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

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ACRONYMS

AEWRS	Army Energy and Water Reporting System
AFCEE	Air Force Center for Engineering and the Environment
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASTM	American Society of Testing and Materials
BLCC	Building Life Cycle Cost program
BTU	British Thermal Unit
CBE	Center for the Built Environment
CERL	Construction Engineering Research Laboratory
CESS	Community Emergency Services Station
cf	cubic feet
CFR	Code of Federal Regulations
CO	carbon monoxide
COS	Centers of Standardization
CT	current transformer
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQO	data quality objective
EAc	Energy and Atmosphere credit (LEED)
EPACT	Energy Policy Act
ESTCP	Environmental Security Technology Certification Program
FEMP	Federal Energy Management Program
FSI	Field Safety Instruction
FY	fiscal year
GFCI	ground fault circuit interrupter
GSA	General Services Administration
gsf	gross square feet
HVAC	Heating, Ventilation, and Air Conditioning
iaw	in accordance with
IEQ	Indoor Environmental Quality
IMCOM-SE	Installation Management Command Southeast
IPR	In-progress Review
kW or kWh	Kilowatt or kilowatt hour
LCCA	Life Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
LEED-NC	LEED New Construction

MBtu	one million BT
MMBtu	A thousand thousand BTU
MCA	Military Construction, Army
MSDS	Material Safety Data Sheet
NAVFAC	Navy Facilities Command
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
PA	programmed amount
PDT	Project Delivery Team
PM10	Particulate Matter 10 microns or smaller
PNNL	Pacific Northwest National Laboratory
POE	Post Occupancy Evaluation
PT	potential transformer
QAPjP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RFP	Request for Proposal
SBIC	Sustainable Buildings Industry Council
sf	square feet
TVOC	total volatile organic compounds
USGBC	U.S. Green Building Council
USACE	U.S. Army Corps of Engineers
WBPM	Whole Building Performance Measurement
WeC	Water Efficiency Credit (LEED)

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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 so as to achieve optimum performance and maximize energy and water efficiency according to sustainable design principles (DoD Directive 4170.11 2009). To help DoD meet building efficiency and conservation challenges, Army Installation Management Command 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 integrated design process. The project was conducted in collaboration with U.S. Army Corps of Engineers (USACE) Construction Engineering Research Laboratory, Southface Energy Institute, and CH2M HILL. The overarching objective of this project was to demonstrate that applying whole building design technology utilizing off-the-shelf building materials and components achieves higher facility performance than traditional design approaches. This report documents the application of integrated whole building design to 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 Longstreet Fire Station, a similar facility built several years earlier on Fort Bragg, North Carolina.

Applying whole building design methods to design and construction resulted in Platinum certification of CESS by the Building Council's Leadership in Energy and Environmental Design (LEED). The ESTCP project team successfully transferred the whole building design technology and individual 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 5 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" (Appendix E), which provide technical and financial information to support design team decision-making. The USACE subsequently adopted the concept of TechNotes as part of their toolset, and is developing additional design-related TechNotes, as well as planning for development of operations and maintenance TechNotes to assist with effective building operations where newer design strategies and technologies are implemented. The strategy and techniques for whole building design have been shared with the 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.

Analysis of 12 months of monitoring data showed that the CESS high-performance building outperformed the Longstreet Fire Station by exhibiting decreases in the total energy use/sq ft, total potable water use, and the number of maintenance and operations calls. CESS' annual energy use intensity (EUI; kBTU/sq ft) was 21% less than annual EUI for its matched pair (Longstreet Fire Station). Reliable estimates of total water savings could not be calculated because of plumbing design and metering issues, but significant water savings were achieved through harvesting rainwater, resulting in a 100% reduction in potable water used for sewage conveyance and significatnt savings in potable water used for vehicle washing,

Although construction costs were slightly higher (~5%) than originally estimated and programmed, site personnel concluded that the increased costs were not a function of sustainable building design, but were partially due to 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—as well as additional costs incurred to provide necessary infrastructure in a new housing development.

Data collection for twelve months is the minimum for evaluating building performance and when monitoring occurs early in the life of a building, data may not reflect optimum building performance, because the occupants and building operations are not settled and routines are not yet set. During the warranty site visit near the end of the 12-month period (July 2012), several necessary repairs were identified that would affect the building's performance. On-going measurement and analysis would offer greater detail on the performance of the buildings and allow an assessment of whether data collected in the 12 months of this study represent the typical performance for these buildings.

When evaluating whole building measured performance, details regarding the performance are often requested that would have required additional submetering or additional monitoring time. On this project, submetering to allow direct comparisons for some end uses such as plug load or lighting was both cost prohibitive and logistically difficult or impossible. Submetering in the existing building could not be installed given the location of the equipment and organization of the electricity panels.

Lessons learned include the need to contract with design and construction firms that have prior experience in whole building, integrated, sustainable design and, preferably, with construction of LEED–certified buildings. The ESTCP project team believes that experienced contractors would have been beneficial as they would have been willing to accept integrated design strategies such as downsized equipment and appropriate design and construction of the solar wall, and would likely provide better quality in the overall building construction (e.g., properly plumbing the building from the water main).

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1.0 INTRODUCTION

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 so as to achieve optimum performance and maximize energy and water efficiency according to sustainable design principles (DOD Directive 4170.11 2009). The U. S. Army Installation Management Command (IMCOM) and the Pacific Northwest National Laboratory (PNNL) led the ESTCP Fort Bragg Community Emergency Services Station (CESS) project to demonstrate and evaluate implementation of the whole building integrated 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 1.1. In contrast, traditional design approaches usually optimize building components, rather than the whole building. This results because design specialists are focused on the benefits of design and specifications for their individual areas of expertise and usually are not 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 1.1. Integrated 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,(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 (IPCC 2006; Climate Trust). In 2010, buildings accounted for 54% of sulfur dioxide emissions, 17% of nitrous oxide emissions and 40% of carbon dioxide emissions (DOE 2012). The impact to DoD is rising costs of operation. DoD occupies over 300,000 buildings and structures worth $600 billion (http://www.serdp.org/Featured-Initiatives/Installation-Energy) 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 is potentially achievable (Fowler et al. 2010). Sustainbly designed buildings have lower costs for water utilities, energy utilities, general maintenance, grounds maintenance, waste and recycling, and janitorial service. Additional benefits include increased building occupant comfort, productivity, and health; reduced water and energy use; reduced air and water pollution; increased mission capability to operate in water-short areas; improved stormwater quality and wildlife habitat, and reduced solid waste and potential for groundwater pollution from landfill leachate.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this project demonstration is to document the use of off-the-shelf building materials, systems, and components in a whole building design strategy to achieve higher facility performance and certify the building as LEED Platinum without substantially 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 FY08 and FY11. The CESS building and the Longstreet Fire Station (a similar building with similar occupancy built in 2003) were monitored and compared for a period of one year to determine and document the differences between the buildings, energy and water use, and occupant comfort, and calculate life-cycle costs for CESS. Specific performance criteria to be measured, and targets to be achieved, are listed in Section 4.1.

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;
- the 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;
- the Energy Policy Act of 2005, which requires minimum energy performance;
- 10 CFR Part 435, which mandates that low-rise residential federal buildings achieve energy performance at least 30 percent 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 (ASTM) standards that are cited in national building and energy codes;

- 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 DoDI 4170.11, which specifies compliance with 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 the other voluntary rating systems.

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, high-performance buildings are the result of whole building design. We tested the process of whole building integrated design to document how a well-designed building performs in comparison to one designed using traditional practices. 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 (POE).

2.1 TECHNOLOGY OVERVIEW

The overall technology being tested is "whole building design," which utilizes numerous existing technologies, such as waterless urinals, that may be incorporated in the demonstration project. Our 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 following description of whole building design is quoted in its entirety from The Whole Building Design Guide website (http://www.wbdg.org/wbdg_ug.php). This website is a collaborative effort to provide definitive guidance and one-stop source of information on the latest integrated whole building design techniques and technologies. The WBDG website is offered as an assistance to building professionals by the National Institute of Building Sciences (NIBS) through the funding of the NAVFAC Engineering Innovation and Criteria Office, the U.S. General Services Administration (GSA), the Department of Energy (through the National Renewable Energy Laboratory (NREL)), and the assistance of the Sustainable Buildings Industry Council (SBIC). A Board of Direction and Advisory Committee, consisting of representatives from over 25 participating federal agencies, private sector companies, and non-profit organizations, guide the development of the WBDG.

> *"Whole Building Design consists of two components: an integrated design approach and an integrated team process. The Whole Building or "integrated" design approach asks all the members of the building stakeholder community, and the technical planning, design, and construction team to look at the project objectives, and building materials, systems, and assemblies from many different perspectives. This approach is a deviation from the typical planning and design process of relying on the expertise of specialists who work in their respective specialties somewhat isolated from each other. Whole Building design in practice also requires an integrated team process in which the design team and all affected stakeholders work together throughout the project phases and to evaluate the design for cost, quality-of-life, future flexibility, efficiency; overall*

environmental impact; productivity, creativity; and how the occupants will be enlivened. The 'Whole Building' process draws from the knowledge pool of all the stakeholders across the life cycle of the project, from defining the need for a building, through planning, design, construction, building occupancy, and operations.

***The Integrated Design Approach**: Each design objective is significantly important in any project, yet a truly successful one is where project goals are identified early on and held in proper balance during the design process; and where their interrelationships and interdependencies with all building systems are understood, evaluated, appropriately applied, and coordinated concurrently from the planning and programming phase. The end result is a high-performance building.*

***The Integrated Team Process**: To create a successful high-performance building, an interactive approach to the design process is required. It means all the stakeholders—everyone involved in the planning, design, use, construction, operation, and maintenance of the facility—must fully understand the issues and concerns of all the other parties and interact closely throughout all phases of the project.*

A design charrette—a focused and collaborative brainstorming session held at the beginning of a project—encourages an exchange of ideas and information and allows truly integrated design solutions to take form. Team members—all the stakeholders— are encouraged to cross fertilize and address problems beyond their field of expertise. The charrette is particularly helpful in complex situations where many people represent the interests of the client and conflicting needs and constituencies. Participants are educated about the issues and resolution enables them to "buy into" the schematic solutions. A final solution isn't necessarily produced, but important, often interdependent, issues are explored."

The differences between using a whole building design approach versus using a traditional design approach are shown graphically in Figure 2.1. As part of the integrated design process for this project, the ESTCP project team took the following steps:

1. Pre-charrette meetings were held with technical experts and the design firm to discuss possible design techniques and to outline the questions and concerns voiced by the design firm.
2. The technologies and design strategies considered for use in reducing water and energy use were summarized and developed as individual "TechNotes" for use in the charrette and design. The full set of TechNotes is included in Appendix E.
3. These technical notes were provided to the design firm and follow-up conversations were held to discuss and answer questions regarding specific technologies considered.
4. The formal design charrette was held April 23, 2008 over a 5-day period with all key stakeholders involved. The participants included the Fort Bragg personnel, fire-fighting

staff and fire chief, and all members of the ESTCP team (PNNL, CERL, IMCOM, CH2MHill, and Southface Energy Institute). Activities included modeling to investigate design options that would optimize energy efficiency while meeting the suite of design objectives. The end result of the charrette was a 35% design drawing and cost analysis before the meeting was concluded.

5. Several design reviews were conducted to allow feedback on the current design.

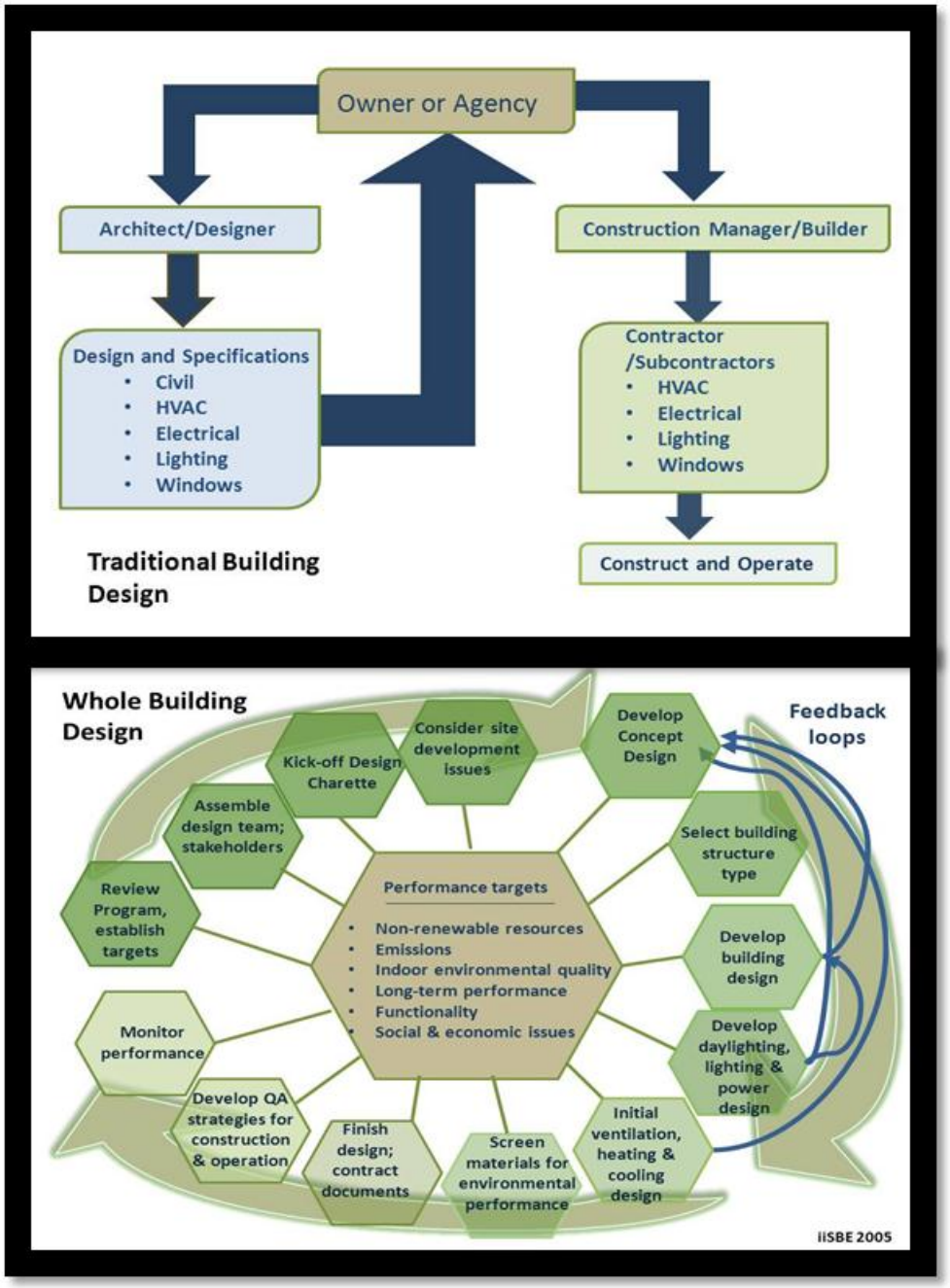


Figure 2.1. Traditional Design Process versus Whole Building Design (after iiSBE 2005)

2.1.1 Monitoring Building Performance

The ESTCP project team monitored the performance of the CESS for the period from June 2011 through June 2012 and compared it to the performance of the Longstreet Fire Station. Details of monitoring and the measurements used to assess building performance are presented in Sections 4 and 5 of this report. Specific goals for energy, water, environmental quality, and sustainability are described in detail in sections 4 and 5 of this report. The ESTCP design team, set a challenge goal for energy performance for the CESS: to attain a 50% reduction in calculated energy costs compared to the modeled ASHRAE baseline building, and to achieve 50% savings in energy consumption/square foot in the CESS over Longstreet Fire Station. The 2006 Federal MOU on high performance buildings requires a 30% energy reduction over the ASHRAE 90.1 "base case" for all buildings, as does the U.S. Army Corps of Engineers (USACE) standard Request for Proposal (RFP) for all buildings.

Once the building design and construction were completed and the CESS was fully operational, the ESTCP team performed a post occupancy evaluation (POE) using whole building performance metrics. The *Building Cost and Performance Metrics: Data Collection Protocol* was used to guide the POE (Fowler et al. 2009). The performance metrics were selected to measure the impact of the performance goals and design features for the high performing building as compared to the traditionally designed and constructed building.

2.1.2 Technology Transfer and Communication

The lessons learned and process improvements identified during the design of the CESS have already had a significant impact on the Army. In addition to providing direct technical assistance to individual design projects, the information gained through engaging in the whole building design process was formalized through the development of 19 individual TechNotes (Appendix E) with the USACE. USACE has made these publically available and are adding additional TechNotes to aid the military in developing sustainably designed buildings (http://www.wbdg.org/ccb/browse_cat.php?c=266). In addition to providing direct design assistance, the ESTCP team has transferred the whole building design approach to the USACE for use in the redesign of five standard building designs for high energy efficient buildings. These five designs are for the buildings most frequently built by the Army: barracks, dining facilities, Brigade Headquarters, maintenance facilities for tactical equipment, and Company Operations Facilities. 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.

As part of the final assessment and transfer of information, the POE results and the whole building integrated performance measurements are reported here to document the operational performance of the CESS. The POE approach has been adapted for use by the General Services Administration, Navy, Department of Energy, and the Air Force to document the performance of their sustainably designed buildings.

2.2 TECHNOLOGY DEVELOPMENT

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 (http://www.eere.energy.gov/femp/highperformance/index.cfm). Whole building design and high performance buildings have been assessed previously based on the design expectations or on the performance of a single metric such as energy. Examples include:

- The *Business Case for Sustainable Design in Federal Facilities* (FEMP 2003) report which compared the estimated life cycle costs of two 20,000 square foot simulated office buildings for the environmental impact, and societal impacts).
- The *GSA LEED*™ *Cost Study* examined the first cost impacts of differing levels of green building rating system certification levels for two building types(Steven Winter 2004).
- The reports, *Examining the Cost of Green* and *Cost of Green Revisited*, provided insight into the variability of construction costs for sustainably designed buildings alongside buildings with traditionally designed buildings with similar functions (Matthiessen 2004, Morris and Matthiessen 2007).
- The *Lessons Learned from Case Studies of Six High-Performance Buildings* report (Torcellini et al. 2006) compared the energy performance of six buildings to the expected performance based on design.
- The WBDG webpage 'Measuring Performance of Sustainable Buildings' offers a summary of performance measurement activities and strategies (http://www.wbdg.org/resources/measperfsustbldgs.php).

Whole building performance measurement was performed on 22 General Services Administration (GSA) buildings (Fowler et al. 2010) using a similar POE methodology. That analysis compared the performance of sustainably designed buildings to industry baseline values and showed that on average the 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 a close examination of the whole building design process and resulting whole building performance, providing a rare opportunity to truly impact future design and whole building performance.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

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, challenge 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," recent studies indicate that, on average, construction costs associated with green buildings and LEED certification are not significantly different compared to non-green buildings (Davis Langdon 2007; USGBC 2009). Other studies find only a 1% to 2% difference in initial costs of construction using green building practices and technologies compared to standard building practices and technologies (Kats et al. 2003). Factors affecting costs of building design and construction for CESS included the experience of the design team with whole building design methods; and experience of the construction contractor with the technologies specified in the design. Many design and construction firms are familiar with green, sustainable building techniques/technologies; experience with LEED and sustainable design should be a requirement within the request for proposal and part of the evaluation criteria for choosing the design/construction teams. The Army's low-bid policy resulted in selection of a design team and construction team 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 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 contractor 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. This lack of experience and understanding of the final objectives resulted in delays in completing construction of the building and some building components that were poorly executed and function below expectations.

Building commissioning is a critical component in the whole building design process and a key to achieving a high-performance building. Commissioning of the CESS building was introduced during the design phase and continued through the construction and acceptance of the building including a warranty site visit after building occupation. This is an important step to ensure that the building functions as designed when occupied, building staff are trained to operate new building systems, and that building systems are operating correctly. Final commissioning of CESS revealed several issues that were corrected after the building was occupied.

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. It is recognized that occupant behavior has an impact on the building they are occupying. 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 these buildings the occupants had 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 fire stations would be needed to offer useful occupancy-based resource use analysis.

3.0 FACILITY/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 what their size.

3.1 FACILITY/SITE LOCATION, OPERATIONS AND CONDITIONS

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 (Figures 3.1 and 3.2). 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 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 3.1 provides information on building parameters and operations for comparison.

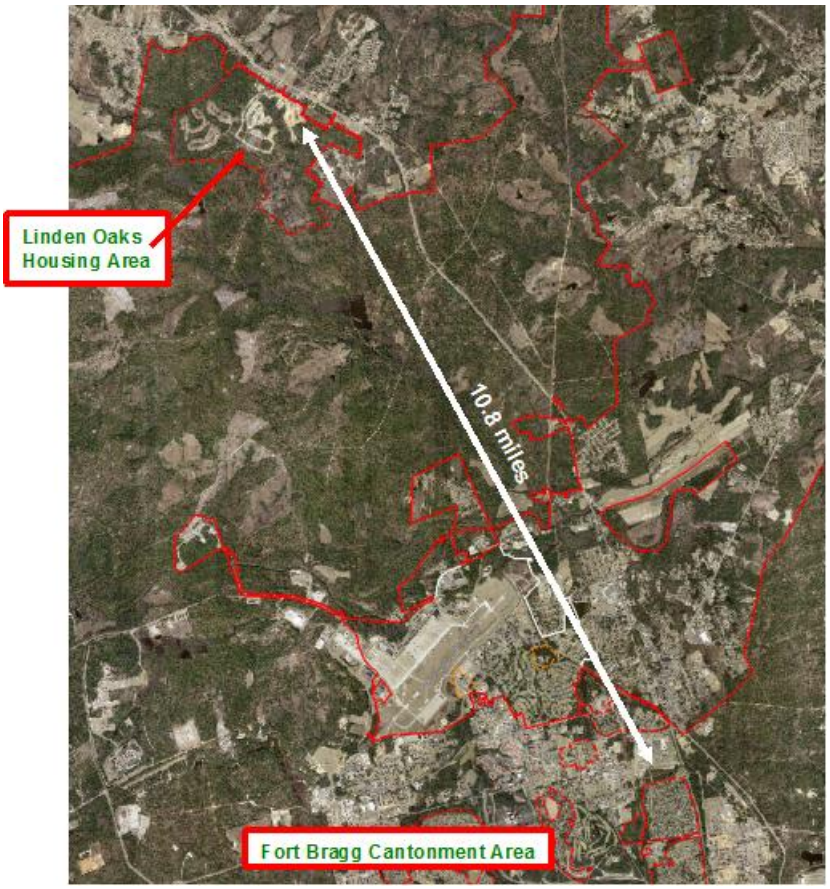


Figure 3.1. Relative Location of the CESS and Longstreet Fire Station at Fort Bragg

Table 3-1 Comparison of Building Characteristics and Operating Conditions

Building Feature	CESS Building	Longstreet Fire Station
Square footage	8295	6125
No. 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
Temperature setpoints	cooling 73˚ F , heating 71˚F*	n/a
*Heat pump 5 servicing the vehicle bay has no cooling setpoint, and a heating setpoint of 60		

3.1.1 Fort Bragg CESS

The Fort Bragg CESS, located at the entrance to the Linden Oaks Housing Area (Figure 3.2), serves a number of functions. The CESS is the first building that people see when they enter the housing area, and as such, was designed to have an aesthetic that enhances the neighborhood. In addition, it is a community facility that Linden Oaks residents enter to seek assistance, and that school children tour. The facility was designed for normal occupancy of six firefighters, two emergency medical technicians, and three military police officers. 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 CESS currently houses four firefighters, two police, and two paramedics on shift, all of whom serve the Linden Oaks housing area. Firefighters occupy the building for 24-hour shifts. The police and paramedics occupy the building for 12-hour shifts. The vehicle bay contains space for one fire truck, one ambulance, and one police cruiser. The entire building, including the bay, is 8295 square feet.

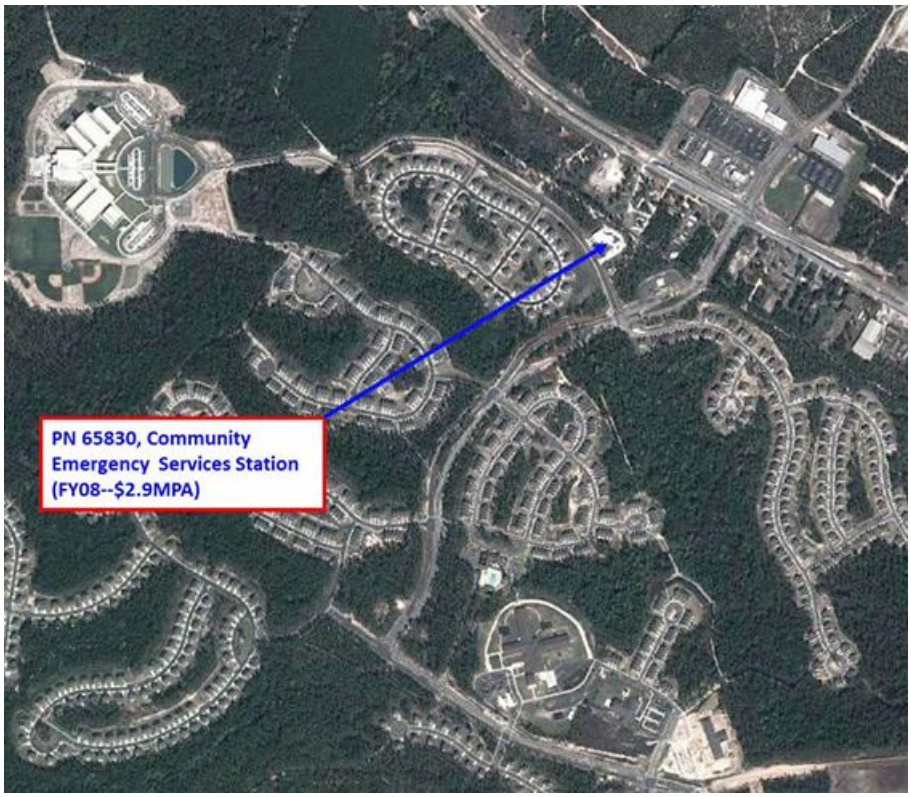


Figure 3.2. Location of the CESS within the Linden Oaks Housing Development

3.1.2 Longstreet Fire Station

The Longstreet Road fire station was occupied in 2003. It is located on Fort Bragg's main post (Figure 3.1) close to the hospital, residential areas, and administrative facilities. It houses Company 3 of the Fort Bragg Fire and Emergency Services Department, which has a first responder and firefighting mission. Ten firefighters are assigned there; at any one time, four firefighters work a 24-hour shift and one works a 12-hour shift, so at a minimum, five firefighters are on duty and occupying the building at one time. The Deputy Fire Chief is at the building during the day, and spends a couple nights a week there. 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; the Chief's vehicle is parked outside behind the facility. The entire building is 6125 square feet.

3.2 SITE/FACILITY IMPLEMENTATION CRITERIA

Fort Bragg, North Carolina lies within ASHRAE Climate Zone 3A (ASHRAE 169-2006), which is defined as Warm – Humid or Mixed Humid (Baechler et al. 2010).The two stations, while similar, are not exactly alike in function, size, or layout. These differences required that cost and performance data be normalized by building average population, number of emergency calls, and square footage. They are approximately 10 miles apart, so climate variation is minimal.

Figure 3.3 shows the floor plan for the 100% design review floor plan for the CESS. As can be inferred from the photos in Figures 3.4 and 3.5, the two buildings have different floor plans, but both contain dormitories for sleeping, kitchen facilities, common rooms, and a high bay vehicle facility.

3.3 SITE-RELATED PERMITS AND REGULATIONS

Standard Fort Bragg permitting, environmental protection and construction procedures were followed during construction of the new CESS. No additional permits or regulatory requirements will apply to this demonstration. No interaction with regulators by the ESTCP team was necessary. Public participation was not required.

