Report No. DRAFT

US Army Corps of Engineers®

MILCON Energy Efficiency and Sustainability Study of Five Types of Army Buildings

Summary Report

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ERDC – CERL
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Executive Summary

ES.1 Purpose and Goals

The purpose of this *Military Construction (MILCON) Energy Efficiency and Sustainability Study of Five Army Buildings* was to investigate current building features and construction methods and materials to optimize energy reduction and sustainability. At a minimum, the study was to ensure that the five selected standard designs meet all applicable energy reduction and sustainable design policies. The building types studied were:

- Unaccompanied Enlisted Personnel Housing (UEPH, 72111)
- Tactical Equipment Maintenance Facility (TEMF, 21410)
- Company Operations Facility (COF, 14185)
- Brigade Headquarters (Bde HQ, 14182)
- Dining Facility (DFAC, 72210).

The goals for the study were as follows:

- Determine the difference in initial investment or “first” cost of the proposed baseline buildings with energy enhancements to meet the energy and sustainability mandates as compared to the original baseline buildings without energy enhancements.
- Compare and analyze the five standard designs as-is to designs with full compliance of energy and sustainability mandates.
    - While the main purpose of this study was to comply with the Energy Independence and Security Act (EISA) of 2007 target of a 65 percent fossil fuel reduction by 2015 achieved by reducing building energy consumption, simultaneously, the study determined compliance with the energy performance option of the American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) Standard 189.1, which is based on a 30 percent reduction of energy from ASHRAE 90.1-2007, including plug loads.
- Determine whether scope, which includes mission requirements, architectural features and building function, would have to be reduced to build the standard design with full compliance of energy and sustainability mandates.
- Develop energy models for buildings that support net zero ready installations that achieve 65 percent energy reduction compared to a similar building in fiscal year 2003 (FY03) (Commercial Building Energy Consumption Survey – CBECS).
    - For this study, the German Passivhaus (passive house) standards were used to go beyond the current ASHRAE standards and develop ultra-low energy buildings. The basic concept behind the passive house approach is to superinsulate a building to reduce the amount of energy required to heat, ventilate, and cool it in addition to other considerations such as building orientation, glazing areas, envelope geometry, etc.
- Reduce both indoor and outdoor potable water usage.

- Account for the impact on operations and maintenance by energy systems.
- Comply with the High Performance Sustainable Building Guiding Principles as stated in Executive Order (EO) 13514.

During the course of this study, several tools were developed to help the U.S. Army Corps of Engineers (USACE) Center of Standardization (COS), District, and Army Installations staff better understand the technologies and mandates they are facing. Nineteen TechNotes, brief summaries of new technologies, were developed and posted to the Whole Building Design Guide website (http://mrsi.usace.army.mil/cos/TechNotes/Forms/AllItems.aspx) to provide brief overviews of specific technologies that are either new or not widely used. The research team also reviewed current mandates, policies, and standards and compared them to LEED 2009 using an Excel spreadsheet format to illustrate potentially attainable levels of LEED certification from meeting current requirements (Mapping to LEED). Finally, a similar Excel spreadsheet format found in the Mapping to LEED tool was developed for the measures evaluated in this study and their compliance with ASHRAE 189.1.

ES.2 Approaches

The approaches used during the study included a preliminary meeting/charrettes with the COS for the five building types as well as integrated schematic charrettes with COS representatives for each professional discipline both before and after energy modeling was completed. A lead Cost Estimator worked with the COS estimators and the U.S. Army Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) to assess what study findings may be incorporated under current project programming and how much additional funding will be necessary to incorporate all study findings into each facility type for the FY13 MILCON program. A webinar was held with representatives from affected installations in the FY13 MILCON program and lessons learned will be shared with COSs and Army Installations staff. Operations and maintenance (O&M) impacts on staff at the Installations level and long-term energy efficiency of the buildings were also considered.

ES.3 Collaborators

Achieving the deliverables required the following contributions from collaborators:

- USACE Headquarters provided coordination with COSs and participated in scheduled working meetings conducted at respective COSs, set and maintained schedule milestones for the entire effort, tracked and revised energy/sustainability targets.
- ERDC/CERL, the National Renewable Energy Laboratory (NREL), and private contractors conducted energy use reduction studies for the five selected building types using modeling and computer simulation analysis.
- ERDC/CERL and Pacific Northwest National Laboratory (PNNL) provided sustainability and LEED validation/analysis of the standard designs and proposed alternatives.
- Fort Worth COS and PNNL provided estimating and life-cycle cost analysis for the proposed alternatives to the standard designs.

ES.4 Barriers

The final savings determination was difficult because there is no clearly defined baseline for these Army building types within the CBECS. In other words, these buildings do not have equivalent building categories within CBECS. Assumptions and compromises had to be made in terms of category selection and Energy Use Intensity (EUI) figures used. Further, since there will be EUI figures from DOE, the results reported in this study will no doubt change when the rule is finalized.

There was also initial confusion over the different energy baselines found in ASHRAE standards (modeled building energy) and Section 433 of EISA 2007 (measured building and plug load energy). This created a challenging "apples to oranges" scenario.

Because of the uncertain baseline, the focus became creating the most efficient building within the constraints of the analysis rather than trying to create an exact match with what were basically arbitrary CBECS targets. Modeling and calculations were done, however, to provide results in terms of EISA 2007 and CBECS requirements.

The study was able to show the energy effectiveness of a range of efficiency measures, but it was not able to show the cost effectiveness of individual measures, nor was it able to optimize the designs for the highest energy performance at the lowest costs. This typically is done early in the design phase.

ES.5 Summary Findings

Summary findings for each of the building types are listed in Table ES.1.

Table ES.1 MILCON Energy Study Summary

Findings	UEPH	TEMF	COF	Bde HQ	DFAC
Range of energy savings	36-66%	37-63%	34-80%	9-53%	16-38%
Range of cost increase	4.4-28.1%	6.6-10.3%	7.7-19.7%	4.8-19.1%	2.0-4.4%
Buildings that support net zero ready installations	Yes	Yes	Yes	Yes	Yes
Achieve energy savings 30% better than ASHRAE 90.1-2007	Yes	Yes	Yes	Yes	Yes
Buildings achieve 65% fossil fuel reduction compared to *source* CBECS 2003 (based on Section 433 of EISA 2007 requirement for 2015 by 2013)	0 climate zones, not met due to plug loads	All 15 climate zones	0 climate zones, 1 climate zones within 10%	0 climate zone, not met due to plug loads	0 climate zones, not met due to plug loads
30% domestic water reduction	Yes	Yes	Yes	Yes	Yes
O&M considered in energy package selection	Yes	Yes	Yes	Yes	Yes
20% reduction in use of indoor potable hot water	Yes	Yes	Yes	Yes	Yes
30% of hot water energy usage supplied by solar hot water	Yes	No	No	No	No

Findings	UEPH	TEMF	COF	Bde HQ	DFAC
Transpired solar collectors?	No	Yes	Yes	No	No
50% less outdoor potable water use	Yes	Yes	Yes	Yes	Yes
75% daylighting factor in all occupied spaces, 2% space for Critical visual tasks	Yes	Yes	Yes	No	Yes, in dining and serving areas
Inclusion of enhanced commissioning and measurement and verification	Yes	Yes	Yes	Yes	Yes
LEED 2009 Silver rating	Yes, may reach Gold on some projects	Yes, may reach Gold on some projects	Yes	Yes	Yes
Compliance with the Guiding Principles as stated in EO 13514	Yes	Yes	Yes	Yes	Yes

