ESTCP
Cost and Performance Report

(EW-200724)

Design, Monitoring, and Validation of a High Performance Sustainable Building

August 2013

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**
4. TITLE AND SUBTITLE **Design, Monitoring, and Validation of a High Performance Sustainable Building**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Security Technology Certification Program (ESTCP),4800 Mark Center Drive, Suite 17D08,Alexandria,VA,22350-3605**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

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

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**52**	

COST & PERFORMANCE REPORT
Project: EW-200724

TABLE OF CONTENTS

Page

This page was intentionally left blank.

LIST OF FIGURES

Page

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

AEWRS	Army Energy and Water Reporting System
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BLCC	Building Life Cycle Cost
BTU	British Thermal Unit
CERL	Construction Engineering Research Laboratory
CESS	Community Emergency Services Station
CFR	Code of Federal Regulations
CO_2	carbon dioxide
COS	Centers of Standardization
DoD	U.S. DUSEPArtment of Defense
DOE	U.S. DUSEPArtment of Energy
EAc	Energy and Atmosphere credit (LEED)
eGRID	Emissions & Generation Resource Integrated Database
EMCS	Engineering Management Control System
USEPACT	Energy Policy Act
EQc	Indoor Environmental Quality Credit
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EU	energy use
EUI	energy use intensity
FEMP	Federal Energy Management Program
FSC	Forest Stewardship Council
FY	fiscal year
GHG	greenhouse gas
GSA	General Services Administration
GSHP	ground source heat pump
HVAC	Heating, Ventilation, and Air Conditioning
IEQ	Indoor Environmental Quality
IESNA	Illuminating Engineering Society of North America
iiSBE	International Initiative for a Sustainable Built Environment
IMCOM	Installation Management Command
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
kBTU	thousand BTU
kW or kWh	kilowatt or kilowatt hour

LCCA	Life Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
MBTU	one million British Thermal Units
MRc	Materials and Resources Credit
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
O&M	operating and maintenance
PNNL	Pacific Northwest National Laboratory
RCRA	Resource Conservation and Recovery Act
SERC	Smithsonian Environmental Research Center
SIOH	supervision, inspection, overhead
SIR	savings to investment ratio
sq ft	square feet
SVRC	SERC Virginia/Carolina
USACE	U.S. Army Corps of Engineers
USUSEPA	U.S. Environmental Protection Agency
USGBC	U.S. Green Building Council
WBDG	Whole Building Design Guide
WEc	Water Efficiency Credit (LEED)
WUI	water use intensity

ACKNOWLEDGEMENTS

This project was funded by the Environmental Security Technology Certification Program (ESTCP). Fort Bragg provided impressive leadership and commitment through their willingness to host this demonstration through the design, construction, and performance measurement. Ray Barbeau's commitment to the completion of this project was greatly appreciated by the ESTCP project team. The leadership of Manette Messenger through her role at Installation Management Command Southeast (IMCOM-SE) is the reason this project came to life and was a success. She facilitated the development of the team and the successful technology transfer to the U.S. Army Corps of Engineers (USACE).

This page left blank intentionally.

EXECUTIVE SUMMARY

The U.S. Department of Defense (DoD) is committed to maximizing energy and water conservation, including efforts to design, construct, operate and maintain DoD facilities to achieve optimum performance. To help DoD meet building efficiency and conservation challenges, Army Installation Management Command (IMCOM) and the Pacific Northwest National Laboratory led the ESTCP Fort Bragg Community Emergency Services Station (CESS) project to demonstrate and evaluate implementation of the whole building design process. The project was conducted in collaboration with U.S. Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL), Southface Energy Institute, and CH2M HILL.

Figure 1. Fort Bragg CESS building.

The objective of this project was to demonstrate, through measured performance, that the whole building design process using off-the-shelf building materials and technologies would perform better than a similar, traditionally designed building without increasing costs. This report documents the application of whole building design process for the design and construction of the CESS high-performance building, and compares the annual energy use, water use, and indoor environmental quality of the CESS with the Longstreet Fire Station, a similar facility built several years earlier at Fort Bragg, North Carolina.

The CESS achieved a key design objective by receiving U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Platinum certification on March 6, 2012. Providing technical information on innovative design strategies and technologies to the design contractor before the design charrette allowed for those technologies to be considered in detail, rather than discussed superficially at the design charrette. The ESTCP project team successfully transferred the whole building design strategies used in this project to USACE's Centers of Standardization (COS) as documented in the Engineering and Construction Bulletin 2012-7. The COS has implemented whole building design strategies to redesign the five building types most often constructed by the Army. In addition to the integrated design techniques used in charrettes and design reviews for new Army buildings, the information gained through engaging in the whole building design process for CESS was formalized through the development of 19 individual "TechNotes," which provide technical and financial information to support design team decision-making. USACE subsequently adopted the concept of TechNotes as part of their toolset, and is developing additional design-related TechNotes and operations and maintenance focused TechNotes. The strategy and techniques for whole building design have been shared with USACE and other design leaders within DoD through workshops and are available through a knowledge portal to inform future designs within DoD. Additional technology transfer has occurred with individual design professionals, design teams, and the broader Federal buildings industry through specific requests for information and public presentations regarding the project.

The performance measurement objectives demonstrate that the whole building design process used for CESS and transferred to the COS can result in lower energy and water use for new DoD buildings. Performance monitoring shows that CESS used less energy/square feet (sq ft) (21% less) than its matched pair (Longstreet Fire Station) and has had fewer maintenance and operations calls. CESS used >50% less energy when compared to the national average energy use for public order and safety buildings; 53 thousand BTU (kBTU)/square foot (sq ft) compared to 110.6 kBTU/sq ft. Significant water savings were achieved through harvesting rainwater, resulting in a 100% reduction in potable water used for sewage conveyance and significant savings in potable water used for vehicle washing.

Construction costs were slightly higher (~5%) than originally estimated and programmed. Site personnel concluded that the increased costs were not a function of building design, but rather reflected the economic situation in the region at the time of construction—construction costs increased in North Carolina between 6% to 10% during each year of the project.

Lessons learned include the need to contract with design and construction firms that have prior experience in whole building, sustainable design and, preferably, with construction of LEED–certified buildings. The ESTCP project team believes that more experienced contractors could have benefited the project overall because they would have experience implementing whole building design strategies, such as downsized equipment, and would likely provide better quality in the overall building construction (e.g., plumbing the building correctly).

1.0 INTRODUCTION

The U.S. DUSEPArtment of Defense (DoD) is committed to maximizing energy and water conservation, including efforts to design, construct, operate and maintain DoD facilities to achieve optimum performance (DoD Directive 4170.11, 2009). The U. S. Army Installation Management Command (IMCOM) and the Pacific Northwest National Laboratory (PNNL) led the Environmental Security Technology Certification Program (ESTCP) Fort Bragg Community Emergency Services Station (CESS) project to demonstrate and evaluate implementation of the whole building design process. The project was conducted in collaboration with U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL), Southface Energy Institute, and CH2M HILL.

Whole building design optimizes for multiple benefits, such as cost, quality of life, future flexibility, resource efficiency, environmental impact, and occupant productivity and health. It consists of an interactive design approach and an integrated team process that includes all stakeholders, as shown in Figure 2. In contrast, traditional design approaches usually optimize individual building components rather than the whole building. This typically happens because design specialists are focused on the benefits of design and specifications for their individual areas of expertise and may not be afforded the opportunity to work with others to integrate design components. The overarching objective of this project is to demonstrate that applying whole building design technology utilizing off-the-shelf building materials and components achieves higher facility performance than traditional design approaches.

Figure 2. Whole building design team.

1.1 BACKGROUND

In the United States, the buildings sector accounted for about 41% of primary energy consumption in 2010, with 75% of the energy demand supplied by fossil fuels, (U.S. DUSEPArtment of Energy [DOE], 2012). Residential and commercial buildings consume more than 70% of electricity produced in the nation and 12% of our water, and affect ecological services and habitat on over 140 million acres of land (Intergovernmental Panel on Climate Change [IPCC], 2006; Climate Trust). In 2010, buildings accounted for 54% of sulfur dioxide emissions, 17% of nitrous oxide emissions, and 40% of carbon dioxide (CO_2) emissions (DOE, 2012). The impact to DoD is rising costs of operation. DoD occupies over 300,000 buildings and structures worth $600 billion (ESTCP, 2013a) and spends close to $4 billion every year on facility energy consumption. Future costs are unpredictable and potentially could rise rapidly over the next decade.

Using whole building design approaches, a 20% decrease in operational costs was achieved in a set of Federal buildings (Fowler et al., 2010). Research has shown that sustainably designed Federal buildings have lower costs for water utilities, energy utilities, general maintenance, grounds maintenance, waste and recycling, and janitorial service. Additional benefits include increased comfort, productivity, and health of building occupants; reduced water and energy use; reduced air and water pollution; increased mission capability to operate in water-short areas; improved storm water quality and wildlife habitat; and reduced solid waste decreasing potential groundwater pollution.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration project is to document the application of whole building design using off-the-shelf building materials, systems, and components to achieve higher facility performance without significantly increasing costs. Whole building design principles were applied to the design, construction, and operation of a Fort Bragg emergency services building designed and built between fiscal year (FY) 2008 and 2011. The measured performance of the building (CESS) was compared to a similar building with similar occupancy (Longstreet). The buildings were monitored and compared for a period of one year to determine and document the differences between the buildings in life-cycle cost, energy and water use, and occupant comfort.