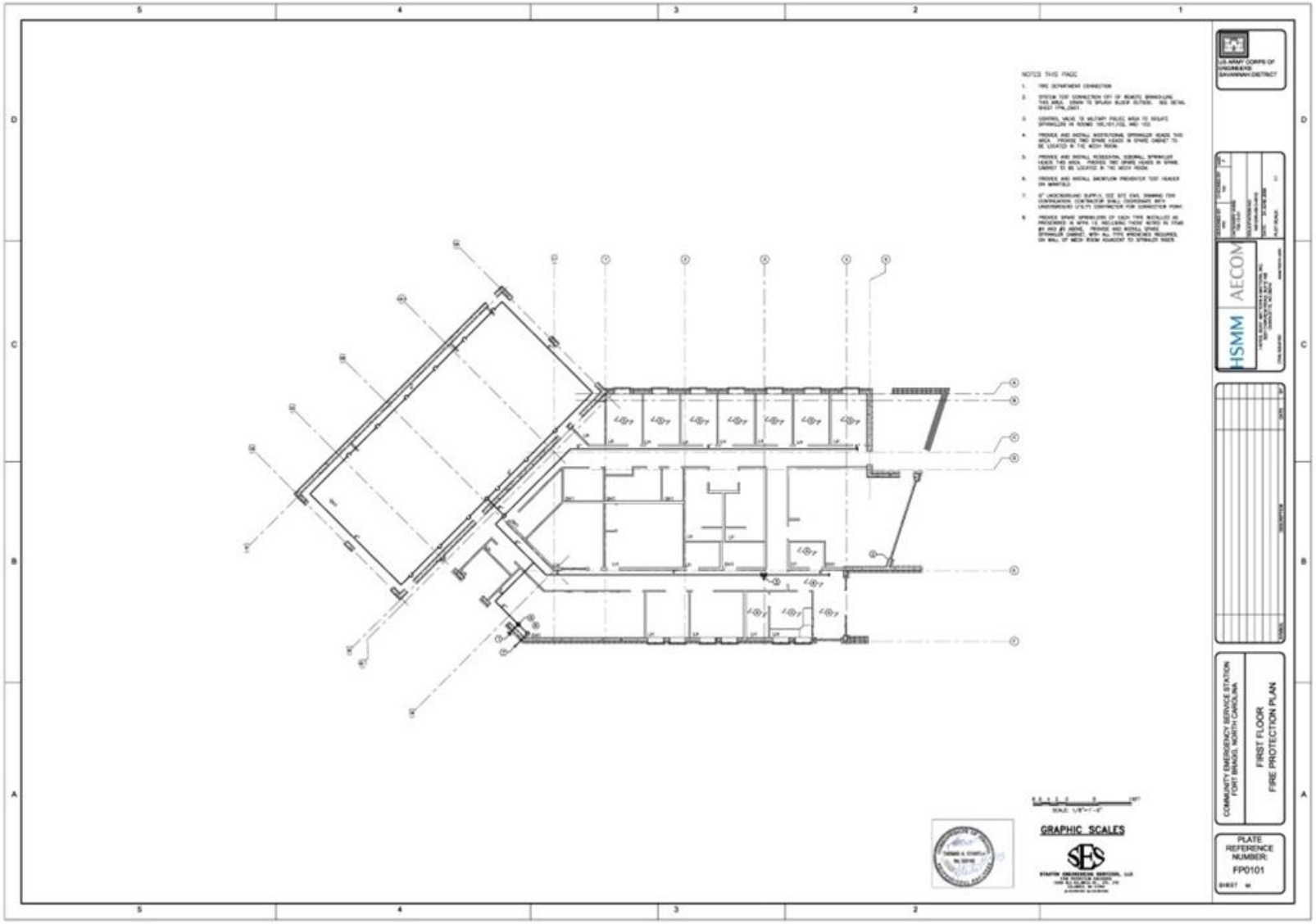


Figure 3.3. CESS Floor Plan at 100% Design

Figure 3.4. Longstreet Fire Station

Figure 3.5. Ft. Bragg CESS Building

4.0 TEST DESIGN AND ISSUE RESOLUTION

This project was designed to demonstrate two technology components: 1) evaluate the integrated whole building design process; and 2) monitor and compare the differences between a high-performance sustainably designed building with a traditionally designed building including comparisons of life-cycle cost, energy and water use, occupant comfort, solid waste, and maintenance and operations. The overarching hypothesis of this project is that applying whole building design technology to design a sustainable building utilizing off-the-shelf building materials and components achieves higher facility performance than traditional design approaches.

4.1 CONCEPTUAL TEST DESIGN

The two primary technology components in this project, integrated design and whole building performance measurement, were demonstrated and evaluated using different approaches. The integrated design process was assessed through modeling and calculations used to support the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating. The whole building performance of the CESS was assessed by conducting a matched pair analysis of CESS and Longstreet. The design and performance assessment objectives developed to demonstrate these technology components are listed in Table 4.1.

Table 4-1. Design and Measurement Objectives for Testing and Demonstration of CESS High-Performance Building

Performance Objective	Metric	Data Requirements
Quantitative Objectives		
1. Reduce DESIGN energy consumption (*Energy*)	Modeled energy use as estimated for LEED credit EAc1	Model energy use of final high performance design and compare it to ASHRAE 90.1-2004 theoretical building baseline
2. Reduce MEASURED facility energy use (*Energy*)	Reduction of building energy use	Energy use of high performance building (CESS) and existing baseline building (Longstreet)
3. Reduce MEASURED greenhouse gas footprint (*Energy)*	Reduction of building related greenhouse gas footprint	Power/fuel sources for natural gas and electrical generation for calculating greenhouse gas impact
4. Reduce DESIGN potable water consumption for domestic uses (*Water*)	Calculated potable water use as estimated for LEED credit WEc3	Model/estimate domestic water use of final high performance design and compare to baseline water use calculated using EPAct 1992 standards for residential and commercial water fixtures
5. 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

Table 4.1. (continued)

Performance Objective	Metric	Data Requirements
6. 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 final high performance design and compare it to estimate for theoretical building baseline
7. 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
8. Reduce construction waste during DESIGN and construction phases (*Waste*)	Reduction of construction waste through recycling as documented through LEED credit MRc2	Provide construction waste recycling documentation
9. Reduce MEASURED post-occupancy solid waste[1] (*Waste*)	Reduction in solid waste	Waste and recycling quantities
Qualitative Objectives		
10. Achieve LEED rating for high performance building (*Whole Building*)	Platinum	LEED documentation
11. Improve MEASURED indoor environmental quality (*IEQ*)	Maintain good thermal comfort in regularly occupied spaces	Measure temperature and humidity for both buildings
12. Reduce environmental impact of materials specified in DESIGN (*Materials*)	Specify environmentally preferable materials in accordance with LEED credits MRc4, MRc5, MRc6, MRc7, and EQc4	Provide construction materials use documentation
13. Increase MEASURED occupant satisfaction	Post-occupancy interviews regarding overall building, lighting quality, maintenance, thermal comfort (*IEQ*)	Document building occupant commentary for both buildings
14. Reduce Required Maintenance[2]	Number of required maintenance calls	Record of routine and repair maintenance calls to Longstreet and CESS buildings

[1] Not measured at the building level, Fort Bragg Green Boot Program measures installation level performance.
[2] This performance objective was added during the analysis period.

4.1.1 Conceptual Design for Demonstrating the Integrated Whole Building Design Process

The design performance objectives (Table 4. 1) for the CESS were developed to correspond to the LEED criteria for high-performance buildings and enable assessment of the success of the integrated design process. The LEED New Construction (NC) Rating System is a performance standard for certifying the design and construction of commercial buildings. The certification

process evaluates building design and construction using the following criteria to assign credits toward certification:

- SUSTAINABLE SITES (SS)--A sustainable site involves reducing negative impacts on the environment through proper site development and includes all aspects of the design outside of the building, such as erosion and sediment control, stormwater management, transportation and light pollution. Strategies to accomplish this include reducing construction activity pollution, protecting natural areas, using existing infrastructure, protecting and restoring the site, encouraging alternative transportation and site remediation of Brownfield development where appropriate.
- ENERGY & ATMOSPHERE (EA)--This credit category aims to reduce the energy consumption of buildings thereby decreasing negative environmental impact. Energy performance can be optimized through building commissioning, energy modeling, and use of non-ozone depleting substances. Strategies to achieve higher energy performance include efficient HVAC design, efficient water heating, energy efficient lighting and building envelope systems, and renewable energy sources.
- WATER EFFICIENCY (WE)--Water efficiency encourages alternative means of water technology and distribution in order to reduce the need for potable water for landscaping and building water use. Strategies to accomplish this generally involve using high efficiency fixtures and waterless urinals, innovative wastewater technologies, and low-impact, drought tolerant landscaping or water re-use, such as rainwater harvesting, to reduce the need for landscape irrigation.
- MATERIALS & RESOURCES (MR)—Credits in this category are achieved by reducing the amount of construction waste that ends up in a landfill, and minimizing the use of rapidly declining resources. This involves construction waste management, storage and collection of recyclables, use of local resources and careful materials specification. Strategies for reducing materials and resources include creating a comprehensive construction waste management plan to divert as much waste as possible from the landfill and specifying reuse, recycled or rapidly renewable products and materials (especially those that are regionally available) in contract requirements.
- INDOOR ENVIRONMENTAL QUALITY (IEQ)—The IEQ category focuses on the health and well-being of the building occupants by providing a comfortable and healthy work environment. Goals include elimination of tobacco smoke, intentional ventilation, maintaining high indoor air quality, daylighting & views, and controllability of building systems. Actions in this category include removing pollutant pathways, increasing ventilation, use of low-emitting materials, providing individual controls for systems, and the incorporating daylighting and views into the overall building design.

The design objectives listed in Table 4.1 were addressed by determining whether or not the identified LEED criteria and credits were achieved. 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 Appendix A. The resources used to optimize the integrated design process include the Whole Building Design Guide (www.wbdg.org) and the U.S. Green Building Council's LEED rating system (www.usgbc.org/LEED/). For the integrated design technology component, the team:

1. identified and communicated sustainable design goals with key stakeholders
2. provided detailed information on potential design strategies and environmentally friendly technologies to the design team in order to inform design decisions
3. brought sustainable design expertise to the integrated design charrette
4. modeled energy use for four potential building footprints using the eQuest energy model for evaluation during the charrette
5. demonstrated the feasibility of using a Building Information Model (BIM) on the fly during the charrette to provide immediate feedback on the impact of major design choices on energy use (http://www.cecer.army.mil/techreports/ERDC-CERL_TR-11-41/ERDC-CERL_TR-11-41.pdf)
6. continued communications with design firm to track design progress and to ensure strategies identified within the design charrette were not eliminated
7. participated in the value engineering evaluation of the design
8. tracked design and construction progress.

Overall success of the project was demonstrated through the sharing of the integrated design strategy and lessons learned with DoD design professionals, especially USACE.

4.1.2 Conceptual Design for Monitoring Whole Building Performance

The measurement of whole building performance was conducted by comparing metrics measured for the new CESS building to measurements made for an existing fire station (Longstreet) in a matched pair analysis (Fowler et al. 2009).

Whole building performance measurement evaluates existing sustainably designed buildings by documenting operational data to determine whether the buildings perform as the design intended. To gather useful information, the operational data need to be:

- measured, not modeled
- relatively easy and inexpensive to collect
- representative of integrated, sustainable design principles, not just individual design strategies such as energy efficiency
- translated into cost values that can be shared with financial decision makers.

The data provide basic information about building performance with respect to sustainable design. The metrics collected include energy, water, maintenance, and indoor environmental quality. Performance measurement of the whole building technology was accomplished through the following steps (Figure 4.1):

1. Identify Matched Pair
    a. identify building(s) of interest for the study

   b. select baseline for comparison for sustainably designed building (e.g., matched pairs)

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 (metering equipment used to measure performance is outlined in section 4.2)
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 4.1 Whole Building Performance Measurement Protocol

4.1.3 **Stages of Test Design**

Demonstration of the two technology components was conducted in four operational phases. Stage one encompassed the demonstration of the design technology component. Stages 2 through 4 describe the steps and timeline for building construction, and subsequent evaluation of the high-performance building compared to its matched pair (Figure 4.2).

Stage one occurred from April 2008 through September of 2008 and involved conducting the whole building, integrated design process for CESS. The ESTCP team participated in and contributed to the design charrette; they assisted the design team with sustainable systems and technology information, and energy modeling assistance to optimize the design including setting the design performance criteria and conducting the modeling for the design building compared to base conditions required for LEED certification. Results of these activities were documented and assessed against the design performance objectives. Through the design process and identification of design objectives, the specifications for metering equipment necessary for stages two through four were also developed. Appendix A contains additional details regarding the models and methods used to aid the design process.

Figure 4.2 Demonstration Stages and Timeline

Stage two included the installation and calibration of energy and water metering equipment at the Longstreet Fire Station and at the high performance building (CESS) during 2010 continuing until March 2011 when construction was completed at CESS.

Stage three consisted of monitoring data collection for both buildings, quality assurance reviews, and data clean-up to provide a continuous year of data documenting the energy and water use. Data collection began in November 2010 for Longstreet and in April 2011 for CESS. After troubleshooting sensors and fixing data stream problems, the energy and water use data were

collected and archived from June 2011 through June 2012 for both buildings for analysis and comparison.

Stage four consisted of analyzing, summarizing and normalizing the data set for specific building performance metrics to allow for a comparison between the high-performance CESS and the Longstreet Fire Station. These summaries and comparisons and development of a draft report to communicate the findings were completed August 2012 through September 2012.

4.2 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The whole building performance assessment required that information on water, energy, indoor environmental quality, and occupant activities be collected on a similar building that had not been designed and constructed using the whole building integrated design process. Monitoring data for energy and water use collected at the Longstreet Fire Station comprise the baseline dataset for comparison with the CESS monitoring data for energy, water use, and indoor environmental quality. 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.

This section describes the installation of sensors and metering systems used to collect building performance data in the following tables, including descriptions of the specific measurements, installation points, and the number and type of devices that were used to assess each measurement performance objective during the operational stage of the project.

Sensors were installed as described in Tables 4.2 and 4.3, and connected to central data acquisitions systems. The data acquisition systems were set up to transmit and store all data captured by devices listed in Tables 4.2 and 4.3, 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. The system was connected to AC power with battery backup.

Table 4.4 lists information (other than metering data) that was collected and used to address performance measurement objectives.

Table 4-2. Parameters Measured and Sensor Installation Points at Longstreet Fire Station

Performance Objective	Parameter	Installation Point(s)	Number and Type of Devices	Brief Description of Device
2. Reduce MEASURED facility energy use (*Energy*)	Total building natural gas	Existing gas meter	One RioTronics or other pulse initiator on register head	Provide digital pulses to data acquisition system proportional to gas volume
	Domestic hot water natural gas	Install new gas meter on natural gas service to hot water heater	One new gas meter sized for hot water heater gas line	Gas meter should provide analog (e.g., 4-20mA or 0-5 VDC) signal to data acquisition system
	Vehicle bay heating natural gas	Install new gas meter on natural gas service to vehicle bay heating system	One new gas meter sized for gas line serving vehicle bay heating	Gas meter should provide analog (e.g., 4-20mA or 0-5 VDC) signal to data acquisition system
	Total building electric	Install three current transformers (CTs) and three potential transformers (PTs) on main service entrance to building	One Wescon 30-channel power meter in main electrical panel utilizing 6 channels for building main measurement	Connect advanced power meter with ModBus communications to Campbell data acquisition system
	Indoor temperature dormitory, operations, and vehicle bay	Install temperature probe	Install Omega Type T thermocouple	Provide thermocouple output to data acquisition system or analog output (e.g., 4-20mA or 0-5 VDC) for Temp/RH probe
5. Reduce MEASURED potable water consumption for domestic uses (*Water*)	Potable water	Install new whole building water meter	Neptune Trident Turbine Meter with Neptune Tricon/E Turbine Transmitter	Building total water meter for 2- to 10-in. pipe (3 gpm to 50 gpm) Provide pulse output from Tricon transmitter to data acquisition system.

Table 4.2. (continued)

Performance Objective	Parameter	Installation Point(s)	Number and Type of Devices	Brief Description of Device
7. Reduce MEASURED potable water use for vehicle washing (*Process Water*)	Potable water	Install meter on entry pipe to vehicle bay	One Neptune T-8 Disc Meters with Tricon Transmitter	End-use water meters in building for pipes 5/8 to 2 in. (0.25 gpm to 2 gpm) Provide pulse output from Tricon transmitter to data acquisition system.
11. Improve MEASURED indoor environmental quality[(a)] (*IEQ*)	Indoor temperature and RH	Install temperature probe	Install Omega Type T thermocouple or Intec Controls Temp/RH	Provide thermocouple output to data acquisition system or analog output (e.g., 4-20mA or 0-5 VDC) for Temp/RH probe

(a) Original test plan specified an Air Advice Indoor Air Quality system to monitor VOC and CO_2 levels. The cost of installing Air Advice equipment as originally planned was prohibitive. Air quality monitoring was not critical to demonstration analyses and post-construction air quality testing data were used to address the objective as well as .relative humidity and air temperature data that were collected and used to evaluate thermal comfort as part of indoor environmental quality.

Table 4-3. Performance Parameters Measured and Sensor Installation Points at the CESS Building

Performance Objective	Parameter	Installation Point(s)	Number and Type of Devices	Brief Description of Device
2. Reduce MEASURED facility energy use (*Energy*)	Total Building Electric	Install three current transformers (CTs) and three potential transformers (PTs) on main service entrance to building	Install two Wescon 30-channel power meters in main electrical panel utilizing six channels for building main measurement	Connect advanced power meter with ModBus communications to Campbell data acquisition system
	Solar hot water flow and temperature	Install temperature probe in thermo well in pipe	Install Omega Type T thermocouple	Provide thermocouple output to data acquisition system
	Solar Wall – delivered air flow (constant volume fan)	Use runtime measurements and one-time measurement to calculate flow	Contact closure to calculate runtime	Connect to data acquisition system
	Solar Wall – delivered air flow (variable volume fan)	Use General-purpose Air Velocity Transducers (hot wire)	Install Omega FMA-900-V or similar with analog output	Connect analog signal (e.g., 4-20mA or 0-5 VDC) to data acquisition system
	Solar wall – outdoor temperature and delivered air temperature	Install two temperature probes	Install Omega Type T thermocouple	Provide thermocouple output to data acquisition system
	Hot water electric and Vehicle bay electric heating	Install CTs on main lighting panel and/or additional lighting circuits	Connect CTs to additional three to six channels	Connect advanced power meter with ModBus communications to Campbell data acquisition system
	Indoor temperature of building and vehicle bay	Install temperature/RH probe	Install Omega Type T thermocouple or Intec Controls Temp/RH	Provide thermocouple output to data acquisition system or analog output (e.g., 4-20mA or 0-5 VDC) for Temp/RH probe
	PV panels – electrical generation	Install CTs on main lighting panel and/or additional lighting circuits	Connect CTs to additional three to six channels	Connect advanced power meter with ModBus communications to Campbell data acquisition system

Table 4.3. (continued)

Performance Objective	Parameter	Installation Point(s)	Number and Type of Devices	Brief Description of Device
5. Reduce MEASURED potable water consumption for domestic uses (*Water*)	Potable water	Install new whole building water meter	Neptune Trident Turbine Meter with Neptune Tricon/E Turbine Transmitter	Building Total water meter for 2- to 10-in. pipe (3 gpm to 50 gpm) Provide pulse output from Tricon transmitter to data acquisition system.
	Potable water	Install meter on entry pipe to vehicle bay	One Neptune T-8 Disc Meters with Tricon Transmitter	End-use water meters in building for pipes 5/8 in. to 2 in. (0.25 gpm to 2 gpm) Provide pulse output from Tricon transmitter to data acquisition system.
	Rain water	Install plumb-bob sensor that measures fluid level in tank	One plumb-bob sensor, sized appropriately for tank size, with analog output connected to data acquisition system	Mount float measurement sensor on top of tank, with plumb-bob at fluid level and provide access to tank water surface level
7. Reduce MEASURED potable water use for vehicle washing (Process *Water*)	Potable water	Install meter on entry pipe to vehicle bay	One Neptune T-8 Disc Meters with Tricon Transmitter	End-use water meters in building for pipes 5/8 in. to 2 in. (0.25 gpm to 2 gpm). Provide pulse output from Tricon transmitter to data acquisition system.
	Rain water	Install plumb-bob sensor that measures fluid level in tank	One plumb-bob sensor, sized for tank, with analog output connected to data acquisition system	Mount float measurement sensor on top of tank, with plumb-bob at fluid level and provide access to tank water surface level
11. Improve MEASURED indoor environmental quality[(a)] (*IEQ*)	Temperature and relative humidity	Install temperature/RH probe	Install Omega Type T thermocouple or Intec Controls Temp/RH	Provide thermocouple output to data acquisition system or analog output (e.g., 4-20mA or 0-5 VDC) for Temp/RH probe

(a) Original test plan specified an Air Advice Indoor Air Quality system to monitor VOC and CO_2 levels. The cost of installing Air Advice equipment as originally planned was prohibitive. Air quality monitoring was not critical to demonstration analyses and post-construction air quality testing data were used to address the objective as well as .relative humidity and air temperature data that were collected and used to evaluate thermal comfort as part of indoor environmental quality .

Table 4-4. Other Sustainable Design Metrics Measured for Comparison between Longstreet and CESS Buildings

Performance Objective	Parameter	Type of Information Collected	Location or Source
3. Reduce MEASURED GHG footprint (*Energy)*	Characteristics of primary fuel sources and measured energy use	Calculated using the eGRID emission factors for the SERC Virginia/Carolina (SRVC) region (EPA 2012)	EPA 2012; Energy use from metering data described in Tables 4.2 and 4.3
9. Reduce MEASURED post-occupancy solid waste (*Waste*) [(a)]	Pounds of solid waste recycled	Installation program summary data	Longstreet and CESS participate in the Fort Bragg "Green Boot" program to reduce, reuse, and recycle. Both buildings participate in the program.
Qualitative Performance Measures			
13. Increase MEASURED occupant satisfaction[(b)]	general building attributes, lighting quality, cleanliness and maintenance, acoustic quality, thermal comfort	Interviewed fire chiefs for each building multiple times. Held discussions with firefighters regarding occupant satisfaction during site visits	On-site and telephone interviews
14. Decrease Required Maintenance Actions	Number of routine and repair maintenance visits	Records of the date and maintenance actions taken over the analysis period for each building	Maintenance logs for Longstreet and CESS obtained from Fort Bragg staff

(a) Individual building data were not collected.
(b) A formal occupant satisfaction survey was initially planned using the CBE survey tool. During the project, it was determined that the CBE survey was not well-suited for the building type and occupancy. Therefore, interviews and on-site discussions were used to evaluate occupant satisfaction

4.3 OPERATIONAL TESTING

As part of this project, building commissioning was performed during and after design and construction to ensure that building systems performed interactively according to design intent and Ft. Bragg's operational needs. Each major system listed below was evaluated with respect to whether the equipment was installed correctly, and whether equipment performed correctly:

- Mechanical Systems
    - Water source heat pumps
    - Condenser water pumps
    - Outside air unit
    - Ductless split system air conditioning
    - Exhaust fans
    - High bay heating system
    - Building automation system (BAS)
    - Testing, adjusting and balancing (TAB)
- Plumbing Systems
    - Domestic hot water system
- Electrical Systems
    - Lighting controls.

The Commissioning Plan for the construction phase and the final summary report detailing the post-construction evaluation are included in Appendix G.

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. Fort Bragg continues to collect the building data through its utility management and control system, which may be useful if any follow-on analysis is deemed appropriate.

4.4 SAMPLING AND DATA COLLECTION PROTOCOL

This section lists the monitoring systems and data collected during the project and summarizes the number and types of samples (Tables 4.5 and 4.6). Building meters for monitoring electricity, natural gas, and water usage will be left in place in both buildings. Active monitoring for building comparison by the ESTCP project team has been concluded. The installation is encouraged to continue to monitor building performance and use the information to optimize how the buildings are working.

Table 4-5. Parameters Measured and Sampling Frequency

Performance Objective	Parameters		Number and Type of Samples
	Longstreet	CESS	
2. Reduce MEASURED facility energy use (*Energy*)	Electric: Total Building	Electric: Total building, HVAC	15-min data collected 24 hours/day, 7 days a week for a 12 months
	Natural Gas: Total Building, Hot water, Vehicle Bay Heating	Solar: hot water flow and temperature Solar Wall: delivered air flow (constant volume and variable volume fans) Solar wall–outdoor temperature and delivered air temperature	
	Indoor Temperature: dorm, Operations, and Vehicle Bay	Indoor temperature, rooms and Vehicle Bay	
5. Reduce MEASURED potable water consumption for domestic uses (*Water*)	Potable water	Rain water	15 minute data collected 24 hours/day, 7 days a week for a minimum of 12 months
		Potable water	
7. Reduce MEASURED potable water use for vehicle washing (*Process Water*)	Potable water	Rain water	15 minute data collected 24 hours/day, 7 days a week for a minimum of 12 months
		Potable water	
11. Improve MEASURED indoor environmental quality (*IEQ*)	Temperature Humidity	Temperature humidity	15 minute data collected 24 hours/day, 7 days a week for a minimum of 12 months

Table 4-6. Other Performance Metrics Collected for Assessment at CESS and Longstreet Fire Station

Performance Objective	Parameters	Number and Type of Samples
Quantitative Objectives		
3. Reduce MEASURED GHG footprint (*Energy)*	Characteristics of GHG emissions for the region and actual energy usage in each building	Energy usage summarized from metering data collected as described in Table 4.5. Emission characteristics defined using the eGRID emission factors for the SERC Virginia/Carolina (SRVC) region
9. Reduce MEASURED post-occupancy solid waste (*Waste*)	Pounds of solid waste disposed	Installation-level data provided by the Green Boot Program
	Pounds of solid waste recycled	Installation-level data provided by the Green Boot Program
13. Increase MEASURED occupant satisfaction	general building, lighting quality, maintenance, acoustic quality	Multiple interviews with fire station personnel
14. Decrease Maintenance Requirements	Number of site maintenance visits	Record of routine and repair maintenance calls during monitoring period

4.5 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

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 and will need to be continued if performance metrics continue to be collected for future assessments.

4.5.1 Calibration of Equipment

Meters and monitoring equipment were installed in the new and existing buildings while the new CESS was under construction. The sensors were calibrated according to manufacturer's instructions. 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.

4.5.2 Quality Assurance and Data Processing

Issues related to data quality and consistency are outlined here and reported in more detail in Appendix A. Inconsistencies and quality issues identified in data received from the subcontractor were classified according to the continuity and congruency of the data. The types of data errors encountered included data spikes or extreme values, and sections of missing or redundant data. These were identified in the incoming data by using a macro that performed checks of the data automatically as it was received.

Once aberrant data or missing data were identified, protocols were used to assess the data and either modify it for inclusion in the analysis or determine that it should not be used in the analysis. Non-continuous data indicates the meter read a negative usage and incongruent data indicates a missing data point. Data identified as missing took one of three forms (Figure 4.3). In each case, a decision must be made with how to treat the data. Discontinuous values that indicate a negative consumption are obviously incorrect; however, it is difficult decide if other missing values are actually bad information or if they merely reflect some atypical behavior of the building’s systems. In the first two cases in Figure 4.3, all data are considered to be valid and data are labeled as interpolated. This label indicates the data may be questionable. Further analysis is performed with the data to ensure the interpolated data convey realistic consumption across the period. In the third case in Figure 4.3, where the meter resumes at a lower value than the last recorded value, the data are simply considered to be lost. The point at which the data resume is considered to be a jog, while all timesteps since the last data point was received are categorized as missing. Missing data were either classified as missing values or identified as questionable meter values as described in Table 4.7.

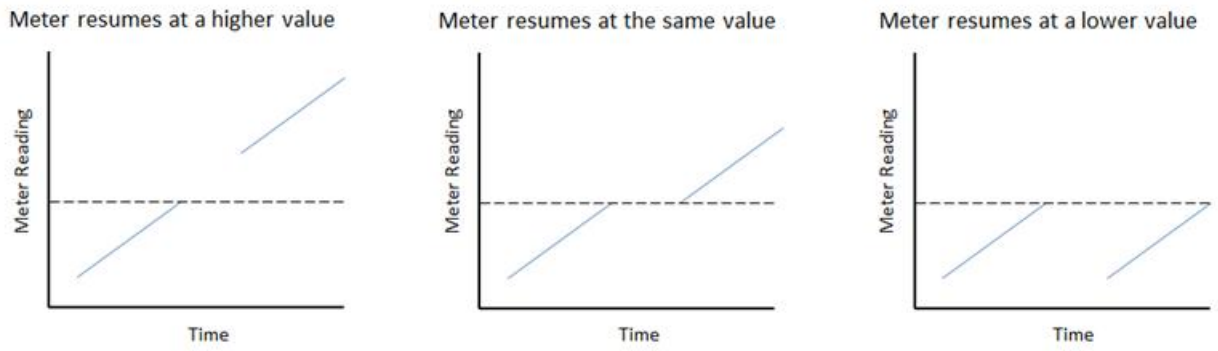


Figure 4.3. Forms of Missing Data in Fort Bragg Metering Data

The steps taken to process data for use in analysis are shown in Figure 4.4. The diagram shows that many data inconsistency errors are addressed in step K. The iteration of this step, followed by all downstream analysis, ensures a log of changes is maintained. This makes it possible to evaluate the effect of adjusted data points on the final values for the building performance assessment. Additional details describing each of the data processing steps are given in Appendix A.

