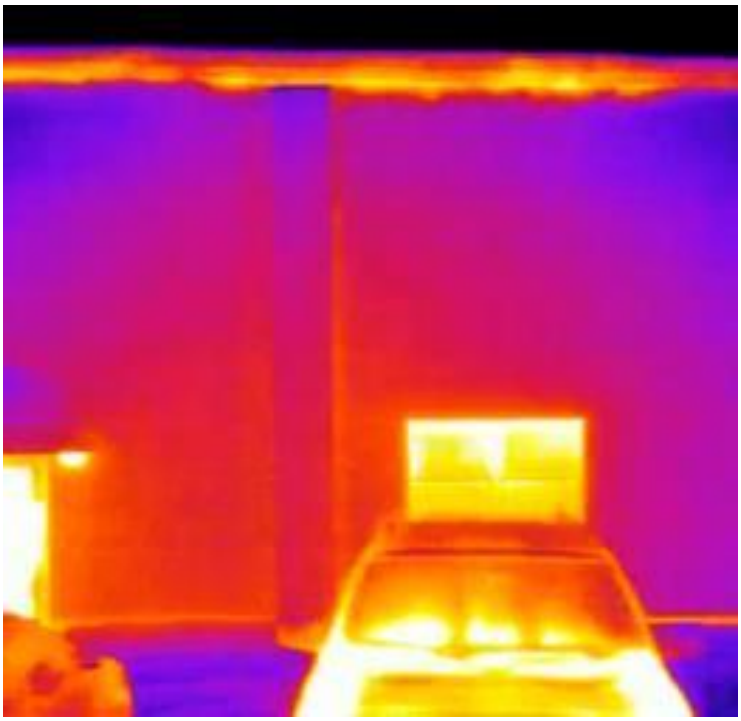

Figure C-13. Typical leaky soffit, Scott AFB.

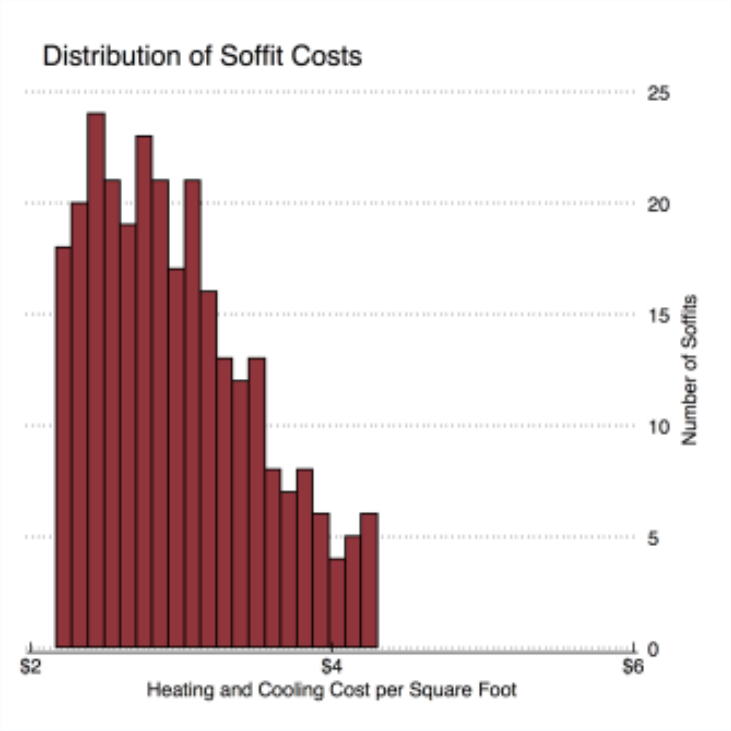

Figure C-14. Distribution of annual heating and cooling costs per square foot due to soffit leaks, Scott AFB.

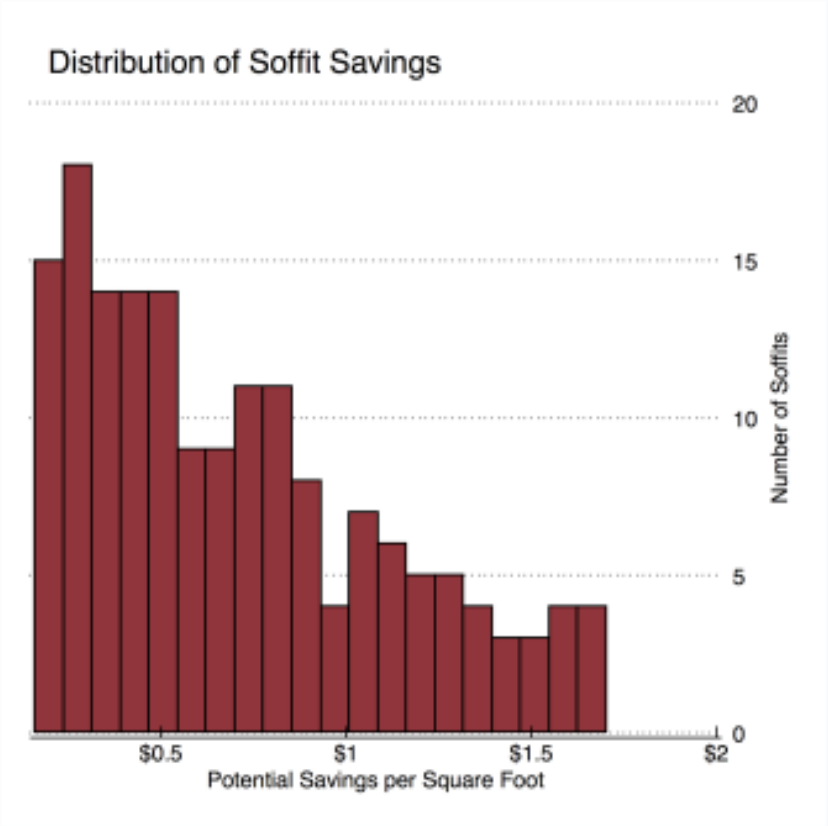

Figure C-15. Distribution of potential annual heating and cooling cost savings due to soffit improvements, Scott AFB.

APPENDIX D: MARINE CORPS BASE CAMP LEJEUNE, NC

This appendix examines specific components found in buildings around Marine Corps Base Camp Lejeune, NC, including window frames, door frames, window glass, brick walls, other walls, and soffits (generally speaking, where the wall meets the roof). These components are examined in detail below, as they are all readily remediable through air sealing and insulation improvements.

D.1 Building Window Frames

Window frames and window glass were differentiated in the 131 buildings on the base that were analyzed in detail to separate out energy loss due to conduction (e.g., poorly insulated single pane windows) and convection (leaks through cracks around window frames, e.g., Figure D-1). The system tagged 1,037 discrete window frames. The measure of leakage is expressed in cubic feet per minute per linear foot of crack. Figure D-2 shows the distribution of estimated leakages across the base.

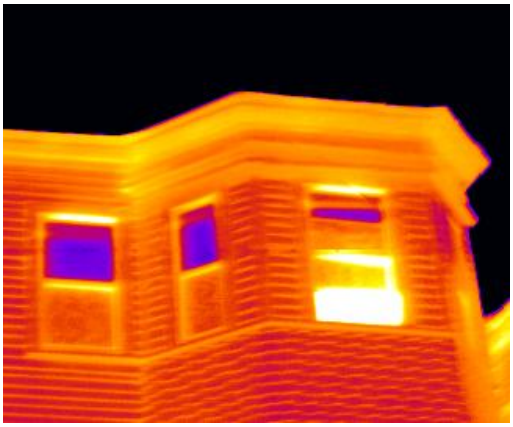

Figure D-1. Examples of window frame leaks, Camp Lejeune.

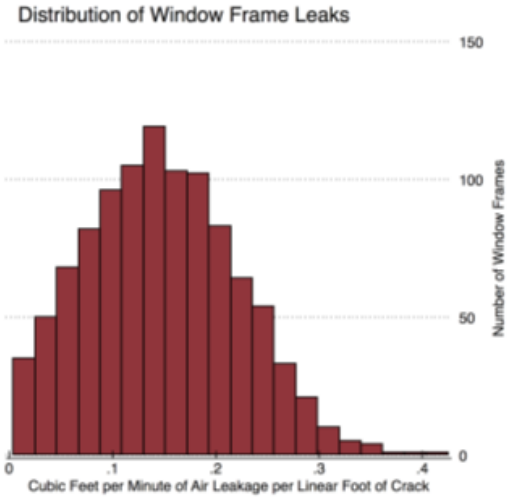

Figure D-2. Distribution of window frame leaks, Camp Lejeune.

Both heating and cooling loss can be calculated once the leakage rate is estimated. Figure D-3 shows the potential remediation savings for each surveyed window. The majority of windows have a savings potential below $20 per year, with a long tail of potentially very leaky window frames. The leakiest window frames have annual savings potentials through air sealing remediation of nearly $75 per year. The leakiest window frames identified on the base were in Bldgs 1, 100, 11, 113, 116, and 117.

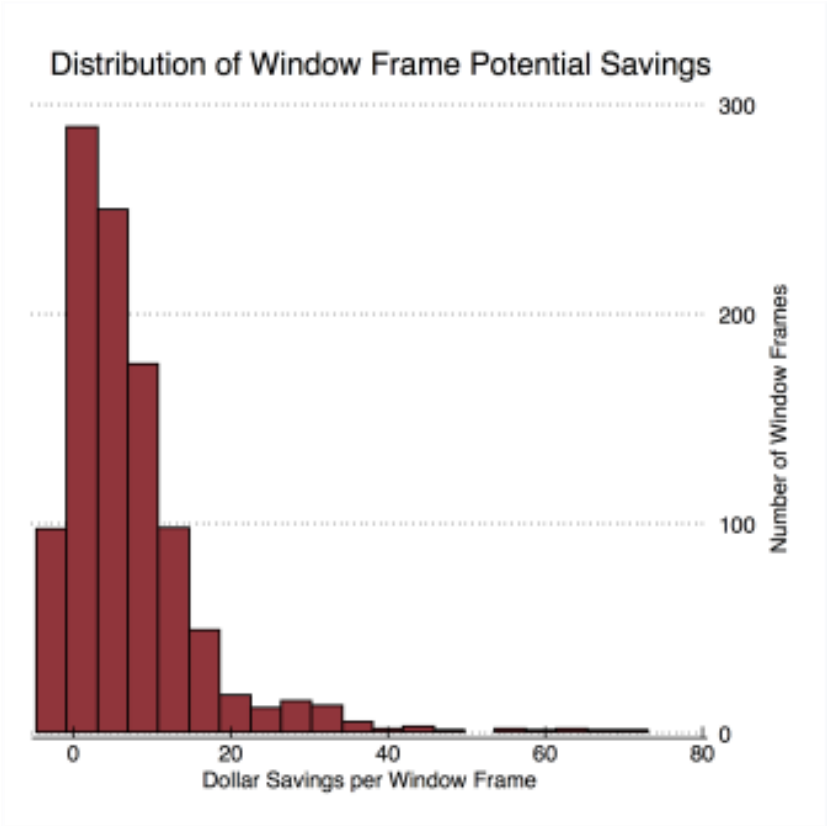

Figure D-3. Distribution of potential annual energy cost savings due to repair of window frame leaks, Camp Lejeune.

D.2 Building Door Frames

Building door frame leakage is estimated through a similar process as window frame leakage by isolating the frame polygon from the door polygon and measuring the emissivity relative to other doors on the base (Figure D-4). There were 201 distinct door frames identified in the buildings analyzed on the base, with a range of leakage from effectively nothing to at or above 0.3 CFM per linear crack foot (Figure D-5).

Figure D-4. Example of door frame energy leaks, Camp Lejeune.

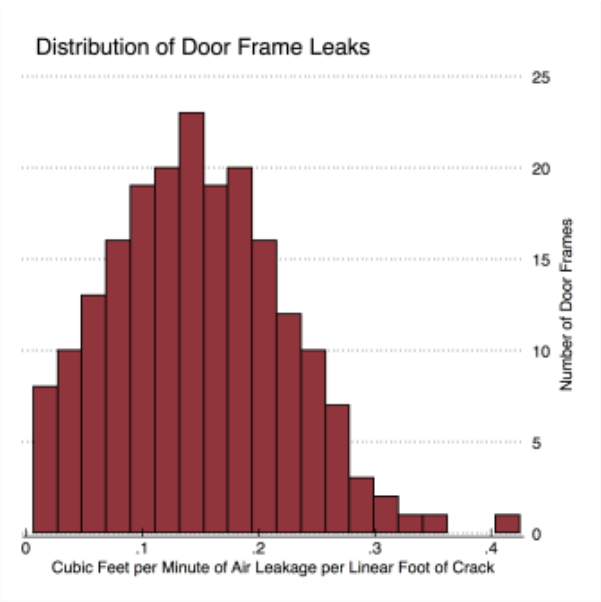

Figure D-5. Distribution of door frame energy leaks, Camp Lejeune.

A distribution of potential annual energy costs savings from remediation of door frame leaks are estimated to range from $0 to greater than $50 per year per door frame for some extreme cases (Figure D-6). The average savings potential is about $20 per door, and remediation through the use of weather-stripping and similar measures is expected to be cost-effective for most doors surveyed on the base. The leakiest door frames identified on the base were in Bldgs 895, 1, HP104, 1688, 20, and 201.

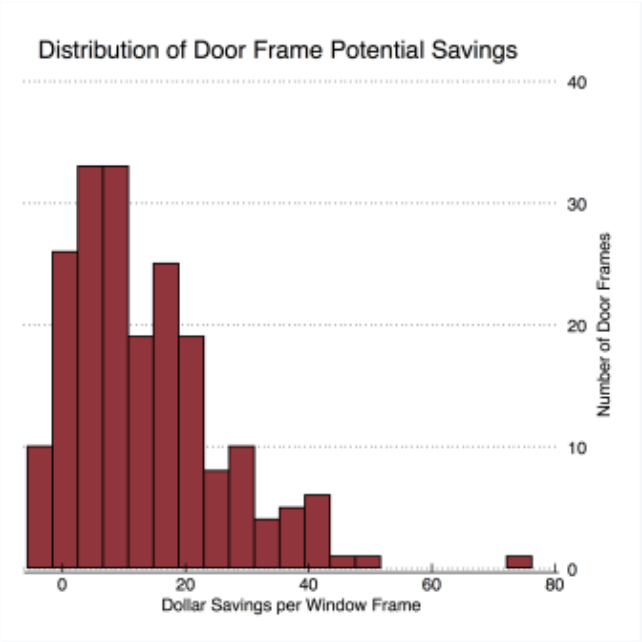

Figure D-6. Distribution of potential annual energy cost savings due to repair of door frame leaks, Camp Lejeune.

D.3 Walls

Walls on the base were categorized as either brick, siding or concrete. The system identified 315 distinct brick wall polygons, 84 siding walls, and 13 concrete walls. Costs associated with wall polygons were estimated based on their time-normalized surface temperatures (Figure D-7) and inferred R-values, as described in Section 5.2 ("Baseline Characterization"). Estimated annual combined heating and cooling costs from wall polygons range from $1.40/sq ft to $3.70/sq ft (Figure D-8). Brick walls in general had lower estimated costs per square foot (~$1.90) than did siding or concrete walls (~$2.70).

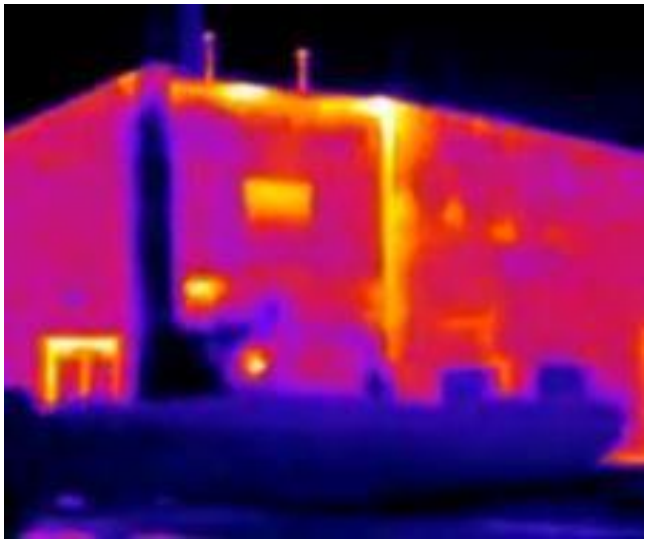

Figure D-7. Example of thermal energy losses in walls, Camp Lejeune.

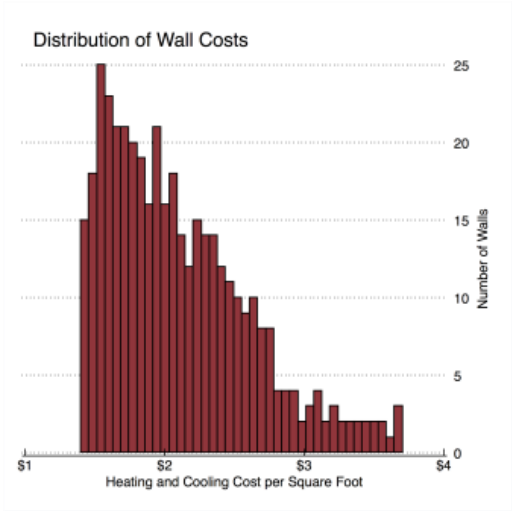

Figure D-8. Distribution of annual energy loss costs per square foot of wall area, Camp Lejeune.

Potential remediation savings for walls were estimated by running the heat flow model on estimated current R-values and post-remediation R-values. Savings range from zero (or negative savings in a few cases of very well insulated walls) up to slightly over $1.40/sq ft Figure D-9. At an average installation and labor cost of around $7/sq ft, walls with particularly high energy leakage are cost-effective to remediate.

Of the 412 wall polygons identified, 291 would have positive savings through improved insulation. Of these, approximately 113 would have a payback period of less than 15 years. The average savings associated with improving wall insulation for these 113 cases was around $0.80/sq ft. The most emissive walls identified on the base were in Bldgs 2812, 2811, 2900, 2901, H65, and H63.

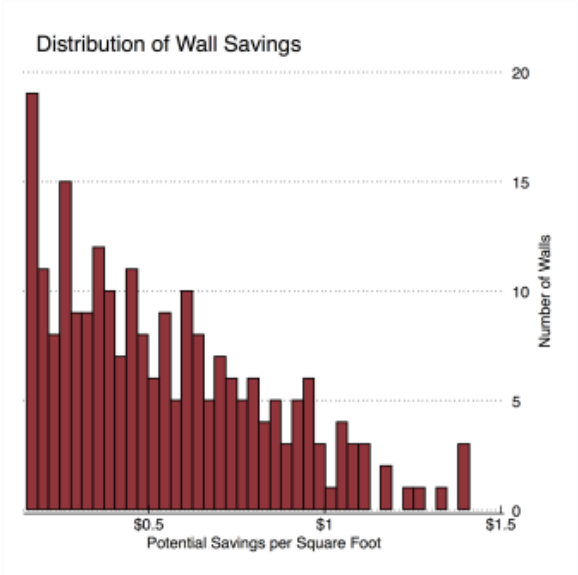

Figure D-9. Distribution of potential annual energy cost savings due to wall insulation repairs, Camp Lejeune.

D.4 Roofs

Roof heat loss is calculated similarly to wall heat loss, by looking at time-normalized surface temperatures (Figure D-10). The system identified 232 distinct roof polygons. (Note that a single roof will usually have more than one polygon identified, as the maximum size of a polygon is dictated by the FOV of the camera in a single image frame.) The estimated heating and cooling cost associated with these roofs ranged from $1.10 to $2.20/sq ft. A distribution of annual energy loss costs per square foot of roof area (Figure D-11).

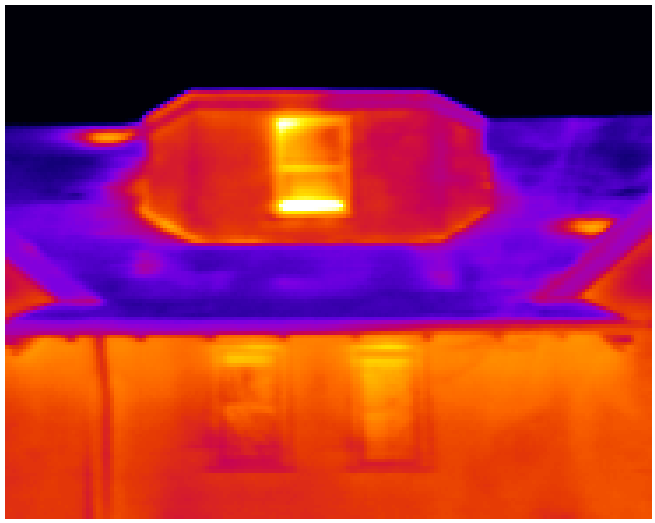

Figure D-10. Example of thermal energy losses in roofs, Camp Lejeune.

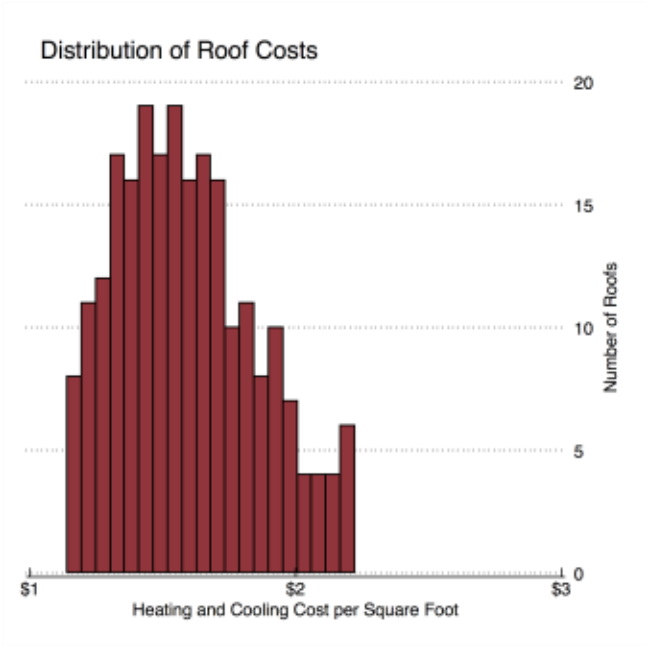

Figure D-11. Distribution of annual energy loss costs per square foot of roof area, Camp Lejeune.

Of the 133 roof polygons identified that had positive remediation savings, 14 had paybacks of less than 15 years. The average savings associated with improving roof insulation for these 14 cases was around $0.60/sq ft (Figure D-12). The most emissive roofs identified on the base were on Bldgs 2900, HP328, 1984, 2901, 504, and 430.

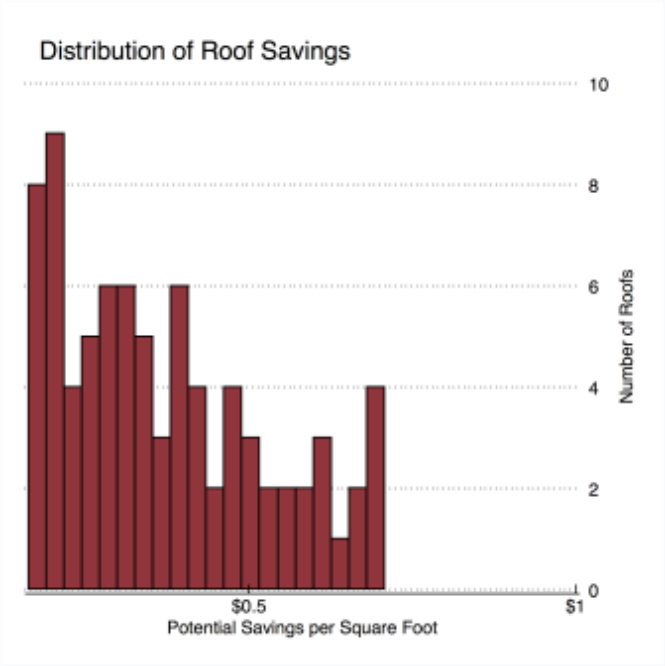

Figure D-12. Potential annual energy cost savings per square foot due to roof insulation repairs, Camp Lejeune.

D.5 Soffits

Soffits are areas where the wall meets the roof and are often spots where insulation is poor and air leaks are more common. The system identified 329 total soffit polygons on buildings in the base. Their R-values were estimated based on surface temperatures (Figure D-13) similar to the calculation for walls and roofs. The average annual heating and cooling costs for soffits range from $1.40 to $2.80/sq ft (Figure D-14).

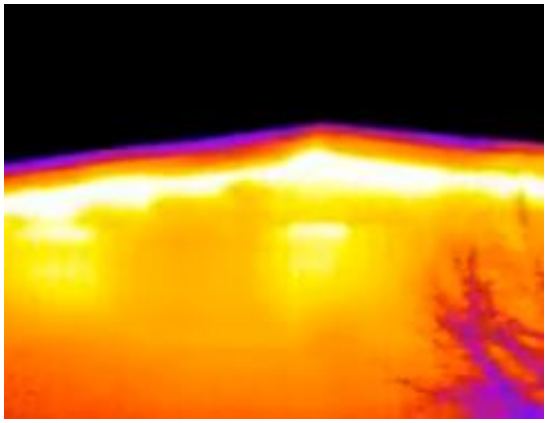

Figure D-13. Example of a leaky soffit, Camp Lejeune.

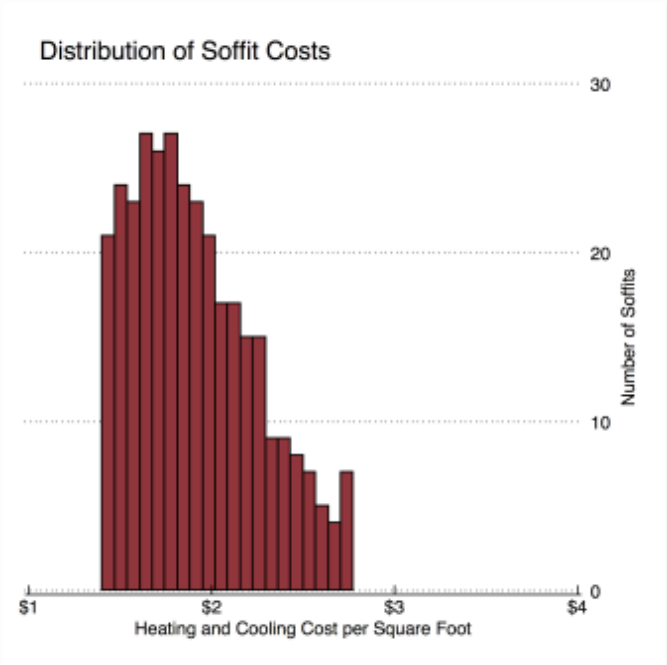

Figure D-14. Distribution of annual energy costs due to thermally inefficient soffits, Camp Lejeune.

Of the 229 soffit polygons that had positive remediation savings, 64 had paybacks of less than 15 years. The average savings associated with improving soffit insulation for these 64 cases was around $0.80/sq ft (Figure D-15). The most emissive soffits identified on the base were on Bldgs 1206, HP210, 319, 2900, 2901, and 302.

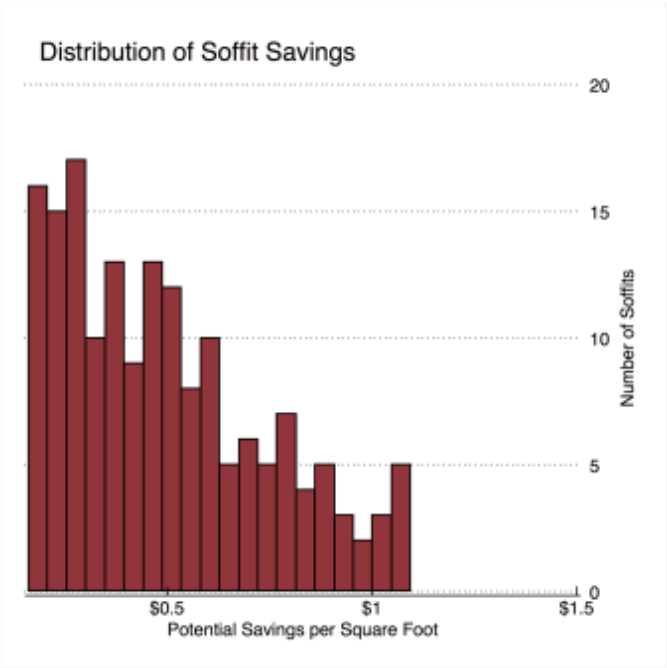

Figure D-15. Distribution of potential annual energy cost savings due to repair of thermally inefficient soffits, Camp Lejeune.

APPENDIX E: THIRTY BUILDING DETAILED ANALYSIS

E.1 Building Detailed Analysis Scott AFB, IL

E.1.1 Bldg 5

E.1.1.1 Description of Bldg 5, Scott AFB

Name: Comm. Facility
Use Type: Office
Square Footage: 17,927
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 16.8 therms
Electricity Score: N/A
Gas Score: 45th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 1,841.9 therms

Bldg 5 (Figures E-1 and E-2) has an annual natural gas usage of 34,197 Btu/sq ft. (No electricity data were available for analysis.) The electricity and gas scores above compare the building to similarly sized buildings of the same type on an energy use per square foot basis. An energy score at the 100th percentile represents the highest energy use per square foot relative to similar buildings, while a score if the 0th percentile represents the lowest. The annual cooling and heating loads are calculated by regressing natural gas bills and electric bills (when available) against degree days for each billing period to disaggregate the heating and cooling components of building energy use.

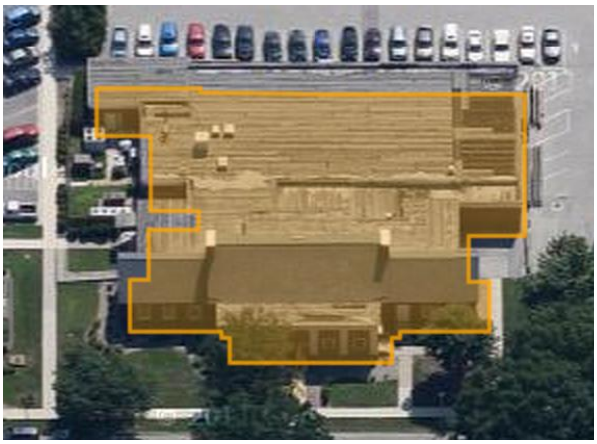

Figure E-1. Aerial view of Bldg 5, Scott AFB.

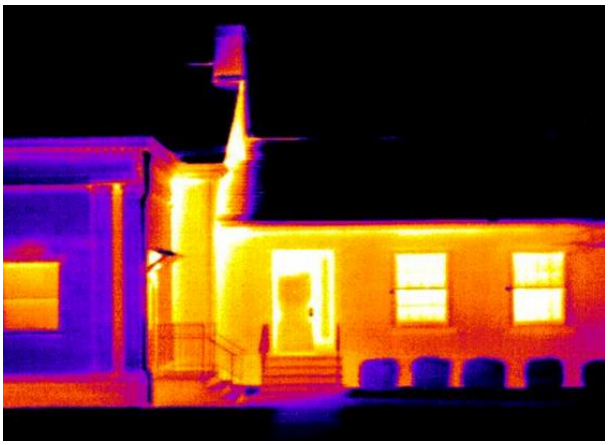

Figure E-2. Thermal image of Bldg 5, Scott AFB.

E.1.1.2 Notable Leaks at Bldg 5, Scott AFB

Figure E-3. NIR image (left) and thermal image (right) of Bldg 5, Scott AFB.

The section of wall at 63:02 in the Drive-by Application (Figure E-3, center of the right picture above as outlined by the blue rectangle) has a notable warm spot that does not correspond with any differentiable feature in the near IR. This may indicate a poorly insulated part of the brick wall, and may be worth investigating further.

The NIR image in Figure E-4 shows that the door frame in the IR image at 63:16 in the Drive-by Application is fairly emissive. The soffit (where the roof meets the wall) also appears abnormally warm. These areas should be investigated further and addressed immediately.

Figure E-4. NIR image (left) and thermal image (right) of Bldg 5, Scott AFB. Highly emissive door frame shown in polygon at the right.

E.1.1.3 Envelope ECMs for Bldg 5, Scott AFB

Figure E-5 shows the relative ROI for envelope ECMs for Bldg 5, Scott AFB.

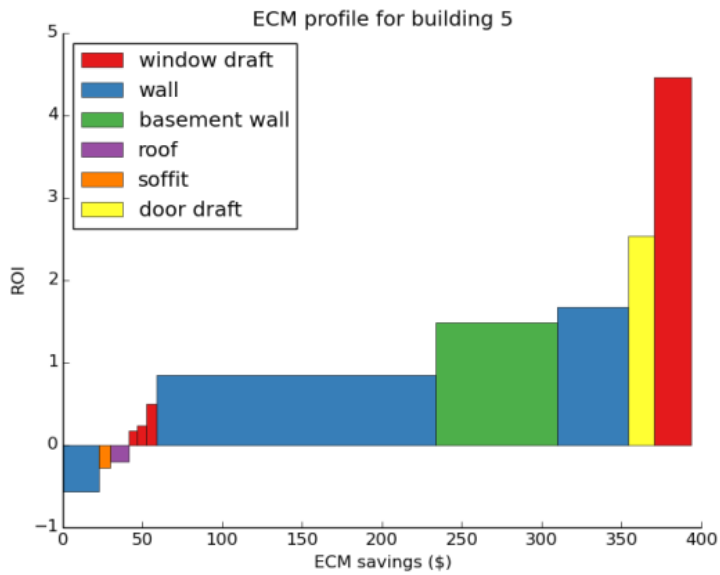

Figure E-5. Envelope ECM profile for Bldg 5, Scott AFB.

Table E-1 lists the recommended envelope ECMs.

Table E-1. Envelope ECMs for Bldg 5, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	149	358	219	1677	7.6
Basement Wall Insulation	52	124	76	461	6.0
Seal Window Frame Leaks	28	67	41	263	6.4
Seal Door Frame Leaks	11	25	16	66	4.3

Annual potential post-remediation energy savings for this building are $352 and total payback is 7.0 years for envelope-related ECMs.

E.1.1.4 Non-Envelope ECMs for Bldg 5, Scott AFB

Table E-2 lists the recommended non-envelope ECMs

Table E-2. Non-envelope ECMs for Bldg 5, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	37273	-485	1994	26811	13.4
Occupancy Sensors	16715	-217	894	896	1.0
LED Exit Signs	4875	-51	267	585	2.2
EnergyStar Vending Machines	1842	0	111	500	4.5

Some lighting-related actions save negative therms because their more efficient replacements emit less waste heat and require a bit of additional work on the part of the building heating system.

Annual potential post-remediation energy savings for this building are $3,266 and total payback is 8.8 years for non-envelope ECMs.

E.1.2 Bldg 6

E.1.2.1 Description of Bldg 6, Scott AFB

Name: Fitness Center
Use Type: Recreation
Square Footage: 25,717
Avg. Daily Electric Use: 1,353.8 kWh
Avg. Daily Gas Use: 42.1 therms
Electricity Score: 60th Percentile
Gas Score: 75th Percentile
Annual Cooling Load: 258,249 kWhrs
Annual Heating Load: 12,995 therms

Bldg 6 (Figures E-6 and E-7) has a relatively high annual gas use (59,738 Btu/sq ft/yr) and roughly average electricity use (19.2 kWh/sq ft/yr) compared to similar buildings on the base.

Figure E-6. Aerial view of Bldg 6, Scott AFB.

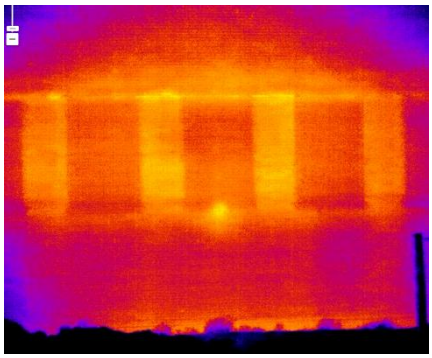

Figure E-7. Thermal image of Bldg 6, Scott AFB.

E.1.2.2 Notable Leaks at Bldg 6, Scott AFB

The wall seen at 65:06 in the Drive-by Application has discernibly poorly insulated patches between the bricked-up windows (Figure E-8). There is also a hot spot in the center of the wall, right below the middle bricked-up window. The base manager should check the insulation around the bricked-up windows to prevent some of the energy loss due to poor insulation.

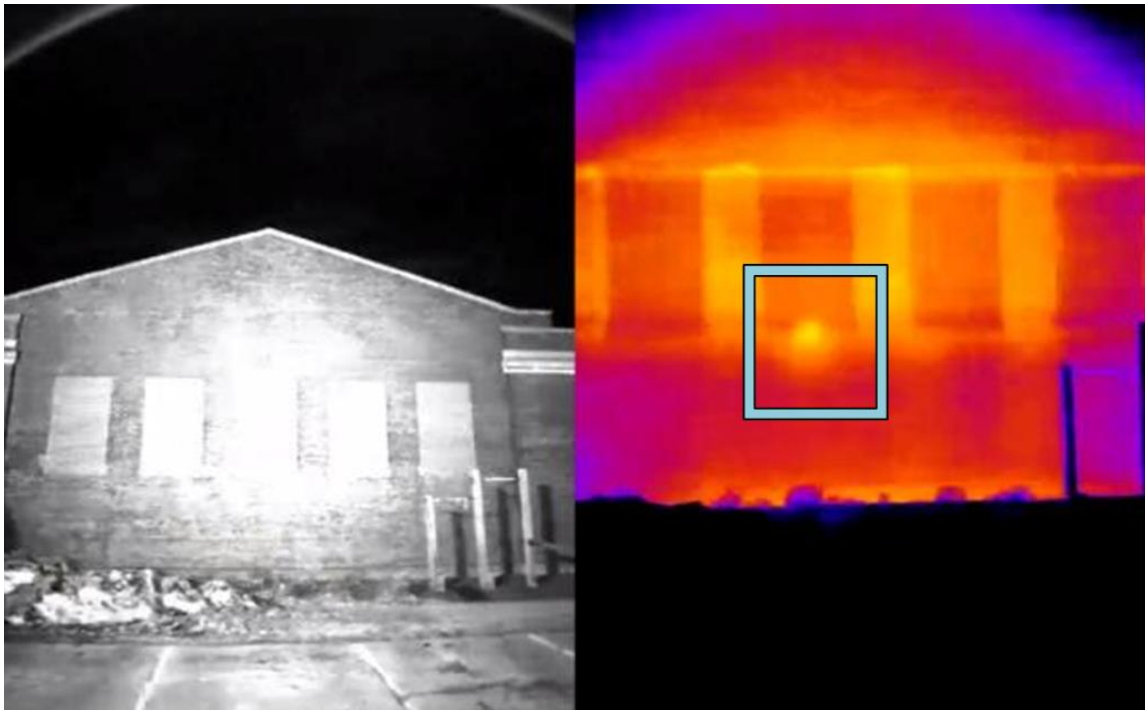

Figure E-8. NIR image (left) and thermal image (right) of Bldg 6, Scott AFB.

E.1.2.3 Envelope ECMs for Bldg 6, Scott AFB

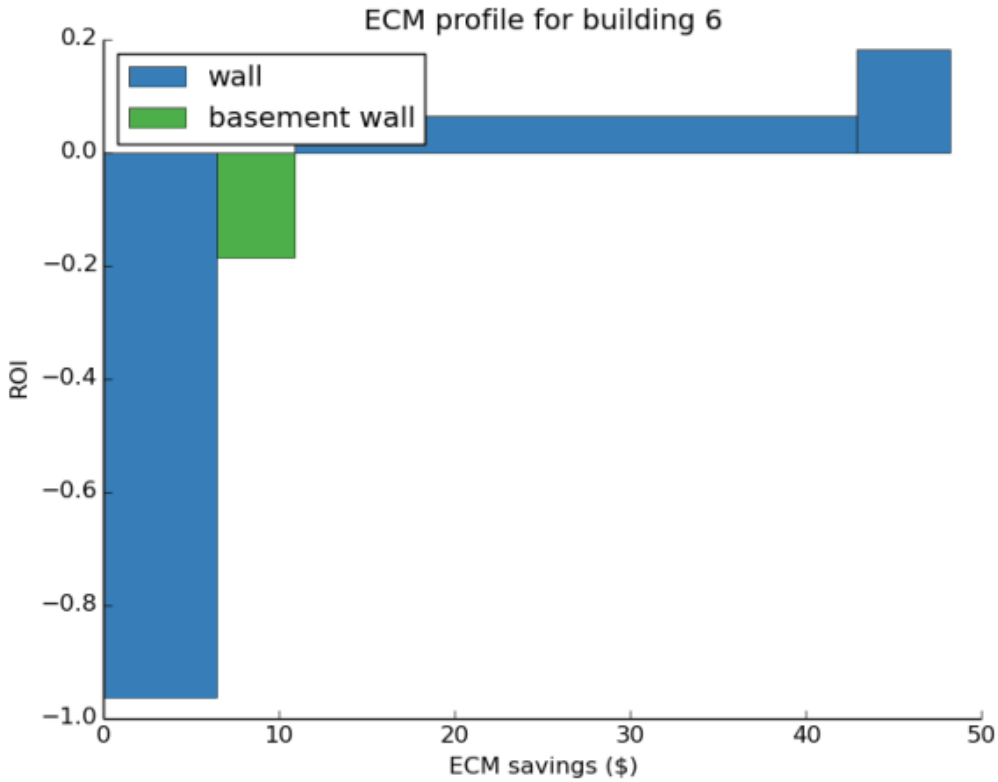

Figure E-9. Envelope ECM profile for Bldg 6, Scott AFB.

Table E-3 lists the recommended envelope ECMs for Bldg 6.

Table E-3. Envelope ECMs, Bldg 6, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	25	61	37	520	13.9

Annual potential remediation savings for this building are $37 and total payback is 13.9 years for envelope-related ECMs.

E.1.2.4 Non-Envelope ECMs for Bldg 6, Scott AFB

Table E-4 lists the recommended non-envelope ECMs for Bldg 6.

Table E-4. Non-envelope ECMs for Bldg 6, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	55568	-717	2976	38462	12.9
Occupancy Sensors	24919	-322	1334	1285	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	208	104	315	3.0

Annual potential remediation savings for Bldg 6 are $5,304 and total payback is 7.9 years for non-envelope ECMs.

E.1.3 Bldg 8

E.1.3.1 Description of Bldg 8, Scott AFB

Name: Pax Terminal
Use Type: Misc.
Square Footage: 11,169
Avg. Daily Electric Use: 795.7 kWh
Avg. Daily Gas Use: 10.4 therms
Electricity Score: 85th Percentile
Gas Score: 35th Percentile
Annual Cooling Load: 48,735 kWhrs
Annual Heating Load: 3,586 therms

Bldg 8 has a gas usage of 33,872 Btu/sq ft/yr and electricity usage of 26 kWh/sq ft/yr.

Figure E-10. Aerial view of Bldg 8, Scott AFB.

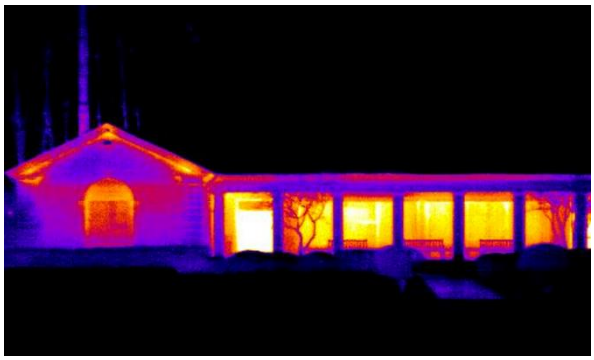

Figure E-11. IR image of Bldg 8, Scott AFB.

E.1.3.2 Notable Leaks at Bldg 8, Scott AFB

The soffit (where the wall meets the roof) at 198:33 in the Drive-by Application is notably emissive (Figure E-12). This should be further investigated.

Figure E-12. NIR image (left) and thermal image (right) of Bldg 8, Scott AFB.

The soffit at 198:44 (Figure E-13) is abnormally emissive. There may be leakage occurring on the wall to the left as well. The area above the door also shows some heat loss, which is most likely caused by poor insulation.

Figure E-13. NIR image (left) and thermal image (right) of Bldg 8, Scott AFB. Note highly emissive area within the rectangle in the right hand image.

Around the back of the building at timestamp 198:53, there are some patches of poorly insulated wall in addition to the leaky soffit (Figure E-14). There may also be a thermal bridge through the insulation represented by the long horizontal line above the window. The immediate fix for this building involves addressing the soffit leaks.

Figure E-14. NIR image (left) and thermal image (right) of Bldg 8, Scott AFB. Areas of the wall and the soffit appear to exhibit high heat loss.

Further along on the same wall, at 198:54, the insulation gaps are even more notable and there is an abnormally emissive door frame (Figure E-15). This may be caused by the door not being closed properly or by a worn out seal around the door.

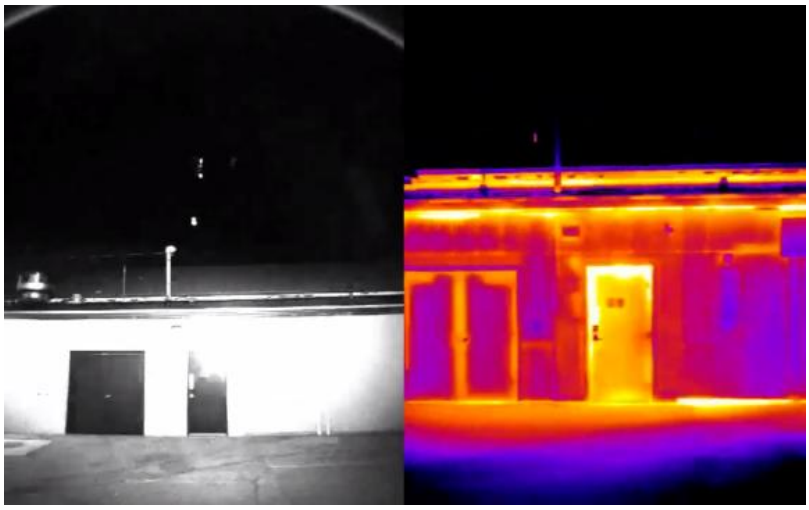

Figure E-15. NIR image (left) and thermal image (right) of Bldg 8, Scott AFB. The soffit and door frame appear to exhibit high heat loss.

E.1.3.3 Envelope ECMs for Bldg 8, Scott AFB

Figure E-16 shows the relative ROI for envelope ECMs for Bldg 8, Scott AFB.

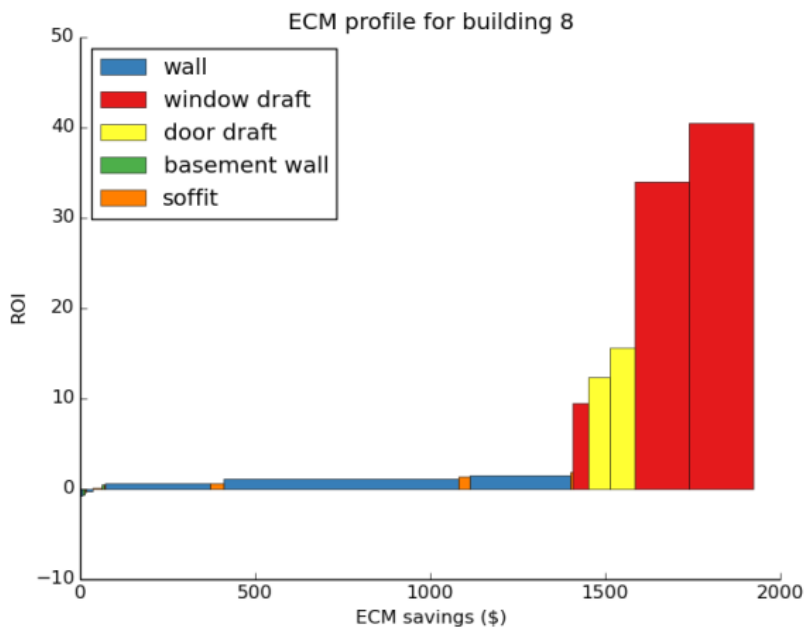

Figure E-16. ECM profile for Bldg 8, Scott AFB.

Table E-5 lists the recommended envelope ECMs for Bldg 8, Scott AFB.

Table E-5. Envelope ECMs for Bldg 8, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	852	2052	1258	9529	7.6
Seal Window Frame Leaks	259	623	382	198	0.5
Seal Door Frame Leaks	89	215	132	132	1.0
Improve Soffit Insulation	73	177	108	1043	9.6

Annual potential remediation savings for this building are $1,881 and total payback is 5.8 years for envelope-related ECMs.

E.1.3.4 Non-Envelope ECMs for Bldg 8, Scott AFB

Table E-6 lists recommended non-envelope ECMs for Bldg 8, Scott AFB.

Table E-6. Non-envelope ECMs for Bldg 8, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	24133	-311	1292	16704	12.9
Occupancy Sensors	10822	-140	580	558	1.0
LED Exit Signs	4875	-51	267	585	2.2
Boiler Tune-up	0	57	29	137	4.8

Annual potential remediation savings for this building are $2,167 and total payback is 8.3 years for non-envelope ECMs.

E.1.4 Bldg 10

E.1.4.1 Description of Bldg 10, Scott AFB

Name: Base Personnel OFC
Use Type: Office
Square Footage: 46,785
Avg. Daily Electric Use: 5,444 kWh
Avg. Daily Gas Use: 38.7 therms
Electricity Score: 95th Percentile
Gas Score: 30th Percentile
Annual Cooling Load: 38,333 kWhrs
Annual Heating Load: 8,947 therms

Bldg 10 (Figures E-17 and E-18) has a gas usage of 30,177 Btu/sq ft/yr and electricity usage of 42.5 kWh/sq ft/yr.

Figure E-17. Aerial view of Bldg 10, Scott AFB.

Figure E-18. Thermal image of Bldg 10, Scott AFB.

E.1.4.2 Notable Leaks at Bldg 10, Scott AFB

There is a particularly emissive patch of wall in the left corner at timestamp 69:25 of the Drive-by Application (Figure E-19). This heat being captured by the camera system may be caused by poor insulation in the wall. However, this type of signature can also be caused by a piece of equipment generating heat. Given the consistent appearance of the remainder of the building, this area should be further investigated by the base energy manager.

Figure E-19. NIR image (left) and thermal image (right) of Bldg 10, Scott AFB.

E.1.4.3 Envelope ECMs for Bldg 10, Scott AFB

Figure E-20 shows the relative ROI for envelope ECMs for Bldg 10, Scott AFB.

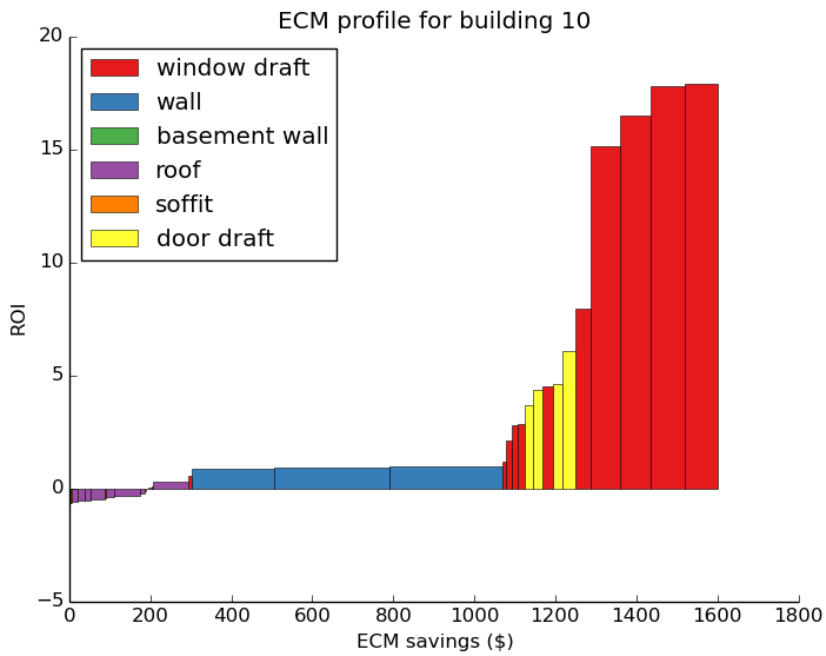

Figure E-20. ECM profile for Bldg 10, Scott AFB.

Figure E-7 lists the recommended envelope ECMs for Bldg 10, Scott AFB.

Table E-7. Envelope ECMs for Bldg 10, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	519	1250	767	5967	7.8
Seal Window Frame Leaks	301	725	445	790	1.8
Seal Door Frame Leaks	68	163	100	264	2.6
Improve Roof Insulation	64	154	94	1103	11.7

Annual potential remediation savings for this building are $1,405 and total payback is 5.8 years for envelope-related ECMs.

E.1.4.4 Non-Envelope ECMs for Bldg 10, Scott AFB

Table E-8 lists the recommended non-envelope ECMs for Bldg 10, Scott AFB.

Table E-8. Non-envelope ECMs for Bldg 10, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	97273	-1265	5204	69971	13.4
Occupancy Sensors	43621	-567	2334	2338	1.0
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	3684	0	221	500	2.3

Annual potential remediation savings for this building are $8,648 and total payback is 8.6 years for non-envelope ECMs.

E.1.5 Bldg 40

E.1.5.1 Description of Bldg 40, Scott AFB

Name: HQ Major Cmd
Use Type: Office
Square Footage: 187,909
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 129 therms
Electricity Score: N/A
Gas Score: 25th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 46,428 therms

Bldg 40 (Figures E-21 and E-22) has a gas usage of 25,044 Btu/sq ft/yr.

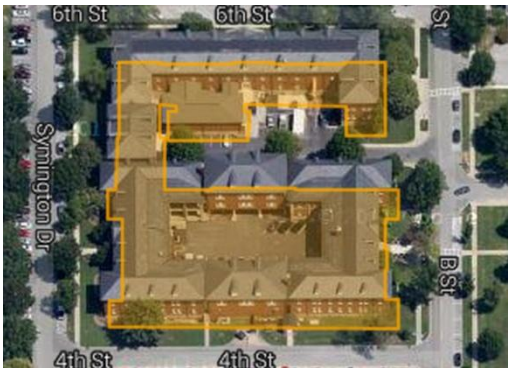

Figure E-21. Aerial view of Bldg 40, Scott AFB.

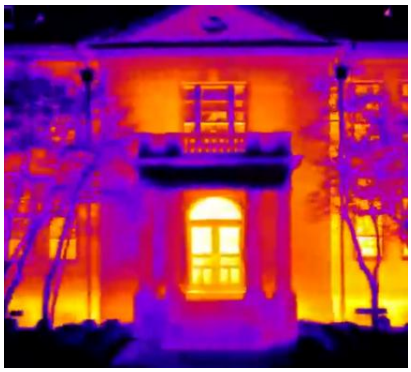

Figure E-22. Thermal image of Bldg 40, Scott AFB.

E.1.5.2 Notable Leaks at Bldg 40, Scott AFB

The corner of the building at 187:20 (Figure E-23) is notably emissive, most likely caused by poor insulation; however, corners can also trap residual solar heat and that effect cannot necessarily be excluded.

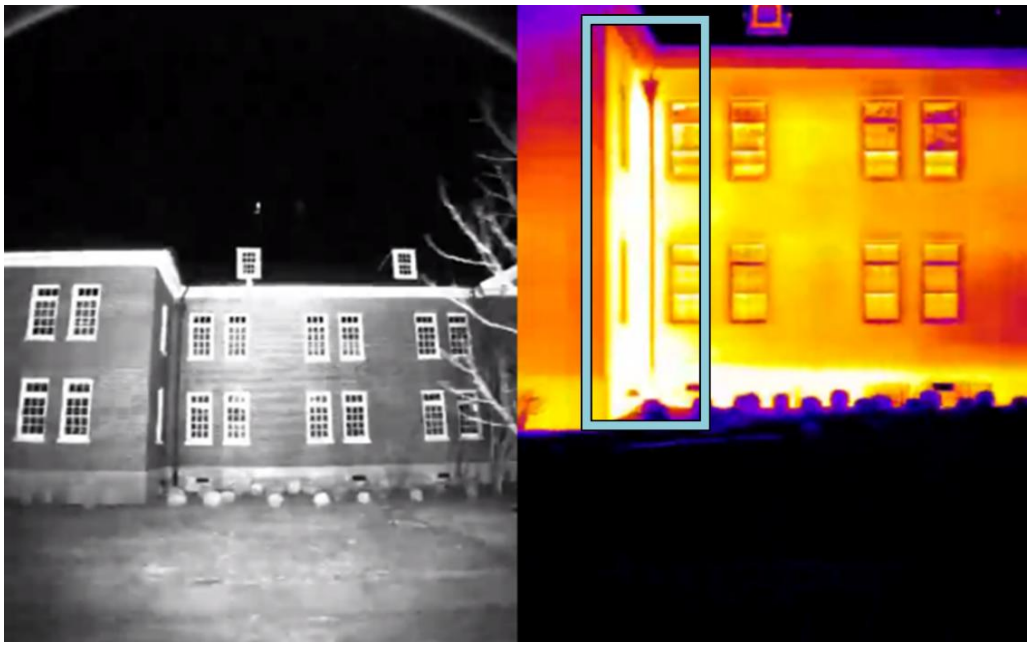

Figure E-23. NIR image (left) and thermal image (right) of Bldg 40, Scott AFB.

E.1.5.3 Envelope ECMs for Bldg 40, Scott AFB

Figure E-24 shows the relative ROI for envelope ECMs for Bldg 40, Scott AFB.

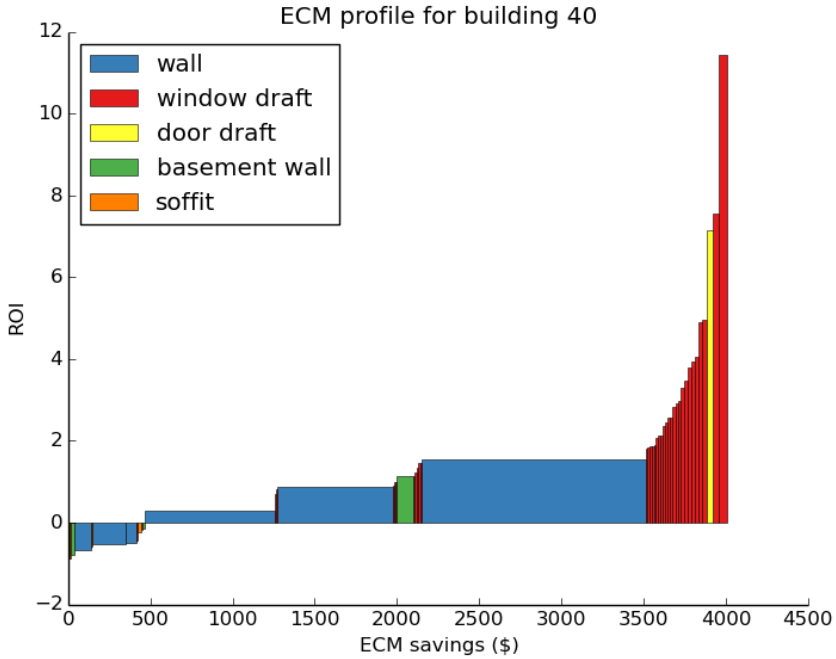

Figure E-24. ECM profile for Bldg 40, Scott AFB.

Table E-9 lists the recommended envelope ECMs for Bldg 40, Scott AFB.

Table E-9. Envelope ECMs for Bldg 40, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1933	4656	2855	22932	8.0
Seal Window Frame Leaks	376	906	555	2237	4.0
Basement Wall Insulation	69	165	101	715	7.1
Seal Door Frame Leaks	24	59	36	66	1.8

Annual potential remediation savings for this building are $3,548 and total payback is 7.3 years for envelope-related ECMs.

E.1.5.4 Non-Envelope ECMs for Bldg 40, Scott AFB

Table E-10 lists the recommended non-envelope ECMs for Bldg 40, Scott AFB.

Table E-10. Non-envelope ECMs for Bldg 40, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	390692	-5082	20900	281035	13.4
Occupancy Sensors	175201	-2279	9373	9392	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	743	371	2300	6.2

Annual potential remediation savings for Bldg 40 are $31,534 and total payback of 9.3 years for non-envelope ECMs.

E.1.6 Bldg 61

E.1.6.1 Description of Bldg 61, Scott AFB

Name: 868 Comm Squadron
Use Type: Office
Square Footage: 17,205
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 18.2 therms
Electricity Score: N/A
Gas Score: 60th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 5,861 therms

Bldg 61 (Figure E-25 and E-26) has a gas usage of 38,534 Btu/sq ft/yr.

Figure E-25. Aerial view of Bldg 61, Scott AFB.

Figure E-26. Highly emissive areas of Bldg 61, Scott AFB.

E.1.6.2 Notable Leaks at Bldg 61, Scott AFB

The wall surface and door frame around timestamp 71:22 (Figure E-27) are notably emissive. The area of the wall outlined by the rectangle is very poorly insulated.

Figure E-27. NIR image (left) and thermal image (right) of Bldg 61, Scott AFB.

The wall of the attached structure at 71:26 (Figure E-28) is much more emissive than other brick surfaces of the building. In fact, this wall is more emissive than nearly all other emissive brick surfaces across the base. It is likely that the area is missing insulation. There is also a notable insulation hole in the wall at timestamp 71:41, to the left of the electrical box.

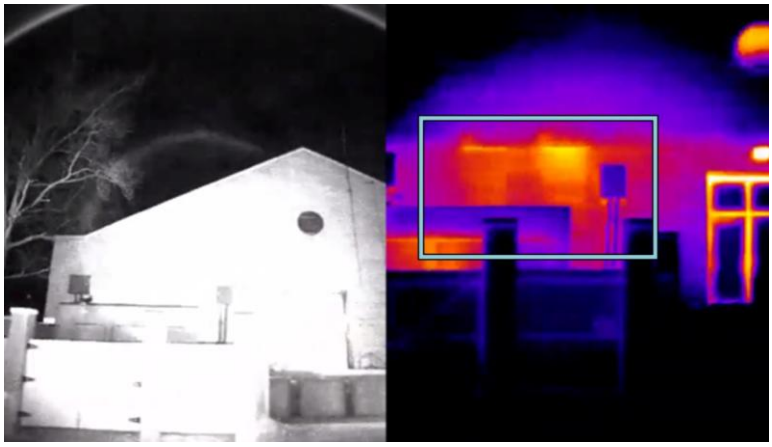

Figure E-28. NIR image (left) and thermal image (right) of Bldg 61, Scott AFB. A highly emissive area is shown within the rectangle in the right hand image.

E.1.6.3 Envelope ECMs for Bldg 61, Scott AFB

Figure E-29 shows the relative ROI for envelope ECMs for Bldg 61, Scott AFB.

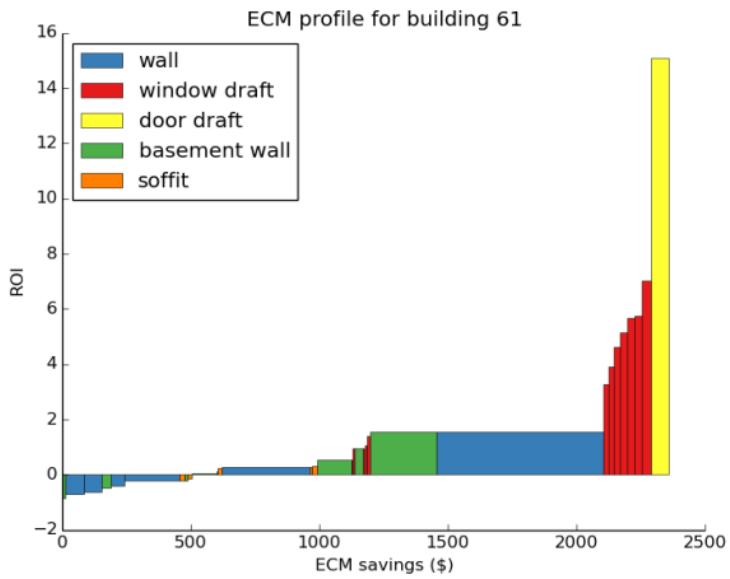

Figure E-29. ECM profile for Bldg 61, Scott AFB.

Table E-11 lists the recommended envelope ECMs for Bldg 61, Scott AFB.

Table E-11. Envelope ECMs for Bldg 61, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	672	1615	991	7818	7.9
Basement Wall Insulation	352	848	520	4481	8.6
Seal Window Frame Leaks	155	374	229	790	3.4
Seal Door Frame Leaks	48	115	71	66	0.9
Improve Soffit Insulation	32	76	47	553	11.8

Annual potential remediation savings for this building are $1,858 and total payback is 7.4 years for envelope-related ECMs.

E.1.6.4 Non-Envelope ECMs for Bldg 61, Scott AFB

E.1.7 Bldg 433

E.1.7.1 Description of Bldg 433, Scott AFB

Name: Sq Ops (Hanger 1)
Use Type: Misc.
Square Footage: 147,405
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 307.5 therms
Electricity Score: N/A
Gas Score: 90th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 113,075 therms

Bldg 433 (Figures E-30 and E-31) has a gas usage of 76,112 Btu/sq ft/yr.

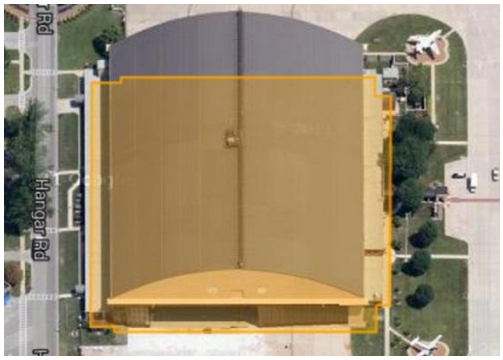

Figure E-30. Aerial view of Bldg 433, Scott AFB.

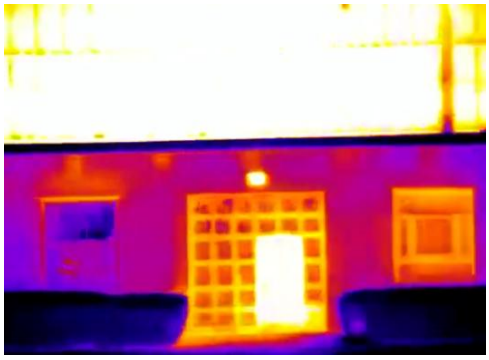

Figure E-31. Thermal image of Bldg 433, Scott AFB.

E.1.7.2 Notable Leaks at Bldg 433, Scott AFB

The wall around timestamp 70:13 of the Drive-by Application appears to have reoccurring insulation gaps near the top (Figure E-32). These continue regularly down the length of the wall and can be caused by missing insulation between structural studs.

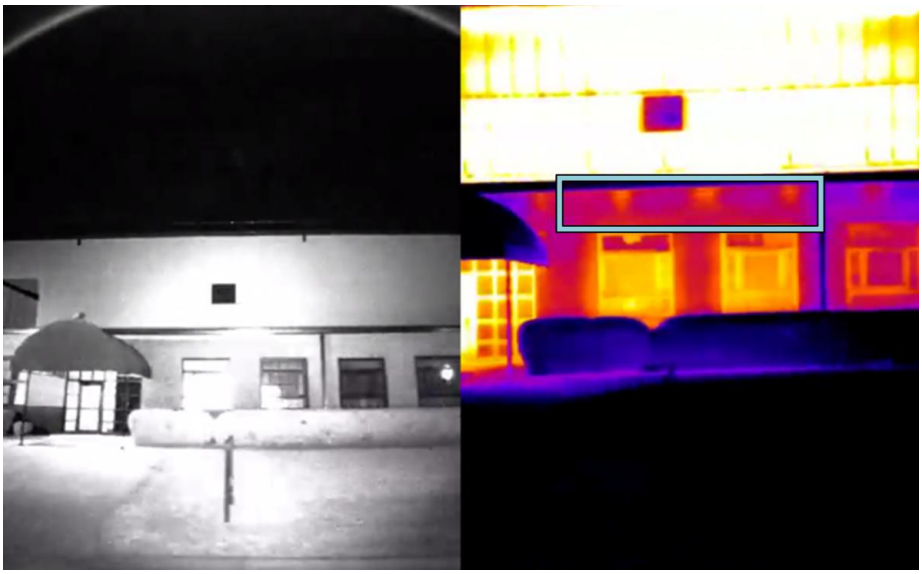

Figure E-32. NIR image (left) and thermal image (right) of Bldg 433, Scott AFB. A highly emissive area is shown within the rectangle in the right hand image.

These insulation holes also appear around timestamp 70:25 (Figure E-33). Additionally, either the walls around the windows are poorly insulated, or abnormal leakage from the windows is heating the walls around them. This should be investigated as the window leakage issue could be solved with simple weather-stripping and caulking.

