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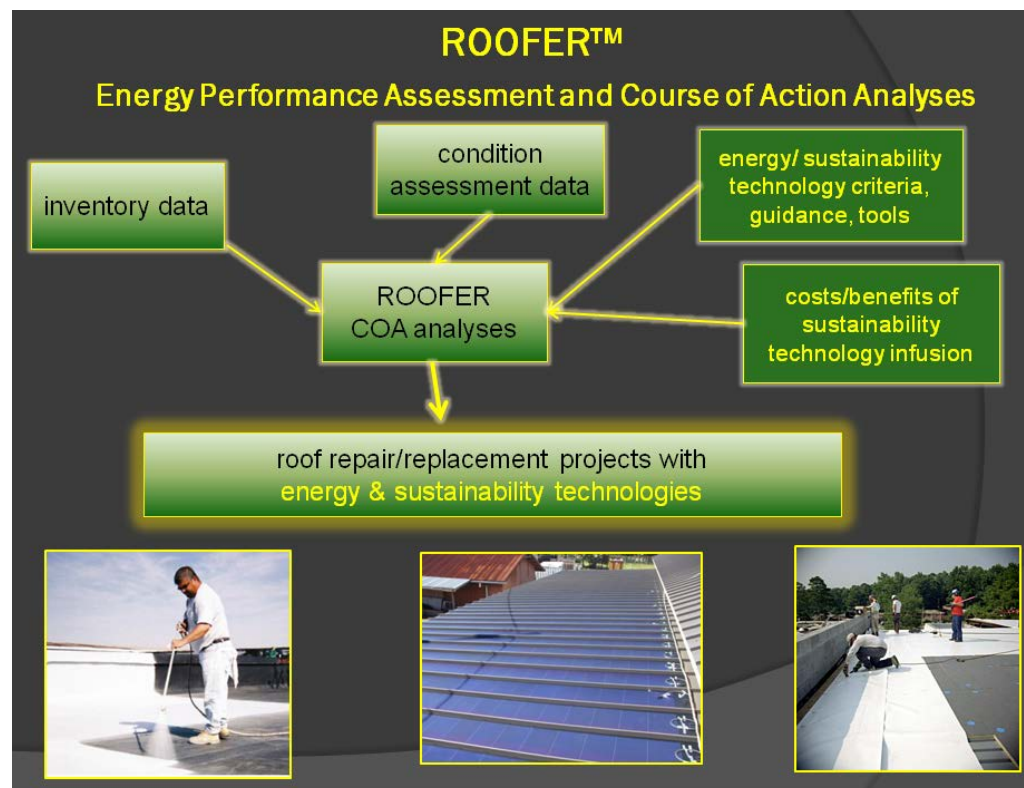
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*Environmental Security Technology Certification Program*

## **ROOFER™ Energy Performance Assessment and Course of Action Analyses**

Samuel J. Vance, Jorge O. Flores, and Kaushik Biswas

October 2018



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# **ROOFER™ ENERGY PERFORMANCE ASSESSMENT AND COURSE OF ACTION ANALYSES**

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**Final Report  
EW-201351  
ERDC/CERL TR-18-33**

**October 2018**

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## **LIST OF ABBREVIATIONS**

AC – alternating current

AFB – Air Force Base

AFCEC – Air Force Civil Engineering Center

ASA (IE&E) – Assistant Secretary of the Army (Installations, Energy and Environment)

ASHRAE – American Society for Heating, Refrigerating and Air-Conditioning Engineers

ASTM – American Society for Testing and Materials

BIPV – building integrated photovoltaic

CI – condition index

COA – course of action

CONUS – continental United States

CRC – Cool Roof Calculator

DAA – Defense Authorization Act

DC – direct current

DIACAP – DoD Information Assurance Certification and Accreditation Process

DoD – Department of Defense

DOE – Department of Energy

DPW – Directorate of Public Works

EISA – Energy Independence and Security Act

EO – Executive Order

EPAct – Energy Policy Act

EPDM – ethylene propylene diene monomer

ERDC-CERL – Engineer Research and Development Center, Construction Engineering Research Laboratory

ESTCP – Environmental Security Technology Certification Program

FY – fiscal year

GREC – Green Roof Energy Calculator

GUI – graphical user interface

HQ – headquarters

HVAC – heating, ventilation, and air conditioning

IDIQ – indefinite delivery, indefinite quantity

IMCOM – Installation Management Command

LCC – life-cycle cost

LEED-NC – Leadership in Energy and Environmental Design–New Construction

M&R – maintenance and repair

MS-DOS – Microsoft® Disc Operating System

NAS – Naval Air Station

NREL – National Renewable Energy Laboratory

O&M – operations and maintenance

ORNL – Oak Ridge National Laboratory

PO – performance objective

PV – photovoltaic

RCI – roof condition index

SMS – Sustainment Management System

SR – solar reflectance

SRI – solar reflective index

SSC – Steep Slope Calculator



TCO – total cost of ownership

TE – thermal emittance

TMY – typical meteorological year

TPO – thermoplastic olefin

UFC – Unified Facilities Criteria

USGBC – U.S. Green Building Council

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The work was performed by the Engineering Processes Branch of the Facilities Division (CEERD-CFN), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Charles G. Schroeder was Chief, CEERD-CFN; Donald K. Hicks was Chief, CEERD-CF; and Lance R. Marrano, CEERD-CZT, was the Director of the Sustainment Management System Technical Center of Expertise. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Lance D. Hansen.

The authors would like to acknowledge the assistance and support of the Oak Ridge National Laboratory (ORNL), the National Renewable Energy Laboratory (NREL), and Portland State University in the providing access to their Cool Roof calculator, Photovoltaic (PV) Watts calculator, and Green Roof Energy Calculator (GREC), respectively. Special thanks are expressed to Fort Riley, KS; Luke Air Force Base (AFB), AZ; and Fort Bragg, NC, for allowing demonstrations at their installations and providing valuable input.

The Commander of ERDC was COL Ivan P. Beckman and the Director was Dr. David W. Pittman.

## EXECUTIVE SUMMARY

Roofs are the first line of defense against environmental hazards for building occupants and asset protection. Failure of roofs in most cases is unacceptable, spawning the creation and use of sophisticated roof asset management methodologies and associated technological tools for large roof asset portfolios. One such tool is the ROOFER™ Sustainment Management System (SMS), developed by the U.S. Army Engineer Research and Development Center - Construction Engineering Research Laboratory (ERDC-CERL).

ROOFER is a condition assessment tool used by facility managers to objectively assess roof condition in order to justify repair/replace decisions. It also allows for programming a constrained budget to optimize use of available roofing maintenance funds. Currently however, ROOFER does not account for energy use and sustainability factors in its repair/replace recommendations. Options such as the installation of solar photovoltaics or replacement with energy-efficient materials such as cool roofs are not considered by ROOFER.

This project was aimed at incorporating energy factors into the ROOFER methodology through the creation of Enhanced ROOFER to provide facility managers with alternative energy-saving options that allow the opportunity to optimize roof life-cycle costs.

The use of existing energy calculators was employed to calculate roof energy and sustainability factors. The output of Enhanced ROOFER is an estimated total cost of ownership over the roof's expected lifespan for alternative energy-efficient roof types to determine an optimal roof replacement option based on maintenance, energy, and installation costs amortized over a roof's life span. Roof options incorporated in Enhanced ROOFER include roof-mounted solar panel arrays, cool roofs, and vegetated green roofs.

Enhanced ROOFER was demonstrated at Fort Riley, Luke Air Force Base (AFB), and Fort Bragg. A variety of low-slope roofs were assessed. Because cool roof maintenance, installation, and heat load costs are relatively low in the majority of roofs analyzed, the recommended course of action was to replace the roof with a cool roof when the in-place roof life cycle is complete. Although all three demonstrations occurred in relatively warm climates, this outcome was surprising because the assigned service life of a cool roof is relatively low compared with other competing roof membrane types.

During the demonstration, the team noted inherent challenges with the approach to incorporate energy factors into the ROOFER assessment. First, data input for the additional energy-related attributes required for the Enhanced ROOFER analysis proved difficult to attain and foreign to the roof inspection community. Second, the installation of traditional photovoltaics does not necessarily need to happen during the repair or replacement of a roof membrane, which is the primary event modeled by ROOFER. Finally, in every case encountered, the comparatively high installation and maintenance costs of vegetated roofs prohibited recommendation of their use.

As a result of these findings, the team concluded that a policy to encourage the use of cool roofs was warranted in lieu of the use of a fully developed Enhanced ROOFER system. Team members reported their findings to the Unified Facilities Criteria (UFC) Roofing Working

Group, supervised by Headquarters, U.S. Army Corps of Engineers. As a result of reporting this project's findings, the UFC 3-110-03 Roofing with Change 2 (published 01 January 2017) was altered to allow for use of thermoplastic Olefin (TPO) roof types and encourage the use of cool roofs in general.

# **1. INTRODUCTION**

The ROOFER Sustainment Management System (SMS) is an established and formalized automated management tool that can be used by facility managers to develop roofing repair and replacement projects. The Department of Defense (DoD) recently mandated the use of ROOFER at the installation level for performing roof asset management. Therefore, to effectively implement energy and sustainability technologies into roofing projects, such projects should be evaluated as part of the course of action (COA) analysis in ROOFER.

To develop and demonstrate this capability, the Environmental Security Technology Certification Program (ESTCP) project team evaluated existing models, protocols, and guidance for energy and sustainability technologies that have been developed by the roofing industry, DoD, and other government agencies. Four web applications were selected for integration with ROOFER. These applications provided the means for determining benefits that can be achieved with the use of increased roof insulation, cool roofing, vegetative roofing, and roof-mounted PV systems.

Necessary modifications were made to improve COA analysis recommendations and to integrate selected web tools for roof repair and replacement into the ROOFER COA analysis. . The existing ROOFER inventory database for roofing system and component characteristics and properties was expanded to accommodate the added tools and features. The product of this effort is a prototype COA analysis for the ROOFER SMS that features multiple COA alternatives that incorporate energy performance considerations as part of project development.

Once this prototype development was completed, an enhanced version of ROOFER was implemented at three military installations (two Army and one Air Force). Using the enhanced COA analyses, the costs and benefits of incorporating energy and sustainability technologies were established on a project-by-project basis-. Projections for total estimated cost savings and potential energy reduction were calculated to give DoD facility managers, energy managers, and other DoD stakeholders additional considerations for managing their roofing assets.

## **1.1 BACKGROUND**

The Department of Energy (DoE) estimates that of the 36% of total energy use for facilities is attributable to building envelopes, with one-fourth of that amount (9%) attributable to the roofing component. With DoD currently spending about \$4 billion per year on facility energy consumption, a reduction in the roofing contribution of as little as 5% would result in annual energy savings of approximately \$18 million. Clearly, roofing projects offer significant opportunities to reduce energy costs at DoD installations.

Within the roofing industry, there are established selection criteria, design guidance, and tools for integrating energy-saving and sustainable technologies such as cool roofing, vegetative roofing, and roof-mounted photovoltaic (PV) systems into roofing design. It is becoming the norm for new DoD building construction projects to consider energy and sustainability technologies early in the design phase. However, the large majority of DoD roofing systems are being installed as replacements on existing buildings, not as roofs for new facilities. To

effectively incorporate energy-reduction and sustainability measures to meet DoD goals for reduced energy consumption, replacement roof projects need to be considered. However, there is no standard business process to perform COA analyses to determine the best options for replacement roofs.

On DoD installations, the ROOFER SMS is the accepted formalized process for developing roofing repair and replacement projects. Facility managers use ROOFER to access a set of systematic, automated procedures and COA analyses developed for managing roof assets. Specific physical and historical data about each individual roof is collected, along with standardized visual inspection information, to assess roof condition and determine repair and replacement requirements. Roofing-related energy savings and sustainability enhancements can be evaluated as part of the ROOFER COA analyses. This capability can guide DoD facility managers to help them efficiently and cost-effectively select and implement optimal repair and performance-improving technologies using multiple COA alternatives.

## **1.2 OBJECTIVE OF THE DEMONSTRATION**

The objective of this project was to demonstrate an enhanced ROOFER SMS that interfaces with existing web tools to enable facility managers to evaluate energy-saving options (enhanced insulation, cool roofing, vegetative roofing, and rooftop PV systems). The four selected tools were the Cool Roof Calculator, Roof Savings Calculator, Green Roof Energy Calculator, and PVWatts™. The key feature of ROOFER is the condition assessment based on inspection data and an inventory of physical and historical information concerning the roofing systems. The decision to repair or replace a roofing system remains predicated on the cost per year for these alternatives. However, Enhanced ROOFER is linked with automated tools that evaluate the energy and sustainability options and then import those results into the ROOFER COA analysis. By being able to evaluate the benefits that can be achieved by incorporating the various technologies as part of a replacement project, the user will be better informed to make decisions whether to repair a particular roof or replace it with a more energy-efficient option.

### **1.2.1 Testing**

Testing of Enhanced ROOFER was performed at three installations (Army and Air Force) to demonstrate the utility and determine the projected benefits of integrating the various options into each service's roof repair/replacement program.