1.3 REGULATORY DRIVERS

The following regulatory drivers were in force at the initiation of this project in 2008:

- Executive Order 13423, Strengthening Federal Environmental, Energy, and Transportation Management, which requires federal agencies to develop and implement sustainable practices for high performance construction, lease, operation, and maintenance of buildings;
- Resource Conservation and Recovery Act (RCRA) (Section 6002), which requires waste reduction, and the use of recycled content and bio-based products and construction materials;
- Energy Policy Act of 2005, which requires minimum energy performance;
- 10 Code of Federal Regulations (CFR) Part 435, which mandates that low-rise residential federal buildings achieve energy performance at least 30 % below the levels of the established baseline, if life cycle cost-effective;

- The 2002 Farm Bill, Section 9002, requiring federal agencies to purchase bio-based products;
- The Clean Water Act (40 CFR 122.26) and implementing state regulations requiring control of stormwater quantity and quality;
- American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) and American Society of Testing and Materials standards that are cited in national building and energy codes; and
- Army, Navy, and Air Force policies on sustainable design of facilities and life cycle costing of facilities.

At project initiation, the goals of this demonstration were well beyond the regulatory requirements. Since then, the regulatory requirements have changed, and the buildings industry has responded. In 2009, the Army issued DoD 4170.11, which specifies ASHRAE Standard 189.1 (ASHRAE, 2011) subtitled "Standard for the Design of High-Performance, Green Buildings Except Low-Rise Residential Buildings." This standard sets minimum requirements for high-performance buildings and was designed to complement other voluntary rating systems.

This page left blank intentionally.

2.0 TECHNOLOGY DESCRIPTION

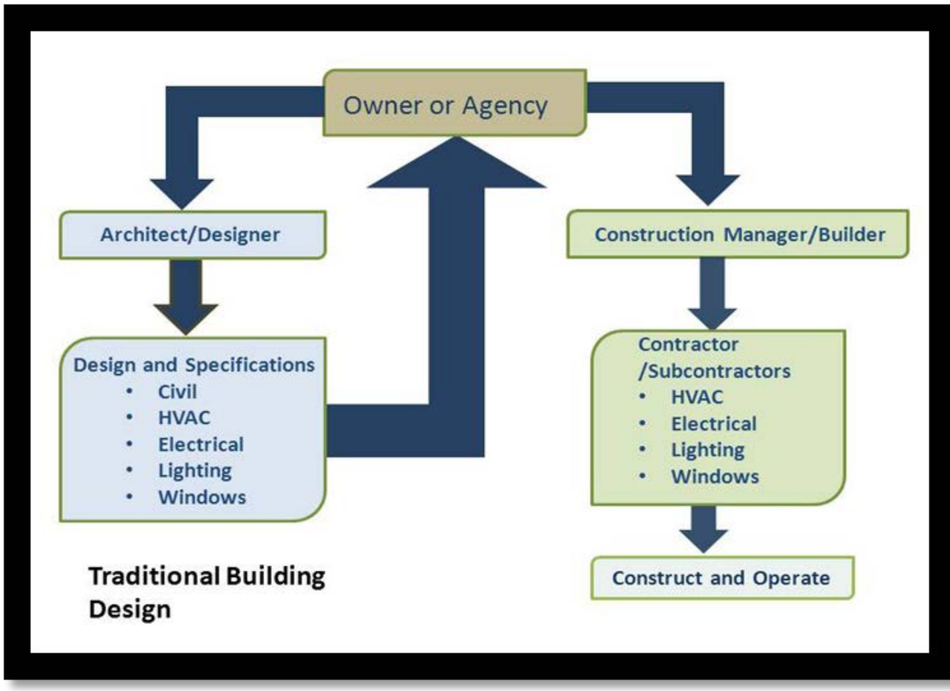
Whole building design uses an integrated design approach that optimizes the interdependencies of building systems and involves a diverse team of stakeholders. According to the Whole Building Design Guide (Whole Building Design Guide [WBDG], 2013a), high-performance buildings are the result of whole building design. The premise of this demonstration project is that buildings designed using whole building design practices can be constructed at equal cost and they will perform better. To the maximum extent feasible, the impact of the design is measured, rather than estimated, by applying whole building performance metrics during a post occupancy evaluation.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The project intent is to evaluate the composite impact of whole building design rather than demonstrating the theory, functionality, and operation of individual building components. To evaluate the composite impact, we measured and monitored the whole building performance for one year and compared the energy use, water use, and maintenance of the CESS high-performance building with the Longstreet Fire Station built in 2003 using a more traditional approach to building design and construction, but still incorporating energy and water efficient design features. The differences between using a whole building design approach versus using a traditional design approach are shown graphically in Figure 3.

Previous DoD case studies of building performance present results in qualitative terms, and were mainly focused on design calculations, not on measured operational performance, though some of them provide summary data on energy performance (Federal Energy Management Program [FEMP], 2013; Matthiessen, 2004; Morris and Matthiessen, 2007; National Renewable Energy Laboratory [NREL], 2013; Torcellini et al., 2006). Whole building performance measurement of 22 General Services Administration (GSA) buildings (Fowler et al., 2010) using a similar post occupancy evaluation methodology showed that on average the sustainably designed buildings GSA buildings performed better than the industry baseline. The study focused solely on building operation and did not include scope to examine the impact of whole building design on the building performance. Evaluation of the design process was identified as a needed next step. This ESTCP demonstration allowed an examination of the whole building design process and resulting whole building performance.

The whole building design technology and individual strategies used in the CESS project were successfully transferred to the U.S. Army Corps of Engineers (USACE)'s Centers of Standardization (COS) as documented in the Engineering and Construction Bulletin 2012-7. The COS implemented whole building design strategies to redesign the five building types most often constructed by the Army (Carpio and Soulek, 2012). The whole building design strategy and techniques have been shared with USACE and other design leaders within DoD through several workshops and have been made available to inform future designs within DoD.



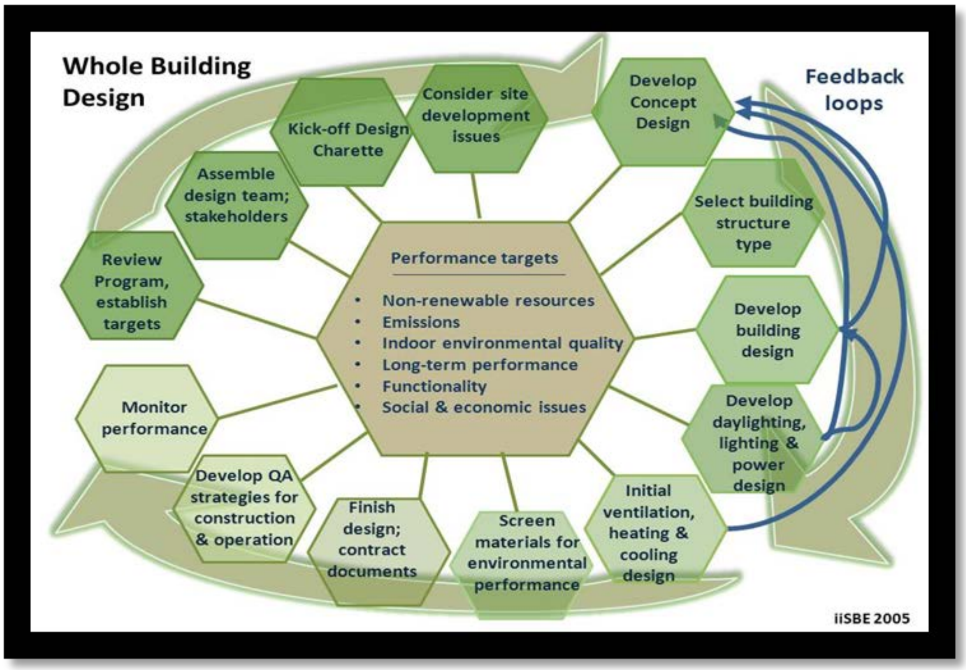


Figure 3. Traditional design process versus whole building design.
(after International Initiative for a Sustainable Built Environment [iiSBE], 2005)

In addition to the integrated design techniques used in design charrettes and design reviews for new Army buildings, the information gained through engaging in the whole building design process for CESS was formalized through the development of 19 individual "TechNotes" (WBDG, 2013b) with USACE. USACE subsequently adopted the concept of TechNotes as part of their toolset, and is developing additional design-related TechNotes and operations and maintenance TechNotes to assist with effective building operations where newer design strategies and technologies are implemented.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

The key advantage of whole building design methods is that specific goals for higher building performance are established and communicated to the design team. For this project, challenging energy goals were set to push the design team to think outside of the typical design strategies. Limitations to this process are a current lack of capacity in the design industry, and the difficulty of scheduling collaborative sessions with all design professionals present. Technologies such as Building Information Modeling start to address the complexity of building design by creating virtual models of buildings that can provide immediate feedback on the consequences of alternative design approaches.

Although public perception of green buildings is that "green costs more," studies indicate that, on average, construction costs associated with green buildings and Leadership in Energy and Environmental Design (LEED) certification are not significantly different compared to non-green buildings (Davis Langdon, 2007; U.S. Green Building Council [USGBC], 2009). Factors affecting costs of building design and construction for high performance buildings include the experience of the design team with whole building design methods; and experience of the construction contractor with the technologies specified in the design. There are many design and construction firms familiar with green, sustainable building techniques/technologies; experience with LEED and sustainable design should be a requirement of the project scope and should be part of the evaluation criteria for choosing the design/construction teams. The Army's low-bid policy resulted in selection of design and construction teams for the Fort Bragg CESS that lacked experience in sustainable design and construction, and that lack of experience affected the timely delivery of CESS as a high-performance building.