Table 4-7. Methods of Identification and Modification of Missing Data

Data Provided at Time Step	Evaluation Step	Data Classification	Inclusion in Calculations
Yes	Data are congruent with previous data points	Data	Yes
Yes	Data show a negative consumption.	Jog	No
No	Values inferred based on a linear consumption between the two known points	Interpolate	Yes
No	Usage was not inferred because the usage would have been negative through the missing period.	Missing	No
Yes	Data was provided or calculated at the time step but it was determined to be erroneous	Override	No

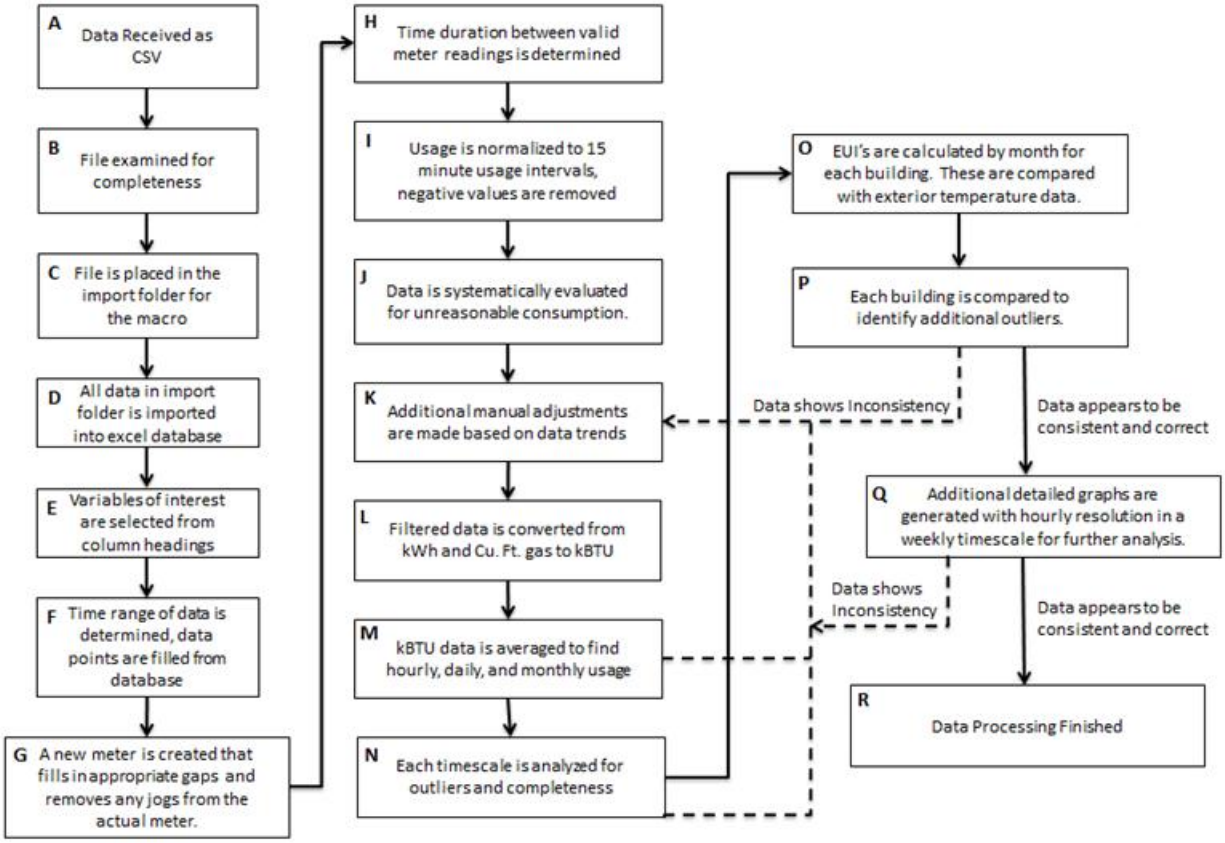


Figure 4.4. Data Flow and Evaluation Process

4.6 LEED CERTIFICATION AND MONITORING RESULTS

LEED documentation was provided by the design and construction team when final design documents and construction was completed. After documentation was collected and uploaded to LEED Online, the project began the formal Green Building Certification Institute (GBCI) review process. The LEED submittal was split into two phases: all design credits possible at the design phase (post final design documents) were submitted first, then the remaining credits or any design changes were submitted once the construction phase was completed. Table 4.8 shows the final LEED scorecard indicating the type and number of credits received for each LEED category. The number of credits achieved for final design and construction allowed the CESS building to be certified at the LEED Platinum level. LEED submittal details related to the ESTCP project objectives can be found in Appendix F.

Table 4-8. LEED Final Online Scorecard for Certification of the CESS Building

LEED-NC				*LEED-NC Version 2.2 Registered Project Checklist* *Community Emergency Services Station, Ft. Bragg, NC*			
Yes	?	No					
11		**3**		**Sustainable Sites**		**14** Points	**Status**
Y				Prereq 1	**Construction Activity Pollution Prevention**	Required	Earned
1				Credit 1	**Site Selection**	1	Earned
		1		Credit 2	**Development Density & Community Connectivity**	1	
		1		Credit 3	**Brownfield Redevelopment**	1	
		1		Credit 4.1	**Alternative Transportation**, Public Transportation Access	1	
1				Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1	Earned
1				Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	1	Earned
1				Credit 4.4	**Alternative Transportation**, Parking Capacity	1	Earned
1				Credit 5.1	**Site Development,** Protect of Restore Habitat	1	Earned
1				Credit 5.2	**Site Development,** Maximize Open Space	1	Earned
1				Credit 6.1	**Stormwater Design,** Quantity Control	1	Earned
1				Credit 6.2	**Stormwater Design,** Quality Control	1	Earned
1				Credit 7.1	**Heat Island Effect,** Non-Roof	1	Earned
1				Credit 7.2	**Heat Island Effect,** Roof	1	Earned
1				Credit 8	**Light Pollution Reduction**	1	Earned
Yes	?	No					
5				**Water Efficiency**		**5** Points	**Status**
1				Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1	Earned
1				Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1	Earned
1				Credit 2	**Innovative Wastewater Technologies**	1	Earned
1				Credit 3.1	**Water Use Reduction**, 20% Reduction	1	Earned
1				Credit 3.2	**Water Use Reduction**, 30% Reduction	1	Earned
Yes	?	No					
12		**5**		**Energy & Atmosphere**		**17** Points	**Status**
Y				Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required	Earned
Y				Prereq 2	**Minimum Energy Performance**	Required	Earned
Y				Prereq 3	**Fundamental Refrigerant Management**	Required	Earned
7		**3**		Credit 1	**Optimize Energy Performance**	1 to 10	Earned
2		**1**		Credit 2	**On-Site Renewable Energy**	1 to 3	Earned
1				Credit 3	**Enhanced Commissioning**	1	Earned
1				Credit 4	**Enhanced Refrigerant Management**	1	Earned
1				Credit 5	**Measurement & Verification**	1	Earned
		1		Credit 6	**Green Power**	1	

Yes	?	No					
Yes	?	No					
8		**5**		**Materials & Resources**		**13** Points	**Status**
Y				Prereq 1	**Storage & Collection of Recyclables**	Required	Earned
		1		Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1	
		1		Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1	
		1		Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1	
1				Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1	Earned
1				Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1	Earned
		1		Credit 3.1	**Materials Reuse**, 5%	1	
		1		Credit 3.2	**Materials Reuse**,10%	1	
1				Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1	Earned
1				Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1	Earned
1				Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regionally	1	Earned
1				Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regionally	1	Earned
1				Credit 6	**Rapidly Renewable Materials**	1	Earned
1				Credit 7	**Certified Wood**	1	Earned
Yes	?	No					
15				**Indoor Environmental Quality**		**15** Points	**Status**
Y				Prereq 1	**Minimum IAQ Performance**	Required	Earned
Y				Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required	Earned
1				Credit 1	**Outdoor Air Delivery Monitoring**	1	Earned
1				Credit 2	**Increased Ventilation**	1	Earned
1				Credit 3.1	**Construction IAQ Management Plan**, During Construction	1	Earned
1				Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1	Earned
1				Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1	Earned
1				Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1	Earned
1				Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1	Earned
1				Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1	Earned
1				Credit 5	**Indoor Chemical & Pollutant Source Control**	1	Earned

LEED-NC				*LEED-NC Version 2.2 Registered Project Checklist* *Community Emergency Services Station, Ft. Bragg, NC*			
Yes	?	No					
1				Credit 6.1	**Controllability of Systems**, Lighting	1	Earned
1				Credit 6.2	**Controllability of Systems**, Thermal Comfort	1	Earned
1				Credit 7.1	**Thermal Comfort**, Design	1	Earned
1				Credit 7.2	**Thermal Comfort**, Verification	1	Earned
1				Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1	Earned
1				Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1	Earned
Yes	?	No					
5				**Innovation & Design Process**		**5** Points	**Status**
1				Credit 1.1	**Innovation in Design: Exemplary Performance in WE 3**	1	Earned
1				Credit 1.2	**Innovation in Design: Public Education Program**	1	Earned
1				Credit 1.3	**Innovation in Design: Green Cleaning**	1	Earned
1				Credit 1.4	**Innovation in Design: Exemplary Performance in SS 7.1**	1	Earned
1				Credit 2	**LEED® Accredited Professional**	1	Earned
Yes	?	No					
56		**13**		**Project Totals (pre-certification estimates)**		**69** Points	
				Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points			

Examples of the monitoring data and selected results describing the water and energy building performance summaries are included here. For each of the energy and water use performance objectives listed in Table 4.4, the cleaned and processed data were reviewed by evaluating daily and monthly summaries of relevant metering information for each building. Table 4.9 provides an example of cleaned, summarized hourly metering data for the CESS building. A similar example summary of hourly metering data for the Longstreet Fire Station is shown in Table 4.10. Tables 4.11 and 4.12 list the record of maintenance calls made for each of the buildings during the monitoring period.

After data were reviewed and checked for consistency, energy and water use were summarized monthly and normalized by building square footage and occupancy. Figure 4.5 shows the monthly summaries of total energy usage (without normalization) by major usage for each of the two buildings. Figure 4.6 shows the average daily EUI (kBtu/sq ft) profile for each month between June 2011 and June 2012 for Longstreet and CESS in two panels. These figures indicate the differences seen in energy usage throughout the year by the two buildings. This difference is further illustrated in Figures 4.7 and 4.8, which highlight the difference in total energy use and EUI between the two buildings in August and January.

Table 4-9. Example of Summarized Hourly Metering Data for CESS

Year	Month	Day	Hour	CESS - Main (kBTU)	CESS - HVAC (kBTU)	CESS - Water Heater (kBTU)	CESS - Vehicle Bay (kBTU)	CESS - Rain Water 1 (Gal)	CESS - Rain Water 2 (Gal)	CESS - Water Main (Gal)	CESS - Water Vehicle Wash (Gal)	CESS - Solar Hot Water (Gal)	CESS - HP-1 Temp (F)	CESS - HP-2 Temp (F)	CESS - HP-3 Temp (F)	CESS - HP-4 Temp (F)	CESS - HP-5 Temp (F)	CESS - High Bay Temp (F)	CESS - Outdoor Temp (F)	CESS - HP-1 RH (%)	CESS - HP-2 RH (%)	CESS - HP-3 RH (%)	CESS - HP-4 RH (%)
2011	6	1	0	46.65	11.69	2.52	0.04474	0.0	0.0	0.0	0.0	9.6	67.3	74.0	70.5	72.0	85.6	85.7	83.1	64.8	62.0	62.0	59.8
2011	6	1	1	44.53	10.71	0.80	0.03412	0.0	0.0	0.0	0.0	0.0	67.3	74.1	70.4	72.0	84.6	84.7	80.8	64.8	62.0	61.8	59.0
2011	6	1	2	48.04	10.54	3.09	0.03412	0.0	0.0	0.0	0.0	0.0	67.2	73.9	70.1	71.9	84.2	84.2	79.0	65.0	61.8	62.0	59.0
2011	6	1	3	47.16	9.96	2.86	0.03412	0.0	0.0	0.0	0.0	0.0	67.2	73.9	69.8	71.8	84.2	84.2	77.8	66.3	61.3	61.0	59.3
2011	6	1	4	41.46	9.55	0.00	0.03412	0.0	0.0	0.0	0.0	0.0	67.1	74.0	69.8	71.8	83.9	83.9	76.0	67.0	63.0	61.8	59.8
2011	6	1	5	44.80	9.14	2.85	0.03412	0.0	0.0	0.0	0.0	0.0	67.1	74.2	69.7	71.8	83.3	83.7	75.3	67.0	65.0	63.8	61.5
2011	6	1	6	47.19	10.51	2.06	0.03412	0.0	0.0	0.0	0.0	0.0	67.3	74.2	69.9	71.7	79.2	79.7	75.0	64.3	65.0	63.3	61.0
2011	6	1	7	43.13	10.13	0.00	0.06824	0.0	0.0	7.0	0.0	0.0	67.4	74.0	70.0	71.9	78.2	78.0	76.9	66.0	65.5	62.5	61.0
2011	6	1	8	45.31	11.09	2.79	0.03412	0.0	0.0	0.0	0.0	0.0	67.3	74.1	70.6	71.7	79.8	79.6	81.2	65.8	64.3	61.0	60.3
2011	6	1	9	48.11	12.39	2.54	0.03412	0.0	0.0	0.0	0.0	86.7	67.3	74.0	70.9	71.8	81.5	81.1	84.4	63.8	62.3	56.8	57.5
2011	6	1	10	50.19	12.39	2.19	0.03412	0.0	0.0	0.0	0.0	-	67.4	74.1	71.6	71.8	83.1	82.9	87.7	64.8	60.5	55.0	57.0
2011	6	1	11	54.29	13.10	2.35	0.03412	0.0	0.0	0.0	0.0	-	67.6	74.1	72.5	72.1	84.4	84.2	89.9	63.3	60.3	53.3	56.5
2011	6	1	12	47.80	14.30	1.91	0.03412	0.0	0.0	0.0	0.0	220.0	67.6	74.2	72.4	72.1	85.8	85.6	92.4	62.8	60.8	52.3	56.0
2011	6	1	13	47.26	14.60	0.00	0.03412	0.0	0.0	0.0	0.0	0.0	67.8	74.4	72.3	72.2	87.1	86.9	95.6	65.3	60.5	53.8	56.5
2011	6	1	14	46.71	14.88	0.00	0.03412	0.0	0.0	0.0	0.0	20.0	67.7	74.4	72.2	72.2	88.2	88.1	96.7	63.8	60.0	54.0	57.3
2011	6	1	15	48.08	15.25	0.00	0.06824	0.0	0.0	0.0	0.0	0.0	67.9	74.6	71.8	72.3	88.6	88.6	95.6	64.8	61.8	54.8	56.5
2011	6	1	16	45.28	15.70	0.00	0.03412	0.0	0.0	0.0	0.0	176.0	67.7	74.5	71.6	72.2	89.0	88.9	96.7	63.3	63.5	55.5	57.3
2011	6	1	17	48.90	15.66	0.00	0.03412	0.0	0.0	0.0	1.0	1.0	67.7	74.5	71.8	72.0	89.1	89.1	95.2	64.3	60.8	55.5	57.8
2011	6	1	18	59.17	14.84	0.00	0.03412	0.0	0.0	0.0	1.0	19.0	67.7	74.5	72.1	71.9	89.6	89.6	94.7	64.0	61.5	55.8	58.0
2011	6	1	19	47.19	14.81	0.00	0.03412	0.0	0.0	0.0	0.0	0.0	67.6	74.4	71.9	72.0	89.1	89.2	92.7	63.8	60.8	56.0	57.8
2011	6	1	20	45.89	13.82	0.00	0.03412	0.0	0.0	0.0	0.0	0.0	67.4	74.2	71.5	71.9	87.4	87.6	88.9	63.5	62.8	55.3	57.3
2011	6	1	21	58.24	13.44	5.19	0.03412	0.0	0.0	0.0	0.0	0.0	67.4	74.1	70.9	71.8	86.1	86.1	86.6	64.5	62.3	55.8	57.0
2011	6	1	22	54.39	12.97	3.03	0.06824	0.0	0.0	0.0	0.0	0.0	67.0	74.1	70.8	72.0	85.6	85.7	86.3	63.8	63.0	56.8	56.8
2011	6	1	23	51.28	13.20	0.12	0.03412	0.0	0.0	0.0	0.0	0.0	66.8	74.0	70.7	71.9	85.0	85.1	83.6	64.8	64.3	60.0	60.0

Table 4-10 Example of Monitoring Data Received for Longstreet Fire Station

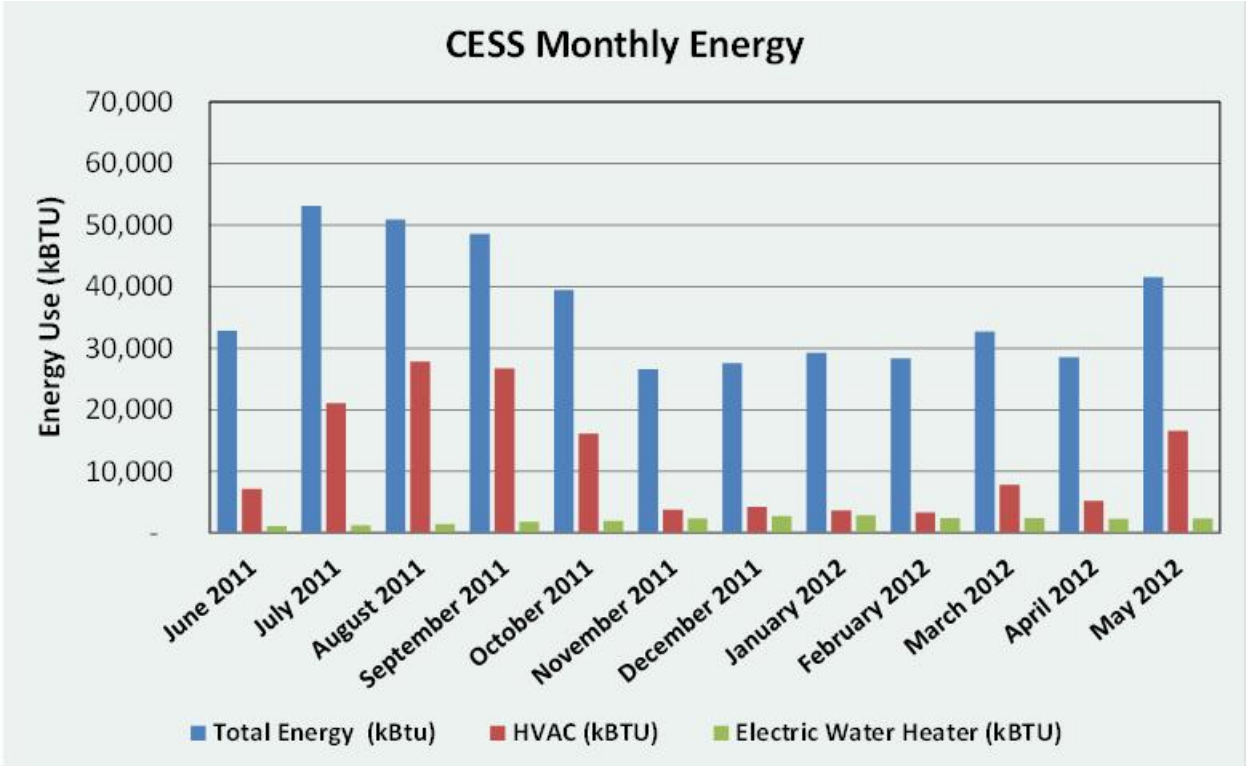
Year	Month	Day	Hour	Periods	LS - Energy Total (kBTU)	LS - Main Energy (kBTU)	LS - MDP Energy (kBTU)	LS - RP Energy (kBTU)	LS - WN-EP Energy (kBTU)	LS - Water Main (Gal)	LS - Water Vehicle Wash 1 (Gal)	LS - Water Vehicle Wash 2 (Gal)	LS - Main Gas (kBTU)	LS - Gas Bay Heat 3 (kBTU)	LS - Gas Bay Heat 4 (kBTU)	LS - Water Heater 2 (kBTU)	LS - Outside Air Temp (F)	LS - Dorm Temp (F)	LS – Oper. Temp (F)	LS - Vehicle Bay Temp (F)
2011	6	1	0	4	39.76	40.21	18.30	12.89	8.48	2.49	0.00	0.00	0.00	6.05	0.00	0.04	83.28	67.83	70.82	83.44
2011	6	1	1	4	39.34	39.34	17.45	8.59	7.51	4.90	0.00	0.00	0.00	0.00	0.00	0.00	81.37	67.44	70.89	82.78
2011	6	1	2	4	47.87	37.57	17.10	8.04	7.29	2.50	0.00	0.00	10.30	5.15	0.00	0.00	79.90	67.00	70.42	82.29
2011	6	1	3	4	37.53	37.53	16.73	7.41	7.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	78.22	66.30	69.92	81.25
2011	6	1	4	4	37.16	37.16	16.43	6.58	7.11	0.00	0.00	0.00	0.00	5.15	0.00	0.00	76.60	65.72	70.15	80.42
2011	6	1	5	4	38.52	28.22	5.24	5.73	4.33	12.20	0.00	0.00	10.30	3.09	0.00	1.03	75.67	66.38	70.44	79.98
2011	6	1	6	4	34.46	34.46	0.19	17.57	4.68	26.80	0.00	0.00	0.00	5.15	0.00	0.00	76.07	68.37	67.28	79.07
2011	6	1	7	4	35.48	25.18	3.49	8.53	4.08	17.10	11.51	0.00	10.30	5.15	0.00	0.00	76.96	69.44	67.57	77.41
2011	6	1	8	4	31.05	31.05	9.76	2.57	4.37	41.50	0.00	0.00	0.00	5.15	0.00	0.00	80.29	69.59	70.77	79.12
2011	6	1	9	4	20.64	20.64	0.19	5.14	2.15	9.70	0.00	0.00	0.00	0.00	0.00	0.00	84.32	70.96	71.57	79.33
2011	6	1	10	4	28.11	17.81	0.19	7.11	2.24	4.90	0.00	0.00	10.30	5.15	0.00	0.00	88.48	72.64	72.34	79.61
2011	6	1	11	4	43.44	43.44	19.54	9.37	6.27	2.40	0.00	0.00	0.00	0.00	0.00	0.00	92.42	72.04	73.67	80.92
2011	6	1	12	4	39.10	39.10	20.36	12.62	6.69	4.90	0.00	0.00	0.00	6.18	0.00	1.03	95.82	71.05	73.87	81.83
2011	6	1	13	4	37.74	37.74	15.45	15.60	5.91	2.50	0.00	0.00	0.00	0.00	0.00	0.00	98.25	70.99	74.37	83.10
2011	6	1	14	4	36.74	26.44	0.19	17.10	3.44	78.00	0.00	73.13	10.30	5.15	0.00	0.00	100.94	73.20	74.40	87.41
2011	6	1	15	4	35.83	35.83	8.15	19.53	5.44	4.90	0.00	0.00	0.00	0.00	0.00	0.00	102.44	74.45	74.39	91.71
2011	6	1	16	4	39.55	39.55	14.06	19.70	6.68	2.50	0.00	0.00	0.00	6.18	0.00	0.00	101.61	73.99	74.68	91.89
2011	6	1	17	4	38.39	38.39	14.65	19.17	6.64	2.40	0.00	0.00	0.00	0.00	0.00	0.00	100.12	73.69	74.74	91.67
2011	6	1	18	4	40.67	30.37	12.57	10.35	6.81	0.00	0.00	0.00	10.30	5.15	0.00	0.00	97.36	73.45	75.40	88.01
2011	6	1	19	4	33.75	33.75	13.41	12.14	7.18	2.40	0.00	0.00	0.00	0.00	0.00	1.03	94.18	73.35	74.81	86.71
2011	6	1	20	4	41.15	41.15	13.00	12.55	6.94	4.90	0.00	0.00	0.00	5.15	0.00	0.00	89.23	73.26	74.94	86.85
2011	6	1	21	4	45.18	45.18	18.72	11.75	7.66	7.30	0.00	0.00	0.00	0.00	0.00	0.00	86.93	71.98	75.11	86.44
2011	6	1	22	4	52.88	42.58	18.33	9.04	7.36	7.40	0.00	0.00	10.30	6.18	0.00	0.00	84.85	70.99	75.25	86.17
2011	6	1	23	4	40.60	40.60	17.63	8.27	7.24	9.70	0.00	0.00	0.00	0.00	0.00	0.00	81.59	70.44	74.78	85.02

Table 4.11. Maintenance Log for the CESS

DMO#	Created	PRI	Shop	Comp	Bldg#	Short Description	Status
100000649770	09/22/2011	1	136	24	L3602	24/L3602/ HVAC SYSTEM BURNING	COMPLETED
100001063377	05/08/2012	2	136	24	L3602	24/L3602/ALARM GOING OFF IN THE INTERIOR	CANCELED
100000829954	01/06/2012	2	130	24	L3602	24/L3602/LOOP PUMP INOP,VFD INOP,24	COMPLETED
100000990136	03/29/2012	2	441	93	L3602	93/L3602 REFUEL GENERATOR	COMPLETED
100001028159	04/19/2012	2	133	07	L3602	07/L3602/REPLACE LIGHT FIXTURES	COMPLETED
100000587618	08/17/2011	2	130	08	L3602	08/L3602/AUTOMATIC SHUT OFF INOP	COMPLETED
100001028355	04/19/2012	2	138	38	L3602	38/L3602/COMPRESSOR AIR LINE IS LEAKING	ACTIVE
100000622808	09/06/2011	2	130	FA	L3602	FA/L3602 NEW FIRE STATION ALARM TROUBLE	COMPLETED
100000902503	02/13/2012	2	130	25	L3602	25/L3602/THE APPARATUS BAY(RM 128)HEAT P	COMPLETED
100001126852	06/11/2012	2	136	24	L3602	24/L3602/AIR HANDLER #3 DOES NOT	COMPLETED
100001109382	06/01/2012	2	133	07	L3602	07/L3602/4 LIGHTS OUT IN MP SECTION	COMPLETED
I 00000791182	12/12/2011	2	137	08	L3602	08/L3602/HOT WATER IN ALL TAPS	COMPLETED
100000788067	12/09/2011	3	133	07	L3602	07/L3602/REPLACE 10 QTY 4 FLUORESCENT LG	COMPLETED
100000582748	08/15/2011	3	130	07	L3602	07/L3602/LIGHT SENSOR INOP IN HALLWAY AR	COMPLETED
100001163002	06/28/2012	3	138	38	L3602	38/L3602/AIR COMPRESSOR NOT WORKING	ACTIVE
100001123406	06/08/2012	3	138	22	L3602	22/L3602 RM 107 RPR LOOSE FLOORING	ACTIVE
100000940680	03/05/2012	3	138	50	L3602	50/L3602/INSTALL I INTERIOR SIGN, 1 OF 5	COMPLETED
100000940689	03/05/2012	3	138	50	L3602	50/L3602/INSTALL ONE EXTERIOR SIGN (24X2	COMPLETED
100000941060	03/05/2012	3	138	50	L3602	50/L3602/INSTALL 1 INTERIOR SIGN, 2 OF 5	COMPLETED
100000941061	03/05/2012	3	138	50	L3602	50/L3602/INSTALL I INTERIOR SIGN, 3 OF 5	COMPLETED
100000941062	03/05!2012	3	138	50	L3602	50/L3602/INSTALL 1 INTERIOR SIGN, 4 OF 5	COMPLETED
100000941063	03/05/2012	3	138	50	L3602	50/L3602/INSTALL I INTERIOR SIGN, 5 OF 5	COMPLETED
100000582746	08/15/2011	3	133	07	L3602	07/L3602/LIGHT BULBS CHANGED IN HALLWAY	COMPLETED

Table 4.12. Maintenance Log for Longstreet

DMO #	Created	PRI	Shop	Comp	Bldg #	Short Description	Status
100000768828	11/30/2011	1	441	56	B7002	56/B7002 FIRE STATION BAY DOOR STUCK ITC	COMPLETED
100000963216	03/15/2012	1	136	25	B7002	25/B7002/AHU MOTOR BLEW OUT	COMPLETED
100000814393	12/28/2011	1	441	56	B7002	56/B7002/BAY DOOR HALF OPEN UJJ	COMPLETED
100000788158	12/09/2011	2	441	56	B7002	56/B7002 BAY DOOR REPAIR UJJ	COMPLETED
100000703603	10/24/2011	2	137	08	B7002	08/B7002/LOCATE PLUMBING LEAK	COMPLETED
100000772941	12/02/2011	2	136	25	B7002	25/B7002/HEAT INOP-TRAINING ROOM	COMPLETED
100000776967	12/05/2011	2	441	56	B7002	56/B7002/BAY DOOR #4 STUCK IN CLOSED POS	COMPLETED
100000487912	06/23/2011	2	133	07	B7002	07/EXIT LIGHTS IN BUNKER AREA INOP	COMPLETED
100001049779	05/01/2012	2	441	FA	B7002	FA/B7002/FIRE ALARM PANEL IS DISPLAYING	COMPLETED
100001050092	05/01/2012	2	441	FA	B7002	FA/B7002 FIRE ALARM DISPLAYING TROUBLE	CANCELED
100000714998	10/31/2011	2	137	08	B7002	08/NO HOT WATER	COMPLETED
100001050736	05/01/2012	2	133	07	B7002	07/B7002/EXIT LIGHT AT FRONT ENTRY INOP	COMPLETED
100000667557	10/05/2011	2	138	72	B7002	72/B7002/RM 101 MOLD	COMPLETED
100000913246	02/17/2012	2	134	27	B7002	27/B7002/LOCK INOP TO LOGISTICS EXIT DR	COMPLETED
100000959282	03/14/2012	2	136	25	B7002	25/AHU MOTOR BLEW OUT	CANCELED
100000667555	10/05/2011	2	137	08	B7002	08/B7002/KITCHEN SINK FAUCET LEAKING	COMPLETED
100000703754	10/24/2011	2	138	72	B7002	72/REMOVE MOLD RM 125	COMPLETED
100000703756	10/24/2011	2	137	08	B7002	08/RM 125/REP LEAK COMING THROUGH DRYWAL	CANCELED
100000693274	10/19/2011	2	137	08	B7002	08/B7002/RM 101 CONTINUED MOLD ISSUE	COMPLETED
100000748318	11/17/2011	2	136	25	B7002	25/B7002/RE-LIGHT PILOT LIGHT ON WATER H	COMPLETED
100000882090	02/03/2012	3	441	56	87002	56/REP BAY DOOR #4/SENSOR INOP UJJ	COMPLETED
100000703840	10/24/2011	3	138	96	B7002	96/RM 125 CUT HOLE IN SHEETROCK FOR PLUM	COMPLETED
100000671228	10/06/2011	3	137	08	B7002	08/B7002 SINK LEAK	CANCELED
100000712590	10/27/2011	3	138	96	B7002	96/B7002/REPAIR SHEETROCK WALLS IN LATRI	COMPLETED
100000508854	07/05/2011	3	137	08	B7002	08/B7002 LOW PRESSURE TO SHOWER	COMPLETED
100000845796	01/17/2012	3	441	56	B7002	56/B7002/BAY DOOR DAMAGED ITC ctj	COMPLETED
100000727384	11/04/2011	3	138	23	B7002	23/B7002/FABRICATE CLEANOUT COVER	COMPLETED
100000681887	10/13/2011	3	133	07	B7002	07/MALE LATRINE LIGHTING INOP	COMPLETED
100000681888	10/13/2011	3	133.	07	B7002	07/DAY ROOM LIGHTING INOP	COMPLETED
100000681889	10/13/2011	3	133	07	B7002	07/KITCHEN LIGHTING INOP	COMPLETED
100000681890	10/13/2011	3	133	07	B7002	07/OPEN BAY EXIT LIGHTS INOP	COMPLETED
100000940582	03/05/2012	3	441	FS	B7002	FS/B7002/INSTALL GOVT ISSUE PARTS ITC ct	COMPLETED
100000482565	06/21/2011	3	138	50	B7002	50/RELOCATE SIGN B7002	COMPLETED
100000903825	02/13/2012	3	441	56	B7002	56/B7002/BAY DOOR #4/SENSOR SENSOR NEEDS	COMPLETED