### **1.2.2 Validation**

The direct outputs generated by executing the ROOFER COA analyses serve as the means of validating the performance, costs, and benefits realized by implementing the different energy-saving and sustainability technologies. Results of the analyses are used to automatically generate repair and replacement projects for individual building roofs. Rollups of the output data determine the total savings and benefits that can be expected on an installation-wide basis.

*Findings and Guidelines:* The types and scopes of projects that are identified for the three installations can be extrapolated DoD-wide. The demonstrations provided measures of the

viability, potential magnitude of use, and projected energy savings and benefits that can be realized in implementing the different technologies at the individual sites. In addition, the adequacy of the roof insulation for the facilities to meet today's standards is assessed. Based on the extrapolations, the DoD is positioned to refine existing related policies and regulations to ensure reasonable and achievable goals and objectives related to energy and sustainability.

*Technology Transfer:* Participating as part of the project team are representatives from the specific agencies involved in facility sustainment management for the two major services—Army Installation Management Command (IMCOM) and Air Force Civil Engineer Center (AFCEC). By performing full-scale implementations at two Army and one Air Force installation, each service gained a good understanding of how best to implement the technology to meet its specific needs and to fit its own work management system. Also, by using the Enhanced ROOFER COA and developing projects in concert with facility managers, the project team gained a good understanding of the level and type of training necessary to ensure successful tech transfer.

Current opportunities to develop implementation and technical support strategies for the ROOFER SMS are being investigated by the Engineering Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL) and the DoD's military service proponents. Training for facility managers will need to be developed to enable them to fully use the analyses and decision-making tools to develop energy-efficient roofing projects that provide optimized roof service life and sustainability benefits.

*Acceptance:* Performing the demonstration at three sites with the service proponents directly involved and thus allowing them to quantify the magnitude of the benefits through use of the Enhanced ROOFER program should prove highly beneficial in achieving DoD-wide acceptance.

*Additional Benefits:* Multiple COA alternatives are provided, thus allowing the user or facility manager to better determine which COA is optimal. In addition, optimization of multiple alternatives is available to aid in the determination. A roof life-cycle analysis provides an estimated cost output to reveal possible savings over the life of the roof against other alternatives or against the baseline case. Because ROOFER is available for use in the private sector and by other governmental agencies, entities beyond the DoD can realize the same benefits. This ESTCP Final Report provides potential users with documentation of the costs, implementation requirements, and benefits achieved through implementation of the program.

*Deliverables:* Deliverables for each of the three demonstration sites included annual work plans for roofing rehabilitation that incorporated energy-efficient technologies. A full report of Enhanced ROOFER analyses and findings was delivered at the end of the project. The experiences gained by the project team were instrumental in identifying and developing ROOFER training requirements for facility managers, to include not only the newly enhanced capabilities of ROOFER but also the features of the recently developed web-based version of the program. Lessons learned in gathering inventory information from the contractor implementations were utilized in developing statement of work requirements for future implementation contracts.

### 1.3 REGULATORY DRIVERS

As stated previously, the DoD is interested in reducing energy consumption and constructing or maintaining sustainable building facilities. This dual policy push is reflected in policies and guidance documents that directly address these issues, including the Energy Policy Act (EPAct) of 2005, Section 102; and the U.S. Energy Independence and Security Act (EISA) of 2007, Section 431. Specific requirements include ensuring that all new construction, major renovations, repairs, and alterations of federal buildings comply with the “Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings.” Those principles include optimizing energy performance through energy efficiency. The technologies (e.g., cool roofing, vegetative roofing, roof-mounted PV) evaluated in the Enhanced ROOFER COA analyses provide a means for reducing energy use. Program reports generated from the analyses provide estimates for energy savings for the various roof-related technologies on a project basis.

Cool roofing and insulation upgrades can significantly reduce the energy use of existing buildings. The Assistant Secretary of the Army (Installations, Energy and Environment) (ASA IE&E) in a Memorandum for Sustainable Design and Development Policy Update, dated 27 October 2010, requires that cool roof design strategies be selected and incorporated into roof replacements. As an additional incentive, cool roofs qualify for 1 point under the 2009 U.S. Green Building Council’s (USGBC’s) Leadership in Energy and Environmental Design–New construction (LEED-NC) Sustainable Sites Credit. Section 109 of EPAct 2005 requires federal building performance standards to exceed American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) requirements by 30%. ASHRAE Standard 90.1 (Energy Standard for Buildings Except Low-Rise Residential Buildings), has specific requirements for the building envelope, including minimum R-values for roof insulation. The Enhanced ROOFER application considers roofing system R-values for all managed buildings, determines compliance, and estimates energy savings to be realized through compliance. The ASHRAE standard also requires that all roofs that do not meet certain minimum R-values are required to have established minimum three-year-aged solar reflectance values (i.e., cool roofing).

Sustainability is also a focus of the EISA because it directs the DoD to implement green technologies in its buildings. Green technologies such as vegetative roofing systems can provide improved storm water runoff and contribute to reducing heat-island effect. Renewable electrical energy (e.g., PV) is addressed in Section 203 of EPAct 2005, which requires that 7.5% of electricity by 2013 and beyond come from renewable sources. The Defense Authorization Act (DAA) for fiscal year (FY) 2007, Section 2852, establishes DoD goals to: (1) produce or procure not less than 25% of the total electric energy it consumes during FY2025 and thereafter from renewable energy sources; and (2) produce or procure such renewable energy when it is life-cycle cost effective to do so. Building-integrated photovoltaics (BIPV) systems and rack-mounted PV panels placed on rooftops can contribute to those goals.



## 2. TECHNOLOGY DESCRIPTION

ROOFER SMS is a decision-support tool that provides facility managers at DoD installations with an automated and systematic approach to managing their inventory of building roofs. The system is a web-based computer application, and it follows procedures for collecting and managing inventory and inspection data and performing roof condition assessments. COA analyses are executed to develop repair and replacement projects and to identify long-range budget requirements that will provide the maximum return on investment. Figure 1 shows ROOFER's major system components.

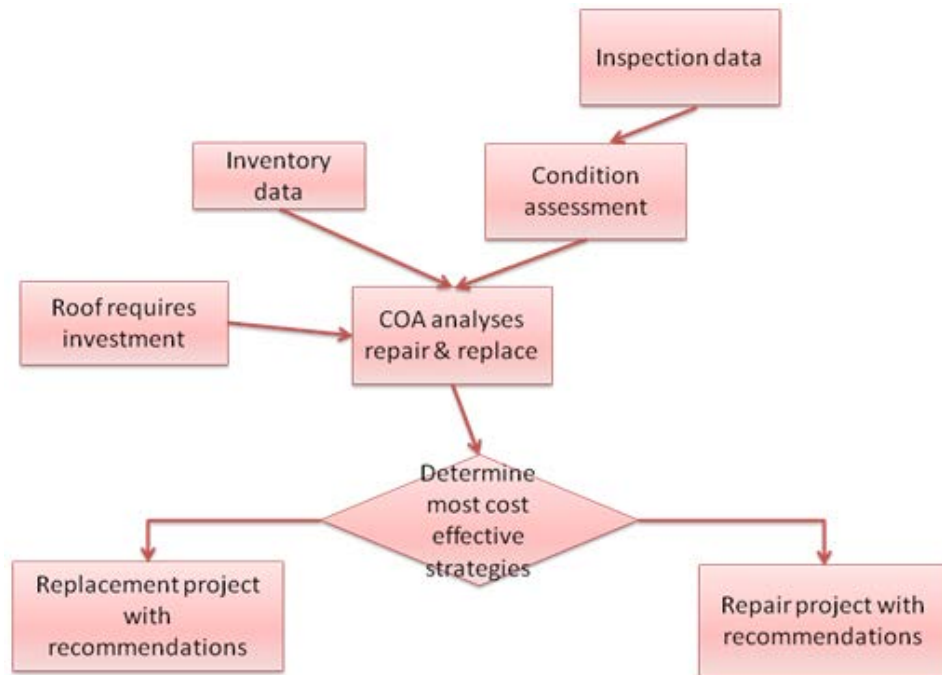


Figure 1. ROOFER SMS components.

During the first year of this ESTCP project, the team evaluated existing roofing-related technologies and tools that could be integrated with the ROOFER COA analyses to evaluate sustainability options as part of these repair/replacement projects. The following tools were selected for interfacing with the ROOFER SMS.

- *Cool Roof Calculator* (CRC) estimates the cooling and heating energy savings from differently colored low-slope roofs and different insulation R-value levels. (<http://web.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm>).
- *Roof Savings Calculator* estimates the cooling and heating energy savings for roofs of different slopes and modern attic and cool-roofing technologies. (<http://web.ornl.gov/sci/roofs+walls/SteepSlopeCalc/index.htm>).
- *Green Roof Energy Calculator* (GREC) allows the comparison of energy performance of a vegetative roof to energy performance of the same building with either a dark or a white roof. ([http://greenbuilding.pdx.edu/GR\\_CALC\\_v2/grcalc\\_v2.php#retain](http://greenbuilding.pdx.edu/GR_CALC_v2/grcalc_v2.php#retain)).

- *PVWatts* calculates energy production and cost savings of grid-connected PV systems, using hour-by-hour performance simulations for estimated energy production. (<http://www.nrel.gov/rredc/pvwatts/>).

Through modification and expansion of the ROOFER COA analyses that occurred in the second year of this project, a cost-benefit analysis of energy-related technologies was incorporated to support the development of optimum roof rehabilitation projects.

## 2.1 TECHNOLOGY OVERVIEW

### 2.1.1 ROOFER

Soon after the release of the original version of ROOFER (Shahin, Bailey, and Brotherson 1987, Vol. I and II), the system was implemented as a software application for microcomputers running the Microsoft Disk Operating System (MS-DOS).<sup>\*</sup> This application, Micro ROOFER, included condition assessment procedures for bituminous built-up roofs (Shahin, Bailey, and Brotherson 1987, Vol. II). Since then, additional roof types have been incorporated, including single plies (Bailey et al. 1993), modified bitumens (Bailey 2010), asphalt shingles (Bailey 1999b), and metal panels (Bailey, Karbarz, and Sweeton 2012). With these additions and ROOFER's 2012 conversion to a web-based platform (Figure 2), greater than 95% of the DoD roofing can be managed at the installation level, with data readily accessible to higher-level managers. In 2010, the ROOFER SMS was approved by the DoD Information Assurance Certification and Accreditation Process (DIACAP), meaning ROOFER could be used on DoD information systems. All DoD installations are required to implement ROOFER along with other SMSs by 2018 (U.S. Department of Defense 2013).

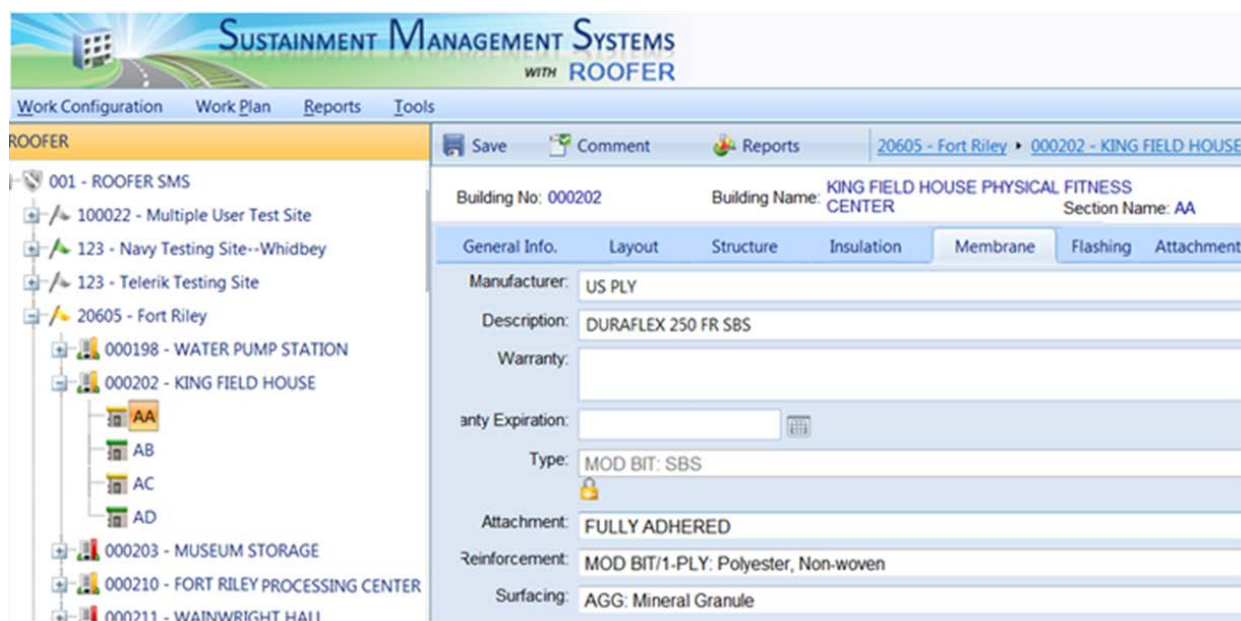


Figure 2. Screenshot of web-based ROOFER sustainment management system program.