The major factors affecting operational cost and performance are the experience of the building operators and maintenance staff; and the behavior of the building occupants. When building systems are integrated, the building operators and occupants need to fully understand the interdependencies of the building systems for the building to operate optimally. The building performance of both the high performance and traditionally designed buildings need to be normalized for the impact of the building occupancy. The building occupants were aware of this study, but were not requested to act differently during the study period. Occupant behavior has an impact on the building performance; for example, how much control they have over building systems, how comfortable they are, and how educated they are regarding building operations can all impact building performance. In the two buildings compared in this demonstration, the occupants engaged in different levels of activity. Longstreet Fire Station is one of the busiest fire stations in the Army, whereas CESS has a relatively low number of calls because it serves a community in an area of recent development. The difference in calls and activity levels is assumed to have impacted resource consumption, especially water use. The combination of scheduled activities along with use-based activities complicated the ability to normalize the resource use to occupancy. Data from a greater number of Army fire stations would be needed to offer useful occupancy-based resource use analysis.

This page left blank intentionally.

3.0 PERFORMANCE OBJECTIVES

Table 1 describes the 14 specific performance objectives tracked for this project. There were two types of objectives—design and measured performance. The six objectives labeled DESIGN apply only to design objectives for CESS—these track the integrated design component of the demonstration. The eight objectives labeled MEASURED refer to measurements and comparisons of the Longstreet Fire Station and CESS. The design and measured performance objectives for energy were set as challenge goals.

Table 1. Performance objectives results.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Objectives–DESIGN				
1. Reduce DESIGN energy consumption (*Energy*)	Modeled energy use as estimated for LEED EAc1	Model energy use of final high performance design and compare it to ASHRAE 90.1-2004 theoretical building baseline	50% reduction in BTU/sq ft	Achieved energy savings of 34% and energy cost savings of 35% using the ASHRAE Standard 90.1-2004 Appendix G. Received EAc1 credits.
2. Reduce DESIGN potable water consumption for domestic uses (*Water*)	Modeled potable water use as estimated for LEED WEc3	Model/estimate domestic water use of final high performance design and compare to (USEPACT) 2005 theoretical building baseline	30% reduction in domestic water use per occupant	Achieved 83% reduction in potable water use over ASHRAE baseline building case. Received WEc3 credit.
3. Reduce DESIGN potable water use for vehicle washing (*Process Water*)	Modeled potable water use for vehicle wash as estimated for LEED credit WEc2	Model/estimate vehicle wash water use of high performance design and compare it to estimate for theoretical building baseline	20% reduction in vehicle wash water use	LEED scorecard verifies 100% reduction in process water use and receipt of WEc2 credit.
4. Reduce construction waste during DESIGN and construction phases *(Waste*)	Reduction of construction waste through recycling as documented through LEED MRc2	Provide construction waste recycling documentation	75% of construction waste is recycled	Diverted 55 tons of material from landfill (90.43% recycled) and received LEED credits for MRc2.
Qualitative Objectives–DESIGN				
5. Achieve LEED rating for high performance building *(Whole Building*)	Platinum	LEED documentation	Certification by USGBC as LEED Platinum building	Achieved LEED Platinum certification March 6, 2012.
6. Reduce environmental impact of materials specified in DESIGN	Specify environmentally preferable materials in accordance with LEED credits MRc4, MRc5, MRc6, MRc7, and EQc4	Provide materials use documentation	20% recycled content, 20% regional materials, 2.5% rapidly renewable materials, 50% of wood FSC certified, and low-emitting materials are used	Achieved the criteria for each requirement through design and construction for LEED credits

Table 1. Performance objectives results (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Objectives–MEASURED				
7. Reduce MEASURED facility energy use (*Energy*)	Reduction of building energy use	Energy use of high performance building (CESS) and existing baseline building (Longstreet)	High performance building uses 50% less energy per square foot than existing baseline building	Achieved 21% decrease in energy use/square feet (sq ft) and 33% decrease in energy use/occupant
8. Reduce MEASURED greenhouse gas footprint (*Energy)*	Reduction of building related greenhouse gas footprint	Analyze building energy use and energy sources for greenhouse impact	Operation of a high performance building results in 25% lower carbon emissions compared to the existing building baseline	Did not achieve reduction over existing baseline building. Longstreet uses natural gas for heating/cooling, which significantly lowers the CO_2 equivalents
9. Reduce MEASURED potable water consumption for domestic uses (*Water*)	Reduction of potable water use for domestic uses	Domestic water use and rainwater capture of high performance building and existing baseline building	High performance building uses 30% less water than existing baseline building	Measured >90% reduction in potable water use, but lack of confidence in values due to metering issues
10. Reduce MEASURED potable water use for vehicle washing (*Process Water*)	Reduction of potable water use for vehicle wash	Vehicle wash water use and rainwater capture of high performance building and existing baseline building	High performance building uses 20% less water than existing baseline building	Based on potable water metering data, CESS used 92% less potable water than Longstreet; The CESS building used 23% less total water (potable + rainwater) than Longstreet for vehicle washing.
11. Reduce MEASURED post-occupancy solid waste[(a)] (*Waste*)	Reduction in solid waste	Calculate waste and recycle quantities for high performance building and existing baseline building	High performance building disposes 25% less solid waste per occupant than existing baseline building, and has a 50% ratio of recycled material to waste disposal	Data are available at the Installation-level only. Both buildings are certified through the “Green Boot” program for recycling and waste reduction at Fort Bragg

EAC = Energy and Atmosphere Credit
USEPACT = Energy Policy Act
WEc = Water Efficiency Credit
IEQ = Indoor Environmental Quality
MRc = Materials Resources Credit
EQc = Indoor Environmental Quality Credit
FSC = Forest Stewardship Council
USUSEPA = U.S. Environmental Protection Agency

Table 1. Performance objectives results (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Objectives–MEASURED				
12. Improve MEASURED indoor environmental quality [(b)]	Air quality meets U.S. Environmental Protection Agency (USEPA) standards (indoor environmental quality [IEQ]) and temperature controls	Measure temperature, humidity, for both buildings; test IEQ using testing protocols consistent with the USEPA report "Compendium of Methods for the Determination of Air Pollutants in Indoor Air"	High performance building will have good temperature control and meet USEPA concentration limits for air quality parameters	Temperature control to heating and cooling setpoints was better at the CESS than for Longstreet. CESS met USEPA concentration limits for air quality metrics when construction was complete.
13. Increase MEASURED occupant satisfaction	Interviews with fire chiefs and occupants at each building noted satisfaction on the following - general building - lighting quality - thermal comfort (IEQ)	Information from occupants regarding satisfaction with building design components and function	Occupants indicate satisfaction with building performance and features.	Building occupants of both buildings expressed high levels of satisfaction and pride. Positive feedback for: - Daylighting in common spaces - Lighting control - Cooling and heating control when systems functioned properly Negative feedback for: - CESS flooring materials in one room - insufficient training for maintenance staff on integrated systems for heating, ventilation, and air conditioning (HVAC) units in CESS
14. Decrease Required Maintenance Actions	Number of routine and rUSEPAir maintenance visits	Log for each building indicating the date, and maintenance action	CESS high-performance building requires less maintenance than Longstreet Fire Station	23 maintenance calls were logged for CESS versus 34 calls for Longstreet; of those, 57% of CESS maintenance was for rUSEPAirs, whereas 91% of maintenance calls at Longstreet Fire Station were for rUSEPAirs.

(a) Not evaluated, no methods for quantifying individual building waste contribution.
(b) Not evaluated because sensors not installed/available.

4.0 SITE DESCRIPTION

Fort Bragg, the host installation, was a partner in developing this demonstration project from its inception. The Command and staff were committed to constructing high performance facilities and increasing the sustainability of all installation operations. Fort Bragg is a very large training installation, with a population of 45,000 soldiers and a daytime population of 100,000 people. The military and "city" functions performed at Bragg are similar to those of all military-training installations DoD-wide, no matter their size.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The site for the new CESS was selected for its proximity to a new housing area that it will protect, 10 miles north of the main post (Figure 4). A fire station was selected for this demonstration because of the opportunity to generalize lessons-learned to similar building types (barracks, office buildings, and maintenance facilities). The Longstreet Road Fire Station, which was constructed in 2003, provides the "baseline" building, and serves as the basis for comparisons of building performance. Both buildings operate 24 hours a day, 7 days a week. Table 2 provides information on building parameters and operations for comparison.

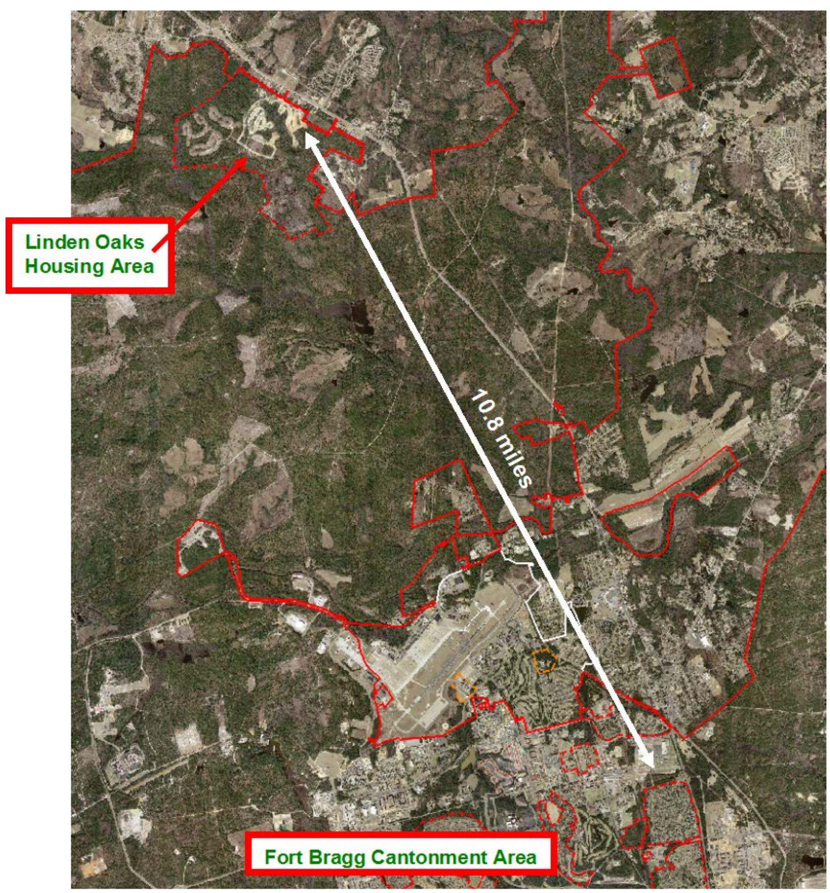


Figure 4. Relative location of the CESS and Longstreet Fire Station at Fort Bragg.