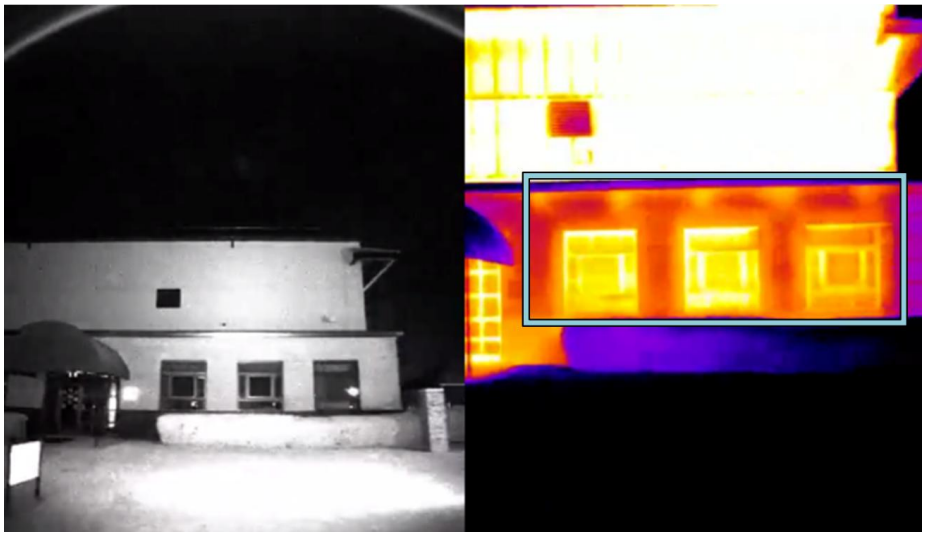

Figure E-33. NIR image (left) and thermal image (right) of Bldg 433, Scott AFB. The window frames appear to be highly emissive.

E.1.7.3 Envelope ECMs for Bldg 433, Scott AFB

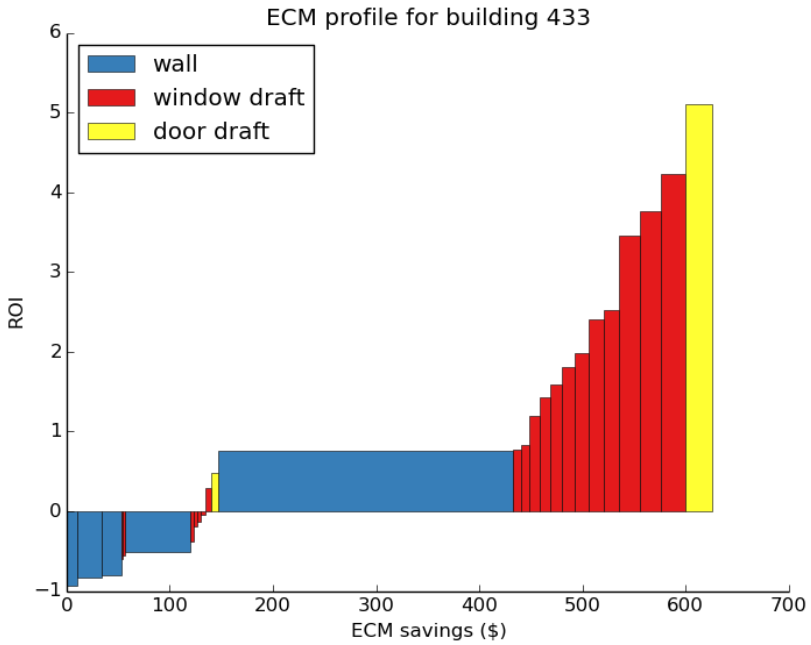

Figure E-34 shows the relative ROI for envelope ECMs for Bldg 433, Scott AFB.

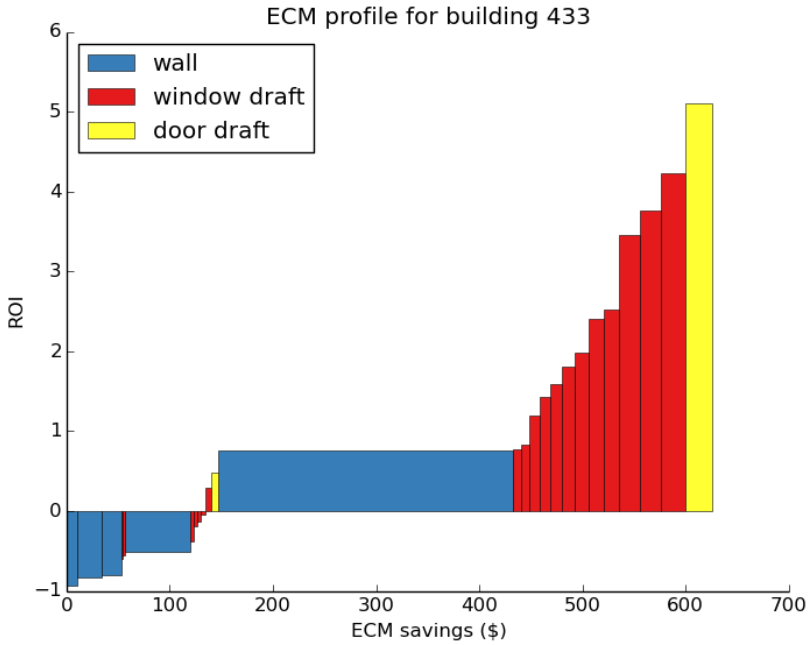

Figure E-34. ECM profile for Bldg 433, Scott AFB.

Table E-12 lists the recommended envelope ECMs for Bldg 433, Scott AFB.

Table E-12. Envelope ECMs for Bldg 433, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	194	466	286	2442	8.5
Seal Window Frame Leaks	117	281	172	855	5.0
Seal Door Frame Leaks	23	55	34	133	4.0

Annual potential remediation savings for this building are $492 and total payback is 7.0 years for envelope-related ECMs.

E.1.7.4 Non-Envelope ECMs for Bldg 433, Scott AFB

Table E-13 lists the recommended non-envelope ECMs for Bldg 433, Scott AFB.

Table E-13. Non-envelope ECMs for Bldg 433, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	261776	-3385	14014	186750	13.3
Occupancy Sensors	117390	-1518	6284	6241	1.0
Boiler Tune-up	0	1809	905	1804	2.0
LED Exit Signs	16250	-171	890	1950	2.2

Total potential remediation savings for this building are $22,093 and total payback is 8.9 years for non-envelope ECMs.

E.1.8 Bldg 470

E.1.8.1 Description of Bldg 470, Scott AFB

Name: 932 Squad Ops
Use Type: Office
Square Footage: 39,907
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 35.4 therms
Electricity Score: N/A
Gas Score: 35th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 9,861 therms

Bldg 470 (Figures E-35 and E-36) has a gas usage of 32,375 Btu/sq ft/yr.

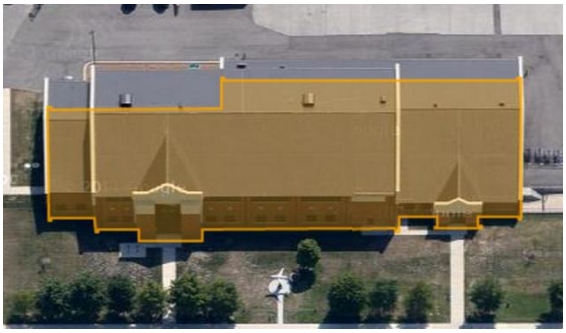

Figure E-35. Aerial view of Bldg 470, Scott AFB.

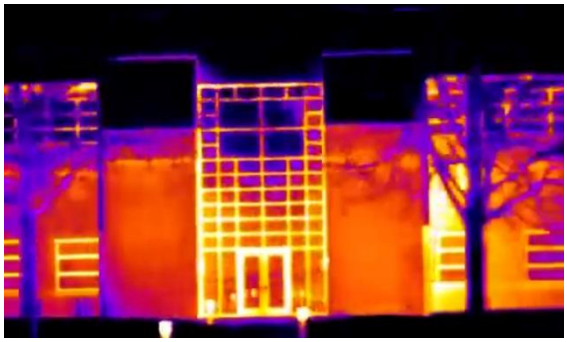

Figure E-36. Thermal image of Bldg 470, Scott AFB.

E.1.8.2 Notable Leaks at Bldg 470, Scott AFB

The soffit seen at timestamp 68:29 is fairly emissive (Figure E-37). There are also some spots on the walls that may represent insulation holes and there are soffit leaks across the top portion of the area outlined by the polygon.

Figure E-37. NIR image (left) and thermal image (right) of Bldg 470, Scott AFB.

The soffit on the right side of the image at timestamp 68:36 also appears leaky, and the corner on the left side of the image has several energy leaks (Figure E-38). The leak profile indicates insulation at the joint where the building joins the larger wall (outlined in the left polygon).

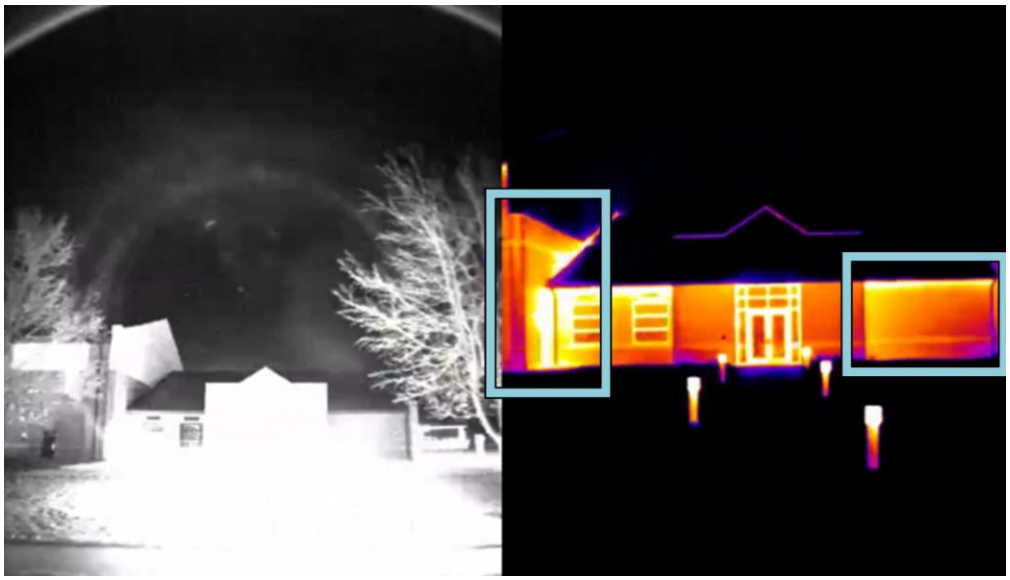

Figure E-38. NIR image (left) and thermal image (right) of Bldg 470, Scott AFB. An area in the corner of the building (left) and a wall section (right) appears to be highly emissive.

E.1.8.3 Envelope ECMs for Bldg 470, Scott AFB

Figure E-39 shows the relative ROI for envelope ECMs for Bldg 470, Scott AFB.

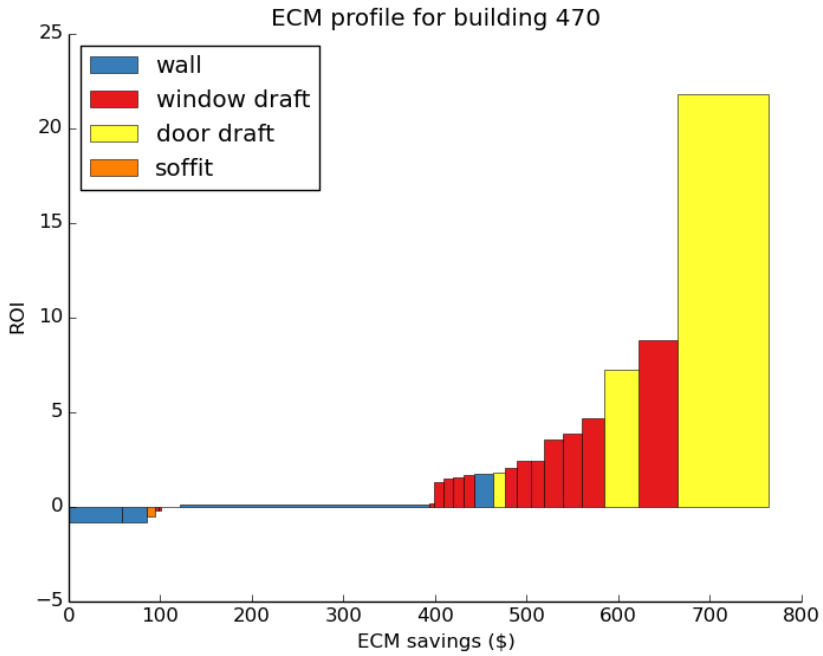

Figure E-39. ECM profile for Bldg 470, Scott AFB.

Table E-14 lists the recommended envelope ECMs for Bldg 470, Scott AFB.

Table E-14. Envelope ECMs for Bldg 470, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	198	478	293	3922	13.4
Seal Window Frame Leaks	136	327	200	790	3.9
Seal Door Frame Leaks	101	243	149	199	1.3

Annual potential remediation savings for this building are $643 and total payback is 7.6 years for envelope-related ECMs.

E.1.8.4 Non-Envelope ECMs for Bldg 470, Scott AFB

Table E-15 lists the recommended non-envelope ECMs for Bldg 470, Scott AFB.

Table E-15. Non-envelope ECMs for Bldg 470, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	82973	-1079	4439	59685	13.4
Occupancy Sensors	37208	-484	1990	1995	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	158	79	488	6.2

Annual potential remediation savings for this building are $7,398 and total payback is 8.7 years for non-envelope ECMs.

E.1.9 Bldg 506

E.1.9.1 Description of Bldg 506, Scott AFB

Name: Hanger Maintenance
Use Type: Misc.
Square Footage: 34,548
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 53.9 therms
Electricity Score: N/A
Gas Score: 75th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 19,393 therms

Bldg 506 (Figures E-41 and E-41) has a gas usage of 56,900 Btu/sq ft/yr.

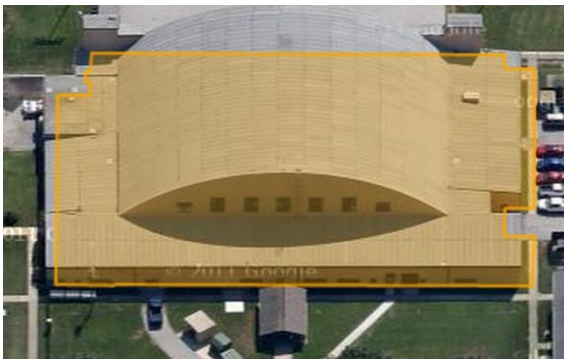

Figure E-40. Aerial view of Bldg 506, Scott AFB.

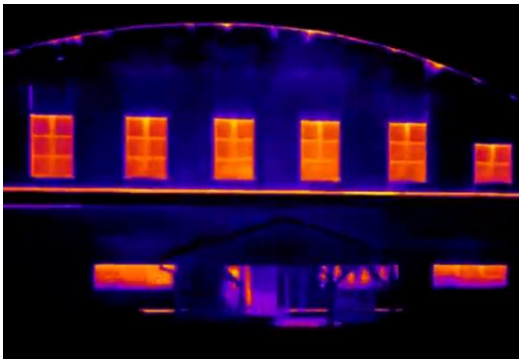

Figure E-41. Thermal image of Bldg 506, Scott AFB.

E.1.9.2 Notable Leaks at Bldg 506, Scott AFB

The roofline of Bldg 506 is notably warm, as is the door frame to the right of the image at timestamp 235:20 in the Drive-By Tool (Figure E-42).

Figure E-42. NIR image (left) and thermal image (right) of Bldg 506, Scott AFB. A particularly emissive area is shown in the rectangle to the right.

E.1.9.3 Envelope ECMs for Bldg 506, Scott AFB

Figure E-43 shows the relative ROI for envelope ECMs for Bldg 506, Scott AFB.

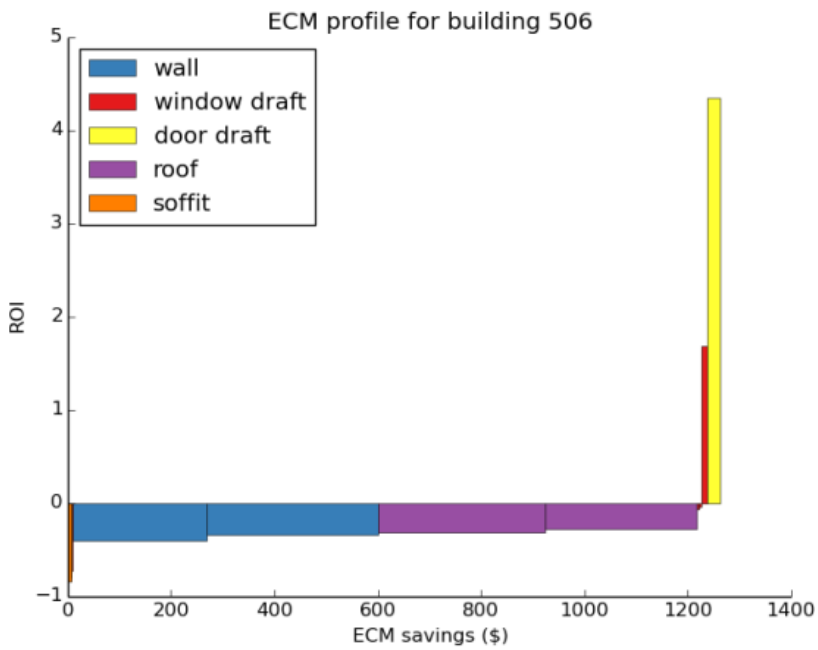

Figure E-43. ECM profile for Bldg 506, Scott AFB.

Table E-16 lists the recommended envelope ECMs for Bldg 506, Scott AFB.

Table E-16. Envelope ECMs for Bldg 506, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Roof Insulation	417	1005	616	13231	21.5
Improve Wall Insulation	400	967	593	14098	23.8
Seal Door Frame Leaks	16	39	24	66	2.8
Seal Window Frame Leaks	14	33	20	197	9.9

Annual potential remediation savings for this building are $1,253 and total payback is 22 years for envelope-related ECMs.

E.1.9.4 Non-Envelope ECMs for Bldg 506, Scott AFB

Table E-17 lists the recommended non-envelope ECMs for Bldg 506, Scott AFB.

Table E-17. Non-envelope ECMs for Bldg 506, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	71831	-934	3843	51670	13.4
Occupancy Sensors	32212	-419	1723	1727	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	310	155	423	2.7

Annual potential remediation savings for this building are $6,611 and total payback is 8.4 years for non-envelope ECMs.

E.1.10 Bldg 548

E.1.10.1 Description of Bldg 548, Scott AFB

Name: Veh Maint Shop
Use Type: Misc.
Square Footage: 34,793
Avg. Daily Electric Use: 7,334 kWh
Avg. Daily Gas Use: 117.1 therms
Electricity Score: 90th Percentile
Gas Score: 95th Percentile
Annual Cooling Load: 131,125 kWhrs
Annual Heating Load: 39,990 therms

Bldg 548 (Figures E-44 and E-45) has a gas usage of 122,769 Btu/sq ft/yr and electricity usage of 76.9 kWh/sq ft/yr.

Figure E-44. Aerial view of Bldg 548, Scott AFB.

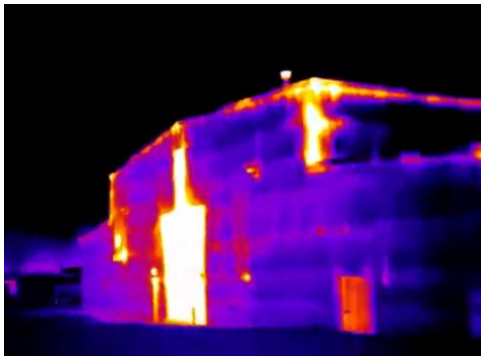

Figure E-45. Thermal image of Bldg 548, Scott AFB.

E.1.10.2 Notable Leaks at Bldg 548, Scott AFB

The wall surface at timestamp 75:36 (Figure E-46) has some large, highly emissive patches to the left of the large garage door. The corner of the wall shown in the middle of the image also seems to be poorly insulated.

Figure E-46. NIR image (left) and thermal image (right) of Bldg 548, Scott AFB. The large door, upper corner and soffit areas appear to be thermally inefficient.

The soffit at the top of the wall at timestamp 75:37 (Figure E-47) is highly emissive. The garage doors themselves are emitting a lot of heat, though this may be difficult to effectively remediate.

Figure E-47. NIR image (left) and thermal image (right) of Bldg 548, Scott AFB. The garage doors and soffit areas appear to be thermally inefficient.

E.1.10.3 Envelope ECMs for Bldg 548, Scott AFB

Figure E-48 shows the relative ROI for envelope ECMs for Bldg 548, Scott AFB.

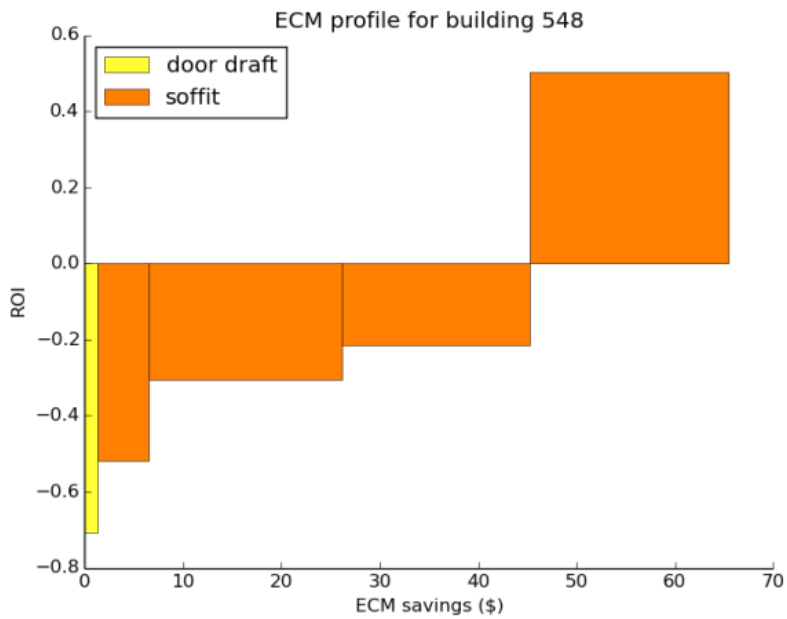

Figure E-48. ECM profile for Bldg 548, Scott AFB.

Table E-18 lists the recommended envelope ECMs for Bldg 548, Scott AFB.

Table E-18. Envelope ECMs for Bldg 548, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Soffit Insulation	14	33	20	202	10.0

Annual potential remediation savings for this building are $20 and total payback is 10 years for envelope-related ECMs.

E.1.10.4 Non-Envelope ECMs for Bldg 548, Scott AFB

Table E-19 lists the recommended non-envelope ECMs for Bldg 548, Scott AFB.

Table E-19. Non-envelope ECMs for Bldg 548, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	72340	-941	3870	52036	13.4
Occupancy Sensors	32440	-422	1735	1739	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	640	320	426	1.3

Annual potential remediation savings for this building are $6,815 and 8.2 years for non-envelope ECMs.

E.1.11 Bldg 700

E.1.11.1 Description of Bldg 700, Scott AFB

Name: Visual Info Service Center
Use Type: Office
Square Footage: 51,782
Avg. Daily Electric Use: 1,016 kWh
Avg. Daily Gas Use: Not Provided
Electricity Score: 35th Percentile
Gas Score: N/A
Annual Cooling Load: N/A
Annual Heating Load: N/A

Bldg 700 (Figures E-49 and E-50) has an electricity usage of 7.1 kWh/sq ft/yr.

Figure E-49. Aerial view of Bldg 700, Scott AFB.

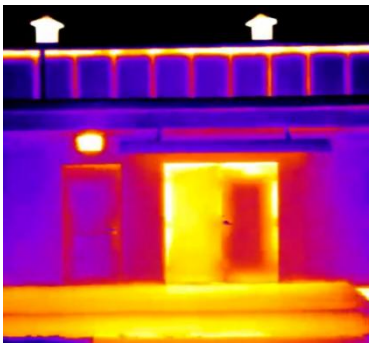

Figure E-50. Thermal image of Bldg 700, Scott AFB.

E.1.11.2 Notable Leaks at Bldg 700, Scott AFB

Figure E-51 shows a patch of wall that appears to have poor insulation relative to the surrounding wall at timestamp 229:04.

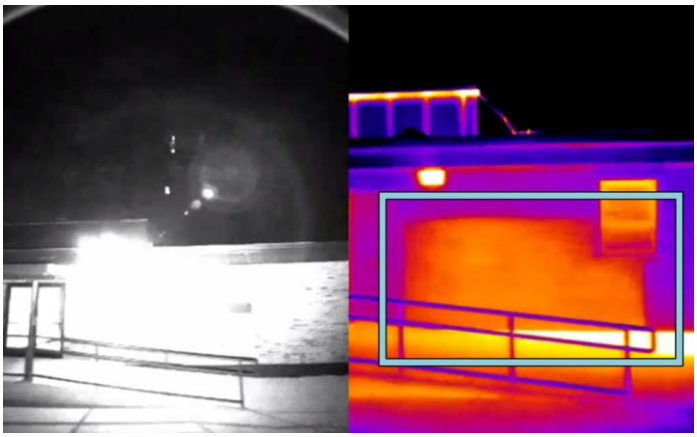

Figure E-51. NIR image (left) and thermal image (right) of Bldg 700, Scott AFB. This wall section appears to be highly emissive.

Figure E-52 shows another similar patch of poorly insulated wall shows up at timestamp 229:06.

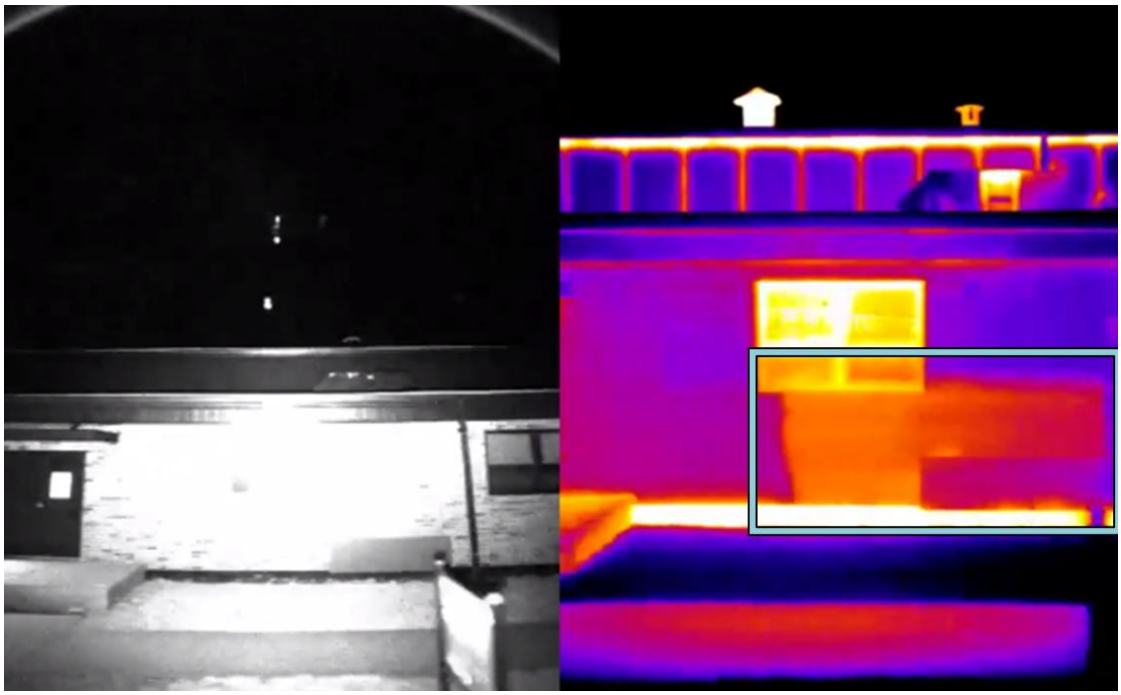

Figure E-52. NIR image (left) and thermal image (right) of Bldg 700, Scott AFB. Another wall section appears to be highly emissive.

Figure E-53 shows that the door at timestamp 229:07 has a highly emissive frame, and that the left part of the door seems to be much more poorly insulated in general than the right.

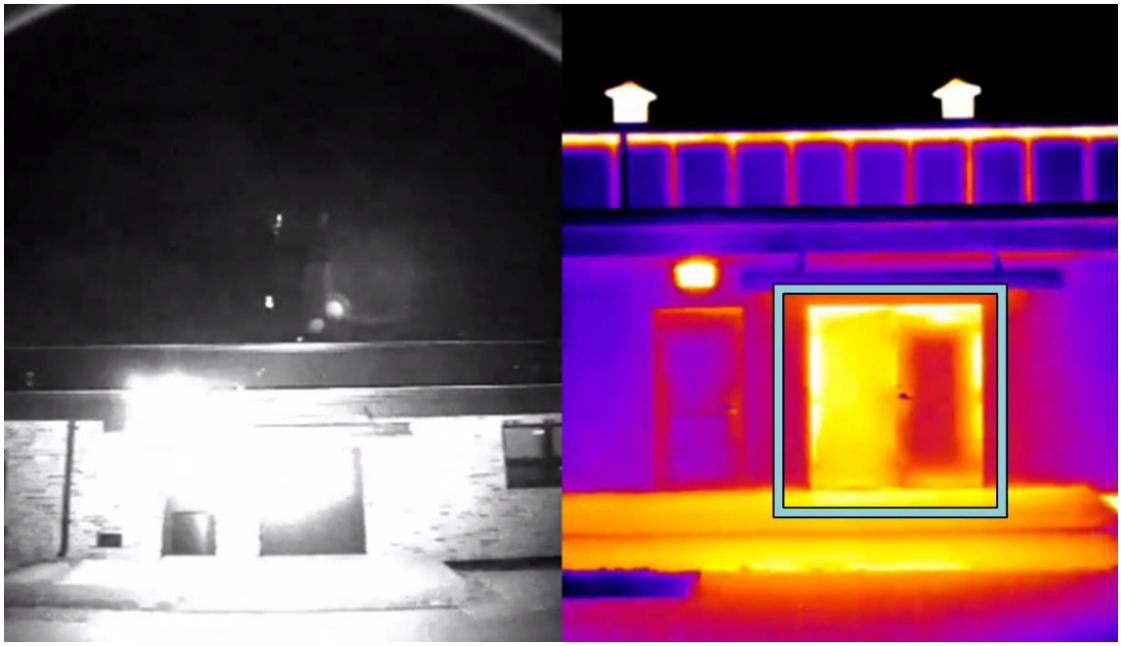

Figure E-53. NIR image (left) and thermal image (right) of Bldg 700, Scott AFB. The door frame and door panel appear to be highly emissive.

Figure E-54 shows another large patch of relatively poorly insulated wall visible at timestamp 229:12, which is particularly noticeable when compared to the area between the two windows.

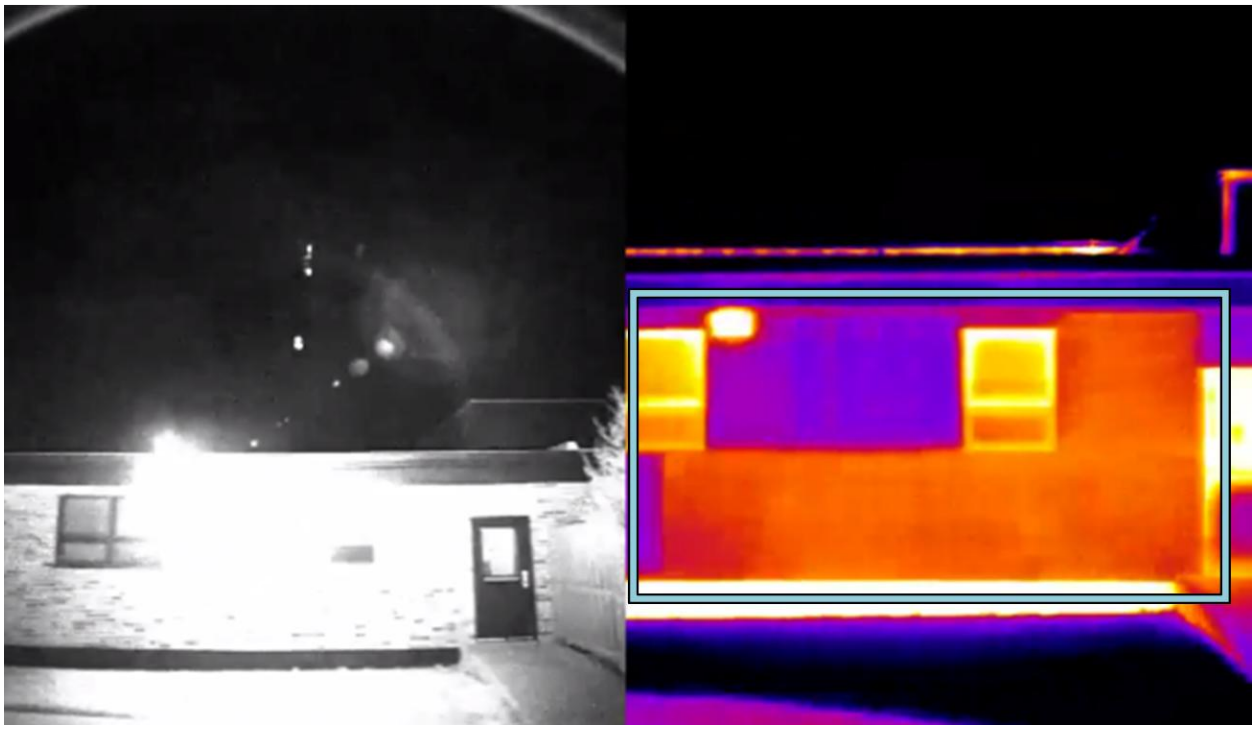

Figure E-54. NIR image (left) and thermal image (right) of Bldg 700, Scott AFB. This wall section appears to be thermally inefficient.

E.1.11.3 Envelope ECMs for Bldg 700, Scott AFB

Figure E-55 shows the relative ROI for envelope ECMs for Bldg 700, Scott AFB.

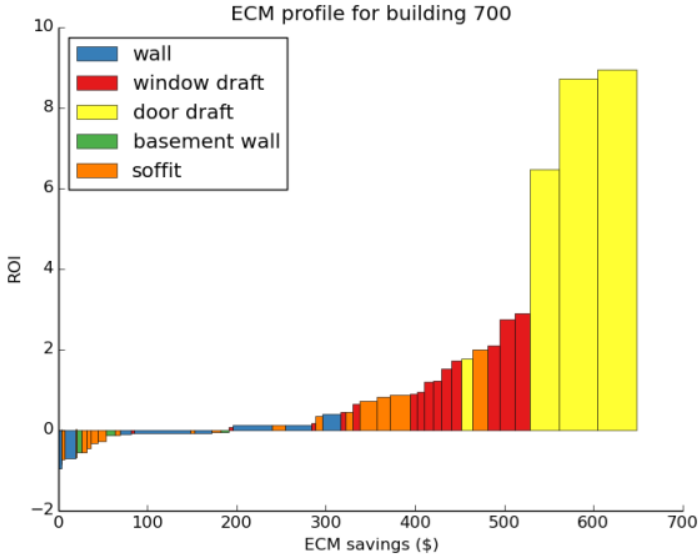

Figure E-55. ECM profile for Bldg 700, Scott AFB.

Table E-20 lists the recommended envelope ECMs for Bldg 700, Scott AFB.

Table E-20. Envelope ECMs for Bldg 700, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Door Frame Leaks	89	214	131	264	2.0
Seal Window Frame Leaks	87	210	129	854	6.6
Improve Soffit Insulation	70	170	104	927	8.9
Improve Wall Insulation	63	151	93	1199	12.9

Annual potential remediation savings for this building are $457 and total payback is 7.1 years for envelope-related ECMs.

E.1.11.4 Non-Envelope ECMs for Bldg 700, Scott AFB

Table E-21 lists the recommended non-envelope ECMs for Bldg 700, Scott AFB.

Table E-21. Non-envelope ECMs for Bldg 700, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	107663	-1400	5760	77445	13.4
Occupancy Sensors	48280	-628	2583	2588	1.0
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	3684	0	221	500	2.3

Annual potential remediation savings for this building are $9,453 and total payback is 8.7 years for non-envelope ECMs.

E.1.12 Bldg 755

E.1.12.1 Description of Bldg 755, Scott AFB

Name: Security Forces
Use Type: Office
Square Footage: 35,900
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 39.8 therms
Electricity Score: N/A
Gas Score: 60th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 10,087 therms
Gas Usage: 40,442 Btu/sq ft/yr.

Bldg 755 (Figures E-56 and E-57) has a gas usage of 40,442 Btu per square foot per year.

Figure E-56. Aerial view of Bldg 755, Scott AFB.

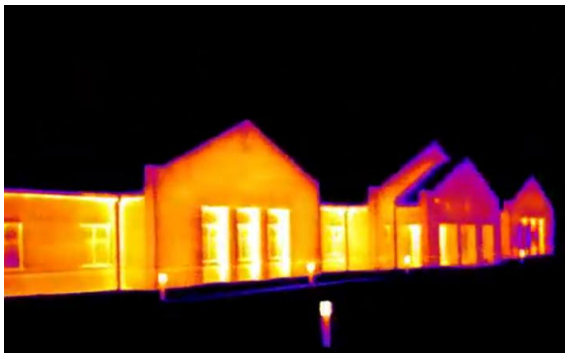

Figure E-57. IR image of Bldg 755, Scott AFB.

E.1.12.2 Notable Leaks at Bldg 755, Scott AFB

There is a suspicious hotspot in the corner of the wall around timestamp 89:07 that may indicate a poorly insulated location (Figure E-58).

Figure E-58. NIR image (left) and thermal image (right) of Bldg 755, Scott AFB. A particularly emissive area is in the rectangle at the right.

The wall at timestamp 89:18 is fairly emissive, and there is a horizontal thermal bridge visible above the windows (Figure E-59).

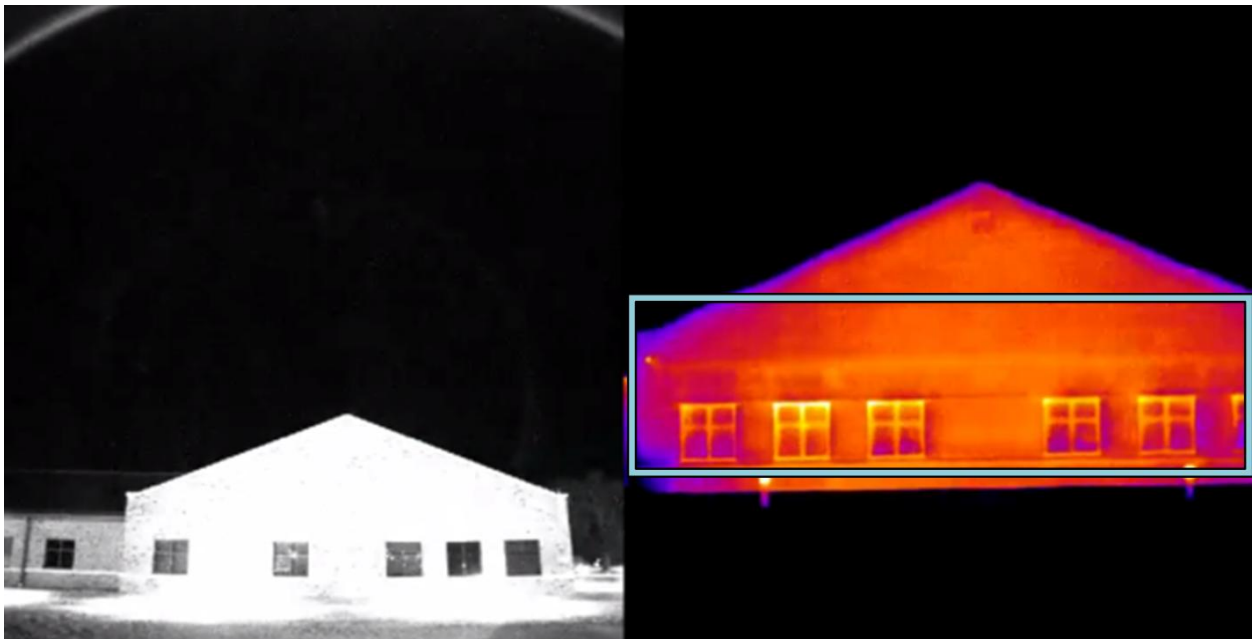

Figure E-59. NIR image (left) and thermal image (right) of Bldg 755, Scott AFB.

The wall around timestamp 89:34 is also highly emissive, with particular bright spots along window frames in the middle of the image (Figure E-60).

Figure E-60. NIR image (left) and thermal image (right) of Bldg 755, Scott AFB. The window frames appear to be particularly emissive.

E.1.12.3 Envelope ECMs for Bldg 755, Scott AFB

Figure E-61 shows the relative ROI for envelope ECMs for Bldg 700, Scott AFB.

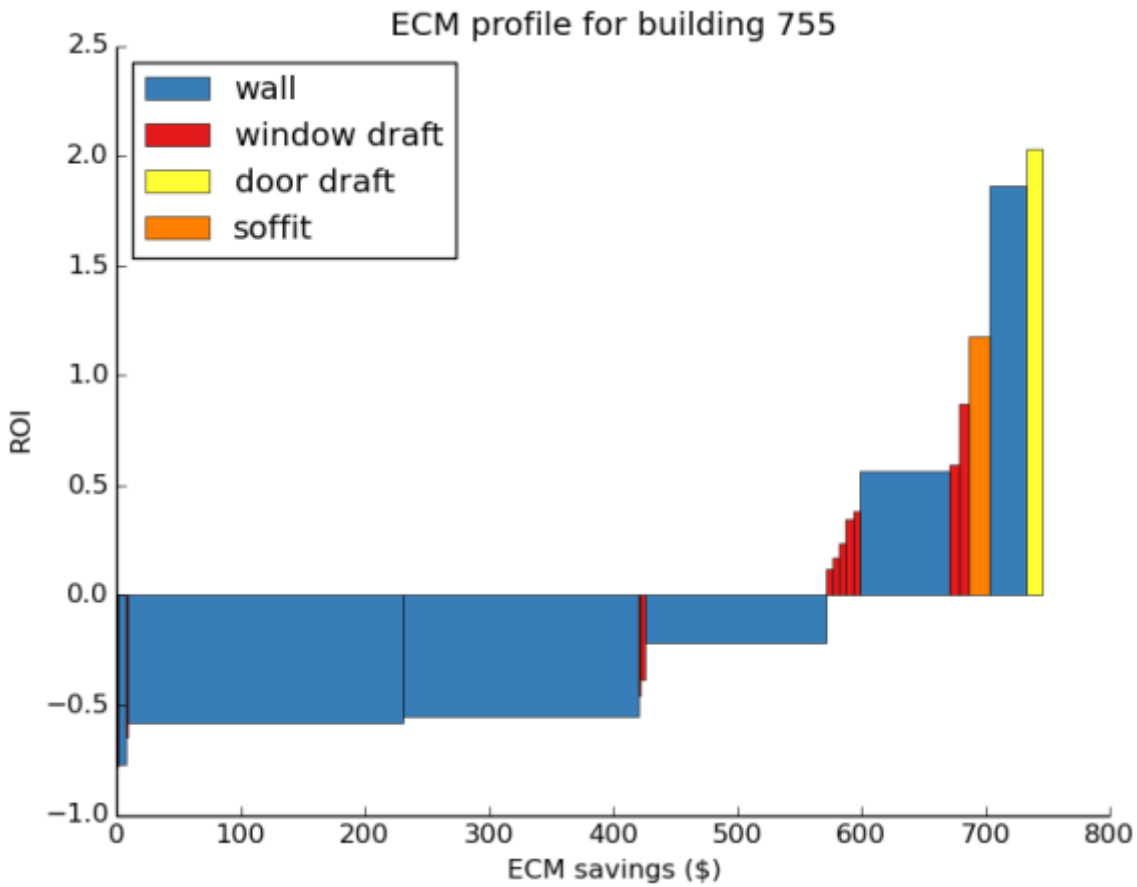

Figure E-61. ECM profile for Bldg 755, Scott AFB.

Table E-22 lists the recommended envelope ECMs for Bldg 755, Scott AFB.

Table E-22. Envelope ECMs for Bldg 755, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	69	166	102	847	8.3
Seal Window Frame Leaks	29	69	43	460	10.8
Improve Soffit Insulation	11	27	16	112	6.9
Seal Door Frame Leaks	9	22	13	66	5.0

Annual potential remediation savings for this building are $174 and total payback is 8.5 years for envelope-related ECMs.

E.1.12.4 Non-Envelope ECMs for Bldg 755, Scott AFB

Table E-23 lists the recommended non-envelope ECMs for Bldg 755, Scott AFB.

Table E-23. Non-envelope ECMs for Bldg 755, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	74642	-971	3993	53692	13.4
Occupancy Sensors	33472	-435	1791	1794	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	161	81	439	5.4

Annual potential remediation savings for this building are $6,754 and total payback is 8.6 years for non-envelope ECMs.

E.1.13 Bldg 861

E.1.13.1 Description of Bldg 861, Scott AFB

Name: HQ AMC/CSS
Use Type: Office
Square Footage: 42,529
Avg. Daily Electric Use: 1,108 kWh
Avg. Daily Gas Use: 21 therms
Electricity Score: 45th Percentile
Gas Score: 10th Percentile
Annual Cooling Load: 162,979 kWhrs
Annual Heating Load: 9,068 therms

Bldg 861 (Figures E-62 and E-63) has a gas usage of 18,011 Btu/sq ft/yr and electricity usage of 9.5 kWh/sq ft/yr.

Figure E-62. Aerial view of Bldg 861, Scott AFB.

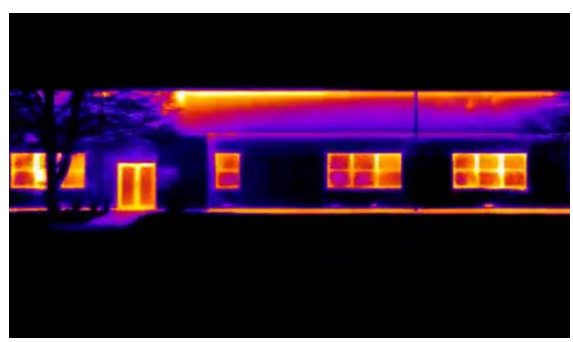

Figure E-63. Thermal image of Bldg 861, Scott AFB.

E.1.13.2 Notable Leaks at Bldg 861, Scott AFB

The roof at timestamp 223:10 is losing significant energy when compared to the rest of the building (Figure E-64).

Figure E-64. NIR image (left) and thermal image (right) of Bldg 861, Scott AFB. Significant heat loss appears to be shown at the roof line.

The roof at timestamp 223:25 is also notably emissive while the rest of the building is not particularly emissive (Figure E-65).

Figure E-65. NIR image (left) and thermal image (right) of Bldg 861, Scott AFB. Another view of apparent heat loss at the roof line.

E.1.13.3 Envelope ECMs for Bldg 861, Scott AFB

Figure E-66 shows the relative ROI for envelope ECMs for Bldg 861, Scott AFB.

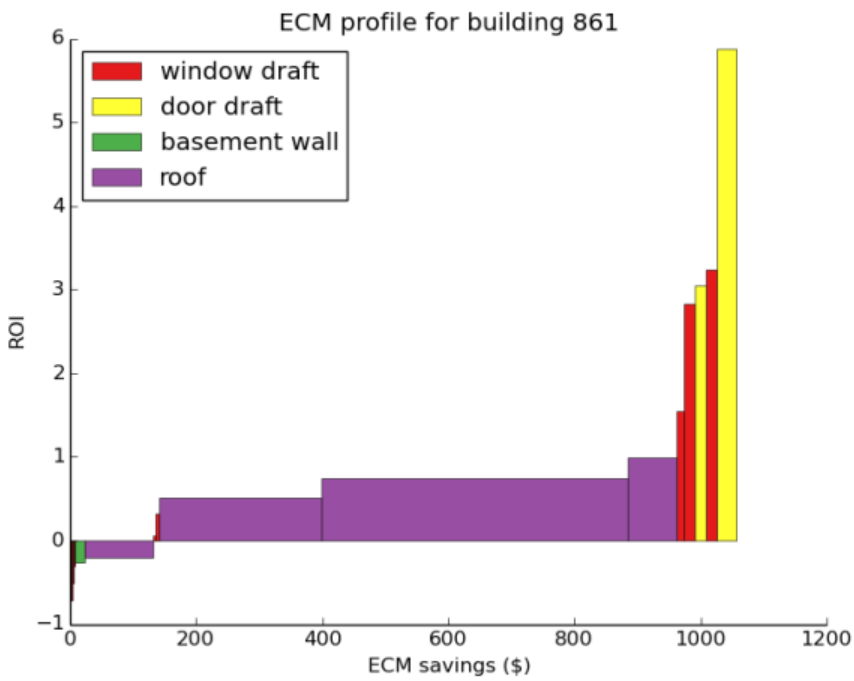

Figure E-66. ECM profile for Bldg 861, Scott AFB.

Table E-24 lists the recommended envelope ECMs for Bldg 861, Scott AFB.

Table E-24. Envelope ECMs for Bldg 861, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Roof Insulation	555	1337	820	7314	8.9
Seal Window Frame Leaks	39	93	57	331	5.8
Seal Door Frame Leaks	33	78	48	132	2.8

Annual potential remediation savings for this building are $925 and total payback is 8.4 years for envelope-related ECMs.

E.1.13.4 Non-Envelope ECMs for Bldg 861, Scott AFB

Table E-25 lists the recommended non-envelope ECMs for Bldg 861, Scott AFB.

Table E-25. Non-envelope ECMs for Bldg 861, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	88424	-1150	4730	63606	13.4
Occupancy Sensors	39653	-516	2121	2126	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	145	73	521	7.2

Annual potential remediation savings for this building are $7,814 and total payback is 8.7 years for non-envelope ECMs.

E.1.14 Bldg 1512

E.1.14.1 Description of Bldg 1512, Scott AFB

Name: Dorm VOQ
Use Type: Multifamily
Square Footage: 22,932
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 24.1 therms
Electricity Score: N/A
Gas Score: 35th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 6,147 therms

Bldg 1512 (Figures E-67 and E-68) has a gas usage of 38,288 Btu/sq ft/yr.

Figure E-67. Aerial view of Bldg 1512, Scott AFB.

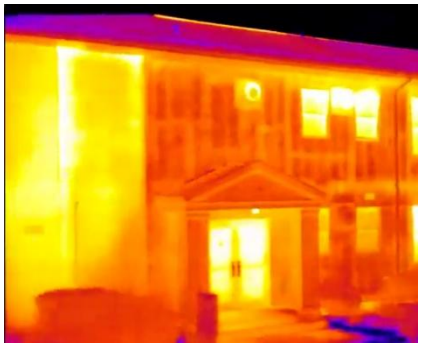

Figure E-68. Thermal image of Bldg 1512, Scott AFB.

E.1.14.2 Notable Leaks at Bldg 1512, Scott AFB

There are notable insulation gaps and thermal bridges along the surface of the wall at timestamp 134:08 (Figure E-69). The entire wall is poorly insulated. The area above the second floor windows also appears to be lacking insulation.

Figure E-69. NIR image (left) and thermal image (right) of Bldg 1512, Scott AFB. The doors and windows appear to be highly emissive.

E.1.14.3 Envelope ECMs for Bldg 1512, Scott AFB

Figure E-70 shows the relative ROI for envelope ECMs for Bldg 1512, Scott AFB.

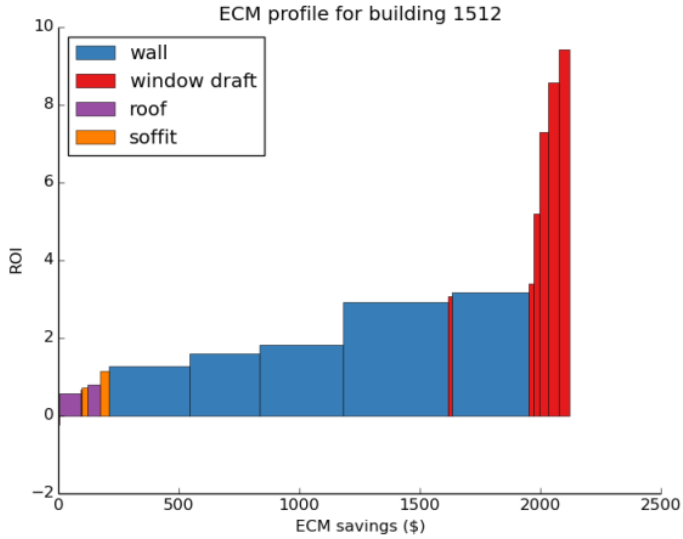

Figure E-70. ECM profile for Bldg 1512, Scott AFB.

Table E-26 lists the recommended Envelope ECMs for Bldg 1512, Scott AFB.

Table E-26. Envelope ECMs for Bldg 1512, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1166	2807	1721	8546	5.0
Seal Window Frame Leaks	132	318	195	460	2.4
Improve Roof Insulation	96	232	142	1295	9.1
Improve Soffit Insulation	40	96	59	448	7.6

Annual potential remediation savings for this building are $2,117 and total payback is 5.1 years for envelope-related ECMs.

E.1.14.4 Non-Envelope ECMs for Bldg 1512, Scott AFB

Table E-27 lists the recommended non-envelope ECMs for Bldg 1512, Scott AFB.

Table E-27. Non-envelope ECMs for Bldg 1512, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Programmable Thermostats	351	381	212	75	0.4
Replace Incandescent Bulbs with CFLs	3751	-85	183	482	2.6
Low Flow Showerhead	0	214	107	183	1.7
Smartstrips	864	0	52	306	5.9

Annual potential remediation savings for this building are $553 and total payback is 1.9 years for non-envelope ECMs.

E.1.15 Bldg 1521

E.1.15.1 Description of Bldg 1521, Scott AFB

Name: HQ AMC
Use Type: Office
Square Footage: 51,315
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 73.8 therms
Electricity Score: N/A
Gas Score: 70th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 12,752 therms

Bldg 1521 (Figures E-71 and E-72) was imaged early in the evening, and while the walls appear highly emissive in thermal images much of this is likely due to residual solar heat. Once the surface temperature has been normalized for observation time, mitigation potential from insulation improvements is relatively small.

Bldg 1521 has a gas usage of 52,465 Btu/sq ft/yr.

Figure E-71. Aerial view of Bldg 1521, Scott AFB.

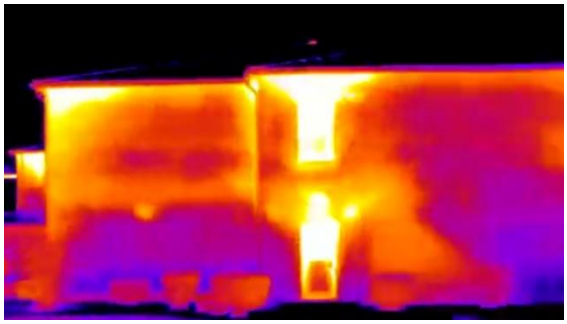

Figure E-72. Thermal image of Bldg 1521, Scott AFB.

E.1.15.2 Notable Leaks at Bldg 1521, Scott AFB

The wall near the beginning of the drive-by video for Bldg 1521 shows highly emissive portions of the brick wall, which indicates poor insulation (Figure E-73). As seen in other buildings, there is heat loss on top of both windows.

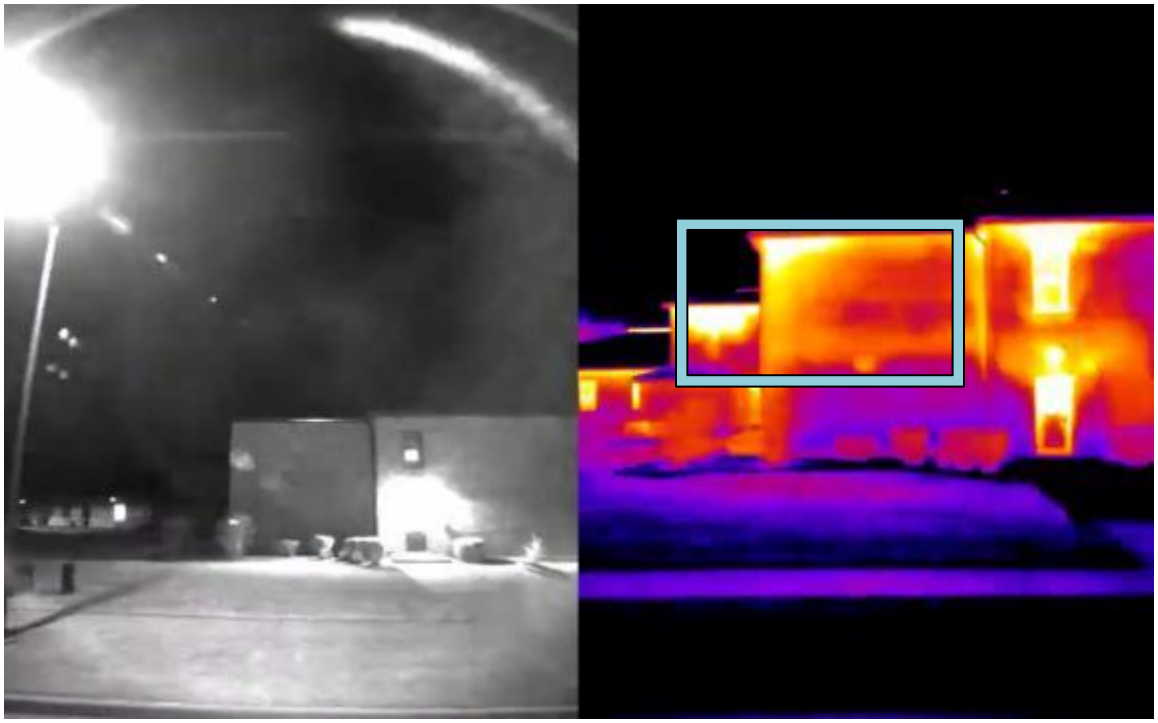

Figure E-73. NIR image (left) and thermal image (right) of Bldg 1521, Scott AFB. A highly emissive wall section is shown in the box to the right.

Near the end of the building video there is a highly emissive wall, which also indicates poor insulation (Figure E-74).

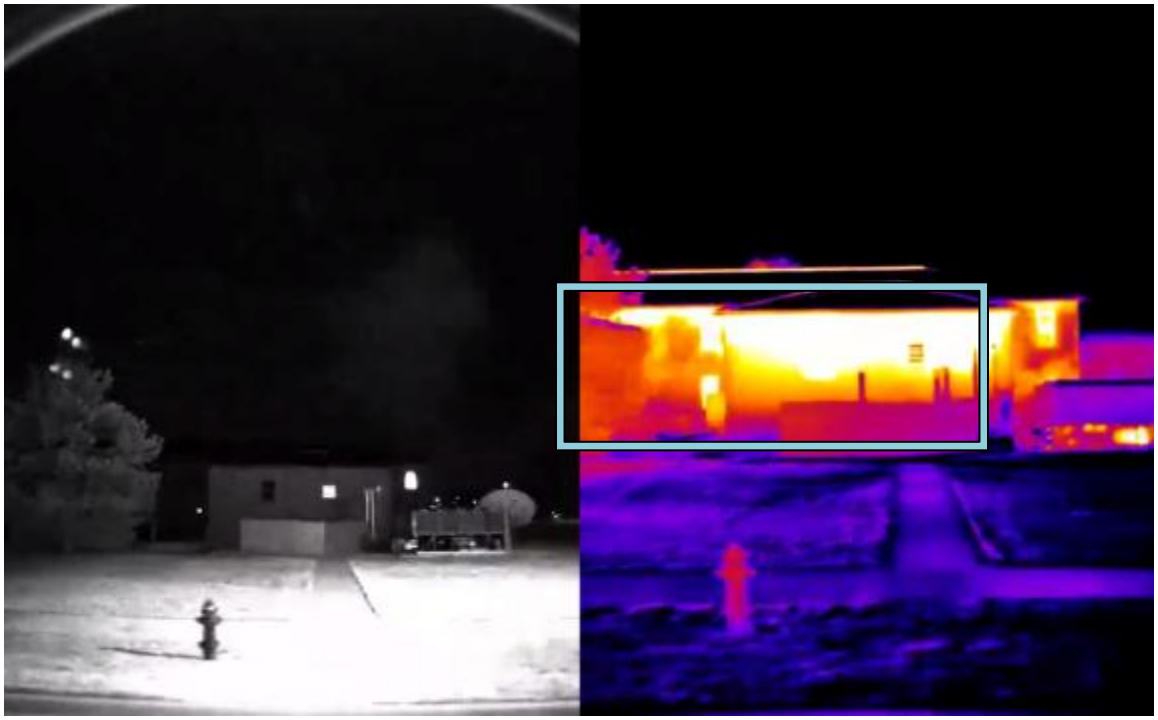

Figure E-74. NIR image (left) and thermal image (right) of Bldg 1521, Scott AFB. Another highly emissive wall section is shown.

E.1.15.3 Envelope ECMs for Bldg 1521, Scott AFB

Figure E-75 shows the relative ROI for envelope ECMs for Bldg 1521, Scott AFB.

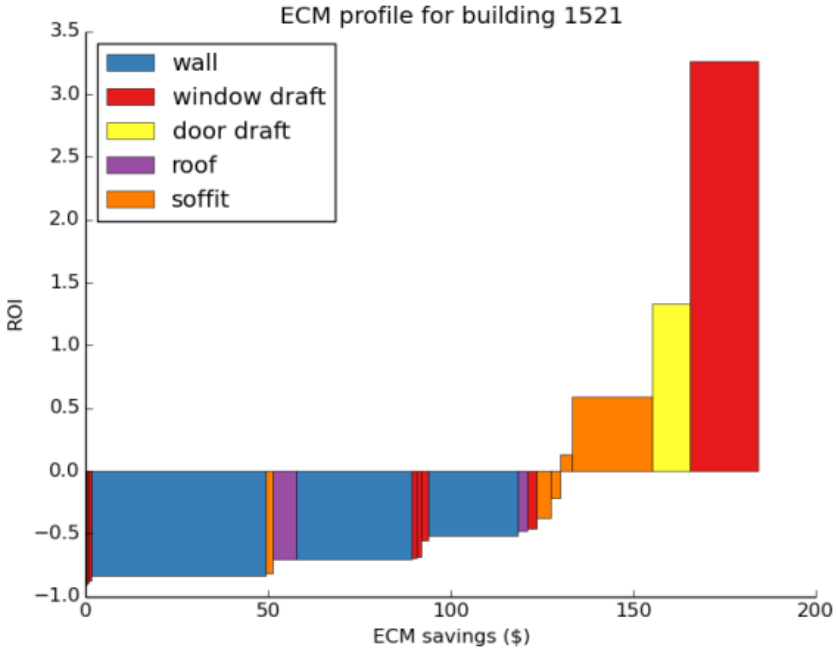

Figure E-75. ECM profile for Bldg 1521, Scott AFB.

Table E-28 lists the recommended envelope ECMs for Bldg 1521, Scott AFB.

Table E-28. Envelope ECMs for Bldg 1521, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Soffit Insulation	17	41	25	251	9.9
Seal Window Frame Leaks	13	30	19	65	3.5
Seal Door Frame Leaks	7	17	10	67	6.4

Annual potential remediation savings for this building are $54 and total payback is 7.1 years for envelope-related ECMs.

E.1.15.4 Non-Envelope ECMs for Bldg 1521, Scott AFB

Table E-29 lists the recommended non-envelope ECMs for Bldg 1521, Scott AFB.

Table E-29. Non-envelope ECMs for Bldg 1521, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	106692	-1388	5708	76746	13.4
Occupancy Sensors	47845	-622	2559	2565	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	204	102	628	6.2

Annual potential remediation savings for this building are $9,259 and total payback is 8.8 years for non-envelope ECMs.

E.1.16 Bldg 1529

E.1.16.1 Description of Bldg 1529, Scott AFB

Name: Aeromed Stg Fclty
Use Type: Misc
Square Footage: 34,028
Avg. Daily Electric Use: 4,694 kWh
Avg. Daily Gas Use: 1.4 therms
Electricity Score: 100th Percentile
Gas Score: 0th Percentile
Annual Cooling Load: 910,825 kWhrs
Annual Heating Load: 487 therms

Bldg 1529 (Figures E-76 and E-77) has a gas usage of 1,509 Btu/sq ft/yr and electricity usage of 50.3 kWh/sq ft/yr.

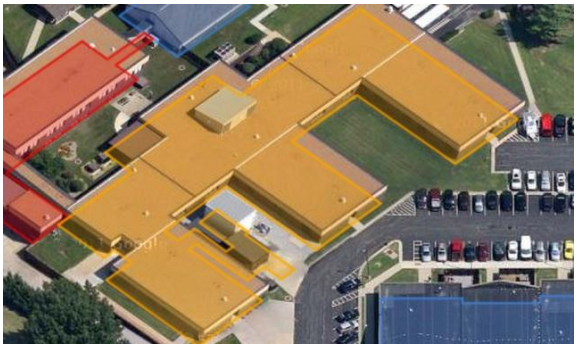

Figure E-76. Aerial view of Bldg 1529, Scott AFB.

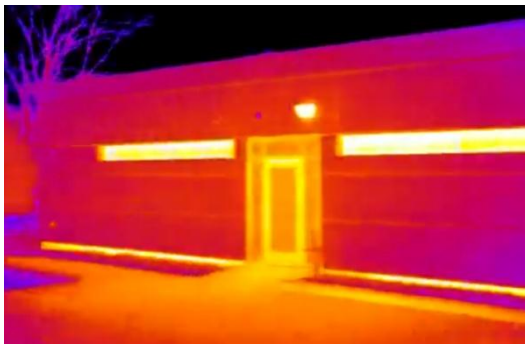

Figure E-77. Thermal image of Bldg 1529, Scott AFB.

E.1.16.2 Notable Leaks at Bldg 1529, Scott AFB

At timestamp 145:53 in the Drive-by Application there is a very emissive loading bay door and entryway (Figure E-78). This is one of the most emissive buildings on the entire base. This building should be investigated for insulation problems and insulation should be added to the entire loading bay.

Figure E-78. NIR image (left) and thermal image (right) of Bldg 1529, Scott AFB.

E.1.16.3 Envelope ECMs for Bldg 1529, Scott AFB

Figure E-79 shows the relative ROI for envelope ECMs for Bldg 1529, Scott AFB.

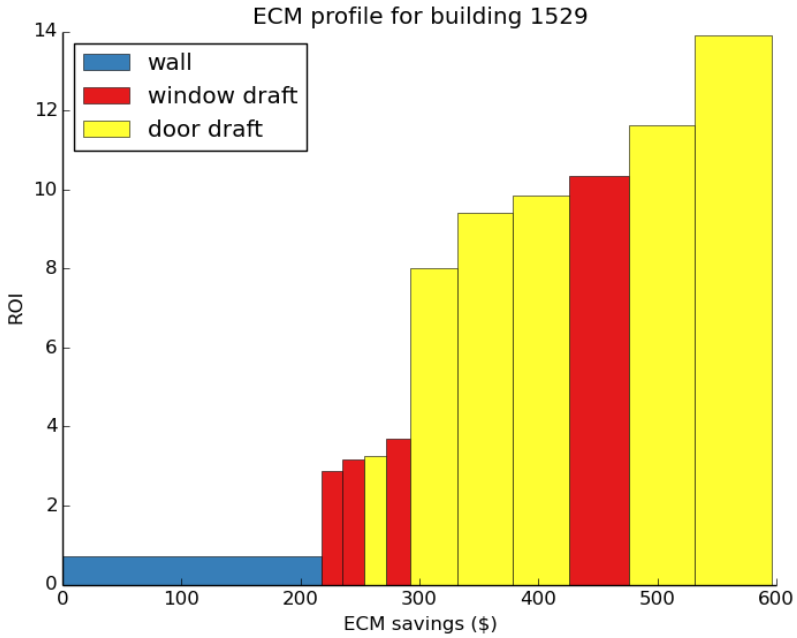

Figure E-79. ECM profile for Bldg 1529, Scott AFB.

Table E-30 lists the recommended envelope ECMs for Bldg 1529, Scott AFB.

Table E-30. Envelope ECMs for Bldg 1529, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Door Frame Leaks	185	444	273	396	1.5
Improve Wall Insulation	147	355	218	1891	8.7
Seal Window Frame Leaks	72	172	106	264	2.5

Annual potential remediation savings for this building are $596 and total payback is 4.3 years for envelope-related ECMs.