<sup>\*</sup> Microsoft, MS-DOS, and Windows are trademarks of Microsoft, Inc., Redmond, WA.

The first step in implementing ROOFER at a DoD installation is to establish an inventory of all the building roofs to be managed by the user (Bailey et al. 1989). For evaluation purposes, each building roof is divided into smaller inspection units called sections, which are the management units for which all repair and replacement decisions are made. Building age, use, and other parameters are extracted from existing real property databases. Standardized forms are used to collect specific information about each roof section. These forms will include historical information (e.g., date of construction, date of last replacement) and physical information concerning dimensions and design/construction/material characteristics of each roof component (e.g., deck, insulation, membrane, surfacing, flashing).

To assess roof condition, an objective and repeatable rating system for identifying the roof's present condition is used (Shahin, Bailey, and Brotherson 1987, Volume I). For low-slope roofs, the membrane, flashing, and insulation components (for insulated roofs only) are evaluated individually. For asphalt shingles and metal roofs, the surfacing and flashings are evaluated. Treating each component separately provides an accurate assessment of component condition, waterproof integrity, and repair needs.

Visual surveys of the field of the roof and flashings are conducted by trained inspectors utilizing the formalized procedures found in the various ROOFER technical reports, which serve as inspection manuals. Existing roof distresses are measured and recorded using standardized techniques and procedures. For insulated membrane roofs, moisture surveys using methods such as infrared thermography are performed to identify potential areas of wet roof insulation. Core cuts from these areas are then extracted and analyzed to determine moisture content.

The inspection data, along with the inventory information, are input into the site's database via the ROOFER web application. For each inspected roof section, the program computes a condition index (CI). The CI is a numerical rating ranging from 0 to 100, with 100 representing excellent condition. The individual component condition indexes are combined to produce a roof condition index (RCI). The RCI uses the same 0 to 100 scale and provides an overall rating of a roof section. The RCI also can aid in planning and prioritizing projects. Steps used to develop CIs from inspection data are as follows:

1. Inspect the roof and determine distress types and severity levels. Measure distress quantities and calculate the densities of the severity levels.
2. Determine the deduct values for each of the individual distresses.
3. Sum the individual distress deduct values, then apply a corrected deduct value adjustment factor to account for multiple distresses.
4. Subtract the total adjusted deduct value from 100 to compute the roof section CI.

Management at the project level consists of analyzing individual roofs and selecting the best alternative (repair or replace) without consideration given to the resource requirements of other projects being evaluated. Repair project requirements are formulated based on the collected distress information and a repair cost database. With an updated ROOFER database, the user is able to manage roofs on a project-by-project basis. The system's knowledge base includes repair requirements, cost data, and roof performance algorithms. When coupled with inspection information, the user can perform an automated ROOFER COA analysis to identify optimal

rehabilitation strategies. Currently, the analyses consider the following two major options: (a) a repair project that includes permanent fixes to the roof covering and flashings to extend service life, and (b) a scheduled replacement project that includes interim temporary repairs to keep the system watertight until a projected replacement date is reached. The annualized repair cost for achieving an estimated additional service life and the projected cost per year for roof replacement provide means for selecting the most cost-effective option. Figure 3 shows the output results of the ROOFER COA analysis for a hypothetical roof section having a single-ply ethylene propylene diene monomer (EPDM) roof. In this particular case, a repair project was recommended to fix all repairable problems that were identified by inspection, thereby extending service life by an estimated 11 years. A Corrective Action Requirement sheet that includes itemized lists of repair tasks to be performed can be generated for each repair project.

**Roof Section Cost Analysis**

Building & Section Description			
Building:	210 - Wing Headquarters		
Section:	F	Roof Type:	Single-Ply
Area:	1,835 (SF)	Membrane Type:	SINGLE-PLY: EPDM
Surface:	NONE	Deck Type:	STEEL
Insulation Type:	POLYISOCYANURATE		

Date Info		Reference Costs	
Visual Inspection Date:	11/7/2011	Cost Book:	Schriever 2012
Insulation Inspection Date:	N/A	Area Cost Index:	1.00
Originally Constructed/Last Replaced:	2002	Repair Setup Charge:	\$935.00
Current Age:	10	Replace Unit Cost:	\$12.54 per

Condition Analysis		
Predicted Year of Replacement w/o Repairs:	2019	
Additional Service Life:	11	
Predicted Year of Replacement w/ Repairs:	2030	
Recommendation:	Repair	

	Existing:	Improved:
RCI:	81	99
FCI:	82	100
MCI:	77	98
ICI:	-	100

**Figure 3. Roof section cost analysis for hypothetical roof.**

ROOFER can also be used to manage the entire inventory of building roofs at a programmatic level. By being able to roll up the inventory and inspection data along with the project-level COA analyses data, facility managers can generate automated reports that aid in developing overall short- and long-range plans for their buildings' roofs. Figure 4 shows a ROOFER 10-year budget plan for a single installation. This budget plan provides a schedule of expected yearly expenditures for the entire database or portion of the database in order to accomplish temporary immediate repairs, major repair projects, roof replacements, and inspections. The repair and replacement project costs are generated from the ROOFER COA analysis results for each building's roof. Costs for immediate repairs, intermediate M&R (maintenance and repair), and inspections are determined by using historical unit area costs.

(Costs in Thousands)											
Installation:	N00178 - Naval Surface Warfare Center DD										
Buildings:	53	Sections: 197				Total Area: 631575					
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Totals
Immediate Repairs	\$1										\$1
Major Repair Projects	\$41	\$41	\$41	\$41							\$164
Replacement Projects	\$199	\$45	\$417	\$23			\$12	\$28	\$10	\$195	\$929
Intermediate M&R		\$19	\$19	\$19	\$19	\$19	\$19	\$19	\$19	\$19	\$171
Insulation Inspection	\$8					\$8					\$16
Visual Inspections	\$5	\$5	\$5	\$5	\$5	\$5	\$5	\$5	\$5	\$5	\$50
Totals	\$254	\$110	\$482	\$88	\$24	\$32	\$36	\$52	\$34	\$219	\$1331

Figure 4. ROOFER 10-year budget report.

### 2.1.2 Cool Roof Calculator

The CRC was developed by the Oak Ridge National Laboratory (ORNL) (Petrie et al. 2001; Petrie, Wilkes, and Desjarlais 2004). The calculator is an online tool that predicts heating and cooling loads per unit area to a low-slope membrane roofing system. These loads take into account user-defined roof-surface optical radiation properties, insulation levels, and building location. The calculator further estimates the difference in annual operating costs between the proposed roof and a ‘black’ roof, using the user-supplied local energy costs and equipment efficiencies. Alternately, it yields the amount of conventional insulation without radiation control that a roof needs in order to have the same annual energy costs as the same roof with the existing amount of conventional insulation and solar radiation control.

The CRC employs a one-dimensional transient heat-transfer model (Wilkes 1989) to calculate the annual heating and cooling loads with local typical meteorological year (TMY) weather data. The annual cooling and heating loads are functions of location, surface radiation properties (solar reflectance), and roof insulation R-value. These predictions can be made for small- and medium-sized facilities that purchase electricity and for large facilities that purchase electricity with a demand charge that is based on peak monthly load.

The CRC user interface screen is shown in Figure 5. The input parameters for the tool include location, building energy costs (e.g., insulation R-value, solar reflectance), HVAC equipment efficiencies (e.g., air conditioner, furnace, heat pump), and any electrical demand charges. The CRC outputs include yearly energy savings and loads for both cooling and heating.

**DOE Cool Roof Calculator**

My State Georgia ▼  
My City Atlanta ▼

Click to see [Data for All 243 Locations](#)

**My Proposed Roof:**

R-value (HIGH=20; AVG=10; LOW=5) [h·ft<sup>2</sup>·°F/Btu] 15  
Solar reflectance, SR (HIGH=80; AVG=50; LOW=10) [%] 50  
Infrared emittance, IE (HIGH=90; AVG=60; LOW=10) [%] 90

**My Energy Costs and Equipment Efficiencies:**

Summertime cost of electricity (HIGH=0.20; AVG=0.10; LOW=0.05) [\$/KWh] .1  
Air conditioner efficiency (COP) over cooling season (HIGH=2.5; AVG=2.0; LOW=1.5) 2  
Energy source for heating (choose one) ☒ Electricity ☐ Fuel  
If electricity, wintertime cost (HIGH=0.20; AVG=0.10; LOW=0.05) [\$/KWh] .1  
If fuel, cost (Natural gas: HIGH=1.00; AVG=0.70; LOW=0.50) [\$/Therm]   
(Fuel oil: 2002 East coast=0.85; 2002 Midwest=0.70) [\$/Therm]   
Heating system efficiency (Furnace or boiler: HIGH=0.8; AVG=0.7; LOW=0.5)   
(Electric heat pump: HIGH=2.0; AVG=1.5) (Electric resistance: 1.0) 1.5

**My Electricity Demand Charges and Duration:**

Demand charge during cooling season (HIGH=15.00; AVG=10.00; LOW=5.00) [\$/KW] 10  
Months charged for peak demand (Typical = 6) [-] 6

Calculate My Annual Savings

**Total Annual Energy + Demand Savings (relative to a black roof) [\$/ft<sup>2</sup> per year]** 0.054

Cooling energy savings [\$/ft<sup>2</sup> per year] 0.041  
Heating energy savings (heating penalty if negative) [\$/ft<sup>2</sup> per year] -0.013  
Cooling season demand savings [\$/ft<sup>2</sup> per year] 0.027

**Insulation in Black Roof for Same Total Annual Energy Savings**  
(ignore demand savings):  
Upgrade from R-15 to R-16.7 [h·ft<sup>2</sup>·°F/Btu]

**Figure 5. Cool Roof Calculator user interface by ORNL/DoE.**

### 2.1.3 Steep Slope Calculator

ORNL also developed a similar tool to the CRC, except for use with steep roofing systems. The Steep Slope Calculator (SSC) estimates heating and cooling loads attributable to ceiling insulation and roof covering characteristics for steep roofs that have ventilated attic spaces. The user specifies roof-surface optical radiation properties, ceiling insulation R-values, and building location (for climate purposes). The calculator (see Figure 6) provides estimated heating and cooling cost savings obtained from the user-proposed roof when compared to a black roof, using local energy costs and HVAC equipment efficiencies. Alternately, it yields the amount of required additional ceiling insulation needed by a black roof to achieve the same annual energy costs as the proposed roof.



## DOE Steep Slope Calculator

**Enter A State:** Illinois

**Enter A City:** Springfield

28

60

60

**Roof Inputs:**

**R-value(Btu-in/(hr ft<sup>2</sup> oF):** 28

**Solar Reflectance (SR) Percentage: (HIGH=60;AVG=25; LOW=5):** 60

**Emittance (E) Percentage: (HIGH=90;AVG=60; LOW=10):** 60

**Energy Costs And Equipment Efficiencies:**

Summertime cost of electricity (HIGH=0.20; AVG=0.10; LOW=0.05) [\$/KWh] : .1

Air conditioner efficiency (Coefficient of Performance) (HIGH=2.5; AVG=2.0; LOW=1.5) 2

Energy source for heating (choose one) :

☐ Electric  
☒ Non-Electric

If electricity, wintertime cost (HIGH=0.20; AVG=0.10; LOW=0.05) [\$/KWh] :

If non-electric, cost (Natural gas: HIGH=1.30; AVG=1.00; LOW=0.70) [\$/Therm] 1.3

(Fuel oil: 2004 East coast=1.40; 2004 Midwest=1.25) [\$/Therm] :

**Heating system efficiency (Furnace or boiler: HIGH=0.8; AVG=0.7; LOW=0.5) (Electric heat pump: HIGH=2.0; AVG=1.5) (Electric resistance: 1.0) :** .8

Click To Calculate Savings

**Net Savings [\$/ft<sup>2</sup> per year] :** .0034

Cooling savings [\$/ft<sup>2</sup> per year] .0081

Heating savings (heating penalty if negative) [\$/ft<sup>2</sup> per year] -0.0048

Figure 6. Steep Slope Calculator (ORNL/DoE).

The SSC is based on simulations performed using AtticSim, a computer tool for predicting the thermal performance of residential attics; the code for AtticSim is publicly available as an American Society for Testing and Materials (ASTM) protocol (New et al. 2011; ASTM C 1340-04). Similar to the CRC, the SSC is founded on simulations performed for several pairs of roof solar reflectance (SR) and thermal emittance (TE), and different levels of ceiling insulation. The simulations were done for several locations in different climate zones, using TMY weather data.

### 2.1.4 Green Roof Energy Calculator

The GREC is based on the vegetative rooftop model described by Sailor (2008). The physical-based model of the energy balance of a vegetated rooftop was developed and integrated into the

National Renewable Energy Laboratory (NREL) EnergyPlus building energy simulation program. It incorporates a vegetation canopy and soil transport model that represents the following green roof physics:

- Long- and short-wave radiation exchange within the canopy (multiple reflections, shading)
- Effect of canopy on sensible heat exchange among ambient air, leaf, and soil surfaces.
- Thermal and moisture transport in the growing media, with moisture inputs from precipitation (and irrigation if desired).
- Evaporation from the soil surface and transpiration from the vegetation canopy.