Table 2. Comparison of building characteristics and operating conditions during the monitoring period.

Building Feature	CESS Building	Longstreet Fire Station
Square footage	8295	6125
Number of Occupants	8	5
Heating	Electric/Ground-source heat pump	Natural gas furnace
Cooling	Electric	Electric
Solar Heating	Solar wall	Not applicable
Domestic hot water	Solar water heater	Natural Gas
Rainwater harvest system	Rainwater collected by roof and drains to the 10,000 gallon cistern below grade	Not applicable
Sewage conveyance	Rainwater	Potable water

*Heat pump 5 servicing the vehicle bay has no cooling setpoint, and a heating setpoint of 60

Fort Bragg CESS

The Fort Bragg CESS (Figure 5) is located near the entrance to the Linden Oaks Housing Area and serves as a community facility that residents enter to seek assistance, and that school children tour. Because it is the first building that people see when they enter the housing area, it was designed to have an aesthetic that enhances the neighborhood. The facility was designed for a higher level of occupancy than it is currently experiencing. The building is a 24-hour facility and there are seven dorm rooms for the staff to sleep, a combined kitchen and dayroom, a laundry room, a training/conference room, physical fitness room, and several offices. The vehicle bay contains space for one fire truck, one ambulance, and one police cruiser. The CESS currently houses four firefighters on 24-hour shifts, along with two police and two paramedics on 12-hour shifts, for a total of 8 regular occupants.

Figure 5. Photograph of CESS.

Longstreet Fire Station

The Longstreet Road Fire Station (Figure 6) was occupied in 2003. It is located on Fort Bragg's main post close to the hospital, residential areas, and administrative facilities. It houses Company 3 of the Fort Bragg Fire and Emergency Services DUSEPArtment, which has a first responder and firefighting mission. The building has six dorm rooms, a meeting room, dayroom, kitchen, laundry room, fitness room and offices. The vehicle bay contains room for two fire trucks, with the Chief's vehicle parked outside behind the facility. Longstreet currently has four firefighters working 24-hour shifts and a Deputy Fire Chief working a 12-hour shift most days and spending several nights a week at the station, for a total of 5 regular occupants.

Figure 6. Photograph of Longstreet Road Fire Station.

4.2 FACILITY/SITE CONDITIONS

The two stations, while similar, are not exactly alike in function, size, or layout. The two buildings have different floor plans, but both contain dormitories for sleeping, kitchen facilities, common rooms, and a high bay vehicle facility. The differences required that cost and performance data be normalized by building average population and square footage. Longstreet had a larger number of emergency calls than CESS, but the ESTCP team did not have access to the specific number of calls. Fort Bragg lies within ASHRAE Climate Zone 3A (ASHRAE 169-2006), which is defined as Warm – Humid or Mixed Humid (Baechler et al., 2010). The buildings are approximately 10 miles apart, so climate variation is minimal.

This page left blank intentionally.

5.0 TEST DESIGN

This project was designed to demonstrate two technology components: 1) evaluate the whole building design process; and 2) monitor and compare the differences between a high-performance sustainably designed building with a traditionally designed building.

5.1 CONCEPTUAL TEST DESIGN

The overarching hypothesis of this project is that applying whole building design process to design a sustainable building utilizing off-the-shelf building materials and components achieves higher facility performance than traditional design approaches. The whole building design process was assessed through modeling and calculations used to support the USGBC's LEED rating. The whole building performance of the CESS was assessed by conducting a matched pair analysis of CESS and Longstreet.

Assessment of the success of the whole building design process was based primarily on achieving the LEED criteria and credits for high-performance buildings. Detailed descriptions of the sustainable building strategies implemented on this project and the calculations supporting the achievement of LEED prerequisites and credits for the various categories are included in the final report for this project (ESTCP, 2013b).

After CESS construction was completed, monitoring of whole building performance was conducted by collecting data to compare energy, water use, and IEQ measured for the new CESS building to measurements made for the Longstreet Fire Station using a matched pair analysis (Fowler et al., 2009). In this context a matched pair analysis compares a sustainably designed building with a traditionally designed building of comparable attributes. Basic building and site characteristics data are collected for each building to establish the pairing. The differences in performance between the matched buildings are then used to evaluate the performance.

5.2 BASELINE CHARACTERIZATION

The LEED rating system was used as the baseline for the whole building design objectives. Monitoring data for energy and water use were collected at the Longstreet Fire Station and comprise the baseline dataset for comparison with the CESS monitoring data. The collected data provide basic information about building performance with respect to sustainable design.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Metering equipment was installed at the Longstreet Fire Station in 2010 and in CESS in 2011, and metering data were collected in 2011 by the subcontractor for delivery to PNNL for quality assurance checks, comparative analysis, and summary. Data acquisition systems were set up to transmit and store all data captured by devices and consisted of Campbell CR1000 data loggers (16 channels that can be set to measure up to 16 analog [e.g., 4-20mA, 0-5VDC] inputs or up to 8 thermocouples or some combination, plus 4 pulse counters with ModBus communications); a pulse input multiplexer (AM16/32A) (16-channel pulse input); and cell phone modem. Sensors were calibrated according to manufacturer's instructions. A detailed description of all the metering equipment is provided in the final report (ESTCP, 2013b).

5.4 OPERATIONAL TESTING

The metrics collected include energy, water, maintenance, and IEQ. Performance measurement of the whole building technology was accomplished through the following steps (Figure 7):

1. Identify Matched Pair
   a. identify building(s) of interest for the study
   b. select baseline for comparison to sustainably designed building
2. Collect Performance Data
   a. select building performance metrics that address the research needs and sustainable design goals of the project
   b. establish data collection system that allows for data processing and analysis
   c. gather building characteristics data that will be used to normalize the building performance data
   d. collect data on each performance measurement metric for a minimum of 12 consecutive months
3. Site Visits
   a. identify metering needs
   b. install and calibrate meters
4. Data Analysis
   a. evaluate data for anomalies and revise measurement protocol as needed to manage incoming data
   b. analyze measured performance data against selected baseline(s)
5. Communicate Findings
   a. report economic and environmental impacts of building performance to key stakeholders.

Figure 7. Whole building performance measurement protocol.

Building commissioning was performed during and after design and construction to ensure that building systems performed interactively according to design intent and Fort Bragg's operational needs. Metering data were collected by a Fort Bragg subcontractor. Collection of preliminary datasets for the Longstreet Fire Station was initiated in November 2010. Collection of preliminary datasets for the CESS building was initiated in April 2011, after commissioning was completed and installation and testing of metering systems was completed. The first few months of preliminary data collection were used to test the data collection systems, identify problems with metering equipment and data acquisition, and then to correct identified data, when feasible. After correction of most metering problems and issues, the dataset for comparing and assessing building performance was collected between June 2011 and June 2012.

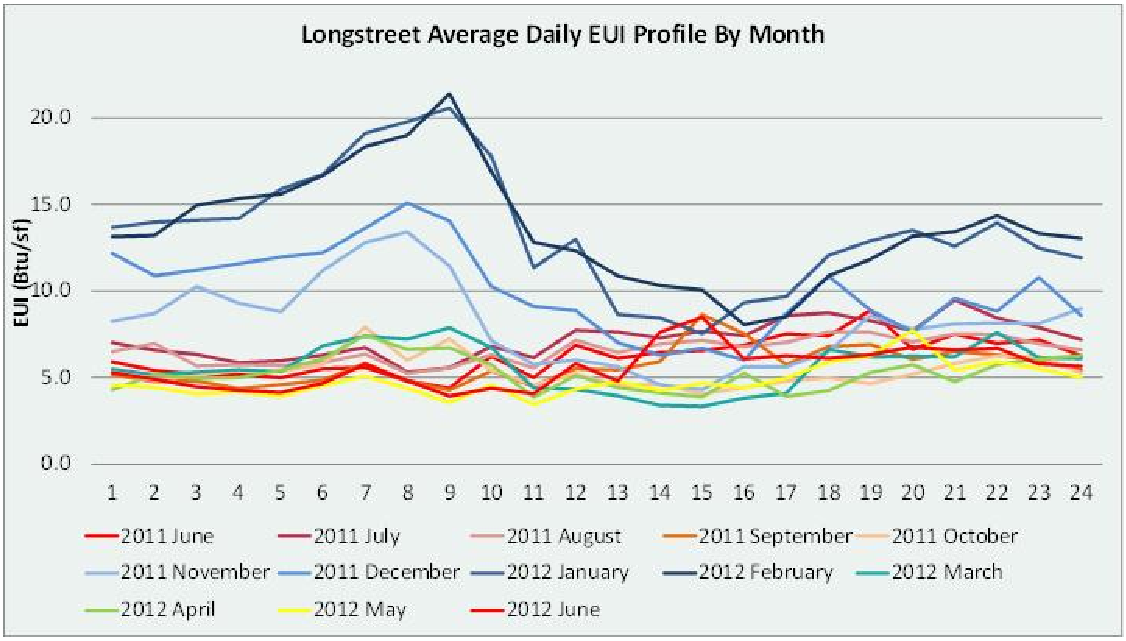
5.5 SAMPLING PROTOCOL

Performance measurement data are useless if metering systems and equipment are not properly calibrated, and if data are not routinely checked and verified for consistency and apparent function. Metering equipment calibration and data quality control were important components of the data collection effort.