E.1.16.4 Non-Envelope ECMs for Bldg 1529, Scott AFB

Table E-31 lists the recommended non-envelope ECMs for Bldg 1529, Scott AFB.

Table E-31. Non-envelope ECMs for Bldg 1529, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	88467	-528	5044	50892	10.1
Occupancy Sensors	39672	-237	2262	1701	0.8
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	1842	0	111	500	4.5

Annual potential remediation savings for this building are $8,306 and total payback is 6.6 years for non-envelope ECMs.

E.1.17 Bldg 1575

E.1.17.1 Description of Bldg 1575, Scott AFB

Name: Comm Facility (NOSC)
Use Type: Office
Square Footage: 50,957
Avg. Daily Electric Use: 26,100 kWh
Avg. Daily Gas Use: 36.4 therms
Electricity Score: 100th Percentile
Gas Score: 30th Percentile
Annual Cooling Load: 274,624 kWhrs
Annual Heating Load: 15,346 therms

Bldg 1575 (Figures E-80 and E-81) has a gas usage of 26,072 Btu/sq ft/yr and electricity usage of 186.9 kWh/sq ft/yr.

Figure E-80. Aerial view of Bldg 1575, Scott AFB.

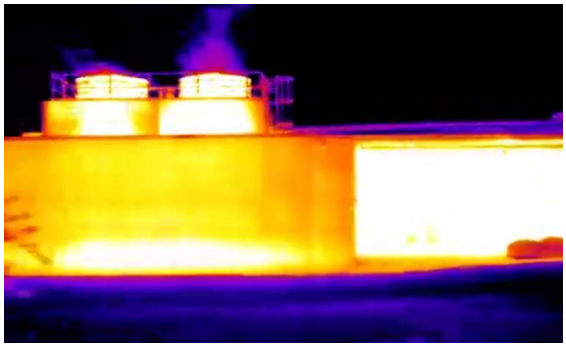

Figure E-81. Thermal image of Bldg 1575, Scott AFB.

E.1.17.2 Notable Leaks at Bldg 1575, Scott AFB

The walls of Bldg 1575, shown at timestamp 151:19, are so highly emissive in general that specific features are not visible (Figure E-82). This was the worst insulation problem of any building on the base. It is recommended to investigate the current insulation levels in the walls and the need to add insulation along the entire wall.

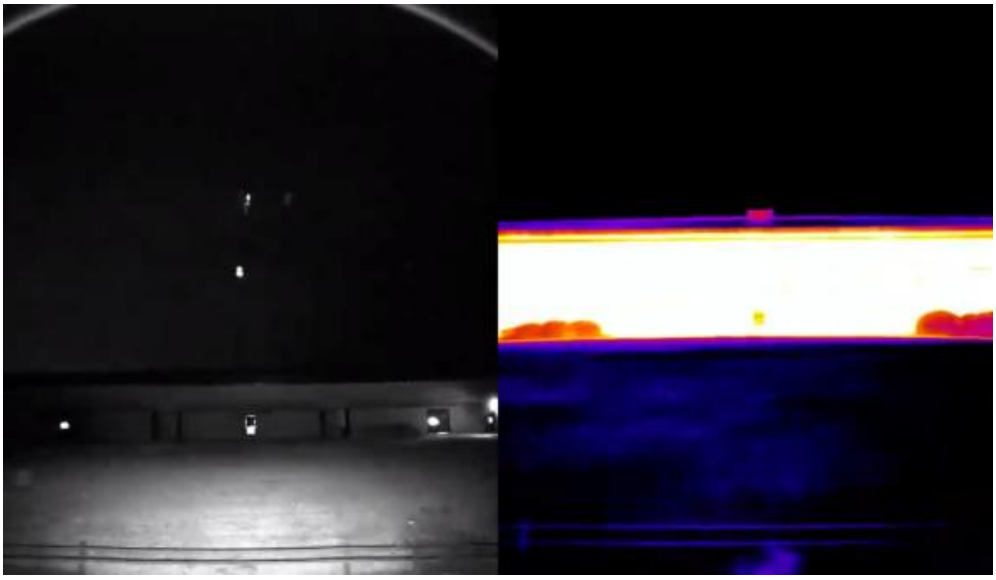

Figure E-82. NIR image (left) and thermal image (right) of Bldg 1575, Scott AFB.

E.1.17.3 Envelope ECMs for Bldg 1575, Scott AFB

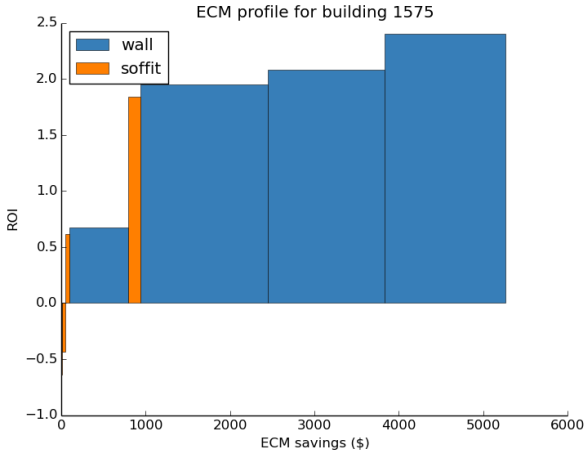

Figure E-83 shows the relative ROI for envelope ECMs for Bldg 1575, Scott AFB.

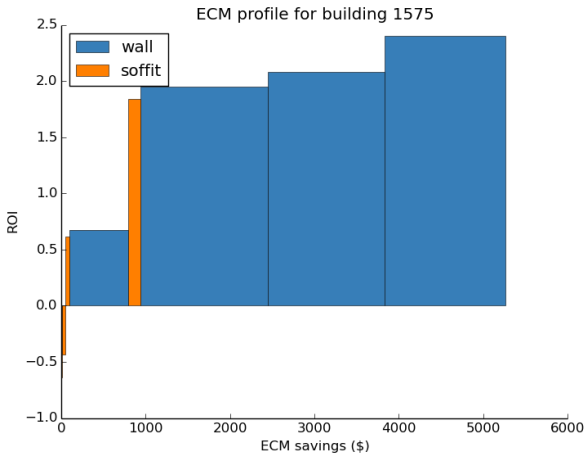

Figure E-83. ECM profile for Bldg 1575, Scott AFB.

Table E-32 lists the recommended envelope ECMs for Bldg 1575, Scott AFB.

Table E-32. Envelope ECMs for Bldg 1575, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	3403	8196	5026	26992	5.4
Improve Soffit Insulation	126	303	186	1138	6.1

Annual potential remediation savings for this building are $5,212 and total payback is 5.4 years for envelope-related ECMs.

E.1.17.4 Non-Envelope ECMs for Bldg 1575, Scott AFB

Table E-33 lists the recommended non-envelope ECMs for Bldg 1575, Scott AFB.

Table E-33. Non-envelope ECMs for Bldg 1575, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	105948	-1378	5668	76211	13.4
Occupancy Sensors	47511	-618	2542	2547	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	246	123	624	5.1

Annual potential remediation savings for this building are $9,222 and total payback is 8.8 years for non-envelope ECMs.

E.1.18 Bldg 1600

E.1.18.1 Description of Bldg 1600, Scott AFB

Name: HQ Major Cmd
Use Type: Office
Square Footage: 313,330
Avg. Daily Electric Use: 37,618 kWh
Avg. Daily Gas Use: 455.1 therms
Electricity Score: 95th Percentile
Gas Score: 80th Percentile
Annual Cooling Load: 549,164 kWhrs
Annual Heating Load: 31,865 therms

Bldg 1600 (Figures E-84 and E-85) has a gas usage of 52,999 Btu/sq ft/yr and electricity usage of 43.8 kWh/sq ft/yr.

Figure E-84. Aerial view of Bldg 1600, Scott AFB.

Figure E-85. Thermal image of Bldg 1600, Scott AFB.

E.1.18.2 Notable Leaks at Bldg 1600, Scott AFB

Bldg 1600 has particularly emissive striations between the windows in the lower part of the building, visible at timestamp 167:11 (Figure E-86). The thermal scan indicates insulation issues between windows for the first two floors of the building. This should be investigated to determine whether the cause is sagging insulation, low insulation, or areas with no insulation.

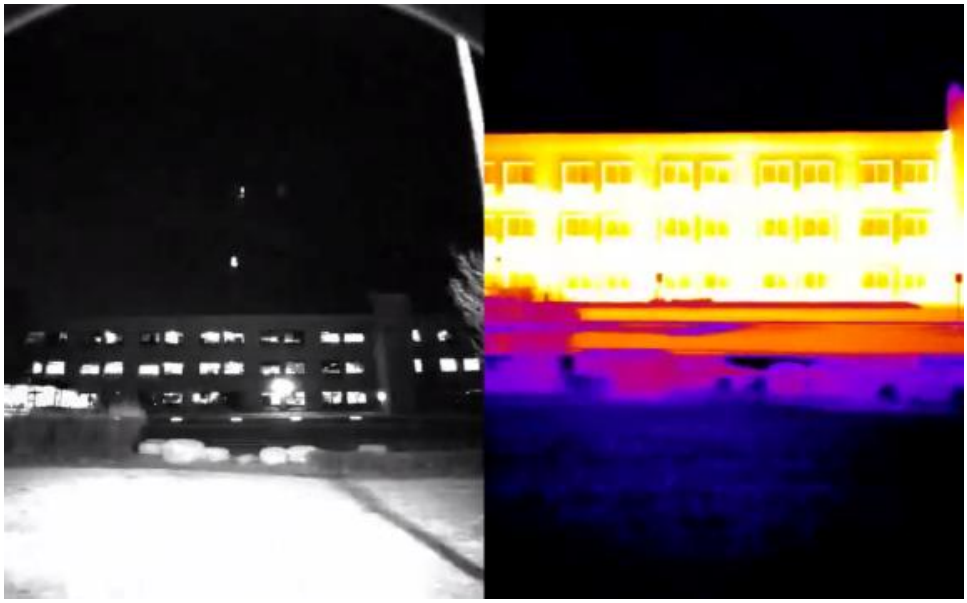

Figure E-86. NIR image (left) and thermal image (right) of Bldg 1600, Scott AFB.

E.1.18.3 Envelope ECMs for Bldg 1600, Scott AFB

Figure E-87 shows the relative ROI for envelope ECMs for Bldg 1600, Scott AFB.

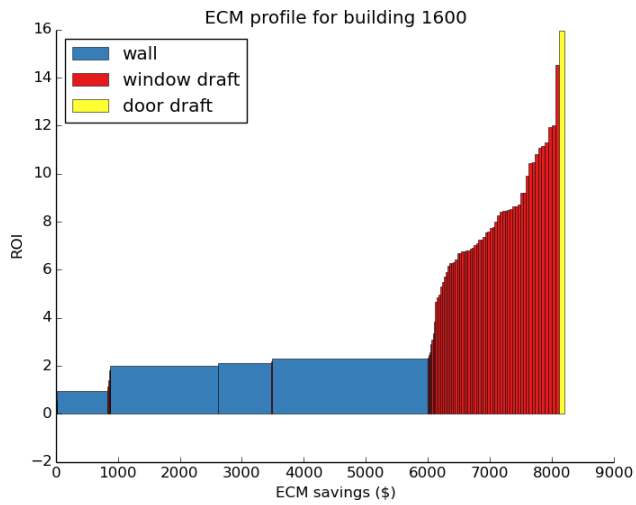

Figure E-87. ECM profile for Bldg 1600, Scott AFB.

Figure E-35 lists the recommended envelope ECMs for Bldg 1600, Scott AFB.

Table E-34. Envelope ECMs for Bldg 1600, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	4008	9648	5917	30557	5.2
Seal Window Frame Leaks	1489	3587	2200	4341	2.0
Seal Door Frame Leaks	51	122	75	66	0.9

Annual potential remediation savings for this building are $8,911 and total payback is 4.3 years for envelope-related ECMs.

E.1.18.4 Non-Envelope ECMs for Bldg 1600, Scott AFB

Table E-35 lists the recommended non-envelope ECMs for Bldg 1600, Scott AFB.

Table E-35. Non-envelope ECMs for Bldg 1600, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	651462	-8474	34851	468614	13.4
Occupancy Sensors	292140	-3800	15628	15660	1.0
EnergyStar Vending Machines	18420	0	1105	500	0.5
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $52474 and total payback is 9.3 years for non-envelope-related ECMs.

E.1.19 Bldg 1650

E.1.19.1 Description of Bldg 1650, Scott AFB

Name: Airman Family Readiness Center
Use Type: School
Square Footage: 72,205
Avg. Daily Electric Use: 1,619 kWh
Avg. Daily Gas Use: 47.9 therms
Electricity Score: 40th Percentile
Gas Score: 20th Percentile
Annual Cooling Load: 77,446 kWhrs
Annual Heating Load: 17,225 therms

Bldg 1650 (Figures E-88 and E-88) has a gas usage of 24,191 Btu/sq ft/yr and electricity usage of 8.2 kWh/sq ft/yr.

Figure E-88. Aerial view of Bldg 1650, Scott AFB.

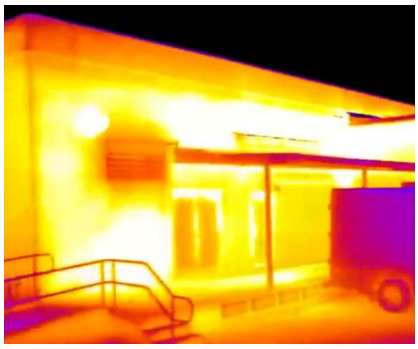

Figure E-89. Thermal image of Bldg 1650, Scott AFB.

E.1.19.2 Notable Leaks at Bldg 1650, Scott AFB

Notable emissive wall surfaces are visible at timestamp 161:21, to the left of the double doors and near the top of the building wall. This building wall has an insulation issue along with significant leaks around both the double doors and the single door to the right. The door energy loss can be remediated through weather-stripping.

Figure E-90. NIR image (left) and thermal image (right) of Bldg 1650, Scott AFB.

The door frame visible at timestamp 162:27 indicates convective leaks along the outer frame. The wall is also losing energy. This would also be a good candidate for adding insulation to the wall and weather-stripping to the door.

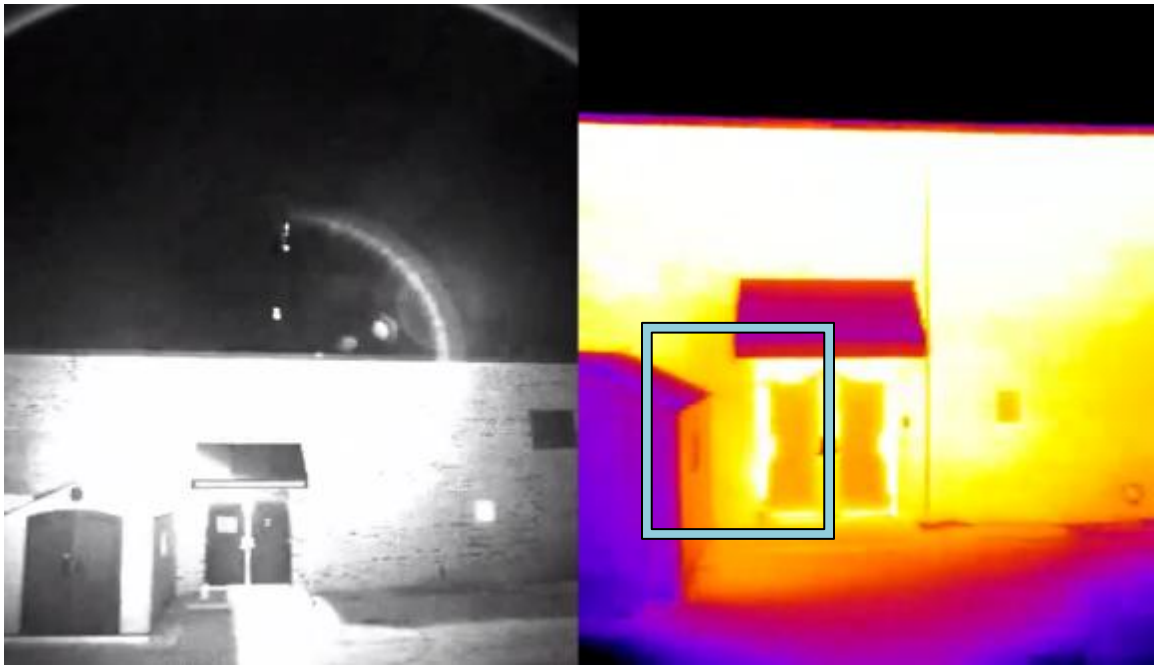

Figure E-91. NIR image (left) and thermal image (right) of Bldg 1650, Scott AFB. There appears to be significant energy loss around the door frame.

E.1.19.3 Envelope ECMs for Bldg 1650, Scott AFB

Figure E-92 shows the relative ROI for envelope ECMs for Bldg 1650, Scott AFB.

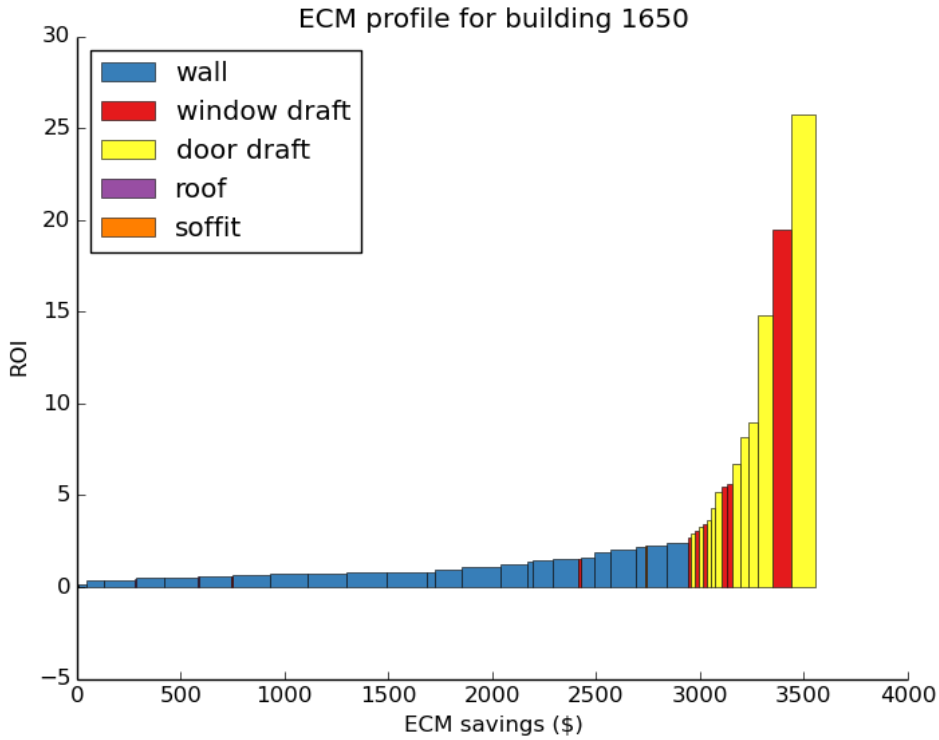

Figure E-92. ECM profile for Bldg 1650, Scott AFB.

Table E-36 lists the recommended envelope ECMs for Bldg 1650, Scott AFB.

Table E-36. Envelope ECMs for Bldg 1650, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1965	4731	2901	23218	8.0
Seal Door Frame Leaks	280	673	413	661	1.6
Seal Window Frame Leaks	148	358	219	527	2.4

Annual potential remediation savings for this building are $3,534 and total payback is 6.9 years for envelope-related ECMs.

E.1.19.4 Non-Envelope ECMs for Bldg 1650, Scott AFB

Table E-37 lists the recommended non-envelope ECMs for Bldg 1650, Scott AFB.

Table E-37. Non-envelope ECMs for Bldg 1650, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	186765	-2540	9936	136121	13.7
Occupancy Sensors	83753	-1139	4456	4549	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	276	138	884	6.4

Annual potential remediation savings for this building are $15,419 and total payback is 9.3 years for non-envelope ECMs.

E.1.20 Bldg 1900

E.1.20.1 Description of Bldg 1900, Scott AFB

Name: USTRANSCOMM
Use Type: Office
Square Footage: 335,771
Avg. Daily Electric Use: 30,958 kWh
Avg. Daily Gas Use: 150.4 therms
Electricity Score: 75th Percentile
Gas Score: 15th Percentile
Annual Cooling Load: 471,562 kWhrs
Annual Heating Load: 17,397 therms

Bldg 1900 (Figures E-93 and E-94) has a gas usage of 16,347 Btu/sq ft/yr and electricity usage of 33.7 kWh/sq ft/yr.

Figure E-93. Aerial view of Bldg 1900, Scott AFB.

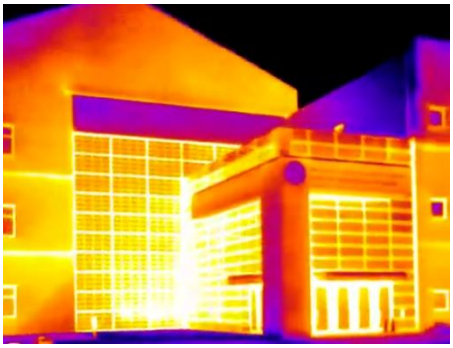

Figure E-94. Thermal image of Bldg 1900, Scott AFB.

E.1.20.2 Notable Leaks at Bldg 1900, Scott AFB

There are some large thermal bridges stretching both across the wall and from ground to roof around timestamp 34:58 (Figure E-95).

Figure E-95. NIR image (left) and thermal image (right) of Bldg 1900, Scott AFB.

Thermal bridges are also visible around the other side of the building at timestamp 35:22 (Figure E-96). The window frames are also fairly emissive. Window frame leaks can be addressed by caulking and weather-stripping. There is also a thermal bridge between the first and second floors and the second and third floor.

Figure E-96. NIR image (left) and thermal image (right) of Bldg 1900, Scott AFB. Thermal bridges are apparent between the rows of windows.

E.1.20.3 Envelope ECMs for Bldg 1900, Scott AFB

Figure E-97 shows the relative ROI for envelope ECMs for Bldg 1900, Scott AFB.

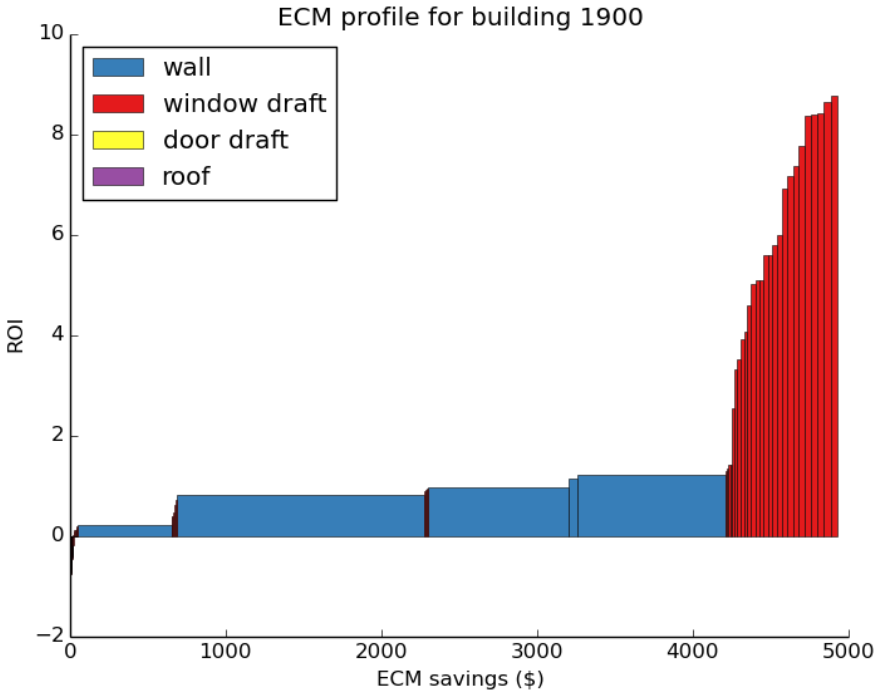

Figure E-97. ECM profile for Bldg 1900, Scott AFB.

E.1.20.4 Non-Envelope ECMs for Bldg 1900, Scott AFB

Table E-38 lists the recommended envelope ECMs for Bldg 1900, Scott AFB.

Table E-38. Non-envelope ECMs for Bldg 1900, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	2775	6690	4102	34463	8.4
Seal Window Frame Leaks	542	1306	801	2570	3.2

Annual potential remediation savings for this building are $4,903 and total payback is 7.6 years for envelope-related ECMs.

Table E-39 lists the recommended non-envelope ECMs for Bldg 1900, Scott AFB.

Table E-39. Non-envelope ECMs for Bldg 1900, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	698121	-9081	37347	502176	13.4
Occupancy Sensors	313063	-4072	16748	16782	1.0
EnergyStar Vending Machines	20262	0	1216	500	0.4
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $56,200 and total payback is 9.3 years for non-envelope ECMs.

E.1.21 Bldg 1961

E.1.21.1 Description of Bldg 1961, Scott AFB

Name: USTRANSCOMM Annex
Use Type: Office
Square Footage: 80,284
Avg. Daily Electric Use: 5,694 kWh
Avg. Daily Gas Use: 63.7 therms
Electricity Score: 60th Percentile
Gas Score: 50th Percentile
Annual Cooling Load: 614,284 kWhrs
Annual Heating Load: 18,071 therms

Bldg 1961 (Figures E-98 and E-99) serves as an interesting example of how energy use per square foot is not always a good predictor of leakiness or remediation potential. The building is perhaps the most obviously incompletely insulated building on the base, with numerous large hot spots scattered all over the exterior. However, its gas score only puts it in the 50th percentile, meaning that about half the buildings of a similar square footage have higher gas usage per square foot. The electricity use is a similarly middling 60th percentile.

Bldg 1961 has a gas usage of 28,960 Btu/sq ft/yr and electricity usage of 25.9 kWh/sq ft/yr.

Figure E-98. Aerial view of Bldg 1961, Scott AFB.

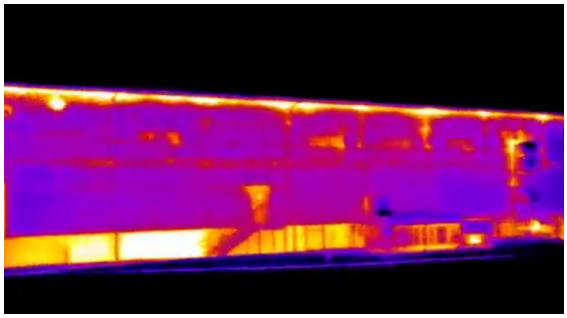

Figure E-99. Thermal image of Bldg 1961, Scott AFB.

E.1.21.2 Notable Leaks at Bldg 1961, Scott AFB

There is a sizable patch of poorly insulated wall on the second story of the building around timestamp 42:55. The soffit also appears to be highly emissive (Figure E-100).

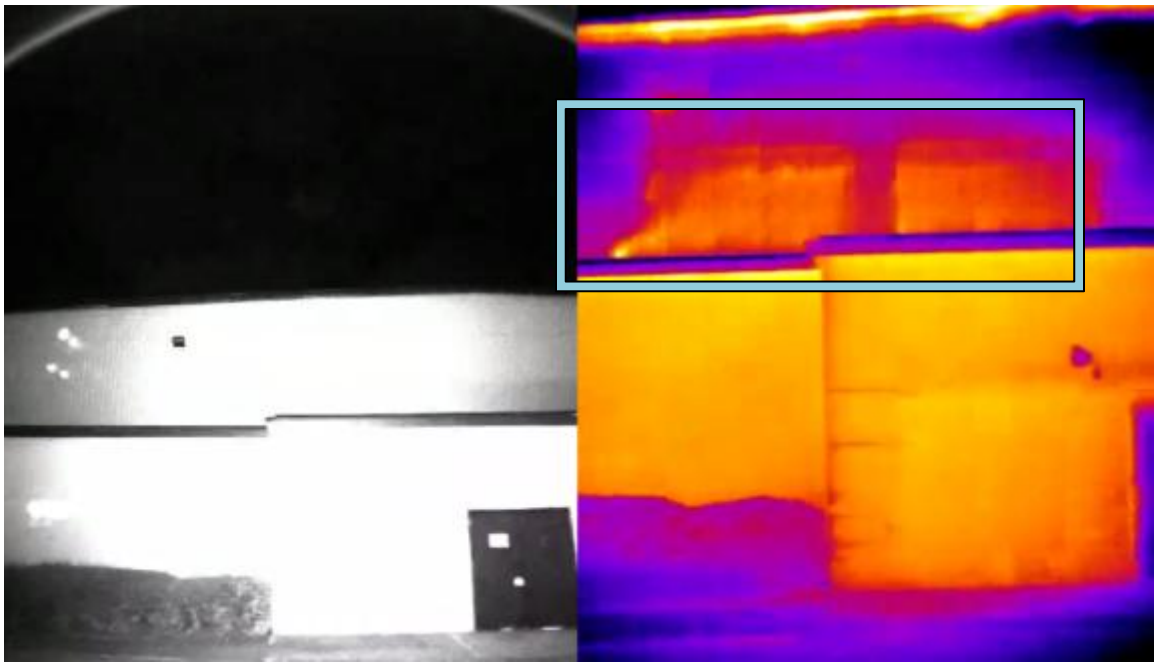

Figure E-100. NIR image (left) and thermal image (right) of Bldg 1961, Scott AFB.

There are numerous wall insulation gaps around the back of the building around timestamp 43:11, as well as a leaky soffit (Figure E-101).

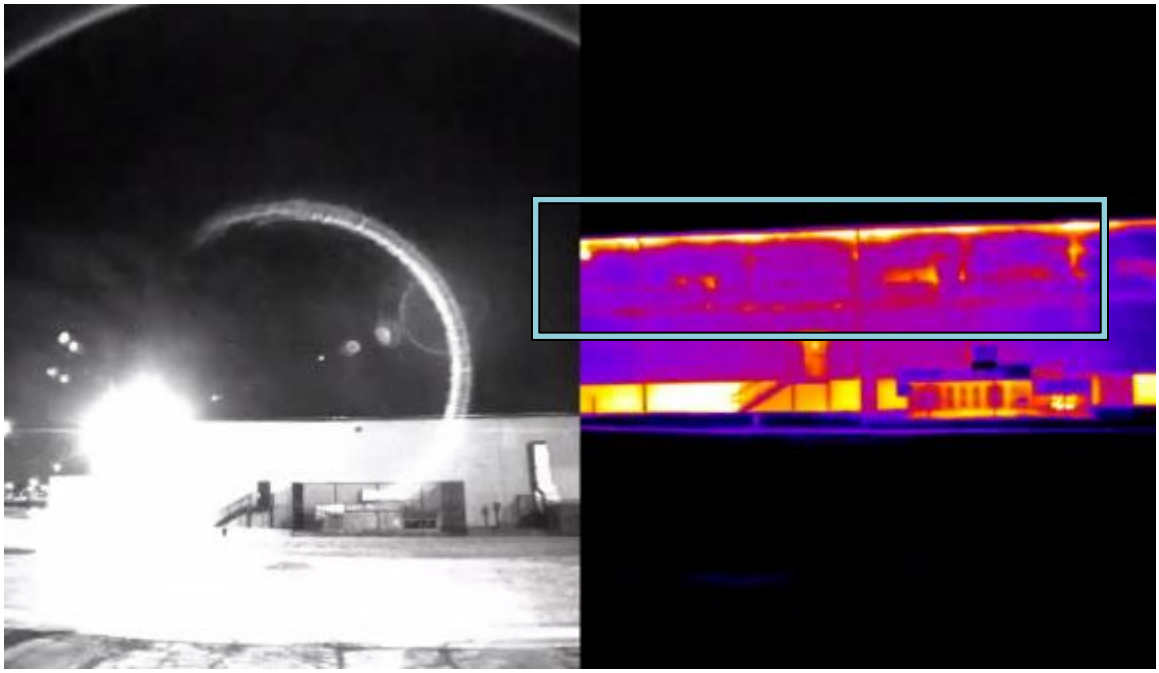

Figure E-101. NIR image (left) and thermal image (right) of Bldg 1961, Scott AFB. Note numerous wall insulation gaps around the back of the building as well as a leaky soffit.

The back of the building around timestamp 43:31 is particularly emissive, with large amounts of heat leaking out (Figure E-102). The wall has insulation problems.

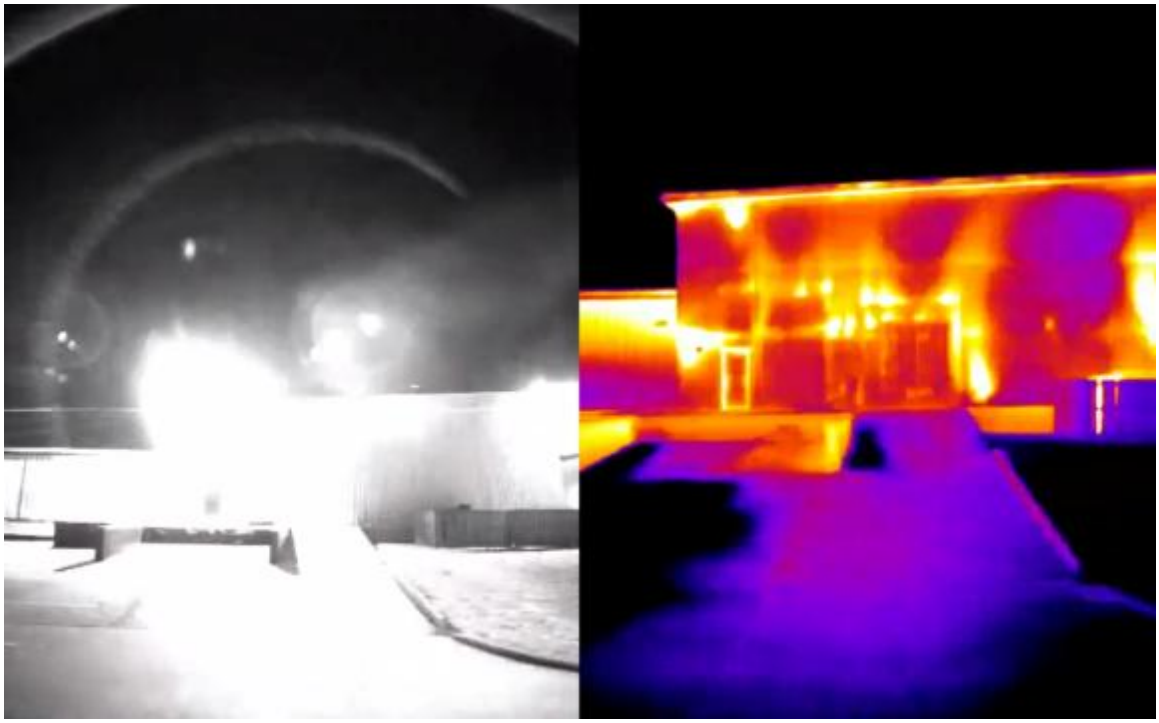

Figure E-102. NIR image (left) and thermal image (right) of Bldg 1961, Scott AFB. Significant energy losses through this wall is indicated.

Similar large leaks are seen on the wall at timestamp 43:32 (Figure E-103). The "patchy appearance" indicates inconsistent insulation throughout the wall. The double doors to the right of the image may also have notable convective leaks around the frame.

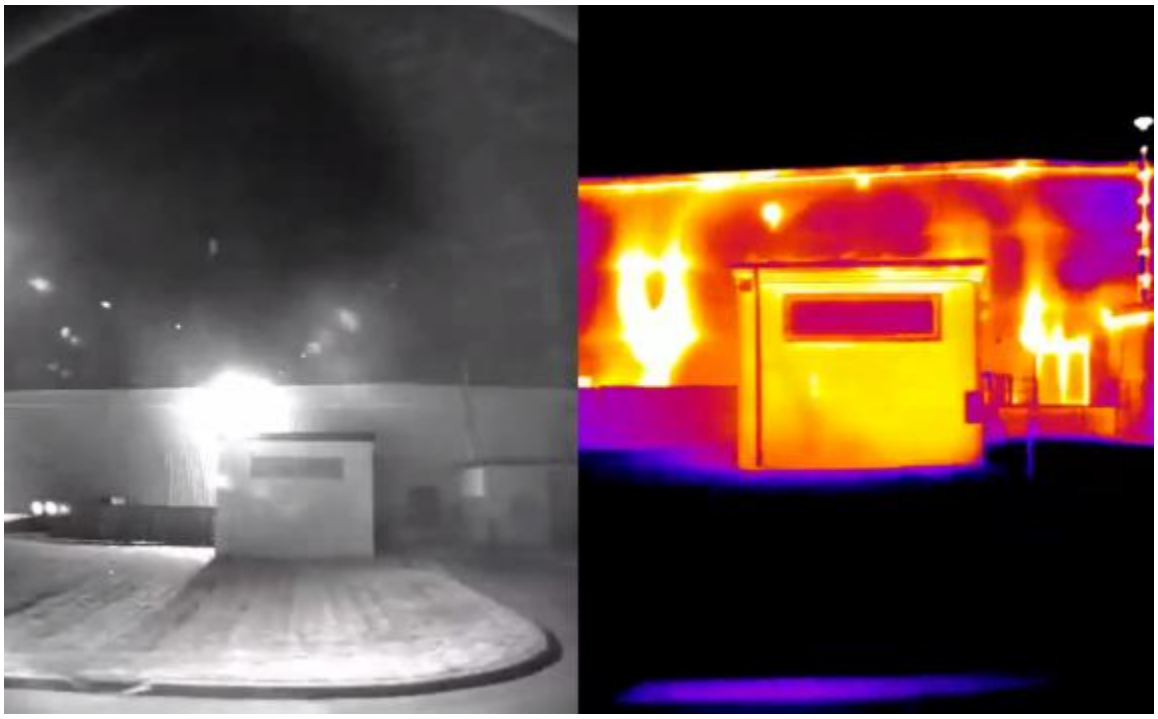

Figure E-103. NIR image (left) and thermal image (right) of Bldg 1961, Scott AFB. The "patchy appearance" indicates inconsistent insulation throughout the wall.

E.1.21.3 Envelope ECMs for Bldg 1961, Scott AFB

Figure E-104 shows the relative ROI for envelope ECMs for Bldg 1961, Scott AFB.

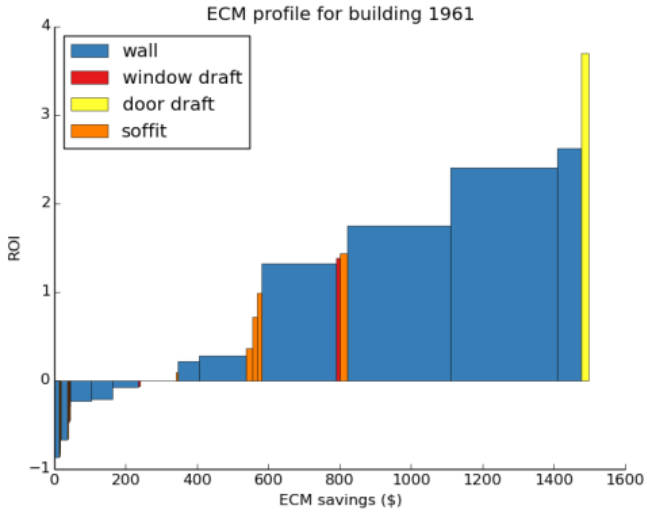

Figure E-104. ECM profile for Bldg 1961, Scott AFB.

Table E-40 lists the recommended envelope ECMs for Bldg 1961, Scott AFB.

Table E-40. Envelope ECMs for Bldg 1961, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	714	1721	1055	6818	6.5
Improve Soffit Insulation	47	114	70	612	8.8
Seal Door Frame Leaks	14	34	21	66	3.2
Seal Window Frame Leaks	7	17	10	66	6.3

Annual potential remediation savings for this building are $1,156 and total payback is 6.5 years for envelope-related ECMs.

E.1.21.4 Non-Envelope ECMs for Bldg 1961, Scott AFB

Table E-41 lists the recommended non-envelope ECMs for Bldg 1961, Scott AFB.

Table E-41. Non-envelope ECMs for Bldg 1961, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	166923	-2171	8930	120072	13.4
Occupancy Sensors	74855	-974	4004	4013	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	289	145	983	6.8

Annual potential remediation savings for this building are $13,968 and total payback is 9.1 years for non-envelope ECMs.

E.1.22 Bldg 1980

E.1.22.1 Description of Bldg 1980, Scott AFB

Name: Store Commissary
Use Type: Grocery
Square Footage: 113,652
Avg. Daily Electric Use: 12,090 kWh
Avg. Daily Gas Use: 116.0 therms
Electricity Score: 85th Percentile
Gas Score: 70th Percentile
Annual Cooling Load: 279,138 kWhrs
Annual Heating Load: 21,977 therms

Bldg 1980 (Figure E-105 and E-106) has a gas usage of 37,240 Btu/sq ft/yr and electricity usage of 38.8 kWh/sq ft/yr.

Figure E-105. Aerial view of Bldg 1980, Scott AFB.

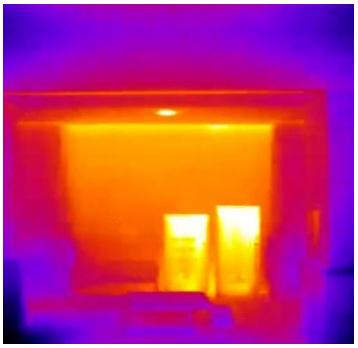

Figure E-106. Thermal image of Bldg 1980, Scott AFB.

E.1.22.2 Notable Leaks at Bldg 1980, Scott AFB

Bldg 1980 has a hot spot on the wall around timestamp 173:46, indicating poor or incomplete wall insulation at that spot (Figure E-107).

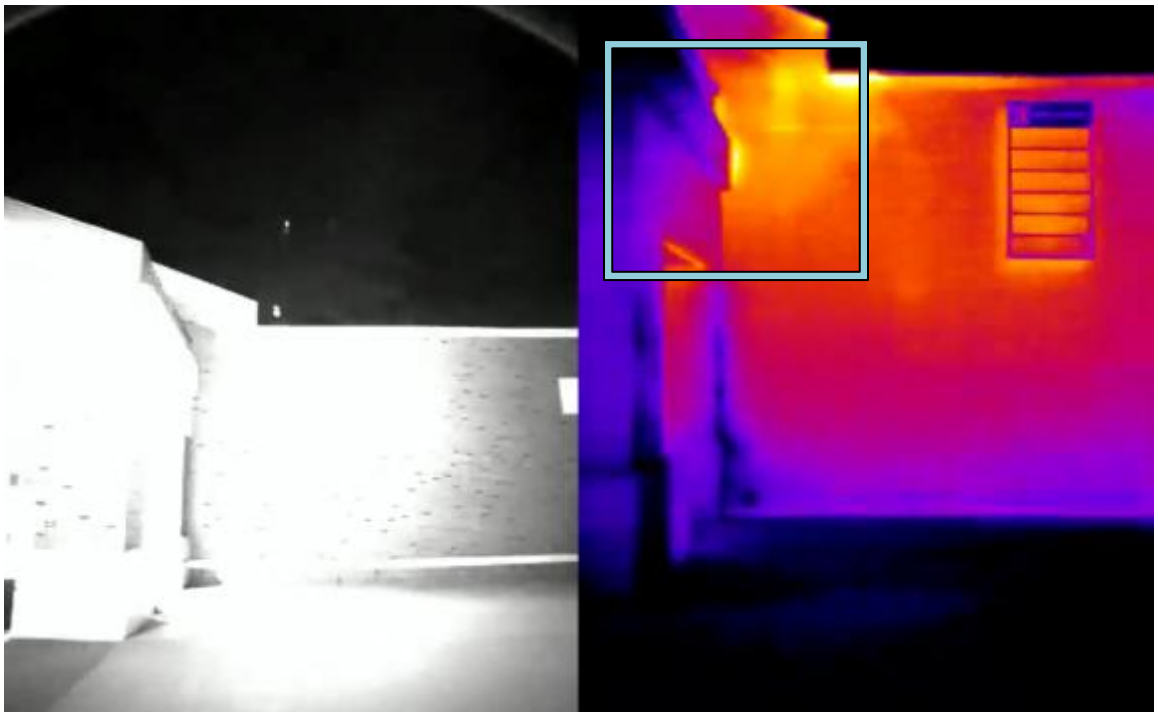

Figure E-107. NIR image (left) and thermal image (right) of Bldg 1980, Scott AFB.

E.1.22.3 Envelope ECMs for Bldg 1980, Scott AFB

Figure E-108 shows the relative ROI for envelope ECMs for Bldg 1980, Scott AFB.

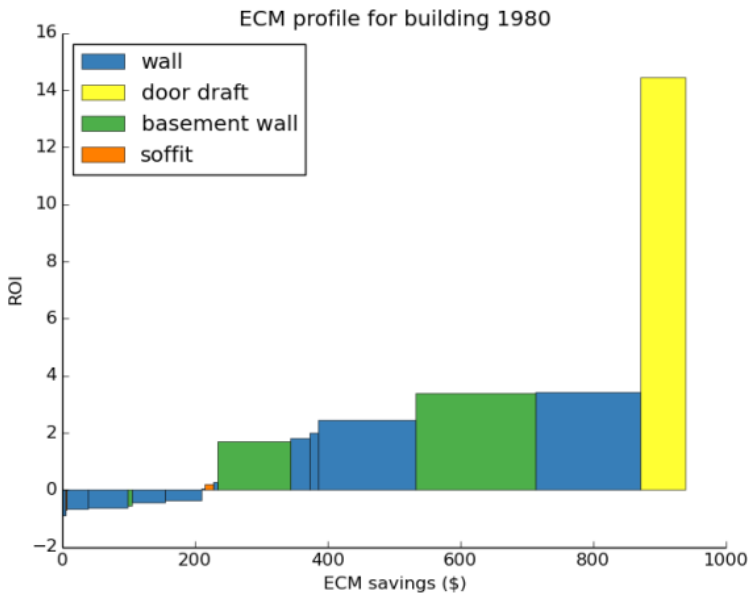

Figure E-108. ECM profile for Bldg 1980, Scott AFB.

Table E-42 lists the recommended envelope ECMs for Bldg 1980, Scott AFB.

Table E-42. Envelope ECMs for Bldg 1980, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	243	584	358	1534	4.3
Basement Wall Insulation	196	472	289	1223	4.2
Seal Door Frame Leaks	46	111	68	66	1.0
Improve Soffit Insulation	9	21	13	165	12.6

Annual potential remediation savings for this building are $729 and total payback is 4.1 years for envelope-related ECMs.

E.1.22.4 Non-Envelope ECMs for Bldg 1980, Scott AFB

Table E-43 lists the recommended non-envelope ECMs for Bldg 1980, Scott AFB.

Table E-43. Non-envelope ECMs for Bldg 1980, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	617070	-5178	34435	292103	8.5
Occupancy Sensors	276717	-2322	15442	9762	0.6
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	7368	0	442	500	1.1

Annual potential remediation savings for this building are $51,209 and total payback is 5.9 years for non-envelope ECMs.

E.1.23 Bldg 3189

E.1.23.1 Description of Bldg 3189, Scott AFB

Name: Admin Ofc Non-Af (DECCO)
Use Type: Office
Square Footage: 71,962
Avg. Daily Electric Use: 5,673 kWh
Avg. Daily Gas Use: 28.7 therms
Electricity Score: 70th Percentile
Gas Score: 10th Percentile
Annual Cooling Load: 55,139 kWhrs
Annual Heating Load: 9,164 therms

Bldg 3189 (Figures E-109 and E-110) has a gas usage of 14,572 Btu/sq ft/yr and electricity usage of 28.8 kWh/sq ft/yr.

Figure E-109. Aerial view of Bldg 3189, Scott AFB.

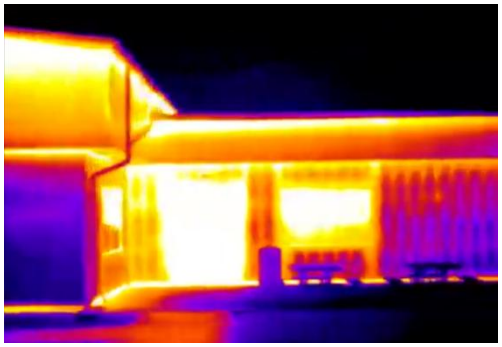

Figure E-110. Thermal image of Bldg 3189, Scott AFB.

E.1.23.2 Notable Leaks at Bldg 3189, Scott AFB

Bldg 3189 has numerous thermal bridges or insulation holes behind the brick wall around timestamp 113:30 (Figure E-111). As seen in other buildings, the large garage door is very leaky. There is also significant energy leakage through the soffit.

Figure E-111. NIR image (left) and thermal image (right) of Bldg 3189, Scott AFB.

The soffit and door frames around timestamp 113:32 are notably leaky (Figure E-112). The area outlined by the polygon is showing poor insulation. Both doors are also very leaky.

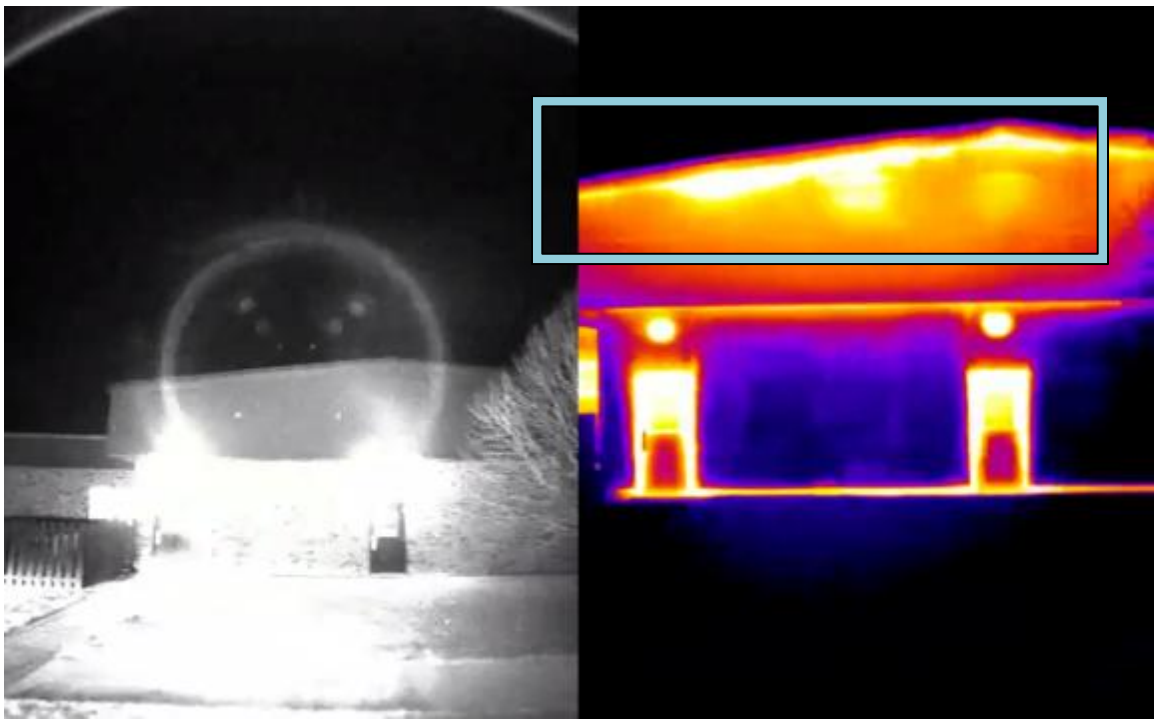

Figure E-112. NIR image (left) and thermal image (right) of Bldg 3189, Scott AFB. The soffit and door frames appear to be notably leaky.

The soffit/roof around 113:49 remains fairly emissive (Figure E-113). The top of the double doors are also losing energy.

Figure E-113. NIR image (left) and thermal image (right) of Bldg 3189, Scott AFB. The top of the double doors are losing considerable energy.

The soffit and roof line at timestamp 113:57 is fairly emissive, and the door frame may have a sizable convective leak (Figure E-114). It is recommended that weather-stripping be added to the door to prevent energy loss from the door frame.

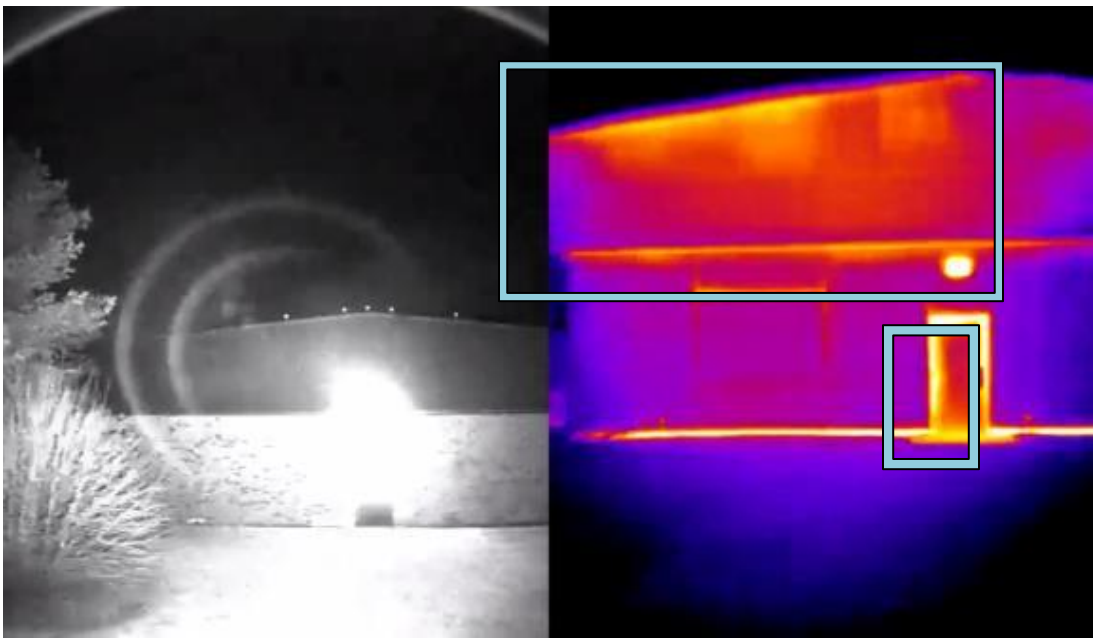

Figure E-114. NIR image (left) and thermal image (right) of Bldg 3189, Scott AFB. The soffit and roof line are fairly emissive.

E.1.23.3 Envelope ECMs for Bldg 3189, Scott AFB

Figure E-115 shows the relative ROI for envelope ECMs for Bldg 3189, Scott AFB.

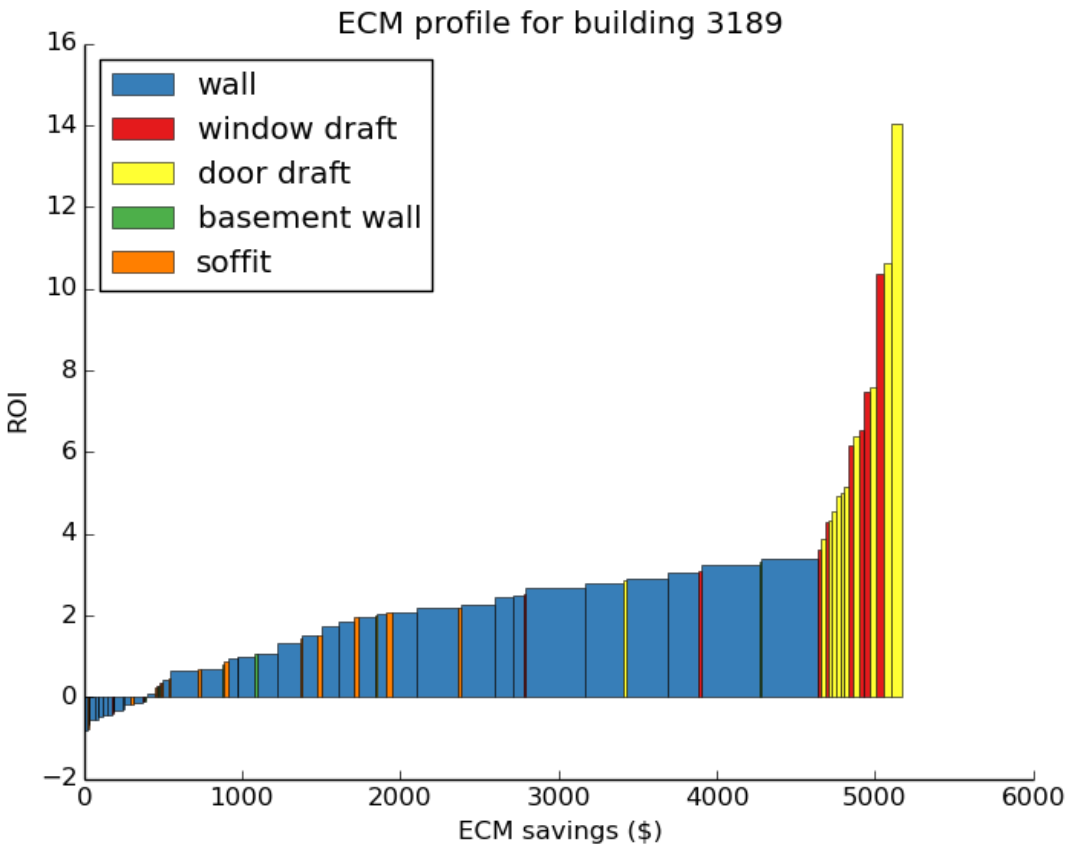

Figure E-115. ECM profile for Bldg 3189, Scott AFB.

Table E-44 lists the recommended envelope ECMs for Bldg 3189, Scott AFB.

Table E-44. Envelope ECMs for Bldg 3189, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	2648	6376	3910	20021	5.1
Seal Door Frame Leaks	248	598	367	791	2.2
Seal Window Frame Leaks	166	399	245	723	3.0
Improve Soffit Insulation	140	336	206	1429	6.9
Basement Wall Insulation	36	86	52	430	8.2

Annual potential remediation savings for this building are $4,780 and total payback is 4.9 years for envelope-related ECMs.

E.1.23.4 Non-Envelope ECMs for Bldg 3189, Scott AFB

Table E-45 lists the recommended non-envelope ECMs for Bldg 3189, Scott AFB.

Table E-45. Non-envelope ECMs for Bldg 3189, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	149620	-1946	8004	107626	13.4
Occupancy Sensors	67095	-873	3589	3597	1.0
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	3684	0	221	500	2.3

Annual potential remediation savings for this building are $12,704 and total payback is 8.9 years for non-envelope ECMs.

E.1.24 Bldg 3689

E.1.24.1 Description of Bldg 3689, Scott AFB

Name: Acw Ops Bldg
Use Type: Misc
Square Footage: 4,720
Avg. Daily Electric Use: 391 kWh
Avg. Daily Gas Use: 4.7 therms
Electricity Score: 80th Percentile
Gas Score: 15th Percentile
Annual Cooling Load: 5,811 kWhrs
Annual Heating Load: 1,681 therms

Bldg 3689 (Figures E-116 and E-117) has a gas usage of 36,307 Btu/sq ft/yr and electricity usage of 30.2 kWh/sq ft/yr.

Figure E-116. Aerial view of Bldg 3689, Scott AFB.

Figure E-117. Thermal image of Bldg 3689, Scott AFB.

E.1.24.2 Notable Leaks at Bldg 3689, Scott AFB

The wall of Bldg 3689 at timestamp 122:48 has a number of emissive patches, which indicate holes (Figure E-118)). There is also a large hot stripe at the juncture in the middle of the image that may be worth investigating further. The double doors on the right of the image are also leaking energy. Weather-stripping is recommended to fix energy leaking around the door frame.

Figure E-118. NIR image (left) and thermal image (right) of Bldg 3689, Scott AFB.

E.1.24.3 Envelope ECMs for Bldg 3689, Scott AFB

Figure E-119 shows the relative ROI for envelope ECMs for Bldg 3689, Scott AFB.

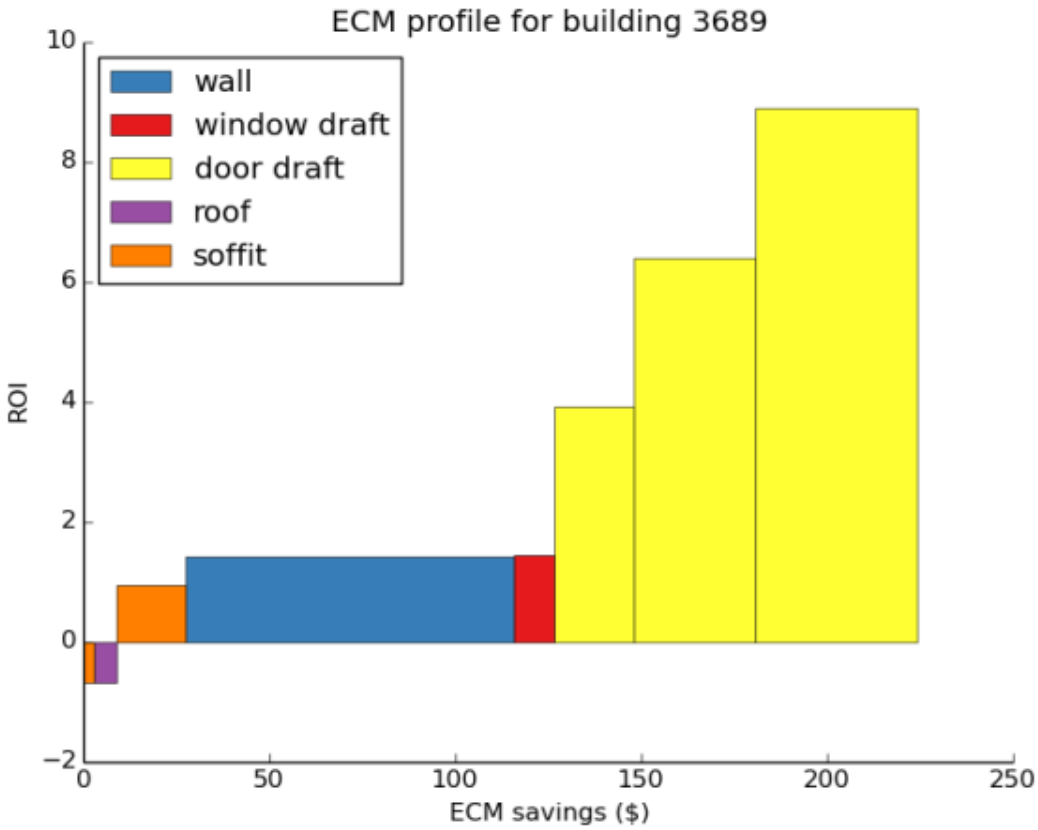

Figure E-119. ECM profile for Bldg 3689, Scott AFB.

Table E-46 lists the recommended envelope ECMs for Bldg 3689, Scott AFB.

Table E-46. Envelope ECMs for Bldg 3689, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Door Frame Leaks	66	159	98	198	2.0
Improve Wall Insulation	60	144	88	547	6.2
Improve Soffit Insulation	13	30	19	144	7.7
Seal Window Frame Leaks	7	17	11	66	6.2

Annual potential remediation savings for this building are $215 and total payback is 4.4 years for envelope-related ECMs.

E.1.24.4 Non-Envelope ECMs for Bldg 3689, Scott AFB

Table E-47 lists the recommended non-envelope ECMs for Bldg 3689, Scott AFB.

Table E-47. Non-envelope ECMs for Bldg 3689, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	10199	-132	546	7059	12.9
Occupancy Sensors	4573	-59	245	236	1.0
LED Exit Signs	1625	-17	89	195	2.2
Boiler Tune-up	0	27	13	58	4.3

Annual potential remediation savings for this building are $893 and total payback is 8.4 years for non-envelope ECMs.

E.1.25 Bldg 4001

E.1.25.1 Description of Bldg 4001, Scott AFB

Name: Whse Sup & Equip Bse
Use Type: Warehouse
Square Footage: 81,094
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 67.5 therms
Electricity Score: N/A
Gas Score: 40th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 23,896 therms

Bldg 4001 (Figures E-120 and E-121) has a gas usage of 30,389 Btu/sq ft/yr.

Figure E-120. Aerial view of Bldg 4001, Scott AFB.

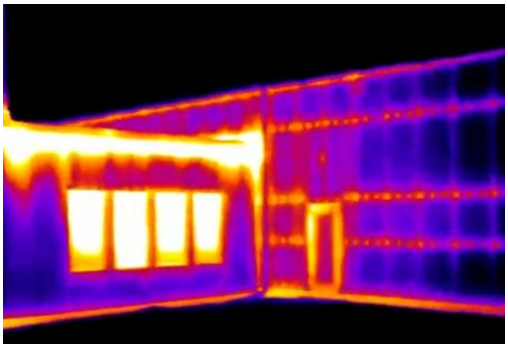

Figure E-121. Thermal image of Bldg 4001, Scott AFB.

E.1.25.2 Notable Leaks at Bldg 4001, Scott AFB

There are thermal bridges due to rivets around timestamp 97:50, as well as some larger hot patches that may be insulation holes (Figure E-122).

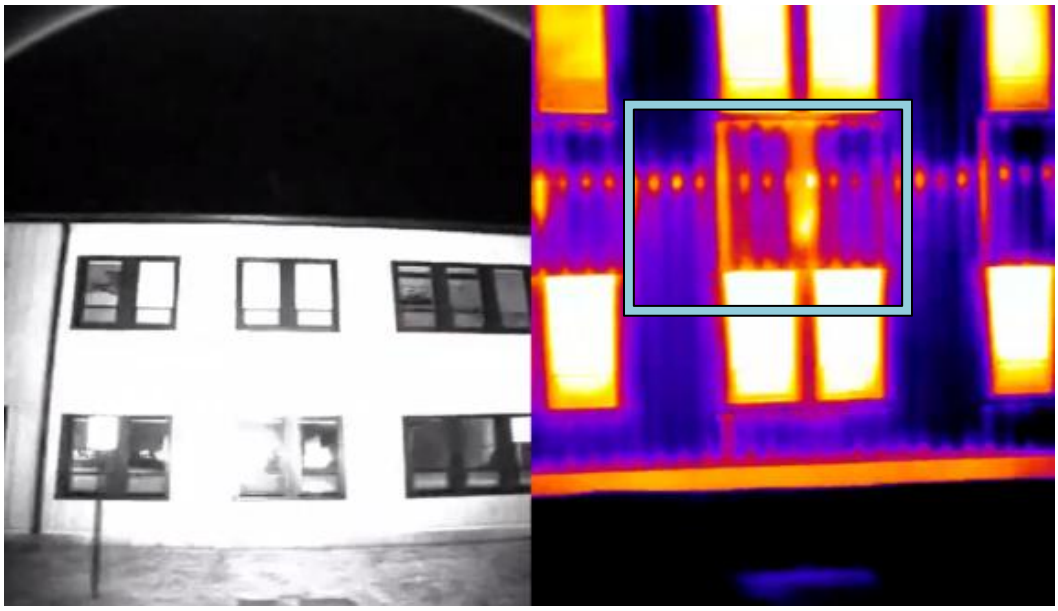

Figure E-122. NIR image (left) and thermal image (right) of Bldg 4001, Scott AFB.

Timestamp 97:51 shows some particularly leaky soffits, as well as a large insulation hole between upper and lower windows on the left side of the image (Figure E-123).