The GREC allows comparison of building annual energy performance with a vegetative green roof as compared to a conventional roof. At present, simulations are available for new construction (ASHRAE 90.1-2004) and old construction (pre-ASHRAE 90.1-2004) of office and residential buildings, driven by data documenting typical precipitation and weather. Simulations for 100 cities were conducted during development of this calculator using 2 building vintages, 2 building categories (office & residential), and 20 roof types. The user inputs the building location, roof area, and building type, along with characteristics of the vegetative roof. The outputs include annual energy savings compared to a dark-colored and a light-colored membrane roof (Figure 7). Additional sustainability attributes are also generated, such as average sensible heat flux to the urban environment, latent heat flux to the urban environment, and estimated reduced volume of rooftop stormwater runoff.

### **2.1.5 PVWatts**

PVWatts™ is an online calculator for estimating the annual energy production and cost savings of grid-connected PV systems. The tool, developed by the National Renewable Energy Laboratory (NREL), creates hourly simulations to provide estimated monthly and annual energy production at selected locations, using the corresponding TMY weather data (Figure 8). The hourly direct current (DC) energy is calculated from the PV system's DC rating and the incident solar radiation, and it is then corrected for the PV cell temperature. The solar radiation data is extracted from the same TMY data used by the other three tools. The PVWatts tool calculates the alternating current (AC) by using the user-provided "DC-to-AC derate" conversion factor and adjusting for inverter efficiency as a function of load. Using the local electricity cost provided by the user, PVWatts then estimates the monthly and yearly AC energy produced by the proposed PV system.



## Estimate Annual Green Roof Performance

Would you prefer to use **US Customary** or SI units?

☒ US Units
 ☐ SI Units

### Building Information

What State/Province is your building located in?

Indiana  
Iowa  
**Kansas**  
Kentucky

Topeka

What city is your building located in?

What is the total area of your **roof**?

Which **Type** is your building?

2450

ft<sup>2</sup> (roof area)

Old Office Bldg.

### Green Roof Information

What is your **Growing Media** Depth? (2 to 11.5)

What is your **Leaf Area Index**? (0.5 to 5)

Is your green roof irrigated?

4


inches

1.5


No

Calculate


Reset



Portland State  
UNIVERSITY



UNIVERSITY OF  
TORONTO



GREEN ROOFS  
FOR HEALTHY CITIES  
[www.greenroofs.org](http://www.greenroofs.org)

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## Impact of a Green Roof

You specified an **Old Office Building** in **Topeka, KS** with a total roof area of **2450 ft<sup>2</sup>**. The Green Roof you specified for this building has a **Growing Media Depth** of **4 inches**, a **Leaf Area Index** of **1.5**, covers approximately **100%** of the total roof area, and is **not irrigated**. For reference, the annual whole building electricity consumption for the specified green roof was 135465 kWh and the annual gas consumption of this green roof was 737 Therms

#### Annual Energy Savings compared to a Dark Roof (albedo = 0.15)

Electrical Savings: **1494.8 kWh**

Gas Savings: **24.3 Therms**

Total Energy Cost Savings(1): **\$187.20**

#### Annual Energy Savings compared to a White Roof (albedo = 0.65)

Electrical Savings: **-689.1 kWh**

Gas Savings: **60.4 Therms**

Total Energy Cost Savings(1): **\$51.16**

#### Average Sensible Heat Flux to the Urban Environment (W/m<sup>2</sup>)

	Dark Roof	White Roof	100% Green Roof System
Annual Average:	37.1	-16.9	42.7
Summer Average:	27.9	-33.2	42.7
Summer Daily Peak Avg.:	-156.2	-355.9	92.0

#### Annual Roof Water Balance (in)

	Conventional Roof	100% Green Roof System
Precipitation:	38.8	38.8
Evapotranspiration:	-	25.9
Irrigation:	-	0.0

**Figure 7. Green Roof Energy Calculator (Portland State University).**

13

**Station Identification:**

WBAN Number: 23183  
City: Phoenix  
State: Arizona

**PV System Specifications:**

DC Rating (kW): 4.0  
DC to AC Derate Factor: 0.77 DERATE FACTOR HELP  
Array Type: Fixed Tilt  
Fixed Tilt or 1-Axis Tracking System:  
Array Tilt (degrees): 33.5 (Default = Latitude)  
Array Azimuth (degrees): 180.0 (Default = South)

**Energy Data:**

Cost of Electricity (cents/kWh): Default = State Average

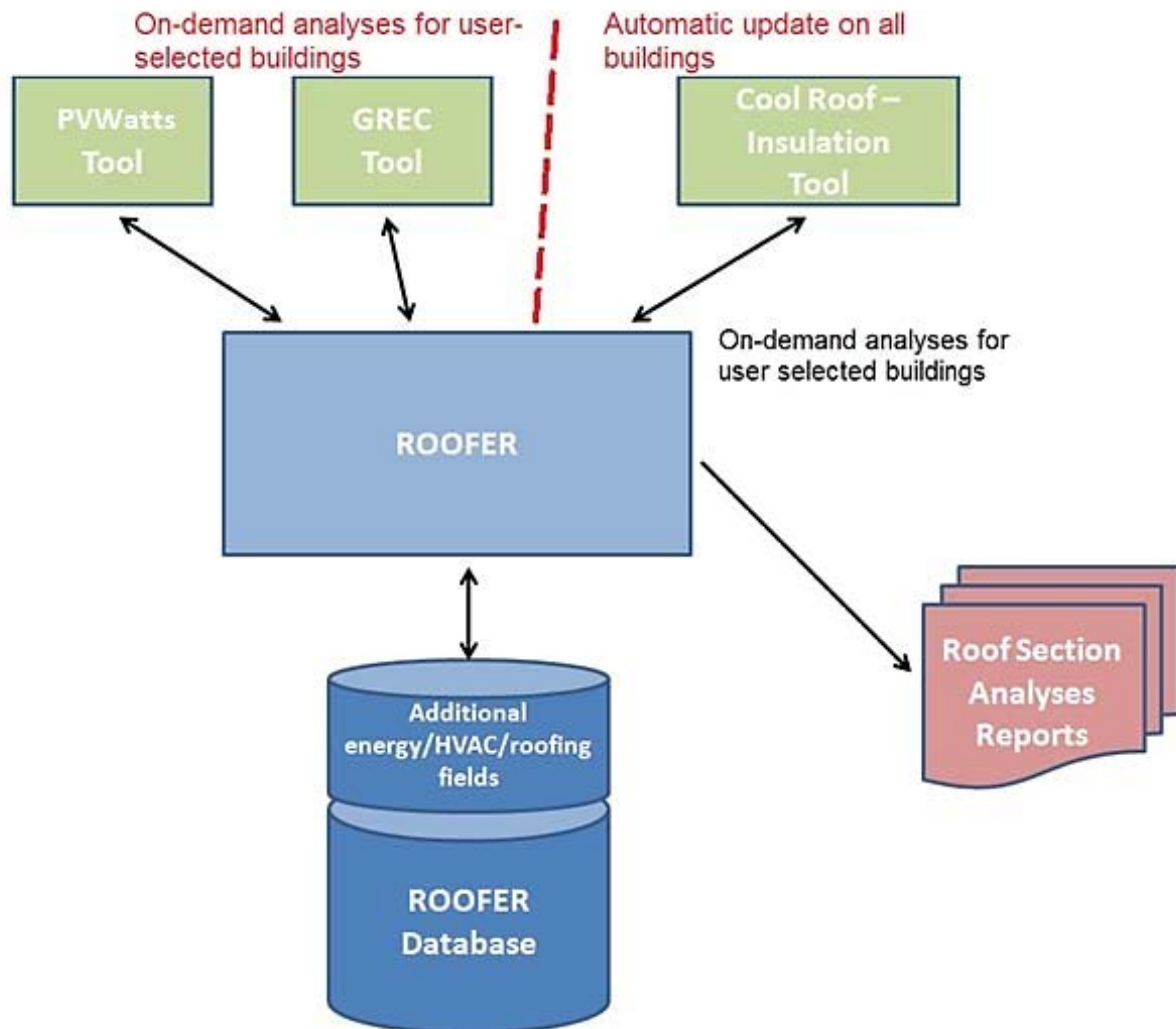
CalculateHELPReset Form

Station Identification	
City:	West_Palm_Beach
State:	Florida
Latitude:	26.68° N
Longitude:	80.10° W
Elevation:	6 m
PV System Specifications	
DC Rating:	4.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	3.1 kW
Array Type:	Fixed Tilt
Array Tilt:	26.7°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	22.0 ¢/kWh

Results			
Month	Solar Radiation (kWh/m <sup>2</sup> /day)	AC Energy (kWh)	Energy Value (\$)
1	4.61	409	89.98
2	5.01	404	88.88
3	5.57	488	107.36
4	5.74	481	105.82
5	5.46	473	104.06
6	5.12	418	91.96
7	5.42	458	100.76
8	5.46	464	102.08
9	5.28	433	95.26
10	4.99	427	93.94
11	4.59	389	85.58
12	4.34	386	84.92
Year	5.13	5229	1150.38

Figure 8. PVWatts™ Calculator (NREL).

*Enhanced ROOFER with Energy Performance Assessment.* As part of the ESTCP project, the two ORNL calculators (CRC and SSC) were converted to one single program, which for current purposes is referred to as the Cool Roof–Insulation Tool, thereby facilitating development of the interface with ROOFER (Figure 9). The remainder of the development work focused on the ROOFER program and the interface between it and the four tools developed by others (i.e., Cool Roof–Insulation Tool, GREC, and PVWatts).



**Figure 9. ROOFER SMS integration with energy and sustainability tools.**

The necessary data elements required for input to each of the tools were identified. These data include characteristics and properties of the existing roofing system, installation energy costs and location, building, HVAC efficiencies, and vegetative roofing parameters. The ROOFER database structure was revised to accommodate the new data elements. Field collection sheets and data input screens were developed along with interface routines that pass the appropriate ROOFER data elements to the four tools.

Figure 10, shows the Enhanced ROOFER’s economic evaluation section analysis report. This report is generated by using the energy performance and cost data that are provided by the

integrated tools to support generation of automated energy cost/benefit analyses. The insulation R-value assessment and cool roofing technology was evaluated for roofing systems on all buildings. Because vegetative roofing systems require unique structural and roof system designs and maintenance requirements, they were evaluated for user-selected buildings only. These systems are generally utilized within DoD on a very limited set of buildings to take advantage of architectural aesthetics. PV implementations were also evaluated on user-selected buildings.

**Report Viewer**

Close Export Type PDF Export Report Help

**ESTCP Roof Section Analysis**

**My Site (ECB)** Unassigned

**Building & Section Description**

Bldg Name: e9b - My Bldg  
 Section: PE Roofing Type: Metal Panel - Separate Cap  
 Section Area: 5,000 (SF)  
 Base Metal: STEEL  
 Panel Finish: FACTORY APPLIED STONE Deck Type: N/A  
 Panel Attachment: N/A

**Date Info**

Visual Inspection Date: 8/26/1977  
 Originally Constructed / Last Replaced: 1987  
 Current Age: 49 FY-2016

**Reference Costs**

Cost Book: CB-EcB My Site  
 Area Cost Factor: 1.00  
 Repair Setup Charge: (\$1.00)  
 Replace Unit Cost: \$12.35 per SF

**Condition Analysis**

Predicted Year of Replacement (w/o repairs): 2016  
 Additional Service Life (w/ repairs): 16  
 Predicted Year of Replacement (w/ repairs): 2032

	Existing:	Improved:
RCI:	62	87
FCI:	92	100
PCI:	49	82

**Recommendation:** REPLACE

**Cost Analysis**

Estimated Cost of Repairs: \$109,919 \$8,870 / Year  
 Estimated Cost of Replacement: \$61,750 \$2,470 / Year  
 Adjusted Repair / Replace Ratio: 2.98

**Enhanced COA**

Cooling load for existing roof	1479.1416 BTUs
Heating load for existing roof	-17015.2852 BTUs
Annual AC system output	.0000 KWh
Cooling load for upgraded roof	-1.0000 BTUs
Heating load for upgraded roof	-1.0000 BTUs
Type of upgraded roof	Photovoltaic

**Work Plan Costs for 2016**

	Current	Optimal
Replacement Cost	\$61,750	\$67,925
Repair Cost	\$28,700.00	\$31,570.00
Maintenance Cost	\$205.00	\$205.00
Operations Cost	-\$25,042.58	-\$3.22

**Figure 10. ROOFER economic evaluation with energy and sustainability features.**

To ensure compliance, roof performance characteristics for insulation and cool roofing that meet current DoD and service requirements (i.e., ASHRAE 90.1 for membrane roofing and ASHRAE 90.2 for steep roofing) were also passed to the tools. After analyses were executed, the tools passed the resulting energy use, cost data, and other outputs for vegetative roofing to ROOFER. Using the outputs and expanded ROOFER inventory, the user is able to automatically execute the Enhanced ROOFER COA analyses. Based on service life performance models, repair cost databases, and repair and replacement algorithms, repair and replacement projects can be

generated. These projects incorporate the energy and sustainability technologies where appropriate (Figure 11).