ES.6 Conclusions

The analysis showed that significant energy savings are possible for all climates. However, it is very difficult to reach the EISA 2007 target for the 2015 goal of 65 percent fossil fuel reduction with building-specific efficiency measures alone. The extent of energy savings achieved is site- and facility-specific. Additional savings may be achievable, but the current study shows the energy savings picture as follows:

- 25 to 35 percent energy savings: The building yields the maximum energy savings for the lowest cost
- 35 to 60 percent energy savings: Each increment of energy saved comes at an increasingly higher cost (plug load reduction, small scale renewable energy, building orientation, site specific design)
- Above 60 percent: May be cost prohibitive without looking beyond the building (significant plug load reduction, clustering, renewable energy, cogeneration, etc.)
- Some facility types in certain regions will never achieve the 65 percent energy target through energy efficiency measures alone

At the start of this study, the EISA 2007 target for a 65 percent energy reduction by 2015 was analyzed in terms of site energy (not based on the source of energy used). However during the study in 2010, a new rule interpreting EISA 2007 and the energy targets was released by DOE (see References section for citation) that shifted the analysis from site energy to source energy, which is based on the reduction of fossil fuels at the point of energy production.

This resulted in fewer building types meeting the targets within climate zones and also resulted in installation of all-electric appliances and equipment to minimize retrofitting from gas or oil to electric at a later date to meet even more stringent requirements. In other words, in this study, the buildings reduced energy usage at the site to meet source energy reduction targets.

In addition, CBECS building categories and their related EUIs are not directly comparable to these five Army building types in most cases. This also negatively affected the ability of the buildings to meet CBECS source energy targets.

In terms of ASHRAE 189.1, there is a high level of confidence from this study that the five building types would meet or exceed the goal of ASHRAE 189.1 to achieve a 30 percent reduction in energy use compared to an ASHRAE 90.1-2007 building including plug loads.

The most effective energy efficiency measures for the building types analyzed in this study are summarized in Table ES.2.

Table ES.2 Summary of Most Effective EEMs

All Buildings
• Increased fan, pump, and HVAC efficiency • Increased daylighting and lighting power density reduction • Increased wall and roof insulation • Reduced infiltration rates • High-efficiency fixtures to reduce potable water demand • Cool roofs in climate zones 1–5 and window shading • Triple pane windows (can be extremely orientation and site specific)
UEPH
• Radiant heating and cooling • Solar hot water for 30% domestic hot water • Improved boiler and chiller efficiencies • DOAS for ventilation • Separate ventilation for living and laundry areas
TEMF
• Reduced ventilation in repair bays • Radiant floors • Transpired solar collectors
COF
• Alternate construction option - reduced volume of conditioned air in readiness bays • VAV fans, ERV, IDEC, DOAS depending on climate zone • Transpired solar collectors depending on climate zone
Bde HQ
• Radiant heating and cooling • High efficiency chiller and boiler with GSHP
DFAC
• High efficiency or high-efficiency all-electric kitchen equipment • Exhaust hood design and flow control • Demand control ventilation on make-up air units • Passive house insulation levels for limited climate zones
DOAS = dedicated outdoor air system; ERV = energy recovery

ventilation; GSHP = ground-source heat pump; HVAC = heating, ventilation, and air-conditioning; IDEC = indirect/direct evaporative cooling; VAV = variable air volume.

ES.7 Costs

The cost increases for the recommended Low Energy Packages for the five building types ranged from 2 percent to 10 percent. This study also performed a life-cycle cost analysis for two buildings in three climate zones. Three of the four building combinations had multiple low-energy packages that were life-cycle cost effective. These results reflect the impact of all regulatory drivers on the standard designs for the five building types.

While using a passive house approach can reduce the heating, ventilation, and air-conditioning (HVAC) system costs, this is balanced against increased costs for technologies or processes like triple-pane windows that would meet Anti-Terrorism/Force Protection (AT/FP) blast-resistant windows, rainwater harvesting, enhanced commissioning that did not previously exist or have not seen widespread use across MILCON projects within a given fiscal year. As can be seen from the building energy reduction results, the increased cost only takes the buildings up to a certain point in terms of energy efficiency unless and until plug loads are reduced. In other words, the buildings are as energy efficient as possible while remaining life-cycle cost effective and would meet the 65 percent energy reduction target in a number of climate zones and for the building types if proportionately high plug loads are not considered.

Assuming proper construction and commissioning, energy savings in these buildings would be immediate. In terms of renewables, however, their cost is over six times higher than the current investment in energy efficiency measures in today’s dollars.

ES.8 Lessons Learned

The study derived the following lessons learned:

- Fully integrated design is a requirement and not an option with high-efficiency buildings. All subject matter experts, including the commissioning agent and O&M staff, need to be involved from the earliest stages of the project. If this is not done, much time is wasted passing the design back and forth for changes and systems, particularly HVAC systems, are not designed to their maximum efficiency to work with exterior insulation levels, roofing materials, etc.
- O&M staff must be properly trained on new systems and technologies or high-efficiency buildings will quickly become less efficient or worse than buildings constructed in the past. Both time and money will have been wasted. Enhanced commissioning is important to ensure that design, installation, and startup of systems are done correctly and measurement and verification (M&V) are important to verify modeling results. Many of the mechanical systems will only operate properly within a narrow set of parameters. Once operating outside of those parameters for extended periods of time, systems will either not function efficiently or fail to function at all.
- There is no single, “silver bullet” answer for these buildings. Climate zone, building site conditions, and other factors play major roles in building performance.

- When buildings are designed to be minimally energy efficient, it is relatively easy to use a "one size fits all," prescriptive approach because the results in terms of energy efficiency are not a factor. With these buildings, the burden is on the designers to take a performance-based rule set and apply it to an individual building by defining strategies that result in achieving overall energy reduction targets.
- While this study focused on passive house approaches and technologies, these should not be the prescribed path for the design team to take when it comes to incorporating measures into standard designs. For example, climate zone 1A may not be found to be appropriate for passive house measures based on actual experience due to concerns over moisture/humidity control. Climate zone 5A may achieve much better results. Another example, it may not be optimal to design triple-pane windows on all four walls of a building if further study and modeling reveal that it is not appropriate on the north side of the building or if a taller building or landscaping shades one or more sides of the building and two-pane, low-e windows can be used with little or no impact on energy performance. In this example, it would be beneficial to also take a look at the window U-value to maintain an acceptable occupant thermal comfort and not just the solar heat gain.
- It is expected that for some buildings in some climate zones, current practices or current practices with relatively few changes, will result in achieving the performance targets. In other buildings and climate zones, real innovation will be needed to achieve the same results.
- In the future, to meet ever more stringent energy targets on the path to net zero energy, buildings will need to be:
  - grouped together to take advantage of larger, more energy efficient technologies. This will allow for the sharing of resources between buildings, e.g., waste heat in a cogeneration facility.
  - combined into one building for multiple life/work purposes (e.g., UEPH on the upper floors, DFAC on the main floor of a barracks complex, and a COF either on the first floor or in the basement of the barracks complex).
- Reducing the plug loads to a level that would achieve the EISA 2007 target for 2015 energy reduction would require a reevaluation of mission and quality of life requirements for some standard designs, for example:
  - UEPH – Prescribe the types of electronic equipment that soldiers can put in their modules, e.g., light-emitting diode (LED) TVs only of a maximum size—no plasma TVs, LED computer screens only, limit kitchen appliances to a microwave, centralized laundry facilities—no in-module facilities, two-person modules versus one person.
  - Bde HQ – Procure only LED computer screens, limit the number per person, procure only top-tier ENERGY STAR® central processing units, laptops, and related/support equipment, mandate and enforce a low maximum wattage usage per person.
  - DFAC – Change the menu to eliminate or minimize the need for high-energy-usage kitchen appliances and equipment. Extend the meal periods over a longer period of time to reduce the peak demand loads currently needed by kitchen appliances and equipment.
- Occupant behavior needs to change. Whether it is turning off lights when not in use, properly using of operable windows, or not blocking HVAC vents, occupants determine the ultimate efficiency of a building. Changing these behavior patterns through education and training is essential to the long-term goal of having a net zero installation.