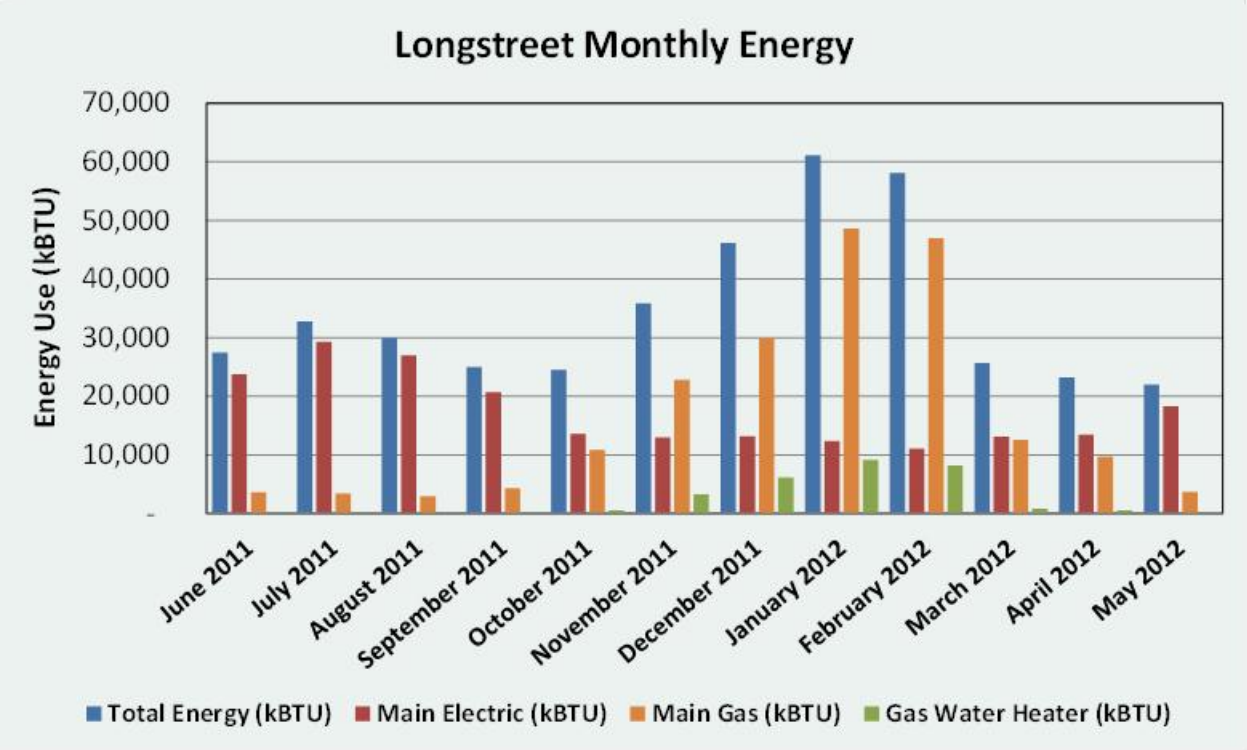


Figure 4.5. Total monthly energy use for the metering points in CESS and Longstreet Fire Station

The CESS annual EUI (kBTU/sq ft) is lower than the annual EUI for Longstreet. The energy use profiles by month are very different because of the type of HVAC equipment used and the differences in fuel source used. CESS uses only electricity and is equipped with a ground source heat pump. Longstreet uses electricity for cooling and plug load and natural gas for heating, hot water, and cooking. The CESS uses less heating energy than Longstreet during the winter months but uses greater energy amounts for cooling during the summer months. HVAC energy use at CESS is less than 50% of the total energy use except during August and September when the HVAC usage increases to 55% of the total energy use. These were the months when a humidistat was temporarily installed that kept the HVAC systems operating at a higher than expected rate, so this type of use may not be seen in future summer/fall months after the designed temperature and humidity control system was repaired and tested. Another difference is that the CESS building is ventilated 24 h/day, 7 days/week (i.e., always using energy to run the fans, and potentially increasing the heating and cooling loads), whereas Longstreet HVAC fans only operate when there is a cooling or heating demand. This difference in systems and operation is related LEED criteria for ventilation as well as updated building codes and thus, is an unavoidable design trade-off.

The CESS building appears to support a higher baseload energy demand during the entire monitoring period. The cause of the higher baseload is not readily apparent when considering the equipment in use at the buildings; however, the control systems and ventilation systems are different for the two buildings. Detailed submetering would need to be installed to identify and resolve the sources of the baseload energy differences between the buildings.

Figure 4.6 shows the average daily 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 4.7 isolates one summer and one winter month to highlight differences in the EUI daily profile.

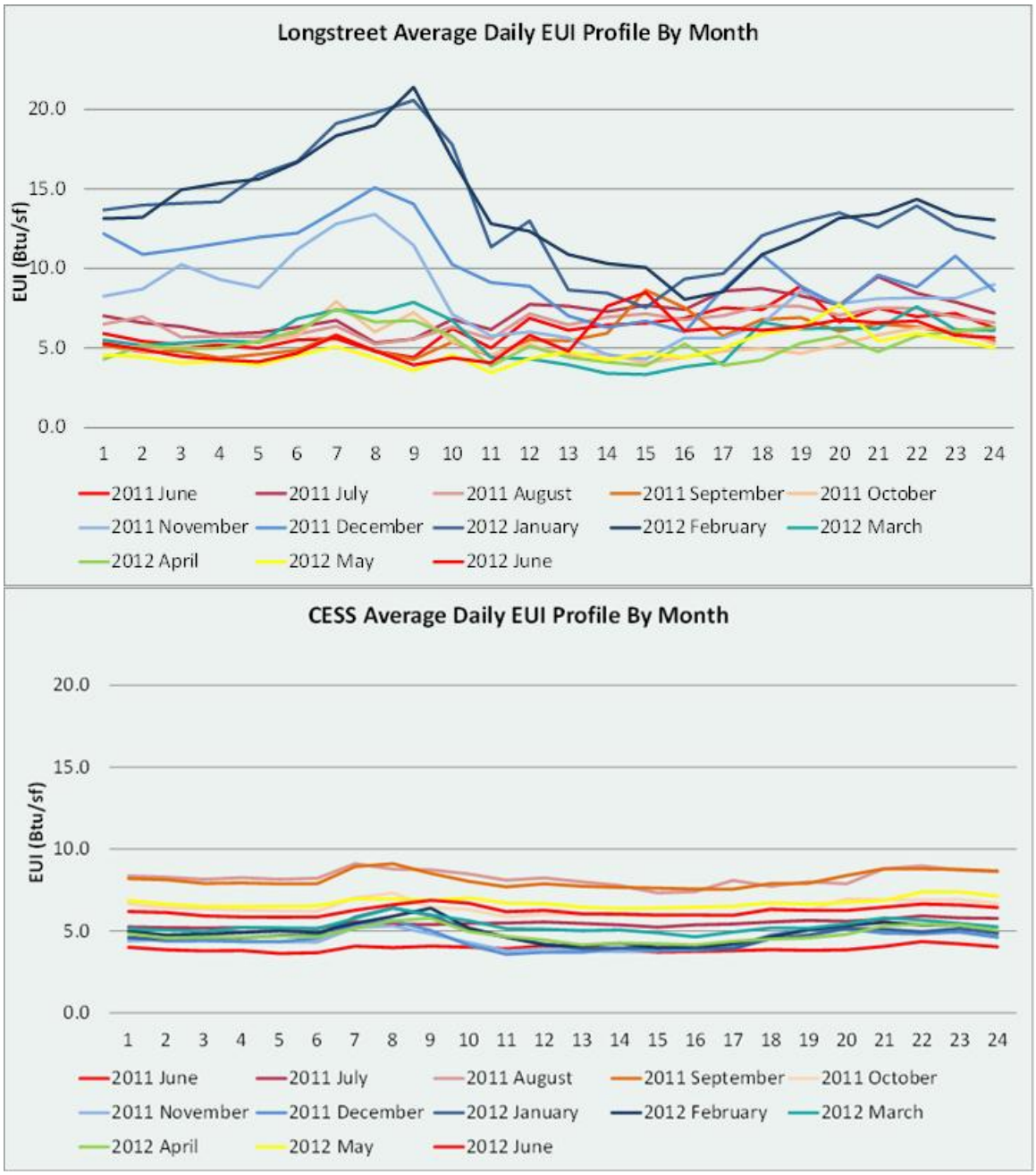


Figure 4.6. Example of the Average Daily Energy Use Intensity Calculated using Daily Average Values for the Monitoring Period

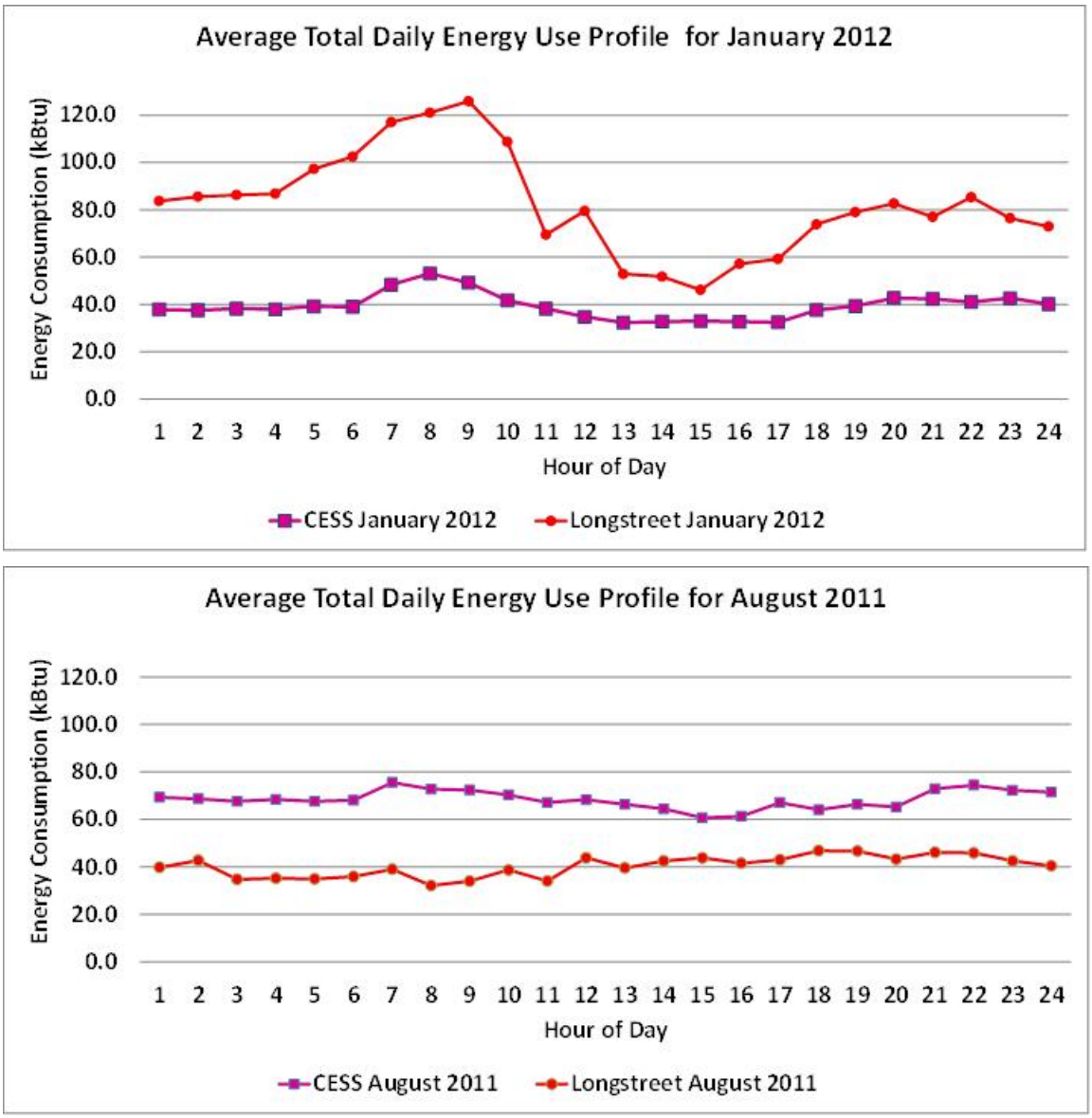


Figure 4.7. Average Total Daily Energy Use for January and August for Longstreet and CESS Buildings

5.0 PERFORMANCE OBJECTIVES

There are two key components of this ESTCP demonstration project. The first component involves bringing together the design team and demonstrating the integrated whole building design process, which includes identifying and analyzing design objectives for all the disciplines considered in whole building design. The design of the high performance building (the Fort Bragg CESS) is intended to meet these sustainable design objectives.

The second demonstration component involves evaluating the performance of CESS in reducing metered energy and water use, while maintaining comfortable indoor temperatures, and not increasing operations and maintenance when compared to a typical building of similar size and function (Longstreet). This required the collection of monitoring data, normalization of those data sets for the size of the buildings and occupancy, and analysis of measured whole building performance. Each performance objective is identified as either a "DESIGN" or a "MEASURED" objective in order to clarify how the data are used in analyzing the two demonstration components. Primary references for this section are the USGBC *LEED for New Construction Reference Guide* Version 2.2 (October 2005) and the *Building Cost and Performance Metrics: Data Collection Protocol* Revision 2 (September 2009).

Fourteen specific performance objectives are listed in Table 5.1, and described in detail in the following sections. The six objectives labeled DESIGN apply only to design factors for the high performance building, that is, CESS—these objectives track the integrated design component of the technology. The seven objectives labeled MEASURED refer to measurements and comparisons of the two buildings considered in the demonstration, that is, the Longstreet Fire Station and CESS. These seven objectives provide the criteria and metrics to assess the second technology demonstration component, the performance of the CESS building.

Thirteen performance objectives were originally specified in the demonstration plan for the project. Over the course of the demonstration, it was determined that two objectives could not be measured as initially planned—numbers 9 and 11, which involved measurement or quantification of building waste and recycling and measurement of indoor air quality, respectively. Waste and recycling is measured at the installation level, and Fort Bragg participates in a Green Boot program that promotes waste reduction and recycling installation-wide. The project team also added a measurement objective to evaluate and compare the required maintenance for the two buildings during the monitoring time period. Table 5.2 provides the quantitative and qualitative performance objectives, metrics used to assess success in obtaining objectives and reports whether objectives were fully attained during the monitoring period.

5.1 DESIGN OBJECTIVES

During the design and construction stages, the USGBC's LEED rating system was used to evaluate the design of the new fire station. The project is registered under the LEED version 2.2. Within LEED there are five main categories of design, which are referenced in the metrics in Table 5.1 below and previously described in Section 4.

- Sustainable Sites (SS)
- Water Efficiency (WEc)
- Energy and Atmosphere (EAc)
- Materials and Resources (MR)
- Indoor Environmental Quality (IEQ).

5.1.1 Design Energy Performance Objectives

Energy use is the most frequently tracked metric for high performance and sustainably designed buildings. Reducing energy consumption has a major impact on a building's environmental footprint, including carbon related impacts.

Objective 1: Reduce DESIGN energy consumption, involved establishing design goals and participating in the design charrette in order to provide integrated design and energy efficiency design expertise. The primary energy design metric tracked for this objective was the LEED Energy and Atmosphere credit 1 (EAc1), *Optimize Energy Performance*. EAc1 is used to measure how much better expected energy performance is over a design baseline established by the ASHRAE/IESNA Standard 90.1-2004. The credit is evaluated based on estimated energy costs during operation, which for the CESS was the same as energy performance. The energy use for the baseline and design building was estimated using the energy model, eQuest. The energy savings was derived by comparing the modeled energy use (EU) of the baseline building to the modeled energy use of the design. The energy models use the same footprint and building orientation. The energy efficiency improvements are typically found in the building envelope, lighting systems, and heating, cooling, and air conditioning (HVAC) systems. Detailed design specifications and energy modeling expertise are needed for this design feature to be correctly implemented. The equation used to determine whether the modeled performance met the success criteria is:

Percent Difference for Design Energy Savings =
100 * [1 – (Modeled EU of Proposed Design in BTUs/sq ft ÷ Modeled EU of Baseline in BTUs/sq ft)]

Objective 1 was not met; success criterion was to achieve a 50% reduction in designed energy use over the ASHRAE baseline case and modeled energy usage of design was only 34% less than ASHRAE baseline building. The modeled percent cost savings of the CESS design compared to ASHRAE baseline building was 35.3%. The original performance design objective for energy was a challenge goal developed to inspire the design team to "think outside" of traditional design approaches for the CESS. In evaluating this objective, In considering this objective, note that energy design is only a single component of whole building design, and some energy technologies or strategies that were considered for the design to provide additional energy savings were not cost-effective for the building site (lack of existing infrastructure) and building functions that were required.

5.1.2 **Design Water Performance Objectives**

Two water design metrics were tracked for this project. The primary indoor domestic water design metric being tracked is the LEED Water Efficiency credit 3 (WEc3), Water Use Reduction, and WEc2, Innovative Wastewater Technologies is used to measure the reduction in wastewater generation and potable water demand.

Table 5-1. Design Performance Objectives and Metrics

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Objectives				
1. Reduce DESIGN energy consumption (*Energy*)	Modeled energy use as estimated for LEED credit EAc1	Model energy use of final high performance design and compare it to ASHRAE 90.1-2004 theoretical building baseline	50% reduction in BTU/square foot	Achieved energy savings of 34% and energy cost savings of 35% using the ASHRAE Standard 90.1-2004 Appendix G. Received EAc1 credits.
4. Reduce DESIGN potable water consumption for domestic uses (*Water*)	Modeled potable water use as estimated for LEED credit WEc3	Model/estimate domestic water use of final high performance design and compare to EPAct 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.
6. 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 final 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.
8. Reduce construction waste during DESIGN and construction phases (*Waste*)	Reduction of construction waste through recycling as documented through LEED credit 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				
10. 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.
12. 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

Objective 4: Reduce DESIGN potable water consumption for domestic uses, was accomplished through establishing design goals and participating in the design charrette to integrate water efficiency design expertise in the building plans. WEc3 is used to measure how much better the building design water use is over a design baseline established using the Energy Policy Act of 1992 fixture performance requirements. This design metric is used to estimate water use efficiency for only toilets, urinals, bathroom faucets, showers, and kitchen sinks. Any additional domestic water use in the building is not included in this metric. The credit is evaluated based on estimated occupant use and fixture flow rates. Water savings is derived by comparing the modeled water use of the baseline design building to the modeled water use of the CESS design. The water efficiency improvements are typically found by using low flow fixtures. The equation used to determine whether the metric met the success criteria follows:

> Percent Difference of Design Water Savings = 100 * 1 – (Modeled Water Use of Proposed Design in gallons per occupant/Modeled Water Use of Baseline in gallons per occupant)

Objective 4 was met; modeled water use for the CESS high performance building achieved an 83% reduction in total potable water use over the baseline building case.

Objective 6: Reduce DESIGN potable water use for vehicle washing, involved replacing potable water used for vehicle washing with captured rainwater. The relevant water design metric tracked for this objective was the LEED Water Efficiency credit 2 (WEc2), Innovative Wastewater Technologies. Similar to the WEc3 calculations performed for Objective 4, the wastewater use is estimated from the fixture types and assumed occupancy use. For the CESS rainwater capture system, the estimated annual volumes of water that would displace potable water use was subtracted from the annual sewage generation volumes.

Wastewater avoidance is derived by comparing the modeled wastewater quantity of the baseline design building to the modeled wastewater quantity of the CESS design. The wastewater reduction strategies for the CESS included using low flow fixtures and rainwater capture for toilet water use and vehicle washing. The equation used to determine whether the metric met the success criteria follows:

> Percent Difference of Design Wastewater Avoidance = 100 * [1 – (Modeled Wastewater generation of Proposed Design in gallons per occupant/Modeled Wastewater generation of Baseline in gallons per occupant)]

Objective 6 was met; the inclusion of rainwater capture and use to displace potable water achieved significant reductions (100% reduction in potable water used for sewage conveyance compared to the baseline building with sufficient amounts of harvested rainwater to support vehicle washing).

5.1.3 Design Material and Resource Objectives

Objective 8: Reduce construction waste during DESIGN and construction phases, involved establishing goals for construction waste reduction through a construction waste management plan. This plan was developed and implemented to divert construction debris from disposal in landfills and incinerators. The design metric tracked for the reduction of construction waste

through recycling and reuse was LEED Materials and Resources credit 2.1 and 2.2 (MRc2). MRc2 evaluates the project's construction waste management plan implementation for 75% of the potential construction waste. The plan should include estimated quantities of each material, a specific area designation on the construction site for recyclable materials and identification of construction haulers and recyclers to handle the materials. These materials may include (but are not limited to) cardboard, metal, brick, acoustical tile, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. Before construction, the team should ensure that jobsite personnel understand their roles in the program. The construction team is responsible for obtaining and retaining verification records to confirm the diverted materials have been recycled or salvaged.

Calculations may be done by weight or volume and are based on the amount of waste diverted from the landfill or incineration compared to the total amount of waste generated on-site. The equation used to determine whether the metric met the success criteria follows:

> Percent Construction Waste Diverted = 100 * [1 – (Amount of Waste Diverted/Total Amount of Waste Generated)]

Objective 8 was met: 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 10: Achieve LEED Platinum rating for high performance building, involved using 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; the design and construction was documented using the LEED rating system and was certified by the USGBC as LEED Platinum (Table 4. and Appendix A).

Objective 12: Reduce environmental impact of materials specified in DESIGN, involved establishing goals for environmentally preferable materials in design documents and ensuring such materials are available for purchase by the contractor.

The design metrics related to materials being tracked for this project were LEED Materials and Resources credits MRc4, MRc5, MRc6, MRc7, and Indoor Environmental Quality credit EQc4. These credits 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.

Objective 12 was met; the LEED submittal received each of these credits:

- achieved a combined recycled content value (as a percentage of total materials cost) of 28.5% for MRc4
- achieved a local material value (as a percentage of total materials cost) of 24.8% for MRc5

- 2.97% of the total materials used are from rapidly renewable sources for MRc6
- 81.99% of the total wood-based building material cost were doors constructed of FSC certified products for MRc7

5.2 MEASUREMENT AND ASSESSMENT PERFORMANCE OBJECTIVES

These performance objectives were developed to compare the energy use, water use, waste generation and indoor environmental quality of the high performance CESS building with the baseline Longstreet Fire Station. Table 5.2 indicates the objectives, success criteria and results for the high-performance CESS building compared to the Longstreet Fire Station.

5.2.1 Measured Performance Objectives for Energy

Objective 2: Reduce MEASURED facility energy use was evaluated by metering energy use, normalizing the energy use by square footage and number of occupants, and comparing the normalized energy use of the high performance building (CESS) to the existing baseline building (Longstreet). The energy use was metered and recorded every 15 minutes from June 2011 through June 2012. The detailed 15-minute data was used to analyze the daily and weekly use of energy for each building. These data were summed into monthly and annual values for summary analysis (Figures 3.1 and 3.2).

The CESS building energy use includes electricity only. The Longstreet building energy use involves electricity and natural gas. The metered energy use is converted to British Thermal Units (BTUs) so that energy use for each building can be compared with like units. The equations used to convert electricity (kilowatt hours) and natural gas (cubic feet) to BTUs are:

1 kilowatt hour (kwh) electricity = 3413 BTUs electricity
1 cubic foot (cf) natural gas = 1029 BTUs natural gas
Total building energy use = BTUs electricity + BTUs natural gas

The total building energy use is commonly normalized using the building size (square footage), creating a metric referred to as Energy Use Intensity (EUI). For the purposes of this demonstration, we normalized energy use not only by building square footage, but also by the number of regular building occupants. The CESS and Longstreet buildings' energy use are compared using these normalized values in Figures 5.1 and 5.2.

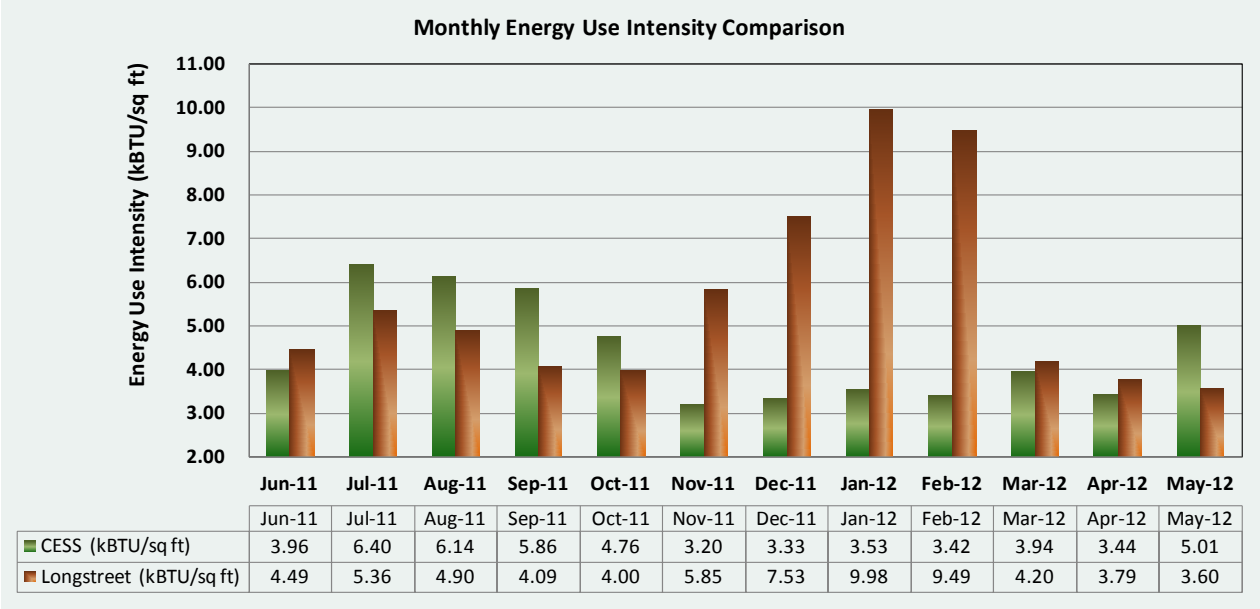
Table 5-2. Performance Measurement Objectives, Success Criteria and Demonstration Results

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Objectives				
2. 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/sq ft and 33% decrease in energy use/occupant
3. 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
5. 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
7. 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. The metering data for potable water used for vehicle washing at CESS may or may not be valid
9. 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 is available at the Installation-level only. Both buildings are certified through the "Green Boot" program for recycling and waste reduction at Fort Bragg

Table 5.2. (continued)

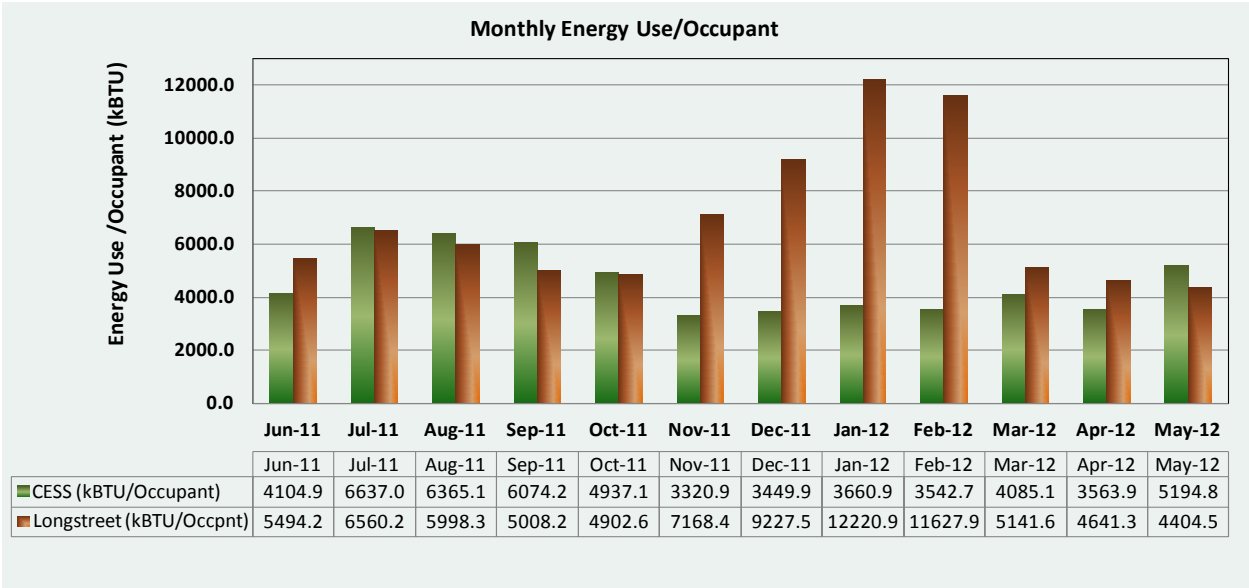
Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Objectives				
11. Improve MEASURED indoor environmental quality [(b)]	Air quality meets EPA standards (*IEQ*) and temperature controls	Measure temperature, humidity, for both buildings; test IAQ using testing protocols consistent with the United States Environmental Protection Agency report "Compendium of Methods for the Determination of Air Pollutants in Indoor Air"	High performance building will have good temperature control and meet EPA concentration limits for air quality parameters	Temperature control to heating and cooling setpoints was better at the CESS than for Longstreet. CESS met EPA 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 and -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 HVAC units in CESS
14. Decrease Required Maintenance Actions	Number of routine and repair 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 repairs, whereas 91% of maintenance calls at Longstreet Fire Station were for repairs.