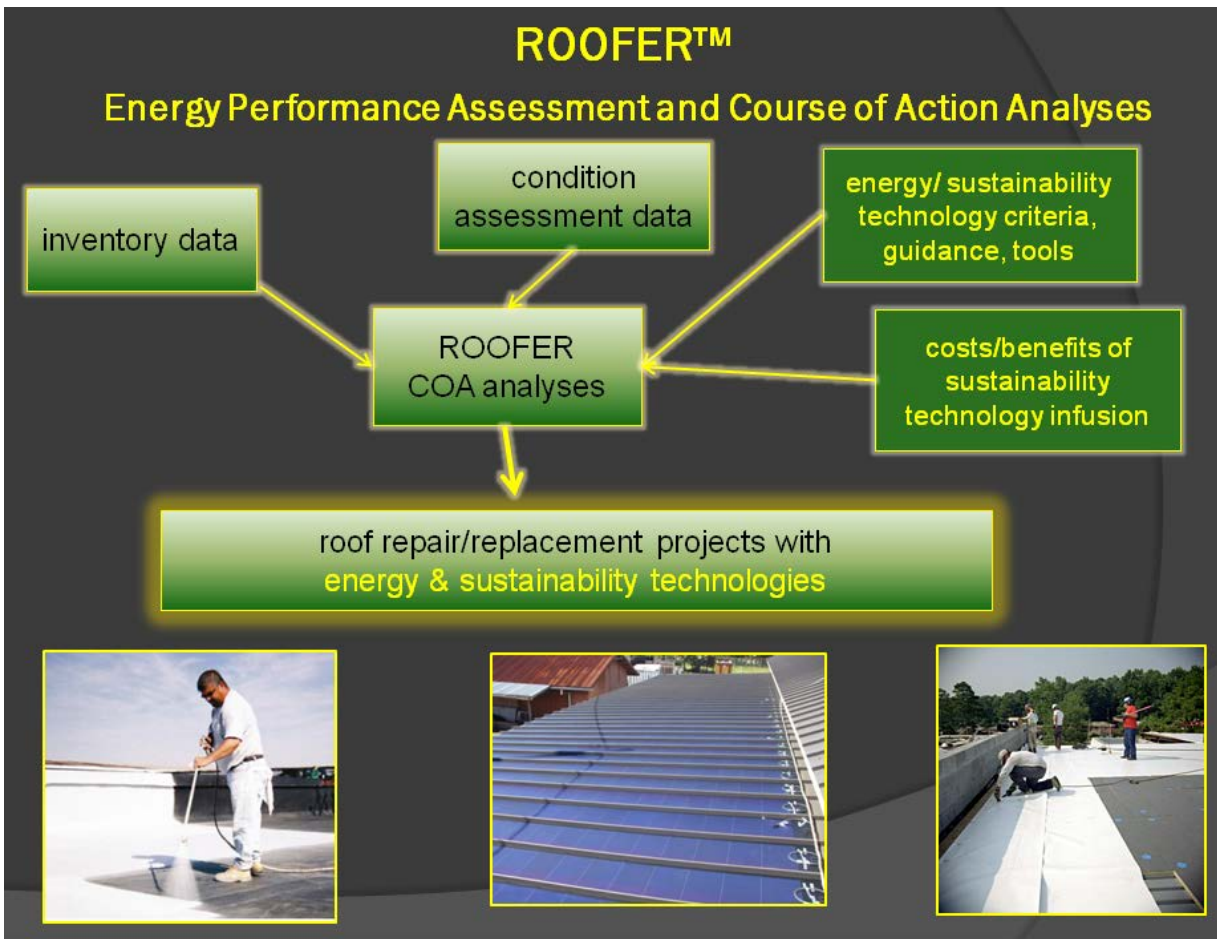


Figure 11. Components of ROOFER with energy performance assessment and COA analyses.

## 2.2 TECHNOLOGY DEVELOPMENT

The basic data structure of the approach consisted of augmentation to the ROOFER graphical user interface (GUI) and tables to allow for input of required third-party calculator data. After user input of the data, the data was transmitted to the energy calculators installed on the same server. Outputs from the energy calculators were then input into a Microsoft Excel spreadsheet on the server. Work with the spreadsheet data heavily utilized the program's solver function to perform multiple iterations of the methodology to identify not only the optimal roof type, but also the most appropriate timeframe to replace the roof (often before the currently installed roof section had completed its life cycle). Output from the Excel model was then sent back to ROOFER, and necessary reports were generated. Figure 12–Figure 21 display the user interface screenshots the user will encounter during energy information entry.





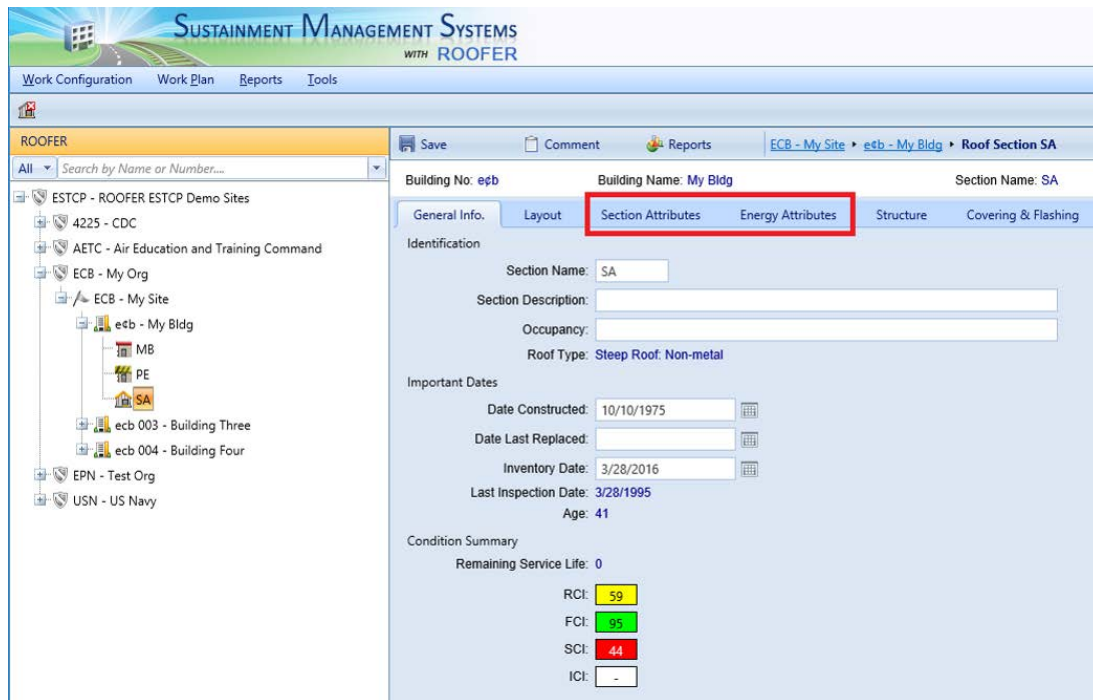


Figure 14. Roof section tabs.

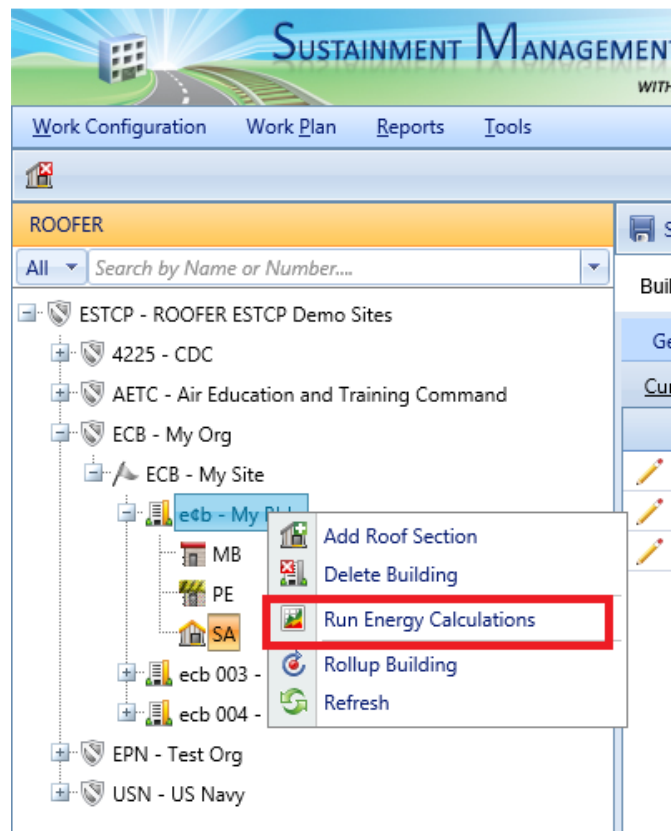


Figure 15. Navigate to “Run Calculation Simulations.”

The image shows two overlapping windows titled "Run Energy Calculations". The background window has the "Building" section with radio buttons for "Cool Roof", "Solar Panel", and "Green Roof", and checkboxes for "MB", "PE", and "SA". A "Generate Work Items" button is at the bottom. The foreground window has "Cool Roof" selected. It includes input fields for "R Value" (unit: h \* F ft<sup>2</sup>/BTU, range: HIGH=20, AVG=10, LOW=5), "Solar Reflectance" (range: HIGH=80, AVG=50, LOW=10), and "Thermal Emittance" (range: HIGH=90, AVG=60, LOW=10). It also has checkboxes for "MB", "PE", and "SA" (which is checked), and a "Generate Work Items" button.

Figure 16. Cool roof alternative selection details.

The image shows two overlapping windows titled "Run Energy Calculations". The background window has "Solar Panel" selected under "Building". It includes input fields for "Azimuth" (degrees, 0=north, 90=east, 180=south, 270=west) and "Tilt" (degrees, 0=flat, 90=vertical). It also has checkboxes for "MB", "PE", and "SA" (which is checked), and a "Generate Work Items" button. The foreground window has "Green Roof" selected. It includes input fields for "Soil Depth" (inches, 2 to 11.5), "Leaf Area Index" (0.5 to 5), "Irrigated" (checkbox), and "Roof Coverage" (% (1 to 100)). It also has checkboxes for "MB" (checked), "PE", and "SA", and a "Generate Work Items" button.

Figure 17. Solar photovoltaic and green roof alternative input details.



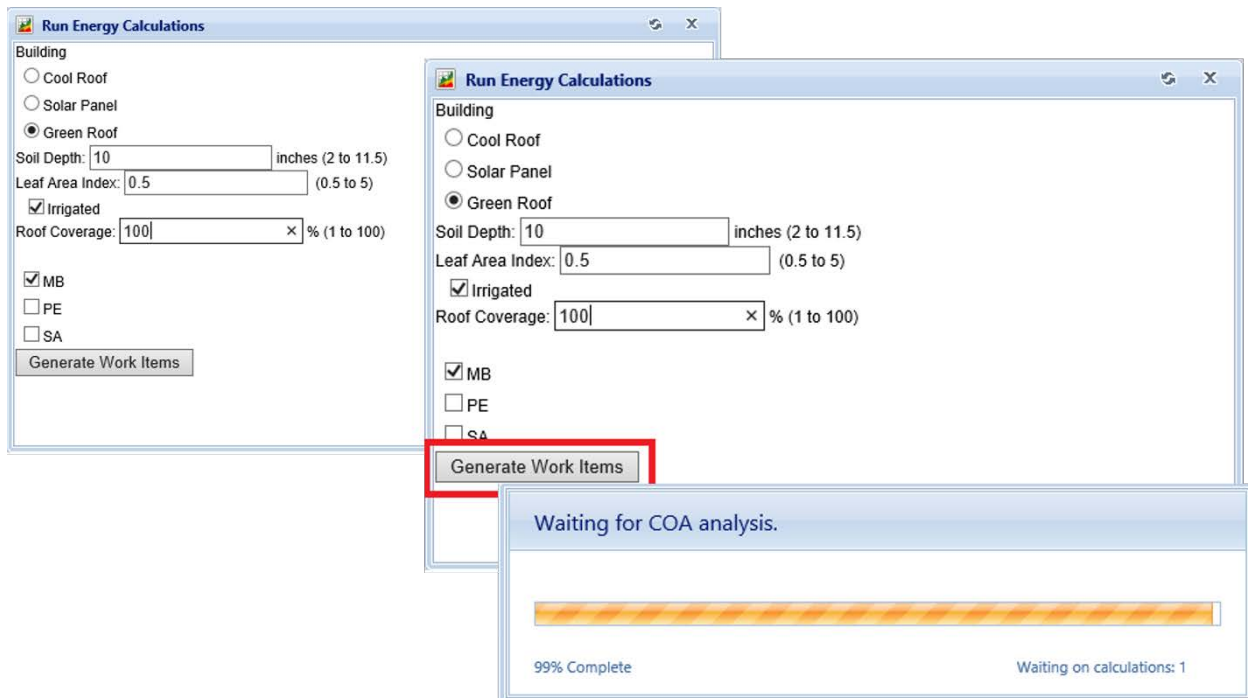


Figure 18. Run simulation.