- Educate everyone to have a uniform goal. Education must be provided to USACE COSs, Army Installations staff, general contractors, architects and engineers (A&Es), and trades on new features, technologies, systems, and approaches.
-
- Enhanced commissioning needs to be fully incorporated into the design phase of MILCON projects which has not been done routinely in the past. This will require a reexamination of the current strategy of waiting until after the RFP is awarded before a commissioning agent is designated.
- Cost optimization needs to be completed for all energy models that were a part of this study and should ideally be completed at the early stages of a project. It is important to complete it early so that the highest energy and cost efficiencies can be determined.
- Determine which technologies need further development/improvement then work with industry directly to make the changes so improved or new products can be brought to market and leverage the buying power of all of the armed services.

ES.9 Recommendations

The following recommendations were derived from the study:

- Complete the cost optimization for each of the energy efficiency packages.
- Conduct a study of other technologies in combination with current practices in some climate zones for the five building types that could produce similar energy savings to those found in this study.
- In cooperation with the COSs, develop guidance on how to achieve a truly integrated design regardless of building type.
- Provide technical assistance as needed to the COSs to determine what changes need to be made to the standard designs to achieve maximum, life-cycle cost effective energy efficient buildings.
- Develop protocols that will ensure performance targets are met for individual projects that are building type- and site-specific.
- Develop tools that will help COSs, Army Installations staff, general contractors, A&Es, trades, and occupants understand what needs to be done to design, implement, operate, maintain, and properly use the technologies and packages that were analyzed in this study. These would need to include tools such as additional TechNotes, guide specs, United Facilities Criteria, and training materials.
- Evaluate and prioritize these study results in terms of major renovations that will be conducted within the next 5 years of specific types of buildings in specific climate zones, e.g., VOLAR barracks.
- Ensure compliance with ASHRAE 189.1 and the results of this study.
- Review mission and quality of life requirements that affect high plug loads for some building types and implement changes as appropriate.
- Develop industry partnerships for specific technologies and products to ensure availability and lower cost over time.

- Work with master planners to redesign the location of several types of buildings and multiple usages for a single building or connected complex of buildings; e.g., barracks, to take maximum advantage of shared resources. Evaluate energy savings for various options and institute changes.
- Some buildings or locations are optimal for minimizing energy demands and should be the preferred ones for upgrades. For example those located below a hill outside of the prevailing wind have much less exposure to the elements and could have a better orientation for renewable technologies like roof top solar.
- Explore strategies related to making good use of the thermal mass of the structure.
- Instrumentation and controls play a vital role in ensuring that HVAC, lighting, and other building systems are functioning as intended. Additional emphasis needs to be given in these areas starting in the design phase and following all the way through construction to operations and maintenance. This includes addressing the issue of where controls/sensors are located within the building and who has authority to change settings, e.g., one person who prefers a specific temperature range due to their office location creates a significant energy impact to a site by changing the setting and impacting an entire area or section of the building.
- Procure only top-tier ENERGY STAR® appliances and equipment.
- Procure appliances and equipment that can be shown to be in the top 10 percent in terms of energy efficiency where an ENERGY STAR® labeling program is unavailable.
- Energy costs vary by season and region and the DoD could take advantage of cost effective renewable energy technology during peak demand periods, avoiding the most expensive fossil fuel based resources and their associated environmental externalities.
- Lessons learned from operators of large portfolios of buildings with similar use to the DOD could offer some very practical and cost effective insights into the payback of various options within specific regions. Many large real estate firms that have taken over BRAC and other facilities and transformed them into profitable and energy efficient installations should be consulted and site visits conducted to see how this "reuse" has progressed and why landowners elected to invest in different building improvements to achieve their financial and other ownership objectives. Has the private sector done better than existing DOD installations in making progress toward similar goals in the last 5-10 years.
- Coordinate work with U.S. Department of Energy commercial building projects and research.

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Acronyms and Abbreviations

A&E	architect and engineer
ACF	Area Cost Factor
ACH	air changes per hour
ACSIM	Assistant Chief of Staff for Installation Management
AHU	air handling unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AT/FP	Anti-Terrorism/Force Protection
Bde HQ	Brigade Headquarters
BLCC	Building Life-Cycle Cost
BOC	Brigade Operations Center
BOD	Basis of Design
Btu/hr/ft^2/°F	British thermal units per hour per square foot/per degree Fahrenheit (U-value, overall heat transfer coefficient)
CBECS	Commercial Building Energy Consumption Survey
CDD	Cooling Degree Days
CEE	Consortium for Energy Efficiency
CERL	Construction Engineering Research Laboratory (USACE)
cfm	cubic (foot) feet per minute
cfm/ft^2	cubic (foot) feet per minute/square feet (outdoor air ventilation rate)
CFR	Code of Federal Regulations
COF	Company Operations Facility
COP	coefficient of performance
COS	(U.S. Army Corps of Engineers) Center of Standardization
CxA	Commissioning Authority
DCV	demand control ventilation
DFAC	Dining Facility
DHW	domestic hot water
DOAS	dedicated outdoor air system
DoD	Department of Defense
DOE	Department of Energy
ECB	(USACE) Engineering Construction Bulletin
EEM	energy efficiency measure
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
EPACT	Environmental Protection Act
EO	Executive Order
ERDC	Engineer Research and Development Center (USACE)
ERV	energy recovery ventilation
ET	evapotranspiration
EUI	Energy Use Intensity
°F	degree(s) Fahrenheit
FCx	Fundamental Commissioning
ft^2	square (foot) feet
FY	fiscal year

gal	gallon(s)
gpm	gallons per minute
GSHP	ground-source heat pump
GSA	General Services Administration
h	hour(s)
HDD	Heating Degree Days
HET	high-efficiency toilet
HPSB GP	High Performance and Sustainable Buildings Guiding Principles
HQ	Headquarters
hr	hour(s)
HVAC	heating, ventilation, and air-conditioning
IAQ	indoor air quality
IDEC	indirect/direct evaporative cooling
IEA ECBCS	International Energy Agency Energy Conservation in Buildings and Community Systems
IEQ	indoor environmental quality
IPT	Integrated Process Team
K	Kelvin
$kBtu/ft^2/yr$	thousand British thermal units per square foot per year (Energy Use Intensity)
kWh	kilowatt hour(s)
$kWh/m^2/yr$	kilowatt hours per square meter per year (annual energy use per area)
L	liter(s)
LCC	life-cycle cost
LCCA	life-cycle cost analysis
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LID	low impact development
MII	Army Detailed Cost Estimating System (MCACES)
MAU	make-up air units
Mbtu	one million British thermal units
M&V	measurement and verification
MILCON	Military Construction
MPS	mandates, policies, and standards
NIST	National Institute of Standards and Technology
NOC	Network Operations Center
NPV	net present value
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OM&R	operations, maintenance, and repair
OPR	Owner's Project Requirements
Pa	pascal(s)
PACES	Parametric Cost Estimating System
PAX	Programming Accounting Execution System
PNNL	Pacific Northwest National Laboratory
s	second(s)
SCIF	Sensitive Compartmented Information Facility