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



	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12
CESS (kBTU/sq ft)	3.96	6.40	6.14	5.86	4.76	3.20	3.33	3.53	3.42	3.94	3.44	5.01
Longstreet (kBTU/sq ft)	4.49	5.36	4.90	4.09	4.00	5.85	7.53	9.98	9.49	4.20	3.79	3.60

Figure 5.1. Comparison of Monthly EUI for 1 Year for the CESS and Longstreet Buildings



	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12
CESS (kBTU/Occupant)	4104.9	6637.0	6365.1	6074.2	4937.1	3320.9	3449.9	3660.9	3542.7	4085.1	3563.9	5194.8
Longstreet (kBTU/Occpnt)	5494.2	6560.2	5998.3	5008.2	4902.6	7168.4	9227.5	12220.9	11627.9	5141.6	4641.3	4404.5

Figure 5.2. Monthly Energy Use Per Occupant for 1 Year for the CESS and Longstreet Buildings

The following equations were used to normalize and compare the energy use on monthly and annual basis:

CESS EUI = CESS monthly measured energy use/square footage of CESS
Longstreet EUI = Longstreet monthly measured energy use/square footage of Longstreet

Annual CESS EUI = CESS summation of annual measured energy use/square footage of CESS

Annual Longstreet EUI = Longstreet summation of annual measured energy use/square footage of Longstreet

CESS Energy Use/Occupant = summation of CESS annual measured energy use/number of CESS regular building occupants
Longstreet Energy Use/Occupant = summation of Longstreet annual measured energy use/number of Longstreet regular building occupants

Percent Difference of Measured Energy Savings/sq ft = 100 * [1 – (CESS EUI÷ Longstreet EUI)]
Percent Difference of Measured Energy Savings/Occupant = 100 * [1 – (CESS energy use per occupant ÷ Longstreet energy use per occupant)]

Table 5-3. Comparison of Annual Energy Use Measured for the CESS and Longstreet Buildings Normalized by Square Footage and Occupancy

	Annual EUI (kBTU/sq ft)	Annual Energy Use (kBTU)/Occupant
CESS	53	54937
Longstreet	67	82394
Percent Difference Energy Use	21%	33%

Objective 2 to reduce measured energy use per square foot in CESS by 50% over the energy use per sq ft in Longstreet was not achieved. The CESS building uses 21% less energy per sq ft and 33% less energy per occupant than measured in Longstreet Fire Station. However, the measured EUI for both of these buildings is below the EUI of 115 kBTU/sq ft reported for commercial public order and safety buildings for 2003 (DOE 2012).

Objective 3: Reduce MEASURED greenhouse gas footprint, was measured by analyzing the buildings' energy use and energy sources to determine the respective greenhouse gas footprints, which are reported in CO_2 equivalents. The source energy used for each building was determined from the eGRID region where the buildings are located (EPA 2012) (http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_SummaryTables.pdf). Because Longstreet uses a mix of electricity and natural gas, the greenhouse gas (GHG) footprint for electricity is calculated using the eGRID emission factors for the SERC Virginia/Carolina (SRVC) region and the natural gas usage is converted to CO_2 equivalents, and summed to calculate the GHG footprint. For CESS, the GHG footprint includes the eGRID emission factors for the SRVC region. The GHG footprint is calculated based on annual energy use and normalized to the building square footage, and number of regular building occupants for comparison purposes. The regional utility mix consists primarily of coal and nuclear power generating facilities, with a small proportion generated from natural gas and biomass. The carbon content of a fuel type can vary for reasons including the type of hydrocarbons in natural gas and the composition of coal (i.e., the mix of carbon, hydrogen, sulfur, ash, oxygen, and nitrogen) (IPCC 2006; Climate Trust 2008). The eGRID regional factors were used instead of local utility mix factors to be consistent with the current Federal GHG reporting guidance (CEQ

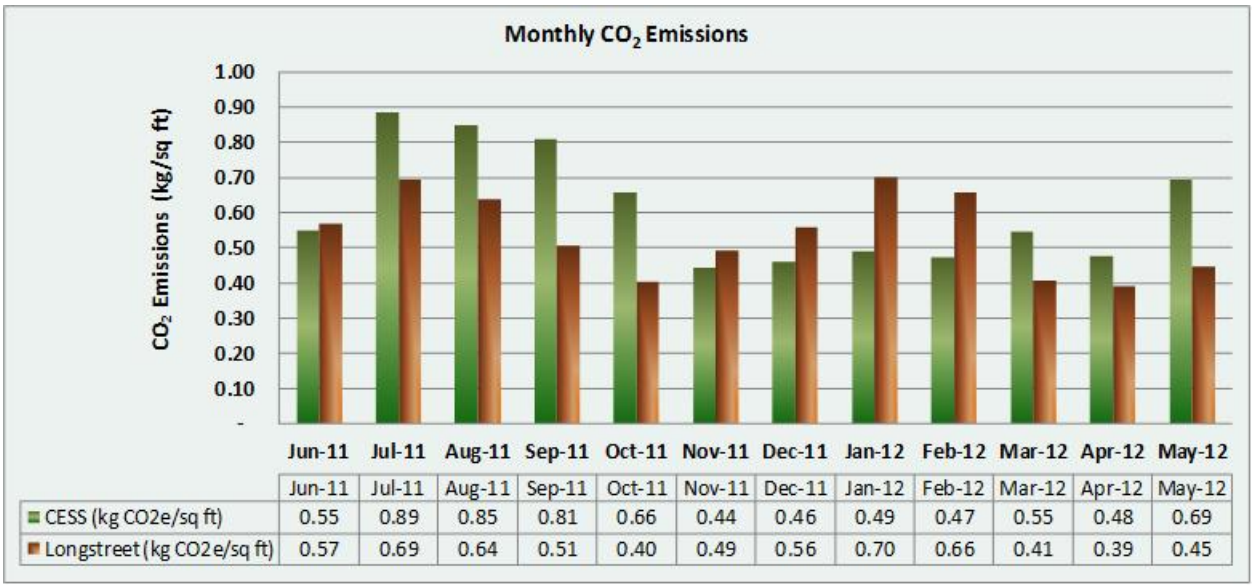
2012). The following equations were used to calculate and compare the GHG footprint (Figure 5.3):

1 million BTU Natural Gas used = 117 pounds CO_2 equivalents (CEQ 2010)
Electricity CO_2 equivalents = eGRID SRVC emission factors CO_2 equivalents

Longstreet Electricity CO_2 equivalents = Total BTUs electricity used * eGRID SRVC emission factors CO_2 equivalents
Longstreet GHG footprint = (Natural Gas CO_2 equivalents + Electricity CO_2 equivalents)/building square footage
Longstreet GHG impact per occupant = (Natural Gas CO_2 equivalents + Electricity CO_2 equivalents)/number of regular building occupants

CESS Electricity CO_2 equivalents = [Total BTUs electricity used* eGRID SRVC emission factors CO_2 equivalents
CESS GHG footprint = Electricity CO_2 equivalents/building square footage
CESS GHG impact per occupant = Electricity CO_2 equivalents/number of regular building occupants

Percent Difference of GHG Footprint = 100 * [1 – (CESS CO_2 equivalents/Longstreet CO_2 equivalents)]



	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12
CESS (kg CO2e/sq ft)	0.55	0.89	0.85	0.81	0.66	0.44	0.46	0.49	0.47	0.55	0.48	0.69
Longstreet (kg CO2e/sq ft)	0.57	0.69	0.64	0.51	0.40	0.49	0.56	0.70	0.66	0.41	0.39	0.45

Figure 5.3. Monthly CO_2 Emissions Per Square Foot for the CESS Building and Longstreet Fire Station

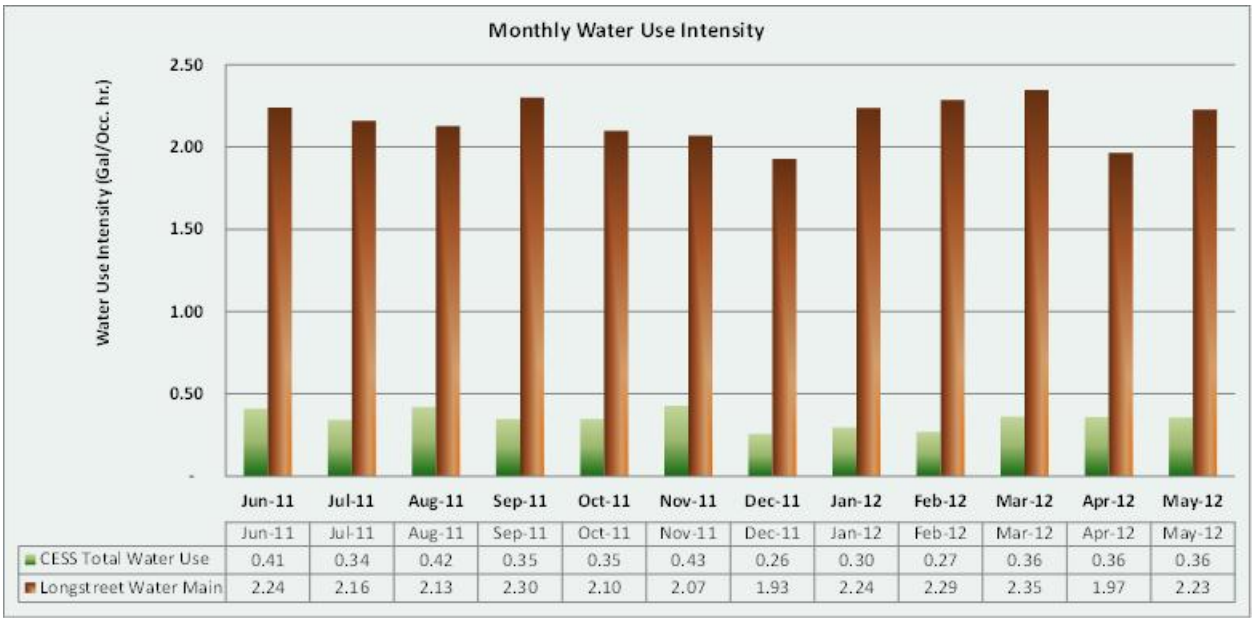
Objective 3 was not met. Calculation of greenhouse gas (GHG) emissions for the annual total energy consumption in each of the two buildings showed, that although the measured total energy use intensity (EUI, kBTU/sq ft) was less in CESS than Longstreet, the emissions of greenhouse gas were greater . Because Longstreet uses a mix of electricity and natural gas, and because the natural gas Natural gas has a lower GHG intensity than the fuel type used to produce electricity for CESS, thus Longstreet has lower GHG emission, Longstreet actually has lower

GHG emission rates (6.46 kg CO_2 equivalents annually versus 7.34 kg CO_2 equivalents annually).

5.2.2 Measured Performance Objectives for Water

Objective 5: Reduce MEASURED potable water consumption, involves metering water use and rainwater capture, normalizing the water use by number of occupants, and square footage. Water use is commonly normalized using the number of building occupants, creating a metric referred to as Water Use Intensity (WUI). The monthly water use values normalized by the number of occupants for the baseline building (Longstreet) and the high performance building (CESS) are shown in Figure 5.4. Fifteen-minute metering data for potable water and rain water system were used to review the daily and weekly use of water for each building and summed into monthly and annual values for analysis as discussed below.

Monthly review of the data revealed larger than expected differences in potable water use that are reflected in Figure 5.4. Inquiries were made to Fort Bragg staff as to whether water meters were working at several points during the monitoring period. Multiple checks of the main water meter using the hose bib in the mechanical room indicated that the main water meter was functioning correctly, yet the data remained significantly lower than expected. During a July 2012 site visit, PNNL and Fort Bragg staff discovered that all of the building's water was not coming from the main water connection, and thus total building water use including bathrooms, was not being collected by the main water meter. Since this visit, the site has been trying to determine where the additional water source is coming from, but that is still undetermined at this time. Given that, we cannot fairly compare the WUI between the two buildings measured during the monitoring period and cannot reliably report against this performance objective.



	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12
CESS Total Water Use	0.41	0.34	0.42	0.35	0.35	0.43	0.26	0.30	0.27	0.36	0.36	0.36
Longstreet Water Main	2.24	2.16	2.13	2.30	2.10	2.07	1.93	2.24	2.29	2.35	1.97	2.23

Figure 5.4. Water Use Intensity for CESS Building Compared to Longstreet

The measured water use was expected to be different from that calculated for design water use because the total building water use involves more equipment (for example a dishwasher and

clothes washer), than are included in the design calculations required for LEED credit submittal. As mentioned previously, these buildings have similar functions and therefore similar types of equipment that use water and the monthly water use intensity was not expected to differ to the degree shown in Figure 5.4, even when the CESS water savings measures were taken into account.

Objective 5 cannot be reliably evaluated, but given the available data (100% of sewage conveyance via harvested rainwater and water saving fixtures) , significant water savings were achieved However, because of the metering discrepancy, we cannot fairly compare the WUI (gal/occupant) 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 separately 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 7).

Objective 7: Reduce MEASURED potable water use for vehicle washing, involves metering the quantity of rainwater captured, quantity of rainwater used for vehicle washing and any potable water used for vehicle washing. The rainwater used for toilet flushing is used in addressing the reduction of total potable water use (Objective 6). CESS used 92% less potable water than Longstreet Fire Station for vehicle washing overall. Longstreet Fire Station is the busiest station on Fort Bragg and CESS receives only about one-quarter as many emergency calls as Longstreet. The amount of potable water used for each station was normalized by considering the number of emergency calls at each station. The normalized values for potable water used for vehicle washing from the baseline building (Longstreet) were compared to the normalized potable water use of the high performance building (CESS). Using data normalized for number of emergency calls in the following equation, the CESS building used 60% less potable water for vehicle washing than did Longstreet.

> Percent Difference of vehicle wash water use = 100 * [1 – ((CESS vehicle wash potable water use/emergency calls) / (Longstreet vehicle wash potable water use/emergency calls))]

Objective 7 was met by reducing the total amount of potable water used for vehicle washing by 92% compared to Longstreet and by reducing the amount of potable water used per emergency call by 60%. Harvested rainwater made up 87% of the total amount of water used for vehicle washing at CESS.

5.2.3 **Measured Waste Performance Objectives**

Objective 9: Reduce MEASURED post-occupancy solid waste, involves measuring the quantity and frequency of solid waste disposal and the quantity of recyclables collected on an annual basis. The weight of the solid waste dumpsters is not typically measured at Ft. Bragg, and the recycling quantities are also not regularly collected or recorded by building at Ft. Bragg, so measurements to support direct comparisons between the two buildings are not available. However, Fort Bragg fire stations and emergency services were certified 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. The fire stations implemented a variety of sustainable practices to achieve Green Boot certification. Environmentally-preferred and cost-effective cleansing products were installed at all of the Installation's fire stations. Additionally, the firefighters implemented a robust recycling program throughout the department. Through this program, occupants at both buildings reduced environmental impacts however it was tracked at the Installation level rather than building level.

5.2.4 Measured Indoor Environmental Quality Performance Objectives

Objective 11: Improve MEASURED indoor environmental quality, was originally proposed to be monitored using a specified Air Advice monitoring system. During the metering equipment stage, these systems were found to be cost-prohibitive and were not used in the demonstration. We have two lines of evidence regarding the indoor environmental quality that can be evaluated. First, we measured temperature and relative humidity (CESS only) throughout the monitoring period, which was used 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 United States Environmental Protection Agency (EPA) report "Compendium of Methods for the Determination of Air Pollutants in Indoor Air."

Indoor temperature measured in each building is compared in Figure 5.5 with outdoor air temperature for the warmest (August) and coolest (January) months. Humidity values were measured only in CESS. Indoor air temperature within the CESS varied less diurnally, and remained close to thermostat setpoints throughout the monitoring period.

The initial air quality test results immediately after construction showed that some of the sampling points exceeded the allowable concentration limits for compliance with EPA limits. These non-compliant areas were flushed with outside air, allowed to re-equilibrate with building air, and retested to confirm compliance with the concentration limits. The project was compliant with the IAQ test limits because low emitting finishes were installed on the project.

Objective 11 was considered to be met because temperature and humidity levels in the CESS were maintained at levels that matched setpoint levels for thermal comfort and the building passed EPA test limits for indoor air quality.

Objective 13: Increase MEASURED occupant satisfaction, involved surveying the occupants to assess their level of satisfaction with the building they inhabit. Our original proposal specified using the Center for the Built Environment (CBE) occupant survey to assess this metric. However, the survey was not used for this assessment because it was designed for commercial office buildings and does not address 24-hour occupancy and satisfaction with living quarters. It was also observed that the personnel in each of the two stations took personal interest and pride in their station, which resulted in a competitive atmosphere. To address occupant satisfaction interviews 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. The following issues were noted during discussions with the occupants:

- Daylighting in common spaces and hallways was viewed as a positive design feature in CESS.

- Lighting control was noted as a key value in Longstreet.

- Occupants of both buildings indicated satisfaction with acoustic properties of the respective buildings.

- Occupants of both buildings were satisfied with heating and cooling when the systems were functioning properly.

- CESS had several HVAC maintenance issues, and occupants noted that maintenance issues with the HVAC systems might have been resolved more easily if maintenance staff were better trained and more familiar with the CESS integrated systems.

- Some CESS flooring materials were noted as being less durable than desired and showing signs of wear in part because of poor installation of materials.

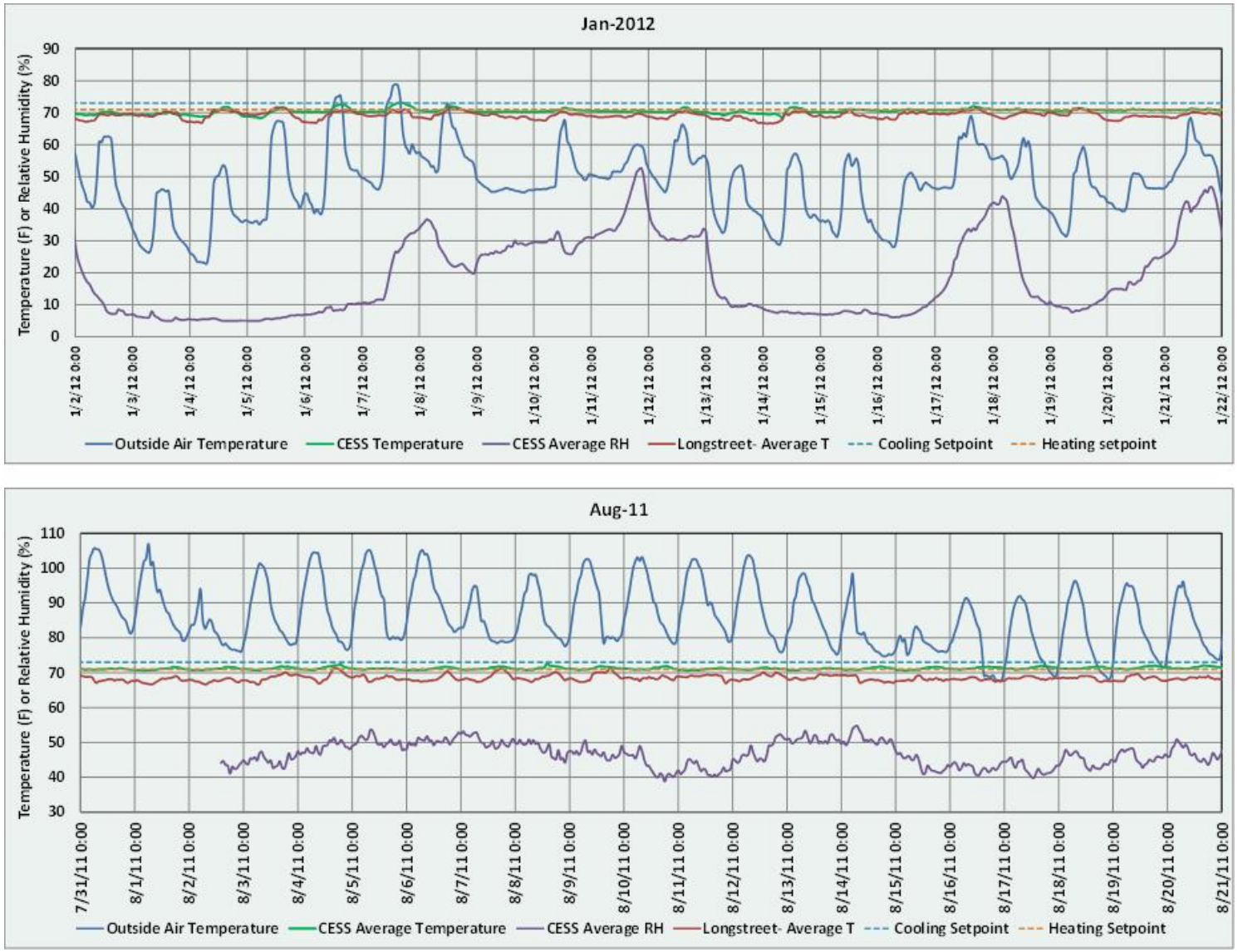


Figure 5.5. Example of Average Room Temperature in Longstreet and CESS and Relative Humidity in CESS in Summer and Winter Months

5.2.5 Building Maintenance

Objective 14: Equivalent maintenance calls was added as a metric 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. Assessing this objective required tabulating the number of maintenance calls received by each of the stations during the monitoring period.

Table 5.4 summarizes the number of calls made for repair and routine maintenance as well as installation of new systems or fixtures during the monitoring period. 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.

Table 5-4. Number and Type of Maintenance Actions Conducted At CESS and Longstreet from June 2011 to June 2012

Type of Maintenance Action	CESS (number of calls)	Longstreet (no. of calls)
Installation	6	3
Repair	13	31
Routine	4	0

5.3 PERFORMANCE SUMMARY

The CESS received LEED Platinum Certification for design and construction. Performance measurement over the monitoring period indicated that CESS used less energy (21% less) than its matched pair (Longstreet Fire Station) and has had fewer maintenance and operations calls. Water conservation was achieved through the use of rainwater for vehicle washing and sewage conveyance, and metering data indicated that potable water use for vehicle washing was reduced by at least 60%.

Assessment of the integrated design process and monitoring building performance shows that the original criteria for 10 of the 14 objectives were successfully met or exceeded. All but one design objective (reduce design energy by 50%) were met successfully. Although our evaluation of building performance showed that the CESS building did not achieve the challenge objectives of a 50% reduction in both designed and measured energy use, the use of whole building design and operation of the high-performance building still achieved significant energy savings. During the design phase, other energy saving technologies were considered as part of the integrated design process to further increase energy savings. However, the cost of additional technologies was not warranted given the overarching goal to design and construct the high performance building using off-the shelf technologies without increasing overall costs.

Compared to the existing Longstreet Fire Station, total EUI in CESS was 21% less than Longstreet. Compared to national energy use consumption data averaged for 71 public order and safety buildings for 2003, the CESS has energy savings >50% ; 53 kbTU/sq ft compared to 110.6 kBTU/sq ft (Energy Data Book table 3.1.9). Although the measured total EUI was less in CESS

than Longstreet, calculated emissions of greenhouse gas were greater. Because Longstreet uses a mix of electricity and natural gas, and the natural gas has a lower GHG intensity than the fuel type mix used for electricity for CESS, Longstreet actually has lower GHG emissions (6.46 kg CO_2 equivalents annually versus 7.34 kg CO_2 equivalents annually).

The CESS building used less energy per square foot and less energy per occupant than measured in Longstreet Fire Station, however, details of energy use and total water use could not be resolved. Detailed submetering of lights, plug load, and other baseload in the existing Longstreet building would be needed to fully examine and better understand differences in energy usage between the buildings. This level of monitoring was not feasible logistically in the existing building and could not be accomplished with the available equipment and funding. Differences in energy sources for heating and cooling in the two buildings also complicates evaluation of differences in energy usage.

The designed and measured goals for reducing water use were both successfully met in this high-performance building by using harvested rain water for sewage conveyance and to replace much of the water used for washing vehicles. It is unfortunate that problems with water metering in CESS were not resolved until very late in the project. Although questioned and checked repeatedly at the early stages of monitoring, the main water meter was shown to be inaccurate in monitoring certain water uses (sinks and showers) near the end of the monitoring period and so no reliable comparisons can be made between total potable water use in CESS and Longstreet. 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 indoor environmental quality, 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. Because the CBE survey questions were not relevant for these buildings, objective 13 involving occupant satisfaction was evaluated through interviews and discussions indicating personnel in both buildings had high levels of satisfaction with building performance.

6.0 COST ASSESSMENT

The programmed amount (PA) for constructing the CESS fire station was set at $2,900,000. One of the design goals was to use integrated, whole building design strategies to design the building as LEED Platinum at the same cost as was originally programmed. The costs included both building costs and infrastructure costs. The CESS building was constructed in a new development area where there was no existing utility infrastructure. Electricity, water, and sewer interconnections were constructed. Natural gas infrastructure was not part of the project.

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.

The National Institute of Standards and Technology (NIST) defines LCCA as "an economic method of project evaluation in which all costs arising from owning, operating, maintaining, and ultimately disposing of a project are considered to be potentially important to that decision" (NIST 1996). LCCA expands the analysis scope beyond initial or "first" costs to include operational, maintenance, and eventual disposal costs of a building. In other words, an LCCA takes into account all the costs associated with acquiring, owning and disposing of a building (NIBS 2010). 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. Cost estimates available for the estimate and final bid are available in Appendix B. The costs were not reported at the same level of detail, thus for this LCCA, total costs were used (Table 6.1).

For construction of the CESS, the programming year was FY 2006. At that time, the initial cost estimate for the CESS was $2,922,000, and the programmed amount was set at $2,900,000. During the design year, FY 2007, the project's construction documents were prepared. The programmed amount remained at $2,900,000 and all of the estimates prepared indicated that value was still correct. In FY 2008, during the advertising and receipt of bids, the contractor's proposal was $2,713,032. When contingencies and SIOH were added to the proposed price, the total price ($3,080,457) exceeded the original program estimates. Because the programmed amount of $2,900,000 was exceeded, a reprogramming action was required to proceed. This action was submitted and approved.

The average costs of energy were extracted from the Army Energy and Water Reporting System (AEWRS), and are summarized in Table 6.2. 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 6.3). 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 6-1. 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**

Table 6-2. Fort Bragg Average 2011 Cost of Energy

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

Table 6-3. 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

6.1 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 (GSHPs) for building heating and cooling. Efficiency of GSHPs varies according to the soil characteristics at a site, and these technologies are typically 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). In addition, a building

emergency generator had to be purchased that was missing from the original design and this also added to the increased overall cost.

Increase in construction costs between the programming year (FY2006), the design year (FY2007), proposal bids (FY2008), and construction (FY2009-FY2011) 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 2007, 2012) and are summarized in Table 6.4.

Table 6-4. Historical North Carolina Construction Cost Summary[a]

Cost Element	2007	2008	2009	2010	2011
Average Cost per square foot ($/sf)	112.71	120.07	121.24	125.08	121.52
Percent change (compared to 2007)		6%	7%	10%	7%
(a) Carrick (2012); Carrick (2007).					

Average construction costs increased by 6% from 2007 (CESS design year) to 2008 (when proposal bids for CESS occurred). Fort Bragg personnel stated the 5% higher construction cost over the programmed amount was consistent with other bids during that timeframe, which is consistent with the average construction cost increase shown in Table 6-4.

6.2 COST ANALYSIS AND COMPARISON

The NIST Life-Cycle Costing Manual (NIST Handbook 135) for FEMP details the LCC methodology and criteria established by FEMP for the economic evaluation of renewable energy (and energy and conservations) projects in federal buildings (NIST 1996). The approach detailed in Handbook 135 was used to estimate the life-cycle cost of the CESS building at Fort Bragg.

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.

Cash outflows included capital expenditures to construct the CESS. The difference in costs between the initial cost estimate and the actual construction costs was used to represent the differential between construction of a typical fire station and the CESS high-performance building. The detailed data on individual system costs for CESS and Longstreet were not available to allow comparisons of differences in costs related only to sustainable design. Using the cost difference between programmed costs and final construction costs should be considered a conservative analysis because it is probable that not all of the 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). Energy costs and fixed operating and maintenance costs were considered outflows.

To measure the financial viability of this project, the net present value (NPV) financial indicator was derived from the discounted cash flow analysis and was used as the performance measure for investment opportunities. The internal rate of return (IRR) was evaluated but could not be effectively calculated because there was no return on investment. These financial indicators

account for the time value of money, and discount the future capital investments or annual cost benefits to the current year.

Financial analysis parameters were obtained from various sources, including CESS project personnel, research, and communication with equipment vendors; data sources are noted in the report and cost model.

6.2.1 Model Parameters and Major Assumptions

A spreadsheet-based discounted cash flow analysis model based on NIST Handbook 135 was developed to conduct the financial analysis. The model uses numerous input variables, which were derived from a wide range of sources. The outputs of the model are commonly used financial indicators. The values of the input parameters directly influence the financial analysis results; changing these input parameters would alter the financial indicators that were calculated by the model. The value and data source for each input parameter is provided in this report section.

6.2.1.1 Capital Cost

The difference 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. This cost differential was $158,456 and was assigned to the year that construction bids were received (FY2008). Documentation for the initial cost estimate and the actual construction costs are included in Appendix B.