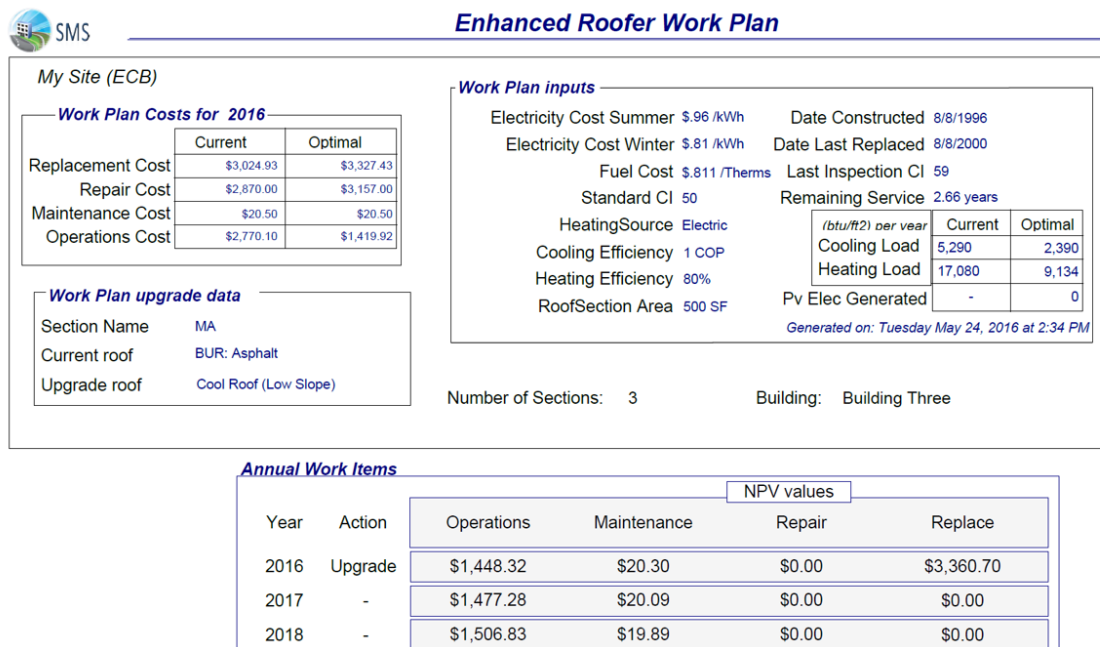


Figure 19. Simulation result reports–annual work plan.

### Annual Work Items

Year	Action	NPV values			
		Operations	Maintenance	Repair	Replace
2036	-	\$2,152.12	\$16.60	\$0.00	\$0.00
2037	Replace	\$2,195.17	\$16.43	\$0.00	\$4,141.70
2038	-	\$2,239.07	\$16.27	\$0.00	\$0.00
2039	-	\$2,283.85	\$16.11	\$0.00	\$0.00
2040	-	\$2,329.53	\$15.95	\$0.00	\$0.00
2041	-	\$2,376.12	\$15.79	\$0.00	\$0.00
2042	-	\$2,423.64	\$15.63	\$0.00	\$0.00
2043	-	\$2,472.11	\$15.47	\$0.00	\$0.00
2044	-	\$2,521.56	\$15.32	\$0.00	\$0.00
2045	-	\$2,571.99	\$15.16	\$0.00	\$0.00
2046	-	\$2,623.43	\$15.01	\$0.00	\$0.00
2047	-	\$2,675.90	\$14.86	\$0.00	\$0.00
2048	-	\$2,729.41	\$14.71	\$0.00	\$0.00
2049	-	\$2,784.00	\$14.57	\$0.00	\$0.00
2050	-	\$2,839.68	\$14.42	\$0.00	\$0.00

Figure 20. Simulation results reports—annual work plan (out-year projections).

## ESTCP Section Analysis Summary

### My Site (ECB)

Roof Section				Without Repairs			With Repairs			Recommendation		
Bldg	Section	Age	Area	RCI	Repl Year	Replace Cost	RCI	Repl Year	Repair Cost	Adj Ratio	Recmnd	Repl Year
ecb 003	MA	16	500	59	2020	3,025	100	2036	127	0.21	Repair	-

#### ESTCP MA Section Analysis

Cooling load for existing roof (5290.48 BTUs)

Annual AC system output ( kWh)

Heating load for upgraded roof (16791.27 BTUs)

Heating load for existing roof (17079.56 BTUs)

Cooling load for upgraded roof (2816.65 BTUs)

Type of upgraded roof ( )

ecb 003	SA	7	1,500	93	2030	8,265	93	2030	0	-	Replace	2016
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#### ESTCP SA Section Analysis

Cooling load for existing roof (2502.89 BTUs)

Annual AC system output ( kWh)

Heating load for upgraded roof (-17015.29 BTUs)

Heating load for existing roof (-14476.2 BTUs)

Cooling load for upgraded roof (1479.14 BTUs)

Type of upgraded roof ( )

ecb 003	PA	17	1,000	86	2016	12,350	100	2041	59,201	4.96	Replace	2016
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#### ESTCP PA Section Analysis

Cooling load for existing roof (2502.89 BTUs)

Annual AC system output ( kWh)

Heating load for upgraded roof (-14229.65 BTUs)

Heating load for existing roof (-14476.2 BTUs)

Cooling load for upgraded roof (1561.27 BTUs)

Type of upgraded roof ( )

### Selection Criteria

Section  
Area

All  
All

Figure 21. Simulation results reports—section analysis summary.

### 3. PERFORMANCE OBJECTIVES

Perhaps in contrast to other ESTCP demonstration projects, the data and metrics for some of the definitive quantitative performance objectives in this project are provided directly as part of the demonstrations. A reduction in implementation costs and a reduction in costs to develop and generate COA recommendations are some of the main points addressed in this project. ROOFER currently provides only recommendations to repair or replace a particular roof in-kind. However, with Enhanced ROOFER, a facility manager benefits from improved COA analysis considerations for providing recommendations. In addition, the facility manager is free to consider only a single type of alternative recommendation or to consider multiple alternative roofing technologies.

#### 3.1 SUMMARY OF PERFORMANCE OBJECTIVES

The quantitative and qualitative performance objectives (POs) are shown in Table 1 (see next page).

#### 3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

##### 3.2.1 Increase in roof assessment alternatives (quantitative)

- *Definition.* Increase in the amount of COA alternatives provided after a roof assessment is completed through improved analytics and available solution alternatives.
- *Purpose.* The PO will provide the current method of developing a COA analysis and will provide COA solution(s) given.
- *Metric.* The amount of COA alternatives are provided after a given roof assessment.
- *Data.* Any and all information needed to perform roof assessment and provide a COA. All resulting COA recommendations should be provided.
- *Analytical Methodology.* The data acquired should be considered in the development of the COA for both the current methodology, which serves as the baseline in the comparative analysis, and for using Enhanced ROOFER.
- *Success Criteria.* Once the roof assessments are completed, the number of COAs provided should be tallied and investigated. Current methods of developing COAs will act as the baseline, and the COAs developed and recommended by Enhanced ROOFER are compared to the baseline. If in the comparison, the number of COAs provided by Enhanced ROOFER is greater, then the success criteria is confirmed. Three alternatives were able to be successfully simulated, as shown in Figure 22 (follows Table 1).

**Table 1. Project performance objectives.**

<b>Performance Objective</b>	<b>Metric</b>	<b>Data Requirement</b>	<b>Success Criteria</b>	<b>Results</b>
<b><i>Quantitative Performance Objectives</i></b>				
Increase in number of roof assessment alternatives	Number of alternatives analyzed	Start-to-finish time reports for duration of analysis	Two or more COA alternatives available for decision making	Three additional COA alternatives made available for decision making.
Reduction in cost to develop COA	Cost (\$)	Cost to run baseline analysis (by manual method)	Reduction in cost from Enhanced ROOFER analysis compared to baseline* by 15% or more	Cost to evaluate each alternative type by hand reduced by at least 15% by collating tools and data in Enhanced ROOFER.
Training – facility manager	Hours of training required and ability to perform tasks without supervision	Required amount of training hours for facility managers, survey results	Less than 4 hours of training	No facility manager training was accomplished due to final recommendation to avoid use of Enhanced ROOFER.
Cost of implementation	Additional cost for ROOFER implementations	Implementation contract cost	Less than 15% additional implementation cost compared to baseline	It is estimated that 15% extra labor is required to complete an Enhanced ROOFER analysis.
<b><i>Qualitative Performance Objectives</i></b>				
Acceptability across all service branches	Number of installations	Survey service technical representatives	Full acceptance of technology from Army, Air Force, and Navy.	Final recommendation is to avoid use of Enhanced ROOFER, therefore acceptance not applicable.
Usability – implementation contractor	Ease of contractor to perform inventory data collection and data input	Survey results	No decrease in contractor satisfaction over baseline.	Input data determined to be cumbersome and foreign to typical contractor.
Usability – facility manager	Ease of installation facility managers in using software and generating reports	Survey results	Satisfactory experience and opinion of system operation.	Satisfactory experience realized.
User satisfaction – facility manager	Degree of satisfaction	Survey results	Satisfaction with system capability versus existing roof asset management practice.	Satisfactory experience realized.
<b>Notes:</b> * The baseline in this table and throughout this document refers to the roof in-kind or current roof type.				

**Run Energy Calculations**

Building

☒ Cool Roof

☐ Solar Panel

☐ Green Roof

R Value: 20 x h °F ft²/BTU (HIGH=20, AVG=10, LOW=5)

Solar Reflectance: 80 % (HIGH=80, AVG=50, LOW=10)

Thermal Emittance: 65 % (HIGH=90, AVG=60, LOW=10)

☐ MB

☐ PE

☒ SA

Generate Work Items

Figure 22. Enhanced ROOFER – roof alternative selection.

### 3.2.2 Reduction in costs to develop COA (quantitative)

- *Definition.* Reduce by 15% or more in the cost required to perform a roof condition assessment and then determine a subsequent COA based on the assessment results.
- *Purpose.* The PO will provide measures of the amount of time it takes to run a typical analysis along with its respective cost. Data related to roof expected life, installation date, etc., will be expected as well. These data will then be used in the comparative analysis of the two methodologies.
- *Metric.* The projected cost in dollars that it will take to perform the roof condition analyses to determine the success of the objective.
- *Data.* The cost attributed to this work from the time contractors begin work on any part of the roof assessment analysis until the analysis is completed. The bulk of the cost in this effort will be realized in the form of labor costs. Also, data related to roof installation date, expected life, roof type, and other roof assessment metrics will be considered.
- *Analytical Methodology.* The cost data acquired should be calculated for both the current and enhanced methodology, which serves as the baseline in the comparative analysis, and by using Enhanced ROOFER. Estimates from industry sources can be used to determine cost of labor per hour per worker. By taking into consideration the amount of workers, the type of workers and the length of time of the work, a reliable cost assessment can be determined. The cost to perform this analysis by hand for various alternatives will be compared to the cost estimated to use Enhanced ROOFER. In addition, the COA recommendation received by the two methodologies is to be considered as well. Costs necessary to determine COA and costs

that will be inherited as a result of decision to accept the recommended COA should be considered. In this decision matrix, a life-cycle cost analysis of the roof will be conducted to illustrate possible savings given the selected alternative. A total cost of ownership (TCO) or a net-present worth cost analysis can be conducted to determine which alternative offers the best cost benefit.

- *Success Criteria.* Once the total cost for each methodology is determined, a comparative analysis can be performed. The total cost includes the initial cost, capital benefit, labor costs, and any other necessary costs in order to determine a COA. The difference in the two costs will confirm the success criteria. To consider life-cycle cost (LCC) benefit, consider the costs incurred as a result of accepting a COA recommendation from the two methodologies. After performing an LCC analysis and a net present worth analysis, the resulting two costs can be compared. The difference in cost will confirm the success criteria if the result shows a reduction of 15% or more.

### **3.2.3 Training – facility manager (quantitative)**

- *Definition.* Effectiveness of hands-on classroom training of existing and new features of the Enhanced ROOFER System, as provided to the installation facility management team.
- *Purpose.* The PO will provide a measure of the level of effectiveness and time efficiency of the provided training for data management, COA analyses, and report generation.
- *Metric.* Degree of satisfaction on a five-point scale from high (5) to low (1).
- *Data.* After the training is completed, the project team will do an assessment of the training session including its content, organization, and time requirements. User satisfaction data will also be collected during informal interviews with the trainees. The project team will reassess this data after the Project Work Plan Development phase of the project is completed.
- *Analytical Methodology.* Responses to informal interviews on satisfaction with training will be reviewed and then combined with project team assessments based on self-critique after training session is completed. The project team will then reevaluate the assessments after being able to monitor the individual user experiences. The project team will modify the content and structure of the training based on the training analyses.
- *Success Criteria.* Training for the Enhanced ROOFER features will be considered successful if the required time for completing the modified training session is four hours or less, and the user satisfaction rating average is 3 or higher.