SFA	skylight to floor area
SHGC	solar heat gain coefficient
R	R-value, thermal resistance
TEMF	Tactical Equipment Maintenance Facility
TER	Total Energy Recovery
TSC	Transpired Solar Collectors
U-value	overall heat transfer coefficient
UEPH	Unaccompanied Enlisted Personnel Housing
UFC	United Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE	United States Army Corps of Engineers
USGBC	United States Green Building Council
US IP	US Customary System/British Units
VAV	variable air volume
VFD	variable frequency drive
W	watt(s)
w.g.	water gauge
Wh/m^3	internal heat generation
W/mK	thermal conductivity
$W/m^2/K$	U-value, overall heat transfer coefficient
yr	year(s)

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1.0 Introduction

In early 2010, a Military Construction (MILCON) Energy Integrated Process Team (IPT) was formed to bring together all the Army stakeholders involved with new construction. Members of this group included the Assistant Chief of Staff for Installation Management (ACSIM), Installation Management Command (IMCOM), U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center–Construction Engineering Research Laboratory (ERDC-CERL), Army Reserves, and invitations were extended to members of other services such as Navy and Air Force. The goals of this group were as follows:

- Determine what measures are necessary to meet Federal energy and sustainability mandates.
- Determine the cost impact of compliance.
- Recommend the path forward to move Army Installations toward full compliance.
- Determine the delta in cost to meet the energy and Leadership in Energy and Environmental Design (LEED)/sustainability mandates.

1.1 Project Purpose

The USACE was tasked to take the lead in determining the building features, construction methods and materials that will optimize energy reduction and sustainability for new construction standard designs in fiscal year 2013 (FY13) for the five most commonly constructed Army building types:

- Unaccompanied Enlisted Personnel Housing (UEPH – barracks, 72111)
- Tactical Equipment Maintenance Facility (TEMF – repair facility, 21210)
- Company Operations Facility (COF – government office and other public assembly, 14185)
- Brigade Headquarters (Bde HQ – government office and data center, 14182)
- Dining Facilities (DFAC, 72210)

At a minimum, the selected standard designs were required to meet all applicable energy reduction and sustainable design mandates (e.g., LEED Silver, Environmental Protection Act [EPACT] 2005, Energy Independence and Security Act [EISA] 2007, Executive Order [EO] 13423, and EO13514), discussed in detail in Section 2 of this report. USACE was asked to evaluate the design of each facility for full mission scope and full energy and sustainability compliance. Specifically, comply with Section 433 of EISA 2007 target of achieving a 65 percent reduction in source energy usage by 2015, provide an indication on how much scope would have to be reduced to build the standard design with full compliance of energy and sustainability mandates, and determine the delta in cost to meet the energy and sustainability mandates. It is important to note that results in this study were based on total energy use as opposed to the fossil-fuel based portion of total energy use alone.

As a reference, in FY08–09 the Army developed revised building designs by working with industry experts and A&E firms to develop a “best of the best” design for each Army facility. The requirements of this effort were to optimize the mission, function, quality, and cost of the buildings. The International Building Code was used as the baseline building code. The baseline design was amended and supplemented to include anti-terrorism and force protection, EPACT 2005 compliance, LEED Silver certifiable, Army Installations, and mission-specific requirements, and select Department of Defense (DoD) Unified Facility Criteria considered critical to life safety and mission.

The approach of this study was to take these existing building designs and optimize the energy performance of each building in order to build the most energy efficient buildings possible before looking at options like renewables and cogeneration. Energy models were developed with various energy packages and options and sustainability features were identified for each building in order to meet Federal mandates. Meetings were held with USACE Centers of Standardization (COSs) to discuss how to improve the energy performance of the buildings and to have a reality check on assumptions, ideas, and options. Cost estimates were developed to determine the cost delta between the baseline buildings and proposed enhanced design options. Lastly, a LEED analysis was completed as an outcome of the energy modeling and estimating.

Specific targets for the study included the following:

- Design Army buildings to be net zero ready.
- Achieve a 65 percent reduction in overall energy consumption compared to the 2003 Commercial Building Energy Consumption Survey (CBECS, by the U.S. Department of Energy's [DOE's] Energy Information Agency).
- Reduce both indoor and outdoor potable water usage.
- Account for the impact of energy systems on operations and maintenance (O&M).
- Comply with the High Performance Sustainable Buildings Guiding Principles (Guiding Principles) as stated in EO 13514.

Many of the features of the buildings, such as the building form and window geometries, were fixed and not allowed to be varied. These were primarily mission-related requirements. While the goal should be to design the most efficient building at the lowest life-cycle cost (LCC), all of the building functional requirements must also be met. Major design changes, e.g., reconfiguration of barracks' room layouts and new window placement, were not considered during this study which impacted the energy savings that could be achieved. It would be beneficial to approach building design without constraints to see what impact this would have on the results and costs.

1.2 Study Collaborators and Overview

This study is a result of work done by a group of government, institutional, and private sector parties. The National Renewable Energy Laboratory (NREL) and ERDC-CERL were responsible for energy modeling. ERDC-CERL and Pacific Northwest National Laboratory (PNNL) were responsible for water and sustainability information and data. Meetings were held with Savannah (COF, TEMF, Bde HQ), Fort Worth (UEPH), and Norfolk (DFAC) COSs. In addition, Fort Worth staff provided all cost estimating work. Project management was provided by HQ USACE and PNNL staff. A complete list of contributors to this study is provided under the Acknowledgements.

For this analysis, parametric studies were conducted to determine energy savings for a suite of energy efficiency measures (EEMs). Subject matter experts consisting of government, institutional, and private sector parties were consulted to recommend certain technologies based on the function and energy use of the buildings. EEMs considered the building envelope construction, lighting and plug load power densities and design, as well as heating, ventilation, and air-conditioning (HVAC) strategies.

Representative model buildings were developed based on typical designs provided by the COS for the respective building types. Target energy budgets were developed using different sets of technologies and were analyzed by running energy simulations. Energy savings were determined compared to the 2003 CBECS database as required by EISA 2007.

Energy simulations were completed using EnergyPlus version 5.0 (DOE 2010), and modeling assumptions are shown in the appendices for each building type (Appendices A–E). The approach to modeling the energy efficiency improvements was to first evaluate each efficiency measure independently, then evaluate the measures that yielded the highest energy savings as a "package," in a single model. Evaluating the efficiency measures as a package is important, because the savings from each individual measure are not additive.