Performance data were transmitted to the Fort Bragg Energy Monitoring and Control System (EMCS), compiled by the subcontractor energy management personnel, and then forwarded to the project team for quality assurance checks, comparative analysis, and summary. The first few months of preliminary data collection were used to test the data collection systems, identify problems with metering equipment and data acquisition, and then to correct identified data, when feasible. Quality assurance checks were conducted for each packet of data received. The raw monitoring data was received for the two buildings on a bi-weekly schedule and was of varying quality. Data anomalies were observed, and the metering equipment was checked multiple times. These trouble-shooting efforts aided in resolving most major data issues other than metering of water use at the CESS building and what seem to be anomalous natural gas usage spikes at the Longstreet Fire Station. Procedures for data collection, processing, and analysis are discussed in detail in the final project report (ESTCP, 2013b).

5.6 SAMPLING RESULTS

Considerable data were collected and analyzed for this project. Graphical representation of the data is one mechanism to see trends and visually identify the differences between the buildings. Figure 8 shows the average daily energy use intensity (EUI) (kBTU/sq ft) profile for each building for each month between June 2011 and June 2012. The CESS profile is consistent with increased cooling load raising overall energy use during the summer months. The heating energy use profile of Longstreet is the most obvious difference between the profiles. Figure 9 isolates one summer and one winter month to highlight differences in the EUI daily profile.



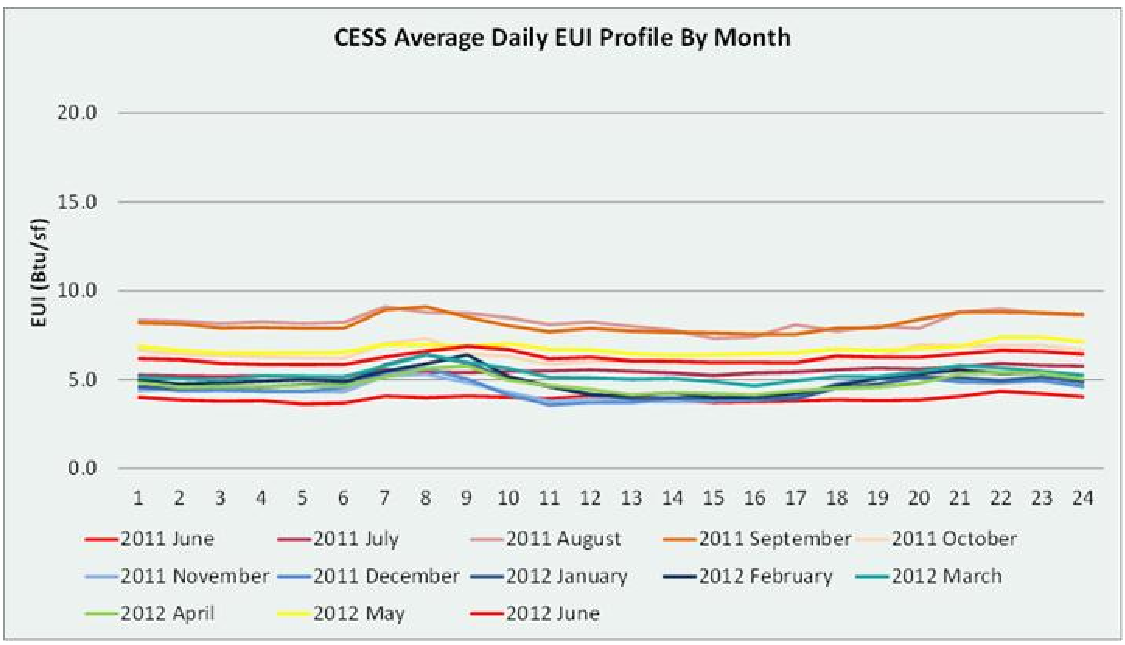
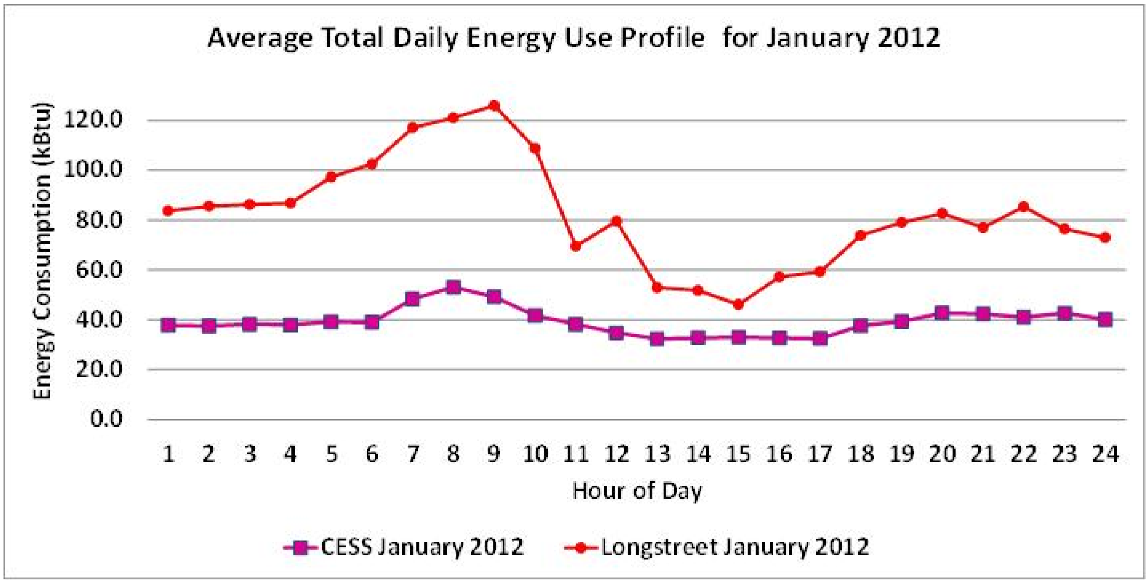


Figure 8. Example of the average daily EUI calculated using daily average values for the monitoring period.



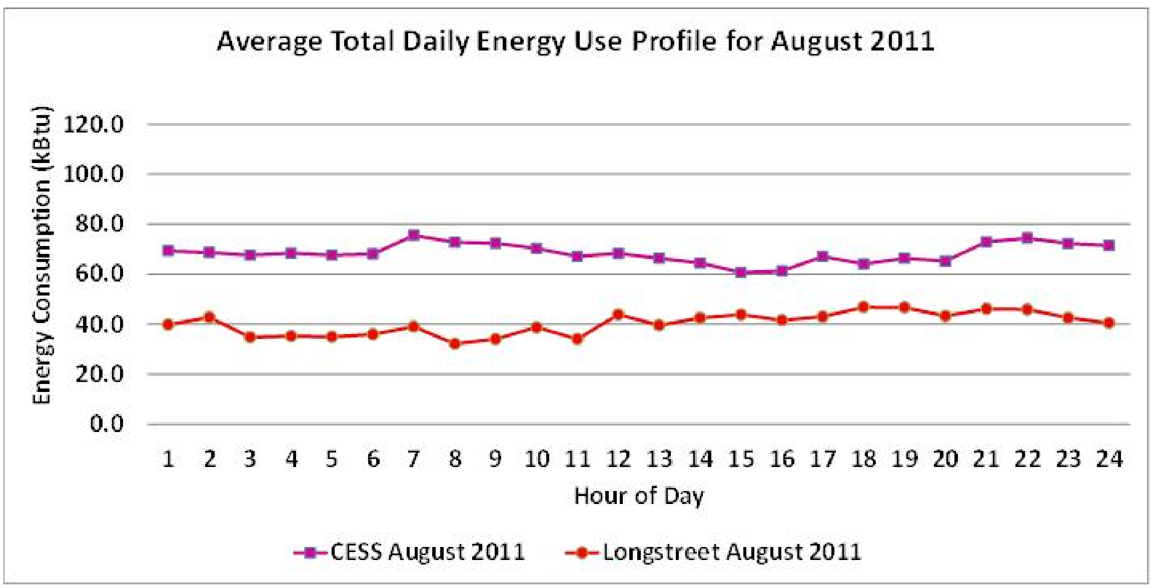


Figure 9. Average total daily energy use for January and August for Longstreet and CESS buildings.

This page left blank intentionally.

6.0 PERFORMANCE ASSESSMENT

Results of the demonstration project are designed to evaluate the two sUSEPArate key technology components: the whole building design process including identification and analysis of design objectives for all the disciplines considered in whole building design; and evaluation of the performance of CESS compared to a building of similar size and function (Longstreet) including comparisons of energy and water use, occupant comfort and indoor temperatures, and required maintenance.