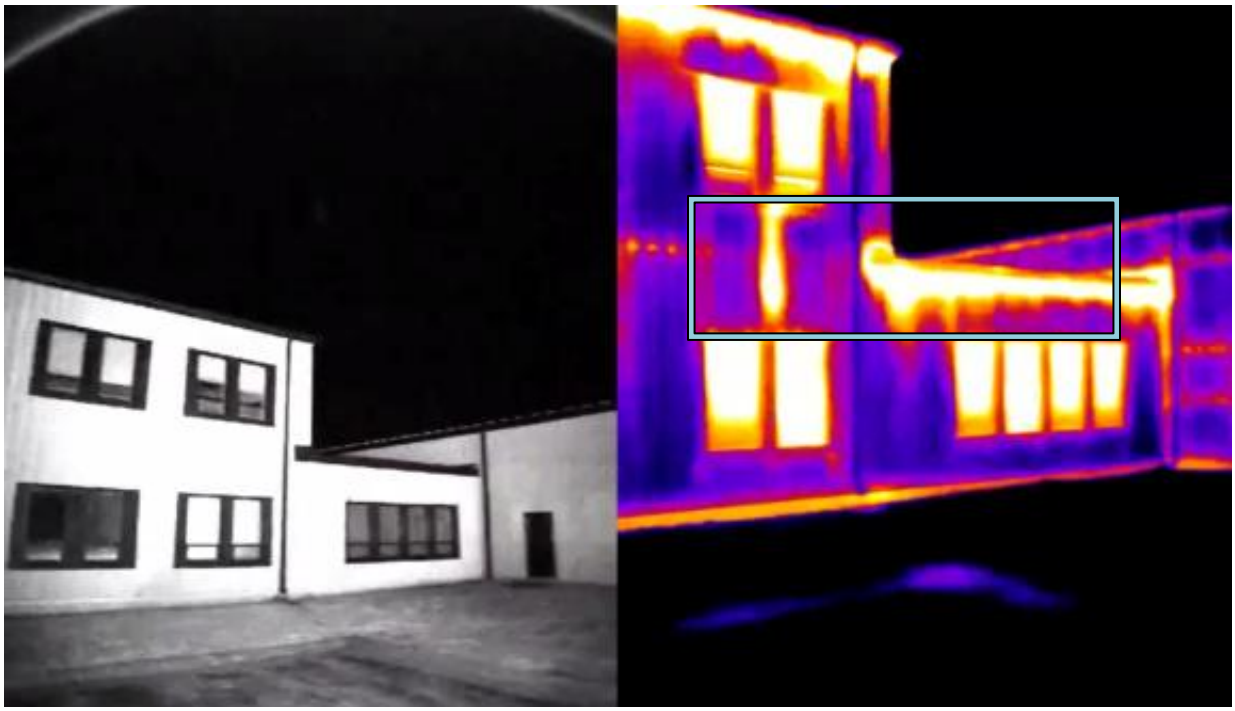

Figure E-123. NIR image (left) and thermal image (right) of Bldg 4001, Scott AFB. Soffits are seen to be very leaky.

There are some additional insulation holes around the back at timestamp 98:12. The hotspots observed through the entire building indicate thermal bridges (Figure E-124).

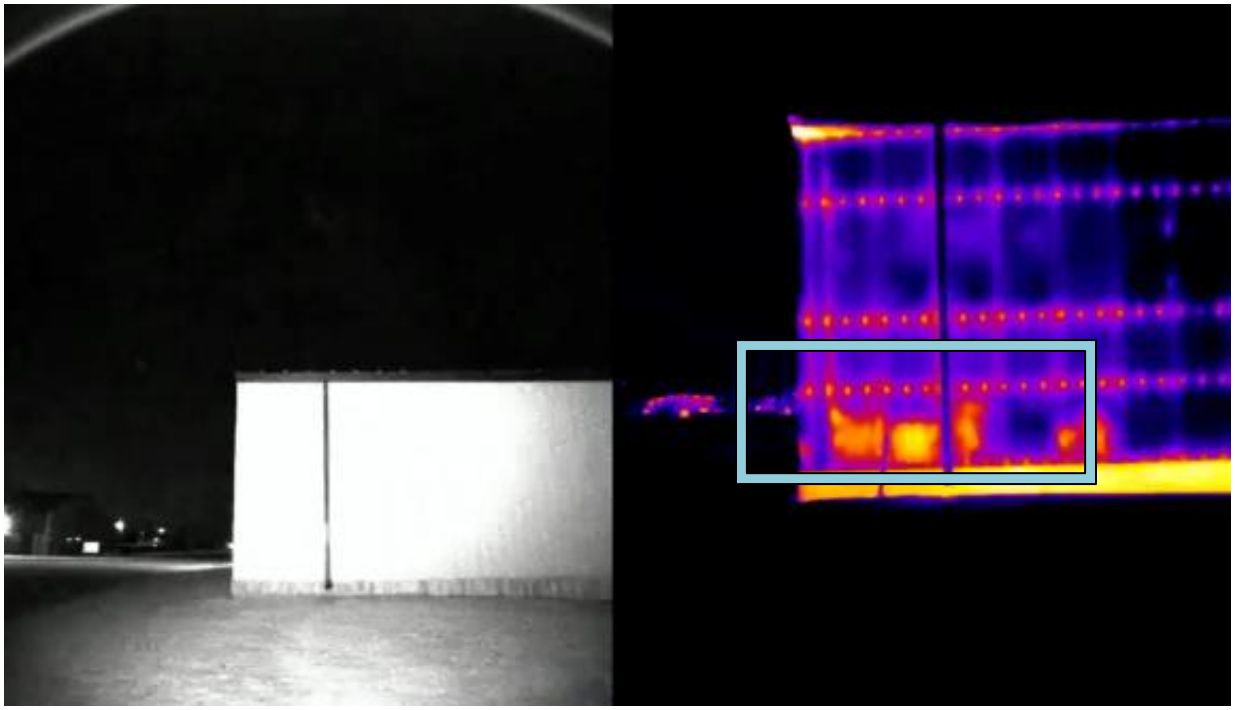

Figure E-124. NIR image (left) and thermal image (right) of Bldg 4001, Scott AFB. The hot spots indicate thermal bridges.

E.1.25.3 Envelope ECMs for Bldg 4001, Scott AFB

Figure E-125 shows the relative ROI for envelope ECMs for Bldg 4001, Scott AFB.

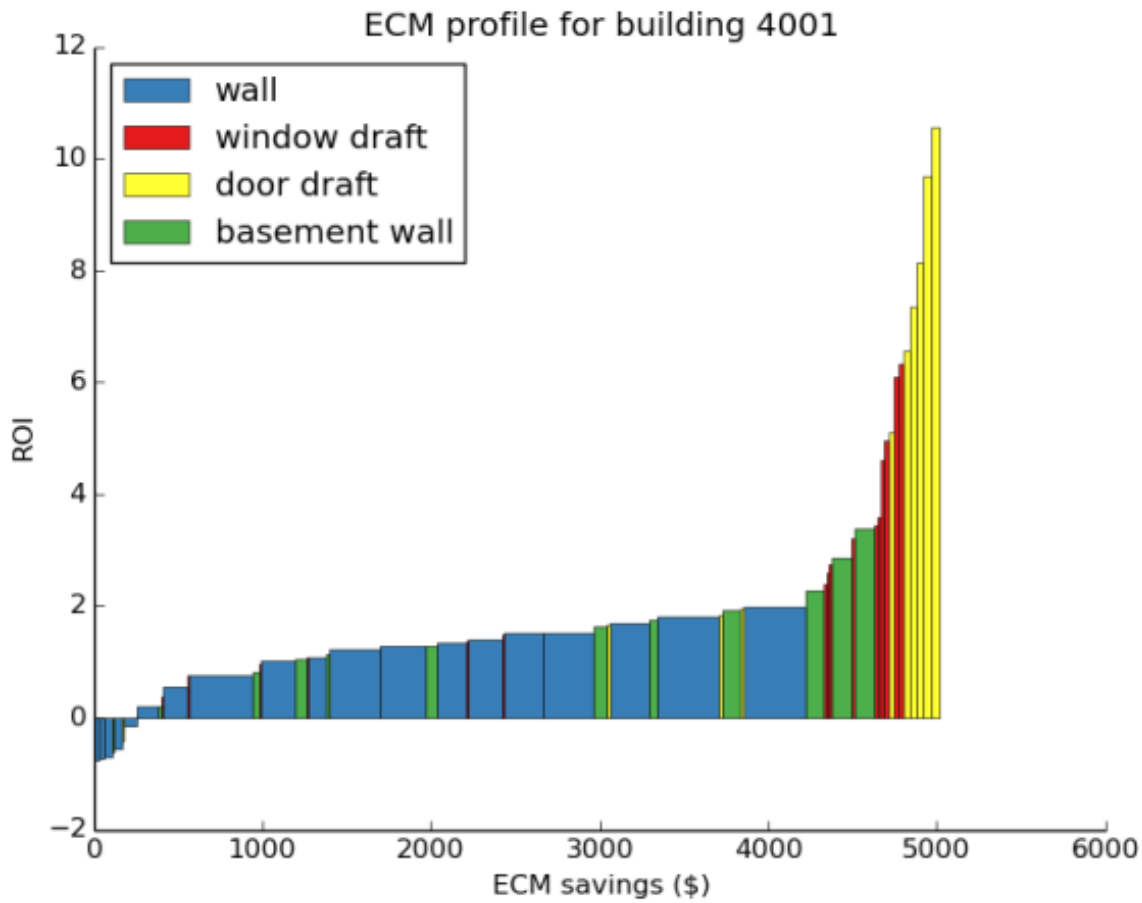

Figure E-125. ECM profile for Bldg 4001, Scott AFB.

Table E-48 lists the recommended envelope ECMs for Bldg 4001, Scott AFB.

Table E-48. Envelope ECMs for Bldg 4001, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	2316	5580	3422	23078	6.7
Basement Wall Insulation	537	1294	794	4258	5.4
Seal Window Frame Leaks	187	450	276	1118	4.0
Seal Door Frame Leaks	184	443	272	594	2.2

Annual potential remediation savings for this building are $4,764 and total payback is 6.1 years for envelope-related ECMs.

E.1.25.4 Non-Envelope ECMs for Bldg 4001, Scott AFB

Table E-49 lists the recommended non-envelope ECMs for Bldg 4001, Scott AFB.

Table E-49. Non-envelope ECMs for Bldg 4001, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	144015	-1862	7710	102739	13.3
Occupancy Sensors	64582	-835	3457	3433	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	382	191	992	5.2

Annual potential remediation savings for this building are $12,248 and total payback is 8.9 years for non-envelope ECMs.

E.1.26 Bldg 4010

E.1.26.1 Description of Bldg 4010, Scott AFB

Name: Traffic Mgt F
Use Type: Misc.
Square Footage: 18,753
Avg. Daily Electric Use: Not Provided
Avg. Daily Gas Use: 44.9 therms
Electricity Score: N/A
Gas Score: 90th Percentile
Annual Cooling Load: N/A
Annual Heating Load: 14,835 therms

Bldg 4010 (Figures E-126 and E-127) has a gas usage of 87,416 Btu/sq ft/yr.

Figure E-126. Aerial view of Bldg 4010, Scott AFB.

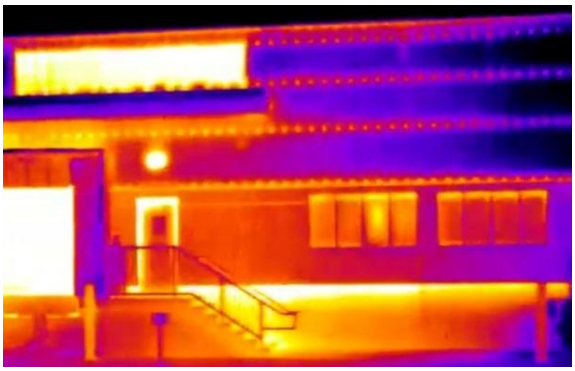

Figure E-127. Thermal image of Bldg 4010, Scott AFB.

E.1.26.2 Notable Leaks at Bldg 4010, Scott AFB

Bldg 4010 (Figure E-128) has some sizable hot patches near the roof line around timestamp 98:29. These may be vents or areas with absolutely no insulation.

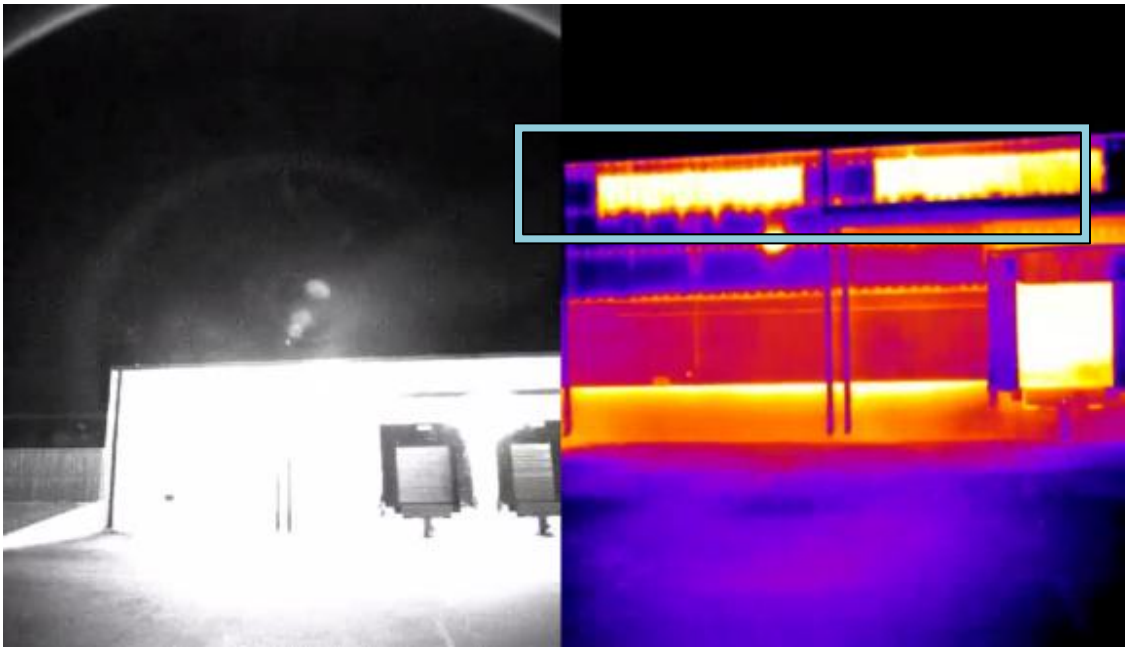

Figure E-128. NIR image (left) and thermal image (right) of Bldg 4010, Scott AFB.

The door around timestamp 98:32 has a fairly emissive frame, which indicates air leaks (Figure E-129). The top of the building has a large hotspot that may be caused by a vent.

Figure E-129. NIR image (left) and thermal image (right) of Bldg 4010, Scott AFB. Note the large hotspot near the top of the building.

E.1.26.3 Envelope ECMs for Bldg 4010, Scott AFB

Figure E-130 shows the relative ROI for envelope ECMs for Bldg 4010, Scott AFB.

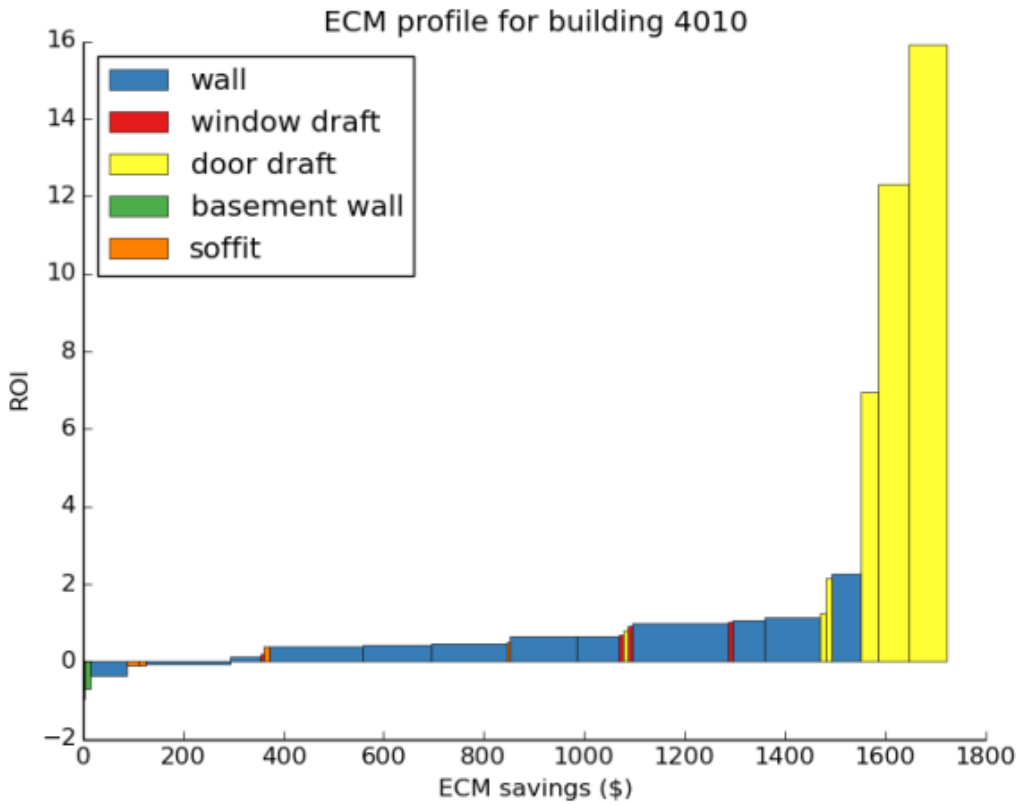

Figure E-130. ECM profile for Bldg 4010, Scott AFB.

Table E-50 lists the recommended envelope ECMs for Bldg 4010, Scott AFB.

Table E-50. Envelope ECMs for Bldg 4010, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	797	1921	1178	10834	9.2
Seal Door Frame Leaks	136	327	201	398	2.0
Seal Window Frame Leaks	20	49	30	262	8.8
Improve Soffit Insulation	13	31	19	206	10.7

Annual potential remediation savings for this building are $1,428 and total payback is 8.2 years for envelope-related ECMs.

E.1.26.4 Non-Envelope ECMs for Bldg 4010, Scott AFB

Table E-51 lists the recommended non-envelope ECMs for Bldg 4010, Scott AFB.

Table E-51. Non-envelope ECMs for Bldg 4010, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	40521	-523	2170	28047	12.9
Occupancy Sensors	18171	-234	973	937	1.0
LED Exit Signs	4875	-51	267	585	2.2
Boiler Tune-up	0	237	119	230	1.9

Annual potential remediation savings for this building are $3,528 and total payback is 8.4 years for non-envelope ECMs.

E.1.27 Bldg 5000

E.1.27.1 Description of Bldg 4010, Scott AFB

Name: Res Forces Opl Tng
Use Type: Office
Square Footage: 27,720
Avg. Daily Electric Use: 1356.6 kWh
Avg. Daily Gas Use: 45.8 therms
Electricity Score: 65th Percentile
Gas Score: 85th Percentile
Annual Cooling Load: 48,796 kWh
Annual Heating Load: 12,262 therms

Bldg 5000 (Figure E-131 and E-132) has a gas usage of 60,280 Btu/sq ft/yr and electricity usage of 17.9 kWh/sq ft/yr.

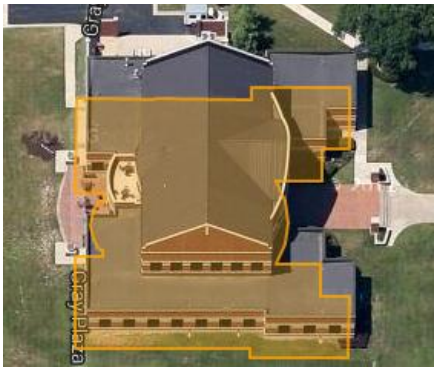

Figure E-131. Aerial view of Bldg 5000, Scott AFB.

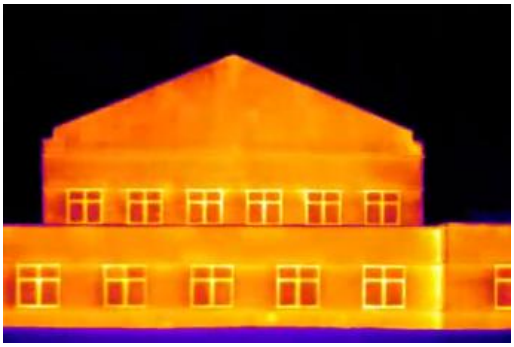

Figure E-132. Thermal image of Bldg 5000, Scott AFB.

E.1.27.2 Notable Leaks at Bldg 4010, Scott AFB

There is a notable vertical hot stripe on the right side of the building, along with a potential thermal bridge above the window frames and some small leaks near the bottom of the wall at timestamp 255:59 (Figure E-133).

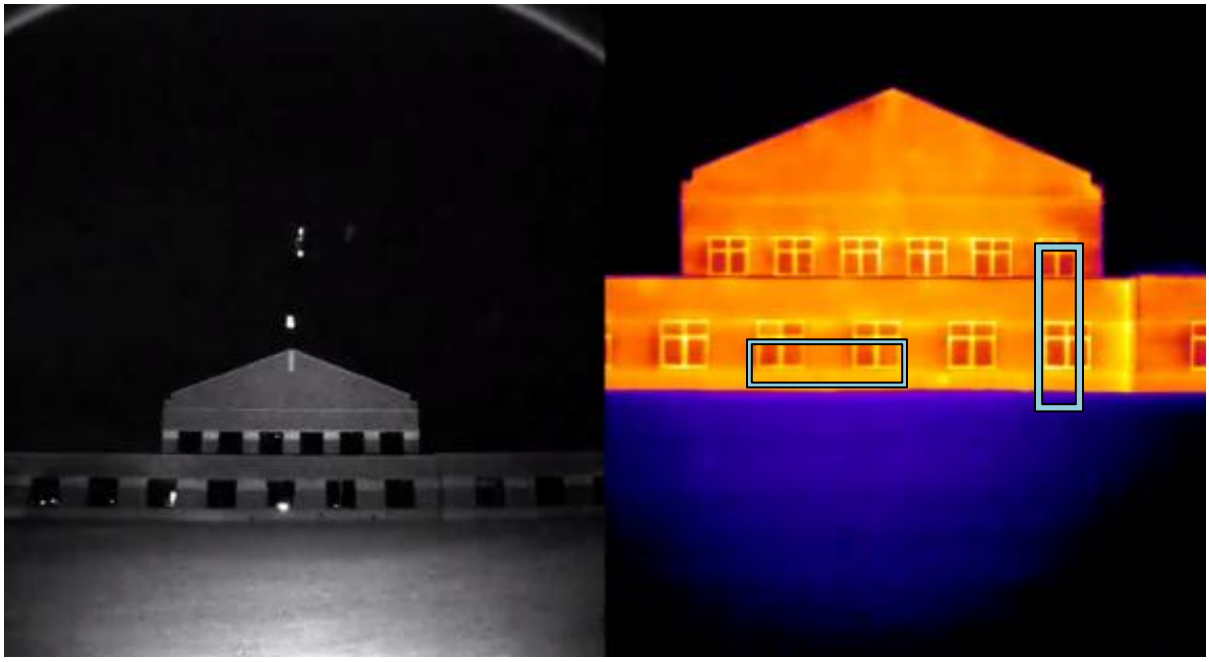

Figure E-133. NIR image (left) and thermal image (right) of Bldg 5000, Scott AFB.

There is a notable bright surface along the far wall on the left side of the image, as well as some hot spots above the windows on the right and an emissive roofline at timestamp 256:04 (Figure E-134).

Figure E-134. NIR image (left) and thermal image (right) of Bldg 5000, Scott AFB. Note hot spots above the windows on the right and an emissive roofline.

E.1.27.3 Envelope ECMs for Bldg 4010, Scott AFB

Figure E-135 shows the relative ROI for envelope ECMs for Bldg 5000, Scott AFB.

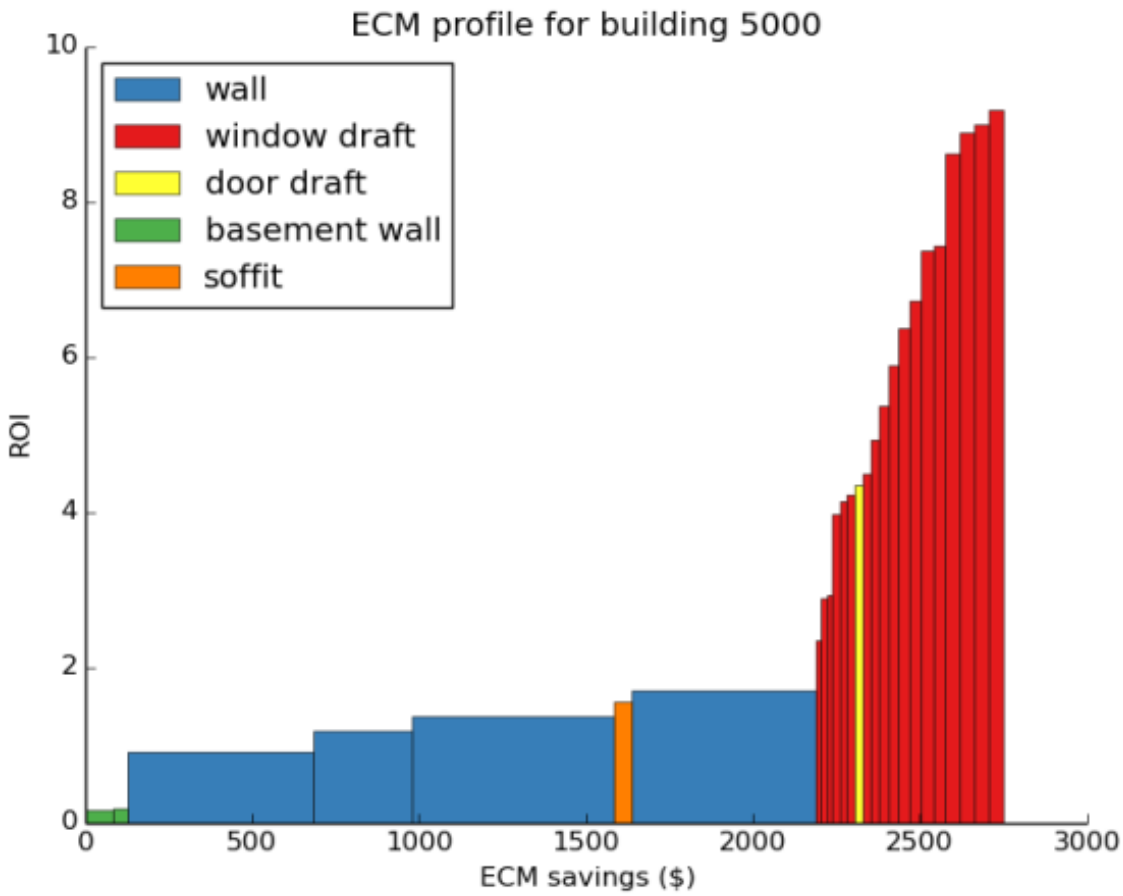

Figure E-135. ECM profile for Bldg 5000, Scott AFB.

Table E-52 lists the recommended envelope ECMs for Bldg 5000, Scott AFB.

Table E-52. Envelope ECMs for Bldg 5000, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1360	3276	2009	13328	6.6
Seal Window Frame Leaks	365	879	539	1186	2.2
Basement Wall Insulation	87	211	129	1665	12.9
Improve Soffit Insulation	35	83	51	299	5.9
Seal Door Frame Leaks	16	38	23	66	2.8

Annual potential remediation savings for this building are $2,751 and total payback is 6 years for envelope-related ECMs.

E.1.27.4 Non-Envelope ECMs for Bldg 4010, Scott AFB

Table E-53 lists the recommended non-envelope ECMs for Bldg 5000, Scott AFB.

Table E-53. Non-envelope ECMs for Bldg 5000, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	57634	-750	3083	41458	13.4
Occupancy Sensors	25845	-336	1383	1385	1.0
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	1842	0	111	500	4.5

Annual potential remediation savings for this building are $5,466 and total payback is 8.3 years for non-envelope ECMs.

E.1.28 Bldg 5008

E.1.28.1 Description of Bldg 5008, Scott AFB

Name: Sq. Ops.
Use Type: Office
Square Footage: 21,913
Avg. Daily Electric Use: 1,677.8 kWh
Avg. Daily Gas Use: 34.2 therms
Electricity Score: 90th Percentile
Gas Score: 75th Percentile
Annual Cooling Load: 71,466 kWh
Annual Heating Load: 9,717 therms

Bldg 5008 (Figure E-136 and E-137) has a gas usage of 56,984 Btu/sq ft/yr and electricity usage of 27.9 kWh/sq ft/yr.

Figure E-136. Aerial view of Bldg 5008, Scott AFB.

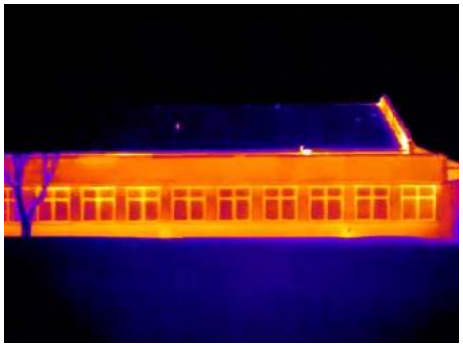

Figure E-137. Thermal image of Bldg 5008, Scott AFB.

E.1.28.2 Notable Leaks at Bldg 5008, Scott AFB

In addition to a generally high-emission wall, there are a number of leaky window frames and a hotspot on the roofline visible at timestamp 255:29 (Figure E-138).

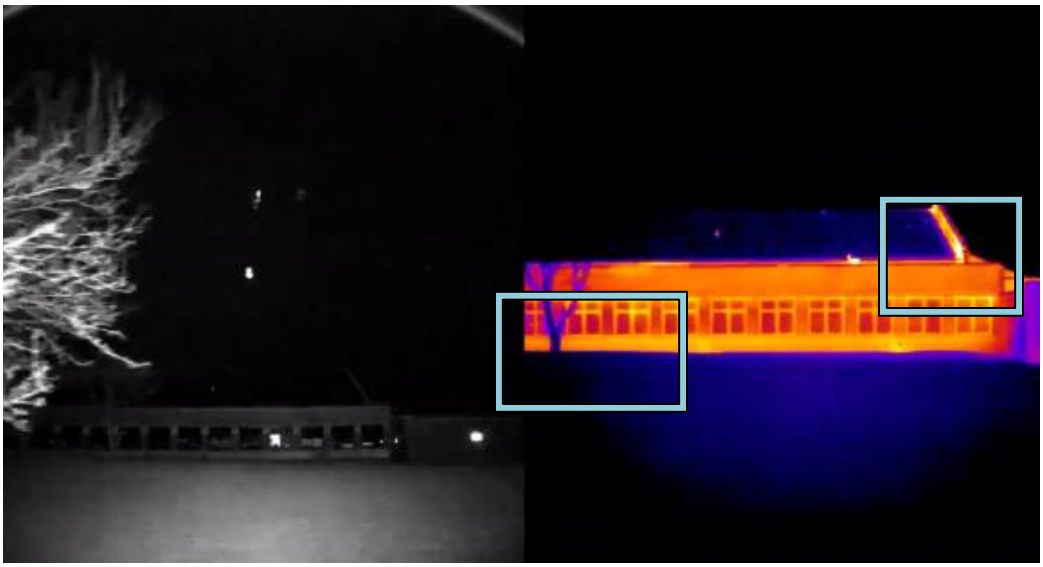

Figure E-138. NIR image (left) and thermal image (right) of Bldg 5008, Scott AFB.

E.1.28.3 Envelope ECMs for Bldg 5008, Scott AFB

Figure E-139 shows the relative ROI for envelope ECMs for Bldg 5008, Scott AFB.

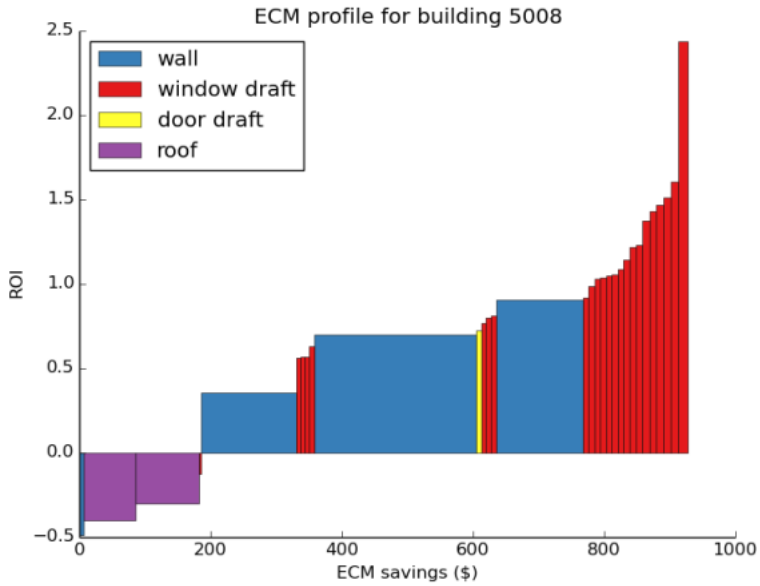

Figure E-139. ECM profile for Bldg 5008, Scott AFB.

Table E-54 lists the recommended envelope ECMs for Bldg 5008, Scott AFB.

Table E-54. Envelope ECMs for Bldg 5008, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	354	852	522	4819	9.2
Seal Window Frame Leaks	144	346	212	1516	7.2

Annual potential remediation savings for this building are $734 and total payback is 8.6 years for envelope-related ECMs.

E.1.28.4 Non-Envelope ECMs for Bldg 5008, Scott AFB

Table E-55 lists the recommended non-envelope ECMs for Bldg 5008, Scott AFB.

Table E-55. Non-envelope ECMs for Bldg 5008, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	45561	-593	2437	32773	13.4
Occupancy Sensors	20431	-266	1093	1095	1.0
LED Exit Signs	16250	-171	890	1950	2.2
EnergyStar Vending Machines	1842	0	111	500	4.5

Annual potential remediation savings for this building are $4,531 and total payback is 8.0 years for non-envelope ECMs.

E.1.29 Bldg 5010

E.1.29.1 Description of Bldg 5010, Scott AFB

Name: Dh Amn (Det)
Use Type: Misc.
Square Footage: 22,698
Avg. Daily Electric Use: 1,176.6 kWh
Avg. Daily Gas Use: 68.3 therms
Electricity Score: 65th Percentile
Gas Score: 90th Percentile
Annual Cooling Load: 33,988 kWh
Annual Heating Load: 7,316 therms

Bldg 5010 (Figure E-140 and E-141) has a gas usage of 109,751 Btu/sq ft/yr and electricity usage of 18.9 kWh/sq ft/yr.

Figure E-140. Aerial view of Bldg 5010, Scott AFB.

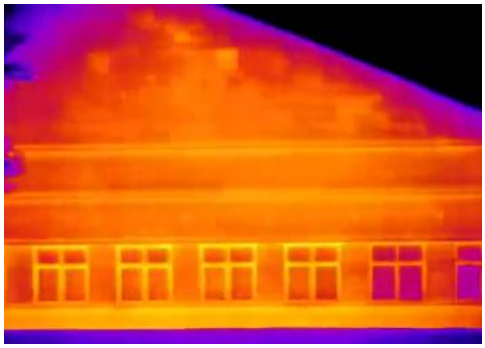

Figure E-141. Thermal image of Bldg 5010, Scott AFB.

E.1.29.2 Notable Leaks at Bldg 5010, Scott AFB

There are a number of splotchy hotspots visible at the top of the wall at timestamp 255:14 (Figure E-142). The wall itself is highly emissive on average, which indicates poor insulation.

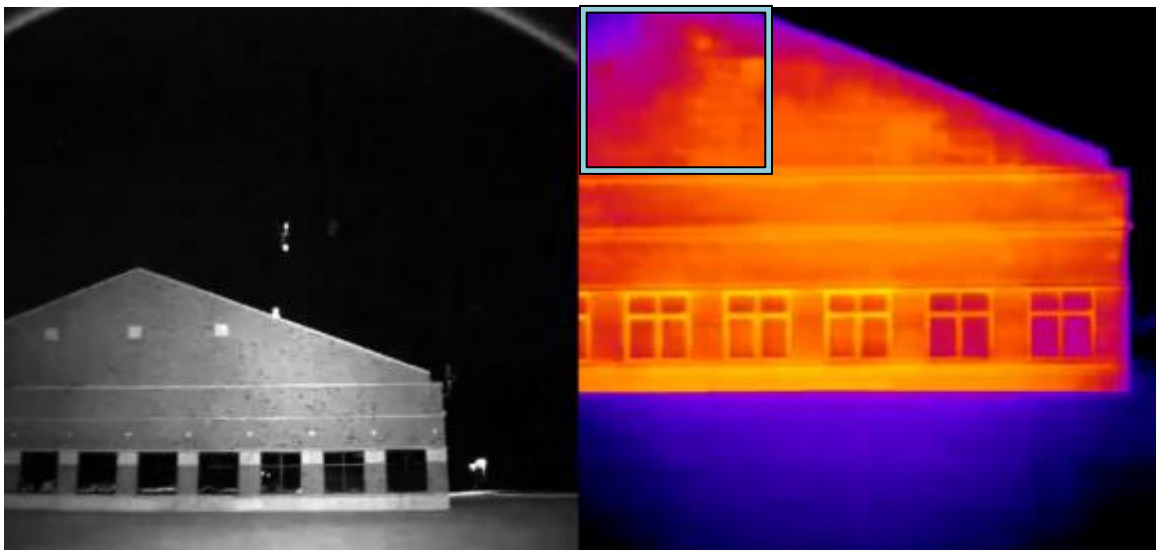

Figure E-142. NIR image (left) and thermal image (right) of Bldg 5010, Scott AFB.

There is a noticeable hot strip along the roofline at timestamp 255:17 (Figure E-143).

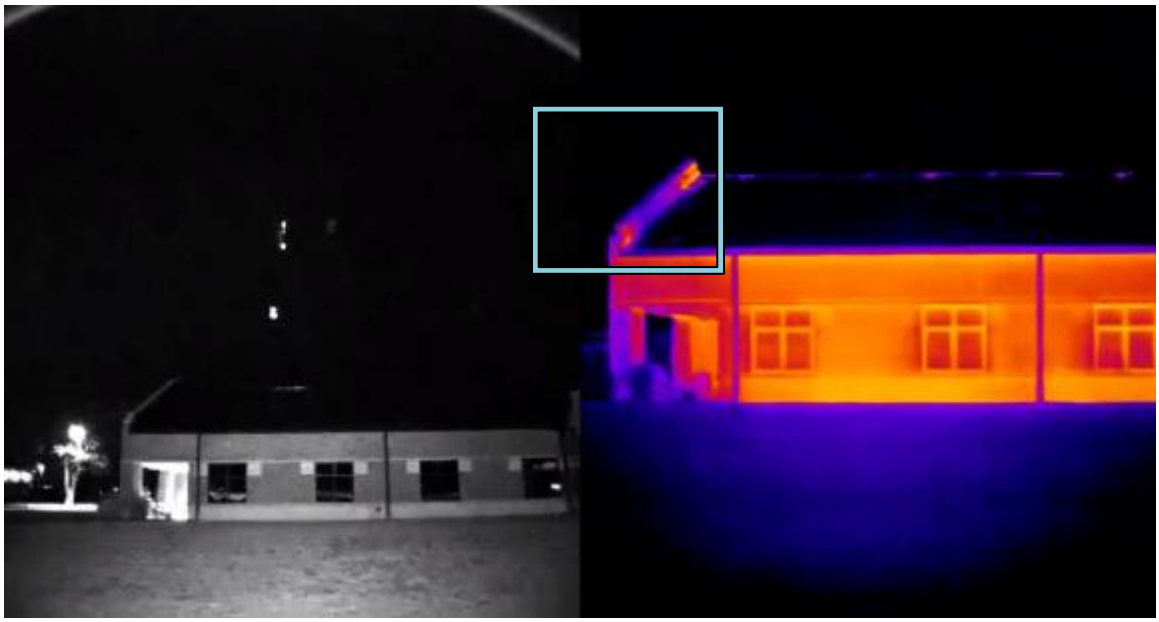

Figure E-143. NIR image (left) and thermal image (right) of Bldg 5010, Scott AFB. A noticeable hot strip is seen along the roofline.

E.1.29.3 Envelope ECMs for Bldg 5010, Scott AFB

Figure E-144 shows the relative ROI for envelope ECMs for Bldg 5010, Scott AFB.

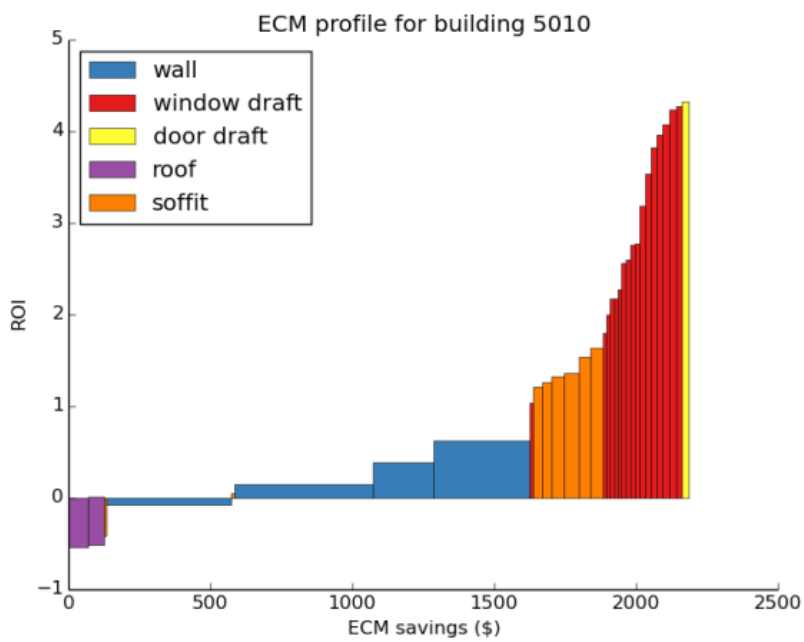

Figure E-144. ECM profile for Bldg 5010, Scott AFB.

Table E-56 lists the recommended envelope ECMs for Bldg 5010, Scott AFB.

Table E-56. Envelope ECMs for Bldg 5010, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	706	1701	1043	11914	11.4
Seal Window Frame Leaks	196	472	290	1116	3.9
Improve Soffit Insulation	175	422	259	1720	6.7
Seal Door Frame Leaks	16	38	23	65	2.8

Annual potential remediation savings for this building are $1,615 and total payback is 9.2 years for envelope-related ECMs.

E.1.29.4 Non-Envelope ECMs for Bldg 5010, Scott AFB

Table E-57 lists the recommended non-envelope ECMs for Bldg 5010, Scott AFB.

Table E-57. Non-envelope ECMs for Bldg 5010, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	47193	-614	2525	33947	13.4
Occupancy Sensors	21163	-275	1132	1134	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	117	59	278	4.7

Annual potential remediation savings for this building are $4,605 and total payback is 8.1 years for non-envelope ECMs.

E.1.30 Bldg 5022

E.1.30.1 Description of Bldg 5022, Scott AFB

Name: Shp Acft Gen Purp
Use Type: Misc.
Square Footage: 45,787
Avg. Daily Electric Use: 1453.9 kWh
Avg. Daily Gas Use: 61.8 therms
Electricity Score: 55th Percentile
Gas Score: 65th Percentile
Annual Cooling Load: 43,624 kWh
Annual Heating Load: 16,628 therms

Bldg 5022 (|Figures E-145 and E-146) has a gas usage of 49,238 Btu/sq ft/yr and electricity usage of 11.6 kWh/sq ft/yr.

Figure E-145. Aerial view of Bldg 5022, Scott AFB.

Figure E-146. Thermal image of Bldg 5022, Scott AFB.

E.1.30.2 Notable Leaks at Bldg 5022, Scott AFB

There is a hotspot visible to the left of the windows on the wall at timestamp 117:43 in the Drive-By Tool (Figure E-147).

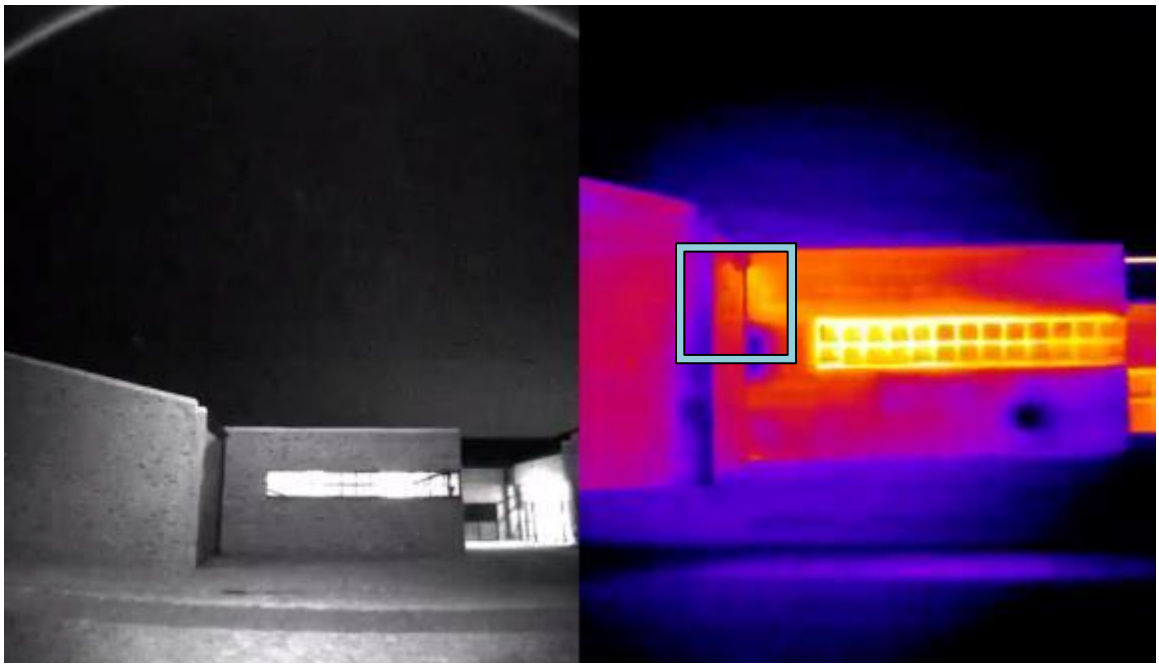

Figure E-147. NIR image (left) and thermal image (right) of Bldg 5022, Scott AFB.

A similar highly emissive spot can be found to the right of the windows on the wall at timestamp 117:49 (Figure E-148).

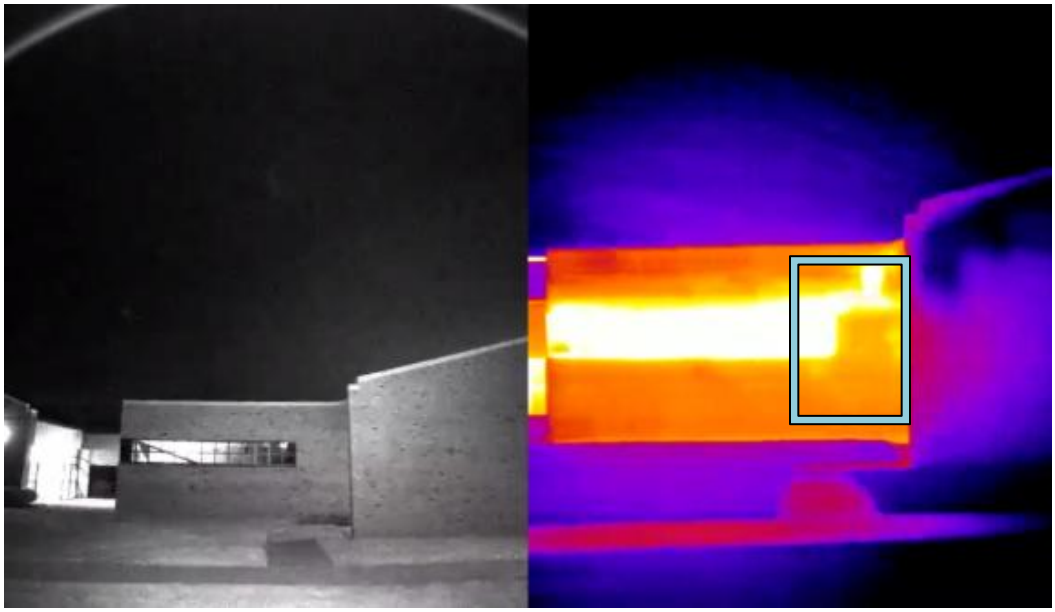

Figure E-148. NIR image (left) and thermal image (right) of Bldg 5022, Scott AFB. A highly emissive spot can be found to the right of the windows on the wall.

E.1.30.3 Envelope ECMs for Bldg 5022, Scott AFB

Figure E-149 shows the relative ROI for envelope ECMs for Bldg 5022, Scott AFB.

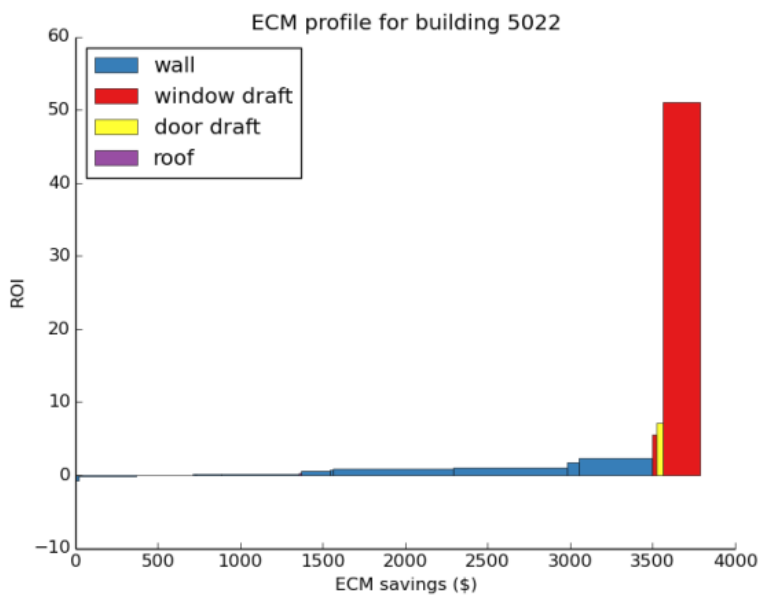

Figure E-149. ECM profile for Bldg 5022, Scott AFB.

Table E-58 lists the recommended envelope ECMs for Bldg 5022, Scott AFB.

Table E-58. Envelope ECMs for Bldg 5022, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1876	4521	2773	23670	8.5
Seal Window Frame Leaks	173	418	256	131	0.5
Seal Door Frame Leaks	24	58	36	66	1.8
Improve Roof Insulation	15	36	22	277	12.6

Annual potential remediation savings for this building are $3,086 and total payback is 7.8 years for envelope-related ECMs.

E.1.30.4 Non-Envelope ECMs for Bldg 5022, Scott AFB

Table E-59 lists the recommended non-envelope ECMs for Bldg 5022, Scott AFB.

Table E-59. Non-envelope ECMs for Bldg 5022, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	95198	-1238	5093	68479	13.4
Occupancy Sensors	42691	-555	2284	2288	1.0
LED Exit Signs	16250	-171	890	1950	2.2
Boiler Tune-up	0	266	133	560	4.2

Annual potential remediation savings for this building are $8,399 and total payback is 8.7 years for non-envelope ECMs.

Table E-60 lists the recommended non-envelope ECMs for Bldg 61, Scott AFB.

Table E-60. Non-envelope ECMs for Bldg 61, Scott AFB.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	35772	-465	1914	25732	13.4
Occupancy Sensors	16041	-209	858	860	1.0
LED Exit Signs	4875	-51	267	585	2.2
Boiler Tune-up	0	94	47	211	4.5

Annual potential remediation savings for this building are $3,086 and total payback is 8.9 years for non-envelope ECMs.

E.2 Detailed Analysis for Marine Corps Base Camp Lejeune, NC

E.2.1 Bldg 1

E.2.1.1 Description of Bldg 1, Marine Corps Base Camp Lejeune, NC

Name: Base Headquarters
Use Type: Office
Square Footage: 36,832
Avg. Daily Electric Use: 2,166 kWh
Electricity Score: 80th Percentile

Bldg 1 (Figure E-150 and E-151) has an electricity usage of 21.5 kWh/sq ft/yr.

Figure E-150. Aerial view of Bldg 1, Camp Lejeune.

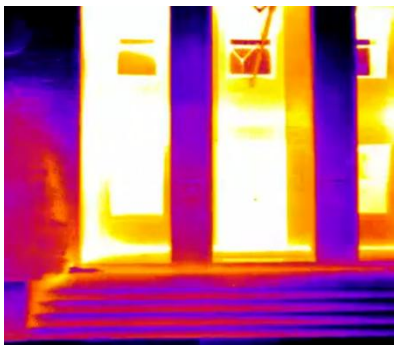

Figure E-151. Thermal image of Bldg 1, Camp Lejeune.

E.2.1.2 Notable Leaks at Bldg 1, Marine Corps Base Camp Lejeune, NC

The brick wall at timestamp 323:17 in the online drive-by application is highly emissive (Figure E-152). There are some insulation holes around the middle of the wall, and the overall surface appears poorly insulated compared to other walls on the base.

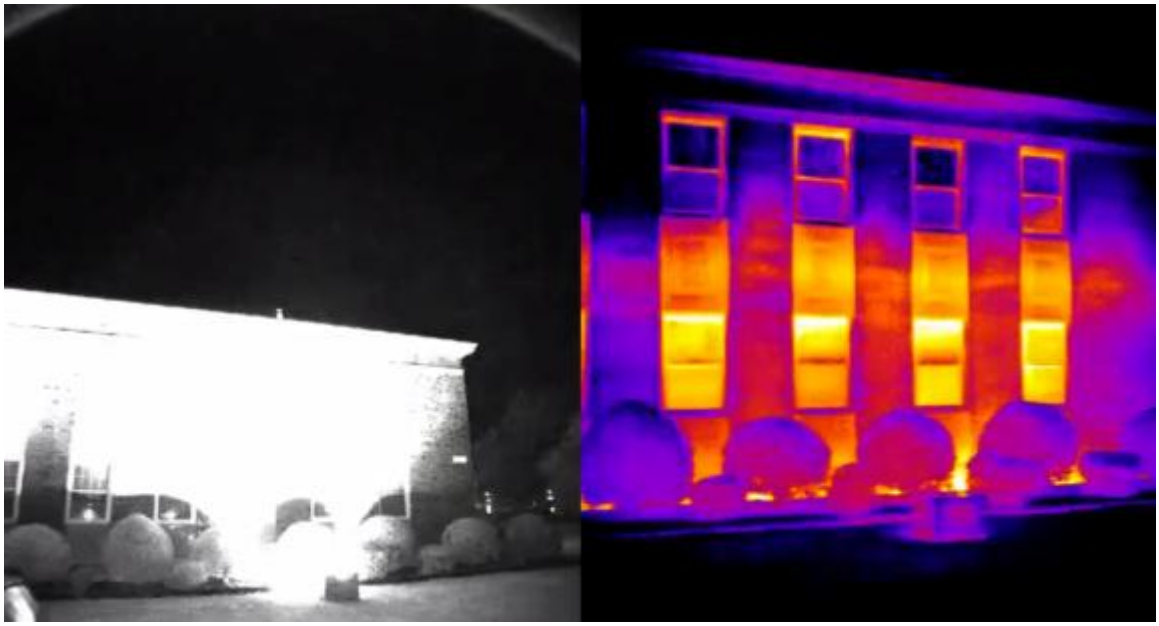

Figure E-152. NIR image (left) and thermal image (right) of Bldg 1, Camp Lejeune.

The wall at timestamp 323:22 is also highly emissive, and has some apparent insulation holes near the middle of the wall (Figure E-153). The soffit is also fairly emissive, and the window frames in the upper left are potentially leaky.

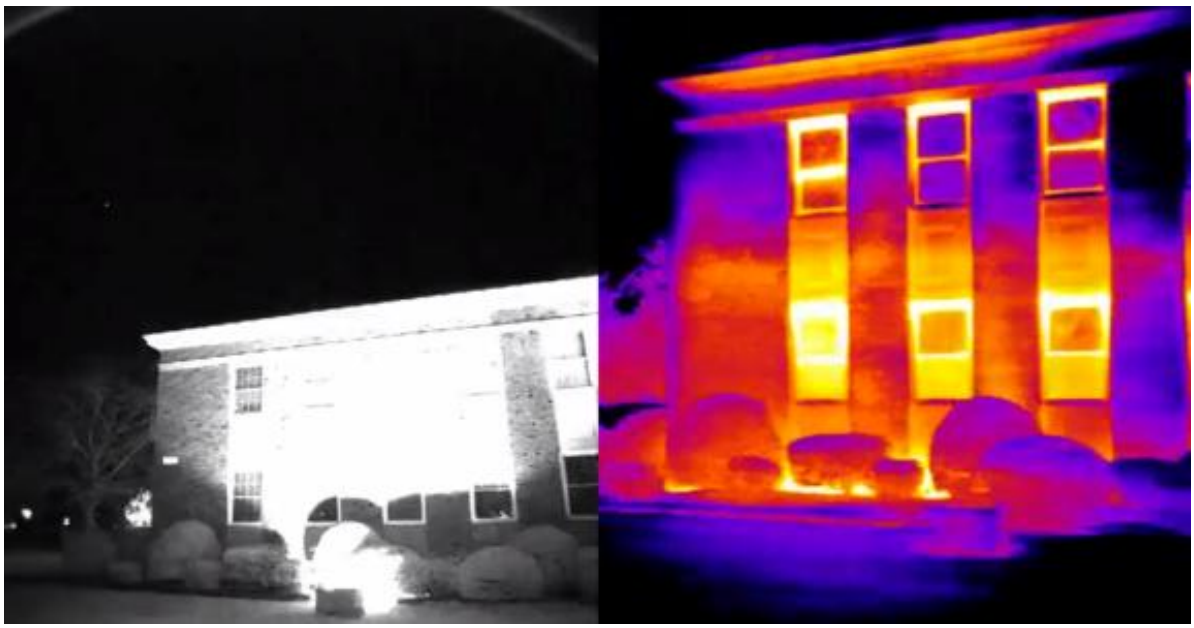

Figure E-153. NIR image (left) and thermal image (right) of Bldg 1, Camp Lejeune. Note apparent insulation holes near the middle of the wall, a fairly emissive soffit and apparently leaky window frames.

E.2.1.3 Envelope ECMs for Bldg 1, Marine Corps Base Camp Lejeune, NC

Figure E-154 shows the relative ROI for envelope ECMs for Bldg 1, Camp Lejeune.

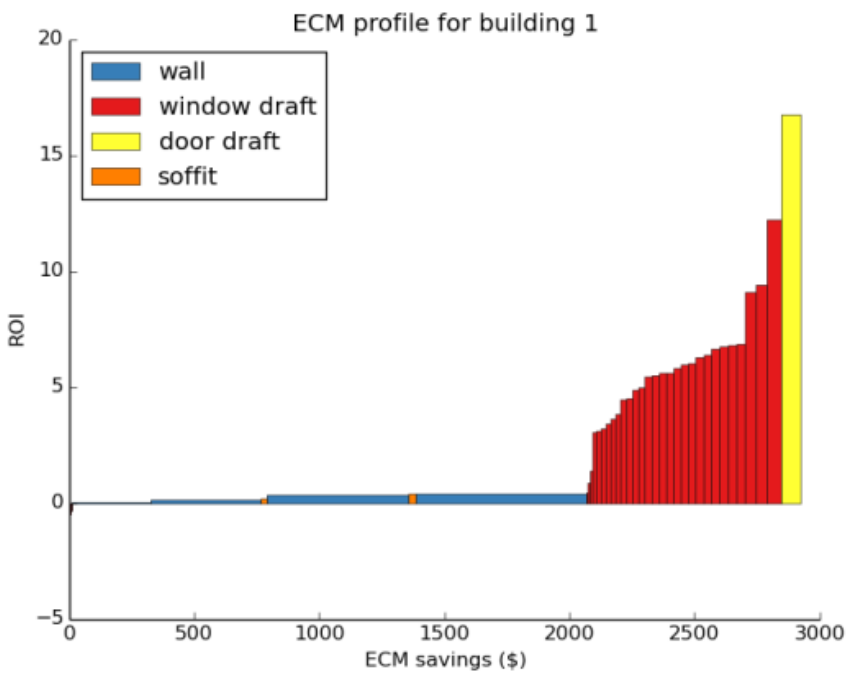

Figure E-154. ECM profile for Bldg 1, Camp Lejeune.

Table E-61 lists the recommended envelope ECMs for Bldg 1, Camp Lejeune

Table E-61. Envelope ECMs for Bldg 1, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	3161	3096	2003	24240	12.1
Seal Window Frame Leaks	1244	1218	788	2069	2.6
Seal Door Frame Leaks	120	118	76	65	0.8
Improve Soffit Insulation	79	77	50	583	11.7

Annual potential remediation savings for this building are $2,918 and total payback is 9.2 years for envelope-related ECMs.

E.2.1.4 Non-Envelope ECMs for Bldg 1, Marine Corps Base Camp Lejeune, NC

Table E-62 lists the recommended non-envelope ECMs for Bldg 1, Camp Lejeune.

Table E-62. Non-envelope ECMs for Bldg 1, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	96157	-565	5487	55086	10.0
Occupancy Sensors	43120	-253	2461	1841	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Some lighting-related actions save negative therms because their more efficient replacements emit less waste heat and require a bit of additional work on the part of the building heating system.

Annual potential remediation savings for this building are $8,837 and total payback is 6.7 years for non-envelope ECMs.

E.2.2 Bldg 8

E.2.2.1 Description of Bldg 8, Marine Corps Base Camp Lejeune, NC

Name: Administrative Office
Use Type: Office
Square Footage: 26,602
Avg. Daily Electric Use: 1,517 kWh
Electricity Score: 95th Percentile

Bldg 8 (Figures E-155 and E-156) has an electricity usage of 20.8 kWh/sq ft/yr.

Figure E-155. Aerial view of Bldg 8, Camp Lejeune.

Figure E-156. Thermal image of Bldg 8, Camp Lejeune.

E.2.2.2 Notable Leaks at Bldg 8, Marine Corps Base Camp Lejeune, NC

The wall of Bldg 8 at timestamp 319:57 is highly emissive relative to other buildings on the base (Figure E-157). The exposed foundation wall is also poorly insulated, allowing heat to escape from the surface. The window frames on the left side of the building are highly emissive.

Figure E-157. NIR image (left) and thermal image (right) of Bldg 8, Camp Lejeune.

The wall at timestamp 319:58 is quite emissive, with a notable thermal bridge around the middle of the wall (Figure E-158).

Figure E-158. NIR image (left) and thermal image (right) of Bldg 8, Camp Lejeune. Note the thermal bridge around the middle of the wall.

E.2.2.3 Envelope ECMs for Bldg 8, Marine Corps Base Camp Lejeune, NC

Figure E-159 shows the relative ROI for envelope ECMs for Bldg 8, Camp Lejeune.

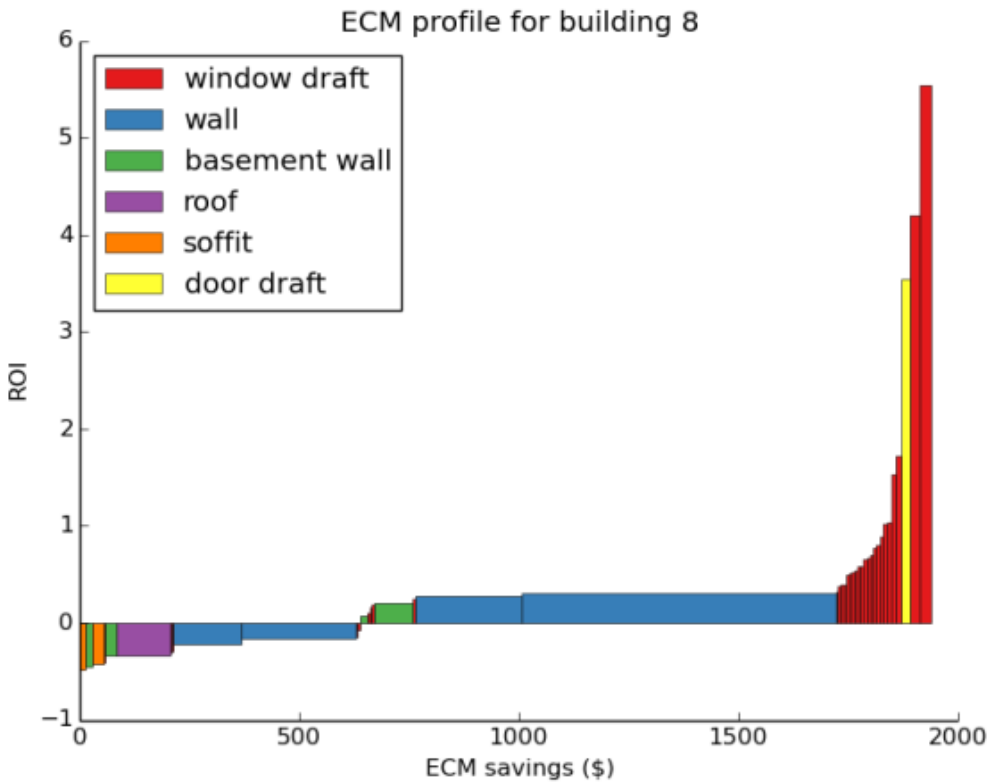

Figure E-159. ECM profile for Bldg 8, Camp Lejeune.

Table E-63 lists the recommended envelope ECMs for Bldg 8, Camp Lejeune.

Table E-63. Envelope ECMs for Bldg 8, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	2168	2123	1374	18682	13.6
Seal Window Frame Leaks	372	364	236	2005	8.5
Basement Wall Insulation	232	227	147	2334	15.9
Improve Roof Insulation	192	188	122	2749	22.5
Improve Soffit Insulation	67	66	42	1144	26.9

Annual potential remediation savings for this building are $1,941 and total payback is 13.9 years for envelope-related ECMs.

E.2.2.4 Non-Envelope ECMs for Bldg 8, Marine Corps Base Camp Lejeune, NC

Table E-64 lists the recommended non-envelope ECMs for Bldg 8, Camp Lejeune.

Table E-64. Non-envelope ECMs for Bldg 8, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	69450	-408	3963	39786	10.0
Occupancy Sensors	31144	-183	1777	1330	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $6,630 and total payback is 6.5 years for non-envelope ECMs.

E.2.3 Bldg 11

E.2.3.1 Description of Bldg 11, Marine Corps Base Camp Lejeune, NC

Name: Administrative Office
Use Type: Office
Square Footage: 3,998
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-160 and E-161, respectively, show the aerial view and thermal image of Bldg 11, Camp Lejeune.

Figure E-160. Aerial view of Bldg 11, Camp Lejeune.

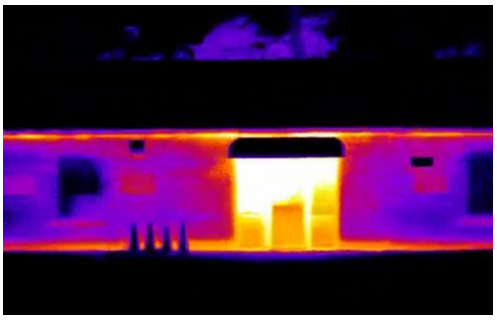

Figure E-161. Thermal image of Bldg 11, Camp Lejeune.

E.2.3.2 Notable Leaks at Bldg 11, Marine Corps Base Camp Lejeune, NC

The soffit at timestamp 322:04 and the door frame are highly emissive, which potentially indicates poor insulation or convective leaks (Figure E-162). There are two notable hot spots to the left and right of the door.

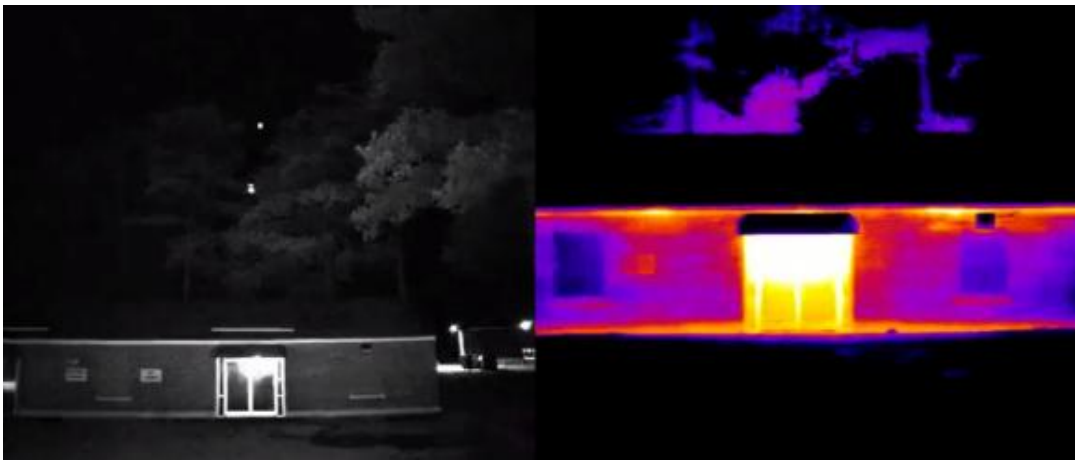

Figure E-162. NIR image (left) and thermal image (right) of Bldg 11, Camp Lejeune.

The wall to the left of the door at timestamp 322:07 has a number of emissive hot spots, as well as an emissive soffit (Figure E-163).