EEMs were modeled for each building type across 15 locations. The 15 locations were selected to represent 15 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zones in the United States. The locations selected were representative cities for the climate zones. Colorado Springs was selected for climate zone 5B instead of Boise, Idaho, to more closely align with the installations at Fort Carson, Colorado. The 15 climate zones and the cities used to represent them are listed in Table 1.1.

Table 1.1 Climate Zones and Cities Used for Simulations

Climate Zone	City	HDD (Base 65ºF)	CDD (base 50ºF)
1A	Miami, FL	200	9474
2A	Houston, TX	1599	6876
2B	Phoenix, AZ	1350	8425
3A	Memphis, TN	3082	5467
3B	El Paso, TX	2708	5488
3C	San Francisco, CA	3016	2883
4A	Baltimore, MD	4707	3709
4B	Albuquerque, NM	4425	3908
4C	Seattle, WA	4908	1823
5A	Chicago, IL	6536	2941
5B	Colorado Springs, CO	6415	2312
6A	Burlington, VT	7771	2228
6B	Helena, MT	7699	1841
7A	Duluth, MN	9818	1536
8A	Fairbanks, AK	13940	1040
CDD = Cooling Degree Days; HDD = Heating Degree Days			

The energy efficient packages started with a base package of low-energy features determined by CERL and NREL. These features focused specifically on a passive house approach (see Section 4.1.2.1), low infiltration rates, improved lighting strategies, reduced hot water usage and improved plug load levels that could then be modeled in combination with various HVAC features and technologies in an iterative process. By modeling the various packages across different climate zones, energy usage and savings could be compared between the low-energy features.

A number of mandates are in effect concerning sustainable design features (see Section 2). EISA 2007 in particular has requirements other than energy targets. In addition to providing component information for sustainable technologies and system for cost estimating purposes, TechNotes were developed to assist USACE staff by providing brief (5- to 6-page) summaries of energy and sustainability measures/technologies. TechNotes are discussed in detail in Section 5.6.2. Another tool, a series of Excel spreadsheets, maps mandates to LEED. Details of this tool are in Section 5.6.3. To address the recent adoption of ASHRAE 189.1 by the Army, an Excel spreadsheet was developed that maps ASHRAE 189.1 requirements to the measures proposed by this study. Section 5.6.1 provides more information about this tool.

The task of cost estimating was to identify the difference in upfront cost for changes to standardized projects. Changes in the projects are reflected in systems selected based on probable life-cycle benefits.

Projects in the award selection stage, or in the case of the UEPH recent award, were used to establish the estimates. These projects were at various locations in the United States: TEMF and DFAC from Fort Bragg, North Carolina, COF and Bde HQ from Fort Stewart, Georgia, and UEPH from Fort Leavenworth, Kansas. As a result, the estimates used COS Adapt Build-level construction drawings that reflected the facilities up-to-date requirements and design solutions. In the case of the UEPH, an estimate using the Parametric Cost Estimating System (PACES) was used to develop an estimate to the same level of detail as the other facilities.

A 40-year life-cycle cost analysis (LCCA) was completed for the UEPH and TEMF buildings using the National Institute of Standards and Technology (NIST) Building Life-Cycle Cost Program (BLCC) version 5.3, which complies with the requirements of Title 10 of the Code of Federal Regulations Part 436 (10 CFR 436). Specifically, the MILCON Analysis, Energy Project module of BLCC was used in the analysis.

1.3 Report Contents and Organization

The ensuing sections of this report present the associated regulatory drivers (Section 2), descriptions of the five building types (Section 3), strategies analyzed to achieve maximum energy efficiency (Section 4), outputs and results (Section 5), recommendations for implementation (Section 6), and a summary of findings (Section 7). References not spelled out in the text, tables, or footnoted are listed in Section 8. In addition, there are appendixes for each building type (A through E), a copy of the advanced lighting report prepared for the study (Appendix F), and Appendix G, which contains general information. The appendixes provide more detailed tables and figures that support the information in the body of the report.

2.0 Regulatory Drivers

Many regulatory drivers affect the design and operation of Federal buildings. Some of the drivers are agency goals that are affected by sustainable design and operations, while others are building-specific. The drivers address energy use, water use, renewable energy, stormwater management, greenhouse gas emissions, pollution prevention, materials selection, integrated design, and indoor environmental quality. Sustainable design is the mechanism that integrates these requirements into a cohesive design. Although all of the drivers were considered during this project, the primary focus was on the following:

- Energy Independence and Security Act of 2007 (EISA 2007), Public Law 110-140 (December 19, 2007) Section 433 Federal Building Energy Efficiency Performance Standards, and
- Executive Order 13514 (EO13514) Federal Leadership in Environmental, Energy, and Economic Performance (October 5, 2009) High Performance Sustainable Buildings Guiding Principles (hereafter Guiding Principles).

This project's energy use baselines were established in anticipation of the updated, energy efficiency performance standards, Federal rulemaking associated with section 433 of EISA 2007. This section of EISA 2007 states that all new Federal buildings "shall be designed so that the fossil fuel-generated energy consumption of the buildings is reduced, as compared with such energy consumption by a similar building in fiscal year 2003 (as measured by Commercial Buildings Energy Consumption Survey or Residential Energy Consumption Survey data from the Energy Information Agency), by the percentage specified in the following table:

Fiscal Year	Percentage Reduction
2010	55
2015	65
2020	80
2025	90
2030	100

The Energy Use Intensities (EUIs) from CBECS 2003 are based on the median value for each building category. The median source energy EUIs were calculated with conversion factors of 11.4 kBtu/kWh for electricity, 1.047 kBtu/kBtu for natural gas, and 1.145 kBtu/kBtu for fuel oil. The EUIs for each climate zone were calculated by adjusting the CBECS median values with climate zone multipliers for each building type from energy simulations of the DOE Reference Building Models (Deru et al. 2011).

Although CBECS 2003 is the basis for EUI targets under EISA 2007, unfortunately, during the timeframe of this study, the underlying rule for determining the CBECS categories and EUIs was being developed. This meant that the team members had to use their best judgment, not only in terms of which targets to use but in dealing with the lack of appropriate categories for Army buildings, e.g., data centers/Sensitive Compartmented Information Facility (SCIF), COF building configuration, and DFAC classification (it does not compare to a small fast food restaurant). The hybrid uses of the buildings and mission requirements initially created a situation of moving EUI targets.

Under the new rule, an alternative method involving calculations of EUI targets could address this issue. USACE would need to justify the basis for its calculations, but this could result in more accurate EUI targets that would better align with the use of the measures recommended by this study. That final determination has not been made.

CBECS categories are not an exact match to Portfolio Manager, but they help establish the basis for selecting the appropriate building categories within Portfolio Manager and related EUIs provided below. In addition, the Performance Targets Table values in Portfolio Manager helped establish EUI values. The site and source CBECS values that were used for the comparison are listed below in Table 2.1.