The CESS demonstration project resulted in becoming a LEED Platinum Certified building on March 6, 2012. Assessment of the whole building design process and analysis of monitoring data for building performance shows that the original criteria for 10 of the 14 performance objectives were successfully met or exceeded. The energy objectives were intentionally set high to get the design team to think outside of the typical technology options. The goal of achieving a 50% reduction in both designed and measured energy use were not reached; however, the design and operation of the high-performance building still achieved significant energy savings: design savings of 34% compared to the modeled baseline building (ASHRAE Standard 90.1-2004) and measured energy use intensity (kBTU/sq ft) of 21% less than measured for Longstreet Road Fire Station. Compared to national energy use consumption data for 2003, the CESS showed annual energy savings >50%; 53 kBTU/sq ft for CESS compared to 110.6 kBTU/sq ft for average energy use of public order and safety buildings (DOE, 2012).

Calculation of greenhouse gas (GHG) emissions for the annual total energy consumed in each of the two buildings showed that although the measured total energy use intensity (kBTU/sq ft) was less in CESS than Longstreet (Table 3), the emissions of GHG were greater due to differences in heating system energy sources. Longstreet uses natural gas for heating, cooking and water heating, where CESS is all electric. Natural gas has lower carbon content than electricity in this region, thus Longstreet has lower GHG emission rates (6.46 kg CO_2 equivalents annually versus 7.34 kg CO_2 equivalents annually).

Table 3. Comparison of annual energy use measured for the CESS and Longstreet buildings normalized by square footage and occupancy.

Building	Annual EUI (kBTU/sq ft)	GHG Emissions (kg CO_2 equivalents/year)
CESS	53	7.34
Longstreet	67	6.46
Percent Difference:	21%	-14%

The design and measurement goals for reducing water use were both successfully met in the high-performance building by using harvested rain water for sewage conveyance and to replace much of the water used for washing vehicles. Problems with the water metering data in CESS were identified and questioned repeatedly early and throughout the monitoring stage of the project, and were not resolved by the end of the ESTCP project. In July 2012, the primary issue was finally identified as the main water meter was because not all fixtures were pulling water from the main water line. This plumbing issue means that no reliable comparisons can be made between total potable water use in CESS and Longstreet. Water metering for harvested rainwater and potable water used in vehicle washing are believed to be reliable.

Fourteen objectives were evaluated and the results are summarized here. Three objectives could not be addressed as originally planned using the metrics and/or sampling systems identified in the test plan (Objectives 9, 11 and 13, dealing with solid waste reduction, indoor environmental quality, and occupant satisfaction). Objective 9 was overtaken by an Installation-wide initiative to reduce waste across the site, called the Green Boot Program. For objective 11 involving IEQ, the project applied temperature and relative humidity data gathered through building monitoring and post-construction air quality testing to verify thermal comfort and good indoor air quality within the CESS facility. The planned survey was not relevant for the occupancy and jobs performed in these buildings therefore objective 13, involving occupant satisfaction was evaluated through interviews and discussions, indicating personnel in both buildings had high levels of satisfaction with building performance.

Objective 1: Reduce DESIGN energy consumption. The primary energy design metric tracked for this objective was the LEED EAc1, *Optimize Energy Performance*, which is used to assess expected energy performance in comparison to a design baseline established by the ASHRAE/Illuminating Engineering Society of North America (IESNA) Standard 90.1-2004. Energy use for the ASHRAE baseline and the CESS design was estimated using the energy modeling software, eQuest, and energy savings were derived by comparing the modeled EU of the baseline building to the modeled EU of the CESS design. The modeled EU of the CESS design compared to ASHRAE baseline building was 35.3%, which did not meet the success criteria of reducing design energy costs by 50%.

Objective 2: Reduce MEASURED facility energy use. The energy use of CESS and Longstreet Fire Station was monitored over a 12-month period and compared after normalizing the EU by square footage of each building and by the number of occupants (Table 5.2). The CESS building energy use includes electricity only; whereas, Longstreet building EU includes electricity and natural gas for heating and hot water. All metered EU was converted to BTUs so that EU for each building could be compared with like units. Our results indicate that CESS used 21% less energy per sq ft and 33% less energy per occupant than measured in Longstreet Fire Station, however, did not meet the performance objective of reducing EU by 50% compared to the existing building. Note that the measured EUI for both of these buildings is below the nationwide average EUI of 115 kBTU/sq ft reported for 71 public order and safety buildings for 2003 (DOE, 2012).

Objective 3: Reduce MEASURED GHG footprint. The respective GHG footprints for CESS and Longstreet were determined by analyzing the buildings' annual EU (normalized to the building square footage and number of regular building occupants) based on individual energy sources and calculating emissions as CO_2 equivalents. The source energy used for each building and calculation of emissions was based on values for the Emissions & Generation Resource Integrated Database (eGRID) region where the buildings are located (USEPA, 2012). Because Longstreet uses a mix of electricity and natural gas, the GHG footprint for electricity used is calculated using the eGRID emission factors for the SERC Virginia/Carolina (SRVC) region, but natural gas usage is converted to CO_2 equivalents, and these values are summed to calculate the GHG footprint. Although the measured total EUI was less in CESS than Longstreet, the GHG emissions were greater because the natural gas used in Longstreet because natural gas has a lower GHG intensity that the fuel type used to produce electricity for CESS. Longstreet has lower annual GHG emission rates (6.46 kg CO_2 equivalents) than CESS (7.34 kg CO_2 equivalents).

Objective 4: Reduce DESIGN potable water consumption for domestic uses. The LEED WEc3 was used to evaluate how much better the building design water use is than a design baseline established using the USEPACT of 1992 fixture performance requirements. The credit is evaluated based on estimated occupant use and fixture flow rates only for toilets, urinals, bathroom faucets, showers, and kitchen sinks, and water savings are derived by comparing the modeled water use of the baseline design building to the modeled water use of the CESS design. The modeled water use for the CESS high performance building was 83% less than the baseline building case. These water savings exceeded the success criteria of a 30% reduction.

Objective 5: Reduce MEASURED potable water consumption. The monthly water use values were normalized by the number of occupants in each building to calculate water use intensity (WUI). Monthly review of the data revealed larger than expected differences in potable water use and indicated unreasonably low water use/occupant in the CESS. During a July 2012 site visit, PNNL and Fort Bragg staff discovered that not all of the building's water was metered through the primary water main connection. Total building water use including sinks and showers, was not being collected by the main water meter. Given this metering discrUSEPAncy, we cannot fairly compare the WUI between the two buildings measured during the monitoring period and cannot reliably report against this performance objective. Note, however, that at the CESS, the rainwater capture system was measured sUSEPArately from the domestic water use. The rainwater was used to displace potable water for toilet flushing and vehicle washing was measured and included in comparisons of total water use (see Objective 6 & 7).

Objective 6: Reduce DESIGN potable water use. The relevant water design metric tracked for this objective was the LEED WEc2, *Innovative Wastewater Technologie*s, and involved the substitution of captured rainwater to replace potable water used for sewage conveyance and supplement potable water used for vehicle washing. The wastewater use is estimated from the fixture types and assumed occupancy use and the estimated annual volumes of water that would displace potable water use were subtracted from the annual sewage generation volumes. Rainwater capture and use to displace potable water achieved significant reductions**—**overall 100% reduction in potable water used for sewage conveyance was experience at CESS than the baseline building with stored rainwater remaining to supplement vehicle wash water needs.

Objective 7: Reduce MEASURED potable water use for vehicle washing. The quantity of rainwater captured, quantity of rainwater used for vehicle washing, and any potable water used for vehicle washing were monitored to assess this objective. Potable water used for vehicle washing was metered sUSEPArately from the water main connection, so these values were assumed to be reliable for analysis, and indicated that CESS used 92% less potable water than Longstreet Fire Station for vehicle washing overall. However, Longstreet Fire Station is the busiest station on Fort Bragg and CESS receives only about one-quarter as many emergency calls as Longstreet, so the amount of potable water used for each station was normalized by the number of emergency calls received at each station. Using data normalized for number of emergency calls, the CESS building used 60% less potable water for vehicle washing than Longstreet.

Objective 8: Reduce construction waste during DESIGN and construction phases. A construction waste management plan was developed and implemented to divert construction debris from disposal in landfills and incinerators. The reduction of construction waste through recycling and reuse was assessed based on LEED MRc2. The CESS project received credit for MRc2 and the project diverted 55.29 tons (90.43%) of on-site generated construction waste from landfill.

Objective 9: Reduce MEASURED post-occupancy solid waste. The weight of the solid waste dumpsters is not typically measured at Fort Bragg, and the recycling quantities are also not regularly collected or recorded by building at Fort Bragg, so measurements to support direct comparisons between the two buildings are not available and this objective was not addressed as originally planned. However, both Fort Bragg fire stations and emergency services were certified during the study period as part of the "Green Boot" program. The Green Boot program is an opportunity for units and organizations on Fort Bragg to conserve resources and support the mission through simple, sustainable practices such as energy and water conservation, recycling, waste reduction, green procurement, air quality improvements, awareness and training.

Objective 10: Achieve LEED platinum rating for high performance building. This performance objective encompasses the use of integrated design strategies that included energy efficient, water efficient, and environmentally preferable purchasing strategies. The target level of certification at project initiation was Platinum, which is the highest standard. Objective 10 was met when the design and construction was documented using the LEED rating system and was certified by the USGBC as LEED Platinum.

Objective 11: Improve MEASURED indoor environmental quality. This objective was evaluated based on two lines of evidence regarding the indoor environmental quality. First, temperature and relative humidity (CESS only) were measured throughout the monitoring period, providing data to confirm that systems performed to maintain thermal comfort. Second, the baseline indoor air quality was tested before initial occupancy using testing protocols consistent with the USEPA report "Compendium of Methods for the Determination of Air Pollutants in Indoor Air." These data indicated that temperature and humidity levels in the CESS were maintained for thermal comfort and the building passed USEPA test limits for indoor air quality.