### **3.2.4 Cost of implementations (quantitative)**

- *Definition.* Contract cost to implement Enhanced ROOFER system.
- *Purpose.* The PO will provide a measure of the additional contract costs for having a contractor collect and input new inventory data related to roof covering, insulation, HVAC energy efficiencies, and installation energy costs that are required for added features of the system.
- *Metric.* The average cost for implementing the Enhanced ROOFER system with the added features will be determined for the three sites.
- *Data.* The contract costs for each of the sites will be used to determine the average additional cost per square feet of roofing for the new system. The most recent contract data for previous

ROOFER implementation using the same contracting mechanism (competitive IDIQ) will provide baseline data.

- *Analytical Methodology.* The project implementation contract data will be compared with baseline data to determine the additional costs for implementing the Enhanced ROOFER system.
- *Success Criteria.* When the additional implementation contract cost is less than 15% of the baseline ROOFER implementation, success will be achieved.

### **3.2.5 Acceptability across all service branches (qualitative)**

- *Definition.* Acceptability of Enhanced ROOFER technology for use throughout the three major services as the standard for roof asset management at the installation level.
- *Purpose.* The PO will provide a measure of the commitment of upper-level managers and decision makers in the intended and continued use at the installation level of ROOFER with energy performance assessment and COA analyses.
- *Metric.* Degree of satisfaction on a five-point scale from high (5) to low (1).
- *Data.* User satisfaction data and recommendations for improvements will be collected during informal interviews with the three services' technical representatives.
- *Analytical Methodology.* Responses to informal interviews on satisfaction with system usability, functionality, and performance will be reviewed and assessed.
- *Success Criteria.* The Enhanced ROOFER features will be considered successful if service technical representatives are satisfied with technology and are committed to supporting implementation at their respective installations.

### **3.2.6 Usability – contractor (qualitative)**

- *Definition.* Level of satisfaction of the contractor regarding the new inventory data collection procedures and program input features of the Enhanced ROOFER system.
- *Purpose.* The PO will provide the measure of satisfaction that the contractor's implementing team had in using the enhanced functionality of the ROOFER system, particularly the collection of additional inventory data and input of this data into the ROOFER database.
- *Metric.* Degree of satisfaction on a five-point scale from high (5) to low (1), when compared to usability of previous ROOFER system.
- *Data.* Contractor will be directed to contact project team concerning any systemic problems with data collection or input that arose during the implementation phase. Contractor satisfaction data will be collected during informal interviews after implementation is completed.
- *Analytical Methodology.* Responses to informal interviews on satisfaction with inventory process and data input will be reviewed and combined with project team assessment based on communications with contractor concerning program integrity related to these features.
- *Success Criteria.* The contractor usability will be considered successful if (1) the contractor's satisfaction rating average achieves 3 or higher, and interviews indicate a positive attitude in use of the system; and (2) all identified data input problems have been resolved by completion of the implementation phase.

### 3.2.7 Usability – facility manager (qualitative)

- *Definition.* Level of satisfaction among the installation facility managers regarding ease of implementing the new features of the Enhanced ROOFER system.
- *Purpose.* The PO will provide a measure of satisfaction that the installation personnel have in using the enhanced functionality of the ROOFER system, particularly the generation of roof repair and replacement requirements that include energy and sustainability technologies.
- *Metric.* Degree of satisfaction on a five point scale from high (5) to low (1).
- *Data.* User satisfaction data will be collected during informal interviews with the facility managers and system users. Information will be collected by the project team during the Project Work Plan Development phase to assess the integrity of the application related to acceptable program processing times and error-free execution of all new features.
- *Analytical Methodology.* Responses to informal interviews on satisfaction with system use, manipulation, and updating of data, and generation of repair and replacement analyses reports will be reviewed and combined with project team assessment of program integrity.
- *Success Criteria.* The Enhanced ROOFER features will be considered successful if the user satisfaction rating average is 3 or higher, and interviews indicate a positive attitude in the system's ease of use.

### 3.2.8 User satisfaction (qualitative)

- *Definition.* Level of user satisfaction among the installation's facility managers with the generated output and results related to energy assessment and COA analyses functions of the ROOFER program.
- *Purpose.* The PO will provide a measure of satisfaction users have in the enhanced functionality of ROOFER and its ability to help them achieve installation energy and sustainability goals.
- *Metric.* Degree of satisfaction on a five-point scale from high (5) to low (1).
- *Data.* User satisfaction data will be collected during informal interviews with the facility managers and system users.
- *Analytical Methodology.* Responses to informal interviews on satisfaction with system value related to developing roofing projects with energy and sustainable technologies.
- *Success Criteria.* Enhanced ROOFER's features will be considered successful if the user satisfaction rating average is 3 or higher, and interviews indicate a positive attitude and confidence in both the system product and system integrity.



## **4. FACILITY/SITE DESCRIPTION**

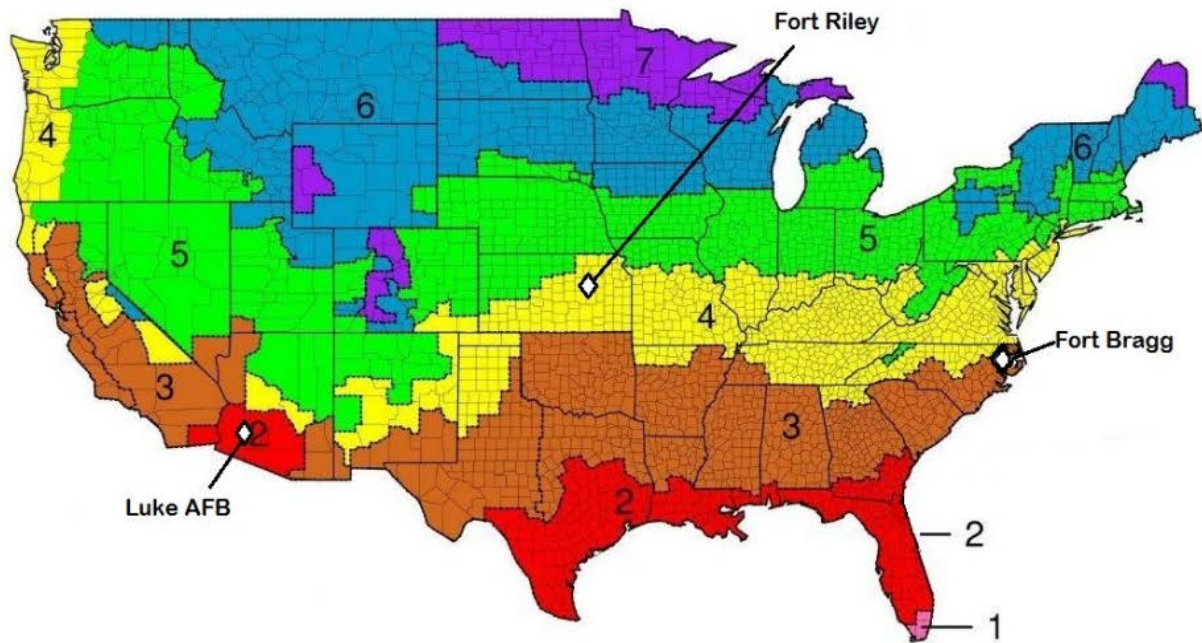
The initial intent of the project team was to demonstrate the Enhanced ROOFER program at three installations, one each at an Army, Navy, and Air Force installation. By demonstrating at three different military branches, the project team sought to engage decision makers responsible for implementing roof management at the individual service's headquarters during the entire process. The project team would also have the benefit of overseeing the various requirements and processes that impact successful implementation for each service.

### **4.1 FACILITY/SITE SELECTION CRITERIA**

A typical military installation has hundreds of buildings and millions of square feet of roofing assets to manage. With these large roofing inventories, military installations also have the need for effective roof asset management. And, because energy and sustainability technologies related to roofing have applications in all climates and geographical locations, all DoD installations can benefit from the Enhanced ROOFER COA analyses—regardless of mission, facility type, and geographical location. However, with cool roofing technology being a required consideration for roofing projects in Climate Zones 1, 2, and 3 (Figure 23), the project team decided to select two installations within these zones. It should also be noted that PV efficiencies are typically better in these regions, as compared to more northern continental United States (CONUS) locations. To help ensure successful demonstrations, the project team agreed that the selected sites should have a public works organization that is dedicated to formalized facility asset management. Upper management should also be enthusiastically committed to implementing sustainable energy technologies as part of the installation's roofing rehabilitation program.

To thoroughly evaluate all aspects of the new features of the Enhanced ROOFER system, it was deemed important to conduct the demonstrations at sites that are currently using ROOFER. This approach allowed the team to evaluate the database import and conversion subroutines, which are crucial for ensuring backward compatibility of the software with existing databases. Fort Riley, Kansas, was the perfect choice to meet all those needs. Over the past 20 years, Fort Riley (located in Climate Zone 4) has managed the repair and replacement of its roofs by using the ROOFER system. Throughout that time, ROOFER inspections have been conducted regularly on their nonfamily housing buildings. Based on these condition assessments and using the ROOFER management reports, they have developed their roof replacement program and long-term budget requirements. However, unlike many installations, they have also utilized ROOFER to develop repair projects, thereby extending roof service life.

With Fort Riley located in Climate Zone 4, the team relied on AFCEC and Naval Facilities Energy Command (NAVFACENCOM) technical representatives to each identify and recruit a candidate installation that met the management requirements and was located in Climate Zone 1, 2, or 3 (Figure 23). Naval Air Station (NAS) Jacksonville, Florida, and Luke AFB, Arizona, were selected by their service's technical representatives. Both were chosen based on their recently expressed interest in implementing ROOFER.



**Figure 23. International Energy Conservation Code (IECC) climate zone map with three demonstration sites indicated (ICC 2012).**

## **4.2 FACILITY/SITE LOCATION AND OPERATIONS**

Like other major DoD installations, each of the three demonstration sites has several hundred buildings and at least a million square feet of roofing area to manage. The facilities house a variety of functions including administration, operations, maintenance, supply, and community support. Both low-slope roofs with bituminous and single-ply membrane systems and steep roofs having asphalt shingles or metal panels are the most common roofing system used. Each of these systems can be inspected and evaluated using the ROOFER system.

### **4.2.1 Fort Riley**

Fort Riley is an Army division-level training installation located in northeast Kansas, just west of the city of Manhattan, and it has facilities and infrastructure to support 18,000 soldiers and 7,000 civilian workers. The Directorate of Public Works (DPW) at Fort Riley currently manages more than 400 buildings totaling 4.8 million square feet of roofing by using the ROOFER SMS. The ROOFER program is maintained within the DPW Engineering Division, which is responsible for developing roof repair and replacement projects. Programming and budgeting information is reported to the DPW Business Operations Division.

#### **4.2.2 Fort Bragg**

Fort Bragg was selected in light of the inability of the team to gain approval to visit NAS Jacksonville. Fort Bragg is the largest military installation in the world (by population), with over 50,000 active duty personnel and is located in North Carolina. Given Fort Bragg's coastal climate and need for roof inspections following Hurricane Matthew in October 2016, the project team, in cooperation with ESTCP and Fort Bragg leadership, visited the installation to conduct Enhanced ROOFER assessments.

#### **4.2.3 Luke AFB**

Luke AFB is near Phoenix in the city of Glendale, Arizona. The installation is a training site for pilots and maintenance crews. Each year, more than 300 active-duty, Guard and Reserve pilots, and more than 550 maintenance crew chiefs are trained. The 56<sup>th</sup> Civil Engineering Squadron is responsible for managing the roofs on approximately 400 buildings on the base. The squadron's Operation Engineering Section is responsible for developing the long-range roof replacement program. As projects are identified, the Engineering Section determines the requirements for individual projects and then executes the projects.

### **4.3 FACILITY/SITE CONDITIONS**

ROOFER assessments were performed by seasoned roof inspectors (private contractor employees) at the installations. The primary concerns were physical security and accessibility to the installation, buildings, and rooftops while performing the surveys. ROOFER assessments performed by contractors required a significant level of coordination between the contractor, facility managers, and security officers, particularly at the outset though such challenges aren't unique to Enhanced ROOFER assessments.

Appendix A of the current ERDC-CERL ROOFER implementation IDIQ (indefinite delivery, indefinite quantity) includes the Safety Plan for Roofing Assessments, which was provided as part of the individual installation contracts. The project team worked with the installation and the contractor to set up an emergency plan prior to commencing field work. The plan addresses appropriate procedures to be followed in case accidents occur.

## 5. TEST DESIGN

### 5.1 DEMONSTRATION QUESTION

For existing buildings, the most practical time to implement energy efficiency measures and new technologies such as increased levels of roof insulation, cool roof systems, vegetative roofing, and PV systems is during a roofing repair/replacement project. Implementation of the Enhanced ROOFER prototype at three sites seeks to demonstrate that a decision to incorporate these measures into an existing roof system can be evaluated efficiently as part of the normal process of performing roof asset management. To achieve this, a ROOFER interface to existing web tools is developed to enable facility managers to evaluate projected energy savings and costs for each alternative.

### 5.2 CONCEPTUAL TEST DESIGN

#### 5.2.1 Hypothesis

ROOFER currently is limited in its capability to analyze, obtain, and consider energy data. However, by enhancing ROOFER with energy performance analysis capabilities, building managers can realize lower life-cycle costs along with improved roof repair or replace recommendations. Considering multiple COA recommendations and taking advantage of optimized results will aid in this effort.