Table 2.1 Site and Source 2003 CBEC EUIs

Site Energy Savings Compared to Baseline [kBtu/ft2]	UEPH	TEMF	COF	Bde HQ	DFAC
	CBECS 2003 EUI (Dormitory/Fraternity/ Sorority)	CBECS 2003 EUI (Other Repair Service)	CBECS 2003 EUI (Whole Building - Government Office + Other Public Assembly)	CBECS 2003 EUI (Government Office)	CBECS 2003 EUI (Other Repair Service)
1A Miami	68	85	56	73	377
2A Houston	69	84	57	75	387
2B Phoenix	67	82	56	73	380
3A Memphis	68	84	55	71	396
3B El Paso	64	79	52	66	381
3C San Francisco	58	76	50	65	370
4A Baltimore	75	93	61	79	430
4B Albuquerque	66	83	53	68	400
4C Seattle	68	86	56	72	406
5A Chicago	84	100	66	85	463
5B Colorado Springs	73	90	57	73	426
6A Burlington	97	111	73	94	503
6B Helena	86	101	65	83	467
7A Duluth	105	119	77	98	540
8A Fairbanks	135	158	104	133	669

Source Energy Savings Compared to Baseline [kBtu/ft2]	UEPH	TEMF	COF	Bde HQ	DFAC
	CBECS 2003 Source Energy EUI (Other Lodging)	CBECS 2003 Source Energy EUI (Other Service)	CBECS 2003 Source Energy EUI (Whole Building - Government Office + Other Public Assembly)	CBECS 2003 EUI (Government Office)	CBECS 2003 EUI (Fast Food)
1A Miami	191	325	160	203	1244
2A Houston	169	198	143	198	1212
2B Phoenix	168	208	149	193	1187
3A Memphis	161	180	122	183	1175
3B El Paso	143	158	121	160	1032
3C San Francisco	141	160	106	163	1161
4A Baltimore	164	187	118	188	1067
4B Albuquerque	155	182	111	170	1221
4C Seattle	148	172	105	168	1159
5A Chicago	170	207	121	185	1142
5B Colorado Springs	158	201	109	170	1256
6A Burlington	180	226	125	194	1188
6B Helena	166	218	116	178	1311
7A Duluth	185	242	123	193	1242
8A Fairbanks	217	317	159	228	1348

EO 13514 requires all new construction to meet the Guiding Principles. The Guiding Principles drove sustainable design features beyond energy efficiency in the standard designs. The Guiding Principles include requirements for the following:

- Employ Integrated Design Principles
  - Integrated Design
  - Commissioning
- Optimize Energy Performance
  - Energy Efficiency
  - Measurement and Verification
- Protect and Conserve Water
  - Indoor Water
  - Outdoor Water
- Enhance Indoor Environmental Quality
  - Ventilation and Thermal Comfort
  - Moisture Control
  - Daylighting
  - Low-Emitting Materials
  - Protect Indoor Air Quality during Construction
- Reduce Environmental Impact of Materials
  - Recycled Content
  - Biobased Content
  - Construction Waste
  - Ozone Depleting Compounds.

Additional requirements are listed in Table 2.2.

Table 2.2 Additional Regulatory Drivers for Sustainable Design

Agency-Wide	
Reference	**Requirement**
Energy Policy Act of 2005 (EPACT 2005), Public Law 109-58 (August 8, 2005)	At least half of the statutorily required renewable energy (7.5 percent by FY13) from new renewable sources.
Executive Order (EO) 13423, Strengthening Federal Environmental, Energy, and Transportation Management (January 29, 2007)	Improve energy efficiency and reduce greenhouse gas emissions of the agency, through reduction of energy intensity by 30 percent by the end of FY15, relative to an agency FY03 baseline.
EO13423	Reduce water consumption intensity relative to agency FY07 baseline by 16 percent by end of FY15.
EO13423	Ensure that 15 percent of an Agency's building inventory complies with the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings.
EISA 2007, Section 431	Reduce Agency Btu per gross square foot 3 percent per year, from a 2003 baseline: o 9% in 2008 21% in 2012 o 12% in 2009 24% in 2013 o 15% in 2010 27% in 2012 o 18% in 2011 30% in 2015
EO13514	Reduce Agency greenhouse gas emissions.
EO13514	Extends the EO13423 goal of reducing potable water consumption intensity by 2 percent annually, by requiring a 26 percent reduction by the end of FY20, relative to baseline of FY07. To be accomplished, at least in part, by using water efficient and low-flow fixtures, and efficient cooling towers.
EO13514	Reduce industrial, landscaping, and agricultural water consumption intensity by 2 percent annually or 20 percent by end of FY20, relative to baseline of FY10 for each use.
EO13514	Divert from disposal at least 50 percent of construction and demolition debris by FY15.
EO13514	Agencies implement and achieve objectives identified in the U.S. Environmental Protection Agency's (EPA's) Stormwater Guidance for Federal Facilities (EPA 841-B- 09-001 issued guidance in December 2009).
EO13514	Minimize the quantity of toxic and hazardous chemicals and materials acquired, used, and disposed of.
EO13514	Implement integrated pest management and other landscape management practices.
EO13514	Ensure that 95 percent of all new contract actions for products and services are energy efficient, water-efficient, bio-based, environmentally preferable, non-ozone depleting, contain recycled content, or are non-toxic or less-toxic than traditional alternatives, where such products and services meet agency performance requirements.

Building Specific	
Reference	**Requirement**
EPACT 2005	New Federal buildings must achieve 30 percent beyond ASHRAE 90.1-2004, if life-cycle cost effective.
EO13423	Ensure that new construction complies with the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings.
EISA 2007, Section 433	Sustainable design principles shall be applied to the siting, design, and construction of buildings subject to the standards,

Table 2.2 (Cont'd)

EISA 2007, Section 438	To address stormwater runoff, predevelopment hydrology shall be maintained or restored to the maximum extent technically feasible by the sponsor of any development or redevelopment project for any Federal facility with a footprint over 5,000 ft^2. Stormwater runoff strategies listed included site planning, design, construction and maintenance.
EISA 2007, Section 523	Requires 30 percent of the hot water demand in new Federal buildings (and major renovations) to be met with solar hot water equipment, provided it is life-cycle cost-effective.
EO13514	Identify, promote and implement water reuse strategies to reduce potable water consumption (consistent with State law).
EO13514	Minimize consumption of energy, water and materials by pursuing cost-effective, innovative strategies such as highly reflective and vegetated roofs.

In addition to the Federal drivers, the Army has clarified its expectations for building design in the Army Sustainable Design and Development Policy Update (Environmental and Energy Performance, October 27, 2010). In summary, the additional requirements provided in the policy include the following:

- All new construction will follow the guidance in ASHRAE 189.1 and achieve U.S. Green Building Council LEED Silver certification.
- Solar hot water heating will be included on all new construction projects meeting specific size and location requirements.

The initial goal of this project was to prepare standard designs that, at a minimum, met the current Federal and Army requirements for sustainable design.

3.0 Five Baseline Building Type Descriptions

The study focused on five building types: UEPH, TEMF, COF, Bde HQ, and DFAC. These most commonly built MILCON facilities each year are described in the following sections. Detailed information about modeling protocols, the rationale behind decisions made, and modeling and cost estimation outputs are found in later sections of this report.