Objective 12: Reduce environmental impact of materials specified in DESIGN. The LEED credits MRc4, MRc5, MRc6, MRc7, and EQc4 were evaluated based on the amount of certain types of materials specified in the design documents. The CESS project goals for these credits included: 20% recycled content materials, 20% regional materials, 2.5% rapidly renewable materials, 50% of wood is FSC certified, and low-emitting materials are used. The LEED submittal for CESS received each of these credits.

Objective 13: Increase MEASURED occupant satisfaction. The Center for the Built Environment occupant survey could not be used for this evaluation because it designed for commercial office buildings and does not address 24-hour occupancy and satisfaction with living quarters. Therefore, interviews with occupants were conducted regarding overall building, lighting, thermal comfort and acoustics. Occupants of both buildings expressed high levels of satisfaction and pride in their respective facilities.

Objective 14: Equivalent maintenance calls. To evaluate whether the new high-performance building would require more calls and repairs to maintain and operate than the Longstreet Fire Station constructed in 2003, the number of maintenance calls received by each of the stations during the monitoring period were tabulated and summarized. Overall, the Longstreet Fire Station had more maintenance calls than CESS (34 versus 23, respectively), and more calls related to repair than the CESS. CESS had 4 routine calls related to fueling the generator and replacing lights.

This page left blank intentionally.

7.0 COST ASSESSMENT

This section describes the life-cycle cost analysis (LCCA) completed for the CESS high-performance building, comparing the original cost estimate including site infrastructure costs, contingencies, and supervision, inspection, overhead (SIOH) of $2,922,000 to the final cost of $3,080,456.

7.1 COST MODEL

In high-performance buildings, initial costs for energy-saving equipment and strategies can be offset by reduced operating costs throughout the life of the building. LCCA allows building owners to look beyond initial investment costs when evaluating building designs. Life-cycle costs of the CESS building at Fort Bragg were estimated using the National Institute of Standard and Technology (NIST) Life-Cycle Costing Manual (NIST Handbook 135). This approach was used rather than using the Building Life Cycle Cost (BLCC) model (http://www1.eere.energy.gov/femp/information/download_blcc.html) because the BLCC does not provide information for the entire project term. This project began in 2007, and the BLCC model would not allow years earlier than 2011 to be input into the model. The financial analysis conducted for this project was based on a discounted cash flow analysis. Cash inflows and outflows were calculated on an annual basis and the financial indicators were derived from these using a defined analysis period and discount rate. The captured benefit of CESS is a reduction in energy usage. Cost estimates were available for the estimate and final bid but final costs were not reported at the same level of detail. Thus for this LCCA, total costs were used (Table 4).

Table 4. Fort Bragg CESS high-performance building cost summary.

Cost Element	Cost
Initial cost estimate for primary facility construction and supporting infrastructure and information systems	$2,536,000
Contingency and SIOH	$386,000
Total initial cost estimate	**$2,922,000**
Total programmed amount	**$2,900,000**
Final cost for primary and supporting facilities (actual construction cost)	$2,713,032
Contingencies and SIOH	$367,424
Total final cost	**$3,080,456**
Difference between initial cost estimate and final design	**$158,456**

One of the design goals was to use a whole building design process to design the building as LEED Platinum at the same cost as was originally programmed. The difference between the original programmed dollar amount and the final costs of construction ($158,456) was used to represent the cost differential for construction of the high-performance building.

The average costs of energy for use in calculating energy savings were extracted from the Army Energy and Water Reporting System (AEWRS), and are summarized in Table 5. Water costs were not evaluated because of the uncertainty in the water data explained in previous sections. The operating and maintenance (O&M) costs related to the routine maintenance of the solar hot water system and the solar wall were also included in the LCCA (Table 6). Routine O&M costs for these systems were not recorded during the demonstration period so typical O&M costs from industry expertise and vendor quotes were used. No other O&M components beyond those of a typical building were identified.

Table 5. Fort Bragg average 2011 cost of energy.

Fuel Type	Cost	Source
Electricity	6.2¢/kWh	AEWRS
Natural Gas	$7.24/MBTU	AEWRS

MBTU = million British thermal units

Table 6. Routine O&M cost summary for renewable energy systems.

Cost Element	Cost	Cost Assumptions	Type of activities
Solar hot water heating system	$192 per year	Assumes average annual maintenance is 1% of capital cost of the system. Capital cost of the system was not provided, so used a cost basis of $100 per square foot of collector area.	Pump maintenance, controls, drainback systems, glycol recharge, and actuators
Solar air heating system	$69 per year	Assumes average annual maintenance is 0.5% of capital cost of the system. Capital cost of the system was $13,772.	Fan and damper actuator maintenance

7.2 COST DRIVERS

The CESS was constructed in a new development area that did not have any existing utility infrastructure, and necessary site improvement costs for utility connections comprised 25% of the total project costs. Because no natural gas service was available at the new housing development, the CESS was designed and constructed as an all-electric facility using ground source heat pumps (GSHP) for building heating and cooling. Efficiency of GSHPs varies according to the soil characteristics at a site and these are most effective in areas with both high winter heating loads and high summer cooling loads. During a CERL interview of Fort Bragg staff, it was noted that the cost for drilling the geothermal wells for CESS GSHPs may have been higher-than-expected because these were the first geothermal systems built at Fort Bragg.

According to project documentation, other additional cost drivers included costs for construction delays ($30,554) and communications ductbank change ($17,478). Documentation for these additional costs is included in the complete project report (ESTCP, 2013b). In addition, a building emergency generator had to be purchased that was missing from the original design and this also added to the increased cost.

Increase in construction costs between the programming year (FY 2006), the design year (FY2007), proposal bids (FY2008), and construction (FY2009-2011) likely also impacted the higher project costs. Average construction costs for fire stations constructed from 2007-2011 in North Carolina increased between 6% and 10% each year (Carrick, 2009; 2012).

7.3 COST ANALYSIS AND COMPARISON

The differential between the initial cost estimate and the actual construction costs was used to represent the differential between construction of a typical fire station and CESS. Detailed data on individual system costs for CESS and Longstreet were not available to compare differences in costs related only to sustainable design costs. Using the cost differential between programmed costs and final construction costs is considered a conservative analysis because it is probable that not the entire cost differential was attributable to sustainable design costs. The cost differential was $158,456 and was assigned to the year that construction bids were received (FY2008). Cash outflows included capital expenditures to construct the CESS. The total capital cost was assigned to the year that construction bids were received (FY2008). Energy costs and fixed operating and maintenance costs were considered outflows. Financial analysis parameters were obtained from various sources, including CESS project personnel, research, and communication with equipment vendors.

Based on this conservative analysis with electricity costs of 6.2¢/kWh, LCCA results show the CESS project is not cost effective. The total energy savings (net present value) do not offset the total cost differential (Table 7). For this project, the internal rate of return (IRR) could not be effectively calculated because there was a negative return on investment within a 25-year project life. The savings to investment ratio (SIR) calculated for CESS was 0.55, including O&M costs.

Designing and constructing a high performance building covers many more aspects than reduced energy cost. There were cost elements that were not considered in this LCCA because details were not available or quantifiable. In evaluating the cost analysis for CESS, it is important to consider several additional factors that influence total cost savings:

- This analysis considers only energy savings because total potable water savings were not accurately measured.
- As stated previously, site personnel stated that the higher construction costs (>5% higher in the years of construction) were consistent with the construction market at the time, which is supported by market data (Carrick, 2009; 2012). It is unlikely that the cost differential between the programmed amount and the final construction costs was solely a result of the sustainable design features.
- The unplanned costs of construction delays and additional communication duct bank changes were not factored into the cost analysis.

Other factors that cannot be easily quantified or included in cost analyses include improvements in occupant satisfaction and beneficial health impacts; environmental benefits of improved construction practices; and the total environmental benefits of reduced EU.

Table 7. Summary of cost savings.

Parameter	Value
System first cost	$158,457.00
Annual costs - O&M	$260.86
Dollar value of monthly energy savings	$351.00
Annual savings	$214.00
Present Value of annual savings over system lifetime (25 years)	$90,903.44
Annual energy savings (baseline modeled energy use -CESS modeled annual energy use)	20,042 kBTU
Dollars/kBTU saved (annual)	$7.91
Dollars/kBTU saved (over 25-year project life)	$0.32
Simple Payback in Years	37.6 years

If it is assumed that the cost differential is solely attributable to sustainable design features, future projects could achieve cost effectiveness in regions where the costs of electricity are 15.1¢/kWh or greater. Other factors that could contribute to the cost-effectiveness of constructing high-performance buildings using whole building design include rebates or incentives for installation of energy-saving systems or features, and better communications between design and construction teams, and the research team or building owners/managers. During construction, some design features could have been dropped to reduce cost that would not have negatively affected the building performance or LEED certification (e.g.,—the solar wall).

8.0 IMPLEMENTATION ISSUES

The implementation issues that were encountered and the lessons learned for this project are categorized into the three main phases of the project: design, construction, and monitoring. In general, lack of experience affected the schedule and delivery of CESS as a high-performance building. The contractor selected to build the Fort Bragg CESS came in with the lowest bid for the building, but had no prior experience in building to LEED specifications and was not readily able to incorporate alternative construction techniques. The design team had experience with only one LEED design and thus over-sized the HVAC equipment, incorporated a roof overhang in the design that shaded and limited the effectiveness of the solar wall, and oversized the solar hot water system.