6.2.1.2 Global

Global parameters and assumptions are summarized in Table 6.5. These parameters are those that apply to the overall analysis, such as rates and study period. Each of these terms is defined in detail:

- **Study Base Year** is the year construction bids were received. All future cash flows were discounted to this year.
- **Occupancy Year** is the year in which the fire station was first occupied. This signifies when operating and maintenance costs begin.
- **Interest/Discount/Escalation Rates** are all given in real rates. This was done to coincide with the FEMP-recommended approach.
- **Discount Rate** was used in the analysis to discount future costs and benefits back to the 2008 date. For this analysis, the real discount rate provided in the Handbook 135 annual supplement of 3.0% was used (NIST 2011).
- **LCCA Study Period** is the number of years for with the cash flow analysis was completed. A 25-year study period is a typical period for which buildings are evaluated. 28 years was the total study period including the 3-year timeframe for building design and construction.
- **Electricity Rate** is Fort Bragg's average calendar year 2011 rate recorded in AEWRS.

- **Electricity Escalation Rates** were documented using the U.S. Department of Commerce projections for electricity in the industrial sector for Census Region 3, which contains North Carolina where Fort Bragg is located. These escalation rates are located in Table Ca-3, as found in the Energy Price Indices and Discount Factors for Life Cycle Cost Analysis 2011 (NIST 2011). These indices and discount factor multipliers are based on energy price projections developed by the Energy Information Administration of the U.S. Department of Energy. These rates were used for 2012 forward. The projected fuel price indices represent the escalation of electricity and natural gas, not accounting for general inflation.
- **Taxes** for this project were not included in the analysis because the CESS was a MILCON facility that was not subject to taxes.

Table 6-5. Global Parameters and Assumptions

Data/Assumption	Value	Source
Study Base Year	2008	Year construction bids were received
Occupancy Year	2011	Actual occupancy April 2011
Interest/Discount/Escalation Rate	Real	Chosen convention
Discount Rate	3.0%	FEMP 100 CFR 436/Handbook 135
LCCA Study Period	28 years	FEMP 100 CFR 436/Handbook 135
Electricity Rate	6.2¢/kWh (Average 2011)	AEWRS
Electricity Escalation Rate	Various as detailed below	U.S. Department of Commerce
Taxes	None	MILCON facilities are not subject to taxes

6.2.1.3 Demonstration Data

Demonstration data used in the analysis are summarized in Table 6.6. These data were the modeled results completed and submitted as part of the LEED documentation. Modeled data were used instead of measured data because Longstreet energy costs are not comparable to CESS energy costs due to the different fuel types.

Table 6-6. Demonstration Data

Building	Annual Energy Use	Source
Baseline Electricity Use	215,948 kWh	Modeled
CESS Electricity Use	147,566 kWh	Modeled

6.2.1.4 Financial Analysis Results

The model developed for this analysis contains all the assumptions and calculations that were used in the analysis; the model is located in Appendix B.

6.2.1.5 Discounted Cash Flow Analysis

The discounted cash flow analysis was conducted by summing the cash inflows (electricity savings) and outflows (capital costs and operating and maintenance costs) detailed above. Table 6.7 provides a snapshot cash flow for key years. Energy costs were escalated and all costs discounted, as described above, to 2008 dollars. O&M costs and electricity savings decrease because they are shown in 2008 dollars, therefore due to the discount factor they decrease over time. In present value dollars, the savings increase due to escalation rate for the price of electricity, and the O&M costs remain the same.

The entire discounted cash flows for the study are located in Appendix B.

Table 6-7. Cash Flow Summary – Key Year Snapshot, 2008 Dollars

Cash Flow	Study Base Year (2008)	First Full Year of Occupancy (2012)	Final Study Year (2035)
Capital Cost	($158,457)	$0	$0
Electricity Cost Savings	$0	$3,635	$1,935
O&M Cost	$0	($225)	($114)
Net Cash Flow	**($158,457)**	**$3,410**	**$1,821**

6.2.1.6 Net Present Value

Net present value is the difference between the capital investment and the present value of future annual cost benefits associated with the project. NPV is the standard method to appraise long-term projects using the time value of money. If the NPV is positive, then the investment return is acceptable and the project would add value to the organization. The NPV was calculated by summing the annual cash inflows and outflows and then discounting these costs and revenues into 2008 dollars using the discount rate. Although cash flow is positive for each year of operation, the NPV in 2008 dollars is ($95,363).

6.2.1.7 Financial Internal Rate of Return

The internal rate of return is used to measure the profitability of an investment. If the IRR is greater than the discount rate, then the project return is acceptable. For this project, the IRR could not be effectively calculated because there was a negative return on investment.

6.2.1.8 Dollars per kBtu of Energy Saved

Dollars per kBtu of energy saved was calculated two ways: 1) dividing the first year investment cost by the cumulative energy savings over the LCCA period and 2) dividing the first cost by the average annual energy savings. Note that dollars per kBtu of energy saved does not account for O&M costs.

6.2.1.9 Simple Payback

Simple payback was calculated by dividing the first year investment cost by the average annual savings; note that simple payback also does not account for O&M costs.

6.2.1.10 Savings to investment ratio

Savings to investment ratio was calculated by dividing the present value of the cumulative savings over the 25 year term by the present value of the investment costs including O&M costs.

6.3 COST SUMMARY

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 6.8). 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 operating and maintenance 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 2007, 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 original cost analysis.

Table 6-8. Summary of Cost Savings

Parameter	Value
System first cost	$ 158,456.00
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)	20042 kBTU
Dollars/kBTU saved (annual)	$ 7.91
Dollars/kBTU saved (over 25-year project life)	$ 0.32
Net Present Value (NPV)	($ 95,363.00)
Simple Payback in Years	37.6 years

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 energy use.

Assuming 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 integrated 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 (for example—the solar wall).

7.0 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.

This section focuses on the lessons learned during the integrated design process and following through construction and monitoring of the high-performance building.

7.1 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.
- 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. This approach has been a key technology transfer component of the project, with the "TechNotes" that were adopted by USACE. (http://www.wbdg.org/ccb/browse_cat.php?c=266).
- Sustainable design experts in mechanical, electrical, structural, and civil engineering are essential at charrette and on the design team to the successful design of a high-performance building.
- Sustainable design goals need to be known by all parties and reiterated throughout the design process.
- 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.
- Load calculation optimization tools should be applied to appropriately size mechanical equipment. Vendor tools have built-in, safety factors that meet the goals of the vendors, not necessarily sustainability goals. If conservative assumptions are used in the load calculations (i.e., number of people in lobby was assumed to be 20, from ASHRAE

guidelines) the systems will be oversized. All assumptions in the equipment sizing models need to be evaluated and optimized.

- Projects need simple energy modeling up front to pick cost effective mechanical systems and envelope, and then more detailed modeling later to fine tune the system.
- Real-time, high quality energy modeling information and/or expertise is helpful to assess impacts of design decisions during the charrette.
- Real-time cost estimation information before and at the design charrette are essential to allow for alternative design strategies to be considered.
- Have a LEED Administrator managing the project that works for the Army rather than a contractor. This is expected to streamline the process, rather than having to manage the transfer of responsibilities from the designer to the contractor in a design-bid-build project.
- Provide people with resources for application for LEED certification using information from successful case studies. This would avoid project teams re-creating different processes for certifying LEED projects. The Army may want to consider developing a set of preferred resources that every LEED project should use.
- For a LEED project, the scope for the Architect/Engineering (A/E) firm contracts needs to clearly identify that the A/E firm needs to complete the LEED design credit templates and that the construction contractors need to complete the LEED construction credits. Information to fill out the templates and calculations from the design team must come from the A/E firm(s).
- Use the USACE LEED Submittal Requirements and LEED Requirements in all projects
- Allow sufficient time for thorough design reviews. One week for 1000 pages of drawings is not sufficient. The project should schedule reviews so as to allow three to four phased reviews possibly by discipline.
- During the design, consider how occupants will be able to maintain and clean the space.

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, so were not integrated in overall design considerations. The design team needed to review the standard building design components to check for basic fire station equipment needs. These included the need for a back-up 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.

Other design and implementation issues that were identified after construction was completed included the following:

- During the value engineering process the roof slope changed, which impacted the solar wall effectiveness. At this time, the solar wall could have been removed for cost considerations since its effectiveness was minimized – design contractor knew of this issue, but chose not to raise it to the ESTCP project team or to modify the design.

- Increased wall thickness combined with metal roofing in the CESS significantly reduced cellular telephone signals and reception within the building.
- Lighting sensors were installed before furniture selection & layout – so the furniture placement blocked the motion sensors. The lights go off, and occupants have to standup or move around periodically in offices to turn lights back on.

7.2 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:

- Engaging a contractor without prior LEED or green building experience affected the schedule and building features. At a minimum, future construction of high-performance buildings should require that the contractor has prior LEED project experience (for example, 3 references with positive feedback).
- When construction teams are dealing with unfamiliar technologies, they should 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 be aware of LEED documentation responsibilities.

7.3 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. The data quality reviews and data processing protocols that PNNL developed were used to mitigate these issues and provide a high-quality data set for analysis.

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. Real-time analysis allows for identification of data anomalies.
- 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 that any potential changes in the data can be noted.

8.0 TECHNOLOGY TRANSFER

This ESTCP project team transferred the integrated whole building design technology through several paths. The ESTCP project team successfully transferred whole building design technology and individual strategies used in this project to the Army Corps of Engineers' Centers of Standardization (COS). The COS has implemented whole building design strategies to redesign the five building types most often constructed by the Army (Carpio and Soulek 2012).

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" (Appendix E) with USACE. USACE subsequently adopted the concept of TechNotes as part of their toolset, and is developing additional design-related TechNotes, as well as planning for development of operations and maintenance TechNotes to assist with effective building operations where newer design strategies and technologies are implemented.

Thirteen original strategies for obtaining LEED credits in different areas were developed specifically for the Fort Bragg CESS. These documents were expanded and additional topics included and finalized as TechNotes (included in Appendix E) to provide information and strategies for consideration in designing high-performance buildings. Nineteen TechNotes (Table 8.1) were developed for use on all relevant building projects:

Table 8-1. TechNotes Developed to Provide Information for Design Strategies

TechNote Titles	
Daylighting Photosensor	Desiccant HVAC Systems
Light Shelf	Solar Hot Water
Light Tube	Overhead Radiant Heating
Sunlight Tracking	Radiant Floor Heating – Commercial
Dual Flush Toilets	Radiant Heating & Cooling – Residential
High Efficiency Toilets [HETs]	Heat Island Effect – Roof
Low Flow Showerheads	Ground Source Heat Pumps
Ultra-Low-Flow Faucets	LED Parking Lights
Enhanced Commissioning	Light Pollution Reduction
Permeable Pavement Systems	

8.1 TRAINING REQUIREMENTS AND RESOURCES

Many presentations were given by the ESTCP project team regarding the whole building design approach. The following list led to the interactions with USACE as well as with individual installations and design projects.

- Fowler KM. 2011. *Assessing Federal Green Building Performance*. Greenbuild 2011, Toronto, Canada, October 2011.

- Fowler KM. 2010. *Potential Additional LEED Points/Sustainable Design Strategies for UEPH*. UEPH Design Options Meeting, August 18, 2010.

- Fowler KM. 2009. *Fighting Fire with Fire: Fort Bragg Goes Platinum with a new LEED Fire Station*. OFEE Federal Environmental Symposium East and West, Bellevue, WA and Bethesda, MD, June 2, 2009.

- Rauch EM and KM Fowler. 2008. *Post Occupancy Evaluations in Federal Buildings*. World Energy Engineering Congress, Washington, D.C., October 1-3, 2008.
- Fowler KM and EM Rauch. 2008. *Whole Building Performance Measurement*. GovEnergy 2008 Conference, Phoenix, Arizona, August 5-7, 2008.
- Rauch EM and KM Fowler. 2008. *Assessing Whole Building Performance*. Air and Waste Management Association ACE Conference, Portland, Oregon, June 23-27, 2008.
- Rauch EM and KM Fowler. 2008. *Sustainably Designed Building Performance*. Office of the Federal Environmental Executive Environmental Symposium East and West, June 3-5 and 17-19, 2008, Washington, D.C., and Big Sky Montana.
- Stumpf A. 2008. *Using Building Information Modeling during Design Charrettes - A Case Study*. Joint Services Environmental Management Conference, Denver, Colorado, May 7, 2008.
- Stumpf A. 2008. *Sustainable Design and Development Workshop - A Case Study at Fort Bragg NC*. Joint Services Environmental Management Conference, Denver, Colorado, May 7, 2008.
- Messenger M. 2007. *High Performance Buildings: Fact or Fiction?* May 2007.
- Messenger M. 2007. *Documenting the Business Case for Sustainable Design*. June 2007.
- Messenger M. 2007. *The Conundrum of a Sustainable Army*. August 2007.
- Shepherd C. 2007. *Center of Standardization Weds Two Ideals in Design for Emergency Services.* Public Works Digest, March/April 2007.

Additionally there were individual requests for technical assistance by design teams for fire stations, child development centers and other building types. There have also been installation-level requests for technical assistance on the whole building design approach and monitoring and analysis of building performance.

8.2 DESIGN COMMUNITY IMPACTS

The USACE TechNotes and COS designs are available for the entire design community to access. The TechNotes are being used, adapted, and expanded upon by individual design projects and installation design project teams. USACE's ownership of the whole building design strategies demonstrated on this ESTCP project is an example of full transfer of a technology. The COS designs offer a less measurable, yet another example of a successful technology transfer as USACE has informed the ESTCP project team that the design teams work in a more integrated manner and consider the cross-cutting impacts of design changes during the design process.

Although individual project technical assistance is not as easy to claim as a design community impact, the observed change, over time, of design team willingness to modify existing designs and willingness to push for previously denied design modifications has been an encouraging trend that has been witnessed by the ESTCP project team.

Performance measurement and analysis still needs to mature within the DoD system. While many more buildings have metering systems, the availability and quality of metered data is still questionable. When the data are collected, data analysis and trending skills are needed at the installation-level to make use of the performance data. Additionally, more performance data are needed to provide a baseline performance level. That baseline will provide clarity on whether design and operations improvements are having a system-wide impact. The ESTCP project team has witnessed greater interest in data analysis recently, which has been highlighting the need for training and tools to make it easier to perform building analysis that provides recommendations for opportunities to reduce resource use.

APPENDICES

APPENDIX A: PERFORMANCE ASSESSMENT METHODOLGIES

This appendix summarizes the data evaluation and analysis conducted to assess the two groups of performance objectives addressed in the body of this report. Performance objectives were grouped into design performance objectives and post-occupancy, measured performance objectives.

A.1 ANALYSIS AND EVALUATION OF INFORMATION FOR DESIGN OBJECTIVES

The measurement and success of design objectives were evaluated using the requirements for LEED certification. This section of Appendix A is modified from portions of a draft ERDC/CERL report on the documentation and certification of the CESS building (Rogers et al. 2012). The LEED NC Rating System is a performance standard for certifying the design and construction of commercial buildings. Application of sustainable building strategies implemented on this project and the achievement of prerequisites and credits for the various categories drives the certification level. Prerequisites and credits in the rating system address the following topics:

- SUSTAINABLE SITES (SS) – A sustainable site involves reducing negative impacts on the environment through proper site development and includes all aspects of the design outside of the building, such as erosion and sediment control, stormwater management, transportation and light pollution. Strategies to accomplish this include reducing construction activity pollution, protecting natural areas, using existing infrastructure, protecting and restoring the site, encouraging alternative transportation and site remediation of Brownfield development where appropriate.

- WATER EFFICIENCY (WE) – Water efficiency encourages alternative means of water technology and distribution in order to reduce the need for potable water for landscaping and building water use. Strategies to accomplish this generally involve using high efficiency fixtures and waterless urinals, innovative wastewater technologies, and low-impact, drought tolerant landscaping or water re-use, such as rainwater harvesting, to reduce the need for landscape irrigation.

- ENERGY & ATMOSPHERE (EA) – This credit category aims to reduce the energy consumption of buildings thereby decreasing negative environmental impact. Energy performance can be optimized through building commissioning, energy modeling, and use of non-ozone depleting substances. Strategies to achieve higher energy performance include efficient HVAC design, efficient water heating, energy efficient lighting and building envelope systems, and renewable energy sources.

- MATERIALS & RESOURCES (MR) – Credits in this category are achieved by reducing the amount of construction waste that ends up in a landfill, and minimizing the use of rapidly declining resources. This involves construction waste management, storage and collection of recyclables, use of local resources and careful materials specification. Strategies for reducing materials and resources include creating a comprehensive construction waste management plan to divert as much waste as possible from the landfill

and specifying reuse, recycled or rapidly renewable products and materials (especially those that are regionally available) in contract requirements.

- INDOOR ENVIRONMENTAL QUALITY (EQ) – The IEQ category focuses on the health and well-being of the building occupants by providing a comfortable and healthy work environment. Goals include elimination of tobacco smoke, intentional ventilation, maintaining high indoor air quality, daylighting and views, and controllability of building systems. Actions in this category include removing pollutant pathways, increasing ventilation, use of low-emitting materials, providing individual controls for systems, and the incorporating daylighting and views into the overall building design.

- INNOVATION & DESIGN PROCESS (ID) – This credit category includes exemplary performance points for achieving a higher level of achievement in certain credit categories, as well as opportunities to achieve points for addressing green building topics not covered in the LEED reference guide. For example: the owner of the building may use his/her facility as an educational tool to educate employees and the general public about LEED-related design strategies and the measures they are taking to improve performance and conserve natural resources.

Multiple credits can be achieved for each of these categories which count toward certification of the building. To achieve LEED Platinum certification, the CESS project had to recieve a minimum of 52 points accepted by the Green Building Certification Institute (GBCI) third-party review team. Section 4 of this report contains the CESS Project LEED Credit Scorecard. The LEED Scorecard lists the credits the project successfully achieved to meet LEED Platinum certification.

A.1.1 LEED Certification Documentation and Template Calculations

This section provides project-specific discussions of the strategies used to achieve each LEED credit and document methods used to achieve LEED Platinum certification for the CESS building. The credits are discussed in order as they appear in the LEED-NC Rating System and include only those credits that were achieved.

Sustainable Sites

SSp1: Construction Activity Pollution Prevention: This prerequisite requires an erosion and sedimentation control plan that conforms to the 2003 EPA Construction General Permit, which outlines the provisions necessary to comply with Phase I and Phase II of the National Pollutant Discharge Elimination System (NPDES) program. Project teams can use local code requirements as long as they are as stringent as the NPDES program. The CESS used local code requirements, and a narrative was submitted to prove that it conformed to the NPDES program. The erosion and sedimentation and control plan was also submitted for review.

SSc1: Site Selection: The requirements of this credit specify the type of land a project should NOT develop. This includes prime farmland, habitat for endangered species, pre-development elevation that is less than 5-feet above the 100-year flood elevation, land located within 100 feet

of wetlands or prior public park land, and previously undeveloped land within 50 feet of a water body. The CESS was located on a site that did not violate any of the above requirements.

SSc4.2: Alternative Transportation: Bicycle Storage and Changing Rooms: The credit requirement is to provide bicycle storage and shower/changing facilities in the building or within 200 yards of a building entrance for 0.5% of FTE occupants. The CESS building includes one secure bicycle storage space within 18 yards of the building entry and two shower/changing facilities within the building.

SSc4.3: Alternative Transportation: Low-Emitting & Fuel Efficient Vehicles: The purpose of this credit is to promote the use of low-emitting or fuel efficient vehicles. This credit was pursued using Option 2: preferred parking for low-emitting vehicles for 5% of total parking capacity. There are 16 parking spots at the Community Emergency Service Station and 1 spot is reserved for low-emitting & fuel efficient vehicles, as indicated by signage.

SSc4.4: **Alternative Transportation: Parking Capacity**: This credit requires that the project meet, but not exceed, the required amount of parking allowed by code, and to provide preferred parking to carpools for 5% of the total parking capacity. The minimum number of code required parking spaces for the Community Emergency Service Station was 16; therefore, the project met, but did not exceed minimum code. One parking space is reserved for carpools, as indicated by signage.

SSc5.1: Site Development: Protect of Restore Habitat: This credit was pursued with Option 1: Undisturbed Greenfield Sites. The site was an undisturbed greenfield, and construction site disturbance was limited to the following: 40 feet beyond the building perimeter; 10 feet beyond surface walkways, surface parking, and utilities less than 12 inches in diameter; 15 feet beyond primary roadway curbs and main utility branch trenches; and 25 feet beyond constructed areas with permeable surfaces. In order to protect habitat, considerations were taken to minimize the project's footprint and hardscape. One area of vegetation within the project boundary was protected and can be identified by a limit of construction boundary (L.O.C.). The rest of the open space within the project boundary was restored with native or adapted vegetation.

SSc5.2: Site Development: Maximize Open Space: This credit is based on whether or not the project has zoning requirements for open space. Because there were no open space requirements in the zoning, this project had to follow Option 1: provide open space greater than or equal to building footprint. The building footprint is 8,276 square feet, so open space equal to that amount was required. The amount of vegetated open space provided was 48,190 square feet.

SSc6.1: **Stormwater Design: Quantity Control**: The existing imperviousness on the site before construction was less than 50%. This required that post-development runoff rates and quantities did not exceed pre-development runoff rates and quantities. The design team originally had a goal of meeting this requirement, but the design runoff rate exceeded the pre-development rate. Therefore, the project team changed their compliance strategy to address a secondary option, Stream Channel Protection. This credit application was a less reliable option because it is more subjective. The difficult requirement for this option is demonstrating that critical capacity values for the receiving stream channels are not exceeded. The civil engineer

provided a narrative that demonstrated the receiving stream channels were not subject to excessive erosion, and the project achieved this credit.

Table A.1. Site Runoff Calculation: Two-Year Design Storm

Time Period	Runoff Parameter	2-Year, 24 Hour Design Storm
Pre-development	Rate (CFS):	0.655
	Quantity (CF/Storm)	2,127
Post-development	Rate (CFS):	0.746
	Quantity (CF/Storm)	1,697

SSc6.2: **Stormwater Design: Quality Control**: This credit requires that 90% of average annual rainfall is captured and treated, and that 80% of the total suspended solids are removed. The project's civil engineer designed a stormwater management system that reduces impervious cover, promotes infiltration, and captures and treats 90% of the stormwater using acceptable BMPs. The project has bioretention cells that consist of depressions in the ground filled with a soil media mixture that supports various types of water-tolerant vegetation. The cells use plants and soils for removal of pollutants from stormwater runoff via absorption, filtration, sedimentation, volatilization, ion exchange, and biological decomposition. In addition, bioretention provides landscaping and habitat enhancement benefits. The bioretention cells can remove 85% of total suspended solids.

SSc7.1: **Heat Island Effect: Non-Roof**: This credit promotes the reduction of the heat island effect through material selection for the site. All of the hardscape on the site is concrete with a Solar Reflectance Index (SRI) of 35, which satisfied Option 1 of this credit. The project also received an Exemplary Performance bonus point because 100% of the hardscape consists of high-albedo concrete.

Even gray concrete has a Solar Reflectance Index that meets LEED requirements for Heat Island Reduction

SSc7.2: **Heat Island Effect: Roof**: This credit promotes the reduction of the heat island effect through material selection for the roof. The entire roof has a Solar Reflectance Index (SRI) of 83, which satisfied Option 1: Reflective Roofing Materials.

SSc8: Light Pollution Reduction: This credit requires that both interior lights and exterior lights do not cause excessive light pollution. For interior lights, this project has no luminaires that shine light directly out of windows. For exterior lights, the allowed lighting power was not exceeded, lamps are night-sky friendly (full cut-off), and the light meets the site boundary trespass requirements.

Water Efficiency

WEc1.1-1.2: **Water Efficient Landscaping**: To achieve this credit, the landscaping and irrigation systems were designed to reduce irrigation water consumption. Landscaping at the CESS used native plants that do not require irrigation beyond natural rain events and thus did not require a permanent irrigation system. Plants were established using temporary irrigation for a year, but after this establishment period no further irrigation was needed to sustain the plants. This strategy reduced the potable water needed for irrigation by 100%.

WEc2: Innovative Wastewater Technologies: This credit requires that the project reduce the amount of potable water used specifically for sewage conveyance. The project team addressed this aspect by selecting high-efficiency flush fixtures and installing dual-flush toilets throughout the facility. In addition, CESS is designed to use captured rainwater to supply the total water demand for sewage conveyance. For the rainwater catchment system, water is collected by the roof and drains to the 10,000 gallon cistern below grade. Based on the rainwater collection calculations, the facility collects 44,924 gallons annually, which is more than enough water to supply the annual flush fixture demand. The project reduced potable water use for sewage conveyance by 100% from a calculated baseline design through the installation of dual-flush water closets and rainwater system.

WEc3.1-3.2: Water Use Reduction – 20% & 30% Reduction: To meet this credit a project must reduce the gallons used on specific indoor water fixtures, such as toilets, urinals, faucets, and spray valves. The credit requires calculations that demonstrate fixtures use at least 20% less potable water than conventional fixtures on the market. The fixture schedule below outlines the type of fixture, the fixture make and model, and the flow rate.

Table A.2. Water Fixture Flow Rates

Fixture	Make & Model	Flow Rate
Dual-Flush Water Closet, Full-Flush	Zurn Z5562	1.6 gpf/0.8 gpf
Conventional Water Closet	Willoughby ETF-1490-FM-10"-FA	1.6 gpm
Low-Flow Lavatory	Zurn Z5344-PED	1.8 gpm
Shower	Florestone 36-3W	1.5 gpm
Decon Shower	Zurn Z7301-SS-MT-DV2P-HW11-S8-VB	1.8 gpm
Low-Flow Kitchen Sink	Elkay LRAD3319	1.8 gpm
Janitor Sink	Zurn z841m4	2.5 gpm

All of the fixtures above were measured in the LEED calculation and surpass the LEED requirements for this credit (fixtures that are not included in the LEED calculation are indicated in the table). The project has reduced potable water use by 52.1% from a calculated baseline design.

Energy Efficiency

EAp1: Fundamental Commissioning of the Building Energy Systems: This project implemented the Fundamental and Enhanced commissioning requirements to meet the prerequisite and additional points in the Energy and Atmosphere credit category. The requirements of Fundamental commissioning include the following:

- Developing Owner's Project Requirements (OPR) and Basis of Design (BOD) documentation
- Incorporating commissioning requirements into construction documents
- Develop and implement a commissioning plan
- Verify installation and performance of commissioned systems
- Complete commissioning report

The commissioning process at the Community Emergency Services Station at Ft. Bragg focused on the following systems:

- Outside air unit
- Exhaust fans
- Ground source heat pumps
- Condenser water pumps
- Ductless split system heat pump
- Solar wall
- High bay heating system
- Solar domestic water heating system
- Building automation system
- The testing, adjusting and balancing process
- Lighting controls

During the commissioning process, several concerns were noted and repaired. Some of the issues identified and repaired include: the dehumidification cycle was not activated in the heat pumps, and the heat pump compressors were cycling when the condenser water valves were closed; the high bay heating system setpoint was too high, which would have caused excessive energy use; the condenser water pumps were running even when there was no cooling or heating demand; and there were several leaks in the exhaust air ductwork. At the completion of the acceptance phase of the commissioning process, the major issues had been repaired and the building was operating as desired.

EAp2: Minimum Energy Performance: The project complies with the mandatory provisions of ASHRAE 90.1-2004. A computer simulation model was used to confirm satisfaction of this

prerequisite. More details on the energy efficiency strategies to go beyond the ASHRAE 90.1 standard and the energy modeling results are included in EAc1: Optimize Energy Performance.

EAp3: Fundamental Refrigerant Management: In order to comply with this credit, all refrigerants used in the building must be non-CFC. The mechanical engineer specified equipment that does not include CFCs and the project easily attained this credit.

EAc1: **Optimize Energy Performance**: The project used a computer simulation model to document improved building energy performance under EA Credit 1. The model results from EA Credit 1 are used to project the annual building energy costs for the project. The modeling software used was eQuest version 3.60.

The project achieved an energy cost savings of 34.1 percent through the use of the energy cost measures described.

EAc2: On-Site Renewable Energy: The project used a computer simulation model to document improved building energy performance under EA Credit 1. The model results from EA Credit 1 are used to project the annual building energy costs for the project. To achieve on-site renewable energy the project installed six flat plate solar panels to heat water for domestic use. As this building is a fire station and residence, the amount of hot water used on site is relatively high for a commercial building and the project sees a greater return on investment by installing this type of technology. Implementation of solar water heating generated a renewable energy cost of 7 percent.

EAc3: Enhanced Commissioning: The commissioning process for the Community Emergency Services Station began prior to the building design. The commissioning agent participated in the design charrette along with the Owner, building occupants, the design team, sustainability consultants, and several other team members. CH2M HILL, the commissioning agent, reviewed the 85% design documents, 100% construction documents, and back checked the comments on the final design. The commissioning agent also reviewed the BOD and OPR as part of the design reviews. Prior to construction the commissioning agent participated in the value engineering conference. The commissioning agent developed a construction phase commissioning plan, and once the general contractor was hired, the commissioning agent conducted a commissioning scoping meeting, reviewed submittals, participated in frequent meetings with the project team, and performed mid-construction site visits. The construction team completed construction checklists to demonstrate that the equipment had been properly installed and was ready for testing.

Two site visits were conducted to perform functional testing. CH2M HILL worked with the general contractor, the testing, adjusting and balancing contractor, and the controls contractor to fully test the systems. For each system, the performance (air flows, water flows, etc.) were tested, the sequences of operation were tested in occupied, unoccupied, and emergency modes. The setpoints and control strategies were reviewed in the building automation system, and modifications were made as appropriate (to meet the design and operating criteria. The Owner has now accepted the building, and a follow-up site visit was performed within 10 months to review building operation and resolve any issues that occur.