3.1 UEPH

Unaccompanied Enlisted Personnel Housing (UEPH or barracks) is a cross between apartment buildings and college dormitories. Within the Army, the different sizes of barracks are based on the number of soldiers living in them. The model for this study had a capacity of 112 personnel in rooms. Each unit has two bedrooms (one soldier per room), one shared bathroom, a small mechanical room, and a kitchen/common area, as shown in Figure 3.1. The first floor has 18 units, a laundry room, a common area, a mechanical room, and a storage area. Figure A1 (in Appendix A) shows an architectural rendering of the first floor. The second and third floors have 19 units. Each floor is 18,257 ft^2 and the building is 54,771 ft^2. An elevation view of the building and a rendering of the baseline computer model is shown in Figure A2 in Appendix A. The baseline building used is at Fort Campbell, Kentucky.

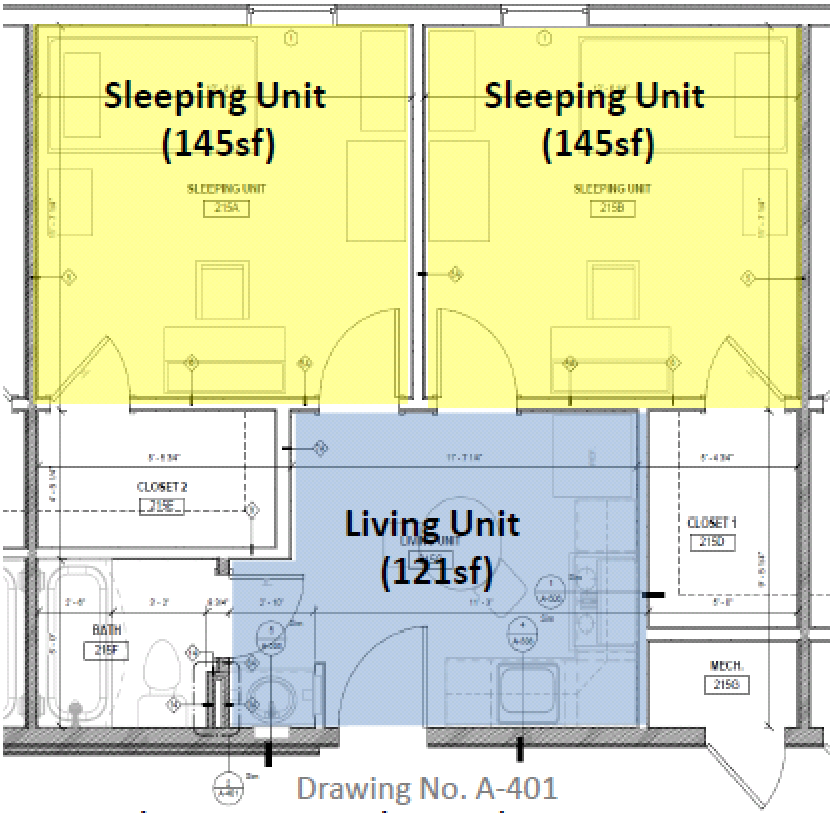

Figure 3.1 UEPH Living Unit Drawing

Modeling was completed for the baseline building. An enhanced baseline Low Energy Package and 12 additional packages were completed for all 15 climate zones. Section 5.1.1 describes the comparison of the modeled packages with the baseline building. Cost estimates for the Low Energy Package and three additional packages were completed for three climate zones: 1 (Fort Shafter, Hawaii), 2A (Fort Hood, Texas), and 8 (Fort Wainwright, Arkansas).

3.2 TEMF

The Tactical Equipment Maintenance Facility (TEMF) is a large-sized vehicle or equipment repair facility with equipment and parts, storage, and administrative offices. Within the Army, the different sizes of TEMFs are based on the type of equipment being maintained. The total square footage of the two-story building is 32,929 ft^2. The baseline building used is located at Fort Bragg, North Carolina. The building is nominally occupied from 8 a.m. to 5 p.m., Monday through Friday. A rendered view of the energy simulation model is shown in Figure B1 and a floor plan is shown in Figure B2 (both in Appendix B).

3.3 COF

Company Operations Facilities (COF) are a hybrid of an open gymnasium-type area (readiness bays) used to store soldiers' equipment in lockers, ammunition vaults, and administrative office space. These facilities house Company administrative operations and are used to store and move supplies. The facilities comprise administrative modules and readiness modules. Within the Army, the different sizes of COFs are based on the number of soldiers assigned to use them. The readiness module has a readiness bay for storing TA50 equipment for 100-, 150-, or 200-person companies; an arms vault; nuclear, biological, and chemical NBC storage; communications storage; and general storage. This report focuses on a three- and four-company version of the COF. The model for both the readiness bays and office are two stories, which combined have a footprint area of approximately 60,712 ft^2. An alternative design was also modeled that uses the same footprint but reduces the height of the ceiling in the readiness bays to decrease the energy needed for heating and cooling. The baseline building used is the 4th Brigade Combat Team Complex (Heavy) in Fort Stewart, Georgia. An architectural drawing of a typical COF first floor plan is presented in Figures C1 through C4 and a floor plan in Figure C2 (all in Appendix C).

3.4 Bde HQ

Brigade Headquarters (Bde HQ), is a hybrid of a government office building and a secure data center. A typical Bde HQ comprises administrative offices, special function rooms, classrooms, and/or a secure section. Private offices are provided for select officers and other staff. Other types of space include conference rooms, staff duty stations, message center and mail sorting, reception areas, secure documents room, showers, supplies, and vending. Within the Army, there are five different sizes of brigade headquarters. The large size of the Brigade HQ was the subject of this study. The building accommodates 122 to 156 personnel and is intended for Brigade Combat Team, battlefield surveillance, and combat support brigades. Bde HQ includes a Brigade Operations Center (BOC), Network Operations Center (NOC), and SCIF (Sensitive Compartmented Information Facility), which equates to a secure data center on the first floor. The total square footage of the two-story building is 39,600 ft^2 and each floor has 19,800 ft^2. The baseline building used is located at Fort Campbell, Kentucky. An EnergyPlus rendering of the building is found in Figure D.1 (Appendix D).

3.5 DFAC

Dining Facilities (DFACs) are a hybrid of a cafeteria and a high-volume fast food restaurant. Within the Army different sizes of dining facilities are based on the number of soldiers served during any one meal period: breakfast, lunch, or dinner. There are three DFAC sizes based on feeding capacity ranges of 251–500, 501–800, or 801-1300 personnel. Functionally, the DFAC consists of a patron dining area, a food service area, a kitchen, and food storage and receiving areas. The baseline building for this study serves 1,300 soldiers per meal period. Total square footage of the one-story building is 27,458 ft^2. The baseline building used is located at Fort Bragg, North Carolina. An architectural drawing of a typical dining facility plan is represented in Figure E.1 and a floor plan in Figure E.2 (Appendix E).

4.0 Strategies

A number of strategies were modeled and reviewed during the course of the study. These included strategies focused on energy savings as well as sustainability measures.

4.1 Energy

Energy strategies were at the heart of this study. For the five building types, this included an analysis of options considered for HVAC systems, building envelope impacts on energy efficiency, control of air infiltration, advanced interior and exterior lighting design, use of renewables, control of plug loads, water efficiency measures, and various sustainability measures, including daylighting.