#### 5.2.2 Variables

- Independent variables are roof property inputs into ROOFER that have a direct effect on roof characteristics, including but not limited to solar reflectance index (SRI), R-value for insulation, materials, roof age, etc.
- Dependent variables include energy use and greenhouse gas emissions, which are outputs of the web application calculators. The COAs generated in both the enhanced version of ROOFER and the baseline version of ROOFER serve as dependent variables.
- Controlled variables in this study include variables that do not change in ROOFER and remain constant by the user. Controlled variables include the ROOFER inventory, which includes roof types, condition of current roofs, location, and weather.

#### 5.2.3 Test Design

To demonstrate the ROOFER energy performance assessment and COA capability, demonstrations were conducted at the three sites (see sections 4.1 and 4.2). Once implementations are completed and the inventory and inspection databases have been established, the installation facility managers, along with the project team participation, will perform the automated ROOFER COA analyses. The users will execute the Roof Section Analyses Reports for individual buildings and accompanying summary reports for their entire databases. As with the original program, the reports will provide optimal strategies for repairing or replacing individual building roofs (see left side of report shown in Figure 10). In addition,

these reports will provide expanded COA recommendations based on an energy performance evaluation through the implemented calculators. Enhanced ROOFER will run a simulation and perform a life-cycle cost analysis according to the inputs put in by the user. Each alternative solution desired will be simulated individually and the life-cycle cost of each can then be compared, along with their respective COA. Once the alternative solutions are derived, facility managers will then compare these solutions to the baseline case, which is to replace the roof in-kind. Users will determine the return on investment for individual projects on a building-by-building basis, with a rollup of data for each of the three demonstration sites.

#### 5.2.4 Test phases

At each of the three sites, the project team will work with the users to select individual roofs to be considered for vegetative roofing systems or roof mounted PV systems. ROOFER will generate the energy and sustainability benefits for these options as typically generated by the GREC and PVWatts tools.

Table 2 illustrates how the results from the conceptual test design will be used to assess the improvements that result from Enhanced ROOFER. For each of the quantitative metrics, the capital values for both the baseline and improved alternatives were calculated. The life-cycle costs for each COA alternative will then be projected, and the results tabulated for the each roof. In this comparative analysis, the roof in its current state during the time of the analysis serves as the baseline case. In the analysis, a recommendation to repair or replace a roof using the current roof type will be indicated by the note “repair or replace roof in kind.” The roof alternative is selected by the user, and a simulation is run for each desired roof COA alternative. Table 2 is a fictitious example that illustrates the process of comparing all the COAs generated to replace two different roofs. Column headings are explained below:

- **ROOF DATA** columns show data characterizing the particular roof being analyzed. Note that more data is included in the analysis than is shown in this example.
- **REPLACE COA ALTERNATIVES** section of table – The “Baseline COA” column illustrates the baseline case and the COA to replace the roof in-kind.
- **REPLACE COA ALTERNATIVES** section of table – The “Enhanced ROOFER COA Alternatives (1–3)” illustrates three COA alternatives to replace the current roof.
- **Performance Objective Analysis** Column – This column focuses on the performance objectives of the work and the success criteria outlined to validate the resulting COA recommendations.

In this example, a facility manager needs to replace a roof. The manager is interested in three types of alternatives: to replace the roof in-kind, replace using a cool roof and lastly to simply upgrade the insulation. The EPA provides estimate values of the capital investment for the alternative COAs selected. In this case, cool roofs are estimated to run just under \$5/sf and about \$5.60/sf for insulation. Of course these values depend heavily on location, methodology, etc.; these are estimated values for general cases. Operation and Maintenance (O&M) costs, repair costs, etc. are considered in the life cycle analysis and are estimated in the table below under the main column *REPLACE COA ALTERNATIVES*.

Three separate analyses were ran using the improved built-in analysis capabilities in Enhanced ROOFER. The results in Table 2 show a life-cycle cost that can be expected over the life of the roof, given the technology type selected. The results shown in the table are to represent the life-cycle cost estimations if these COA alternatives were implemented, which were replace in-kind, replace using cool roof or replace by upgrading insulation.

**Table 2. Comparison of Enhanced ROOFER COA alternatives (illustration only).**

ROOF DATA			REPLACE COA ALTERNATIVES				Performance Objective Analysis–Success Criteria
Building / Roof Section	Roof Size (sf)	Roof Type	Baseline COA	Enhanced ROOFER COA Alternatives (1–3)			
			In-Kind	Alt 1: In-Kind (improved)	Alt 2: Cool Roof	Alt 3: Upgrade Insulation	
1040 Vehicle Maintenance Shop	25,000	Built-up Roof (BUR)	\$750,000	\$710,000	\$270,000	\$320,000	Alt 1: 5.3% Alt 2: 64% Alt 3: 57.3%
2090 Life Science Test Facility Sec BB	12,000	Metal panel	\$250,000	\$200,000	\$120,000	\$75,000	Alt 1) 20% Alt 2) 52% Alt 3) 70%

**Note:** Numbers are for illustration only, and do not represent actual results.

The Table 2 example shows that two performance objectives from the quantitative section in Table 1 are met—*increase number of roof assessment alternatives* and *reduction in cost to develop COA*. The first objective is confirmed by illustrating that Enhanced ROOFER has successfully provided three COA alternatives, realized through the output data seen under the section *Enhanced ROOFER COA alternatives (1-3)*. Although Enhanced ROOFER is capable of providing up to five alternatives, only three were selected in this example. The second performance objective, *reduction in cost to develop COA*, is confirmed by illustrating a reduction in cost of 15% or more for each of COA alternatives 1, 2, and 3. All the results in the last column, *Performance Objective Analysis-Success Criteria* ended up meeting the success criteria for the second performance objective except for alternative 1 for the first example, the first row. This result tells the user that alternative 1 is not an economic alternative (based on the criteria set), while the other alternatives are.

### 5.3 BASELINE CHARACTERIZATION

The project team used the accepted energy calculation models on each current roof design to establish the baseline energy use. The phenomenon for roof energy performance is well understood and existing models can be used to accurately calculate the energy performance of the existing roof design. The models are already well accepted and understood, and this project is not testing the models (thereby requiring measurement to validate). Rather, the intent of this project is to validate the deployment of the models as an analysis tool. As such any comparisons

between current and expected designs and the resulting change in energy performance can be reasonably calculated by the model(s).

## **5.4 DESIGN AND LAYOUT OF SYSTEM COMPONENTS**

The enhanced version of ROOFER SMS will incorporate data elements to capture the energy supply rates for each location, the energy supply type (electricity, natural gas, etc.) for each building, and the mechanical system information needed to calculate the energy performance characteristics of each roof. ROOFER will integrate with the energy models using a service-based architecture (the work plan calls for modifications to the Cool Roof Calculator and the Steep Slope Calculator to act as a service) to provide the existing roof inventory data, and these data elements, and receive results back from the energy models. ROOFER will submit and retrieve these model results in the background as part of the interactive process of performing a roof maintenance and repair (M&R) analysis; the result of which is a formal recommendation of repair actions to take or whole roof replacement. In the case where roof replacement is recommended, ROOFER's cost calculations will be updated to incorporate the various energy-saving alternatives and their related costs as calculated by the energy models and make a suitable alternative recommendation.

## **5.5 OPERATIONAL TESTING**

To validate the usability of the new program features, obtain user buy-in to the process, and provide appropriate training, it will be necessary to have uninterrupted working sessions of several hours in duration with the "ROOFER manager" over the course of a week. To ensure success, these activities, the level of required participation, and its importance will be discussed with upper management. Schedules will be established early, and periods of heavy workload (i.e., end of fiscal year) will be avoided. No travel by installation personnel will be required.

## **5.6 SAMPLING PROTOCOL**

Approximately 320,000 square feet of roof area at each installation was inspected and input into Enhanced ROOFER. Roof characteristics considered for selection included but were not limited to: roof type, roof category, physical access and roof material. The roof types inspected at each installation was judiciously selected so as to best test the functionality of Enhanced ROOFER.

## **5.7 EQUIPMENT CALIBRATION**

This section is not applicable to this test as no equipment is being deployed, nor are measurements requiring calibrated equipment.

## **6. COST ASSESSMENT**

Enhanced ROOFER requires many additional inputs be made to an already input-intensive roof management program. The types of inputs required are often unfamiliar to roof inspectors, as evidenced by discussion with experienced roof inspectors during the project's demonstration. Because most roof inspections in the DoD are performed via contract, an inspector's unfamiliarity with the additional data inputs poses a cost risk in addition to a performance risk for such contracts. The research team estimates that the extra time needed to gather necessary energy-related information constitutes a 35% increase in roof inspection time. This significant time increase would further strain already constrained preventive maintenance budgets and may result in fewer roofs being inspected if adopted.



## **7. PERFORMANCE ASSESSMENT AND IMPLEMENTATION ISSUES**

### **7.1 RELIANCE ON THIRD-PARTY ENERGY CALCULATORS**

An implicit assumption was made at the onset of this project that the third-party calculators used were static in their development. Throughout the execution time frame of this project, multiple third-party energy calculators were revised, both in terms of their web layout and their coding. In the development of a system which is reliant upon static input, this dynamic state was very challenging to the software team. Version issues as well as application program interface changes plagued the project. To mitigate this issue to an extent, ERDC-CERL requested stand-alone versions of the calculators, which were then installed on local servers.

### **7.2 INSTALLATION COOPERATION**

NAS Jacksonville was originally slated to be a demonstration site. When the team was prepared to demonstrate the technology at NAS Jacksonville in August-September 2016, installation personnel disallowed demonstration, citing the time frame requested (end of FY2016). The demonstration had been significantly delayed by the research team due to multiple performance related issues.

### **7.3 CUMBERSOME DATA QUANTITY AND UNFAMILIARITY**

The cumulative amount of inputs to the methodology is cumbersome to the roof inspection process. Existing ROOFER methodology, while robust, requires comparatively more input data than most roof inspection methodologies. Energy-related data, including utility costs, exacerbates an already elongated process.

Numerous Enhanced ROOFER-specific energy inputs are unfamiliar to many roof inspectors. For example, the size of chillers and heating equipment is beyond the scope of most roof inspection contracts. This unfamiliarity with required inputs would undoubtedly present a cost and performance risk to many roof inspection contracts.

#### *Challenges in Methodology*

The fundamental challenge faced by this project, as in many sustainable enhancement projects, is how to measure and optimize sustainability and environmental decisions. A qualitative argument could be made that, of the roof types considered, vegetated roofs are the most environmentally friendly. However, quantitative analysis cannot easily be accomplished to reach a similar recommendation unless consideration is given to CO<sub>2</sub> reduction, heat island effect, and other measures. To consider such measures, a crippling complex algorithm would need to be developed and is beyond the scope of this project. Optimization of yearly costs (continuously accrued and amortized) was chosen as the only factor which could be combined with a robust condition assessment methodology.

The methodology and algorithms employed in this project require further refinement to provide maximum utility to roof managers. In many cases, the methodology yielded a recommended

replacement with a more energy-efficient roof well before a replacement was warranted by service-life expiration or condition issues. In a funding-constrained environment, such recommendations are difficult to defend politically and do not take into account typical DoD funding arrangements.

#### *Rack-Mounted Photovoltaic Panels are not Roof Types*

The methodology employed considers both the overall costs and condition state of the roof. Rack-mounted PV panels have no wear surface in terms of waterproofing and therefore, they cannot be assessed in terms of roof condition, although their mounting does slightly degrade the condition rating of the roof upon which they are set due to roofing penetrations required in mounting the panels.

#### *Vegetated Roofs are Cost Prohibitive*

When evaluating roof selection to optimize for lowest life-cycle cost (to include construction, maintenance, and operating costs), vegetated roofs are not selected by the model for any of the demonstration roofs. The higher initial construction costs are found to be cost prohibitive by the model unless offset by providing a value for CO<sub>2</sub> reduction, as discussed under the above section, Challenges in Methodology.

## **8. RECOMMENDATIONS AND PATH FORWARD**

In the vast majority of cases at all demonstration sites, the analysis concluded that replacement of the in-place roof with a cool roof to be the best COA. Since the specific properties of the roof had little impact on identifying different COAs, the use of an Enhanced ROOFER module that incorporates potential energy cost savings is not considered necessary to support this facility management decision. The current ROOFER system can still be used to determine when a roof needs intermediate repairs or replacement based on its condition, but the development of an enhanced ROOFER capability is not necessary to determine the type of roof to replace it with.

Instead, the team concluded that a policy to encourage the use of cool roofs would be warranted when replacement is required based on an installation's knowledge of its roofing inventory conditions. Team members reported the findings to the Unified Facilities Criteria (UFC) Roofing working group, led by Headquarters, U.S. Army Corps of Engineers. As a result, the UFC 3-110-03, Roofing with Change 2 (Published 01-01-2017) was altered to allow for use of thermal plastic olefin (TPO) roof types and to encourage the use of cool roofs in general.

This approach and final outcome was approved by the ESTCP panel during the May 2017 ESTCP In-Progress Review meeting.

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