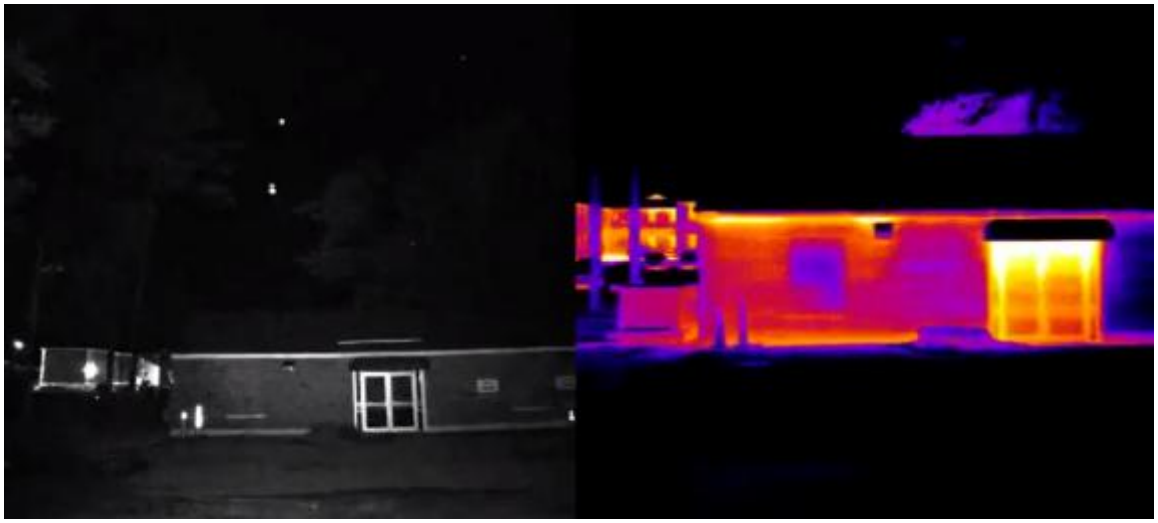

Figure E-163. NIR image (left) and thermal image (right) of Bldg 11, Camp Lejeune. The wall to the left of the door has a number of emissive hot spots, as well as an emissive soffit.

E.2.3.3 Envelope ECMs for Bldg 11, Marine Corps Base Camp Lejeune, NC

Figure E-164 shows the relative ROI for envelope ECMs for Bldg 11, Camp Lejeune.

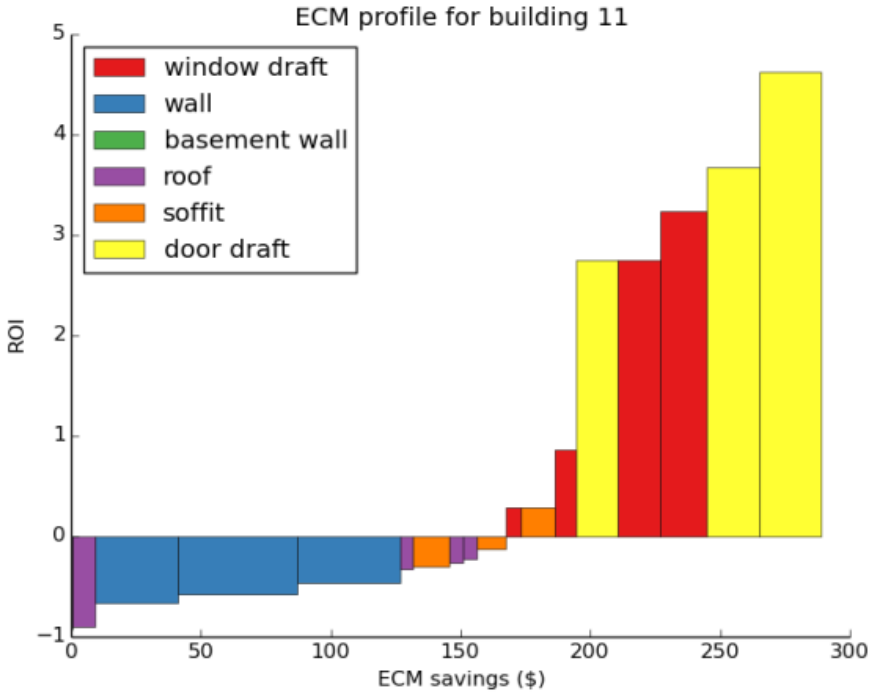

Figure E-164. ECM profile for Bldg 11, Camp Lejeune.

Table E-65 lists the recommended envelope ECMs for Bldg 11, Camp Lejeune.

Table E-65. Envelope ECMs for Bldg 11, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Door Frame Leaks	95	93	60	193	3.2
Seal Window Frame Leaks	76	74	48	260	5.4
Improve Wall Insulation	62	61	40	1123	28.4
Improve Soffit Insulation	61	60	39	661	17.0
Improve Roof Insulation	24	24	15	317	20.8

Annual potential remediation savings for this building are $202 and total payback is 12.6 years for envelope-related ECMs.

E.2.3.4 Non-Envelope ECMs for Bldg 11, Marine Corps Base Camp Lejeune, NC

Table E-66 lists the recommended non-envelope ECMs for Bldg 11, Camp Lejeune.

Table E-66. Non-envelope ECMs for Bldg 11, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	10849	-63	619	5980	9.7
Occupancy Sensors	4865	-28	278	200	0.7
EnergyStar Vending Machines	1842	0	111	500	4.5

Annual potential remediation savings for this building are $986 and total payback is 6.5 years for non-envelope ECMs.

E.2.4 Bldg 15

E.2.4.1 Description of Bldg 15, Marine Corps Base Camp Lejeune, NC

Name: Medical/Dental Clinic
Use Type: Health
Square Footage: 18,222
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-165 and E-166, respectively, show the aerial view and thermal image of Bldg 15, Camp Lejeune.

Figure E-165. Aerial view of Bldg 15, Camp Lejeune.

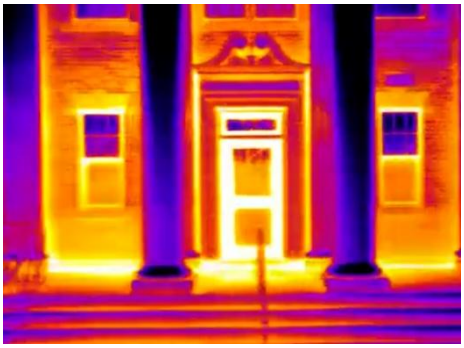

Figure E-166. Thermal image of Bldg 15, Camp Lejeune.

E.2.4.2 Notable Leaks at Bldg 15, Marine Corps Base Camp Lejeune, NC

The wall and exposed foundation of Bldg 15 at timestamp 324:17 are quite emissive, which indicates poor insulation (Figure E-167). The two window frames in the bottom right corner are notably hot, and may have high convective air leakage.

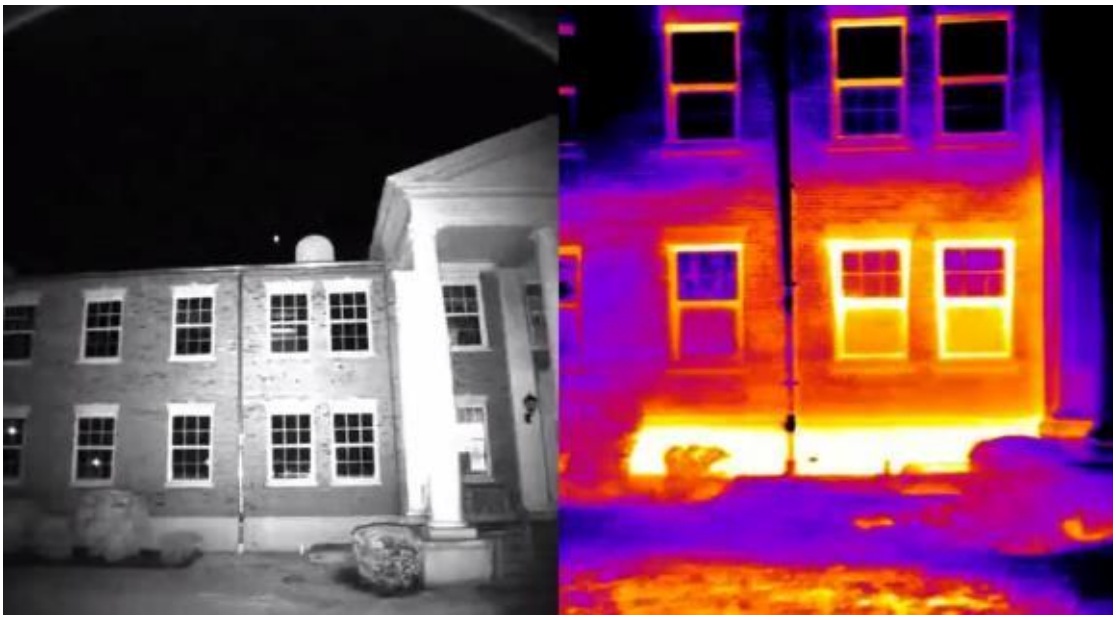

Figure E-167. NIR image (left) and thermal image (right) of Bldg 15, Camp Lejeune.

E.2.4.3 Envelope ECMs for Bldg 15, Marine Corps Base Camp Lejeune, NC

Figure E-168 shows the relative ROI for envelope ECMs for Bldg 15, Camp Lejeune.

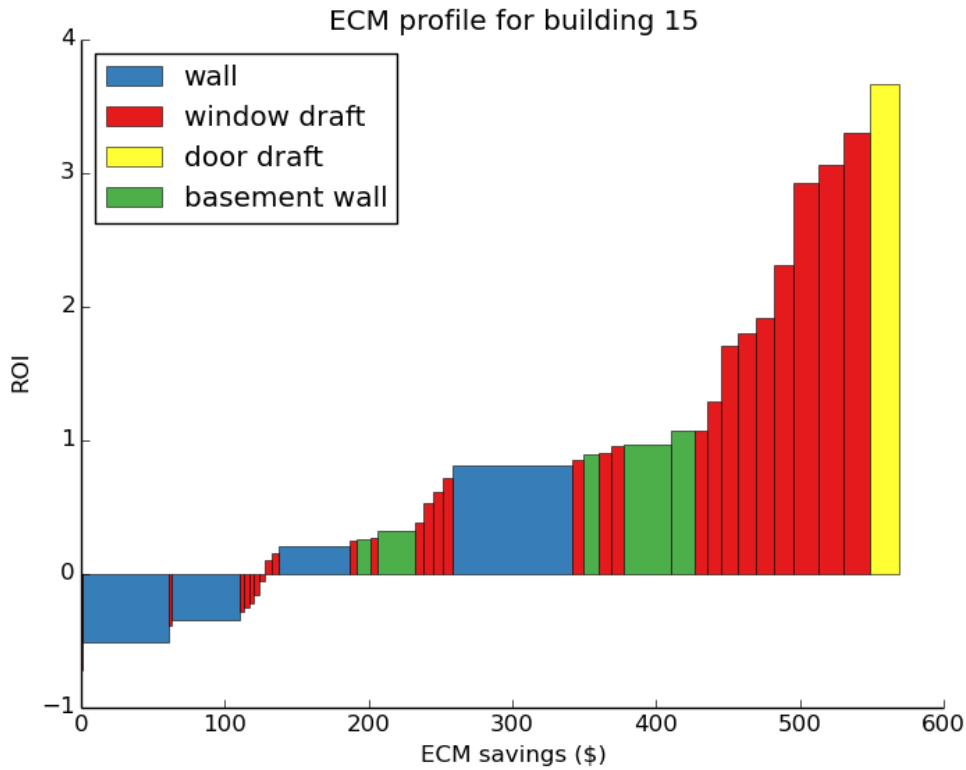

Figure E-168. ECM profile for Bldg 15, Camp Lejeune.

Table E-67 lists the recommended envelope ECMs for Bldg 15, Camp Lejeune.

Table E-67. Envelope ECMs for Bldg 15, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Window Frame Leaks	338	331	214	1681	7.9
Improve Wall Insulation	282	276	179	2382	13.3
Basement Wall Insulation	150	147	95	860	9.0
Seal Door Frame Leaks	32	31	20	65	3.2

Annual potential remediation savings for this building are $508 and total payback is 9.8 years for envelope-related ECMs.

E.2.4.4 Non-Envelope ECMs for Bldg 15, Marine Corps Base Camp Lejeune, NC

Table E-68 lists the recommended non-envelope ECMs for Bldg 15, Camp Lejeune.

Table E-68. Non-envelope ECMs for Bldg 15, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	49440	-288	2822	27253	9.7
Occupancy Sensors	22171	-129	1266	911	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $4,355 and total payback is 6.6 years for non-envelope ECMs.

E.2.5 Bldg 18

E.2.5.1 Description of Bldg 18, Marine Corps Base Camp Lejeune, NC

Name: Fire Headquarters
Use Type: Misc.
Square Footage: 13,122
Avg. Daily Electric Use: 560.7 kWh
Electricity Score: 65th Percentile

Bldg 18 (Figures E-169 and E-170) has an electricity usage of 15.6 kWh/sq ft/yr.

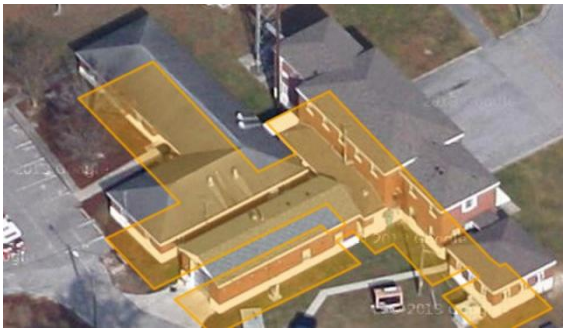

Figure E-169. Aerial view of Bldg 18, Camp Lejeune.

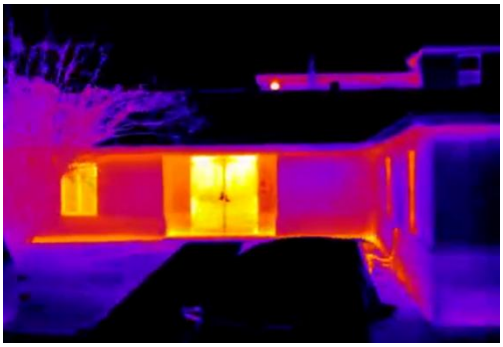

Figure E-170. Thermal image of Bldg 18, Camp Lejeune.

E.2.5.2 Notable Leaks at Bldg 18, Marine Corps Base Camp Lejeune, NC

The soffit on Bldg 18 at timestamp 91:18 is highly emissive. There is also a small hot spot on the wall on the left side of the image (Figure E-171).

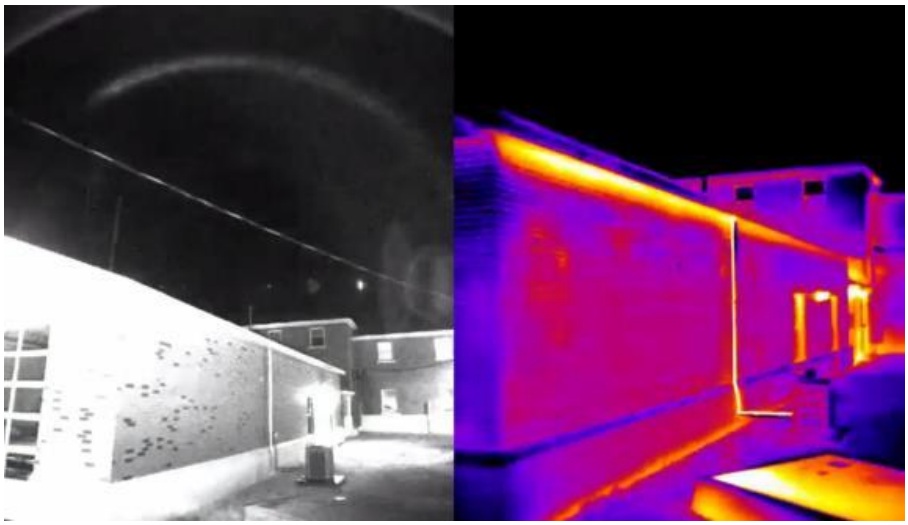

Figure E-171. NIR image (left) and thermal image (right) of Bldg 18, Camp Lejeune.

The wall near the center of the building at timestamp 91:23 and the exposed foundation/basement wall are highly emissive, which indicates poor insulation (Figure E-172).

Figure E-172. NIR image (left) and thermal image (right) of Bldg 18, Camp Lejeune. The wall near the center of the building and the exposed foundation/basement wall are highly emissive.

E.2.5.3 Envelope ECMs for Bldg 18, Marine Corps Base Camp Lejeune, NC

Figure E-173 shows the relative ROI for envelope ECMs for Bldg 18, Camp Lejeune.

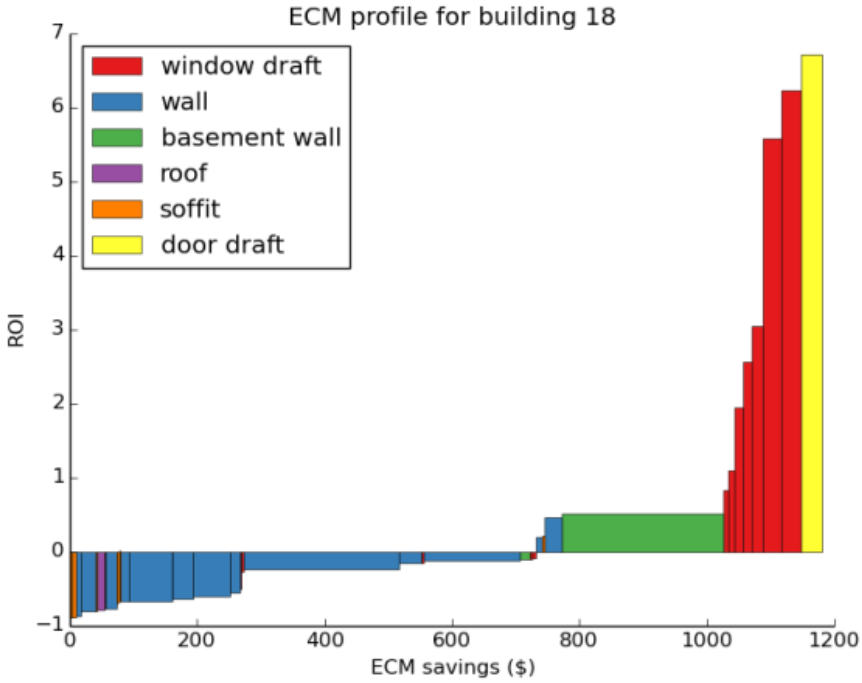

Figure E-173. ECM profile for Bldg 18, Camp Lejeune.

Table E-69 lists the recommended envelope ECMs for Bldg 18, Camp Lejeune.

Table E-69. Envelope ECMs for Bldg 18, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	740	724	468	8456	18.0
Basement Wall Insulation	427	418	271	2801	10.4
Seal Window Frame Leaks	216	211	137	713	5.2
Seal Door Frame Leaks	52	51	33	64	1.9

Annual potential remediation savings for this building are $909 and total payback is 13.2 years for envelope-related ECMs.

E.2.5.4 Non-Envelope ECMs for Bldg 18, Marine Corps Base Camp Lejeune, NC

Figure E-69 lists the recommended non-envelope ECMs for Bldg 18, Camp Lejeune.

Table E-70. Non-envelope ECMs for Bldg 18, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	35602	-207	2032	19625	9.7
Occupancy Sensors	15965	-93	911	656	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $3,211 and total payback is 6.5 years for non-envelope ECMs.

E.2.6 Bldg 20

E.2.6.1 Description of Bldg 20, Marine Corps Base Camp Lejeune, NC

Name: Water Treatment
Use Type: Misc.
Square Footage: 10,690
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-174 and E-175, respectively, show the aerial view and thermal image of Bldg 15, Camp Lejeune.

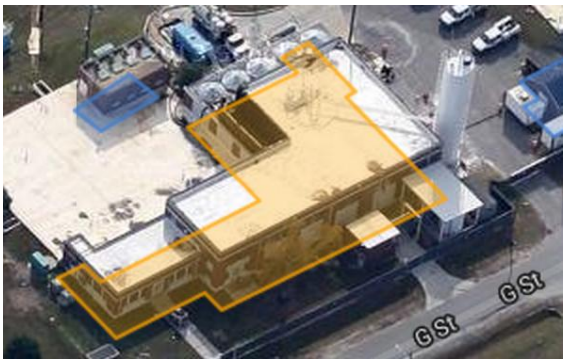

Figure E-174. Aerial view of Bldg 20, Camp Lejeune.

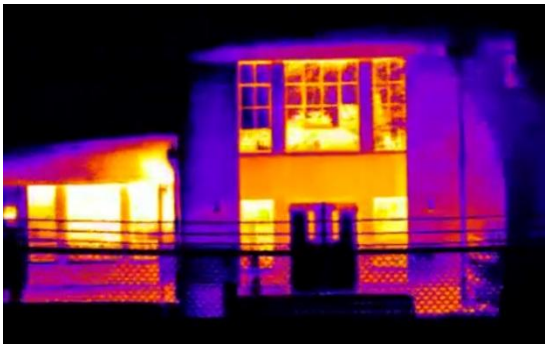

Figure E-175. Thermal image of Bldg 20, Camp Lejeune.

E.2.6.2 Notable Leaks at Bldg 20, Marine Corps Base Camp Lejeune, NC

There is a hot spot on the middle of the wall of Bldg 20 at timestamp 313:13 that may indicate a hole in the wall insulation (Figure E-176).

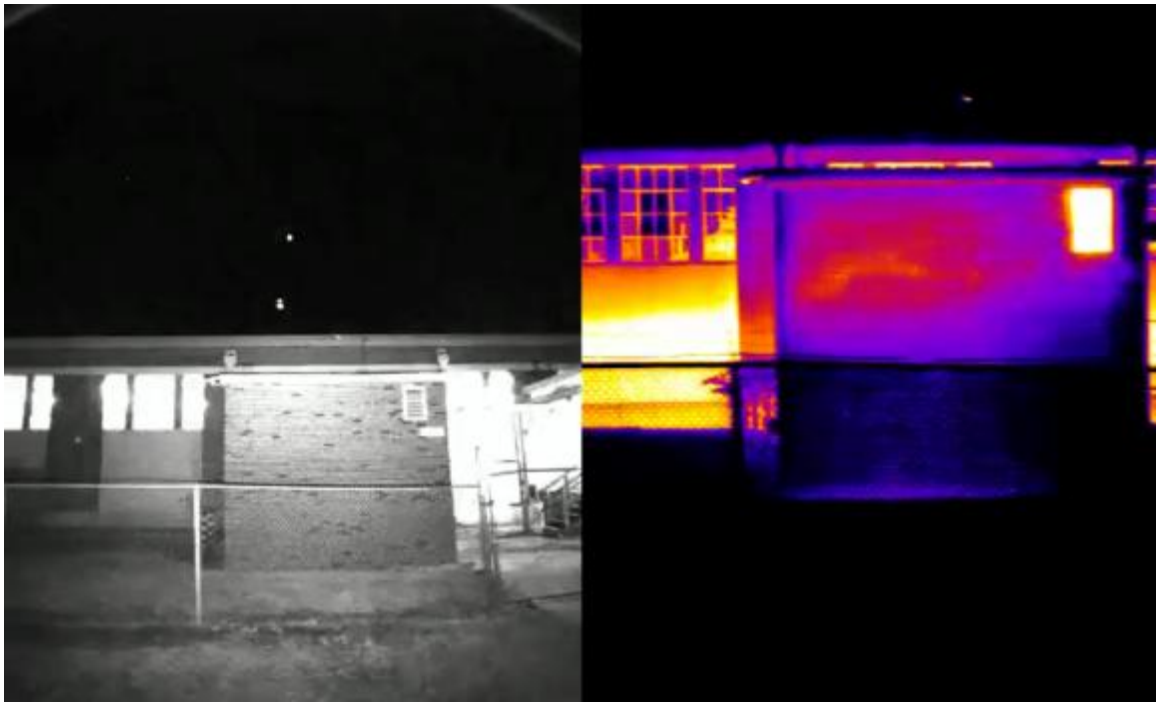

Figure E-176. NIR image (left) and thermal image (right) of Bldg 20, Camp Lejeune.

The windows visible at timestamp 313:16 are notably emissive. There are also some leaks along the door in the center of the image (Figure E-177).

Figure E-177. NIR image (left) and thermal image (right) of Bldg 20, Camp Lejeune. The windows are notably emissive and there are leaks along the door in the center of the image.

E.2.6.3 Envelope ECMs for Bldg 20, Marine Corps Base Camp Lejeune, NC

Figure E-178 shows the relative ROI for envelope ECMs for Bldg 20, Camp Lejeune.

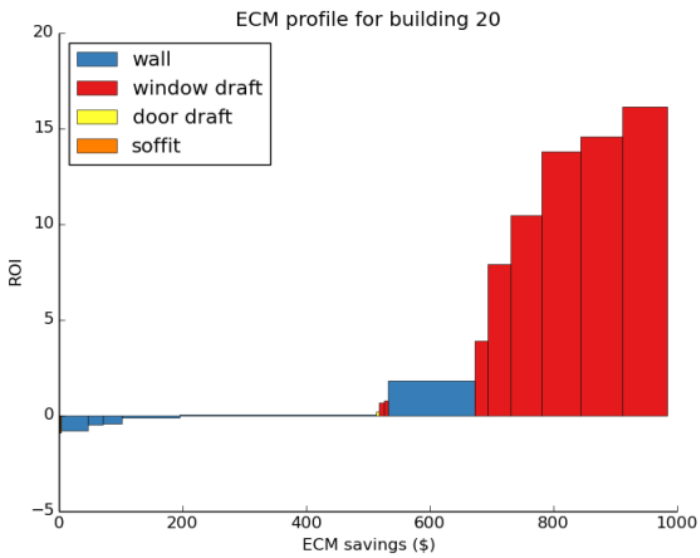

Figure E-178. ECM profile for Bldg 20, Camp Lejeune.

Table E-71 lists the recommended envelope ECMs for Bldg 20, Camp Lejeune.

Table E-71. Envelope ECMs for Bldg 20, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	916	897	581	7958	13.7
Seal Window Frame Leaks	516	506	327	517	1.6

Annual potential remediation savings for this building are $908 and total payback is 9.3 years for envelope-related ECMs.

E.2.6.4 Non-Envelope ECMs for Bldg 20, Marine Corps Base Camp Lejeune, NC

Table E-72 lists the recommended non-envelope ECMs for Bldg 20, Camp Lejeune.

Table E-72. Non-envelope ECMs for Bldg 20, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	29006	-169	1656	15989	9.7
Occupancy Sensors	13007	-76	743	534	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $2,665 and total payback 6.4 years for non-envelope ECMs.

E.2.7 Bldg 26

E.2.7.1 Description of Bldg 26, Marine Corps Base Camp Lejeune, NC

Name: Training Material Storage
Use Type: Misc.
Square Footage: 3,553
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-179 and E-180, respectively, show the aerial view and thermal image of Bldg 26, Camp Lejeune.

Figure E-179. Aerial view of Bldg 26, Camp Lejeune.

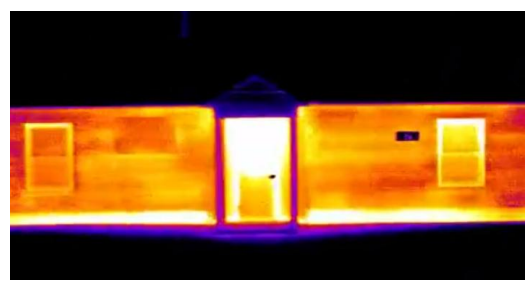

Figure E-180. Thermal image of Bldg 26, Camp Lejeune.

E.2.7.2 Notable Leaks at Bldg 26, Marine Corps Base Camp Lejeune, NC

The wall of Bldg 26 visible at timestamp 321:34 had particularly poor insulation, with large notable hotspots (Figure E-181). The door in the center has large leaks in the frame that could potentially be mitigated through air sealing.

Figure E-181. NIR image (left) and thermal image (right) of Bldg 26, Camp Lejeune.

E.2.7.3 Envelope ECMs for Bldg 26, Marine Corps Base Camp Lejeune, NC

Figure E-182 shows the relative ROI for envelope ECMs for Bldg 26, Camp Lejeune.

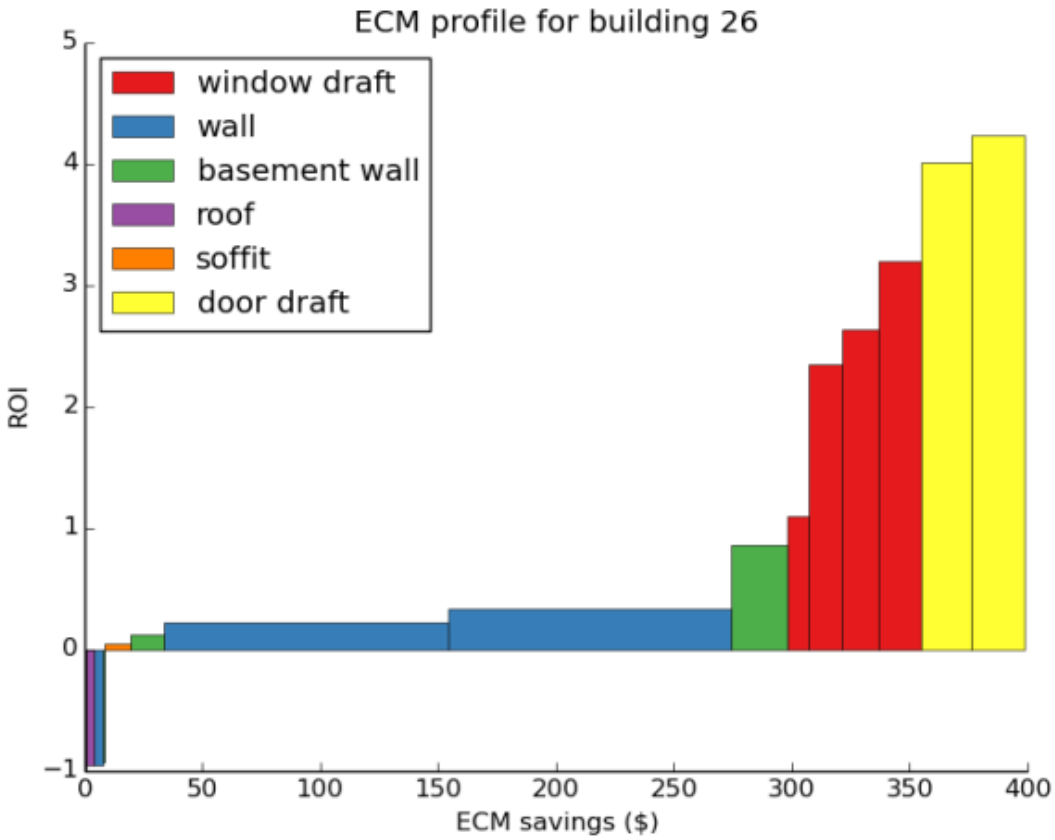

Figure E-182. ECM profile for Bldg 26, Camp Lejeune.

Table E-73 lists the recommended envelope ECMs for Bldg 26, Camp Lejeune.

Table E-73. Envelope ECMs for Bldg 26, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	379	371	240	2837	11.8
Seal Window Frame Leaks	90	88	57	259	4.5
Seal Door Frame Leaks	69	68	44	129	2.9
Basement Wall Insulation	61	59	38	388	10.1
Improve Soffit Insulation	17	17	11	154	14.4

Annual potential remediation savings for this building are $390 and total payback is 9.6 years for envelope-related ECMs.

E.2.7.4 Non-Envelope ECMs for Bldg 26, Marine Corps Base Camp Lejeune, NC

Table E-74 lists the recommended non-envelope ECMs for Bldg 26, Camp Lejeune.

Table E-74. Non-envelope ECMs for Bldg 26, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	9640	-56	550	5314	9.7
Occupancy Sensors	4323	-25	247	178	0.7
EnergyStar Vending Machines	1842	0	111	500	4.5

Annual potential remediation savings for this building are $886 and total payback is 6.4 years for non-envelope ECMs.

E.2.8 Bldg 37

E.2.8.1 Description of Bldg 37, Marine Corps Base Camp Lejeune, NC

Name: CI HunInt Support Company
Use Type: Office
Square Footage: 10,068
Avg. Daily Electric Use: 405.5 kWh
Electricity Score: 60th Percentile
Electricity Usage: 14.7 kWh/sq ft/yr.

Figures E-183 and E-184, respectively, show the aerial view and thermal image of Bldg 37, Camp Lejeune.

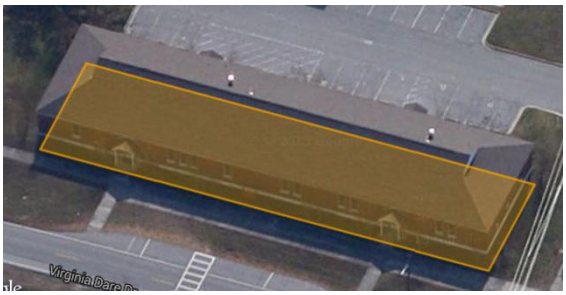

Figure E-183. Aerial view of Bldg 37, Camp Lejeune.

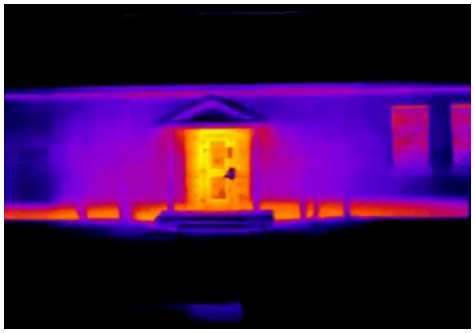

Figure E-184. Thermal image of Bldg 37, Camp Lejeune.

E.2.8.2 Notable Leaks at Bldg 37, Marine Corps Base Camp Lejeune, NC

The exposed foundation of Bldg 37 at timestamp 133:58 is highly emissive (Figure E-185). The window frames are also much warmer than typical window frames on Lejeune buildings, which indicates convective leakage.

Figure E-185. NIR image (left) and thermal image (right) of Bldg 37, Camp Lejeune.

E.2.8.3 Envelope ECMs for Bldg 37, Marine Corps Base Camp Lejeune, NC

Figure E-186 shows the relative ROI for envelope ECMs for Bldg 37, Camp Lejeune.

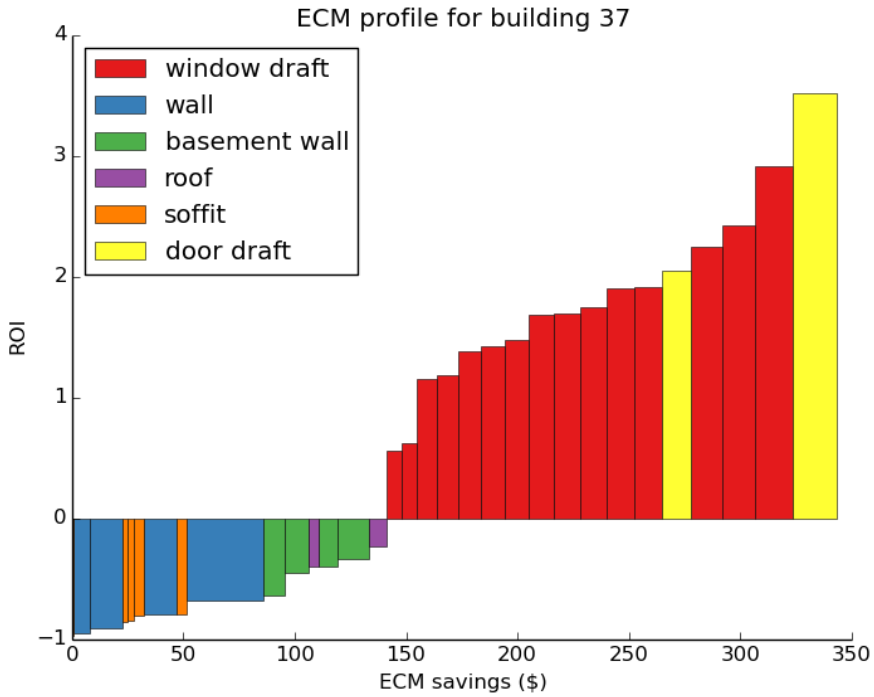

Figure E-186. ECM profile for Bldg 37, Camp Lejeune.

Table E-75 lists the recommended envelope ECMs for Bldg 37, Camp Lejeune.

Table E-75. Envelope ECMs for Bldg 37, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Window Frame Leaks	268	262	170	972	5.7
Basement Wall Insulation	53	51	33	828	24.9
Seal Door Frame Leaks	51	50	32	128	4.0

Annual potential remediation savings for this building are $247 and total payback is 8.8 years for envelope-related ECMs.

E.2.8.4 Non-Envelope ECMs for Bldg 37, Marine Corps Base Camp Lejeune, NC

Table E-76 lists the recommended non-envelope ECMs for Bldg 37, Camp Lejeune.

Table E-76. Non-envelope ECMs for Bldg 37, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	27316	-159	1559	15058	9.7
Occupancy Sensors	12250	-71	699	503	0.7
LED Exit Signs	4875	-51	267	585	2.2

Total potential non-envelope remediation savings for this building are $2,526 and total payback is 6.4 years for non-envelope ECMs.

E.2.9 Bldg 58

E.2.9.1 Description of Bldg 58, Marine Corps Base Camp Lejeune, NC

Name: Administrative Office
Use Type: Office
Square Footage: 31,043
Avg. Daily Electric Use: 1,898 kWh
Electricity Score: 95th Percentile

Bldg 58 (Figures E-187 and E-187) has an electricity usage of 22.3 kWh/sq ft/yr.

Figure E-187. Aerial view of Bldg 58, Camp Lejeune.

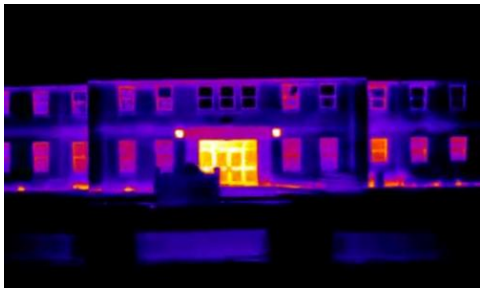

Figure E-188. Thermal image of Bldg 58, Camp Lejeune.

E.2.9.2 Notable Leaks at Bldg 58, Marine Corps Base Camp Lejeune, NC

Bldg 58 has a thermal bridge noticeable near the middle of the wall on the right side at timestamp 134:44 (Figure E-189). There is also a hot spot on the wall on the left side of the image.

Figure E-189. NIR image (left) and thermal image (right) of Bldg 58, Camp Lejeune.

There are some leaks near the foundation at timestamp 134:49. The doorframe is also particularly emissive (Figure E-190).

Figure E-190. NIR image (left) and thermal image (right) of Bldg 58, Camp Lejeune. Note leaks near the foundation and at the door frame.

E.2.9.3 Envelope ECMs for Bldg 58, Marine Corps Base Camp Lejeune, NC

Figure E-191 shows the relative ROI for envelope ECMs for Bldg 58, Camp Lejeune.

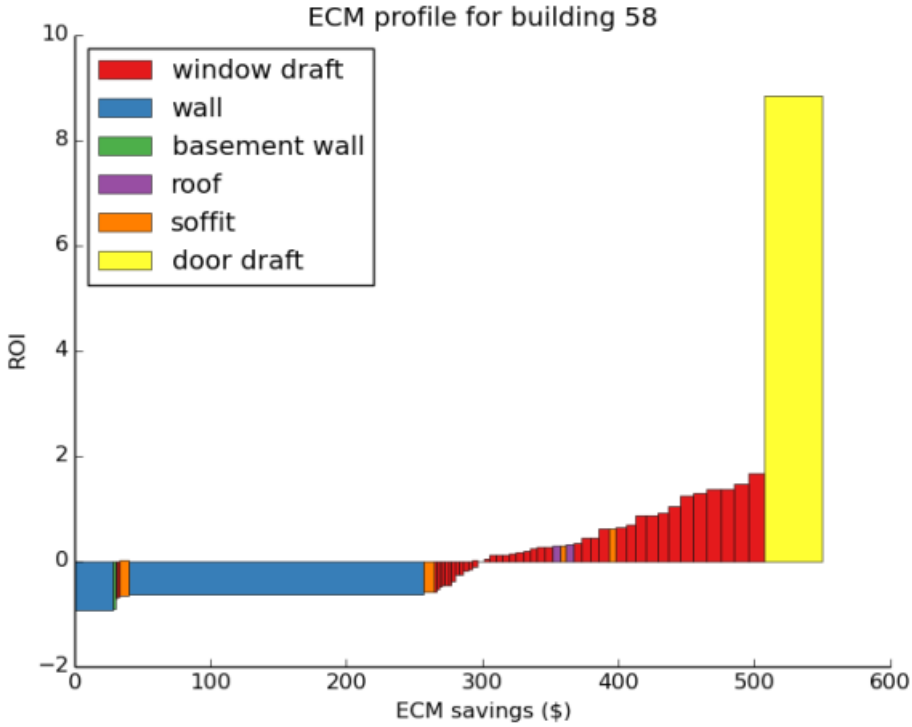

Figure E-191. ECM profile for Bldg 58, Camp Lejeune.

Table E-77 lists the recommended envelope ECMs for Bldg 58, Camp Lejeune.

Table E-77. Envelope ECMs for Bldg 58, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Window Frame Leaks	344	337	218	2392	11.0
Seal Door Frame Leaks	66	65	42	64	1.5
Improve Roof Insulation	19	18	12	136	11.6

Annual potential remediation savings for this building are $272 and total payback is 9.5 years for envelope-related ECMs.

E.2.9.4 Non-Envelope ECMs for Bldg 58, Marine Corps Base Camp Lejeune, NC

Table E-78 lists the recommended non-envelope ECMs for Bldg 58, Camp Lejeune.

Table E-78. Non-envelope ECMs for Bldg 58, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	81044	-476	4625	46428	10.0
Occupancy Sensors	36343	-213	2074	1552	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $7,588 and total payback is 6.6 years for non-envelope ECMs.

E.2.10 Bldg 62

E.2.10.1 Description of Bldg 62, Marine Corps Base Camp Lejeune, NC

Name: Recreation Center
Use Type: Recreation
Square Footage: 16,426
Avg. Daily Electric Use: 1,482 kWh
Electricity Score: 95th Percentile
Electricity Usage: 32.9 kWh/sq ft/yr

Figures E-192 and E-193, respectively, show the aerial view and thermal image of Bldg 62, Camp Lejeune.

Figure E-192. Aerial view of Bldg 62, Camp Lejeune.

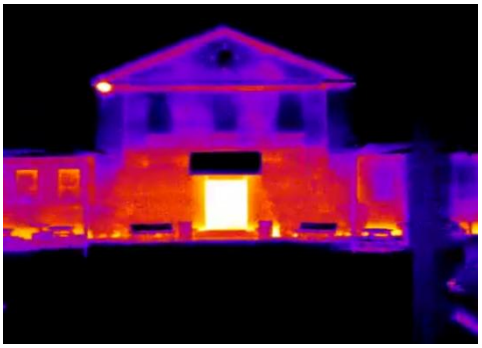

Figure E-193. Thermal image of Bldg 62, Camp Lejeune.

E.2.10.2 Notable Leaks at Bldg 62, Marine Corps Base Camp Lejeune, NC

The walls of Bldg 62 at timestamp 325:33 are poorly insulated (Figure E-194).

Figure E-194. NIR image (left) and thermal image (right) of Bldg 62, Camp Lejeune.

The soffit at timestamp 325:36 is emissive, as are the window frames visible in the image (Figure E-195).

Figure E-195. NIR image (left) and thermal image (right) of Bldg 62, Camp Lejeune. The soffit and window frames appear to be highly emissive.

E.2.10.3 Envelope ECMs for Bldg 62, Marine Corps Base Camp Lejeune, NC

Figure E-196 shows the relative ROI for envelope ECMs for Bldg 62, Camp Lejeune.

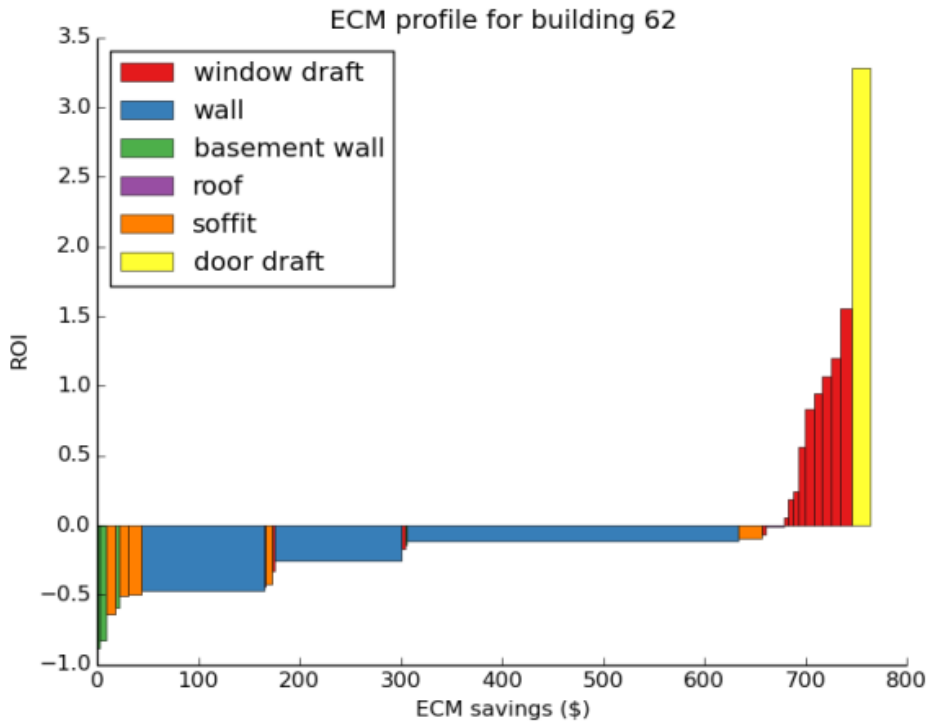

Figure E-196. ECM profile for Bldg 62, Camp Lejeune.

Table E-79 lists the recommended envelope ECMs for Bldg 62, Camp Lejeune.

Table E-79. Envelope ECMs for Bldg 62, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	903	884	572	11474	20.0
Seal Window Frame Leaks	127	124	80	841	10.5
Improve Soffit Insulation	46	45	29	543	18.5
Seal Door Frame Leaks	29	28	18	64	3.5
Improve Roof Insulation	27	27	17	261	15.1

Annual potential remediation savings for this building are $718 and total payback is 18.4 years for envelope-related ECMs.

E.2.10.4 Non-Envelope ECMs for Bldg 62, Marine Corps Base Camp Lejeune, NC

Table E-80 lists the recommended non-envelope ECMs for Bldg 62, Camp Lejeune.

Table E-80. Non-envelope ECMs for Bldg 62, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	44566	-260	2544	24567	9.7
Occupancy Sensors	19985	-116	1141	821	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $3,952 and total payback is 6.6 years for non-envelope ECMs.

E.2.11 Bldg 116

E.2.11.1 Description of Bldg 116, Marine Corps Base Camp Lejeune, NC

Name: Strategic Air/Ground Org Marine
Use Type: Office
Square Footage: 3,688
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-197 and E-198, respectively, show the aerial view and thermal image of Bldg 116, Camp Lejeune.

Figure E-197. Aerial view of Bldg 116, Camp Lejeune.

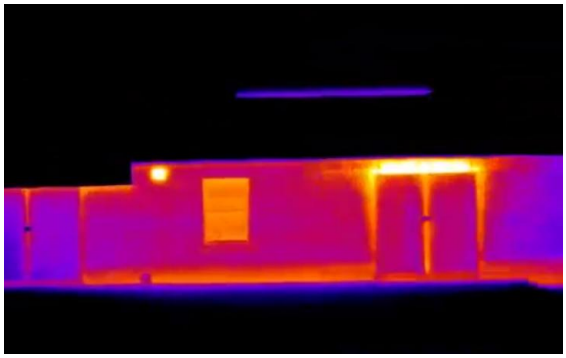

Figure E-198. Thermal image of Bldg 116, Camp Lejeune.

E.2.11.2 Notable Leaks at Bldg 116, Marine Corps Base Camp Lejeune, NC

The wall of Bldg 116 is fairly emissive compared to most buildings on the base (Figure E-199). The door frame at timestamp 87:26 is also noticeably leaky.

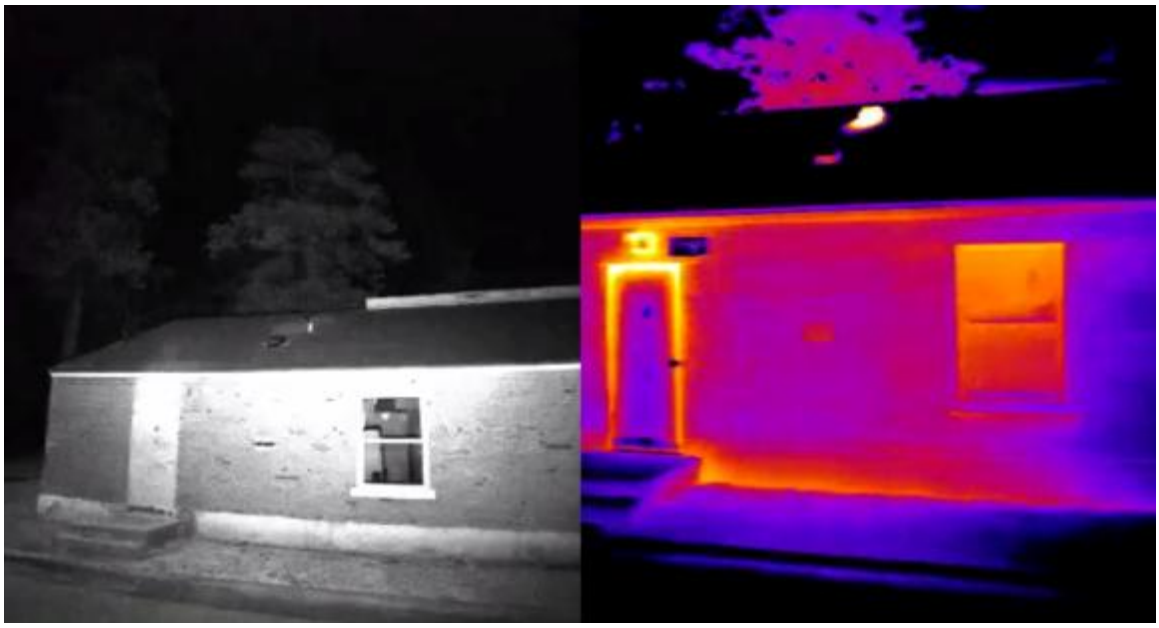

Figure E-199. NIR image (left) and thermal image (right) of Bldg 116, Camp Lejeune.

The door frames and window frame visible at timestamp 87:43 are unusually leaky (Figure E-199).

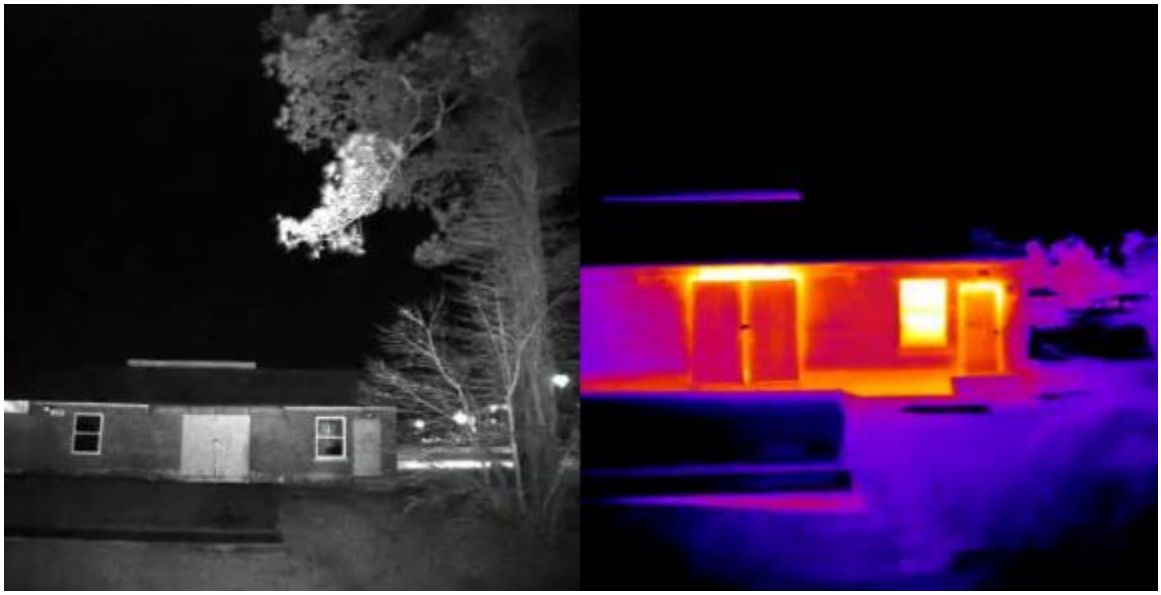

Figure E-200. NIR image (left) and thermal image (right) of Bldg 116, Camp Lejeune. The door frames and window frame visible are unusually leaky.

E.2.11.3 Envelope ECMs for Bldg 116, Marine Corps Base Camp Lejeune, NC

Figure E-201 shows the relative ROI for envelope ECMs for Bldg 116, Camp Lejeune.

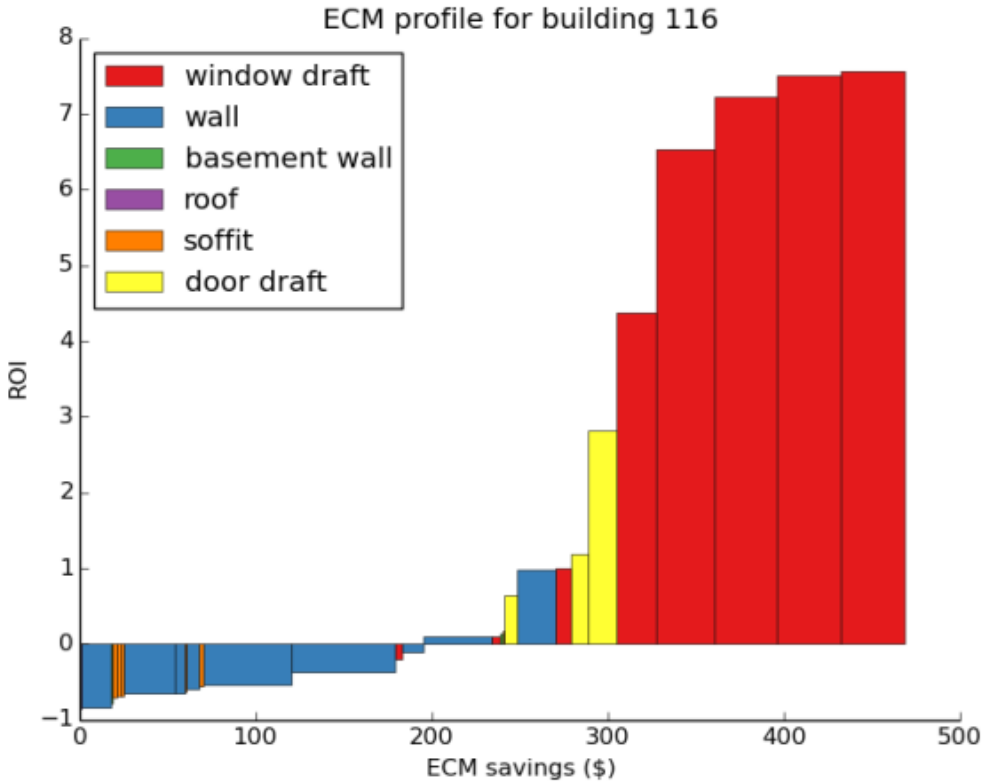

Figure E-201. ECM profile for Bldg 116, Camp Lejeune.

Table E-81 lists the recommended envelope ECMs for Bldg 116, Camp Lejeune.

Table E-81. Envelope ECMs for Bldg 116, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Window Frame Leaks	285	279	181	516	2.9
Improve Wall Insulation	209	205	133	2345	17.7
Seal Door Frame Leaks	52	51	33	193	5.9

Annual potential remediation savings for this building are $346 and total payback is 8.8 years for envelope-related ECMs.

E.2.11.4 Non-Envelope ECMs for Bldg 116, Marine Corps Base Camp Lejeune, NC

Table E-82 lists the recommended non-envelope ECMs for Bldg 116, Camp Lejeune.

Table E-82. Non-envelope ECMs for Bldg 116, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	10007	-58	571	5516	9.7
Occupancy Sensors	4487	-26	256	184	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $916 and 6.4 years for non-envelope ECMs.

E.2.12 Bldg 117

E.2.12.1 Description of Bldg 116, Marine Corps Base Camp Lejeune, NC

Name: Electric/Comm Maintenance Shop
Use Type: Office
Square Footage: 3,407
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-202 and E-203, respectively, show the aerial view and thermal image of Bldg 117, Camp Lejeune.

Figure E-202. Aerial view of Bldg 117, Camp Lejeune.

Figure E-203. Thermal image of Bldg 117, Camp Lejeune.

E.2.12.2 Notable Leaks at Bldg 116, Marine Corps Base Camp Lejeune, NC

The wall of Bldg 117 at timestamp 290:20 (Figure E-204) is more emissive than the walls of most other buildings on the base. The soffits and window frames are also fairly emissive.

Figure E-204. NIR image (left) and thermal image (right) of Bldg 117, Camp Lejeune.

E.2.12.3 Envelope ECMs for Bldg 116, Marine Corps Base Camp Lejeune, NC

Figure E-205 shows the relative ROI for envelope ECMs for Bldg 117, Camp Lejeune.

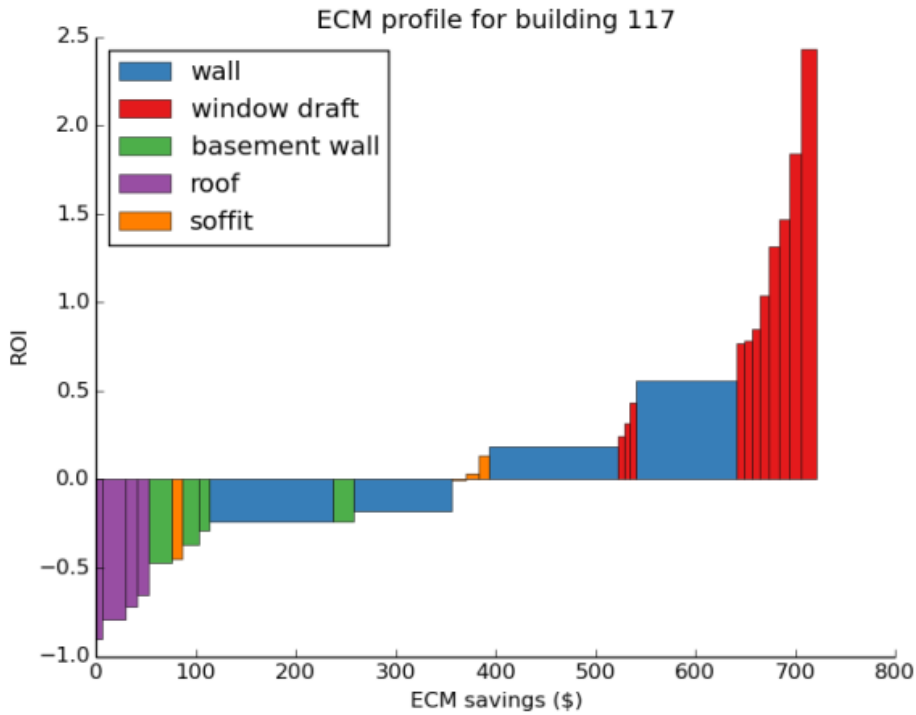

Figure E-205. ECM profile for Bldg 117, Camp Lejeune.

Table E-83 lists the recommended envelope ECMs for Bldg 117, Camp Lejeune.

Table E-83. Envelope ECMs for Bldg 117, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	717	702	454	6878	15.1
Seal Window Frame Leaks	153	150	97	712	7.3
Basement Wall Insulation	111	109	70	1666	23.7
Improve Soffit Insulation	75	73	48	823	17.3

Annual potential remediation savings for this building are $669 and total payback is 15.1 years for envelope-related ECMs.

E.2.12.4 Non-Envelope ECMs for Bldg 116, Marine Corps Base Camp Lejeune, NC

Table E-84 lists the recommended non-envelope ECMs for Bldg 117, Camp Lejeune.

Table E-84. Non-envelope ECMs for Bldg 117, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	9244	-54	528	5096	9.7
Occupancy Sensors	4145	-24	237	170	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $853 and total payback is 6.4 years for non-envelope ECMs.

E.2.13 Bldg 201

E.2.13.1 Description of Bldg 201, Marine Corps Base Camp Lejeune, NC

Name: Indoor Physical Fit Ctr
Use Type: Recreation
Square Footage: 16,922
Avg. Daily Electric Use: 1,010 kWh
Electricity Score: 70th Percentile
Electricity Usage: 21.7 kWh/sq ft/yr

Figures E-206 and E-207, respectively, show the aerial view and thermal image of Bldg 201, Camp Lejeune.

Figure E-206. Aerial view of Bldg 201, Camp Lejeune.

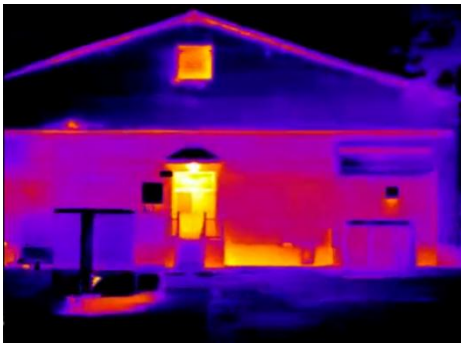

Figure E-207. Thermal image of Bldg 201, Camp Lejeune.

E.2.13.2 Notable Leaks at Bldg 201, Marine Corps Base Camp Lejeune, NC

The wall and roof of Bldg 201 are notable emissive, as shown at timestamp 111:58 (Figure E-208). There is a hot spot on the left side of the wall, as well as an apparent insulation hole near the top-left of the building.

Figure E-208. NIR image (left) and thermal image (right) of Bldg 201, Camp Lejeune.

E.2.13.3 Envelope ECMs for Bldg 201, Marine Corps Base Camp Lejeune, NC

Figure E-209 shows the relative ROI for envelope ECMs for Bldg 201, Camp Lejeune.

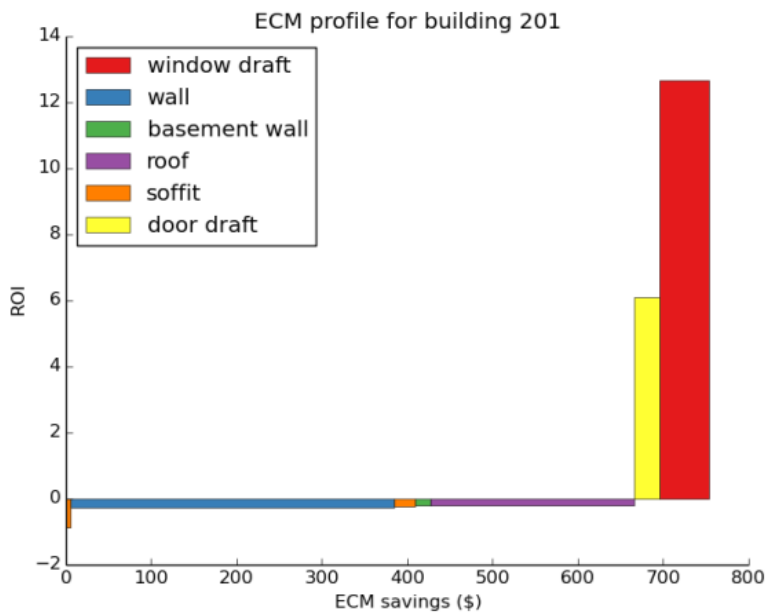

Figure E-209. ECM profile for Bldg 201, Camp Lejeune.

Table E-85 lists the recommended envelope ECMs for Bldg 201, Camp Lejeune.

Table E-85. Envelope ECMs for Bldg 201, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	598	586	379	8099	21.4
Improve Roof Insulation	376	368	238	4468	18.8
Seal Window Frame Leaks	92	90	58	64	1.1
Seal Door Frame Leaks	48	47	30	64	2.1
Improve Soffit Insulation	39	38	24	483	19.8
Basement Wall Insulation	30	29	19	362	19.0

Annual potential remediation savings for this building are $749 and total payback is 18.1 years for envelope-related ECMs.

E.2.13.4 Non-Envelope ECMs for Bldg 201, Marine Corps Base Camp Lejeune, NC

Table E-86 lists the recommended non-envelope ECMs for Bldg 201, Camp Lejeune.

Table E-86. Non-envelope ECMs for Bldg 201, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	45912	-267	2621	25308	9.7
Occupancy Sensors	20589	-120	1175	846	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $4,063 and total payback is 6.6 years for non-envelope ECMs.

E.2.14 Bldg 203

E.2.14.1 Description of Bldg 203, Marine Corps Base Camp Lejeune, NC

Name: Administrative Office
Use Type: Office
Square Footage: 3,431
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-210 and E-211, respectively, show the aerial view and thermal image of Bldg 203, Camp Lejeune.

Figure E-210. Aerial view of Bldg 203, Camp Lejeune.

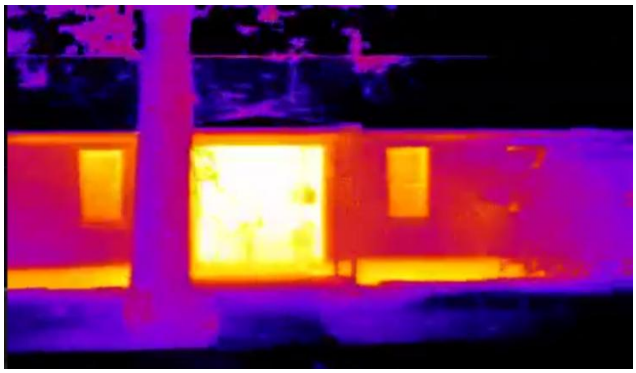

Figure E-211. Thermal image of Bldg 203, Camp Lejeune.

E.2.14.2 Notable Leaks at Bldg 203, Marine Corps Base Camp Lejeune, NC

The wall and exposed foundation of Bldg 203 as shown at timestamp 108:33 are both quite emissive and poorly insulated (Figure E-212). The windows and door frame are also more emissive than most.

Figure E-212. NIR image (left) and thermal image (right) of Bldg 203, Camp Lejeune.

E.2.14.3 Envelope ECMs for Bldg 203, Marine Corps Base Camp Lejeune, NC

Figure E-205 shows the relative ROI for envelope ECMs for Bldg 203, Camp Lejeune.

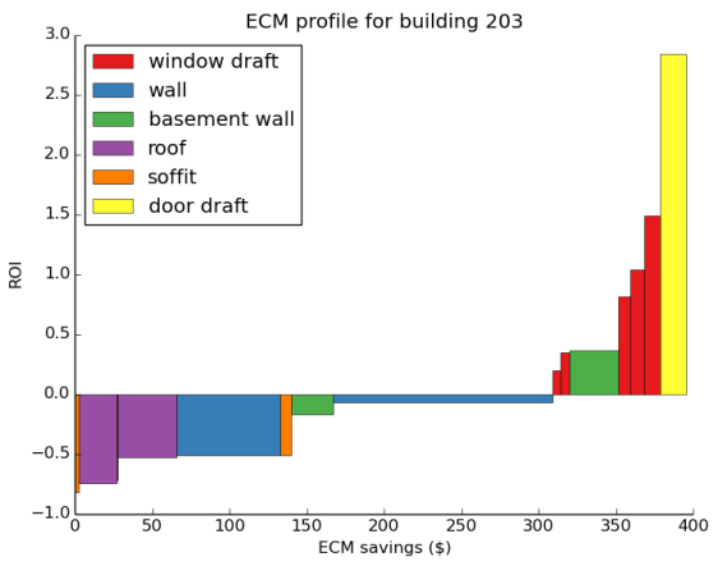

Figure E-213. ECM profile for Bldg 203, Camp Lejeune.

Table E-87 lists the recommended envelope ECMs for Bldg 203, Camp Lejeune.

Table E-87. Envelope ECMs for Bldg 203, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	223	219	142	2283	16.1
Basement Wall Insulation	93	91	59	847	14.3
Seal Window Frame Leaks	61	59	38	324	8.4
Seal Door Frame Leaks	26	26	17	65	3.9

Annual potential remediation savings for this building are $256 and total payback is 13.8 years for envelope-related ECMs.

E.2.14.4 Non-Envelope ECMs for Bldg 203, Marine Corps Base Camp Lejeune, NC

Table E-88 lists the recommended non-envelope ECMs for Bldg 203, Camp Lejeune.