8.1 DESIGN PHASE LESSONS LEARNED

The ESTCP project team was involved with the design phase prior to the design charrette, participated in the design charrette, provided design drawing reviews, and collected the LEED certification documentation for the design submittal. A number of lessons were learned during this phase of the project:

- Communicating sustainable design goals with the design contractor prior to a design charrette helped keep design options available. Sustainable design goals need to be known by all parties and reiterated throughout the design process.
- Providing technical information on innovative design strategies and technologies to the design contractor prior to the design charrette allowed for those technologies to be considered in detail, rather than discussed superficially at the design charrette. The "TechNotes" (http://www.wbdg.org/ccb/browse_cat.php?c=266 that were adopted by USACE) were developed to provide such information on sustainable design features.
- Sustainable design experts in mechanical, electrical, structural, and civil engineering are essential participants at the charrette and on the design team to aid in successful design of a high-performance building.
- Design charrette energy modeling should include estimations of load calculations so that the chosen systems are appropriately sized. This did not happen at the CESS design charrette. Sizing was performed by the design contractor during the design drawings and the ESTCP project team comments regarding this aspect of the design were not accepted.
- Have a LEED Administrator managing the project that works for the Army rather than a contractor.
- Allow sufficient time for thorough design reviews. The project should schedule reviews so as to allow three to four phased reviews possibly by discipline.

There were also issues inherent to design of a fire station/emergency service center that were not clearly understood at the beginning of the design process, and therefore, were not integrated in overall design considerations. These included the need for a backup generator, men's urinals in bathrooms, a "toner" system for audio announcements and signals, and a simplified control and heating system for the vehicle bays. The design team needed to review the standard building design components to check for basic fire station equipment needs and could have benefited by including a battalion chief or other lead firefighter in design reviews.

8.2 CONSTRUCTION PHASE LESSONS LEARNED

The project team was not involved with the contractor selection process or the construction phase of the project, other than commissioning and the LEED certification documentation. Construction delays impacted overall project timing. Lessons learned from this phase of the project include:

- At a minimum, future construction of high-performance buildings should require that the contractor has prior experience on LEED-certified projects (e.g., three references with positive feedback).
- When construction teams are dealing with unfamiliar technologies, they should be required/encouraged to bring in experts to assist in cost-related decisions. For example, the solar wall vendor informed the construction team that the design for the solar wall would be ineffective and that it shouldn't be installed. The construction team insisted it be installed despite that warning. The ESTCP team learned of this at a conference when one of the team members happened to talk with the solar wall vendor.
- Construction contractor needs to review and acknowledge the LEED documentation responsibilities identified in the design specifications.

8.3 MONITORING PHASE LESSONS LEARNED

The ESTCP project team was responsible for procuring the monitoring equipment and analyzing the monitoring data. Recurring issues with sensor outputs and lost data streams were problems encountered at the start-up of the data collection phase. Lessons learned from this phase of the project include:

- Having a competitive bid for monitoring systems is preferred to a single bidder in order to reduce cost and increase responsiveness on installation and data management issues.
- Data need to be directly provided to the parties that will be analyzing the data so that real-time or near real-time analyses and quality control checks can be performed.
- Personnel responsible for on-site data monitoring should be members of the research team to facilitate rapid response when data issues arise.
- Re-calibration of monitoring equipment needs to be communicated when it occurs, as it may impact data analysis.
- Changes to the building systems and/or other operations need to be communicated to the monitoring team so any potential changes in the data can be noted.

Additional lessons learned are summarized in the final report (ESTCP, 2013b).

9.0 REFERENCES

10 Code of Federal Regulations (CFR) Part 435. 2012. "Energy Efficiency Standards for New Federal Low-Rise Residential Buildings." Code of Federal Regulations, U.S. Department of Energy.

40 CFR 122.26. 2012. "USEPA Administered Permit Programs: The National Pollution Discharge Elimination System." Subpart B, "Permit Applications and Special NPDES Program Requirements." Section 26, "Storm Water Discharges." Code of Federal Regulations, U.S. Environmental Protection Agency.

2002 Farm Bill. 2002. "The Farm Security and Rural Investment Act, Section 9002, Federal Procurement of Biobased Products." Public Law 107-171, as amended, 116 STAT. 134, et seq.

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). 2011. Standard for the Design of High-Performance, Green Buildings, Except Low-Rise Residential Buildings. Standard 189.1, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

Carpio, D.M., and A.B. Soulek. 2012. MILCON Energy Efficiency and Sustainability Study of Five Types of Army Buildings: Summary Report. July 2011, U.S. Army Corps of Engineers – Engineer Research and Development Center – Construction Engineering Laboratory, National Renewable Energy Laboratory, Pacific NW National Laboratory, Washington, DC 20314-1000.

Carrick, A. 2009. "RSMeans' dollars-per-square-foot construction costs: four public service types of structure." Reed Construction Data. Accessed September 2012 at http://www.reedconstructiondata.com/construction-forecast/news/2012/01/rsmeans-dollar-per-square-foot-construction-costs-auditorium-gymnasium-fire/

Carrick, A. 2012. "RSMeans' dollar-per-square-foot construction costs: auditorium, gymnasium, fire station and library. Reed Construction Data. Accessed September 2012 at http://www.reedconstructiondata.com/construction-forecast/news/2009/12/rsmeans-dollars-per-square-foot-construction-costs-four-public-service-type/

Davis, Landgon, 2007 + U.S. Green Building Council, 2009

Environmental Security Technology Certification Program (ESTCP). 2013a. Installation Energy Test Bed (website). http://www.serdp.org/Featured-Initiatives/Installation-Energy

ESTCP. 2013b. Design, Monitoring, and Validation of a High Performance Sustainable Building Final Report, Project SI-0724. Pacific Northwest National Laboratory, Richland, Washington.

Federal Energy Management Program (FEMP). 2003. Business Case for Sustainable Design in Federal Facilities. Federal Energy Management Program, U.S. Department of Energy, Energy Efficiency and Renewable Energy, Washington, D.C.

FEMP. 2013. High Performance Federal Buildings (website). http://femp.buildinggreen.com/

Fowler, K.M., E.M. Rauch, K. Spees, J. Hathaway, A.R. Kora, and A.E. Solana. 2009. Whole Building Cost and Performance Measurement: Data Collection Protocol, Revision 2. PNNL-18325, Pacific Northwest National Laboratory, Richland, Washington.

Fowler, K.M., E.M. Rauch, J.W. Henderson, and A.R. Kora. 2010. Re-Assessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. PNNL-19369, Pacific Northwest National Laboratory, Richland, WA.

International Initiative for a Sustainable Built Environment (iiSBE). 2005. Integrated Design Process, Ottawa, Canada.

Kats, G.H. 2003. Green Building Costs and Financial Benefits. Massachusetts Technology Collaborative

Matthiessen, L. 2004. Examining the Cost of Green. Davis Langdon, Santa Monica, California.

Morris, P., and L. Matthiessen. 2007. Cost of Green Revisited, Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adoption. Davis Langdon, Santa Monica, California.

National Institute of Building Sciences (NIBS). 2010. Life-Cycle Cost Analysis (LCCA). Whole Building Design Guide, http://www.wbdg.org/resources/lcca.php, last updated 06/28/10.

National Institute of Standards and Technology (NIST). 1996. "Life-Cycle Costing Manual for the Federal Energy Management Program." National Institute of Standards and Technology Handbook 135, 1996 Edition, Section 1-1.

NIST. 2011. Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011 (Rev. 9/11).

Steven Winter and Associates. 2004. GSA LEED Cost Study, Final Report. U.S. General Services Administration, Washington, D. C.

Torcellini et al, 2006

U.S. Department of Defense (DoD) Directive 4170.11. 2009. Department of Defense Instruction-Installation Energy Mangement. December 11, 2009. Under Secretary of Defense for Acquisition, Technology, and Logistics.

U.S. Department of Energy (DOE). 2012. 2011 Buildings Energy Data Book, Table 3.1.9 (website). http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.9. Buildings Technology Program, Energy Efficiency and Renewable Energy, US Department of Energy.

U.S. Environmental Protection Agency (USEPA). 2012. The Emissions &Generation Resource Integrated Database For 2012 (Egrid2012) Technical Support Document. U.S. Environmental Protection Agency, Office of Atmospheric Programs, Washington, DC.

Whole Building Design Guide (WBDG). 2013a. User's Guide (website). http://www.wbdg.org/wbdg_ug.php

WBDG. 2013b. TechNotes (website). http://www.wbdg.org/ccb/browse_cat.php?c=266

Torcellini, P., S. Pless, M. Deru, B. Griffith, N. Long, and R. Judkoff. 2006. Lessons Learned from Case Studies of Six High-Performance Buildings. NREL/TP-550-37542, National Renewable Energy Laboratory, Golden, Colorado.

This page left blank intentionally.

APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone E-Mail	Role In Project
Kim Fowler	Pacific Northwest National Laboratory 902 Battelle Blvd. Richland, WA 99354	Phone: (509) 372-4233 E-mail: kim.fowler@pnl.gov	Principle Investigator
Manette Messenger			Original Project Manager (Retired)
Anne Rogers	Southface Energy Institute 241 Pine Street NE Atlanta, GA 30308	Phone: (404) 604-3614 E-mail: arogers@southface.org	LEED Guidance
Annette Stumpf	Construction Engineering Research Laboratory 2902 Newmark Dr. Champaign, IL 61826	Phone: (217) 373-4492 E-mail: Annette.L.Stumpf@usace.army.mil	Building Information Modeling
Christy Etter	CH2MHILL Northpark 400 1000 Abernathy Road Suite 1600 Atlanta, GA 30328	Phone: (404) 483-7335 E-mail: Christy.Etter@CH2M.com	Commissioning
Ray Barbeau	Fort Bragg Directorate of Public Works IMSE-BRG-PWP-P Fayetteville, NC 28310	Phone: (910) 396-5469 E-mail: ray.barbeau@us.army.mil	Project Oversight

This page left blank intentionally.

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org