EAc4: Enhanced Refrigerant Management: In order to comply with this credit all refrigerants used in the building must be non-HCFC. This project easily complied with these requirements by installing heat pumps that used R-410a refrigerant.

EAc4: Measurement & Verification: The building's energy and water use are being carefully monitored in order to compare the measured energy use to the modeled energy, but also to the measured energy use of an existing fire station at Fort Bragg. The energy use comparison will be at the whole building level, rather than at individual building systems.

Based on the requirements outlined by the IPMVP, this project will follow the specifications for "Option D", which applies to new construction where there is a lack of measured baseline data with which to compare the post construction metered results. Option D uses detailed, whole building energy simulation in order to predict the energy consumption of the completed building. The project team developed and implemented a Measurement and Verification Plan that is consistent with IPMVP Option D: Calibrated Simulation (Savings Estimation Method 2) to describe the measurement and verification strategies implemented over the course of a year after occupancy.

The plan is intended to verify the cost savings associated with energy efficiency measures incorporated into the design, and to provide a recalibrated energy model that will serve as a tool for building operators in identifying and remedying causes of underperformance. Energy conservation measures (ECMs) found to deliver anticipated savings will be considered by the Army for inclusion in architecture and design standards for future builds of similar properties.

Through the use of data collected from the Fort Bragg Utility Management Control System, the Fort Bragg energy management contractor, Johnson Controls, will work with the Pacific Northwest National Laboratory to measure and the actual utility usage of the building and key end uses for the first year of post-occupancy consumption. The second year of post-occupancy consumption will be measured and assess by Johnson Controls and the Fort Bragg energy manager. During the first year, the energy use will not only be normalized and compared to the energy model, it will also be compared to the measured energy use of an existing fire station at Fort Bragg. The whole building measurements and comparisons will be used to identify potential ECMs for CESS and design lessons learned for the Army standard designs.

Materials & Resources

MRp1: Storage and Collection of Recyclables: This prerequisite requires the building to provide an easily accessible dedicated space where building occupants can recycle paper, corrugated cardboard, glass, metals, and plastics. This area must be included whether or not the local municipality provides recycling services to the building. The project team achieved this prerequisite through providing a designated recycling area in the corridor next to the dorms and laundry area. There are also recycling bins located throughout the building for the office staff and visitors. This facility recycles paper, glass bottles, aluminum cans, cardboard, and plastic bottles.

MRc2: Construction Waste Management: At the beginning of the construction phase, the project team had a goal to divert 75% of the total construction waste of the project. In order to

meet this goal a Waste Management Plan was developed by the contractor to communicate and manage the implementation of recycling on site. The goals and objectives of the Construction Waste Management Plan were emphasized to all subcontractors via subcontract agreement, enforcement of the specifications, weekly construction meetings and quality control meetings.

Waste Management Corporation (WMC) was chosen as the waste and recycling hauler. Items that could be recycled within a reasonable distance from the site were chosen for recycling. WMC provided commingling containers for recycling and separate waste & debris containers to reduce contamination of recyclable materials. Loads were separated and weighed at the WMC transfer station. WMC provided monthly reports for tracking and RA Connelly (general contractor for CESS project) maintained a comprehensive waste management log that was available to the project team.

The project diverted 55.29 tons (90.43%) of on-site generated construction waste from landfill.

MRc4: **Recycled Content**: The goal to achieve points for this credit is to install 10% recycled materials (based on cost) for 1 point or 20% for 2 points. In the early stages of design, the project team identified what building materials contained recycled content and made sure there were clear specifications that communicated the importance of selecting materials with recycled content. Generally, replacing the highest cost items with recycled content materials will result in the largest impact to meet the 10% limit. The contractor also required product vendors to document the recycled content value for their product as a requirement for payment. This information was collected and tracked into a comprehensive spreadsheet maintained by the contractor. Monthly reviews of this information were performed by Southface throughout construction to verify the information was being collected and on track with the sustainability goals. The project achieved a combined recycled content value (as a percentage of total materials cost) of 28.5 percent.

MRc5: **Regional Materials**: The project was well suited to source a variety of materials regionally (within a 500 mile radius of the project site) for a minimum of 10% or 20%, based on cost, of the total materials value. 24.83% of the total building materials value includes building materials and/or products that have been extracted, harvested, or recovered, as well as manufactured, within 500 miles of the project site. The following are high cost items that helped achieve this credit:

- Tile Flooring
- Tile Grout
- Concrete
- Insulated Concrete Forms (ICF)
- Rebar
- Structural steel
- Brick masonry

Similar to the process implemented in to manage recycled materials, the construction team required product vendors to document the local material content value and manufacturing locations for their product as a requirement for payment. This information was collected and tracked into a comprehensive spreadsheet maintained by the contractor. Monthly reviews of this

information were performed by Southface throughout construction to verify the information was being collected and on track with the sustainability goals. The project achieved a local material value (as a percentage of total materials cost) of 24.8 percent.

MRc6: Rapidly Renewable Materials: To qualify for this credit the percentage of rapidly renewable materials must be at least 2.5% of the total materials cost. In Community Emergency Service Station, 2.97% of the total materials used are from rapidly renewable sources. The following are rapidly renewable materials that helped achieve this credit:

- Rubber Flooring
- Linolium Flooring
- Wheatboard Cabinets

MRc7: Certified Wood: This credit is achieved when a project installs more than 50% of wood-based materials that are FCS certified (based on costs). The doors are the only FSC certified products in the project which is 81.99% of the total wood-based building material cost.

Indoor Environmental Quality

IEQp1: Minimum Indoor Air Quality Performance: The project complies with the minimum requirements of ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality, using the Ventilation Rate Procedure. The building is designed with a Dedicated Outside Air System (100% outside air unit) for the building to provide outside air that exceeds the ASHRAE 62.1-2004 minimums by more than 30%. The unit is designed to deliver 900 cfm to the building and exhaust 800. The outside air unit has an integral airflow measuring device that is accurate to well within ±10% and will provide an alarm to the Building Automation System if the unit fails to deliver the design outside air quantity.

The method for ventilating this building is through active/mechanical ventilation. The truck bay is a parking garage space, and the only space that is not cooled - only mechanically heated and ventilated through a vent fan. The truck bay was not designed with air conditioning to save energy in the summer months. An exhaust fan (3200 cfm of airflow) is designed to ventilate the truck bay and is turned on when CO levels reach 9 ppm.

Since this building is a half residence, the building was designed to have operable windows for ease and comfort for the occupants. However, the ventilation design meets ASHRAE mechanical ventilation requirements in all of the building's rooms.

IEQp2: Environmental Tobacco Smoke (ETS) Control: Community Emergency Service Station is a non-smoking establishment indoors. Exterior signage prohibiting smoking within 25 feet from the building was developed to comply with this credit.

IEQc1: Outdoor Air Delivery Monitoring: The requirement to achieve this credit is to install a permanent CO_2 monitoring system that provides feedback on ventilation system performance to ensure that ventilation systems maintain design minimum ventilation requirements. In this project, the mechanical designer added CO_2 sensors with visual alarms to densely occupied area like the training room, day room, and office area. Consistent with LEED requirements, the

CO_2 sensors were installed 3 to 6 feet above the finished floor. When the visual alarm indicates that more outside air is needed, the ventilation will be adjusted manually by a team member.

IEQc2: Increased Ventilation: This credit is achieved when a project's ventilation system is designed to provide at least 30% more outside air per space above ASHRAE 62.1-2007. This project meets the requirement through the strategies outlined in IEQp1: Minimum Indoor Air Quality Performance.

IEQc3.1: Construction Indoor Air Quality Management Plan - During Construction: The project developed and implemented a construction IAQ Management Plan that followed the referenced SMACNA Guidelines. The SMACNA Guidelines require construction sites to meet the following best practices throughout construction:

- Stored material management and protection.
- Source control to ensure through submittal and Materials Safety Data Sheet (MSDS) review that the materials meet air quality standards.
- Protection of all supply and return air systems from contamination during delivery, through installation, and preconstruction use.
- Pathway interruption to reduce and/or prevent the migration of contaminants through a building during construction.
- Scheduling work to include on time delivery and minimization of on-site material storage to limit the risk of contamination.
- Establishing minimum standards for housekeeping to prevent the buildup of dust and other construction contaminants that could become airborne or otherwise transported into a clean space.

RA Connelly took photos on a monthly basis to document that best practices were being met.

Since permanently installed air handling equipment was not operated during construction, MERV 8 filters were not installed while the building was under construction.

IEQc3.2: Construction Indoor Air Quality Management Plan - Before Occupancy: Prior to initial occupancy, baseline IAQ testing was conducted using testing protocols consistent with the United States Environmental Protection Agency report "Compendium of Methods for the Determination of Air Pollutants in Indoor Air". The initial test results showed that some of the sampling points exceeded the allowable concentration limits. These non-compliant areas were flushed with outside air and retested to confirm compliance with the concentration limits. The project was able to comply with the IAQ test procedure because low emitting finishes were installed on the project.

IEQc4.1: **Low-Emitting Materials – Adhesives and Sealants**

IEQc4.2: Low-Emitting Materials – Paints and Coatings: Low-emitting materials were researched and incorporated into the specifications in order to follow the criteria for this credit. The project's general contractor used the lists of allowable VOC levels in the LEED NC rating system to determine which adhesives, sealants, paints and coatings satisfied the credit

requirements and which did not before purchasing products on site. The VOC requirements were also included in the specifications as a performance spec.

IEQc4.3: Low-Emitting Materials – Carpet Systems: The design team thoroughly researched carpet products that met the low-emitting carpet requirements of the LEED program. This information was also included in the specifications as a requirement. The project installed carpet that complies with the testing and product requirements of the CRI Green Label Plus Program, there are no installed carpet cushions, and all carpet adhesives comply with the requirements of EQc4.1: Low-Emitting Materials, Adhesives and Sealants.

IEQc4.4: Low-Emitting Materials – Composite Wood & Agrifiber Products: All permanently installed composite wood products inside the water-proofing membrane had "no added urea formaldehyde" (NAUF). Urea formaldehyde is a chemical in the glues which off gasses at room temperature, polluting the air and harming the health of building occupants. The drawings and specifications included this requirement early in the design document development process and the contractor was knowledgeable about finding vendors of NAUF composite wood products.

IEQc5: Indoor Chemical & Pollutant Source Control: The purpose of this credit is to prevent chemicals and other indoor pollutants from harming building occupants. To prevent dirt and debris from entering the building the main entryways have permanently installed recessed grilles that will be cleaned weekly by the janitorial staff. There are also specific rooms in the building that are designated as chemical use areas. These rooms include the janitor's closet, the decontamination room and the laundry room. Effective room separation is required and specific construction details were implemented including enclosing walls to the structural deck with sealant at the seam and installing a door with a closer and seals. To reduce the amount of chemicals and particulate matter in the air the project installed MERV 13 rated filters prior to occupancy.

IEQc6.1: **Controllability of Systems – Lighting**: This building has a variety of lighting controls including manual on switching with dimming, occupancy sensors, photocell sensors, time clock switching, and emergency on inputs. Emergency on inputs force lights on when the dispatch station activates the fire alert signal and alerts fire fighters that a call has been made.

All of the individual workstations have lighting controls. In the Police Office, EMS Office, and Captain's Office, there is manual on switching with dimming, occupancy sensors, and photocell sensors that adjust the dimming of the lights. There is a light switch for each workstation in these offices. The seven individual dorms each have manual on switching with dimming, an occupancy sensor, and an emergency on input.

The multi-occupant Physical Training and Training rooms have manual on switching with dimming, occupancy sensors, and photocell sensors. The Break Room/Dayroom has manual on switching with dimming, an occupancy sensor, and an emergency on input. The Apparatus Bay has manual on switching with dimming, occupancy sensors, and photocell sensors. The corridor areas have time clock switching and emergency on inputs. The strategies employed throughout the building spaces allows flexibility for building occupants and allows the project to meet this LEED credit.

IEQc6.2: Controllability of Systems – Thermal Comfort: This credit requires controllability of thermal comfort for building occupants. This project is mechanically controlled, but operable windows have also been provided as this is a residence for building occupants. Operable windows serve as the thermal comfort control strategy in the building for the individual office spaces and the dorm rooms. Each multi-occupant space has a thermostat that controls the air temperature. With this design approach, each room has a thermal comfort control.

IEQc7.1: **Thermal Comfort – Design**: The heating, ventilating, and air conditioning systems and the building envelope designs met ASHRAE Standard 55-2004, which specifies thermal comfort conditions in buildings. The HVAC system includes thermostat set points targeted for energy efficiency and occupant comfort during the varying seasons.

IEQc7.2: **Thermal Comfort – Verification**. A thermal comfort survey was developed that will be distributed to building occupants within the first 6 to 18 months of occupancy. The survey is part of a multi-year Department of the Army study to show how the sustainable building performs during operations. The CESS building will undergo monitoring of its energy consumption, water consumption, indoor air temperature, and indoor air quality and occupant feedback is another metric by which sustainability is assessed.

IEQc8.1: **Daylight and Views – Daylight 75% of Spaces**: Harvesting natural light was a key sustainable principle prioritized at the beginning of the project. Passive solar design strategies were implemented and discussed at the charrette such as North-South building orientation, external light shelves on the southern exposure, and high efficiency glazing to minimize heat gain. The use of clerestory windows helped interior rooms have access to daylight as well. All of these strategies improve the capacity to harvest natural light which reduces lighting energy loads and provides an improved indoor environment. For credit compliance, the project measured the square footage of the building spaces that have at least a two percent Glazing Factor. The project achieved a minimum of 2 percent glazing factor in 94 percent of all regularly occupied spaces.

Both credits IEQ 8.1 and IEQ 8.2 utilized a CIR ruling that allowed the training room to be exempt from the daylight and views calculations. The Training Room (108) is a computer training/multi-media room where occasional meetings of the staff will take place. Each meeting will include an audio visual presentation, film, and/or use of the computers. While these meetings are taking place, the room will be darkened and the occupants' focus should remain on the instructor. The project argued that daylighting and views would be detrimental to the function of this room by creating unwanted glare and taking students' focus away from the instructor. Because daylighting and vision glazing would be detrimental to the function of this room, this room was not included in the daylighting or vision calculations. This method of compliance is confirmed in EQ c 8.1 CIR ruling 5/24/04.

IEQc8.2: **Daylight and Views – Views for 90% of Spaces**: Access to views and the outside was an important goal for the project as the occupants reside there for extended periods of time. Glazing was designed to allow for views in all of the regularly occupied spaces such as the dorm rooms, individual offices and dayroom. The project has provided direct line of sight views for 92 percent of all regularly occupied areas. For reasons explained in IEQ 8.1, the training room was excluded.

A.1.2 LEED Models

The Fort Bragg Community Emergency Service Station (CESS) in Fort Bragg, North Carolina, was designed and constructed with the target of achieving LEED-NCv2.2 Platinum certification. The CESS provides general emergency services in addition to fire protection to its community. It operates twenty-four hours a day, seven days a week. The CESS design model calculated annual energy use would be 34% lower than the modeled baseline.

Based on the requirements outlined in Volume 3 of the International Performance Measurement and Verification Protocol (IPMVP), the ESTCP project followed the specifications for "Option D," which applies to new construction where there is a lack of measured baseline data with which to compare the post-construction metered results. Option D uses detailed, whole building energy simulation in order to predict the energy consumption of the completed building.

M&V Objectives

The process for conducting energy modeling was described in the Measurement and Verification (M&V) plan for the project (ESTCP is based on Option D: Calibrated Simulation of IPMVP Volume III: Concepts and Options for Determining Energy Savings in New Construction, (IPMVP 2003). One of the objectives of the M&V plan was to provide a recalibrated energy model that will serve as a tool for building operators in identifying and remedying causes of underperformance. Energy conservation measures (ECMs) found to deliver anticipated savings will be considered by the Army for inclusion in architecture and design standards for future builds of similar properties.

The M&V plan described the process and responsible parties for:

- Predicting energy use by end use in the project building
- Measuring energy use by end use in the project building
- Calculating actual cost savings
- Corrective action when underperformance occurs

The Pacific Northwest National Laboratory was responsible for establishing the M&V plan (Table A.3). Fort Bragg energy management personnel are primarily responsible for the M&V Plan's coordination and implementation. Johnson Controls and building operations staff will support implementation of the plan.

Table A.3. M&V Responsibilities

M&V Activity	Responsible Party
Baseline energy model	Southface Energy Institute
Recalibrate baseline energy model to reflect as-built and post-occupancy conditions	Southface Energy Institute
Identification of ECMs for inclusion in the M&V plan	Pacific Northwest National Laboratory (year 1) Johnson Controls (year 2)
Development of M&V plan	Pacific Northwest National Laboratory
Compilation of all occupancy, controls, BAS data, and scheduling information during the M&V period	Johnson Controls
Spot metering during M&V period	Johnson Controls
Installation of required sub-metering equipment	Johnson Controls
M&V Report	Pacific Northwest National Laboratory (year 1) Fort Bragg Energy Management Personnel (year 2)
Corrective Action	Fort Bragg Energy Management Personnel

A.2 ELECTRICITY M&V PLAN

A.2.1 Electricity Baseline Simulation

IPMVP Option D has been selected for the M&V plan because a) the integrated design process yielded efficiency strategies intended to work in concert with each other, making isolation of ECMs inappropriate, and b) a computer simulation was used during the design phase to predict whole building energy usage. The computer simulation was performed using eQuest to demonstrate achievement with LEED-NCv2.2 EA Credit 1: Optimize Energy Performance. Model inputs are recorded in the LEED Certification Application materials. The eQuest energy model files have been supplied to Fort Bragg Energy Management Personnel and are available for calibration.

The energy analysis used climatic data for Raleigh, North Carolina, which is proximate and climatically similar to Fort Bragg, North Carolina.

Operating schedules were confirmed at 24 hours per day, 7 days a week, and building occupancy confirmed with the Fire Chief.

Projections reflect annual electricity consumption, and are summarize in Table A.4.

Table A.4. Modeled Baseline and CESS Projects Electricity Usage by End Use

End Use	Baseline Annual Electricity (kWh)	Expected Annual Electricity (kWh)
Total Building	215,948	147,566
HVAC	89,782	36,550
Electric Hot Water (backup system)	0	800

Energy Conservation Measures (ECMs)

Table A.5 lists the ECMs input into the energy model for the proposed design using eQuest version 3.60.

Table A.5. Energy Conservation Measures

Model Input Parameter	Proposed Design Input
Exterior Wall Construction	Insulated concrete form (ICF) with 5" of polystyrene foam insulation and 6" of concrete: U=0.042
Roof Construction	Metal roof panels with 5" of continuous polystyrene insulation (R-20); reflectivity of 0.45 (SRI = 83)
Floor/Slab Construction	6" concrete slab with no insulation F-Factor = 0.80
Window-to-gross wall ratio	.134
Fenestration type	Glazing: PPG Sungate 100 and Solexia low-e double pane. Frame: YKK AP 45 TUH thermally broken impact resistant storefront system.
Fenestration U-factor	0.31
Fenestration SHGC - All	0.41
Fenestration Visual Light Transmittance	0.63
Interior Lighting Power Density (W/sf)	0.90
Daylighting Controls	Yes, in Garage, Training room and Offices
Other Lighting Control Credits	10% LPD reduction for Occupancy sensors in several rooms (See Design building lighting file for details)
Exterior Lighting Power (kW)	2979 watts total (2603 watts tradable; 376 watts non-tradable)
Primary HVAC System Type	Climate Master TT series ground loop heat pump with dual speed compressor and ECM fan motor
Other HVAC System Type	Split system ductless mini-split A/C in IT room
Fan Supply Volume and Power	HP-1: 1600 cfm; 0.375 w/cfm HP-2: 1200 cfm; 0.375 w/cfm HP-3: 1400 cfm; 0.375 w/cfm HP-4: 1400 cfm; 0.375 w/cfm HP-5: 1750 cfm; 0.375 w/cfm DS-1: 300 cfm; fan power included in EIR
Unitary Equipment Cooling Efficiency	HP-1: 17.9 EER; 0.1444 CEIR HP-2: 18.2 EER; 0.1416 CEIR HP-3: 17.9 EER; 0.1444 CEIR HP-4: 17.9 EER; 0.1444 CEIR HP-5: 17.5 EER; 0.1551 CEIR DS-1: 11.2 EER; 0.3047 CEIR
Unitary Equipment Heating Efficiency	HP-1: 4.0 COP; 0.2067 HEIR HP-2: 4.0 COP; 0.2081 HEIR HP-3: 4.0 COP; 0.2067 HEIR HP-4: 4.0 COP; 0.2067 HEIR HP-5: 3.9 COP; 0.2200 HEIR DS-1: 3.5 COP; 0.2857 HEIR

Table A.5. (continued)

Model Input Parameter	Proposed Design Input
Ground water loop & pump parameters	Vertical wells: 3×5 rectangular configuration; 60 gpm water flow max.
Domestic Hot Water Heater	A.O. Smith Cyclone BTH 300; 130 gal.; propane; 96% thermal efficiency; 1084 Btus/hr SL
Solar water heater parameters	Glazed, SolarH2Ot, S-SC-179P32, Solar Fraction = 65%

Baseline and Expected Energy Savings

Anticipated annual savings are based on energy modeling performed during the design process using eQuest, which showed a building-wide reduction in energy costs of 35% compared to ASHRAE 90.1-2004 *efficiency* levels. This projection was developed based on the Building Performance Rating Method in Appendix G of ASHRAE 90.1-2004, and is shown in Table A.6.

Table A.6. Expected Annual Energy Savings

Energy Type	Baseline Annual Usage	Projected Annual Usage	Projected Annual Savings	Percent Energy Savings	Projected Annual Cost Savings ($)	Percent Cost Savings
Electricity (kWh)	215,948	147,566	68,682	31.7%	$3,680	32.8%
Propane (MBtu)	166	131	35	21.1%	$732	21%
Solar Water Heating (MBtu)	0	-37	37	-	$775	-
Total (kBtu/yr)	902,918	597,191	305,727	33.9%	$4,412	35.3%

The expected annual consumption values above will be adjusted based on weather data, occupancy levels, and system operating parameters realized during the year-long period during which energy consumption measurements are in place. The adjusted expected savings will then be compared to actual savings.

Electricity costs will be calculated using the Fort Bragg rates provided by Johnson Controls. Natural gas usage costs will be calculated using the Fort Bragg rate structure provided by Johnson Controls. Energy savings will be determined by comparing measured energy use to the projected based on the following equation:

Energy Savings = Projected Baseline Energy Use – Measured Post-Construction Energy Use

Measured Post-Construction Energy Use is the energy use of the as-built facility. This is in accordance with the Method 2, Option D: Savings Estimation protocol in the IPMVP standard.

Table A.7. Include Building and Use Characteristics

	Longstreet	CESS
Staffing	4 fire fighters plus 1 extra fire personnel for 1 12-h shift per week	4 fire fighters plus 2 Emergency Medical Staff 2 Military Police
Square Footage	6125	8295

A.2.2 Electricity Baseline Simulation

IPMVP Option D was selected for the M&V plan because a) the integrated design process yielded efficiency strategies intended to work in concert with each other, making isolation of ECMs inappropriate, and b) a computer simulation was used during the design phase to predict whole building energy usage. The computer simulation was performed using eQuest to demonstrate achievement with LEED-NCv2.2 EA Credit 1: Optimize Energy Performance. Model inputs are recorded in the LEED Certification Application materials. The eQuest energy model files have been supplied to Fort Bragg Energy Management Personnel and are available for calibration.

The energy analysis used climatic data for Raleigh, North Carolina, which is proximate and climatically similar to Fort Bragg, North Carolina.

Operating schedules will be confirmed at 24 hours per day, 7 days a week, and building occupancy will be confirmed with the Fire Chief.

A.2.3 Electricity Baseline and Expected Usage Projections

The projected baseline is based on the minimum requirements of ASHRAE 90.1-2004 for buildings with similar mechanical systems. Total building energy use will be measured. Where additional submetering can be aligned with the modeled end use projections and comparison of measured to modeled energy use will be made.

Projections reflect annual electricity consumption, and are summarize in Table A.8.

Table A.8. Baseline an Expected Electricity Usage Projects by End Use

End Use	Baseline Annual Electricity (kWh)	Expected Annual Electricity (kWh)	Actual Annual Electricity (kWh)
Total Building	215,948	147,566	TBD
HVAC	89,782	36,550	TBD
Electric Hot Water (backup system)	0	800	TBD

Equipment Commissioning

Commissioning activities occurred in CESS for the following energy-related systems in November 2010, prior to building occupancy which was in March 2011.

- Heating
- Ventilation
- Air conditioning
- Refrigeration
- Lighting
- Domestic hot water
- Controls

Commissioning was performed by CH2M HILL in accordance to LEED EA Prerequisite 1, Fundamental Commissioning of the Building Energy Systems. The Commissioning Report is included in the LEED Certification Application and in Appendix G.

A.3 ANALYSIS AND EVALUATION OF INFORMATION FOR MEASURED OBJECTIVES

Our analysis uses a 'matched pairs' approach (Fowler et al. 2009), which attempts to match each sustainably designed building with a typically designed building of comparable attributes. Basic building and site characteristics data were collected for each building—Longstreet Fire Station and the CESS building to establish the pairing (Table A.4). The differences in performance between the matched buildings were then used to evaluate the performance. The buildings in a matched pairs design must be matched by the following criteria:

- Be the same building type or function (e.g., office, courthouse, training center, etc.) and have similar water, energy, waste, and maintenance needs;

- Be located near each other to minimize the impact of different weather considerations over the measurement period;

- House a similar occupant type (e.g., active military, government employees, contractors, etc.), to minimize differences in policies, procedures and work ethic; and

- Have been in operation for at least 6-months and for a comparable number of years. This reduces the impacts of equipment differences.

The Longstreet Fire Station met these criteria; however, Longstreet Fire Station uses natural gas for heating and cooling, and this energy source was not available for the CESS building, which relies completely on generated electricity for heating and cooling.

Data collected at 15-min intervals for the CESS and Longstreet Fire Station were processed into hourly and daily summaries for comparison. The data were normalized either by the square footage of each building, the number of occupants in the building, or by the number of emergency calls.

A.3.1 Data Analysis and Quality Control

The data received from Fort Bragg contained varying levels of quality. These quality issues were identified and dealt with using an excel macro for consistency, followed by human intervention for specific issues such as extreme values. There were five types of data that were identified, they included: actual data, missing data, smoothed data, overridden data, and data jogs. The data from the meter is initially classified by its continuity and congruency. Non-continuous data indicates the meter read a negative usage and incongruent data indicates a missing data point. Missing data can either be classified as a missing value or a questionable meter value. The system denotes these questionable points using "???". When data incongruent data (missing) is obtained there are three options for the next piece of data. These are described in Figure A.1.

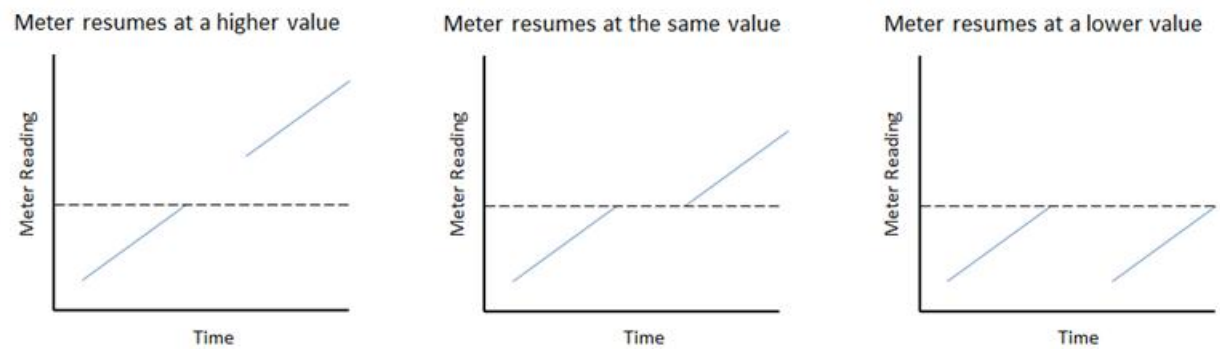


Figure A.1. Meter Options when Data is Missing (blue line indicates data)

In each case, a decision must be made with how to treat the data. Other than a negative usage step, it is difficult decide if these values are actually faulty or if they merely reflect some atypical behavior of the building's systems. In the first two cases, all data is considered to be valid and it is labeled as smoothed. This label indicates the data may be questionable. Further analysis is performed with the data to ensure the smoothed data conveys realistic consumption across the period. In the third case, the data is simply considered to be lost. The point at which the data resumes is considered to be a jog, while all other points are categorized as missing. A descriptive summary of each of the data types is presented in Table A.9.

Table A.9. Data Types Identified

Data Type	Data Provided at Time Step	Description	Inclusion in Calculations
Data	Yes	Data is congruent with previous data points	Yes
Jog	Yes	Data shows a negative consumption.	No
Smooth	No	Usage was inferred based on a linear consumption between the two known points	Yes

Missing	No	Usage was not inferred because the usage would have been negative through the missing period.	No
Override	Yes	Data was provided or calculated at the time step but it was determined to be erroneous	No

EUI Calculation and Averaging

Calculating the EUI for a building over a given time period is a simple task if the data are congruent and consistent across the period. However, if data points are missing, it is possible to understate the building consumption across the period if adjustments are not made to account for the data gaps.

There are three way of measuring the calculating the consumption of a building with questionable data. The first is to simply subtract the final metered data point from the initial metered data point. This process does not take any meter events into consideration throughout the period. If there are gaps in the data, as shown in Figure A.1, the validity of the EUI data cannot be determined.