Table E-88. Non-envelope ECMs for Bldg 203, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	9310	-54	531	5132	9.7
Occupancy Sensors	4175	-24	238	171	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $859 and total payback is 6.4 years for non-envelope ECMs.

E.2.15 Bldg 207

E.2.15.1 Description of Bldg 207, Marine Corps Base Camp Lejeune, NC

Name: General Storage Shed
Use Type: Office
Square Footage: 3,691
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-214 and E-215, respectively, show the aerial view and thermal image of Bldg 207, Camp Lejeune.

Figure E-214. Aerial view of Bldg 207, Camp Lejeune.

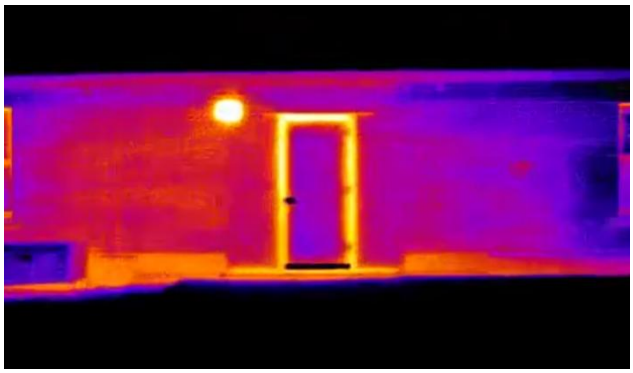

Figure E-215. Thermal image of Bldg 207, Camp Lejeune.

E.2.15.2 Notable Leaks at Bldg 207, Marine Corps Base Camp Lejeune, NC

The wall of Bldg 207 at timestamp 302:44 is notable hot, with some discrete hot spots near the center of the image (Figure E-216).

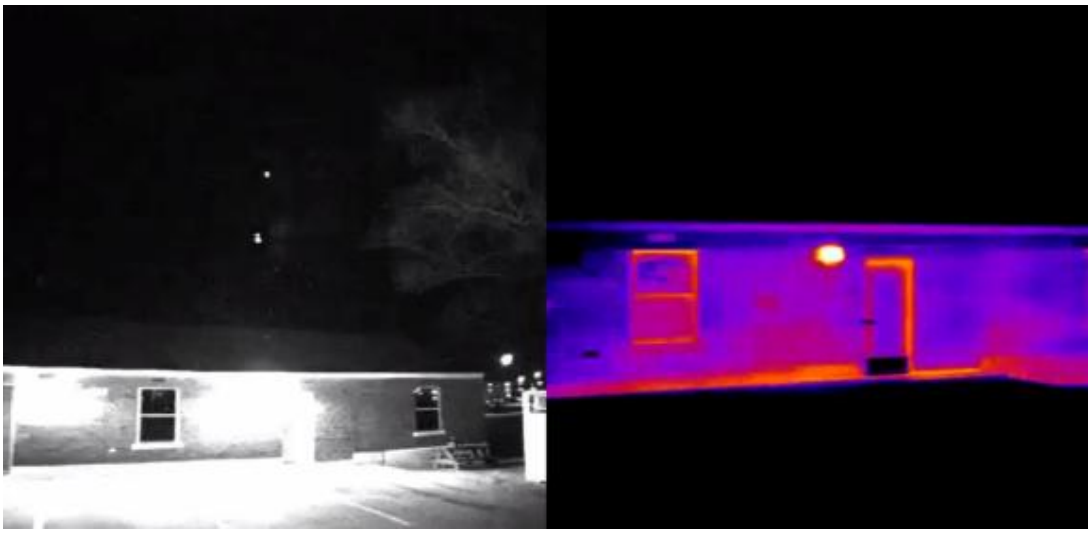

Figure E-216. NIR image (left) and thermal image (right) of Bldg 207, Camp Lejeune.

The window frame and the wall to the right of it at timestamp 302:46 are quite hot and may be effectively remediated with improved insulation and air sealing (Figure E-217).

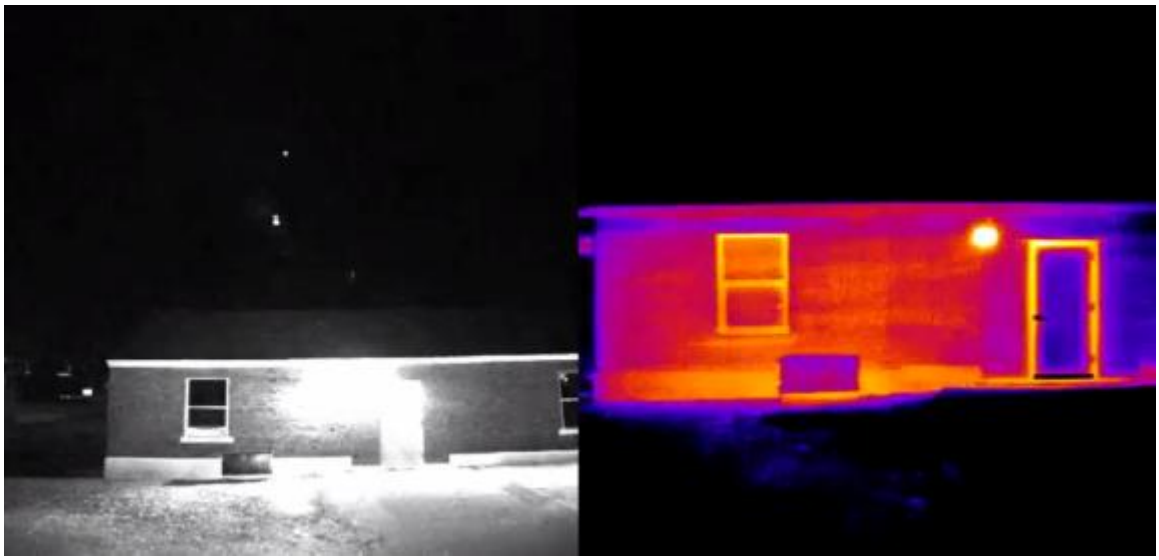

Figure E-217. NIR image (left) and thermal image (right) of Bldg 207, Camp Lejeune. The window frame and the wall to the right of it are quite hot.

E.2.15.3 Envelope ECMs for Bldg 207, Marine Corps Base Camp Lejeune, NC

Figure E-218 shows the relative ROI for envelope ECMs for Bldg 207, Camp Lejeune.

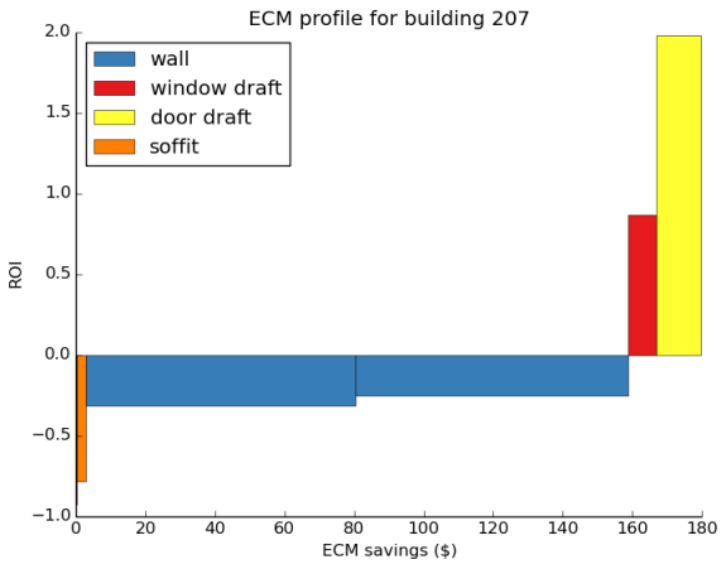

Figure E-218. ECM profile for Bldg 207, Camp Lejeune.

Table E-89 lists the recommended envelope ECMs for Bldg 207, Camp Lejeune.

Table E-89. Envelope ECMs for Bldg 207, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	246	241	156	3269	21.0
Seal Door Frame Leaks	20	20	13	64	5.0

Annual potential remediation savings for this building are $169 and total payback is 19.8 years for envelope-related ECMs.

E.2.15.4 Non-Envelope ECMs for Bldg 207, Marine Corps Base Camp Lejeune, NC

Table E-90 lists the recommended non-envelope ECMs for Bldg 207, Camp Lejeune.

Table E-90. Non-envelope ECMs for Bldg 207, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	10015	-58	572	5520	9.7
Occupancy Sensors	4491	-26	256	184	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $917 and total payback is 6.4 years for non-envelope ECMs.

E.2.16 Bldg 217

E.2.16.1 Description of Bldg 217, Marine Corps Base Camp Lejeune, NC

Name: Administrative Office
Use Type: Office
Square Footage: 26,602
Avg. Daily Electric Use: 427 kWh
Electricity Score: 5th Percentile

Bldg 217 (Figures E-219 and E-220) has an electricity usage of 5.9 kWh/sq ft/yr.

Figure E-219. Aerial view of Bldg 217, Camp Lejeune.

Figure E-220. Thermal image of Bldg 217, Camp Lejeune.

E.2.16.2 Notable Leaks at Bldg 217, Marine Corps Base Camp Lejeune, NC

The wall of Bldg 217 at timestamp 308:58 is highly emissive, particularly in the right side of the image and in the back-right corner (Figure E-221).

Figure E-221. NIR image (left) and thermal image (right) of Bldg 217, Camp Lejeune.

The wall in the back left and right of the image at timestamp 309:01 is very highly emissive, which likely indicates poor insulation (Figure E-222).

Figure E-222. NIR image (left) and thermal image (right) of Bldg 217, Camp Lejeune. The wall in the rear left and rear right of the image is very highly emissive.

E.2.16.3 Envelope ECMs for Bldg 217, Marine Corps Base Camp Lejeune, NC

Figure E-223 shows the relative ROI for envelope ECMs for Bldg 217, Camp Lejeune.

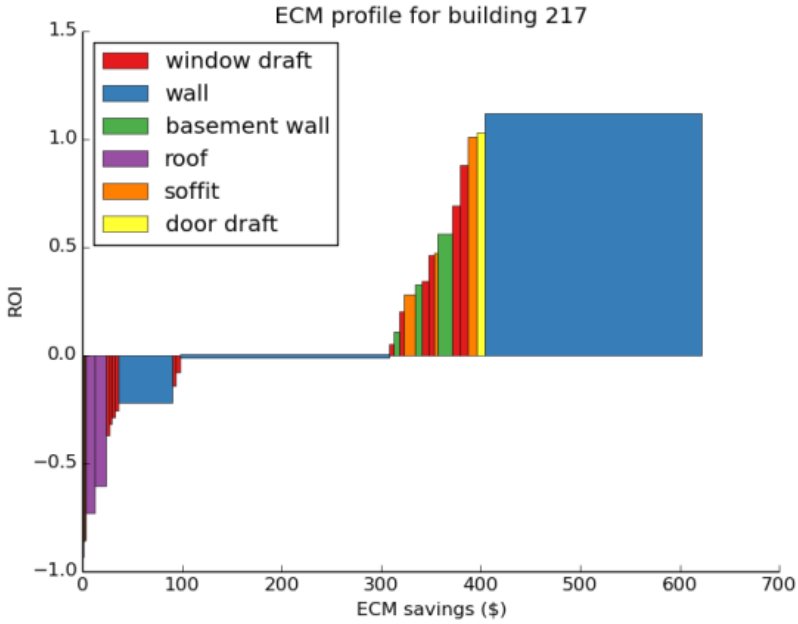

Figure E-223. ECM profile for Bldg 217, Camp Lejeune.

Table E-91 lists the recommended envelope ECMs for Bldg 217, Camp Lejeune

Table E-91. Envelope ECMs for Bldg 217, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	760	744	482	5783	12.0
Seal Window Frame Leaks	90	88	57	776	13.7
Basement Wall Insulation	43	42	27	293	10.8
Improve Soffit Insulation	37	36	23	230	9.9

Annual potential remediation savings for this building are $589 and total payback is 12.0 years for envelope-related ECMs.

E.2.16.4 Non-Envelope ECMs for Bldg 217, Marine Corps Base Camp Lejeune, NC

Table E-92 lists the recommended non-envelope ECMs for Bldg 217, Camp Lejeune.

Table E-92. Non-envelope ECMs for Bldg 217, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	69450	-408	3963	39786	10.0
Occupancy Sensors	31144	-183	1777	1330	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $6,630 and total payback is 6.5 years for non-envelope ECMs.

E.2.17 Bldg 233

E.2.17.1 Description of Bldg 233, Marine Corps Base Camp Lejeune, NC

Name: Administrative Building
Use Type: Office
Square Footage: 4,068
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-224 and E-225, respectively, show the aerial view and thermal image of Bldg 233, Camp Lejeune.

Figure E-224. Aerial view of Bldg 233, Camp Lejeune.

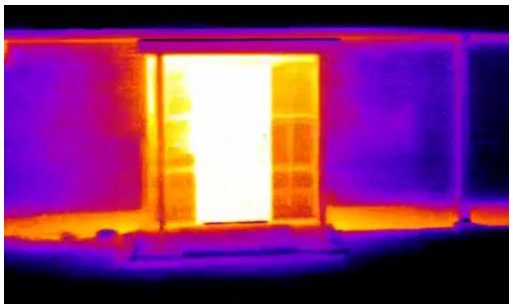

Figure E-225. Thermal image of Bldg 233, Camp Lejeune.

E.2.17.2 Notable Leaks at Bldg 233, Marine Corps Base Camp Lejeune, NC

The foundation wall, door frame, and soffit at timestamp 304:06 are all highly emissive (Figure E-226).

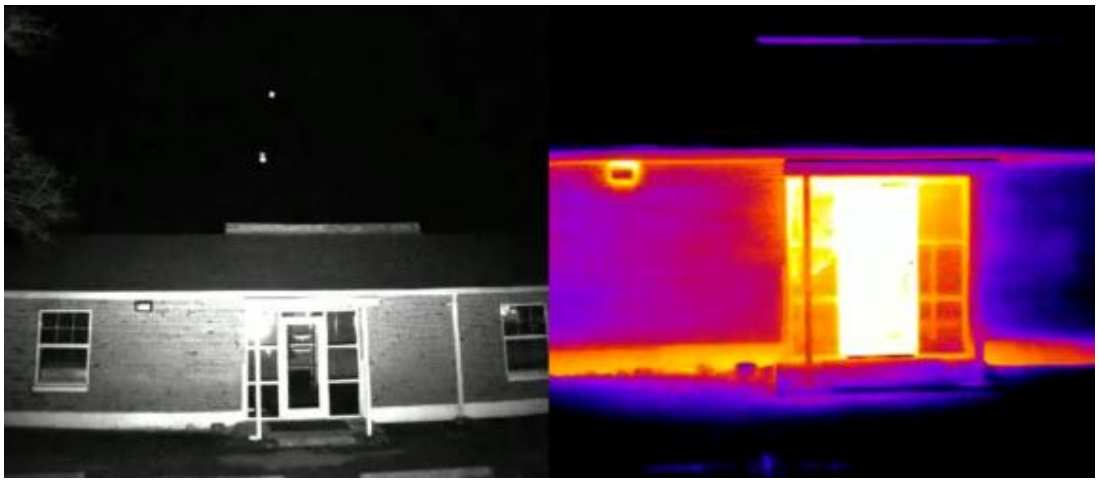

Figure E-226. NIR image (left) and thermal image (right) of Bldg 233, Camp Lejeune.

E.2.17.3 Envelope ECMs for Bldg 233, Marine Corps Base Camp Lejeune, NC

Figure E-227 shows the relative ROI for envelope ECMs for Bldg 233, Camp Lejeune.

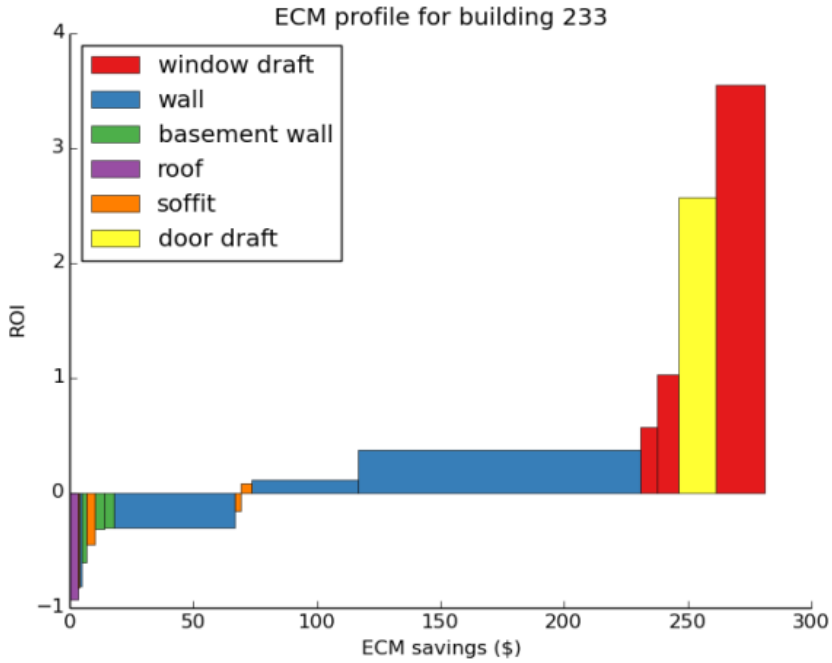

Figure E-227. ECM profile for Bldg 233, Camp Lejeune.

Table E-93 lists the recommended envelope ECMs for Bldg 233, Camp Lejeune.

Table E-93. Envelope ECMs for Bldg 233, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	325	318	206	2879	14.0
Seal Window Frame Leaks	55	54	35	195	5.5
Seal Door Frame Leaks	24	24	15	64	4.2
Improve Soffit Insulation	16	16	10	201	19.3

Annual potential remediation savings for this building are $267 and total payback is 12.5 years for envelope-related ECMs.

E.2.17.4 Non-Envelope ECMs for Bldg 233, Marine Corps Base Camp Lejeune, NC

Table E-94 lists the recommended non-envelope ECMs for Bldg 233, Camp Lejeune.

Table E-94. Non-envelope ECMs for Bldg 233, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	11038	-64	630	6085	9.7
Occupancy Sensors	4950	-29	283	203	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $1,002 and total payback is 6.5 years for non-envelope ECMs.

E.2.18 Bldg 235

E.2.18.1 Description of Bldg 235, Marine Corps Base Camp Lejeune, NC

Name: Bus Station
Use Type: Misc.
Square Footage: 8,592
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-228 and E-229, respectively, show the aerial view and thermal image of Bldg 235, Camp Lejeune.

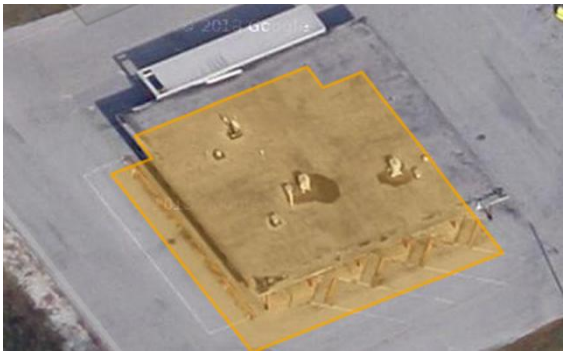

Figure E-228. Aerial view of Bldg 235, Camp Lejeune.

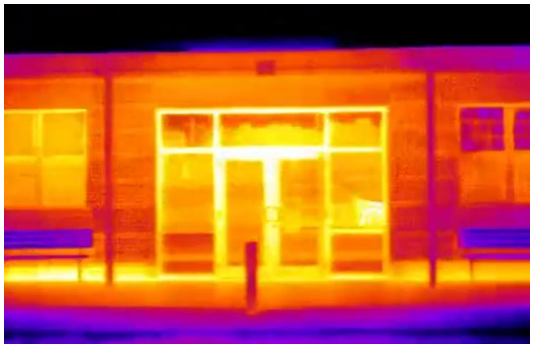

Figure E-229. Thermal image of Bldg 235, Camp Lejeune.

E.2.18.2 Notable Leaks at Bldg 235, Marine Corps Base Camp Lejeune, NC

Bldg 235 has generally poor insulation in all of it walls (Figure E-230). This can be seen at timestamp 110:43, in addition to a highly emissive door frame indicating air leakage.

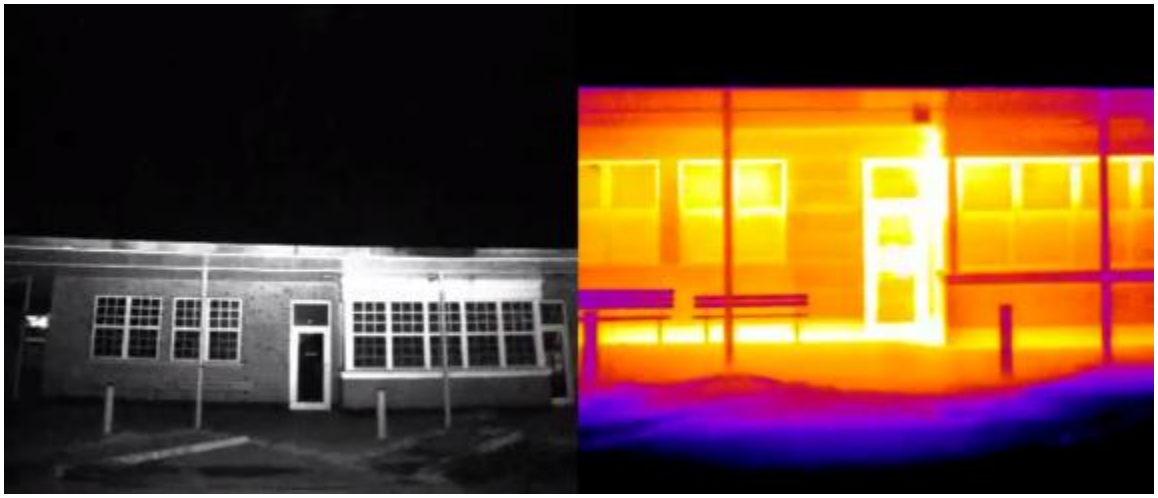

Figure E-230. NIR image (left) and thermal image (right) of Bldg 235, Camp Lejeune.

The wall at timestamp 110:48 is also quite emissive, as is the door frame near the left side of the image (Figure E-231).

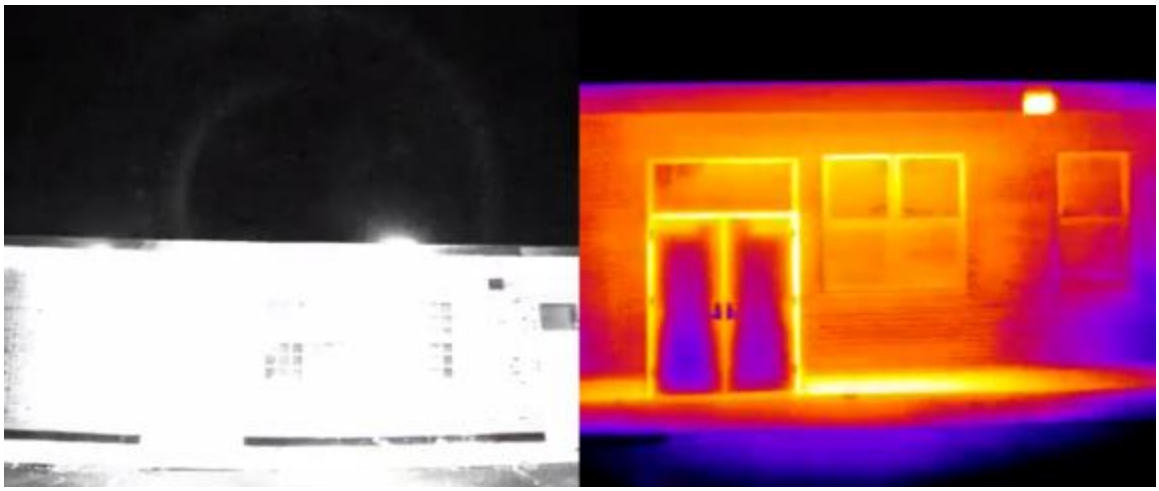

Figure E-231. NIR image (left) and thermal image (right) of Bldg 235, Camp Lejeune. The wall and door frame are also quite emissive.

E.2.18.3 Envelope ECMs for Bldg 235, Marine Corps Base Camp Lejeune, NC

Figure E-232 shows the relative ROI for envelope ECMs for Bldg 235, Camp Lejeune.

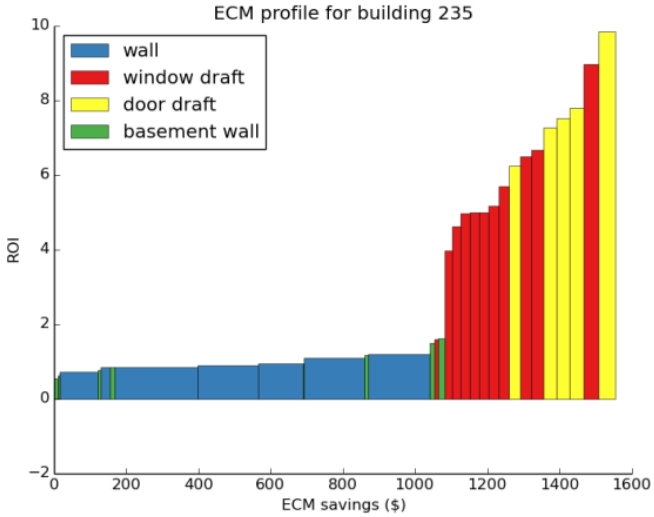

Figure E-232. ECM profile for Bldg 235, Camp Lejeune.

Table E-95 lists the recommended envelope ECMs for Bldg 235, Camp Lejeune.

Table E-95. Envelope ECMs for Bldg 235, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1557	1525	987	7643	7.7
Seal Window Frame Leaks	470	460	298	711	2.4
Seal Door Frame Leaks	295	289	187	322	1.7
Basement Wall Insulation	131	128	83	619	7.5

Annual potential remediation savings for this building are $1,555 and total payback is 6 years for envelope-related ECMs.

E.2.18.4 Non-Envelope ECMs for Bldg 235, Marine Corps Base Camp Lejeune, NC

Table E-96 lists the recommended non-envelope ECMs.

Table E-96. Non-envelope ECMs for Bldg 235, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	23313	-136	1331	12851	9.7
Occupancy Sensors	10454	-61	597	429	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $2,017 and total payback is 6.7 years for non-envelope ECMs.

E.2.19 Bldg 322

E.2.19.1 Description of Bldg 322, Marine Corps Base Camp Lejeune, NC

Name: North Section Building
Use Type: Office
Square Footage: 62,793
Avg. Daily Electric Use: 1,329 kWh
Electricity Score: 10th Percentile
Electricity Usage: 7.7 kWh/sq ft/yr

Figures E-233 and E-234, respectively, show the aerial view and thermal image of Bldg 322, Camp Lejeune.

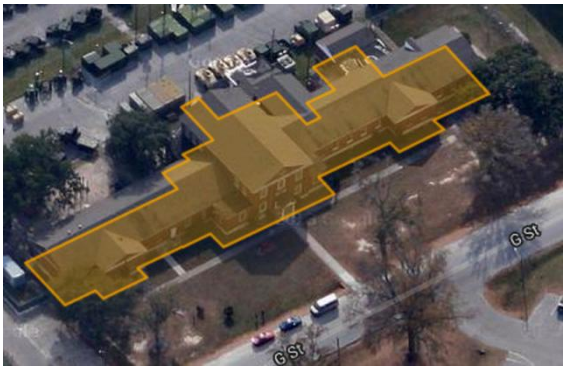

Figure E-233. Aerial view of Bldg 322, Camp Lejeune.

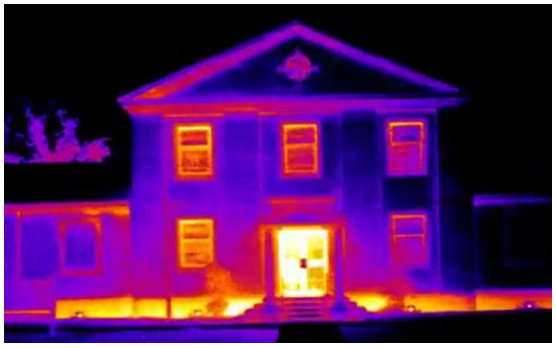

Figure E-234. Thermal image of Bldg 322, Camp Lejeune.

E.2.19.2 Notable Leaks at Bldg 322, Marine Corps Base Camp Lejeune, NC

The exposed foundation visible at timestamp 312:50 is notably emissive, as is the window frame near the center of the image (Figure E-235).

Figure E-235. NIR image (left) and thermal image (right) of Bldg 322, Camp Lejeune.

The window frame near the center of the image at timestamp 312:57 is quite emissive, as is the foundation and soffit (Figure E-236).

Figure E-236. NIR image (left) and thermal image (right) of Bldg 322, Camp Lejeune. The window frame, foundation and soffit are also quite emissive.

E.2.19.3 Envelope ECMs for Bldg 322, Marine Corps Base Camp Lejeune, NC

Figure E-237 shows the relative ROI for envelope ECMs for Bldg 322, Camp Lejeune.

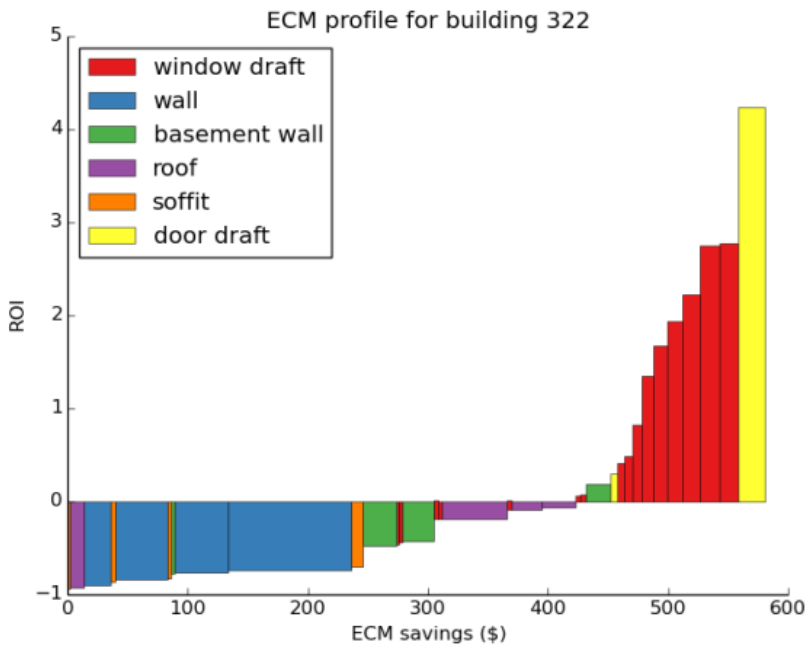

Figure E-237. ECM profile for Bldg 322, Camp Lejeune.

Table E-97 lists the recommended envelope ECMs for Bldg 322, Camp Lejeune.

Table E-97. Envelope ECMs for Bldg 322, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Window Frame Leaks	198	194	126	1036	8.2
Improve Roof Insulation	168	165	107	1860	17.4
Basement Wall Insulation	118	115	75	1762	23.6
Seal Door Frame Leaks	44	43	28	129	4.6

Annual potential remediation savings for this building are $335 and total payback is 14.3 years for envelope-related ECMs.

E.2.19.4 Non-Envelope ECMs for Bldg 322, Marine Corps Base Camp Lejeune, NC

Table E-98 lists the recommended non-envelope ECMs for Bldg 322, Camp Lejeune.

Table E-98. Non-envelope ECMs for Bldg 322, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	163933	-963	9355	93913	10.0
Occupancy Sensors	73514	-432	4195	3138	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $14,439 and total payback is 6.9 years for non-envelope ECMs.

E.2.20 Bldg 401

E.2.20.1 Description of Bldg 401, Marine Corps Base Camp Lejeune, NC

Name: Gymnasium
Use Type: Recreation
Square Footage: 12,402
Avg. Daily Electric Use: 204.7 kWh
Electricity Score: 20th Percentile
Electricity Usage: 6.0 kWh/sq ft/yr

Figures E-238 and E-239, respectively, show the aerial view and thermal image of Bldg 401, Camp Lejeune.

Figure E-238. Aerial view of Bldg 401, Camp Lejeune.

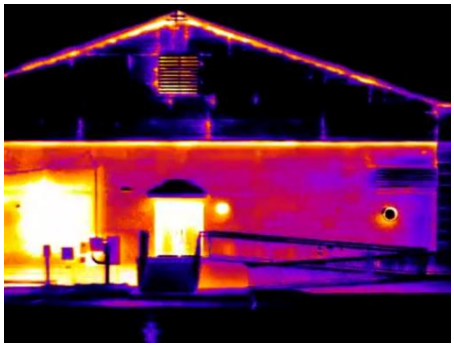

Figure E-239. Thermal image of Bldg 401, Camp Lejeune.

E.2.20.2 Notable Leaks at Bldg 401, Marine Corps Base Camp Lejeune, NC

There is a large poorly insulated hot spot on the left side of the image at timestamp 354:09. The soffits at the top of the brick wall and at the roofline are both quite poorly insulated (Figure E-240).

Figure E-240. NIR image (left) and thermal image (right) of Bldg 401, Camp Lejeune.

E.2.20.3 Envelope ECMs for Bldg 401, Marine Corps Base Camp Lejeune, NC

Figure E-241 shows the relative ROI for envelope ECMs for Bldg 401, Camp Lejeune.

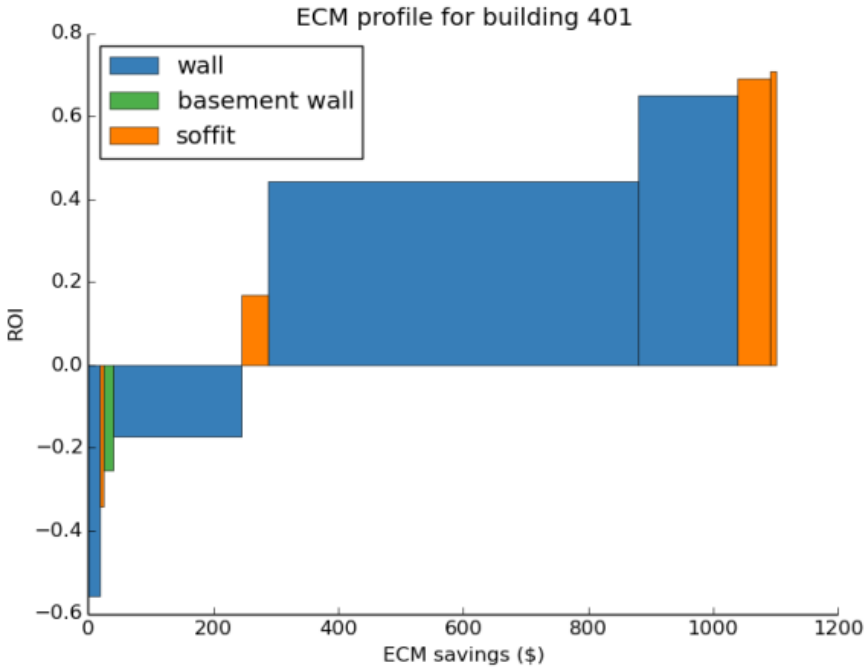

Figure E-241. ECM profile for Bldg 401, Camp Lejeune.

Table E-99 lists the recommended envelope ECMs for Bldg 401, Camp Lejeune.

Table E-99. Envelope ECMs for Bldg 401, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1508	1477	956	11325	11.8
Improve Soffit Insulation	177	174	112	1260	11.2
Basement Wall Insulation	23	23	15	297	20.1

Annual potential remediation savings for this building are $1,083 and total payback is 11.9 years for envelope-related ECMs.

E.2.20.4 Non-Envelope ECMs for Bldg 401, Marine Corps Base Camp Lejeune, NC

Table E-100 lists the recommended non-envelope ECMs for Bldg 401, Camp Lejeune.

Table E-100. Non-envelope ECMs for Bldg 401, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	33648	-196	1921	18548	9.7
Occupancy Sensors	15089	-88	861	620	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $3,049 and total payback is 6.5 years for non-envelope ECMs.

E.2.21 Bldg 407

E.2.21.1 Description of Bldg 407, Marine Corps Base Camp Lejeune, NC

Name: Battalion Squadron Headquarters
Use Type: Office
Square Footage: 26,602
Avg. Daily Electric Use: 1,265 kWh
Electricity Score: 70th Percentile

Bldg 407 (Figures E-242 and E-243) has an electricity usage of 17.3 kWh/sq ft/yr

Figure E-242. Aerial view of Bldg 407, Camp Lejeune.

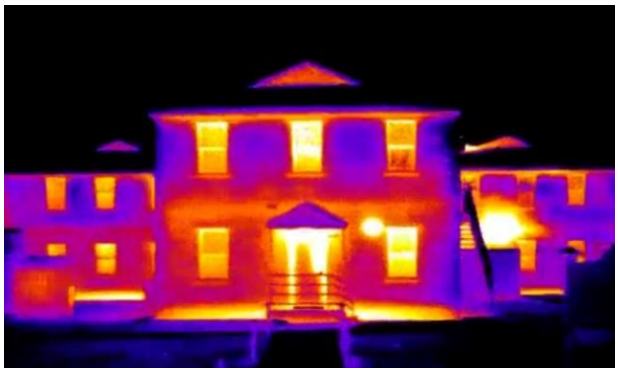

Figure E-243. Thermal image of Bldg 407, Camp Lejeune.

E.2.21.2 Notable Leaks at Bldg 407, Marine Corps Base Camp Lejeune, NC

The walls of Bldg 407 at timestamp 354:25 are highly emissive, with hot spots on the right side of the image and in the back center (Figure E-244).

Figure E-244. NIR image (left) and thermal image (right) of Bldg 407, Camp Lejeune.

The wall in the left corner of the back of the image at timestamp 354:28 is notably hot, which indicates poor insulation (Figure E-245).

Figure E-245. NIR image (left) and thermal image (right) of Bldg 407, Camp Lejeune. The wall in the left and right rear corners is notably hot, which indicates poor insulation.

E.2.21.3 Envelope ECMs for Bldg 407, Marine Corps Base Camp Lejeune, NC

Figure E-246 shows the relative ROI for envelope ECMs for Bldg 407, Camp Lejeune.

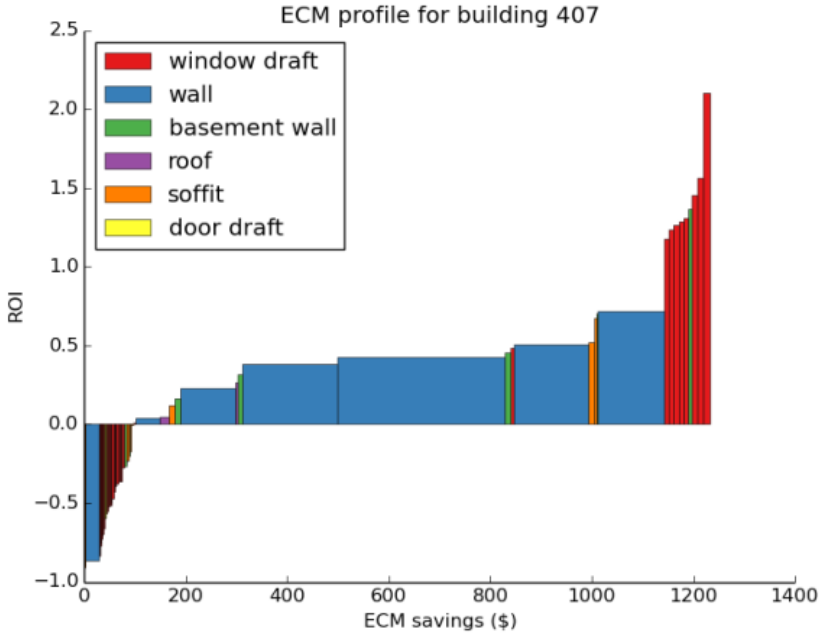

Figure E-246. ECM profile for Bldg 407, Camp Lejeune.

Table E-101 lists the recommended envelope ECMs for Bldg 407, Camp Lejeune.

Table E-101. Envelope ECMs for Bldg 407, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1503	1472	953	10144	10.6
Seal Window Frame Leaks	182	179	116	1163	10.1
Basement Wall Insulation	79	77	50	623	12.5
Improve Soffit Insulation	60	58	38	497	13.1
Improve Roof Insulation	32	32	21	286	13.9

Annual potential remediation savings for this building are $1,177 and total payback is 10.8 years for envelope-related ECMs.

E.2.21.4 Non-Envelope ECMs for Bldg 407, Marine Corps Base Camp Lejeune, NC

Table E-102 lists the recommended non-envelope ECMs for Bldg 407, Camp Lejeune.

Table E-102. Non-envelope ECMs for Bldg 407, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	69450	-408	3963	39786	10.0
Occupancy Sensors	31144	-183	1777	1330	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $6,630 and total payback is 6.5 years for non-envelope-related ECMs.

E.2.22 Bldg 408

E.2.22.1 Description of Bldg 408, Marine Corps Base Camp Lejeune, NC

Name: Strategic Air/Ground Org Units
Use Type: Office
Square Footage: 21,759
Avg. Daily Electric Use: 358.4
Electricity Score: 25th Percentile
Electricity Usage: 6.0 kWh/sq ft/yr

Figures E-247 and E-248, respectively, show the aerial view and thermal image of Bldg 408, Camp Lejeune.

Figure E-247. Aerial view of Bldg 408, Camp Lejeune.

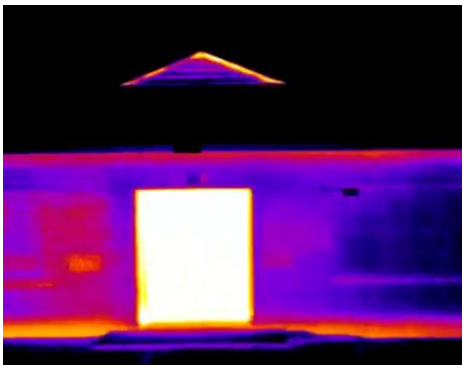

Figure E-248. Thermal image of Bldg 408, Camp Lejeune.

E.2.22.2 Notable Leaks at Bldg 408, Marine Corps Base Camp Lejeune, NC

There is a large poorly insulated hot spot at timestamp 356:55 on the left side of the image. The door frame in the center of the image is also fairly leaky and would benefit from air sealing (Figure E-249).

Figure E-249. NIR image (left) and thermal image (right) of Bldg 408, Camp Lejeune.

The wall at timestamp 356:57 has a hot spot around the center of the image, and the exposed foundation/basement wall is also quite emissive (Figure E-250).

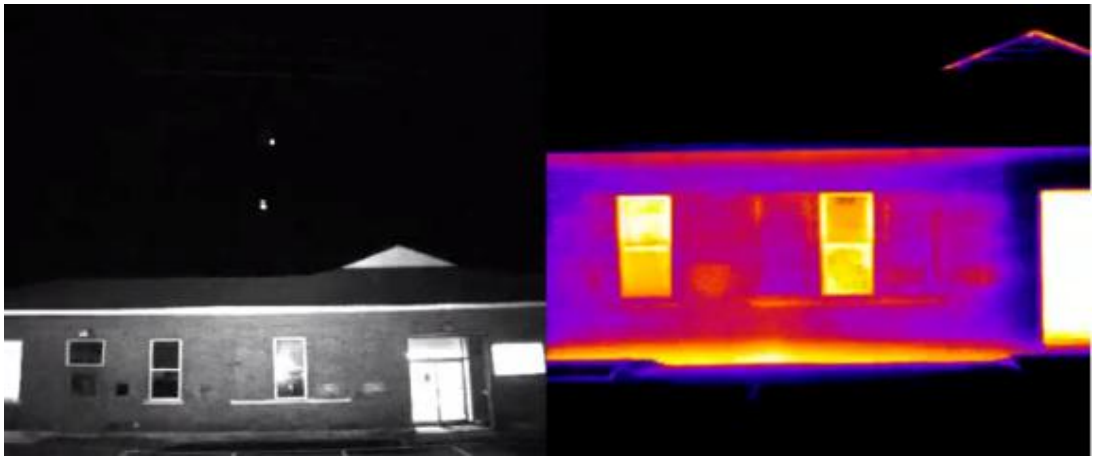

Figure E-250. NIR image (left) and thermal image (right) of Bldg 408, Camp Lejeune. The wall has a hot spot around the center of the image, and the exposed foundation/basement wall is also quite emissive.

E.2.22.3 Envelope ECMs for Bldg 408, Marine Corps Base Camp Lejeune, NC

Figure E-251 shows the relative ROI for envelope ECMs for Bldg 408, Camp Lejeune.

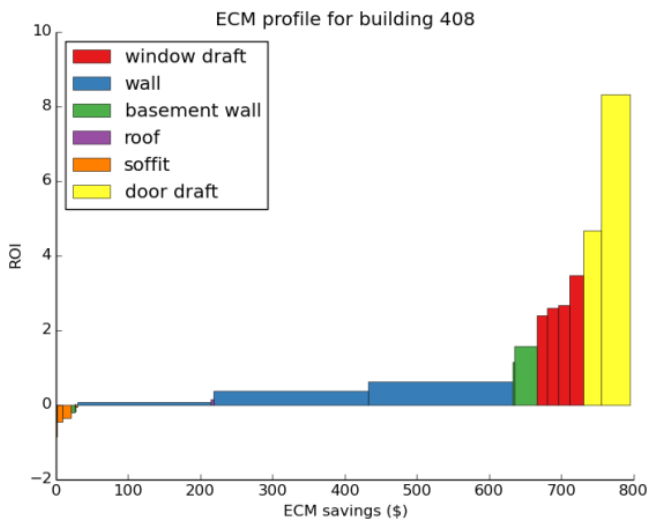

Figure E-251. ECM profile for Bldg 408, Camp Lejeune.

Table E-103 lists the recommended envelope ECMs for Bldg 408, Camp Lejeune.

Table E-103. Envelope ECMs for Bldg 408, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	944	925	599	6834	11.4
Seal Window Frame Leaks	103	101	65	258	4.0
Seal Door Frame Leaks	100	98	64	127	2.0
Basement Wall Insulation	61	60	39	308	7.9
Improve Soffit Insulation	35	34	22	527	23.9

Annual potential remediation savings for this building are $789 and total payback is 10.2 years for envelope-related ECMs.

E.2.22.4 Non-Envelope ECMs for Bldg 408, Marine Corps Base Camp Lejeune, NC

Table E-104 lists the recommended non-envelope ECMs for Bldg 408, Camp Lejeune.

Table E-104. Non-envelope ECMs for Bldg 408, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	59035	-344	3370	32543	9.7
Occupancy Sensors	26474	-154	1511	1088	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $5,771 and total payback is 6.2 years for non-envelope ECMs.

E.2.23 Bldg 424

E.2.23.1 Description of Bldg 424, Marine Corps Base Camp Lejeune, NC

Name: Strategic Air/Ground Org. Units
Use Type: Office
Square Footage: 22,867
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-252 and E-253, respectively, show the aerial view and thermal image of Bldg 424, Camp Lejeune.

Figure E-252. Aerial view of Bldg 424, Camp Lejeune.

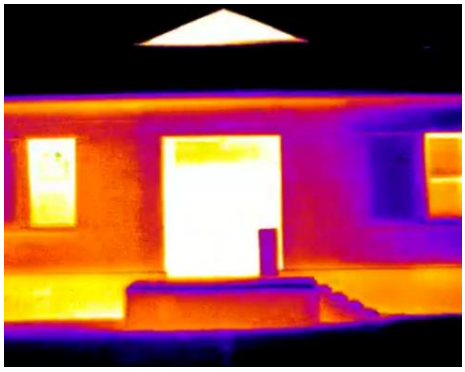

Figure E-253. Thermal image of Bldg 424, Camp Lejeune.

E.2.23.2 Notable Leaks at Bldg 424, Marine Corps Base Camp Lejeune, NC

The walls of Bldg 424 appear poorly insulated, particularly the portion on the left side of the image shown at timestamp 356:22 (Figure E-254).

Figure E-254. NIR image (left) and thermal image (right) of Bldg 424, Camp Lejeune.

E.2.23.3 Envelope ECMs for Bldg 424, Marine Corps Base Camp Lejeune, NC

Figure E-255 shows the relative ROI for envelope ECMs for Bldg 424, Camp Lejeune.

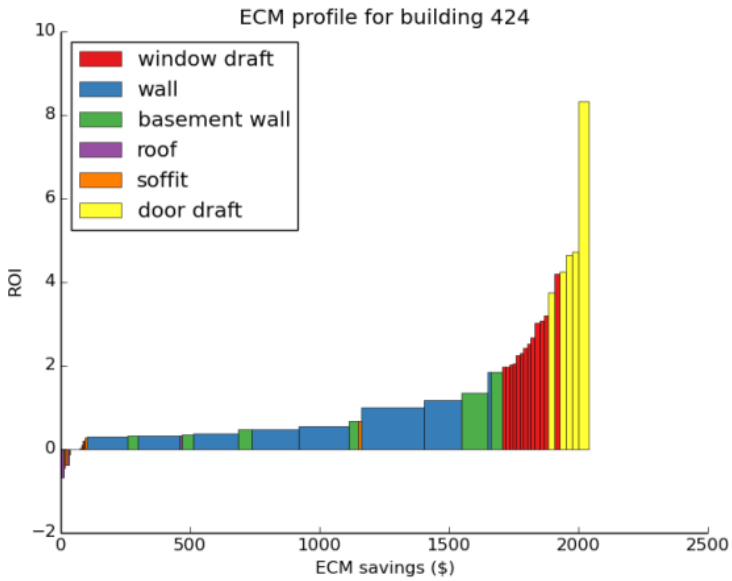

Figure E-255. ECM profile for Bldg 424, Camp Lejeune.

Table E-105 lists the recommended envelope ECMs for Bldg 424, Camp Lejeune.

Table E-105. Envelope ECMs for Bldg 424, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1994	1953	1264	12177	9.6
Basement Wall Insulation	560	548	355	3249	9.2
Seal Window Frame Leaks	332	325	211	970	4.6
Seal Door Frame Leaks	208	204	132	322	2.4
Improve Soffit Insulation	78	77	50	735	14.8
Improve Roof Insulation	25	24	16	294	18.6

Annual potential remediation savings for this building are $2,026 and total payback is 8.8 years for envelope-related ECMs.

E.2.23.4 Non-Envelope ECMs for Bldg 424, Marine Corps Base Camp Lejeune, NC

Table E-106 lists the recommended non-envelope ECMs for Bldg 424, Camp Lejeune.

Table E-106. Non-envelope ECMs for Bldg 424, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	62041	-361	3542	34199	9.7
Occupancy Sensors	27821	-162	1588	1143	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $6,020 and total payback is 6.2 years for non-envelope ECMs.

E.2.24 Bldg 430

E.2.24.1 Description of Bldg 430, Marine Corps Base Camp Lejeune, NC

Name: Small Arms Range
Use Type: Misc.
Square Footage: 7,536
Avg. Daily Electric Use: Not Provided
Electricity Score: N/A

Figures E-256 and E-257, respectively, show the aerial view and thermal image of Bldg 430, Camp Lejeune.

Figure E-256. Aerial view of Bldg 430, Camp Lejeune.

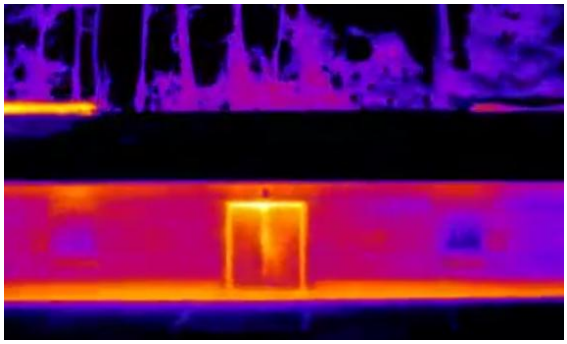

Figure E-257. Thermal image of Bldg 430, Camp Lejeune.

E.2.24.2 Notable Leaks at Bldg 430, Marine Corps Base Camp Lejeune, NC

The walls of Bldg 430 are noticeably hot, as shown at timestamp 163:58 (Figure E-258). There is a hot spot in the wall on the left of the image, as well as around the door frame on the right side of the image.

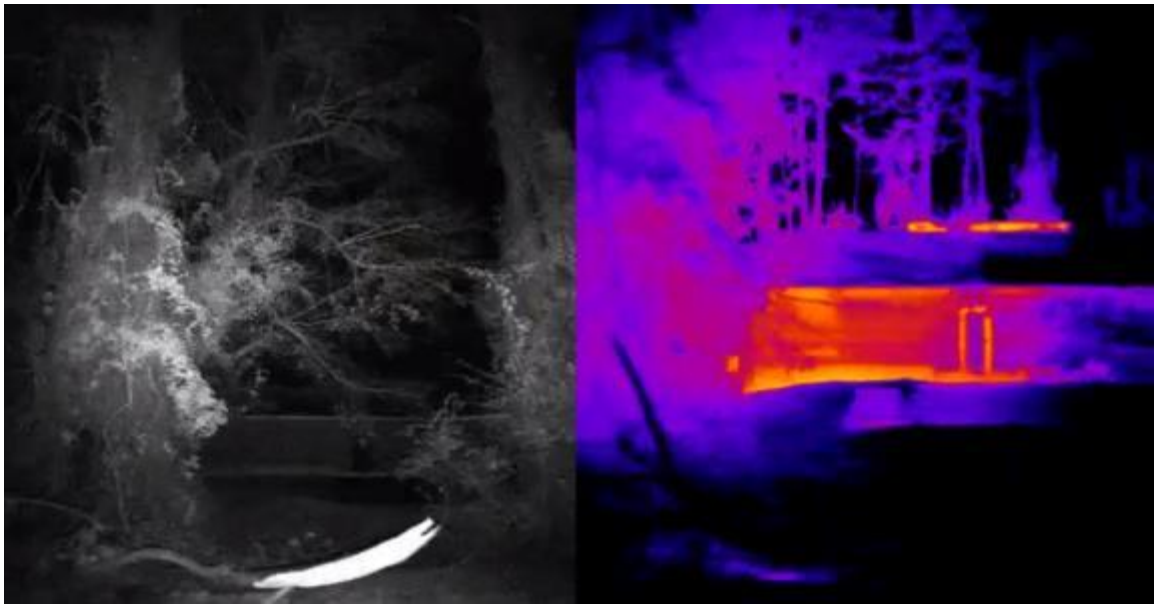

Figure E-258. NIR image (left) and thermal image (right) of Bldg 430, Camp Lejeune.

The door frame at the center of the image at timestamp 164:00 is fairly emissive (Figure E-259).

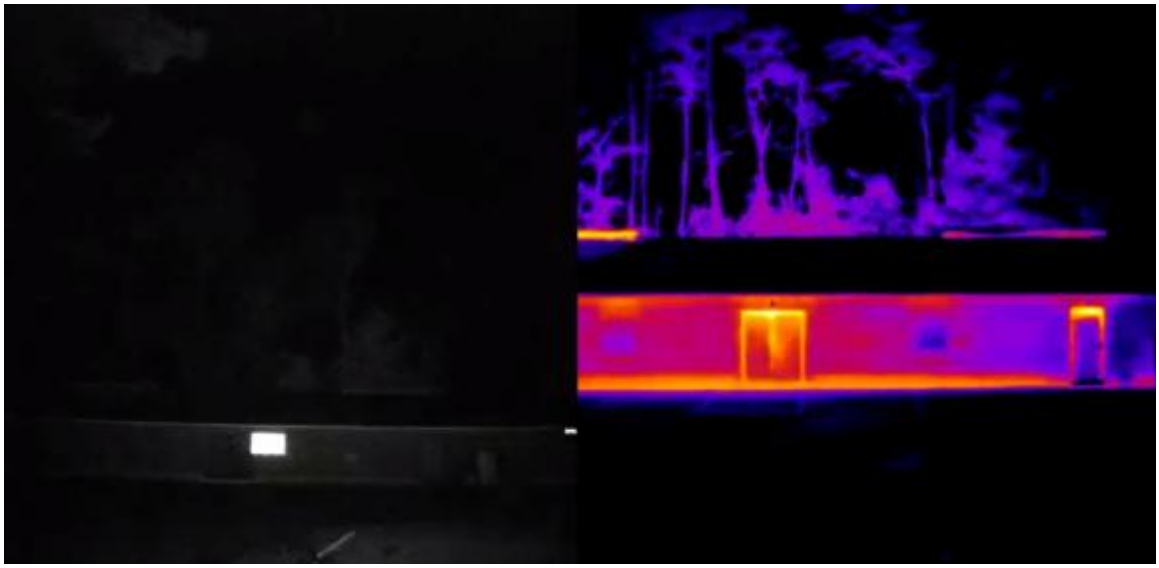

Figure E-259. NIR image (left) and thermal image (right) of Bldg 430, Camp Lejeune. The door frame at the center of the image is fairly emissive.

E.2.24.3 Envelope ECMs for Bldg 430, Marine Corps Base Camp Lejeune, NC

Figure E-260 shows the relative ROI for envelope ECMs for Bldg 430, Camp Lejeune.

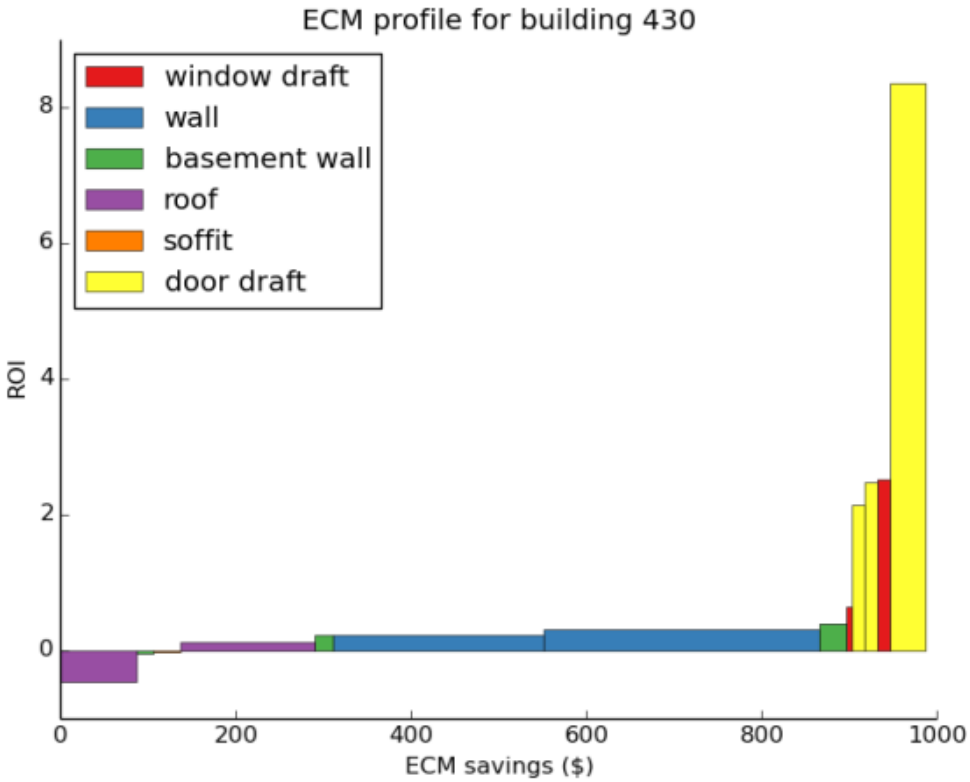

Figure E-260. ECM profile for Bldg 430, Camp Lejeune.

Table E-107 lists the recommended envelope ECMs for Bldg 430, Camp Lejeune.

Table E-107. Envelope ECMs for Bldg 430, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	874	857	554	6542	11.8
Improve Roof Insulation	378	370	240	4502	18.8
Basement Wall Insulation	112	110	71	892	12.6
Seal Door Frame Leaks	109	106	69	194	2.8
Improve Soffit Insulation	49	48	31	486	15.6
Seal Window Frame Leaks	35	35	22	130	5.8

Annual potential remediation savings for this building are $987 and total payback is 12.9 years for envelope-related ECMs.

E.2.24.4 Non-Envelope ECMs for Bldg 430, Marine Corps Base Camp Lejeune, NC

Table E-108 lists the recommended non-envelope ECMs for Bldg 430, Camp Lejeune.

Table E-108. Non-envelope ECMs for Bldg 430, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	20447	-119	1167	11271	9.7
Occupancy Sensors	9169	-53	523	377	0.7
LED Exit Signs	1625	-17	89	195	2.2

Annual potential remediation savings for this building are $1,780 and total payback is 6.7 years for non-envelope ECMs.

E.2.25 Bldg 508

E.2.25.1 Description of Bldg 508, Marine Corps Base Camp Lejeune, NC

Name: Strategic Marine Corps
Use Type: Office
Square Footage: 23,073
Avg. Daily Electric Use: 202.6 kWh
Electricity Score: 5th Percentile
Electricity Usage: 3.2 kWh/sq ft/yr.

Figures E-261 and E-262, respectively, show the aerial view and thermal image of Bldg 508, Camp Lejeune.

Figure E-261. Aerial view of Bldg 508, Camp Lejeune.

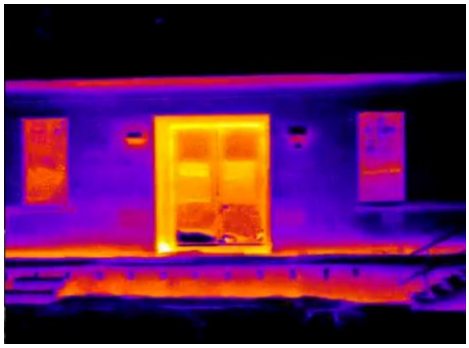

Figure E-262. Thermal image of Bldg 508, Camp Lejeune.

E.2.25.2 Notable Leaks at Bldg 508, Marine Corps Base Camp Lejeune, NC

The door frame at timestamp 353:20 is quite emissive, which indicates potential air leaks (Figure E-263).

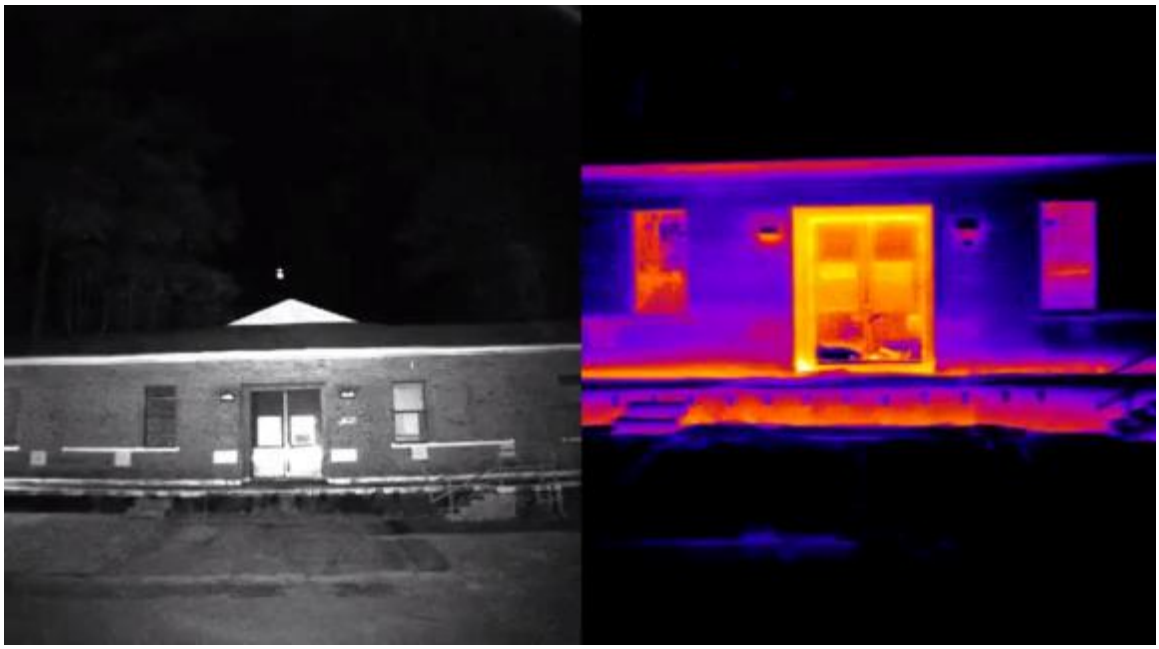

Figure E-263. NIR image (left) and thermal image (right) of Bldg 508, Camp Lejeune.

The wall in the center of the image at timestamp 353:22 is highly emissive, with a large warm hot spot in the center and an emissive foundation/basement wall (Figure E-264).

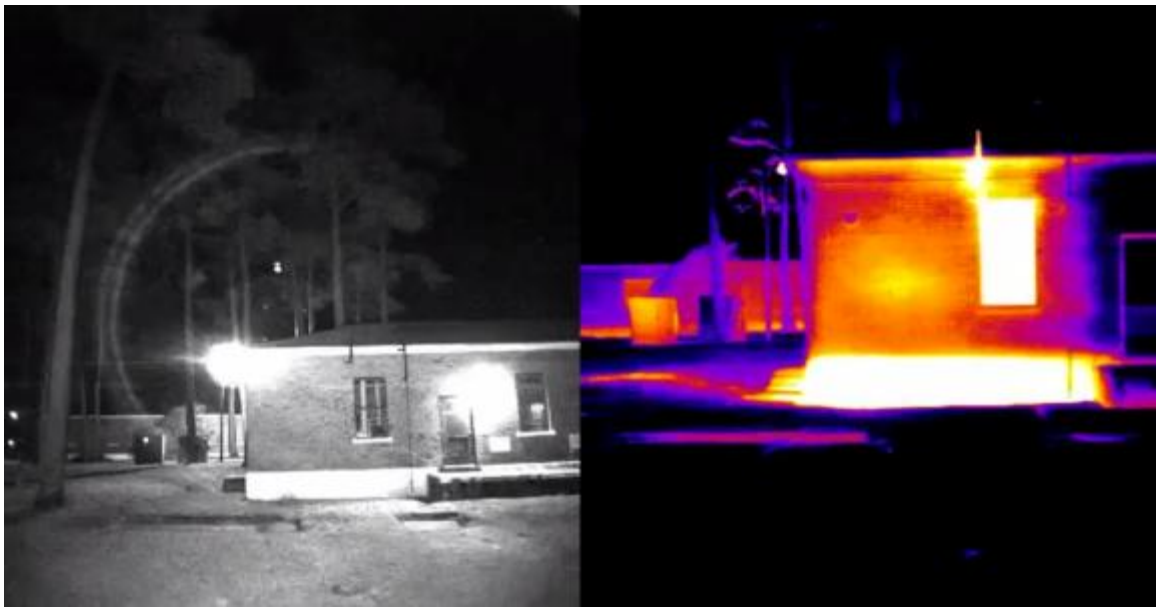

Figure E-264. NIR image (left) and thermal image (right) of Bldg 508, Camp Lejeune. The wall in the center of the image is highly emissive, with a large warm hot spot in the center and an emissive foundation/basement wall.

E.2.25.3 Envelope ECMs for Bldg 508, Marine Corps Base Camp Lejeune, NC

Figure E-265 shows the relative ROI for envelope ECMs for Bldg 508, Camp Lejeune.

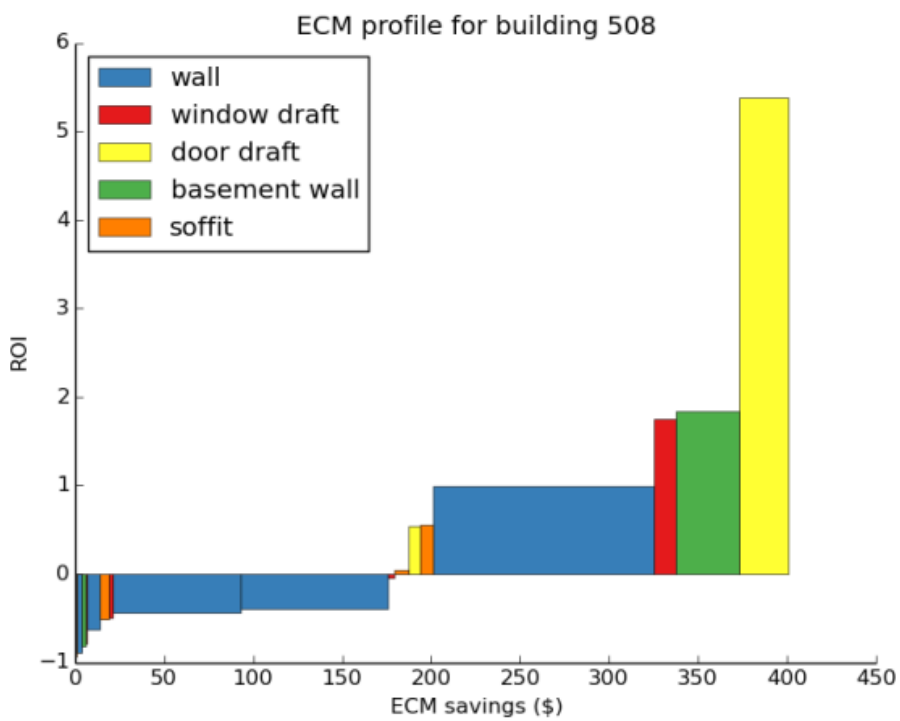

Figure E-265. ECM profile for Bldg 508, Camp Lejeune.

Table E-109 lists the recommended envelope ECMs for Bldg 508, Camp Lejeune.

Table E-109. Envelope ECMs for Bldg 508, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	439	430	278	4870	17.5
Basement Wall Insulation	57	56	36	190	5.3
Seal Door Frame Leaks	54	52	34	129	3.8
Seal Window Frame Leaks	25	25	16	130	8.1
Improve Soffit Insulation	24	24	15	183	12.0

Annual potential remediation savings for this building are $379 and total payback is 14.5 years for envelope-related ECMs.

E.2.25.4 Non-Envelope ECMs for Bldg 508, Marine Corps Base Camp Lejeune, NC

Table E-110 lists the recommended non-envelope ECMs for Bldg 508, Camp Lejeune.

Table E-110. Non-envelope ECMs for Bldg 508, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	62600	-365	3574	34508	9.7
Occupancy Sensors	28072	-164	1603	1153	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $6,066 and total payback is 6.2 years for non-envelope ECMs.

E.2.26 Bldg 509

E.2.26.1 Description of Bldg 509, Marine Corps Base Camp Lejeune, NC

Name: Command Building
Use Type: Office
Square Footage: 23,073
Avg. Daily Electric Use: 276 kWh
Electricity Score: 5th Percentile
Electricity Usage: 4.4 kWh/sq ft/yr.

Figures E-266 and E-267, respectively, show the aerial view and thermal image of Bldg 509, Camp Lejeune.

Figure E-266. Aerial view of Bldg 509, Camp Lejeune.

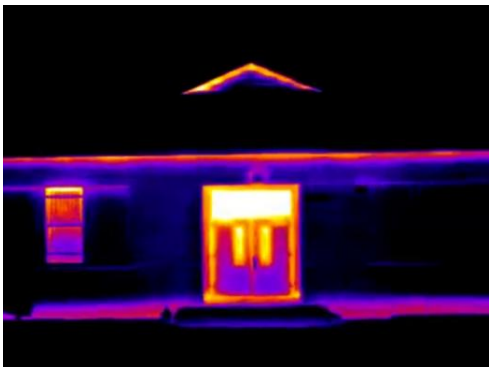

Figure E-267. Thermal image of Bldg 509, Camp Lejeune.

E.2.26.2 Notable Leaks at Bldg 509, Marine Corps Base Camp Lejeune, NC

The soffits at timestamp 169:06 are noticeably emissive, and there is a hot strip to the right of the image above the window (Figure E-268).

Figure E-268. NIR image (left) and thermal image (right) of Bldg 509, Camp Lejeune.

E.2.26.3 Envelope ECMs for Bldg 509, Marine Corps Base Camp Lejeune, NC

Figure E-269 shows the relative ROI for envelope ECMs for Bldg 509, Camp Lejeune.

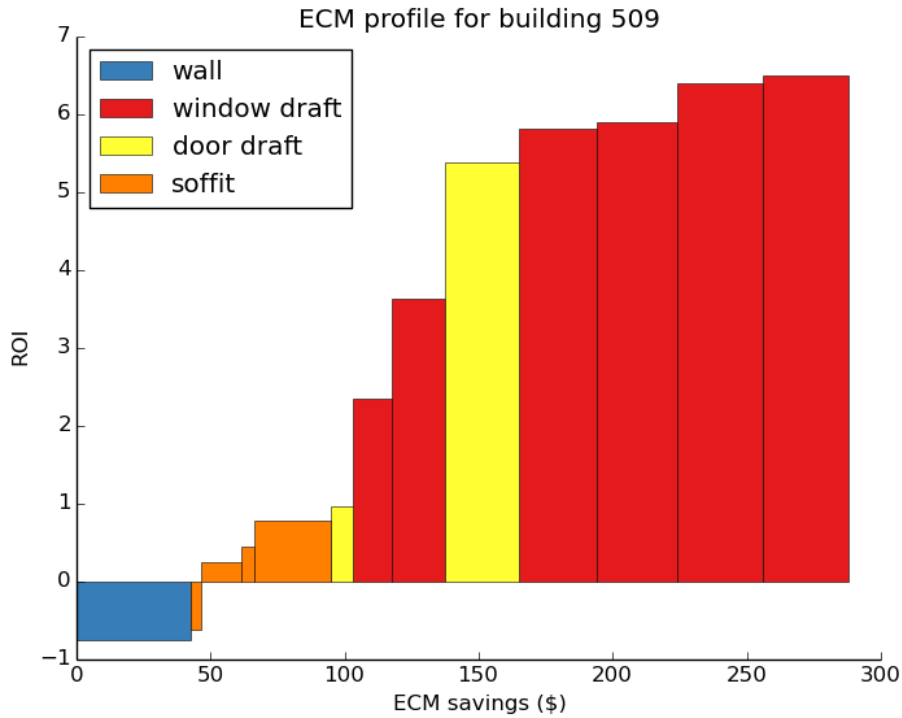

Figure E-269. ECM profile for Bldg 509, Camp Lejeune.

Table E-111 lists the recommended envelope ECMs for Bldg 509, Camp Lejeune.

Table E-111. Envelope ECMs for Bldg 509, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Seal Window Frame Leaks	248	243	157	388	2.5
Improve Soffit Insulation	76	75	49	476	9.8
Seal Door Frame Leaks	57	55	36	129	3.6

Annual potential remediation savings for this building are $242 and total payback is 4.1 years for envelope-related ECMs.

E.2.26.4 Non-Envelope ECMs for Bldg 509, Marine Corps Base Camp Lejeune, NC

Table E-112 lists the recommended non-envelope ECMs for Bldg 509, Camp Lejeune.

Table E-112. Non-envelope ECMs for Bldg 509, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	60237	-354	3437	34508	10.0
Occupancy Sensors	27012	-159	1541	1153	0.7
LED Exit Signs	16250	-171	890	1950	2.2

Annual potential remediation savings for this building are $5,868 and total payback is 6.4 years for non-envelope ECMs.

E.2.27 Bldg 895

E.2.27.1 Description of Bldg 895, Marine Corps Base Camp Lejeune, NC

Name: Exch Ctrl Restricted
Use Type: Misc.
Square Footage: 16,782
Avg. Daily Electric Use: 877.7 kWh
Electricity Score: 70th Percentile
Electricity Usage: 19.1 kWh/sq ft/yr.

Figures E-270 and E-271, respectively, show the aerial view and thermal image of Bldg 895, Camp Lejeune.

Figure E-270. Aerial view of Bldg 895, Camp Lejeune.

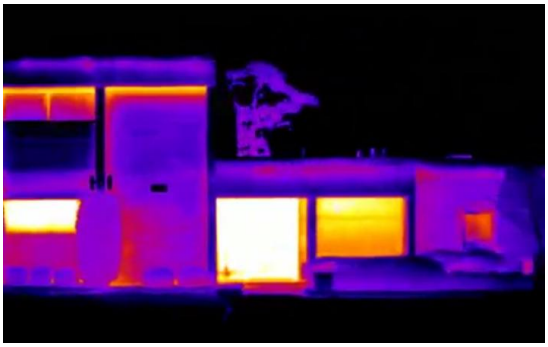

Figure E-271. Thermal image of Bldg 895, Camp Lejeune.

E.2.27.2 Notable Leaks at Bldg 895, Marine Corps Base Camp Lejeune, NC

The windows of Bldg 895 are quite a bit more emissive than any other windows that were scanned on the base. They can be seen at timestamp 135:44 (Figure E-272).

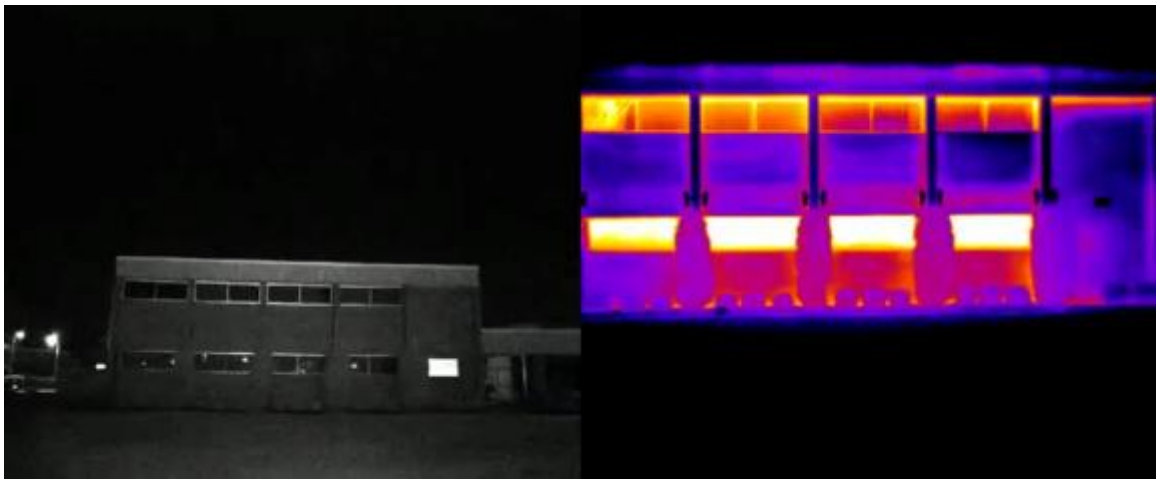

Figure E-272. NIR image (left) and thermal image (right) of Bldg 895, Camp Lejeune.

E.2.27.3 Envelope ECMs for Bldg 895, Marine Corps Base Camp Lejeune, NC

Figure E-273 shows the relative ROI for envelope ECMs for Bldg 895, Camp Lejeune.

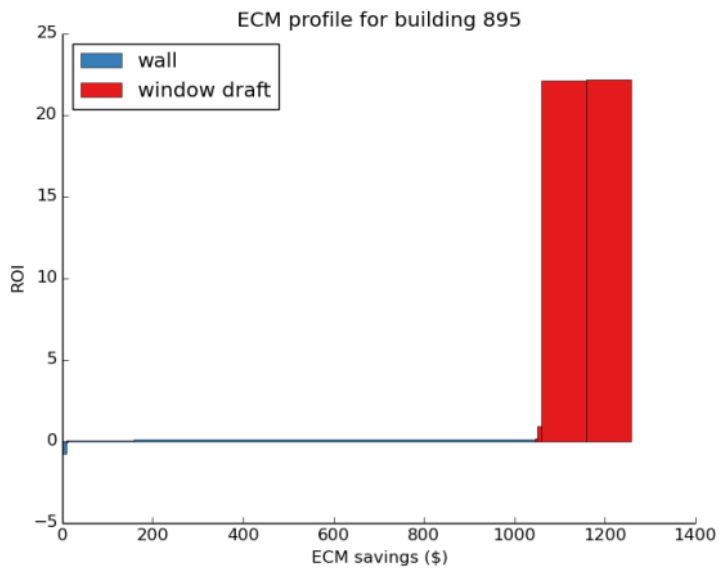

Figure E-273. ECM profile for Bldg 895, Camp Lejeune.

Table E-113 lists the recommended envelope ECMs for Bldg 895, Camp Lejeune.

Table E-113. Envelope ECMs for Bldg 895, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	1631	1597	1034	14135	13.7
Seal Window Frame Leaks	591	579	217	324	1.5

Annual potential remediation savings for this building are $1,251 and total payback is 11.6 years for envelope-related ECMs.

E.2.27.4 Non-Envelope ECMs for Bldg 895, Marine Corps Base Camp Lejeune, NC

Table E-114 lists the recommended non-envelope ECMs for Bldg 895, Camp Lejeune.

Table E-114. Non-envelope ECMs for Bldg 895, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Efficient Fluorescent Lights	45532	-265	2599	25099	9.7
Occupancy Sensors	20418	-119	1166	839	0.7
LED Exit Signs	4875	-51	267	585	2.2

Annual potential remediation savings for this building are $4,032 and total payback is 6.6 years for non-envelope ECMs.

E.2.28 Bldg 2603

E.2.28.1 Description of Bldg 2603, Marine Corps Base Camp Lejeune, NC

Name: BOQ W1-02
Use Type: Multifamily
Square Footage: 14,237
Avg. Daily Electric Use: 400 kWh
Electricity Score: 65th Percentile
Electricity Usage: 10.3 kWh/sq ft/yr.

Figures E-274 and E-275, respectively, show the aerial view and thermal image of Bldg 2603, Camp Lejeune.

Figure E-274. Aerial view of Bldg 2603, Camp Lejeune.

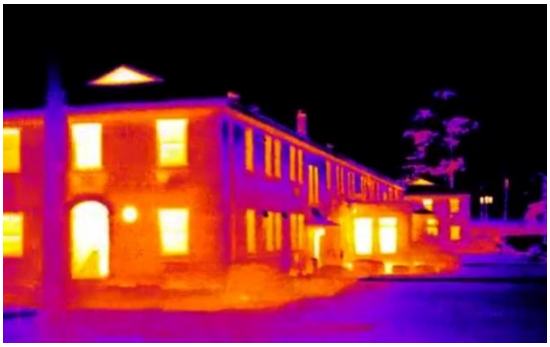

Figure E-275. Thermal image of Bldg 2603, Camp Lejeune.

E.2.28.2 Notable Leaks at Bldg 2603, Marine Corps Base Camp Lejeune, NC

The wall at timestamp 221:37 is poorly insulated, with a notable hot spot above the door frame (Figure E-276).

Figure E-276. NIR image (left) and thermal image (right) of Bldg 2603, Camp Lejeune.

E.2.28.3 Envelope ECMs for Bldg 2603, Marine Corps Base Camp Lejeune, NC

Figure E-277 shows the relative ROI for envelope ECMs for Bldg 2603, Camp Lejeune.

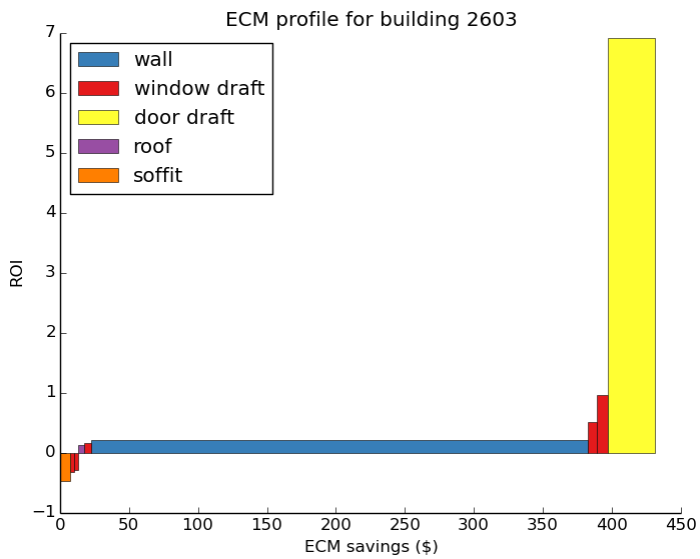

Figure E-277. ECM profile for Bldg 2603, Camp Lejeune.

Table E-115 lists the recommended envelope ECMs for Bldg 2603, Camp Lejeune.

Table E-115. Envelope ECMs for Bldg 2603, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	568	556	360	4470	12.4
Seal Door Frame Leaks	54	52	34	64	1.9
Seal Window Frame Leaks	41	40	26	323	12.5

Annual potential remediation savings for this building are $420 and total payback is 11.6 years for envelope-related ECMs.

E.2.28.4 Non-Envelope ECMs for Bldg 2603, Marine Corps Base Camp Lejeune, NC

Table E-116 lists the recommended non-envelope ECMs for Bldg 2603, Camp Lejeune.

Table E-116. Non-envelope ECMs for Bldg 2603, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Replace Incandescent Bulbs with CFLs	2329	-52	113	299	2.6
Low Flow Showerhead	0	133	66	114	1.7
Smartstrips	536	0	32	190	5.9

Annual potential remediation savings for this building are $212 and total payback is 2.8 years for non-envelope ECMs.

E.2.29 Bldg HP285

E.2.29.1 Description of Bldg HP285, Marine Corps Base Camp Lejeune, NC

Name: BEQ
Use Type: Multifamily
Square Footage: 47,709
Avg. Daily Electric Use: 1063 kWh
Electricity Score: 30th Percentile
Electricity Usage: 8.1 kWh/sq ft/yr

Figures E-278 and E-279, respectively, show the aerial view and thermal image of Bldg HP285, Camp Lejeune.

Figure E-278. Aerial view of Bldg HP285, Camp Lejeune.

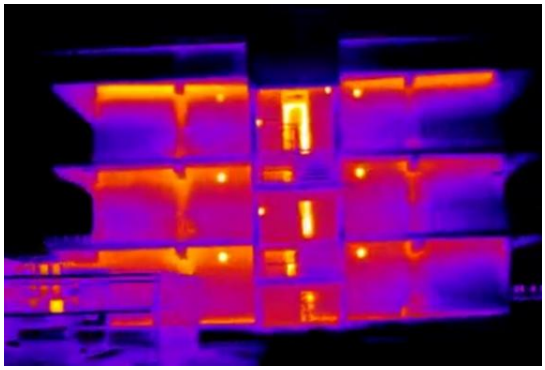

Figure E-279. Thermal image of Bldg HP285, Camp Lejeune.

E.2.29.2 Notable Leaks at Bldg HP285, Marine Corps Base Camp Lejeune, NC

The walls and door shown at timestamp 118:23 are notable emissive (Figure E-280).

Figure E-280. NIR image (left) and thermal image (right) of Bldg HP285, Camp Lejeune.

E.2.29.3 Envelope ECMs for Bldg HP285, Marine Corps Base Camp Lejeune, NC

Figure E-281 shows the relative ROI for envelope ECMs for Bldg HP285, Camp Lejeune.

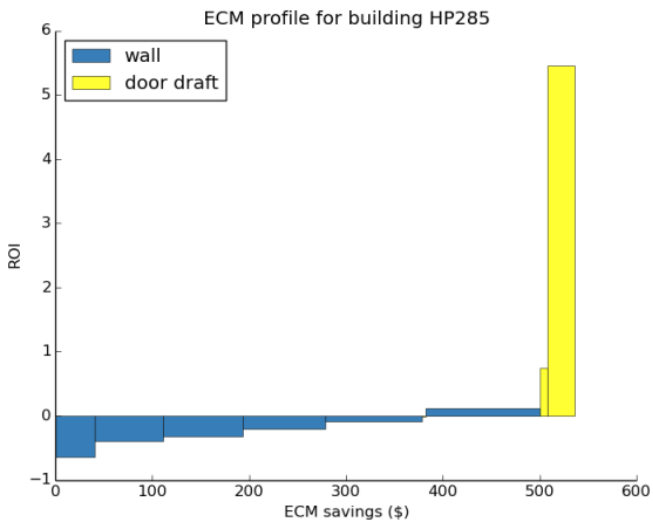

Figure E-281. ECM profile for Bldg HP285, Camp Lejeune.

Table E-117 lists the recommended envelope ECMs for Bldg HP285, Camp Lejeune.

Table E-117. Envelope ECMs for Bldg HP285, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	720	705	456	8390	18.4
Seal Door Frame Leaks	62	61	39	193	4.9

Annual potential remediation savings for this building are $496 and total payback is 17.3 years for envelope-related ECMs.

E.2.29.4 Non-Envelope ECMs for Bldg HP285, Marine Corps Base Camp Lejeune, NC

Table E-118 lists the recommended non-envelope ECMs for Bldg HP285, Camp Lejeune.

Table E-118. Non-envelope ECMs for Bldg HP285, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Replace Incandescent Bulbs with CFLs	7803	-176	380	1002	2.6
Low Flow Showerhead	0	445	223	382	1.7
Smartstrips	1797	0	108	636	5.9

Annual potential remediation savings for this building are $711 and total payback is 2.8 years for non-envelope ECMs.

E.2.30 Bldg HP507

E.2.30.1 Description of Bldg HP507, Marine Corps Base Camp Lejeune, NC

Name: BEQ E1-E4 VIC HP508
Use Type: Multifamily
Square Footage: 42,090
Avg. Daily Electric Use: 1,027 kWh
Electricity Score: 65th Percentile
Electricity Usage: 8.9 kWh/sq ft/yr.

Figures E-282 and E-283, respectively, show the aerial view and thermal image of Bldg HP570, Camp Lejeune.

Figure E-282. Aerial view of Bldg HP507, Camp Lejeune.

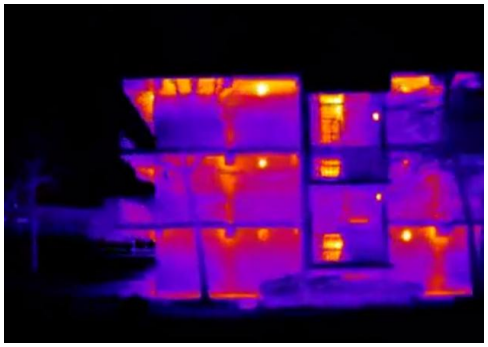

Figure E-283. Thermal image of Bldg HP570, Camp Lejeune.

E.2.30.2 Notable Leaks at Bldg HP507, Marine Corps Base Camp Lejeune, NC

The walls at timestamp 160:11 show a similar highly emissive pattern, with heat loss both at the top and down the middle of each wall (Figure E-284).

Figure E-284. NIR image (left) and thermal image (right) of Bldg HP507, Camp Lejeune.

E.2.30.3 Envelope ECMs for Bldg HP507, Marine Corps Base Camp Lejeune, NC

Figure E-285 shows the relative ROI for envelope ECMs for Bldg HP570, Camp Lejeune.

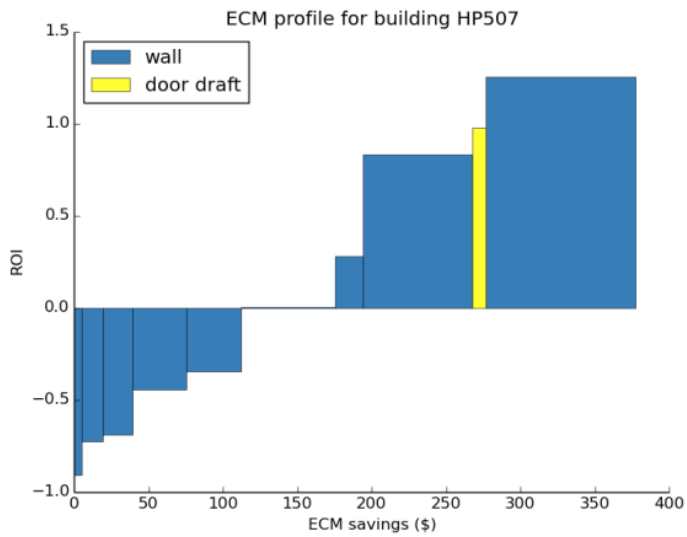

Figure E-285. ECM profile for Bldg HP507, Camp Lejeune.

Table E-119 lists the recommended envelope ECMs for Bldg HP570, Camp Lejeune.

Table E-119. Envelope ECMs for Bldg HP570, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Improve Wall Insulation	520	509	329	4257	12.9

Annual potential remediation savings for this building are $329 and total payback is 12.9 years for envelope-related ECMs.

E.2.30.4 Non-Envelope ECMs for Bldg HP507, Marine Corps Base Camp Lejeune, NC

Table E-120 lists the recommended non-envelope ECMs for Bldg HP570, Camp Lejeune.

Table E-120. Non-envelope ECMs for Bldg HP570, Camp Lejeune.

ECM Name	kWh Saved	Therms Saved	Dollars Saved	Upfront Cost	Payback Period
Replace Incandescent Bulbs with CFLs	6884	-155	335	884	2.6
Low Flow Showerhead	0	393	196	337	1.7
Smartstrips	1585	0	95	561	5.9

Annual potential remediation savings for this building are $627 and total payback is 2.8 years for non-envelope ECMs.

APPENDIX F: REMEDIATION COST ESTIMATES

This appendix provides details on the approaches used to estimate mitigation costs associated with window frame sealing, door frame sealing, wall insulation, and roof insulation. For the purposes of this analysis, it was assumed that soffit insulation shares the same characteristic costs as roof insulation, as soffit-specific remediation costs were not readily available. All of these calculations use a standard labor cost per hour, L_{cost}, which is assumed to be $60.

F.1 Window Frame Sealing

The cost of window frame sealing can be modeled as:

$$C_w = W_{num} \cdot M_{window} + L_{cost} \cdot \frac{W_{time}}{60} \quad \text{(F-1)}$$

where:

W_{num}	is the number of windows sealed
M_{window}	is the material cost per window sealed, assumed to be $33[1]
W_{time}	is the labor time required per window sealed, assumed to be 37 minutes.[1]

This resulted in a typical window sealing cost of $70 per window, assuming that enough windows will be sealed during a single trip that other time costs (e.g., travel time) will be negligible.

F.2 Door Frame Sealing

Doorframe sealing and weather-stripping is calculated similarly to window frame sealing:

$$C_d = D_{num} \cdot \left(M_{door} + L_{cost} \cdot \frac{D_{time}}{60}\right) \quad \text{(F-2)}$$

where:

D_{num}	is the number of doors sealed
M_{door}	is the material cost per door sealed, assumed to be $14.9[2]
D_{time}	is the labor time required per door sealed, assumed to be 57 minutes.[2]

This results in a typical door sealing/weather-stripping cost of $72 per door.

F.3 Wall Insulation

Wall insulation costs are comprised of access time, installation time, insulation costs, and other material costs related in the equation below:

$$C_w = W_{sqft} \cdot M_{wall} + L_{cost} \cdot \left(\frac{W_{sqft}}{W_{rate}}\right) \quad \text{(F-3)}$$

where:

W_{sqft} is the square footage of the wall in question

M_{wall} is the material cost per square foot of insulation installed, assumed to be $2.87[3]

W_{rate} is the square footage of wall insulation that can be installed in an hour by a single worker, including preparation and access time, assumed to be 13.[3]

For a 100 sq ft section of poorly insulated wall, this would amount to a total cost of $784.

F.4 Roof Insulation

Roof insulation costs are calculated similarly to wall insulation costs, and are comprised of access time, installation time, insulation costs, other material costs, and fixed material costs related in the equation below:

$$C_r = R_{sqft} \cdot M_{roof} + L_{cost} \cdot \left(\frac{R_{sqft}}{R_{rate}}\right) \quad \text{(F-4)}$$

where:

R_{sqft} is the square footage of the wall in question

M_{roof} is the material cost per square foot of insulation, assumed to be $2.66.[4]

R_{rate} is the square footage of roof/ceiling insulation that can be installed in an hour by a single worker, including preparation and access time, assumed to be 11.5.[3]

For a 100 sq ft section of poorly insulated roof, this would amount to a total cost of $788.

F.5 References

1. Homewyse. 2014. Cost to Seal Windows – 2014 Cost Calculator. Available: http://www.homewyse.com/services/cost_to_seal_windows.html
2. Homewyse. 2014. Cost to Seal Doors – 2014 Cost Calculator. Available: http://www.homewyse.com/services/cost_to_seal_door.html
3. Pacific Northwest National Laboratory. 2011. Advanced Energy Retrofit Guide — Office Buildings. Insulate Walls Measure, pages 153-154.
4. Pacific Northwest National Laboratory. 2011. Advanced Energy Retrofit Guide — Office Buildings. Insulate Roof Measure, pages 154-155.

APPENDIX G: CALCULATIONS FOR RECOMMENDED NON-ENVELOPE ECMS

The following ECM calculations are potentially relevant and cost-effective for implementing in base buildings. The text and equations are adapted from the 2014 Illinois Technical Resource Manual version 3.0, with relevant information retained and numbers adapted to be applicable to Scott AFB and Camp Lejeune climate zones.

G.1 Hot Water ECMs

G.1.1 Low Flow Faucet Aerators

G.1.1.1 Description

This measure relates to the direct installation of a low flow faucet aerator in a commercial building. Expected applications include small business, office, restaurant, or motel. For multifamily or senior housing, the residential low flow faucet aerator should be used.

If applied to other program types, the measure savings should be verified.

G.1.1.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be an energy efficient faucet aerator, for bathrooms rated at 1.5 gallons per minute (GPM) or less, or for kitchens rated at 2.2 GPM or less. Savings are calculated on an average savings per faucet fixture basis.

G.1.1.3 Definition of Baseline Equipment

The baseline condition is assumed to be a standard bathroom faucet aerator rated at 2.25 GPM or more, or a standard kitchen faucet aerator rated at 2.75 GPM or more.

G.1.1.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 9 years.[14]

G.1.1.5 Incremental and Full Measure Cost

Both the incremental and full measure costs for this measure are $8. Note: Direct-install price per faucet assumes cost of aerator and install time (in 2011, Market research average of $3 and assess and install time of $5 [20min @ $15/hr]).

G.1.1.6 Electric Energy Savings [1]

$$\Delta kWh = \%ElectricDHW * ((GPM_base - GPM_low)/GPM_base) * Usage * EPG_electric * ISR \qquad (G\text{-}1)$$

where:

%ElectricDHW = proportion of water heating supplied by electric resistance heating (See Table G-1)

GPM_base = Average flow rate, in gallons per minute, of the baseline faucet "as used"

= 1.39[2] or custom based on metering studies[3] or if measured during DI:

= Measured full throttle flow * 0.83 throttling factor[4]

GPM_low = Average flow rate, in gallons per minute, of the low flow faucet aerator "as used"

= 0.94[5] or custom based on metering studies[6] or if measured during DI:

= Rated full throttle flow * 0.95 throttling factor[4]

Usage = Estimated usage of mixed water (mixture of hot water from water heater line and cold water line) per faucet (gallons per year)

= If data are available to provide a reasonable custom estimate it should be used, if not use the defaults (or substitute custom information in to the calculation) listed in Table G-2).

EPG_electric = Energy per gallon of mixed water used by faucet (electric water heater)

= (8.33 * 1.0 * (WaterTemp - SupplyTemp)) / (RE_electric * 3412)

= (8.33 * 1.0 * (90 – 54.1)) / (0.98 * 3412)

= 0.0894 kWh/gal

8.33= Specific weight of water (lbs/gallon)

1.0 = Heat Capacity of water (Btu/lb-°F)

WaterTemp = Assumed temperature of mixed water

= 86F for Bath, 93F for Kitchen 91F for Unknown[10]

SupplyTemp = Assumed temperature of water entering building

= 54.1°F[11]

RE_electric = Recovery efficiency of electric water heater

= 98%[12]

3412 = Converts Btu to kWh (Btu/kWh)

ISR = In service rate of faucet aerators dependent on install method as listed Table G-3.[13]

Table G-1. Percent of hot water heating by electric resistance heating.

DHW fuel	%Electric_DHW
Electric	100%
Fossil Fuel	0%

Table G-2. Estimated annual domestic hot water (DHW) usage by building type.

Building Type	Gallons hot water per unit per day[7] (A)	Unit	Estimated % hot water from Faucets[8] (B)	Multiplier[9] (C)	Unit	Days per year (D)	Annual gallons mixed water per faucet (A*B*C*D)
Small Office	1	person	100%	10	employees per faucet	250	2,500
Large Office	1	person	100%	45	employees per faucet	250	11,250
Fast Food Rest	0.7	meal/day	50%	75	meals per faucet	365	9,581
Sit-Down Rest	2.4	meal/day	50%	36	meals per faucet	365	15,768
Retail	2	employee	100%	5	employees per faucet	365	3,650
Grocery	2	employee	100%	5	employees per faucet	365	3,650
Warehouse	2	employee	100%	5	employees per faucet	250	2,500
Elementary School	0.6	person	50%	50	students per faucet	200	3,000

Building Type	Gallons hot water per unit per day[7] (A)	Unit	Estimated % hot water from Faucets[8] (B)	Multiplier[9] (C)	Unit	Days per year (D)	Annual gallons mixed water per faucet (A*B*C*D)
Jr High/High School	1.8	person	50%	50	students per faucet	200	9,000
Health	90	patient	25%	2	Patients per faucet	365	16,425
Motel	20	room	25%	1	faucet per room	365	1,825
Hotel	14	room	25%	1	faucet per room	365	1,278
Other	1	employee	100%	20	employees per faucet	250	5,000

Table G-3. In service rate of faucet aerators.

Selection	ISR
Direct-Install - Deemed	0.95

G.1.1.7 Summer Coincident Peak Demand Savings

$$\Delta kW = (\Delta kWh / Hours) * CF$$

where:

ΔkWh = calculated value above on a per faucet basis

Hours = Annual electric DHW recovery hours for faucet use

= (Usage * 0.545)/GPH (See note.)

= Calculate if usage is custom, if using default usage use (Table G-4).

Note: 54.5% is the proportion of hot 120 °F water mixed with 54.1 °F supply water to give 90 °F mixed faucet water.

where:

GPH = Gallons per hour recovery of electric water heater calculated for 85.9F temp rise (140-54.1), 98% recovery efficiency, and typical 12kW electric resistance storage tank.

= 56

CF = Coincidence Factor for electric load reduction (see Table G-5)

= Dependent on building type.

Note: The calculation is done as follows. Assumptions for percentage of usage during peak period (1-5 p.m.) were made and then multiplied by 65/365 (65 being the number of days in peak period) and by the number of total annual recovery hours to give an estimate of the number of hours of recovery during peak periods. There are 260 hours in the peak period so the probability you will see savings during the peak period is calculated as the number of hours of recovery during peak divided by 260.

Table G-4. Default annual electric DHW recovery hours.

Building Type	Annual Recovery Hours
Small Office	24
Large Office	109
Fast Food Rest	93
Sit-Down Rest	153
Retail	36
Grocery	36
Warehouse	24
Elementary School	29
Jr High/High School	88
Health	160
Motel	18
Hotel	12
Other	49

Table G-5. Coincidence factor for electric load reduction.

Building Type	Coincidence Factor
Small Office	0.0064
Large Office	0.0288
Fast Food Rest	0.0084
Sit-Down Rest	0.0184
Retail	0.0043
Grocery	0.0043
Warehouse	0.0064
Elementary School	0.0096
Jr High/High School	0.0288
Health	0.0144
Motel	0.0006
Hotel	0.0004
Other	0.0128

G.1.1.8 Natural Gas Energy Savings

ΔTherms = %FossilDHW * ([GPM_base - GPM_low]/GPM_base) * Usage * EPG_gas * ISR

where:

%FossilDHW	=	proportion of water heating supplied by fossil fuel heating (see Table G-6).
EPG_gas	=	Energy per gallon of mixed water used by faucet (gas water heater)
	=	(8.33 * 1.0 * (WaterTemp - SupplyTemp)) / (RE_gas * 100,000)
	=	0.00446 Therm/gal.

where:

RE_gas = Recovery efficiency of gas water heater

= 67% (See note.)

100,000 = Converts Btu to Therms (Btu/Therm)

Other variables as defined above.

Note: Review of AHRI Directory suggests range of recovery efficiency ratings for new Gas DHW units of 70-87%. Average of existing units is estimated at 75%. Commercial properties are more similar to multi-family (MF) homes than single-family (SF) homes. MF hot water is often provided by a larger commercial boiler. This suggests that the average recovery efficiency is somewhere between a typical central boiler efficiency of 0.59 and the 0.75 for single family home. An average is used for this analysis by default.

Table G-6. Fraction of DHW heating supplied by fossil fuel heating.

DHW fuel	%Fossil_DHW
Electric	0%
Fossil Fuel	100%

G.1.1.9 Water Impact Descriptions and Calculation

Δgallons = ((GPM_base - GPM_low)/GPM_base) * Usage * ISR

Variables as defined above

G.1.2 Low Flow Showerheads

G.1.2.1 Description

This measure relates to the direct installation of a low flow showerhead in a commercial building. Expected applications include small business, office, restaurant, or small motel. For multifamily or senior housing, the residential low flow showerhead should be used.

This measure was developed to be applicable to the following program types: DI.

If applied to other program types, the measure savings should be verified.

G.1.2.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be an energy efficient showerhead rated at 2.0 GPM or less. Savings are calculated on a per showerhead fixture basis.

G.1.2.3 Definition of Baseline Equipment

The baseline condition is assumed to be a standard showerhead rated at 2.5 GPM.

G.1.2.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 10 years.[14]

G.1.2.5 Incremental and Full Measure Cost

Both the incremental and full measure costs for this measure are $12. Note: Direct-install price per showerhead assumes the cost of showerhead based on the market research average of $7, and a cost to assess and install of $5 [20min @ $15/hr].)

G.1.2.6 Electric Energy Savings

Note these savings are per showerhead fixture

ΔkWh =%ElectricDHW * ((GPM_base * L_base - GPM_low * L_low) * NSPD * 365.25) * EPG_electric * ISR

where:

%ElectricDHW	=	proportion of water heating supplied by electric resistance heating
	=	1 if electric DHW, 0 if fuel DHW, if unknown assume 16%[15]
GPM_base	=	Flow rate of the baseline showerhead
	=	2.67 for Direct-install programs (See note.)
GPM_low	=	As-used flow rate of the low flow showerhead, which may, as a result of measurements of program evaluations deviate from rated flows, see Table G-7. (Note: Based on measured data from Ameren IL EM&V of Direct-Install program. Program targets showers that are rated 2.5 GPM or above.)
L_base	=	Shower length in minutes with baseline showerhead
	=	8.20 min (Representative value from sources 1, 2, 3, 4, 5, and 6; see Source Table at end of measure section.
L_low	=	Shower length in minutes with low flow showerhead
	=	8.20 min (Set equal to L_base.)
365.25	=	Days per year, on average.
NSPD	=	Estimated number of showers taken per day for one showerhead
EPG_electric	=	Energy per gallon of hot water supplied by electric
	=	(8.33 * 1.0 * (ShowerTemp - SupplyTemp)) / (RE_electric * 3412)
	=	(8.33 * 1.0 * (105 – 54.1)) / (0.98 * 3412)
	=	0.127 kWh/gal
8.33	=	Specific weight of water (lbs/gallon)
1.0	=	Heat Capacity of water (Btu /lb-°F)
ShowerTemp	=	Assumed temperature of water
	=	105°F[16]
SupplyTemp	=	Assumed temperature of water entering house
	=	54.1°F[17]

RE_electric = Recovery efficiency of electric water heater

= 98% (electric water heaters recovery efficiency)

3412 = Converts Btu to kWh (Btu/kWh)

ISR = In service rate of showerhead (see Table G-8).

= Dependent on program delivery method (Table G-7).

Table G-7. Rated flow.

Rated Flow
2.0 GPM
1.75 GPM
1.5 GPM
Custom or Actual*
*Note that actual values may be either: (a) a program-specific minimum flow rate, or (b) a program-specific evaluation-based value of actual effective flow rate due to increased duration or temperatures. The latter increases in likelihood as the rated flow drops; this may become significant at or below rated flows of 1.5 GPM. The impact can be viewed as the inverse of the throttling described in the footnote for baseline flow rate.

Table G-8. In service rate.

Selection	ISR*
Direct-Install - Deemed	0.98
*Source: http://www.ahridirectory.org/ahridirectory/pages/home.aspx	

G.1.2.7 Summer Coincident Peak Demand Savings

$\Delta kW = \Delta kWh/Hours * CF$

where:

ΔkWh = calculated value above

Hours = Annual electric DHW recovery hours for showerhead use

= ((GPM_base * L_base) *NSPD * 365.25) * 0.773 / GPH. (Note: 77.3% is the proportion of hot 120F water mixed with 54.1°F supply water to give 105°F shower water.)

where:

GPH = Gallons per hour recovery of electric water heater calculated for 65.9F temp rise (120-54.1), 98% recovery efficiency, and typical 4.5kW electric resistance storage tank.

= 27.51

CF = Coincidence Factor for electric load reduction

= 0.0278 (see note).

Note: Calculated as follows: Assume 11% showers take place during peak hours (based on: http://www.aquacraft.com/sites/default/files/pub/DeOreo-%282001%29-Disaggregated-Hot-

Water-Use-in-Single-Family-Homes-Using-Flow-Trace-Analysis.pdf). There are 65 days in the summer peak period, so the percentage of total annual aerator use in peak period is 0.11*65/365.25 = 1.96%. The number of hours of recovery during peak periods is therefore assumed to be 1.96% * 369 = 7.23 hours of recovery during peak period where 369 equals the average annual electric DHW recovery hours for showerhead use including SF and MF homes with Direct-Install and Retrofit/TOS measures. There are 260 hours in the peak period so the probability you will see savings during the peak period is 7.23/260 = 0.0278

G.1.2.8 Natural Gas Energy Savings

ΔTherms = %FossilDHW * ((GPM_base * L_base - GPM_low * L_low) * NSPD* 365.25) * EPG_gas * ISR

where:

%FossilDHW	=	proportion of water heating supplied by fossil fuel heating (see Table G-9)
EPG_gas	=	Energy per gallon of Hot water supplied by gas
	=	(8.33 * 1.0 * (ShowerTemp - SupplyTemp)) / (RE_gas * 100,000)
	=	0.0063 Therm/gal.

where:

RE_gas	=	Recovery efficiency of gas water heater
	=	67% (See note.)
100,000	=	Converts Btu to Therms (Btu/Therm)

Other variables as defined above.

Note: A review of AHRI Directory suggests range of recovery efficiency ratings for new Gas DHW units of 70-87%. Average of existing units is estimated at 75%. Commercial properties are more similar to MF homes than SF homes. MF hot water is often provided by a larger commercial boiler. This suggests that the average recovery efficiency is somewhere between a typical central boiler efficiency of 0.59 and the 0.75 for single family home. An average is used for this analysis by default.

Table G-9. Proportion of water heating supplied by fossil fuel heating

DHW Fuel	%Fossil_Dhw
Electric	0%
Fossil Fuel	100%
Unknown	84%*

* Default assumption for unknown fuel is based on EIA Residential Energy Consumption Survey (RECS) 2009 for Midwest Region, data for the state of IL. If utilities have specific evaluation results providing a more appropriate assumption for homes in a particular market or geographical area then that should be used

G.1.2.9 Water Impact Descriptions and Calculation

Δgallons = ((GPM_base * L_base - GPM_low * L_low) * NSPD * 365.25 * ISR

Variables as defined above

G.2 HVAC ECMs

Tables G-10 and G-11 list load hours for heating and cooling for both military bases, which will be used in calculations of HVAC ECM savings.

Table G-10. Heating equivalent full load hours (heating EFLH) by building type.

	Heating EFLH*	
Building Type	**Scott AFB**	**Camp Lejeune**
Office - High Rise	2,155	1,629
Office - Mid Rise	519	392
Office - Low Rise	343	259
Convenience Store	272	206
Healthcare Clinic	694	525
Manufacturing Facility	771	583
Lodging Hotel/Motel/Multifamily	1,365	1,032
Multifamily	197	149
High School	569	430
Hospital	1,497	1,132
Elementary School	524	396
Religious Facility	1,276	965
Restaurant	872	659
Retail - Strip Mall	732	553
Retail - Department Store	578	437
College/ University	187	141
Warehouse	226	171
Unknown	752	568

* Heating EFLHs for IL are from the IL TRM for Belleville. Those for North Carolina are scaled based on the ratio of full load heating hours in St. Louis, MO and Wilmington, NC from the U.S. Environmental Protection Agency (USEPA) ENERGY STAR Air Source Heat Pump savings calculator.

Table G-11. Cooling equivalent full load hours by building type.

System Type*	EFLH by Zone[18]	
	Scott AFB	Camp Lejeune
CV reheat, no economizer	3,872	5,602
CV reheat, economizer	1,237	1,790
VAV reheat, economizer	1,142	1,652

* Cooling EFLHs for IL are from the IL TRM for Belleville. Those for North Carolina are scaled based on the ratio of full load cooling hours in St. Louis MO and Wilmington NC from the EPA's ENERGY STAR Air Source Heat Pump savings calculator.

G.2.1 Air Conditioner Tune-up

G.2.1.1 Description

An air-conditioning system that is operating as designed saves energy and provides adequate cooling and comfort to the conditioned space

G.2.1.2 Definition of Efficient Equipment

For this characterization to apply, the efficient equipment is assumed to be a unitary or split system air conditioner least 3 tons and preapproved by program. The measure requires that a certified technician performs the following items:

- Check refrigerant charge
- Identify and repair leaks if refrigerant charge is low
- Measure and record refrigerant pressures
- Measure and record temperature drop at indoor coil
- Clean condensate drain line
- Clean outdoor coil and straighten fins
- Clean and straighten indoor and outdoor fan blades
- Clean indoor coil with spray-on cleaner and straighten fins
- Repair damaged insulation – suction line
- Change air filter
- Measure and record blower amp draw
- Measure and record compressor integrity (MOhm)
- Measure and record condenser fan motor amp draw.

A copy of contractor invoices that detail the work performed to identify tune-up items, as well as additional labor and parts to improve/repair air conditioner performance must be submitted to the program

G.2.1.3 Definition of Baseline Equipment

For this characterization to apply, the baseline condition is assumed to be an Alternating Current (AC) system that does not have a standing maintenance contract, or that has not had a tune-up within in the past 36 months.

G.2.1.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 3 years.[18]

G.2.1.5 Incremental Measure Cost

The incremental capital cost for this measure is $35 per ton.[18]

G.2.1.6 Electric Energy Savings

The measure has a deemed savings that applies to all building types and air-conditioning unit size and equals an average value of 878 kWh a year.[18]

G.2.1.7 Summer Coincident Peak Demand Savings

The measure has a deemed savings that applies to all building types and air-conditioning unit size and equals an average value 0.39 kW a year.[18] (These deemed values should be compared to PY evaluation and revised as necessary.)

G.2.2 Space Heating Boiler Tune-up

G.2.2.1 Description

This measure is for a non-residential boiler that provides space heating. The tune-up will improve boiler efficiency by cleaning and/or inspecting burners, combustion chamber, and burner nozzles. Adjust air flow and reduce excessive stack temperatures, adjust burner and gas input. Check venting, safety controls, and adequacy of combustion air intake. Combustion efficiency should be measured before and after tune-up using an electronic flue gas analyzer.

G.2.2.2 Definition of Efficient Equipment

To qualify for this measure, the facility must, as applicable, complete the tune-up requirements[19] listed below, by an approved technician:

- Measure combustion efficiency using an electronic flue gas analyzer
- Adjust airflow and reduce excessive stack temperatures
- Adjust burner and gas input, manual or motorized draft control
- Check for proper venting
- Complete visual inspection of system piping and insulation
- Check safety controls
- Check adequacy of combustion air intake
- Clean fireside surfaces
- Inspect all refractory; patch and wash coat as required
- Inspect gaskets on front and rear doors and replace as necessary
- Seal and close front and rear doors properly
- Clean low and auxiliary low water cutoff controls, then re-install using new gaskets
- Clean plugs in control piping

- Remove all hand hole and manhole plates; flush boiler with water to remove loose scale and sediment
- Replace all hand hole and manhole plates with new gaskets
- Open feedwater tank manway, then inspect and clean as required; replace manway plate with new gasket.
- Clean burner and burner pilot
- Check pilot electrode and adjust or replace
- Clean air damper and blower assembly
- Clean motor starter contacts and check operation
- Make necessary adjustments to burner for proper combustion
- Perform all flame safeguard and safety trip checks
- Check all hand hole plates and man hole plates for leaks at normal operating temperatures and pressures
- Troubleshoot any boiler system problems as requested by on-site personnel.

G.2.2.3 Definition of Baseline Equipment

The baseline condition of this measure is a boiler that has not had a tune-up within the past 36 months

G.2.2.4 Deemed Lifetime of Efficient Equipment

The life of this measure is 3 years[19]

G.2.2.5 Deemed Measure Cost

The cost of this measure is $0.83/MBtu/hr[20] per tune-up

G.2.2.6 Natural Gas Energy Savings

$$\Delta therms = Ngi * SF * EFLH / (100))$$

where:

Ngi = Boiler gas input size (kBtu/hr)

= custom

SF = Savings factor

Note: Savings factor is the percentage reduction in gas consumption as a result of the tune-up

= 1.6% or custom[21]

EFLH = Equivalent Full Load Hours for heating.

G.3 Lighting ECMs

The commercial lighting measures use a standard set of variables for hours of use, waste heat factors, coincident factors and HVAC interaction effects. Table G-12 lists information provided by the various stakeholders. For ease of review, the table is included here and referenced in each measure.

Table G-12. Hours of use, waste heat factors, coincident factors and HVAC interaction effects of commercial lighting measures by building type.

Building Type	Fixture Annual Operating Hours*	Screw-based Bulb Annual Operating hours**	Waste Heat Cooling Energy WHFe†	Waste Heat Cooling Demand WHFd‡	Coincidence Factor CF§	Waste Heat Gas Heating IFTherms¥	Waste Heat Electric Resistance Heating IFkWh£	Waste Heat Electric Heat Pump Heating IFkWh
Office	4,439	3,088	1.25	1.30	0.66	0.016	0.366	0.183
Grocery	5,802	3,650	1.43	1.52	0.69	0.012	0.274	0.137
Healthcare Clinic	5,095	4,207	1.34	1.57	0.75	0.008	0.183	0.091
Hospital	6,038	4,207	1.35	1.69	0.75	0.011	0.251	0.126
Heavy Industry	5,041	2,629	1.03	1.06	0.89	0.008	0.183	0.091
Light Industry	5,360	2,629	1.03	1.06	0.92	0.008	0.183	0.091
Hotel/Motel Common Areas	5,311	4,542	1.15	1.51	0.21	0.022	0.503	0.251
Hotel/Motel Guest Rooms	777	777	1.15	1.51	0.21	0.022	0.503	0.251
High School/Middle School	4,311	2,327	1.23	0.74	0.22	0.017	0.389	0.194
Elementary School	2,422	2,118	1.21	1.33	0.22	0.019	0.434	0.217
Restaurant	3,673	4,784	1.34	1.65	0.80	0.023	0.526	0.263
Retail/Service	4,719	2,935	1.24	1.44	0.83	0.024	0.549	0.274
College/University	3,540	2,588	1.14	1.50	0.56	0.021	0.480	0.240
Warehouse	4,746	4,293	1.16	1.17	0.7	0.015	0.343	0.171
Garage	3,540	3,540	1.00	1.00	1.00	0.000	0.000	0.000
Garage, 24/7 lighting±	8,766	8,766	1.00	1.00	1.00	0.000	0.000	0.000
Exterior	4,903	4,903	1.00	1.00	0.00	0.000	0.000	0.000
Multifamily Common Areas	5,950	5,950	1.34	1.57	0.75	0.015	0.343	0.171
Religious Worship/Church***	1,664	1,664	1.24	1.46	0.66	0.014	0.320	0.160
Low-Use Small Business #	2,954	2,954	1.24	1.46	0.66	0.014	0.320	0.160
Miscellaneous!	4,576	3,198	1.24	1.46	0.66	0.014	0.320	0.160
Uncooled Building	Varies	varies	1.00	1.00	varies	varies	varies	varies
Refrigerated Cases	5,802	n/a	1.29	1.29	0.69	0	0.000	0.000
Freezer Cases	5,802	n/a	1.5	1.5	0.69	0	0.000	0.000

* As above except Heat Pump efficiency is assumed to be 200%.

** Hours of use for screw-based bulbs are derived from Database for Energy Efficiency Resources (DEER) 2008 by building type for CFLs. Garage, exterior and multifamily common area values are from the Hours of Use Table in this document.

*** Religious worship/church hours are based on DOE 2003 Commercial Building Energy Survey (CBECS) assumption of 32 hours 52 weeks a year. Coincident factor is estimated based on assumption that system peak times (1-5pm M-F) are not likely to be heavy usage periods for religious buildings.

Other assumptions are consistent with miscellaneous assumptions.

[†] The Waste Heat Factor for Energy is developed using EQuest models for various building types averaged across five climate zones for Illinois for the following building types: office, grocery, healthcare/clinic, manufacturing, motel, high school, hospital, elementary school, restaurant, retail, college and warehouse. Exterior and garage values are 1, miscellaneous is an average of all indoor spaces.

[‡] Waste Heat Factor for Demand is developed using EQuest models consistent with methodology for Waste Heat Factor for Energy.

[§] Coincident diversity factors are from the EPY4 values developed for Com Ed based on DEER 2005, DEER 2008, EPY1 and EPY2 evaluation results. Miscellaneous value for Coincident Diversity Factor is from DEER 2008.

[¥] IF Therms value is developed using EQuest models consistent with methodology for Waste Heat Factor for Energy.

[£] Electric heat penalty assumptions are based on converting the IFTherm multiplier value in to kWh and then applying relative heating system efficiencies. The gas efficiency was assumed to be 78% AFUE based on standard TRM assumption for existing unit average efficiency, and the electric resistance is assumed to be 100%: IFElectricHeat = IFTherms * 29.3 kWh/therm * 78% (Gas Heating Equipment Efficiency) / 100% (Electric Resistance Efficiency)

[±] Miscellaneous is an average of interior space values. Some building types are averaged when DEER has two values: these include office, restaurant and retail. Healthcare clinic uses the hospital value.

[#] Religious worship/church hours are based on DOE 2003 CBECS assumption of 32 hours 52 weeks a year. Coincident factor is estimated based on assumption that system peak times (1-5pm M-F) are not likely to be heavy usage periods for religious buildings. Other assumptions are consistent with miscellaneous assumptions.

[!] Miscellaneous hours are based on an average of all other space types. Values for EIF, DIF and IFtherms are an average of the other values excluding garage, uncooled building and exterior. Coincident Diversity Factor is from DEER 2008

G.3.1 Commercial ENERGY STAR CFL

G.3.1.1 Description

A low wattage ENERGY STAR qualified compact fluorescent screw-in bulb (CFL) is installed in place of a baseline screw-in bulb. This characterization assumes that the CFL is installed in a commercial location

G.3.1.2 Definition of Efficient Equipment

For this characterization to apply, the high efficiency equipment must be a standard ENERGY STAR qualified CFL.

G.3.1.3 Definition of Baseline Equipment

The baseline equipment is assumed to be an EISA qualified incandescent or halogen as provided in the table provided in the Electric Energy Savings section.

G.3.1.4 Deemed Lifetime of Efficient Equipment

The expected measure life (number of years that savings should be claimed) should be calculated by dividing the rated life of the bulb (10,000 hours) by the run hours. (Energy Star bulbs have a rated life of at least 8000 hours. In commercial settings you expect significantly less on/off switching than residential and so a rated life assumption of 10,000 hours is used.) For example using Miscellaneous at 4,589 hours would give 2.2 years. When the number of years exceeds June 2020, the number of years to that date should be used.

G.3.1.5 Deemed Measure Cost

The incremental capital cost assumption for all bulbs under 2600 lumens is $1.25, from June 2014 – May 2015, $1.60 from June 2015 to May 2016, and $1.70 from June 2017 to May 2018 (based on pricing forecast developed by Applied Proactive Technologies Inc (APT), which is based on industry input and provided to Ameren).

For bulbs over 2600 lumens, the assumed incremental capital cost is $5.

G.3.1.6 Electric Energy Savings

$$\Delta kWh = ((WattsBase - WattsEE)/1000) * ISR * Hours * WHFe$$

where:

WattsBase	=	Actual (if retrofit measure) or based on lumens of CFL bulb and program year installed (see Table G-13).
WattsEE	=	Actual wattage of CFL purchased or installed
ISR	=	In Service Rate or the percentage of units rebated that get installed.
	=	100%if application form completed with sign off that equipment is not placed into storage

(Illinois evaluation of PY1 through PY3 has not found that fixtures or lamps placed into storage to be a significant enough issue to warrant including an "In Service Rate" when commercial customers complete an application form.(

Hours = Average hours of use per year are provided in Reference Table G-12 (p 282), in the column labeled "Screw-based bulb annual operating hours" for each building type (based on Com Ed analysis taking DEER 2008 values and averaging with PY1 and PY2 evaluation results). If unknown, use the Miscellaneous value.

WHFe = Waste heat factor for energy to account for cooling energy savings from efficient lighting (see Table G-13) for each building type. If unknown, use the Miscellaneous value.

Table G-13. Incandescent equivalent of CFL bulb lumens.

Minimum Lumens	Maximum Lumens	Incandescent Equivalent Post-EISA 2007 (WattsBase)
5280	6209	300
3000	5279	200
2601	2999	150
1490	2600	72
1050	1489	53
750	1049	43
310	749	29
250	309	25

If the sign off form is not completed, assume the 3-year ISR assumptions listed in Table G-14.

Table G-14. Three-year ISR assumptions.

Weighted Average 1st year In Service Rate (ISR)	2nd year Installations	3rd year Installations	Final Lifetime ISR
75.5%	12.1%	10.3%	98.0%

* 1st year in service rate is based on review of PY4-5 evaluations from Com Ed's commercial lighting program (BILD) (see "IL Commercial Lighting ISR.xls" for more information. The average first year ISR was calculated weighted by the number of bulbs sold.

** The 98% Lifetime ISR assumption is based on a review of two evaluations: (1) Nexus Market Research, RLW Analytics and GDS Associates study; "New England Residential Lighting Markdown Impact Evaluation, 20 January 2009" and (2) KEMA Inc, Feb 2010, "Final Evaluation Report:, Upstream Lighting Program, Volume 1." This implies that only 2% of bulbs purchased are never installed. The second and third year installations are based on Ameren analysis of the Californian KEMA study showing that 54% of future installs occur in year 2 and 46% in year 3. The 2nd and 3rd year installations should be counted as part of those future program year savings.

G.3.1.7 Heating Penalty

If electrically heated building:

$$\Delta kWh_{heatpenalty} = (((WattsBase-WattsEE)/1000) * ISR * Hours * -IFkWh$$

where:

IFkWh = Lighting-HVAC Interaction Factor for electric heating impacts; this factor represents the increased electric space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Values are provided in Table G-12. If unknown, use the Miscellaneous value.

Note: $\Delta kWh_{heatpenalty}$ is a negative value because this is an increase in heating consumption due to the efficient lighting.

G.3.1.8 Natural Gas Energy Savings

Heating Penalty if fossil fuel heated building (or if heating fuel is unknown):

$$\Delta Therms = (((WattsBase-WattsEE)/1000) * ISR * Hours *- IFTherms$$

where:

IFTherms = Lighting-HVAC Interaction Factor for gas heating impacts; this factor represents the increased gas space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Values are provided in Table G-12. If unknown, use the Miscellaneous value

Other factors as defined above.

Note: ΔTherms is a negative value because this is an increase in heating consumption due to the efficient lighting.

G.3.2 High Performance and Reduced Wattage T8 Fixtures and Lamps

G.3.2.1 Description

This measure applies to "High Performance T8" (HPT8) lamp/ballast systems that have higher lumens per watt than standard T8 systems. This measure applies to the installation of new equipment with efficiencies that exceed that of the equipment that would have been installed following standard market practices and is applicable to time of sale as well as retrofit measures. Retrofit measures may include new fixtures or relamp/reballast measures. In addition, options have been provided to allow for the "Reduced Wattage T8 lamps" or RWT8 lamps that result in re-lamping opportunities that produce equal or greater light levels than standard T8 lamps while using fewer watts.

The measure applies to all commercial HPT8 installations excluding new construction and major renovation or change of use measures (see lighting power density measure). Lookup tables have been provided to account for the different types of installations. Whenever possible, actual costs and hours of use should be used for savings calculations. Default new and baseline assumptions have been provided in the reference tables. Default component costs and lifetimes have been provided for Operating and Maintenance Calculations. Please see the Definition Table to determine applicability for each program. HPT8 configurations not included in the TRM may be included in custom program design using the provided algorithms as long as energy savings is achieved. Table G-15 lists the applicability for different programs

Table G-15. Reference tables associated with baseline fixture configurations.

Program	Reference Table
Time of Sale	A-1: HPT8 New and Baseline Assumptions
Retrofit	A-2: HPT8 New and Baseline Assumptions
Reduced Wattage T8, time of sale or retrofit	A-3: RWT8 New and Baseline Assumptions

G.3.2.2 Deemed Lifetime of Efficient Equipment

Fixture lifetime is 15 years.

G.3.2.3 Electric Energy Savings

$$\Delta kWh = ((Watts_{base} - Watts_{EE})/1000) * Hours * WHF_e * ISR$$

where:

$Watts_{base}$ = Input wattage of the existing system that depends on the baseline fixture configuration (number and type of lamp) and number of fixtures. Value can be selected from the appropriate reference table, of a custom value can be entered if the configurations in the tables is not representative of the existing system.

$Watts_{EE}$ = New Input wattage of EE fixture that depends on new fixture configuration (number of lamps) and ballast factor and number of fixtures. Value can be selected from the appropriate reference table,

of a custom value can be entered if the configurations in the tables is not representative of the existing system.

Hours = Average hours of use per year as provided by the customer or selected from Table G-12, Fixture annual operating hours. If hours or building type are unknown, use the Miscellaneous value.

WHFe = Waste heat factor for energy to account for cooling energy savings from efficient lighting is selected from Table G-12 for each building type. If building is uncooled, the value is 1.0.

ISR = In Service Rate or the percentage of units rebated that get installed.

= 100% if application form completed with sign off that equipment is not placed into storage. (Illinois evaluation of PY1 through PY3 has not found that fixtures or lamps placed into storage to be a significant enough issue to warrant including an ISR when commercial customers complete an application form).

If sign off form not completed assume the 3 year ISR assumptions listed in Table G-16.

Table G-16. Three-year ISR assumptions.

Weighted Average 1st year ISR	2nd year Installations	3rd year Installations	Final Lifetime ISR
96%*	1.1%	0.9%	98.0%**

* 1st year in service rate is based on review of PY4-5 evaluations from Com Ed's commercial lighting program (BILD) (see "IL Commercial Lighting ISR.xls" for more information

** The 98% Lifetime ISR assumption is based on review of two evaluations:
(1) Nexus Market Research, RLW Analytics and GDS Associates study; "New England Residential Lighting Markdown Impact Evaluation, 20 January 2009" and (2) KEMA Inc, Feb 2010, "Final Evaluation Report: Upstream Lighting Program, Volume 1." This implies that only 2% of bulbs purchased are never installed. The second and third year installations are based on an Ameren analysis of the Californian KEMA study showing that 54% of future installs occur in year 2 and 46% in year 3. The 2nd and 3rd year installations should be counted as part of those future program year savings.

G.3.2.4 Heating Penalty

If electrically heated building:

$$\Delta kWh_{heatpenalty} = ((WattsBase-WattsEE)/1000) * ISR * Hours * -IFkWh$$

where:

IFkWh	=	Lighting-HVAC Interaction Factor for electric heating impacts; this factor represents the increased electric space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Values are provided in Table G-12, p 282. If unknown, use the Miscellaneous value.
Note:		$\Delta kWh_{heatpenalty}$ is a negative value because this is an increase in heating consumption due to the efficient lighting.

G.3.2.5 Natural Gas Savings

$$\Delta Therms = (((_{WattsBase}-WattsEE)/1000) * ISR * Hours *- IFTherms$$

where:

IFTherms	=	Lighting-HVAC Integration Factor for gas heating impacts; this factor represents the increased gas space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Please select from Table G-12 (p 282) for each building type.

Note: ΔTherms is a negative value because this is an increase in heating consumption due to the efficient lighting.

G.3.2.6 Reference Tables

Tables G-17 to G-19 list new and baseline assumptions for fluorescent lamps.

Table G-17. Time of sale: HPT8 new and baseline assumptions.*

EE Measure Description	$Watts_{EE}$	Baseline Description**	$Watts_{BASE}$	Measure Cost	$Watts_{SAVE}$
4-Lamp HPT8 w/ High-BF Ballast High-Bay	146	200 Watt Pulse Start Metal-Halide	232	$75	86
6-Lamp HPT8 w/ High-BF Ballast High-Bay	221	320 Watt Pulse Start Metal-Halide	350	$75	129
8-Lamp HPT8 w/ High-BF Ballast High-Bay	280	Proportionally Adjusted according to 6-Lamp HPT8 Equivalent to 320 PSMH	455	$75	175
1-Lamp HPT8-high performance 32 w lamp	25	1-Lamp Standard F32T8 w/ Elec. Ballast	32	$15	7
1-Lamp HPT8-high performance 28 w lamp	22	1-Lamp Standard F32T8 w/ Elec. Ballast	32	$15	10
1-Lamp HPT8-high performance 25 w lamp	19	1-Lamp Standard F32T8 w/ Elec. Ballast	32	$15	13
2-Lamp HPT8 -high performance 32 w lamp	49	2-Lamp Standard F32T8 w/ Elec. Ballast	59	$18	10
2-Lamp HPT8-high performance 28 w lamp	43	2-Lamp Standard F32T8 w/ Elec. Ballast	59	$18	16
2-Lamp HPT8-high performance 25 w lamp	35	2-Lamp Standard F32T8 w/ Elec. Ballast	59	$18	24
3-Lamp HPT8-high performance 32 w lamp	72	3-Lamp Standard F32T8 w/ Elec. Ballast	88	$20	16
3-Lamp HPT8-high performance 28 w lamp	65	3-Lamp Standard F32T8 w/ Elec. Ballast	88	$20	23
3-Lamp HPT8-high performance 25 w lamp	58	3-Lamp Standard F32T8 w/ Elec. Ballast	88	$20	30
4-Lamp HPT8 -high performance 32 w lamp	94	4-Lamp Standard F32T8 w/ Elec. Ballast	114	$23	20
4-Lamp HPT8-high performance 28 w lamp	86	4-Lamp Standard F32T8 w/ Elec. Ballast	114	$23	28
4-Lamp HPT8-high performance 25 w lamp	77	4-Lamp Standard F32T8 w/ Elec. Ballast	114	$23	37
2-lamp High Performance HPT8 Troffer	49	3-Lamp F32T8 w/ Elec. Ballast	88	$100	39

*Adapted from Efficiency Vermont TRM, *Measure Savings Algorithms and Cost Assumptions*, 26 October 2011.

**Table developed using a constant ballast factor of 0.77. Input wattages are an average of manufacturer inputs that account for ballast efficacy

Table G-18. Retrofit HPT8 new and baseline assumptions[22] (note: see definition for validity after 2016).