The second method is to create a new meter that only includes positive values from the original meter. Gaps can be smoothed using the approach described above, and a general idea of the consumption of a building can be determined. This case helps ensure consumption will not be significantly overstated, but does offer risk of understatement from missing data and jogs.

The third approach, and the approach used in this analysis, involves averaging the consumption over a time period. Given a time period (t), and a set of usage values (U), it is possible to determine the average consumption across the period (AC). The total consumption across the period is defined as AC*t. Figure A.2 provides a graphical representation.

In the second approach, the consumption over the time period would be defined by summation of usage within time period t. This may underestimate the usage, or overestimate in the case of an unrealistically large reading in the meter value. The third approach determines the average usage (AC) and multiplies it by the duration of interest. An example is presented in Table A.10 to illustrate the effect of the two methods using hypothetical data. The time period analyzed can vary. For EUI calculations, the average was calculated over a month interval. Data is also presented on a daily and hourly basis.

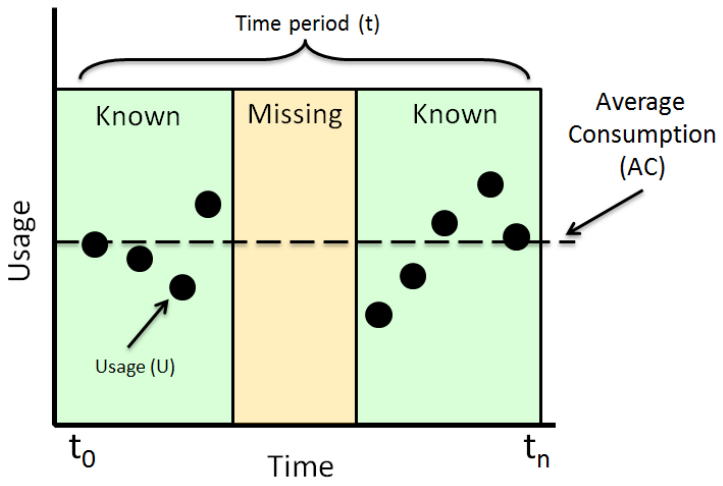


Figure A.2. Graphical Example of Data Conditioning

Table A.10 shows hypothetical data for 24 time steps. The Meter Reading column shows the value as it would be originally received from Ft Bragg. The hypothetical actual usage is presented in the far right column. The hypothetical usage was used to guide the generation of the meter reading column and is presented for comparison, this is never part of the data and is shown here as a hypothetical comparison. The Meter Reading column is used to calculate the Calculated Usage, which is simply the difference between the current and last known meter reading. The Conditioned Usage column averages any necessary points and fills them across missing time periods. Each type of reading is categorized in the Data Type column. The final column shows the theoretical meter readings that would generate the initial meter reading column. This column is not known for analyzed data and is simply provided here as a comparison. Through this table it is possible to understand how the conditioning process was performed. This only applies to usage values for continuously increasing meters such as water, gas and electricity. No filling was performed on temperature data. In this example the average of the conditioned data was 5, while the hypothetical actual usage used to generate the meter was 5.0. By multiplying this average across the period of interest, it results in a difference of 2 meter units, or 1.6%. Simply summing the usage across the period, without the clearly erroneous data, produces a difference of 17 meter units, or 14%.

Data Processing

The general data analysis and approval process is described in Figure A.3. The diagram shows many data inconsistency errors being address in step K. The continued repetition of this step, followed by all downstream analysis, ensures a log of changes is maintained. This makes it possible to evaluate the effect of adjusted data points on the final EUI values for the building.

A: Receiving Data

The CESS data collection process begins with a spreadsheet delivered bi-weekly via e-mail from the UMCS manager at Ft Bragg, Figure A.4.

Table A.10. Hypothetical Data to Illustrate Data Cleanup Process

Time	Meter Reading	Calculated Usage	Conditioned Usage	Data Type	Actual Usage
0	**0**	-	-	-	-
1	4	4	4	Data	4
2	9	5	5	Data	5
3	17	8	8	Data	8
4	25	8	8	Data	8
5			3.75	Smooth	4
6			3.75	Smooth	3
7			3.75	Smooth	3
8	40	15	3.75	Smooth	5
9	48	8	8	Data	8
10	53	5	5	Data	5
11	61	8	8	Data	8
12			4	Smooth	4
13			4	Smooth	3
14			4	Smooth	3
15	77	16	4	Smooth	6
16	82	5	5	Data	5
17	88	6	6	Data	6
18	7000	6,912		Override	4
19	57	-6,488		Jog	6
20	63	6	6	Data	7
21	5066	5003		Jog	3
22			5.5	Smooth	4
23	5077	11	5.5	Smooth	7
24	5080	3	3	Data	3

This spreadsheet contains 15-minute interval data and includes the following data points:

- For each Phase
  - Instantaneous Power
  - Incremental Energy
  - Power Factor
  - Reactive Power
  - Voltage
  - Current
- For the Total Service being measured
  - Instantaneous Power
  - Incremental Energy

- Average Power Factor
- Total Reactive Power
- Total Reactive Energy
- Frequency
- Historical Peak Demand

- For each of the following Energy use points
  - Total Building Energy Use
  - HVAC Energy Use
  - DHW Energy Use
  - Vehicle Bay.

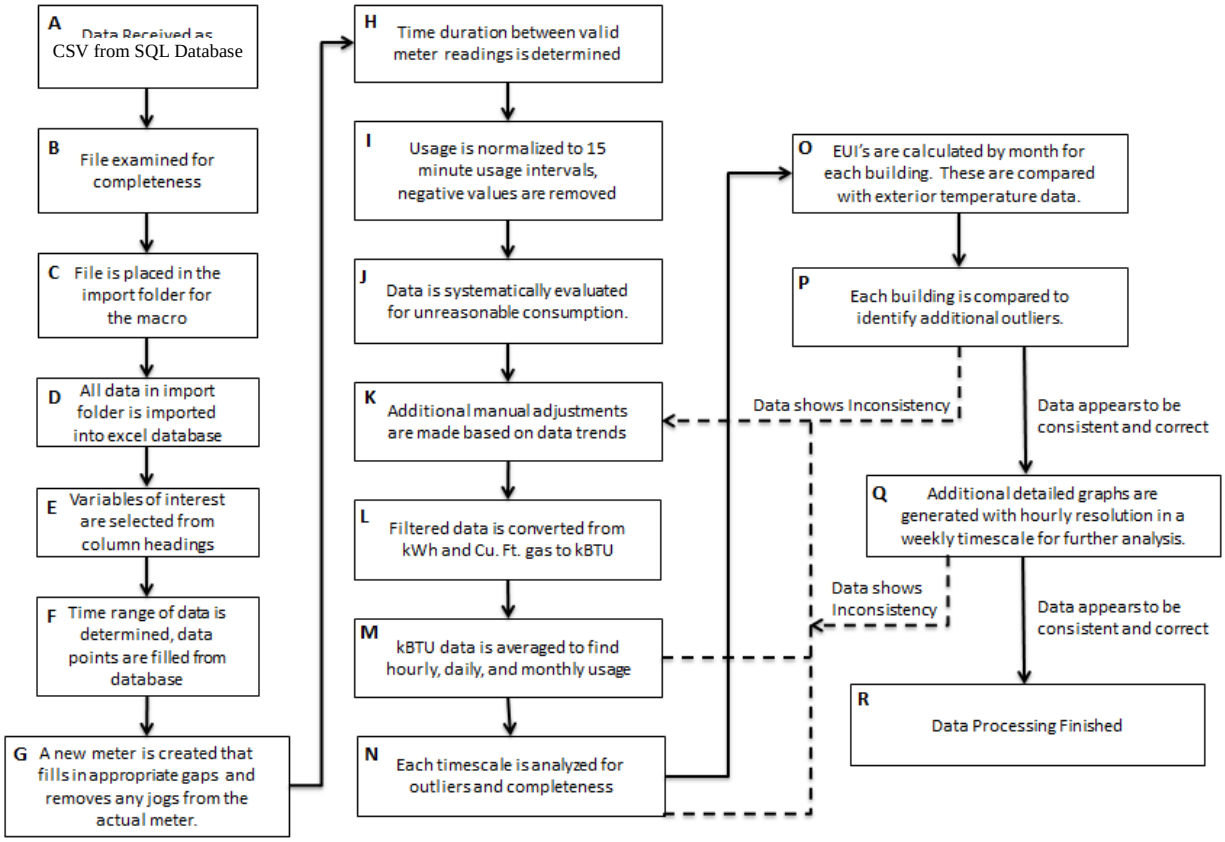


Figure A.3. Process Flow for Data Analysis and Approval

1	Time	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Power R	3802 Wattnode Main Building EnergyS	3802 Wattnode Main Building Energy V	3802 Wattnode Main Building Energy V	3802 Wattnode Main Building Energy V	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Power R	3802 Wattnode Main Building Reactiv	3802 Wattnode Main Building Reactiv	3802 Wattnode Main Building Reactiv	3802 Wattnode Main Building Reactiv	3802 Wattnode Main Building Reactiv	3802 Wattnode Main Building Voltage	3802 Wattnode Main Building Voltage	3802 Wattnode Main Building Voltage	3802 Wattnode Main Building Current	3802 Wattnode Main Building Current	3802 Wattnode Main Building Current	3802 Wattnode Main Building Frequer	3802 Wattnode Main Building Demand	3802 Wattnode Main Building Peak De
2	1/1/12 12:00:00 AM EST	9.329032	2.805887	3.615956	2.957513	56808.6	22507.9	22870.1	11430.6	0.978607	0.963783	0.972191	0.999848	1.711992	0.778852	0.881024	0.051624	9279	122.5874	121.7873	122.8603	23.82364	30.35515	23.76667	60.01115	7.981861	33.80492
3	1/1/12 12:15:00 AM EST	7.195517	2.762927	2.720306	1.712284	56811.2	22508.9	22871.1	11431.1	0.989796	0.969692	0.999848	0.999848	0.78006	0.694635	0.047483	0.029888	9279.3	122.4025	121.4296	122.6815	23.19179	22.40059	13.89736	60.01115	9.478473	33.80492
4	1/1/12 12:30:00 AM EST	7.011605	2.730984	2.616622	1.663999	56813.1	22509.7	22871.8	11431.6	0.999848	0.999848	0.999848	0.999848	0.122388	0.04767	0.045673	0.028905	9279.4	122.4025	121.6085	121.6085	22.26944	21.53648	13.5991	60.01115	10.09394	33.80492
5	1/1/12 12:45:00 AM EST	6.083313	1.786484	2.639782	1.657046	56814.9	22510.3	22872.5	11432.1	0.999848	0.999848	0.999848	0.999848	0.106239	0.031183	0.046078	0.029143	9279.5	122.4025	121.4296	122.6815	14.57537	21.67864	13.48929	60.01115	7.769191	33.80492
6	1/1/12 1:00:00 AM EST	9.980137	4.112836	4.233671	1.633629	56817	22511	22873.3	11432.6	0.976762	0.943189	0.987248	0.999848	0.794668	1.448823	-0.68267	0.028515	9279.6	121.2931	121.6085	121.4296	35.9808	35.26363	13.43556	60.01115	7.268806	33.80492
7	1/1/12 1:15:00 AM EST	11.24298	4.114296	4.13817	2.995514	56819.7	22512.2	22874.3	11433.2	0.988594	0.999848	0.981047	0.999848	0.961016	0.071815	0.836913	0.052287	9279.9	121.1082	121.4296	121.6085	34.27774	34.65905	24.81545	60.01115	8.418225	33.80492
8	1/1/12 1:30:00 AM EST	10.86647	3.799381	3.64627	3.437846	56822.2	22513.2	22875.2	11433.8	0.991066	0.999848	0.978502	0.999848	0.997548	0.066279	0.853047	0.060089	9280	121.2931	121.6085	121.6085	31.35777	30.72035	28.31574	60.01115	11.00565	33.80492
9	1/1/12 1:45:00 AM EST	15.81609	6.45669	6.029769	3.29235	56824.4	22514.1	22876	11434.3	0.985273	0.956724	0.999848	0.999848	2.126574	1.963856	0.10525	0.057468	9280.2	121.1082	121.2508	121.4296	55.81626	49.8174	27.29075	60.01115	9.816358	33.80492
10	1/1/12 2:00:00 AM EST	8.705014	3.897654	2.554618	2.227266	56827.2	22515.3	22877.1	11434.7	0.980417	0.999848	0.999848	0.943706	0.882768	0.068034	0.044591	0.770148	9280.4	122.4025	121.6085	121.6085	31.86399	21.10843	19.42336	60.01115	9.295665	33.80492
11	1/1/12 2:15:00 AM EST	8.606709	3.803896	2.600433	2.125794	56829.4	22516.2	22877.9	11435.3	0.982427	0.999848	0.999848	0.947584	0.796137	0.066397	0.04531	0.68672	9280.6	121.2931	121.6085	121.6085	31.31823	21.38691	19.1122	60.01115	10.86955	33.80492
12	1/1/12 2:30:00 AM EST	7.362432	3.088962	2.648951	1.760978	56831.3	22516.9	22878.6	11435.8	0.999848	0.999848	0.999848	0.999848	0.130859	0.053741	0.046045	0.028726	9280.9	121.478	121.4296	121.6085	25.45431	21.78593	14.50426	60.01115	8.56844	33.80492
13	1/1/12 2:45:00 AM EST	7.173873	2.935291	2.537817	1.700766	56833.8	22517.9	22879.5	11436.4	0.988597	0.968464	0.999848	0.999848	0.858442	0.789575	0.044225	0.029824	9281.2	121.2931	121.6085	121.4296	26.13612	20.90267	14.00832	60.01115	7.781086	33.80492
14	1/1/12 3:00:00 AM EST	7.276121	3.013146	2.510416	1.75256	56836.4	22519	22880.5	11436.9	0.987275	0.962738	0.999848	0.999848	0.92081	0.846399	0.04382	0.030591	9281.5	121.478	121.6085	121.6085	25.1595	20.69497	14.2979	60.01115	9.81164	33.80492
15	1/1/12 3:15:00 AM EST	9.758231	3.565089	3.586077	2.607066	56838.7	22519.9	22881.3	11437.4	0.964354	0.924839	0.968374	0.999848	2.445547	1.487095	0.912946	0.045507	9282	121.478	121.6085	121.6085	31.95811	30.49326	21.24686	60.01115	10.47097	33.80492
16	1/1/12 3:30:00 AM EST	9.699574	3.536855	3.505766	2.661319	56840.9	22520.9	22882	11438	0.961584	0.908398	0.976507	0.999848	2.44274	1.628772	0.769175	0.046454	9282.5	121.1082	121.4296	121.4296	32.11709	29.39556	22.00184	60.01115	9.044845	33.80492
17	1/1/12 3:45:00 AM EST	12.56023	5.057496	5.022641	2.480093	56844	22522.3	22883.3	11438.4	0.969778	0.90964	0.999848	0.999848	2.440529	2.509568	0.087671	0.04829	9283.1	121.1082	121.2508	121.2508	45.83847	41.36886	20.42722	60.01115	9.06572	33.80492
18	1/1/12 4:00:00 AM EST	11.00722	3.657187	4.694534	2.655496	56846.6	22523.4	22884.2	11439	0.979703	0.939414	0.999848	0.999848	1.450045	1.32175	0.081943	0.046352	9283.3	121.2931	121.2508	121.4296	32.81992	39.32323	21.99997	60.01115	12.66952	33.80492
19	1/1/12 4:15:00 AM EST	7.190852	2.809364	2.751587	1.628832	56848.7	22524.2	22885	11439.5	0.999848	0.999848	0.999848	0.999848	0.125541	0.048792	0.048008	0.0285	9283.5	121.2931	120.1778	121.4296	28.16531	22.99148	13.43562	60.01115	10.24664	33.80492
20	1/1/12 4:30:00 AM EST	7.14818	2.740113	2.739303	1.668765	56851.2	22525.2	22886	11440.1	0.999848	0.999848	0.999848	0.999848	0.124772	0.047829	0.047815	0.029128	9283.8	121.2931	120.1778	121.6085	22.65405	22.85129	13.56145	60.01115	8.22691	33.80492
21	1/1/12 4:45:00 AM EST	12.23816	5.300822	5.286296	1.599606	56853.8	22526.2	22887	11440.6	0.970002	0.928056	0.981947	0.999848	1.141207	2.147585	-1.0248	0.027975	9284.1	121.1082	121.4296	121.4296	47.15791	44.32724	13.19959	60.26982	9.957206	33.80492
22	1/1/12 5:00:00 AM EST	6.92268	2.685954	2.673383	1.58372	56856.2	22527.1	22887.9	11441.1	0.999848	0.999848	0.999848	0.999848	0.120836	0.046884	0.046664	0.027288	9284.3	121.2931	121.4296	121.4296	22.18867	21.8069	13.04427	60.01115	10.77306	33.80492
23	1/1/12 5:15:00 AM EST	10.66682	4.926109	4.272857	1.437606	56858.4	22527.9	22888.8	11441.6	0.968351	0.917036	0.98817	0.999848	1.504647	2.142293	-0.66315	0.025508	9284.5	121.2931	121.6085	121.6085	44.35518	35.55683	12.03624	60.01115	9.176689	33.80492
24	1/1/12 5:30:00 AM EST	8.124699	3.895264	2.83613	1.393304	56861.2	22529.2	22889.9	11442.1	0.985707	0.957424	0.999848	0.999848	1.248333	1.198452	0.965557	0.02432	9285	121.2931	121.4296	121.6085	33.54258	23.35971	11.45904	60.01115	8.927102	33.80492
25	1/1/12 5:45:00 AM EST	8.293999	2.73738	3.595588	2.463146	56863.3	22530.1	22890.6	11442.6	0.987638	0.999848	0.963218	0.999848	1.088586	0.047781	0.997847	0.042958	9285.2	121.2931	121.4296	121.6085	22.63006	20.72275	20.28764	60.01115	11.2381	33.80492

Figure A.4. Data as it Arrives from UMCS

B: File is Examined for Completeness

After the spreadsheet has been received, the data is checked to ensure that it is in the proper format and doesn't contain any extraneous information. Extraneous information is defined by any information that isn't directly related to the meter readings. Along with this check, the continuity of the data in the sheets is ensured, this ensures all of the data in the file is imported properly by ensuring the data is labeled properly in the document (on a few occasions mislabeled or mis-transcribed data has been delivered to PNNL (e.g., domestic hot water energy table actually contain HVAC energy data).

C/D: File Transfer and Importing

A macro has been developed to import all data in a folder. This folder only includes approved data. The macro is then run which imports all data from all files. This ensures a complete database is built for analysis.

E: Variables of Interest are Selected

The XLS file contains many extra pieces of data that are not necessary for the current level of analysis (e.g., power factor). At the completion of the import, the macro lists all available variables. The user selects the appropriate variables, generally energy and environmental variables, for further processing.

F: Time Range is Determined

After importing, the earliest and latest time are recorded. These times generate the time steps for the complete new meter. By regenerating these intervals it ensures all skipped data points are

identified and adjusted. For example, it is possible that t-here is a missing hour from the meter, by creating a new set of time intervals, this data gap is immediately obvious.

G: Filled Meter is Created

The filled meter contains the most complete set of data possible. If a data point is missing, the last known valid point will be substituted in its place. This data forms the basis for further analysis.

H/I: Time Duration is Determined

This important step allows for smoothing of data across large gaps. By recreating a complete set of time intervals, it is much simpler to determine the duration between the current and last known good data point. This total duration serves as the denominator for the usage calculation. The usage is then multiplied by 0.25 to ensure the time step is correct. This usage forms the basis for averaging.

In the example there is a meter reading at 8:15 and 9:00, but there is no data at 8:30 and 8:45. The Filled Meter column copies the last known meter reading until a new meter reading is provided, hence 110 is filled from 8:15 through 8:45. When data is missing, it is necessary to determine the total span for the gap. This span is measured in the Time Step column. When both data points are available, the time step is 15 minutes or ¼ of an hour. When a Meter Data point is not available, the time is incremented by an additional 15 minute or ¼ of an hour. This increased time step is important because becomes the denominator to normalize the usage. In the example below, the usage at 9:00 would initially be shown as 30 meter units, which is substantially higher than the other usage values shown. By smoothing it over the entire missing period, the usage appears to be high, but valid.

Example:

Time	Meter Reading	Filled Meter	Time Step	Usage
8:00 AM	102	102	-	-
8:15 AM	110	110	0.25	8
8:30 AM		110	0.25	10
8:45 AM		110	0.5	10
9:00 AM	140	140	0.75	10
9:15 AM	145	145	0.25	5

Equation 1. *Usage calculation at 9:00 AM*

$$\frac{Current\ Meter\ Reading - Previous\ Known\ Meter\ Reading}{Total\ time\ spanned\ by\ two\ meter\ readings} * standard\ time\ step$$

$$\frac{140 - 110}{0.75} * 25 = \frac{30}{3} = 10$$

J: Systematic Evaluation of Unrealistic Consumption

Using the usage values that were calculated in step I, the macro identifies any points that exhibit consumption above 100 kWh/15 minute. These values are removed from any further calculations and are labeled for future analysis.

K: Manual Evaluation of Data

At any point in the analysis process a set of data may be observed that is determined to be erroneous. During this step, these data points are identified and removed from future analysis steps. All future processes must be repeated if any data is changed in this step.

L/M/N: Conversion, Averaging, and Evaluation

Data is converted to kBTU at the most granular scale available, 15 minute data. This data is then used to generate an average consumption (AC) over a period of interest (t). The total consumption during the period is defined as AC*t. Hourly, daily, and monthly time periods are presented. At the conclusion of these steps the data is reviewed for erroneous data. Some examples would include a long period of zero consumption in the heating or cooling season, or a consumption that is an order of magnitude or more than what is expected. Any data inconsistencies are then addressed by repeating step K.

O: Comparison of Degree Days and Consumption

At this point, the consumption is evaluated versus the number of cooling or heating degree days in the month. This graph offers context for consumption and can show months that would be expected to have similar consumption. Any data inconsistencies are then addressed by repeating step K.

P: Between Building Comparison

The water and electricity usage between the buildings is evaluated in this step. It offers context to the presented numbers and can therefore highlight additional erroneous data. As with the previous steps, this data is corrected by repeating step K.

Q: Additional Graphs

Additional graphs are created using Statsoft Statistica to observe weekly, seasonal and daily trends. Statistica was chosen for its robust graphing capability as well as the Lowess curve fit. This curve fit calculates a locally weighted least square curve fit around a subset of the graphed data. By adjusting this window, it is possible to more accurately smooth data than with a simple average or a moving average. The graphs generated in this step are intended to evaluate the relationship between HVAC consumption and external environmental conditions. Any abnormalities discovered in this step are addressed in step K.

APPENDIX B: BUILDING LIFE CYCLE COST MODEL RESULTS

The spreadsheet-based model used to complete the LCCA is attached. All cash flows calculated for the 28-year period are included, along with all data sources used.

CostModel_Bragg_v3.xlsx

The following documents were used as references for the LCCA, and are attached:

- Initial project cost estimate (CCS 65830.pdf)
- Contractor submittals for additional project funding (CCS SF30 - R00001.pdf, CCS SF30 - R00002.pdf)
- Current Working Estimate (CWE) for the CESS showing the difference between the original programmed amount and the final cost (CWE PN 65830 Community Emergency Services Facility 18 Jun 12.xlsm)
- Detailed cost summary for final project design elements (Activity Summary by CLIN.pdf)

CCS 65830.pdf

CCS SF30 - R00001.pdf

CCS SF30 - R00002.pdf

CWE PN 65830 Community Emergenc

Activity Summary by CLIN.pdf

APPENDIX C: MANAGEMENT AND STAFFING

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Kim Fowler Will Gorrissen	Pacific Northwest National Laboratory	(509) 372-4233 kim.fowler@pnnl.gov (509) 372-6447 will.gorrissen@pnnl.gov	Manager and PI
Manette Messenger	U.S. Army Installation Management Command, Southeast (Retired)	n/a	Original Project Manager
Anne M. Rogers, Adam M. West	Southface Energy Institute 241 Pine Street NE Atlanta, GA 30308	(404) 604-3614 arogers@southface.org (404) 604-3643 awest@southface.org	LEED Administrator and Energy Modeling
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APPENDIX D: REFERENCES

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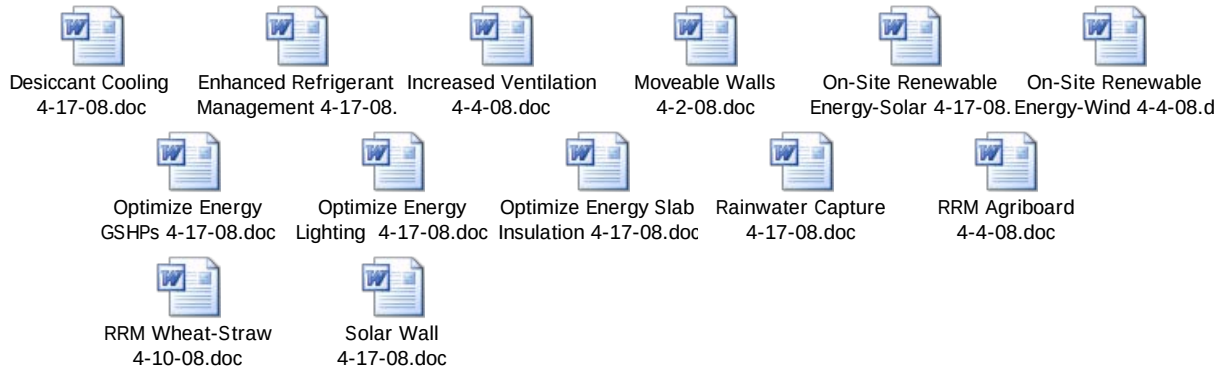
APPENDIX E: TECHNOTES

Appendix E contains the following CESS specific TechNotes that were originally referred to as LEED Strategy documents and copies of the 19 generic TechNotes developed for USACE.

CESS specific TechNotes covered the following technical topics:

- Desiccant Cooling
- Enhanced Refrigeration Management
- Increased Ventilation
- Moveable Walls
- On-site Renewable Energy – Solar
- On-site Renewable Energy – Wind
- Ground Source Heat Pumps
- Lighting Optimization
- Slab Insulation
- Rainwater Capture
- Agriboard Materials
- Wheat-Straw Materials
- Solar Wall



USACE generic TechNotes covered the following technical topics (also available at: http://www.wbdg.org/ccb/browse_cat.php?c=266):

- TechNote 01 Daylight Dimming Photosensor
- TechNote 02 Daylight Light Shelf
- TechNote 03 Daylight Light Tubes
- TechNote 04 Daylight Sunlight Tracking
- TechNote 05 Fixtures Dual Flush Toilets
- TechNote 06 Fixtures High Efficiency Toilets
- TechNote 07 Fixtures Low-Flow Showerheads
- TechNote 08 Fixtures Ultra Low Flow Faucets
- TechNote 10 Enhanced Cx
- TechNote 11 Permeable Pavement
- TechNote 12 Desciccant HVAC

- TechNote 13 Solar Hot Water
- TechNote 14 Overhead Radiant Heating
- TechNote 15 Radiant Floor Heating-Commercial
- TechNote 16 Radiant Floor Heating Cooling-Residential
- TechNote 17 Heat Island Roof
- TechNote 18 Ground Source Heat Pumps
- TechNote 19 LED Parking Lot
- TechNote 20 Light Pollution Reduction

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technote14.pdf technote15.pdf technote16.pdf technote17.pdf technote18.pdf technote19.pdf

technote20.pdf

APPENDIX F: LEED SUBMITTAL AND SCORECARD

Appendix F contains the final LEED scorecard for the Fort Bragg CESS high-performance building and contains copies of the LEED templates that show the calculations and model results used to achieve certification of the CESS building.

CESS LEED Platinum Scorecard Final 6.17.1

The LEED submittals included in this appendix include:

- Indoor Environmental Quality credit 4.1: Low-Emitting Materials – Adhesives & Sealants
- Indoor Environmental Quality credit 4.2: Low-Emitting Materials – Paints and Coatings
- Indoor Environmental Quality credit 4.3: Low-Emitting Materials – Flooring Systems
- Indoor Environmental Quality credit 4.4: Low-Emitting Materials – Composite Wood and Agrifiber Products
- Energy and Atmosphere credit 5: Measurement and Validation Plan
- Materials and Resources credit 2: and the Construction Waste Management Plan
- Materials and Resources credit 4: Recycled Content
- Materials and Resources credit 5: Regional Materials
- Materials and Resources credit 6: Rapidly Renewable Materials
- Materials and Resources credit 7: Certified Wood
- Water Efficiency credit 2: Innovative Wastewater Technologies

EQc4.1_Template_SubmittedOn_09122011.

EQc4.2_Template_SubmittedOn_09112011.

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EQc4.4_Template_SubmittedOn_09112011.

Fort Bragg CESS - MV Plan - Option D.pd

MRc2_Template_SubmittedOn_02042011.p

RA Connelly Inc - Construction Waste M

MRc4_Template_SubmittedOn_07012010.p

MRc5_Template_SubmittedOn_07012010.p

MRc6_Template_SubmittedOn_07012010.p

MRc7_Template_SubmittedOn_01202012.p

WEc2_Template_SubmittedOn_01152009.p

APPENDIX G: COMMISSIONING PLAN AND SUMMARY

Appendix G contains the Commissioning Plan and the Commissioning Summary report documenting design and equipment function for the Fort Bragg CESS high-performance building. This work was conducted as part of demonstration project ESTCP SI-0724.

Final CESS Cx Plan.pdf

cess Cx_Summary_Report.

cess warranty site visit.pdf

HP FT.pdf

issues log.pdf