EE Measure Description	$Watts_{EE}$	Baseline Description	$Watts_{BASE}$	Incremental cost	$Watts_{SAVE}$
4-Lamp HPT8 w/ High-BF Ballast High-Bay	146	200 Watt Pulse Start Metal-Halide	232	$200	86
4-Lamp HPT8 w/ High-BF Ballast High-Bay	146	250 Watt Metal Halide	295	$200	149
6-Lamp HPT8 w/ High-BF Ballast High-Bay	206	320 Watt Pulse Start Metal-Halide	350	$225	144
6-Lamp HPT8 w/ High-BF Ballast High-Bay	206	400 Watt Metal Halide	455	$225	249
8-Lamp HPT8 w/ High-BF Ballast High-Bay	280	Proportionally Adjusted according to 6-Lamp HPT8 Equivalent to 320 PSMH	476	$250	196
8-Lamp HPT8 w/ High-BF Ballast High-Bay	280	Proportionally Adjusted according to 6-Lamp HPT8 Equivalent to 400 W Metal halide	618	$250	338
1-Lamp Relamp/Reballast T12 to HPT8	25	1-Lamp F34T12 w/ EEMag Ballast	40	$50	15
2-Lamp Relamp/Reballast T12 to HPT8	49	2-Lamp F34T12 w/ EEMag Ballast	68	$55	19
3-Lamp Relamp/Reballast T12 to HPT8	72	3-Lamp F34T12 w/ EEMag Ballast	110	$60	38
4-Lamp Relamp/Reballast T12 to HPT8	94	4-Lamp F34T12 w/ EEMag Ballast	139	$65	45
1-Lamp Relamp/Reballast T12 to HPT8	25	1-Lamp F40T12 w/ EEMag Ballast	48	$50	23
2-Lamp Relamp/Reballast T12 to HPT8	49	2-Lamp F40T12 w/ EEMag Ballast	82	$55	33
3-Lamp Relamp/Reballast T12 to HPT8	72	3-Lamp F40T12 w/ EEMag Ballast	122	$60	50
4-Lamp Relamp/Reballast T12 to HPT8	94	4-Lamp F40T12 w/ EEMag Ballast	164	$65	70
1-Lamp Relamp/Reballast T12 to HPT8	25	1-Lamp F40T12 w/ Mag Ballast	57	$50	32
2-Lamp Relamp/Reballast T12 to HPT8	49	2-Lamp F40T12 w/ Mag Ballast	94	$55	45
3-Lamp Relamp/Reballast T12 to HPT8	72	3-Lamp F40T12 w/ Mag Ballast	147	$60	75
4-Lamp Relamp/Reballast T12 to HPT8	94	4-Lamp F40T12 w/ Mag Ballast	182	$65	88
1-Lamp Relamp/Reballast T8 to HPT8	25	1-Lamp F32T8 w/ Elec. Ballast	32	$50	7
2-Lamp Relamp/Reballast T8 to HPT8	49	2-Lamp F32T8 w/ Elec. Ballast	59	$55	10
3-Lamp Relamp/Reballast T8 to HPT8	72	3-Lamp F32T8 w/ Elec. Ballast	88	$60	16
4-Lamp Relamp/Reballast T8 to HPT8	94	4-Lamp F32T8 w/ Elec. Ballast	114	$65	20
2-lamp High-Performance HPT8 Troffer or high efficiency retrofit troffer	49	3-Lamp F32T8 w/ Elec. Ballast	88	$100	39

Table G-19. Time of sale T8 component costs and lifetime[22]

EE Measure Description	EE Lamp Cost	EE Lamp Life (hrs)	EE Lamp Rep. Labor Cost per lamp	EE Ballast Cost	EE Ballast Life (hrs)	EE Ballast Rep. Labor Cost	Baseline Description	Base Lamp Cost	Base Lamp Life (hrs)	Base Lamp Rep. Labor Cost	Base Ballast Cost	Base Ballast Life (hrs)	Base Ballast Rep. Labor Cost
4-Lamp HPT8 w/ High-BF Ballast High-Bay	$5.00	24000	$6.67	$32.50	70000	$15.00	200 Watt Pulse Start Metal-Halide	$21.00	10000	$6.67	$88	40000	$22.50
6-Lamp HPT8 w/ High-BF Ballast High-Bay	$5.00	24000	$6.67	$32.50	70000	$15.00	320 Watt Pulse Start Metal-Halide	$21.00	20000	$6.67	$109	40000	$22.50
8-Lamp HPT8 w/ High-BF Ballast High-Bay	$5.00	24000	$6.67	$32.50	70000	$15.00	Lamp HPT8 Equivalent to 320 PSMH	$21.00	20000	$6.67	$109	40000	$22.50
1-Lamp HPT8 - all qualifying lamps	$5.00	24000	$2.67	$32.50	70000	$15.00	1-Lamp Standard F32T8 w/ Elec. Ballast	$2.50	20000	$2.67	$15	70000	$15.00
2-Lamp HPT8 - all qualifying lamps	$5.00	24000	$2.67	$32.50	70000	$15.00	2-Lamp Standard F32T8 w/ Elec. Ballast	$2.50	20000	$2.67	$15	70000	$15.00
3-Lamp HPT8 - all qualifying lamps	$5.00	24000	$2.67	$32.50	70000	$15.00	3-Lamp Standard F32T8 w/ Elec. Ballast	$2.50	20000	$2.67	$15	70000	$15.00
4-Lamp HPT8 - all qualifying lamps	$5.00	24000	$2.67	$32.50	70000	$15.00	4-Lamp Standard F32T8 w/ Elec. Ballast	$2.50	20000	$2.67	$15	70000	$15.00
2-lamp High-Performance HPT8 Troffer	$5.00	24000	$2.67	$32.50	70000	$15.00	3-Lamp F32T8 w/ Elec. Ballast	$2.50	20000	$2.67	$15	70000	$15.00

G.3.3 Commercial LED Exit Signs

G.3.3.1 Description

This measure characterizes the savings associated with installing an LED exit sign in place of a fluorescent or incandescent exit sign in a Commercial building. Light Emitting Diode exit signs have a string of very small, typically red or green, glowing LEDs arranged in a circle or oval. The LEDs may also be arranged in a line on the side, top or bottom of the exit sign. LED exit signs provide the best balance of safety, low maintenance, and very low energy usage compared to other exit sign technologies.

G.3.3.2 Definition of Efficient Equipment

The efficient equipment is assumed to be an exit sign illuminated by LEDs.

G.3.3.3 Definition of Baseline Equipment

The baseline equipment is assumed to be a fluorescent or incandescent model.

G.3.3.4 Deemed Lifetime of Efficient Equipment

The measure life is assumed to be 16 years.[23]

G.3.3.5 Deemed Measure Cost

The incremental cost for this measure is assumed to be $30.[24] (Labor cost assumes 25 minutes @ $18/hr.)

G.3.3.6 Electric Energy Savings

$$\Delta kWh = ((WattsBase - WattsEE) / 1000) * HOURS * WHF_e$$

where:

WattsBase	=	Actual wattage if known, if unknown assume the values listed in Table G-20.
WattsEE	=	Actual wattage if known, if unknown assume 2W[26]
HOURS	=	Annual operating hours
	=	8766
WHFe	=	Waste heat factor for energy to account for cooling energy savings from efficient lighting are provided for each building type in Table G-12 (p 282). If unknown, use the Miscellaneous value.

Table G-20. Assumed WattsBase values.

Baseline Type	WattsBase
Incandescent	35W*
Fluorescent	11W[25]
Unknown (e.g., time of sale)	23W**

*Based on review of available product.

** Com Ed has been using a weighted baseline of 70% incandescent and 30% compact fluorescent, reflecting program experience and a limited sample of evaluation verification findings considered to be reasonable (Navigant, through comment period February 2013)

G.3.3.7 Heating Penalty

If electrically heated building:

$$\Delta kWh_{heatpenalty} = ((WattsBase-WattsEE)/1000) * Hours * -IFkWh$$

where:

IFkWh = Lighting-HVAC Interaction Factor for electric heating impacts; this factor represents the increased electric space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Values are provided in Table G-12 (p 282). If unknown, use the Miscellaneous value.

Note: $\Delta kWh_{heatpenalty}$ has a negative value because this is an increase in heating consumption due to the efficient lighting.

G.3.3.8 Natural Gas Savings

Heating Penalty if natural gas heated building (or if heating fuel is unknown):

$$\Delta therms = (((WattsBase-WattsEE)/1000) * Hours *- IFTherms$$

where:

IFTherms = Lighting-HVAC Integration Factor for gas heating impacts; this factor represents the increased gas space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Values are provided in Table G-12 (p 282). If unknown, use the Miscellaneous value.

G.3.4 Occupancy Sensor Lighting Controls

G.3.4.1 Description

This measure relates to the installation of new occupancy sensors on a new or existing lighting system. Lighting control types covered by this measure include wall, ceiling or fixture-mounted occupancy sensors. Passive IR, ultrasonic detectors, and fixture-mounted sensors or sensors with a combination thereof are eligible. Lighting controls required by state energy codes are not eligible. This must be a new installation and may not replace an existing lighting occupancy sensor control.

G.3.4.2 Definition of Efficient Equipment

For this characterization to apply, the existing system is assumed to be manually controlled or an uncontrolled lighting system that is being controlled by one of the lighting controls systems listed above. All sensors must be hard wired and control interior lighting.

G.3.4.3 Definition of Baseline Equipment

The baseline is assumed to be a lighting system uncontrolled by occupancy.

G.3.4.4 Deemed Lifetime of Efficient Equipment

The expected measure life for all lighting controls is assumed to be 8 years.[23]

G.3.4.5 Deemed Measure Cost

When available, the actual cost of the measure shall be used. When not available, the default values listed in Table G-21 may be used.

Table G-21. Default costs for lighting control types.

Lighting Control Type	Cost
Full cost of wall-mounted occupancy sensor	$42[27]
Full cost mounted occupancy sensor	$66[27]
Full cost of fixture-mounted occupancy sensor	$125[28]

G.3.4.6 Electric Energy Savings

$$\Delta kWh = KW_{Controlled} * Hours * ESF * WHF_e$$

where:

$Kw_{Controlled}$ = Total lighting load connected to the control in kilowatts. Savings is per control. The total connected load per control should be collected from the customer or the default values listed in Table G-22

Hours = total operating hours of the controlled lighting circuit before the lighting controls are installed. This number should be collected from the customer. Average hours of use per year are provided in Table G-12 (p 282), in the column labeled "Fixture Annual Operating Hours," for each building type if customer specific information is not collected. If unknown building type, use the Miscellaneous value.

ESF = Energy Savings factor (represents the percentage reduction to the operating hours from the non-controlled baseline lighting system, see Table G-23).

WHFe = Waste heat factor for energy to account for cooling energy savings from efficient lighting is provided in Table G-12 (p 282) for each building type. If building is uncooled, the value is 1.0.

Table G-22. Total connected load per control default values.

Lighting Control Type	Default kW controlled
Wall-mounted occupancy sensor	0.350[27]
Remote mounted occupancy sensor	0.587[27]
Fixture-mounted sensor	0.073[28]

Table G-23. Energy savings factor.

Lighting Control Type	Energy Savings Factor[29]
Wall or Ceiling-Mounted Occupancy Sensors	41% or custom
Fixture-Mounted Occupancy Sensors	30% or custom
Wall-Mounted Occupancy Sensors Configured as "Vacancy Sensors"	53% or custom[30]

G.3.4.7 Heating Penalty

If electrically heated building:

$$\Delta kWh_{heatpenalty} = KW_{Controlled} * Hours * ESF * -IFkWh$$

where:

IFkWh = Lighting-HVAC Interaction Factor for electric heating impacts; this factor represents the increased electric space heating requirements due to the reduction of waste heat rejected by the efficient lighting. Values are provided in Table G-12 (p 282). If unknown, use the Miscellaneous value.

Note: $\Delta kWh_{heatpenalty}$ takes a negative value because this is an increase in heating consumption due to the efficient lighting.

G.3.4.8 Natural Gas Energy Savings

$$\Delta therms = KW_{Controlled} * Hours * ESF * - IFTherms$$

where:

IFTherms = Lighting-HVAC Integration Factor for gas heating impacts; this factor represents the increased gas space heating requirements due to the reduction of waste heat rejected by the efficient lighting and provided in Table G-12 (p 282) by building type.

G.4 Food Service ECMs

G.4.1 Combination Oven

G.4.1.1 Description

This measure applies to natural gas fired high efficiency combination convection and steam ovens installed in a commercial kitchen replacing existing equipment at the end of its useful life.

G.4.1.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be a new natural gas combination convection with steam oven cooking efficiency ≥ 38% and convection mode cooking efficiency ≥ 44% using ASTM Standard F2861 and meet idle requirements listed in Table G-24.[31]

Table G-24. Idle rate requirements for commercial combination ovens/steamers.

Combination Oven Type	Steam Mode Idle Rate	Convection Mode Idle Rate
Gas Combi < 15 pan capacity	15,000 Btu/hr	9,000 Btu/hr
Gas Combi 15-28 pan capacity	18,000 Btu/hr	11,000 Btu/hr
Gas Combi > 28 pan capacity	28,000 Btu/hr	17,000 Btu/hr

G.4.1.3 Definition of Baseline Equipment

The baseline equipment is a new or existing natural gas combination convection and steam ovens that do not meet the efficient equipment criteria

G.4.1.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 12 years[32]

G.4.1.5 Incremental Measure Cost

The incremental capital cost for this measure is $4300[32]

G.4.1.6 Full Measure Cost

The full capital cost for this measure is around $15816.

G.4.1.7 Natural Gas Energy Savings

The annual natural gas energy savings from this measure is a deemed value equaling 644 therms.[33]

G.4.2 Commercial Solid and Glass Door Refrigerators and Freezers

G.4.2.1 Description

This measure relates to the installation of a new reach-in commercial refrigerator or freezer meeting ENERGY STAR efficiency standards. ENERGY STAR labeled commercial refrigerators and freezers are more energy efficient because they are designed with components such as ECM evaporator and condenser fan motors, hot gas anti-sweat heaters, or high efficiency compressors, which will significantly reduce energy consumption.

G.4.2.2 Definition of Efficient Equipment

For this characterization to apply, the efficient equipment is assumed to be a new vertical solid or glass door refrigerator or freezer or vertical chest freezer meeting the minimum ENERGY STAR efficiency level standards.

G.4.2.3 Definition of Baseline Equipment

For this characterization to apply, the baseline equipment is assumed to be an existing solid or glass door refrigerator or freezer meeting the minimum Federal manufacturing standards as specified by the Energy Policy Act of 2005.

G.4.2.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 12 years.[34]

G.4.2.5 Incremental Measure Cost

Table G-25 lists the incremental capital cost for this measure.

Table G-25. Incremental capital cost for commercial solid and glass door refrigerators and freezers.

Type	Refrigerator incremental Cost, per unit	Freezer Incremental Cost, per unit
Solid or Glass Door		
$0 < V < 15$	$143	$142
$15 \leq V < 30$	$164	$166
$30 \leq V < 50$	$164	$166
$V \geq 50$	$249	$407

G.4.2.6 Full Measure Cost

The full capital cost for this measure is around $2764.

G.4.2.7 Electric Energy Savings

$$\Delta kWh = (kWhbase - kWhee) * 365.25$$

where:

kWhbase = baseline maximum daily energy consumption in kWh

= calculated using actual chilled or frozen compartment volume (V) of the efficient unit (see Table G-26).

kWhee = efficient maximum daily energy consumption in kWh[35]

= calculated using actual chilled or frozen compartment volume (V) of the efficient unit (see Table G-27).

V = the chilled or frozen compartment volume (ft3) (as defined in the Association of Home Appliance Manufacturers Standard HRF1–1979)

= Actual installed

365.25 = days per year.

Table G-26. Chilled or frozen compartment volume of the efficient unit (kWhbase).

Type	kWhbase*
Solid Door Refrigerator	0.10 * V + 2.04
Glass Door Refrigerator	0.12 * V + 3.34
Solid Door Freezer	0.40 * V + 1.38
Glass Door Freezer	0.75 * V + 4.10
Source: Energy Policy Act of 2005	

Table G-27. Chilled or frozen compartment volume of the efficient unit (kWhee).

Type	Refrigerator kWhee	Freezer kWhee
Solid Door		
$0 < V < 15$	$\leq 0.089V + 1.411$	$\leq 0.250V + 1.250$
$15 \leq V < 30$	$\leq 0.037V + 2.200$	$\leq 0.400V - 1.000$
$30 \leq V < 50$	$\leq 0.056V + 1.635$	$\leq 0.163V + 6.125$
$V \geq 50$	$\leq 0.060V + 1.416$	$\leq 0.158V + 6.333$
Glass Door		
$0 < V < 15$	$\leq 0.118V + 1.382$	$\leq 0.607V + 0.893$
$15 \leq V < 30$	$\leq 0.140V + 1.050$	$\leq 0.733V - 1.000$
$30 \leq V < 50$	$\leq 0.088V + 2.625$	$\leq 0.250V + 13.500$
$V \geq 50$	$\leq 0.110V + 1.500$	$\leq 0.450V + 3.500$

G.4.2.8 Summer Coincident Peak Demand Savings

$\Delta kW = \Delta kWh / HOURS * CF$

where:

HOURS = equipment is assumed to operate continuously, 24 hours per day, 365.25 days per year.

= 8766

CF = Summer Peak Coincidence Factor for measure

= 0.937.

G.4.3 Commercial Steam Cooker

G.4.3.1 Description

To qualify for this measure, the installed equipment must be an ENERGY STAR® steamer in place of a standard steamer in a commercial kitchen. Savings are presented dependent on the pan capacity and corresponding idle rate at heavy load cooking capacity and if the steamer is gas or electric.

G.4.3.2 Definition of Efficient Equipment

Table G-28 lists the equipment that must be installed to qualify for this measure.

Table G-28. Equipment that must be installed to qualify as energy efficient commercial steam cookers.

Gas	Electric
ENERGY STAR® qualified with 38% minimum cooking energy efficiency at heavy load (potato) cooking capacity for gas steam cookers.	ENERGY STAR® qualified with 50% minimum cooking energy efficiency at heavy load (potato) cooking capacity for electric steam cookers.

G.4.3.3 Definition of Baseline Equipment

The baseline condition is assumed to be a non-ENERGY STAR® commercial steamer at end of life. It is assumed that the efficient equipment and baseline equipment have the same number of pans.

G.4.3.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 12 years[34]

G.4.3.5 Incremental Measure Cost

The incremental capital cost for this measure is $998[36] for a natural gas steam cooker or $2490[37] for an electric steam cooker.

G.4.3.6 Full Measure Cost

The full capital cost for this measure is around $9341.

G.4.3.7 Energy Savings

ΔSavings = (ΔIdle Energy + ΔPreheat Energy + ΔCooking Energy) * Z

For a gas cooker: ΔSavings = ΔBtu * 1/100,000 *Z

For an electric steam cooker: ΔSavings = ΔkWh *Z

where:

Z = days/yr steamer operating (use 365.25 days/yr if heavy use restaurant and exact number unknown).

where:

ΔIdle Energy = $((((1- CSM_{\%Baseline})* IDLE_{BASE} + CSM_{\%Baseline} * PC_{BASE} * E_{FOOD} / EFF_{BASE})*(HOURS_{day} - (F / PC_{Base}) - (PRE_{number} *0.25))) - (((1- CSM_{\%ENERGYSTAR}) * IDLE_{ENERGYSTAR} + CSM_{\%ENERGYSTAR} * PC_{ENERGY} * E_{FOOD} / EFF_{ENERGYSTAR}) * (HOURS_{Day} - (F l/ PC_{ENERGY}) - (PRE_{number} * 0.25))))$.

where:

CSM%Baseline = Baseline Steamer Time in Manual Steam Mode (% of time)

= 90%[38]

IDLEBase = Idle Energy Rate of Base Steamer (see Table G-29) [38]

PCBase = Production Capacity of Base Steamer (see Table G-30)[39]

EFOOD = Amount of Energy Absorbed by the food during cooking known as ASTM Energy to Food (Btu/lb or kW/lb)

= 105 Btu/lb[40] (gas steamers) or 0.03088 (electric steamers)

EFFBASE = Heavy Load Cooking Efficiency for Base Steamer

= 15%[41] (gas steamers) or 26%9 (electric steamers)

HOURSday = Average Daily Operation (hours) (see Table G-31)

F = Food cooked per day (lbs/day)

= custom or if unknown, use 100 lbs/day (i.e., reference amount used by both Food Service Technology Center and ENERGY STAR® savings calculator)

CSM%ENERGYSTAR = ENERGY STAR Steamer's Time in Manual Steam Mode (% of time)[42]

= 0%

IDLEENERGYSTAR = Idle Energy Rate of ENERGY STAR® (see Table G-32)[38]

PCENERGY = Production Capacity of ENERGY STAR® Steamer (see Table G-33)[43]

EFFENERGYSTAR = Heavy Load Cooking Efficiency for ENERGY STAR® Steamer(%)

= 38%[39] (gas steamer) or 50% (electric steamer)

PREnumber = Number of preheats per day

= 1[40] (if unknown, use 1).

where:

ΔPreheat Energy = (PREnumber * Δ Preheat)

where:

PREnumber = Number of Preheats per Day

= 1[40] (if unknown, use 1)

PREheat = Preheat energy savings per preheat

= 11,000 Btu/preheat[45] (gas steamer) or 0.5 kWh/preheat[38] (electric steamer).

where:

ΔCooking Energy = ((1/ EFFBASE) - (1/ EFFENERGY STAR®)) * F * E_{FOOD}

where:

EFFBASE = Heavy Load Cooking Efficiency for Base Steamer

= 15%[46] (gas steamer) or 26%28 (electric steamer)

EFFENERGYSTAR = Heavy Load Cooking Efficiency for ENERGY STAR® Steamer

= 38%[46] (gas steamer) or 50%23 (electric steamer)

F = Food cooked per day (lbs/day)

= custom or if unknown, use 100 lbs/day[38,40]

EFOOD = Amount of energy absorbed by the food during cooking known as ASTM Energy to Food (see Table G-34).[40]

Table G-29. Idle energy rate of base steamer.

Number of Pans	$IDLE_{BASE}$ - Gas, Btu/hr	$IDLE_{BASE}$ - Electric, kW
3	11,000	1.0
4	14,667	1.33
5	18,333	1.67
6	22,000	2.0

Table G-30. Production capacity of base steamer.

Number of Pans	PC_{BASE}, gas (lbs/hr)	PC_{BASE}, electric (lbs/hr)
3	65	70
4	87	93
5	108	117
6	130	140

Table G-31. Average daily operation by type of food service.

Type of Food Service	Hours/day*
Fast Food, limited menu	4
Fast Food, expanded menu	5
Pizza	8
Full Service, limited menu	8
Full Service, expanded menu	7
Cafeteria	6
Unknown**	6
Custom	Varies

*Source: Minnesota 2012 Technical Reference Manual, Electric Food Service_v03.2.xls

**Unknown is average of other locations

Table G-32. ENERGY STAR® idle energy rates.

Number of Pans	$IDLE_{ENERGY\ STAR}$ – gas, (Btu/hr)	$IDLE_{ENERGY\ STAR}$ – electric, (kW)
3	6250	0.40
4	8333	0.53
5	10417	0.67
6	12500	0.80

Table G-33. ENERGY STAR® steamer production capacities.

Number of Pans	PC_{ENERGY} - gas(lbs/hr)	PC_{ENERGY} – electric (lbs/hr)
3	55	50
4	73	67
5	92	83
6	110	100

Table G-34. Amount of energy absorbed by the food during cooking ("ASTM Energy to Food").

E_{FOOD} - gas(Btu/lb)	E_{FOOD} (kWh/lb)
105[40]	0.0308[40]

G.4.3.8 Summer Coincident Peak Demand Savings

This calculation is only applicable to the electric steam cooker:

$$\Delta kW = (\Delta kWh/(HOURSDay * DaysYear)) * CF$$

where:

CF = Summer Peak Coincidence Factor for measure for different locations (see Table G-35)[47]

DaysYear = Annual Days of Operation

= custom or 365.25 days a year

Other values as defined above.

Table G-35. Summer peak coincidence factor for measure for different locations.

Location	CF
Fast Food Limited Menu	0.32
Fast Food Expanded Menu	0.41
Pizza	0.46
Full Service Limited Menu	0.51
Full Service Expanded Menu	0.36
Cafeteria	0.36

G.4.3.9 Water Impact Descriptions and Calculation

This is calculation applicable to both gas and electric steam cookers:

$$\Delta Water = [(W_{BASE} - W_{ENERGYSTAR®})*HOURS_{Day} *Days_{Year}$$

where:

WBASE = Water Consumption Rate of Base Steamer (gal/hr)
= 40[48]

WENERGYSTAR = Water Consumption Rate of ENERGY STAR® Steamer look up (see Table G-36)[49]

DaysYear = Annual Days of Operation
= custom or 365.25 days a year.[50]

Table G-36. Water consumption rate of ENERGY STAR® steamer.

CEE Tier	gal/hr
Tier 1A	15
Tier 1B	4
Avg. Efficient	10
Avg. Most Efficient	3

G.4.4 Conveyor Oven

G.4.4.1 Description

This measure applies to natural gas fired high efficiency conveyor ovens installed in commercial kitchens replacing existing natural gas units with conveyor width greater than 25 in.

Conveyor ovens are available using four different heating processes: IR, natural convection with a ceramic baking hearth, forced convection or air impingement, or a combination of IR and forced convection. Conveyor ovens are typically used for producing a limited number of products with similar cooking requirements at high production rates. They are highly flexible and can be used to bake or roast a wide variety of products including pizza, casseroles, meats, breads, and pastries.

Some manufacturers offer an air curtain feature at either end of the cooking chamber that helps to keep the heated air inside the conveyor oven. The air curtain operates as a virtual oven wall and helps reduce both the idle energy of the oven and the resultant heat gain to the kitchen.

G.4.4.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be a natural gas conveyor oven with a tested baking energy efficiency > 42% and an idle energy consumption rate < 57,000 Btu/hr using ASTM Standard F1817.

G.4.4.3 Definition of Baseline Equipment

The baseline equipment is an existing pizza deck oven at end of life.

G.4.4.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 17 years.[32]

G.4.4.5 Incremental Measure Cost

The incremental capital cost for this measure is $1800.[32]

G.4.4.6 Full Measure Cost

The full capital cost for this measure is around $12407.

G.4.4.7 Natural Gas Energy Savings

The annual natural gas energy savings from this measure is a deemed value equaling 733 Therms.[32] (These deemed values should be compared to PY evaluation and revised as necessary.)

G.4.5 ENERGY STAR Convection Oven

G.4.5.1 Description

This measure applies to natural gas fired ENERGY STAR convection ovens installed in a commercial kitchen.

G.4.5.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be a natural gas convection oven with a cooking efficiency ≥ 44% using ASTM Standard 1496 and an idle energy consumption rate < 13,000 Btu/hr

G.4.5.3 Definition of Baseline Equipment

The baseline equipment is a natural gas convection oven that is not ENERGY STAR certified and is at end of life.

G.4.5.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 12 years[51]

G.4.5.5 Incremental Measure Cost

The incremental capital cost for this measure is $50[52]

G.4.5.6 Full Measure Cost

The full capital cost for this measure is around $5117.

G.4.5.7 Natural Gas Energy Savings

Custom calculation below, otherwise use deemed value of 306 therms.[53]

ΔTherms = (ΔDailyIdle Energy + ΔDailyPreheat Energy + ΔDailyCooking Energy) * Days /100000

where:

ΔDailyIdleEnergy = (IdleBase* IdleBaseTime) - (IdleENERGYSTAR * IdleENERGYSTARTime)
ΔDailyPreheatEnergy = (PreHeatNumberBase * PreheatTimeBase / 60 * PreheatRateBase) – (PreheatNumberENERGYSTAR* PreheatTimeENERGYSTAR/60 * PreheatRateENERGYSTAR)
ΔDailyCookingEnergy = (LB * EFOOD/ EffBase) - (LB * EFOOD/ EffENERGYSTAR)

where:

HOURSday = Average Daily Operation
= custom or if unknown, use 12 hours
Days = Annual days of operation
= custom or if unknown, use 365.25 days a year
LB = Food cooked per day
= custom or if unknown, use 100 pounds
EffENERGYSTAR = Cooking Efficiency ENERGY STAR
= custom or if unknown, use 44%
EffBase = Cooking Efficiency Baseline
= custom or if unknown, use 30%
PCENERGYSTAR = Production Capacity ENERGY STAR
= custom or if unknown, use 80 pounds/hr
PCBase = Production Capacity base
= custom or if unknown, use 70 pounds/hr
PreheatNumberENERGYSTAR = Number of preheats per day
= custom or if unknown, use 1
PreheatNumberBase = Number of preheats per day
= custom or if unknown, use 1
PreheatTimeENERGYSTAR = preheat length
= custom or if unknown, use 15 minutes
PreheatTimeBase = preheat length
= custom or if unknown, use 15 minutes
PreheatRateENERGYSTAR = preheat energy rate high efficiency
= custom or if unknown, use 44000 Btu/h

PreheatRateBase = preheat energy rate baseline

= custom or if unknown, use 76000 Btu/h

IdleENERGYSTAR = Idle energy rate

= custom or if unknown, use 13000 Btu/h

IdleBase = Idle energy rate

= custom or if unknown, use 18000 Btu/h

IdleENERGYSTARTime = ENERGY STAR Idle Time

= HOURSday-LB/PCENERGYSTAR –PreHeatTimeENERGYSTAR/60

= 12 – 100/80 – 15/60

= 10.5 hours

IdleBaseTime = BASE Idle Time

= HOURSday-LB/PCbase –PreHeatTimeBase/60

= Custom or if unknown, use

= 12 – 100/70-15/60

= 10.3 hours

EFOOD = ASTM energy to food

= 250 Btu/pound.

G.4.6 ENERGY STAR Dishwasher

G.4.6.1 Description

This measure applies to ENERGY STAR high and low temp under counter single tank door type, single tank conveyor, and multiple tank conveyor dishwashers installed in a commercial kitchen.

G.4.6.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be an ENERGY STAR certified dishwasher meeting idle energy rate (kW) and water consumption (gallons/rack) limits, as determined by both machine type and sanitation approach (chemical/low temp versus high temp).

G.4.6.3 Definition of Baseline Equipment

The baseline equipment is a dishwasher that is not ENERGY STAR certified and at end of life.

G.4.6.4 Deemed Lifetime of Efficient Equipment

Table G-37 lists the assumed expected measure life.[54]

Table G-37. Assumed expected measure life of efficient equipment.

Dishwasher type		Equipment Life
Low Temp	Under Counter	10
	Door Type	15
	Single Tank Conventional	20
	Multi-Tank Conventional	20
High Temp	Under Counter	10
	Door Type	15
	Single Tank Conventional	20
	Multi-Tank Conventional	20

G.4.6.5 Incremental Measure Cost

Table G-39 lists the incremental capital cost for this measure.[55]

Table G-38. Incremental capital cost of ECM "ENERGY STAR dishwasher."

Dishwasher type		Incremental Cost
Low Temp	Under Counter	$530
	Door Type	$530
	Single Tank Conventional	$170
	Multi-Tank Conventional	$0
High Temp	Under Counter	$1000
	Door Type	$500
	Single Tank Conventional	$270
	Multi-Tank Conventional	$0

G.4.6.6 Full Measure Cost

The full capital cost for this measure is around $3200.

G.4.6.7 Energy Savings

ENERGY STAR dishwashers save energy in three categories, building water heating, booster water heating and idle energy. Building water heating and booster water heating could be either electric or natural gas. These deemed values are presented in a table format. Savings all water heating combinations are found in Tables G-39 to G-42 below.[56]

Table G-39. Savings associated with electric building and booster water heating.

Dishwasher type		kWh	Therms
Low Temp	Under Counter	1,213	0
	Door Type	12,135	0
	Single Tank Conventional	11,384	0
	Multi-Tank Conventional	17,465	0
High Temp	Under Counter	7471	0
	Door Type	14143	0
	Single Tank Conventional	19235	0
	Multi-Tank Conventional	34153	0

Table G-40. Savings associated with electric building and natural gas booster water heating.

Dishwasher type		kWh	Therms
Low Temp	Under Counter	9089	0
	Door Type	21833	0
	Single Tank Conventional	24470	0
	Multi-Tank Conventional	29718	0
High Temp	Under Counter	7208	110
	Door Type	19436	205
	Single Tank Conventional	29792	258
	Multi-Tank Conventional	34974	503

Table G-41. Savings associated with natural gas building and electric booster water heating.

Dishwasher type		kWh	Therms
Low Temp	Under Counter	0	56
	Door Type	0	562
	Single Tank Conventional	0	527
	Multi-Tank Conventional	0	809
High Temp	Under Counter	2717	220
	Door Type	5269	441
	Single Tank Conventional	8110	515
	Multi-Tank Conventional	12419	1007

Table G-42. Savings associated with natural gas building and booster water heating.

Dishwasher type		kWh	Therms
Low Temp	Under Counter	0	56
	Door Type	0	562
	Single Tank Conventional	0	527
	Multi-Tank Conventional	0	809
High Temp	Under Counter	0	330
	Door Type	198	617
	Single Tank Conventional	1752	773
	Multi-Tank Conventional	0	1510

G.4.6.8 Water Savings

Table G-43 lists water savings calculated using standard assumptions.

Table G-43. Water savings using standard assumptions.

Dishwasher type		Savings (gallons)
Low Temp	Under Counter	6,844
	Door Type	6,8474
	Single Tank Conventional	64,240
	Multi-Tank Conventional	98,550
High Temp	Under Counter	26,828
	Door Type	50,078
	Single Tank Conventional	62,780
	Multi-Tank Conventional	122,640

G.4.6.9 Summer Coincident Peak Demand Savings

$\Delta kW = \Delta kWh / AnnualHours$

where:

AnnualHours = Hours * Days
= 365.25 * 18
= 6575 annual hours.

Example:

A low temperature undercounter dishwasher with electric building and booster water heaters would save:

$\Delta kW = \Delta kWh / AnnualHours$
= 1213/6575
= 0.184 kW.

G.4.7 ENERGY STAR Fryer

G.4.7.1 Description

This measure applies to natural gas fired ENERGY STAR fryer installed in a commercial kitchen.

G.4.7.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be a natural gas fryer with a heavy load cooking efficiency ≥ 50% using ASTM Standard F1361 or F2144.

G.4.7.3 Definition of Baseline Equipment

The baseline equipment is a natural gas fryer that is not ENERGY STAR certified at end of life.

G.4.7.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 15 years.[57]

G.4.7.5 Incremental Measure Cost

The incremental capital cost for this measure is $1200.[59]

G.4.7.6 Full Measure Cost

The full capital cost for this measure is around $4876.

G.4.7.7 Natural Gas Energy Savings[59]

Calculate natural gas energy savings using this custom calculation below, otherwise use deemed value of 505 Therms:

$$\Delta Therms = (\Delta DailyIdle\ Energy + \Delta DailyPreheat\ Energy + \Delta DailyCooking\ Energy) * Days / 100000$$

where:

ΔDailyIdleEnergy = (IdleBase* IdleBaseTime) – (IdleENERGYSTAR * IdleENERGYSTARTime)

ΔDailyPreheatEnergy = (PreHeatNumberBase * PreheatTimeBase / 60 * PreheatRateBase) – (PreheatNumberENERGYSTAR* PreheatTimeENERGYSTAR/60 * PreheatRateENERGYSTAR)

ΔDailyCookingEnergy = (LB * EFOOD/ EffBase) - (LB * EFOOD/ EffENERGYSTAR)

where:

HOURSday = Average Daily Operation

= custom or if unknown, use 16 hours

Days = Annual days of operation

= custom or if unknown, use 365.25 days a year

LB = Food cooked per day

= custom or if unknown, use 150 pounds

EffENERGYSTAR = Cooking Efficiency ENERGY STAR

= custom or if unknown, use 50%

EffBase = Cooking Efficiency Baseline

= custom or if unknown, use 35%

PCENERGYSTAR = Production Capacity ENERGY STAR

= custom or if unknown, use 65 pounds/hr

PCBase = Production Capacity base

= custom or if unknown, use 60 pounds/hr

PreheatNumberENERGYSTAR = Number of preheats per day

= custom or if unknown, use 1

PreheatNumberBase = Number of preheats per day

= custom or if unknown, use 1

PreheatTimeENERGYSTAR = preheat length

= custom or if unknown, use 15 minutes

PreheatTimeBase = preheat length

= custom or if unknown, use 15 minutes

PreheatRateENERGYSTAR = preheat energy rate high efficiency

= custom or if unknown, use 62000 Btu/h

PreheatRateBase = preheat energy rate baseline

= custom or if unknown, use 64000 Btu/h

IdleENERGYSTAR = Idle energy rate

= custom or if unknown, use 9000 Btu/h

IdleBase = Idle energy rate

= custom or if unknown, use 14000 Btu/h

IdleENERGYSTARTime = ENERGY STAR Idle Time

= HOURSday-LB/PCENERGYSTAR –PreHeatTimeENERGYSTAR/60

= Custom or if unknown, use

= 16 – 150/65-15/60

= 13.44 hours

IdleBaseTime = BASE Idle Time

= HOURSday-LB/PCbase –PreHeatTimeBase/60

= Custom or if unknown, use

= 16 – 150/60-15/60

= 13.25 hours

EFOOD = ASTM energy to food

= 570 Btu/pound.

G.4.8 ENERGY STAR Griddle

G.4.8.1 Description

This measure applies to electric and natural gas fired high efficiency griddle installed in a commercial kitchen.

G.4.8.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be an ENERGY STAR natural gas or electric griddle with a tested heavy load cooking energy efficiency of 70% (electric) 38% (gas) or greater and an idle energy rate of 2,650 Btu/hr/sq ft of cooking surface or less, using ASTM F1275. The griddle must have an idle energy consumption rate < 2,600 Btu/hr/sq ft of cooking surface.

G.4.8.3 Definition of Baseline Equipment

The baseline equipment is an existing natural gas or electric griddle that is not ENERGY STAR certified and is at end of use.

G.4.8.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 12 years[60]

G.4.8.5 Incremental Measure Cost

The incremental capital cost for this measure is $0 for and electric griddle and $60 for a gas griddle.[61]

G.4.8.6 Full Measure Cost

The full capital cost for this measure is around $3935.

G.4.8.7 Electric Energy Savings

ΔkWh = (ΔIdle Energy + ΔPreheat Energy + ΔCooking Energy) * Days /1000

where:

ΔDailyIdleEnergy = [IdleBase * Width * Length (LB/ PCBase) – (PreheatNumberBase* PreheatTimeBase/60)] - IdleENERGYSTAR * Width * Length (LB/ PCENERGYSTAR) – (PreheatNumberENERGYSTAR* PreheatTimeENERGYSTAR/60]

ΔDailyPreheatEnergy = (PreHeatNumberBase * PreheatTimeBase / 60 * PreheatRateBase * Width * Depth) – (PreheatNumberENERGYSTAR* PreheatTimeENERGYSTAR/60 * PreheatRateENERGYSTAR * Width * Depth)

ΔDailyCookingEnergy = (LB * EFOOD/ EffBase) - (LB * EFOOD/ EffENERGYSTAR)

where:

HOURSday = Average Daily Operation
= custom or if unknown, use 12 hours
Days = Annual days of operation
= custom or if unknown, use 365.25 days a year
LB = Food cooked per day
= custom or if unknown, use 100 pounds
Width = Griddle Width
= custom or if unknown, use 3 feet
Depth = Griddle Depth
= custom or if unknown, use 2 feet
EffENERGYSTAR = Cooking Efficiency ENERGY STAR
= custom or if unknown, use 70%
EffBase = Cooking Efficiency Baseline
= custom or if unknown, use 65%
PCENERGYSTAR = Production Capacity ENERGY STAR
= custom or if unknown, use 6.67 pounds/hr/sq ft
PCBase = Production Capacity base
= custom or if unknown, use 5.83 pounds/hr/sq ft
PreheatNumberENERGYSTAR = Number of preheats per day
= custom or if unknown, use 1
PreheatNumberBase = Number of preheats per day
= custom or if unknown, use 1
PreheatTimeENERGYSTAR = preheat length
= custom or if unknown, use 15 minutes
PreheatTimeBase = preheat length
= custom or if unknown, use 15 minutes
PreheatRateENERGYSTAR = preheat energy rate high efficiency
= custom or if unknown, use 1333 W/sq ft
PreheatRateBase = preheat energy rate baseline
= custom or if unknown, use 2667 W/sq ft
IdleENERGYSTAR = Idle energy rate
= custom or if unknown, use 320 W/sq ft
IdleBase = Idle energy rate
= custom or if unknown, use 400 W/sq ft
EFOOD = ASTM energy to food
= 139 W/lb.

G.4.8.8 Summer Coincident Peak Demand Savings

kW = ΔkWh/Hours * CF

For example, an ENERGY STAR griddle in a cafeteria with a tested heavy load cooking energy efficiency of 70% or greater and an idle energy rate of 320 W/sq ft of cooking surface or less would save:

= 2595 kWh/4308 * 0.36

= 0.22 kW.

G.4.8.9 Natural Gas Energy Savings

ΔTherms = (ΔIdle Energy + ΔPreheat Energy + ΔCooking Energy) * Days /100000

where:

ΔDailyIdleEnergy = [IdleBase * Width * Length (LB/ PCBase) – (PreheatNumberBase* PreheatTimeBase/60)] - IdleENERGYSTAR * Width * Length (LB/ PCENERGYSTAR) – (PreheatNumberENERGYSTAR* PreheatTimeENERGYSTAR/60]

ΔDailyPreheatEnergy = (PreHeatNumberBase * PreheatTimeBase / 60 * PreheatRateBase * Width * Depth) – (PreheatNumberENERGYSTAR* PreheatTimeENERGYSTAR/60 * PreheatRateENERGYSTAR * Width * Depth)

ΔDailyCookingEnergy = (LB * EFOOD/ EffBase) - (LB * EFOOD/ EffENERGYSTAR)

where (new variables only):

EffENERGYSTAR = Cooking Efficiency ENERGY STAR
= custom or if unknown, use 38%

EffBase = Cooking Efficiency Baseline
= custom or if unknown, use 32%

PCENERGYSTAR = Production Capacity ENERGY STAR
= custom or if unknown, use 7.5 pounds/hr/sq ft

PCBase = Production Capacity base
= custom or if unknown, use 4.17 pounds/hr/sq ft

PreheatRateENERGYSTAR = preheat energy rate high efficiency
= custom or if unknown, use 10000 Btu/h/sq ft

PreheatRateBase = preheat energy rate baseline
= custom or if unknown, use 14000 Btu/h/sq ft

IdleENERGYSTAR = Idle energy rate
= custom or if unknown, use 2650 Btu/h/sq ft

IdleBase = Idle energy rate
= custom or if unknown, use 3500 Btu/h/sq ft

EFOOD = ASTM energy to food
= 475 Btu/pound.

G.4.9 ENERGY STAR Hot Food Holding Cabinets

G.4.9.1 Description

This measure applies to electric ENERGY STAR hot food holding cabinets (HFHC) installed in a commercial kitchen.

G.4.9.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be an ENERGY STAR certified HFHC.

G.4.9.3 Definition of Baseline Equipment

The baseline equipment is an electric HFHC that is not ENERGY STAR certified and at end of life.

G.4.9.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 12 years[62]

G.4.9.5 Incremental Measure Cost

Table G-44 lists the incremental capital cost for this measure is[63]

Table G-44. Incremental capital costs for ENERGY STAR HFHCs.

HFHC Size	Incremental Cost
Full Size (20 cubic feet)	$1200
¾ Size (12 cubic feet)	$1800
½ Size (8 cubic feet)	$1500

G.4.9.6 Full Measure Cost

The full capital cost for this measure is around $4160.

G.4.9.7 Electric Energy Savings

Custom calculation below, otherwise use default values depending on HFHC size (Table G-45).

$$\Delta kWh = HFHCBaselinekWh _ HFHCENERGYSTARkWh$$

where:

HFHCBaselinekWh	=	PowerBaseline* HOURSday * Days/1000
PowerBaseline	=	Custom, otherwise use default values listed in Table G-46.
HOURSday	=	Average Daily Operation
	=	custom or if unknown, use 15 hours

Days = Annual days of operation

= custom or if unknown, use 365.25 days a year

HFHCENERGYSTARkWh = PowerENERGYSTAR* HOURSday * Days/1000

PowerENERGYSTAR = Custom, otherwise use default values listed in Table G-47

HOURSday = Average Daily Operation

= custom or if unknown, use 15 hours

Days = Annual days of operation

= custom or if unknown, use 365.25 days a year.

Table G-45. Electric energy savings based on default values.

Cabinet Size	Savings (kWh)
Full Size HFHC	9308
¾ Size HFHC	3942
½ Size HFHC	2628

Table G-46. Default powerbaseline values.

Cabinet Size	Power (W)
Full Size HFHC	2500
¾ Size HFHC	1200
½ Size HFHC	800

Table G-47. Default power ENERGYSTAR values.

Cabinet Size	Power (W)
Full Size HFHC	800
¾ Size HFHC	480
½ Size HFHC	320

G.4.10 ENERGY STAR Ice Maker

G.4.10.1 Description

This measure relates to the installation of a new ENERGY STAR qualified commercial ice machine. The ENERGY STAR label applied to air-cooled, cube-type machines including ice-making head, self-contained, and remote condensing units. This measure excludes flake and nugget type ice machines. This measure could relate to the replacing of an existing unit at the end of its useful life, or the installation of a new system in a new or existing building.

G.4.10.2 Definition of Efficient Equipment

For this characterization to apply, the efficient equipment is assumed to be a new commercial ice machine meeting the minimum ENERGY STAR efficiency level standards.

G.4.10.3 Definition of Baseline Equipment

For this characterization to apply, the baseline equipment is assumed to be a commercial ice machine meeting Federal equipment standards established 1 January 2010.

G.4.10.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 10 years.[23]

G.4.10.5 Incremental and Full Measure Cost

Table G-48 lists the incremental and full capital costs for the ENERGY STAR Ice Maker ECM.[65]

Table G-48. Incremental and full capital costs for the ENERGY STAR ice maker ECM.

Harvest Rate (H)	Incremental Cost	Full Measure Cost
100-200 lb ice machine	$296	$2407
201-300 lb ice machine	$312	$2407
301-400 lb ice machine	$559	$2769
401-500 lb ice machine	$981	$2769
501-1000 lb ice machine	$1,485	$4098
1001-1500 lb ice machine	$1,821	$4312
>1500 lb ice machine	$2,194	$7191

G.4.10.6 Electric Energy Savings

$$\Delta kWH = [(kWh_{base} - kWh_{ee}) / 100] * (DC * H) * 365.25$$

where:

kWh_{base} = maximum kWh consumption per 100 pounds of ice for the baseline equipment
= calculated as shown in the table below using the actual harvest rate (H) of the efficient equipment.

kWh_{ee} = maximum kWh consumption per 100 pounds of ice for the efficient equipment
= calculated (see Table G-49) using the actual harvest rate (H) of the efficient equipment.

100 = conversion factor to convert kWhbase and kWhee into maximum kWh consumption per pound of ice.

DC = Duty Cycle of the ice machine
= 0.57[68]

H = Harvest Rate (pounds of ice made per day)
= Actual installed

365.35 = days per year.

Table G-49. Calculated actual harvest rate of efficient ice maker equipment.

Ice Machine Type	kWhbase*	kWhee[67]
Ice-Making Head (H < 450)	10.26 - 0.0086*H	9.23 - 0.0077*H
Ice-Making Head (H ≥ 450)	6.89 – 0.0011*H	6.20 - 0.0010*H
Remote Condensing Unit, without remote compressor (H < 1000)	8.85 – 0.0038*H	8.05 - 0.0035*H
Remote Condensing Unit, without remote compressor (H ≥ 1000)	5.1	4.64
Remote Condensing Unit, with remote compressor (H < 934)	8.85 – 0.0038*H	8.05 - 0.0035*H
Remote Condensing Unit, with remote compressor (H ≥ 934)	5.3	4.82
Self-Contained Unit (H < 175)	18 - 0.0469*H	16.7 - 0.0436*H
Self-Contained Unit (H ≥ 175)	9.8	9.11
* Baseline reflects Federal standards that apply to units manufactured on or after 1 January 2010[66]		

G.4.10.7 Summer Coincident Peak Demand Savings

$$\Delta kW = \Delta kWh / (HOURS * DC) * CF$$

where:

HOURS = annual operating hours

= 8766 (Unit is assumed to be connected to power 24 hours per day, 365.25 days per year.)

CF = 0.937.

G.4.10.8 Water Impact Descriptions and Calculation

While the ENERGY STAR labeling criteria require that certified commercial ice machines meet certain "maximum potable water use per 100 pounds of ice made" requirements, such requirements are intended to prevent equipment manufacturers from gaining energy efficiency at the cost of water consumptions. A review of the AHRI Certification Directory[69] indicates that approximately 81% of air-cooled, cube-type machines meet the ENERGY STAR potable water use requirement. Therefore, there are no assumed water impacts for this measure.

G.4.11 Kitchen Demand Ventilation Controls

G.4.11.1 Description

Installing of commercial kitchen demand ventilation controls that vary the ventilation based on cooking load and/or time of day.

G.4.11.2 Definition of Efficient Equipment

To qualify for this measure, the installed equipment must be a control system that varies the exhaust rate of kitchen ventilation (exhaust and/or makeup air fans) based on the energy and effluent output from the cooking appliances (i.e., the more heat and smoke/vapors generated, the

more ventilation needed). This involves installing a new temperature sensor in the hood exhaust collar and/or an optic sensor on the end of the hood that sense cooking conditions that allows the system to automatically vary the rate of exhaust to what is needed by adjusting the fan speed accordingly.

G.4.11.3 Definition of Baseline Equipment

The baseline equipment is kitchen ventilation that has constant speed ventilation motor.

G.4.11.4 Deemed Lifetime of Efficient Equipment

The expected measure life is assumed to be 15 years.[70]

G.4.11.5 Full and Incremental Measure Cost

Table G-50 lists the full and incremental capital costs for the kitchen demand ventilation controls ECM.[70]

Table G-50. Full and incremental capital costs for the kitchen demand ventilation controls ECM.

Measure Category	Cost, $/fan
DVC Control Retrofit (full)	$1,988
DVC Control New (incremental)	$1,000

G.4.11.6 Electric Energy Savings

Table G-51 list the electric energy savings (kWh) of the kitchen demand ventilation controls ECM.

Table G-51. Electric energy savings of the kitchen demand ventilation controls ECM.

Measure Name	Annual Energy Savings Per Unit (kWh/fan)
DVC Retrofit and New	4,486

G.4.11.7 Summer Coincident Peak Demand Savings

Table G-52 list the summer coincident peak demand savings (kWh) of the kitchen demand ventilation controls ECM.

Table G-52. Summer coincident peak demand savings (kWh) of the kitchen demand ventilation controls ECM.

Measure Name	Coincident Peak Demand Reduction (kW)
DVC Retrofit and New	0.76

G.4.11.8 Natural Gas Energy Savings

ΔTherms = CFM * HP* Annual Heating Load /(Eff(heat) * 100,000)

where:

CFM = the average airflow reduction with ventilation controls per hood
= 611 cfm/HP[71]

HP = actual if known, otherwise assume 7.75 HP

Annual Heating Load = Annual heating energy required to heat fan exhaust makeup air, Btu/cfm dependent on location (see Table G-53).[72]

Eff(heat) = Heating Efficiency
= actual if known, otherwise assume 80%[73]

100,000 = conversion from Btu to Therm.

Table G-53. Annual heating energy required to heat fan exhaust makeup air.

Location	Annual Heating Load, Btu/cfm
Scott AFB	102,000
Camp Lejeune	63,522

G.4.11.9 Misc. ECMs

G.4.12 ENERGY STAR Refrigerated Beverage Vending Machine

G.4.12.1 Description

ENERGY STAR qualified new and rebuilt vending machines incorporate more efficient compressors, fan motors, and lighting systems as well as low power mode option that allows the machine to be placed in low-energy lighting and/or low-energy refrigeration states during times of inactivity.

G.4.12.2 Definition of Efficient Equipment

The refrigerated vending machine can be new or rebuilt, but must meet the ENERGY STAR specifications that include low power mode.

G.4.12.3 Definition of Baseline Equipment

The baseline vending machine is a standard unit.

G.4.12.4 Deemed Lifetime of Efficient Equipment

The deemed lifetime of this measure is 14 years.[40]

G.4.12.5 Deemed Measure Cost

The incremental cost of this measure is $500.[40]

G.4.12.6 Calculation of Savings

Beverage machine savings are taken from the ENERGY STAR savings calculator and summarized in the following table. ENERGY STAR provides savings numbers for machines with and without control software. The average savings are calculated here.

G.4.12.7 Electric Energy Savings

Table G-54 lists ENERGY STAR vending machine savings.[74]

Table G-54. ENERGY STAR vending machine savings.

Vending Machine Capacity (cans)	kWh Savings Per Machine w/o software	kWh Savings Per Machine w/ software
<500	1,099	1,659
500	1,754	2,231
699	1,242	1,751
799	1,741	2,283
800+	713	1,288

G.5 Footnotes and References

[1] This algorithm calculates the amount of energy saved per aerator by determining the fraction of water consumption savings for the upgraded fixture. Due to the distribution of water consumption by fixture type, as well as the different number of fixtures in a building, several variables must be incorporated.

[2] DeOreo, William B., Peter W. Mayer. 2013. *Residential End Uses of Water Study Update*. Table 56, http://www.aquacraft.com/sites/default/files/img/REUWS2%20Project%20Report%2020131204.pdf

[3] Measurement should be based on actual average flow consumed over a period of time rather than a onetime spot measurement for maximum flow. Studies have shown maximum flow rates do not correspond well to average flow rate due to occupant behavior that does not always use maximum flow.

[4] Schultdt, Marc, and Debra Tachibana. 2008. Energy Related Water Fixture Measurements: Securing the Baseline for Northwest Single Family Homes. *ACEEE Summer Study on Energy Efficiency in Buildings*. pp 1-265, www.seattle.gov/light/Conserve/Reports/paper_10.pdf

[5] Average retrofit flow rate for kitchen and bathroom faucet aerators from sources 2, 4, 5, and 7. This accounts for all throttling and differences from rated flow rates. Assumes all kitchen aerators at 2.2 gpm or less and all bathroom aerators at 1.5 gpm or less. The most comprehensive available studies did not disaggregate kitchen use from bathroom use, but instead looked at total flow and length of use for all faucets. This makes it difficult to reliably separate kitchen water use from bathroom water use. It is possible that programs

installing low flow aerators lower than the 2.2 gpm for kitchens and 1.5 gpm for bathrooms will see a lower overall average retrofit flow rate.

[6] Measurement should be based on actual average flow consumed over a period of time rather than a onetime spot measurement for maximum flow. Studies have shown maximum flow rates do not correspond well to average flow rate due to occupant behavior that does not always use maximum flow.

[7] 2007 ASHRAE Handbook, HVAC Applications. Chapter 49, Service Water Heating, Table 2-45.

[8] Estimated based on data provided in Appendix D; "Waste Not, Want Not: The Potential for Urban Water Conservation in California"; http://www.pacinst.org/reports/urban_usage/appendix_e.pdf

[9] Based on review of the Illinois plumbing code (Employees and students per faucet). Retail, grocery, warehouse and health are estimates. Meals per faucet estimated as 4 bathroom and three kitchen faucets and average meals per day of 250 (based on California study above) – 250/7 = 36. Fast food assumption estimated.

[10] Cadmus and Opinion Dynamics Showerhead and Faucet Aerator Meter Study Memorandum dated June 2013, directed to Michigan Evaluation Working Group. If the aerator location is unknown an average of 91% should be used, which is based on the assumption that 70% of household water runs through the kitchen faucet and 30% through the bathroom (0.7*93)+(0.3*86)=0.91.

[11] U.S. DOE Building America Program. Building America Analysis Spreadsheet. For Chicago, IL http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.

[12] Electric water heaters have recovery efficiency of 98%, http://www.ahridirectory.org/ahridirectory/pages/home.aspx

[13] Com Ed Energy Efficiency/ Demand Response Plan: Plan Year 2 (6/1/2009-5/31/2010) Evaluation Report: All Electric Single Family Home Energy Performance Tune-up Program Table 3-8 http://ilsagfiles.org/SAG_files/Evaluation_Documents/ComEd/ComEd%20EPY2%20Evaluation%20Reports/ComEd_All_Electric_Single_Family_HEP_PY2_Evaluation_Report_Final.pdf

[14] GDS Associates. June 2007., Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures. Table C-6. Evaluations indicate that consumer dissatisfaction may lead to reductions in persistence, particularly in Multifamily, http://neep.org/uploads/EMV%20Forum/EMV%20Studies/measure_life_GDS%5B1%5D.pdf

[15] Water Heating in U.S. Homes in Midwest Region, Divisions, and States. 2009. (RECS). Table HC8.9.

[16] Shower temperature cited from SBW Consulting, Evaluation for the Bonneville Power Authority. 1994, http://www.bpa.gov/energy/n/reports/evaluation/residential/faucet_aerator.cfm

[17] U.S. DOE Building America Program. Building America Analysis Spreadsheet. For Chicago, IL http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.

[18] Act on Energy Commercial Technical Reference Manual No. 2010-4

[19] Act on Energy Commercial Technical Reference Manual No. 2010-4, 9.2.2 Gas Boiler Tune-up

[20] Work Paper – Tune-up for Boilers serving Space Heating and Process Load by Resource Solutions Group, January 2012

[21] Work Paper WPRRSGNGRO301 Resource Solutions Group "Boiler Tune-up," which cites Focus on Energy Evaluation Business Programs: Deemed Savings Manual V1.0, PA Consulting, KEMA, 22 March 2010

[22] Adapted from Efficiency Vermont Technical Reference User Manual (TRM) Measure Savings Algorithms and Cost Assumptions, 26 October 2011.

[23] 2008 Database for Energy Efficiency Resources (DEER), Version 2008.2.05, "Effective/Remaining Useful Life Values," California Public Utilities Commission, 16 December 2008.

[24] NYSERDA Deemed Savings Database, Labor cost assumes 25 minutes @ $18/hr.

[25] Efficiency Vermont TRM, *Measure Savings Algorithms and Cost Assumptions*, 19 February 2010

[26] Efficiency Vermont TRM, *Measure Savings Algorithms and Cost Assumptions*, 19 February 2010

[27] Goldberg et al, State of Wisconsin, Public Service Commission of Wisconsin, Focus on Energy Evaluation Business programs Incremental Cost Study, KEMA, 28 October 2009

[28] Efficiency Vermont TRM, 26 October 2011.

[29] Kuiken, Tammy eta al, State of Wisconsin/Public Service Commission of Wisconsin, Focus on Energy Evaluation, Business Programs, Deemed Savings Manual V1.0, PA Consulting Group and KEMA, 22 March 2010 pp 4-192-194.

[30] Papamichael, Konstantions, Bi-Level Switching in Office Spaces, California Lighting Technology Center, February 1,2010. Note: See Figure 8 on page 10 for relevant study results. The study shows a 30% extra savings above a typical occupancy sensor; 41% * 1.3 = 53%.

[31] http://www.fishnick.com/saveenergy/rebates/combis.pdf

[32] Deemed values from Nicor Gas were used. Nicor Gas Energy Efficiency Plan 2011-2014. Revised Plan Filed Pursuant to Order Docket 10-0562, 27 May 2011.

[33] Nicor Gas Energy Efficiency Plan 2011-2014. Revised Plan Filed Pursuant to Order Docket 10-0562, 27 May 2011.These deemed values should be compared to PY evaluation and revised as necessary.

[34] 2008 DEER, Version 2008.2.05, "Effective/Remaining Useful Life Values," California Public Utilities Commission, 16 December 2008, http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf

[35] ENERGY STAR Program Requirements for Commercial Refrigerators and Freezers Partner Commitments Version 2.0, U.S. Environmental Protection Agency, Accessed on 7/7/10, http://www.energystar.gov/ia/partners/product_specs/program_reqs/commer_refrig_glass_prog_req.pdf

[36] RSG Commercial Gas Steamer Workpaper, January 2012 (Source for incremental cost for efficient natural gas steamer).

[37] 2009 PG&E Workpaper - PGECOFST104.1 — Commercial Steam Cooker — Electric and Gas as reference by KEMA in the Com Ed C & I TRM (Source for efficient electric steamer incremental cost of $2,490).

[38] Food Service Technology Center 2011 Savings Calculator, http://www.fishnick.com/saveenergy/tools/calculators/

[39] Production capacity per Food Service Technology Center 2011 Savings Calculator of 23.3333 lb/hr per pan for electric baseline steam cookers and 21.6667 lb/hr per pan for natural gas baseline steam cookers. ENERGY STAR® savings calculator uses 23.3 lb/hr per pan for both electric and natural gas baseline steamers.

[40] ENERGY STAR® savings calculator, http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COC

[41] Reference Food Service Technology Center 2011 Savings Calculator values as used by Consortium for Energy Efficiency, Inc. for baseline electric and natural gas steamer heavy cooking load energy efficiencies.

[42] Reference information from the Food Service Technology Center siting that ENERGY STAR® steamers are not typically operated in constant steam mode, but rather are used in timed mode. Reference ENERGY STAR® savings calculator at http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COC for efficient steamer. Both baseline & efficient steamer mode values should be considered for users in Illinois market.

[43] Production capacity per Food Service Technology Center 2011 Savings Calculator of 18.3333 lb/hr per pan for gas ENERGY STAR® steam cookers and 16.6667 lb/hr per pan for electric ENERGY STAR® steam cookers. ENERGY STAR® savings calculator uses 16.7 lb/hr per pan for electric and 20 lb/hr for natural gas ENERGY STAR® steamers.

[44] Reference Food Service Technology Center 2011 Savings Calculator values as used by Consortium for Energy Efficiency, Inc. for Tier 1A and Tier 1B qualified electric and natural gas steamer heavy cooking load energy efficiencies and http://www.energystar.gov/ia/partners/product_specs/program_reqs/Commercial_Steam_Cookers_Program_Requirements.pdf?7010-36eb

[45] Ohio TRM, which references 2002 Food Service Technology Center "Commercial Cooking Appliance Technology Assessment" Chapter 8: Steamers. This is time also used by ENERGY STAR® savings calculator (Reference [40]). 11,000 Btu/preheat is from 72,000 Btu/hr * 15 min/hr /60 min/hr for gas steamers and 0.5 kWh/preheat is from 6 kW/preheat * 15 min/hr / 60 min/hr

[46] Reference Food Service Technology Center 2011 Savings Calculator values as used by Consortium for Energy Efficiency, Inc. for baseline electric and natural gas steamer heavy cooking load energy efficiencies.

[47] Minnesota 2012 Technical Reference Manual, Electric Food Service_v03.2.xls, http://mn.gov/commerce/energy/topics/conservation/Design-Resources/Deemed-Savings.jspech

[48] Food Service Technology Center (FSTC) (2002). Commercial Cooking Appliance Technology Assessment. Chapter 8: Steamers.

[49] Source Consortium for Energy Efficiency, Inc. September 2010 "Program Design Guidance for Steamers" for Tier 1A and Tier 1B water requirements. Ohio Technical Reference Manual 2010 for 10 gal/hr water consumption, which can be used when Tier level is not known.

[50] Source for 365.25 days/yr is ENERGY STAR® savings calculator, which references Food Service Technology research on average use, 2009.

[51] Lifetime from ENERGY STAR commercial griddle, which cites reference as "FSTC research on available models, 2009" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[52] Measure cost from ENERGY STAR, which cites reference as "EPA research on available models using AutoQuotes, 2010" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[53] Algorithms and assumptions derived from ENERGY STAR Oven Commercial Kitchen Equipment Savings Calculator,

http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[54] Lifetime from ENERGY STAR HFHC, which cites reference as "FSTC research on available models, 2009" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[55] Measure cost from ENERGY STAR, which cites reference as "EPA research on available models using AutoQuotes, 2010" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[56] Algorithms and assumptions derived from ENERGY STAR Commercial Kitchen Equipment Savings Calculator.http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[57] Lifetime from ENERGY STAR commercial griddle, which cites reference as "FSTC research on available models, 2009" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[58] Measure cost from ENERGY STAR, which cites reference as "EPA research on available models using AutoQuotes, 2010" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[59] Algorithms and assumptions derived from ENERGY STAR fryer Commercial Kitchen Equipment Savings Calculator. http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[60] Lifetime from ENERGY STAR commercial griddle, which cites reference as "FSTC research on available models, 2009" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[61] Measure cost from ENERGY STAR, which cites reference as "EPA research on available models using AutoQuotes, 2010" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[62] Lifetime from ENERGY STAR HFHC, which cites reference as "FSTC research on available models, 2009" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[63] Measure cost from ENERGY STAR, which cites reference as "EPA research on available models using AutoQuotes, 2010" http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[64] Algorithms and assumptions derived from ENERGY STAR Commercial Kitchen Equipment Savings Calculator.http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COG

[65] These values are from electronic work papers prepared in support of San Diego Gas & Electric's "Application for Approval of Electric and Gas Energy Efficiency Programs and Budgets for Years 2009-2011," SDGE, 2 March 2009. Accessed on 7/7/10, http://www.sdge.com/regulatory/documents/ee2009-2011Workpapers/SW-ComB/Food%20Service/Food%20Service%20Electic%20Measure%20Workpapers%2011-08-05.DOC

[66] Baseline reflects Federal standards, which apply to units manufactured on or after 1 January 2010, http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div6&view=text&node=10:3.0.1.4.17.8&idno=10

[67] ENERGY STAR Program Requirements for Commercial Ice Machines, Partner Commitments, U.S. Environmental Protection Agency, Accessed on 7/7/10 http://www.energystar.gov/ia/partners/product_specs/program_reqs/ice_machine_prog_req.pdf

[68] Duty cycle varies considerably from one installation to the next. TRM assumptions from Vermont, Wisconsin, and New York vary from 40 to 57%, whereas the ENERGY STAR Commercial Ice Machine Savings Calculator http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_Ice_Machines.xls assumes a value of 75%. A field study of eight ice machines in California indicated an average duty cycle of 57% ("A Field Study to Characterize Water and Energy Use of Commercial Ice-Cube Machines and Quantify Saving Potential," Food Service Technology Center, December 2007). Furthermore, a report prepared by ACEEE assumed a value of 40% (Nadel, S., Packaged Commercial Refrigeration Equipment: A Briefing Report for Program Planners and Implementers, ACEEE, December 2002). The value of 57% was used since it appears to represent a high quality data source.

[69] AHRI Certification Directory, Accessed on 7/7/10., http://www.ahridirectory.org/ahridirectory/pages/home.aspx

[70] PG&E Workpaper: Commercial Kitchen Demand Ventilation Controls-Electric, 2004 – 2005

[71] PGE Workpaper, Commercial Kitchen Demand Ventilation Controls, PGECOFST116, 1 June 2009, 4,734 cfm reduction on average, with 7.75 fan horsepower on average.

[72] Food Service Technology Center Outside Air Load Calculator, http://www.fishnick.com/ventilation/oalc/oac.php, with inputs of one cfm, and hours from Commercial Kitchen Demand Ventilation Controls (Average 17.8 hours a day 4.45 am to 10.30 pm). Savings for Rockford, Chicago, and Springfield were obtained from the calculator; values for Belleview and Marion were obtained by using the average savings per heating degree day (HDD) from the other values.

[73] Work Paper WPRRSGNGRO301 CLEAResult "Boiler Tune-up," which cites Focus on Energy Evaluation Business Programs: Deemed Savings Manual V1.0, PA Consulting, KEMA, 22 March 2010

[74] Savings from Vending Machine Calculator: http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=VMC

APPENDIX H: COLLECTED DATA SAMPLE

Data Description: Essess collected terabytes of data at each base. Below is an example summary data file for 14 seconds of Essess data. Green text is the system data file and the black text is the explanation of what was actually happening in the system.

Sample Data:
path: 2014-02-22-19-16-22_7.bag
version: 2.0
duration: 14.0s
start: Feb 22 2014 19:16:22.46 (1393114582.46)
end: Feb 22 2014 19:16:36.50 (1393114596.50)
size: 2.0 GB
/diagnostics
System Diagnostic Information
/driver_bottom_camera/camera_info
Camera Information & Intrinsics
/driver_bottom_camera/color_remapped
8bit color image remapped from 16bit mono image data
/driver_bottom_camera/flir_info
FLIR thermal coefficients and hardware information
/driver_bottom_camera/image_info
Image Statstics
/driver_bottom_camera/image_raw
Raw 16bit Image Data
/driver_bottom_camera/image_raw_throttle
2Hz Throttled Raw 16bit Image Data
/driver_nir/camera_info
Camera Information & Intrinsics
/driver_nir/hardware_info
Camera hardware information
/driver_nir/image_info
Image Statstics
/driver_nir/image_raw
Raw 16bit Image Data
/driver_nir/image_raw_throttle
2Hz Throttled Raw 16bit Image Data
/driver_nir/reduced_and_throttled
2Hz Throttled 8bit Image at half resolution
/driver_top_camera/camera_info
/driver_top_camera/color_remapped
/driver_top_camera/flir_info
/driver_top_camera/image_info
/driver_top_camera/image_raw
/driver_top_camera/image_raw_throttle
See /driver_bottom_camera
/environmental_data

Internal and External ambient temperature sensors
/lidar_sick/hw_info
2D LIDAR Hardware Information
/lidar_sick/scan
2D LIDAR scan data
/passenger_bottom_camera/camera_info
/passenger_bottom_camera/color_remapped
/passenger_bottom_camera/flir_info
/passenger_bottom_camera/image_info
/passenger_bottom_camera/image_raw
/passenger_bottom_camera/image_raw_throttle
See /driver_bottom_camera
/passenger_nir/camera_info
/passenger_nir/hardware_info
/passenger_nir/image_8bit
/passenger_nir/image_info
/passenger_nir/image_raw
/passenger_nir/image_raw_throttle
/passenger_nir/reduced_and_throttled
See /driver_nir
/passenger_top_camera/camera_info
/passenger_top_camera/color_remapped
/passenger_top_camera/flir_info
/passenger_top_camera/image_info
/passenger_top_camera/image_raw
/passenger_top_camera/image_raw_throttle
See /driver_bottom_camera
/rosout
/rosout_agg
ROS Diagnostic logging
/tf
Geometric transformation information
/trimble/hw_info
Trimble GPS Information
/trimble/nav_sat_fix
Trimble GPS position
/trimble/nav_sat_fix_fast
High rate Trimble GPS position estimate
/trimble/raw
Trimble GPS raw data
/trimble/temperature
Trimble GPS case temperature
/velodyne/fix
Velodyne LIDAR integrated GPS position
/velodyne/hw_info
Velodyne LIDAR hardware information

/velodyne/imu
Velodyne LIDAR integrated IMU
/velodyne/nmea
Velodyne raw NMEA GPS data
/velodyne/temp
Velodyne case temperature
/velodyne/time_reference
Velodyne time reference
/velodyne/vel
Velodyne velocity estimate from integrated GPS
/velodyne_ins/raw
Raw Velodyne inertial navigation data
/velodyne_packets
Raw Velodyne LIDAR data
/velodyne_points
Pointcloud data