4.1.1 HVAC Strategies

The general HVAC strategy for Army buildings was to provide high-efficiency HVAC systems which offset the sensible heating and cooling loads in the spaces and to provide separate high-efficiency dedicated outdoor air systems (DOASs), which includes a Total Energy Recovery (TER) exhaust air system to handle the ventilation requirements and the latent (moisture) load in the spaces. The outdoor air ventilation quantity provided by the DOAS should maintain the building, including the hallways, at a slightly positive pressure relative to outside to eliminate uncontrolled infiltration into the building. High-efficiency, variable-speed pumps and fans should be used throughout the HVAC system. High-efficiency boilers and chillers should be used in all cases. Although HVAC strategies vary somewhat from building to building, the following lists some common examples of energy efficient options that were considered:

- DOAS with condenser reheat and individual room fan coils for soldier comfort
- advanced HVAC systems; DOAS for ventilation, pressurization and make-up air, with condenser heat recovery and Energy Recovery Ventilators, both sensible and total
- central exhaust that is used for heat recovery to pre-condition the ventilation air with Energy Recovery, sensible and total recovery at 80 percent
- High Efficiency Air Cooled Chiller package, COP from 2.87 to 4.4
- condensing boilers, 80 percent to 95 percent efficient
- variable and high-efficiency fans and pumps.
- radiant heating and cooling in the ceilings
- ground-source heat pump (GSHP).

4.1.1.1 UEPH

The UEPH baseline HVAC system uses a DOAS with condenser reheat. The space loads are met with 4-pipe fan coil units connected to a central chiller and boiler in the baseline model and with radiant heating and cooling in one of the energy efficient models. The domestic water-heating system in the baseline building models uses an 80 percent efficient boiler and the energy efficient models use a 95 percent efficient condensing boiler. Options and modeling assumptions are shown in Tables A.1 of Appendix A.

The ventilation was set to provide 90 cfm of outside air to each apartment unit to make up for the bathroom exhaust and control humidity, which is greater than the ventilation requirements from ASHRAE 62.1-2004 for the baseline model. Additional outside air was added to the whole building to make up for the leakage rate at 0.02 in. w.g. (5 Pa) pressurization as shown in Table A.2 in Appendix A. For the efficient model, the ventilation air was reduced to 65 cfm per living unit with excess ventilation air as listed in Table A.2 of Appendix A. The 65 cfm was based on the standard design provided by the COS.

4.1.1.2 TEMF

A large potential for energy savings is associated with the HVAC system in the TEMF, especially when considering the current ventilation requirements of the repair bays. The closest ASHRAE 62.1-2007, Appendix B, occupancy category available for a TEMF—shipping and receiving—was used to model a flow-reduction strategy for the repair bays.

The original baseline building model ran the ventilation fans at 1.5 cfm/ft^2 during occupied hours. For this study, ventilation fan flow rates were reduced to 1.5 cfm/ft^2 for 2 hours and 0.12 cfm/ft^2 for the remainder of the operating hours each day. The reduced flow rates are acceptable under the condition that ventilation rates could increase to 1.5 cfm/ft^2 if contaminant levels from vehicle exhaust rose to detectable levels and would continue run at a 1.5-cfm/ft^2 level for as long as necessary to decrease the contaminant level to meet indoor air quality (IAQ) requirements.

The 2-hour-a-day run time was based on information from district staff that have hands-on experience with TEMF demand controls. The district staff felt that this would be a conservative run time.

Increased fan and cooling coil efficiencies were also considered along with savings associated with transpired solar collectors, radiant floors, and GSHPs. A more detailed analysis needs to be completed to determine contaminant sources, contaminant concentration targets, and perceived acceptability targets. A summary of the EEMs considered in this study is presented and described in greater detail in Table B.1 of Appendix B.

4.1.1.3 COF

An area for energy savings in the COF is the design of the readiness bay modules. In the current design, the platoon offices are located on a second-floor mezzanine. The mezzanine allows the footprint of this building to remain the same, but it increases the volume of conditioned air in the readiness bays significantly. The volume of conditioned air can drastically be reduced by slightly increasing the footprint of the readiness bays and moving the platoon offices to the first floor. An illustration of this model is presented below in Figure 4.1.

Increased fan efficiencies and chiller COP, variable-air-volume (VAV) fans instead of constant-volume fans, and a condensing boiler were also modeled. A condensing boiler is currently in the baseline building design as well. Energy recovery was modeled for climate zones 1A through 4B in both the readiness bays and the administration building. Indirect evaporative cooling and demand control ventilation was modeled for the administration building alone for climate zones 4C-8A, and a DOAS with fan coils was modeled in climate zones 2B and 3B for the readiness bays.

Transpired solar collectors were also considered for installation on the south façade of each building in climate zones 2B and 3B. The baseline and energy efficient building model assumptions are summarized in Table C.1 in Appendix C.

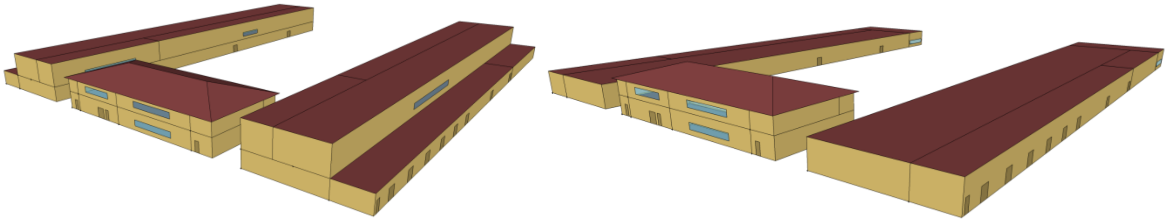

Figure 4.1 Standard and Alternative COF Design. Left: whole building as modeled in EnegyPlus, based on drawings from the 4th Brigade Combat Team Complex in Fort Stewart, Georgia. Right: alternative construction option for the readiness bays, reducing the volume of conditioned air in each readiness bay module.

4.1.1.4 Bde HQ

The office and NOC/BOC/SCIF sections of the building were modeled separately and together. The baseline HVAC system uses a VAV system with a central cooling coil, an outside air economizer, and terminal reheat boxes to meet space loads connected to a central chiller and boiler. Several building specific energy efficient options were considered, as follows:

- advanced VAV modeled with energy recovery ventilation (ERV), indirect/direct evaporative cooling (IDEC) for outside air pre-cooling
- Pre-cooling with indirect evaporative coolers for VAV and DOAS systems
- DOAS system with radiant heating and cooling system in the ceilings.

Cold (free) outside air brought in through air economizer provides (free) cooling required to condition interior space that has been heated by equipment that produces a lot of heat. With the high internal loads in the building, the VAV system was hard to improve upon because it can use free cooling with the temperature controlled outside air economizer. The problem with air-free cooling is the introduction of moisture or latent load from the outside air. Something to consider is water-free cooling when larger systems are used or the air-cooled chillers with an integrated free cooling system. Integrated free cooling systems and coil with variable frequency drive (VFD) fan speed control offers unmatched efficiencies using cold ambient air to pre-cool or completely cool the process load. The baseline and energy efficient building model assumptions are summarized in Table D.1 in Appendix D.

4.1.1.5 DFAC

Process loads for a commercial kitchen are very large and make up a significant portion of HVAC and overall building energy use. For the DFAC, the army supplied the layout of the kitchen, equipment specification sheets, a 21-day menu, and the number of meals served per day. Based upon this information, the cooking energy for each piece of equipment was evaluated and high-efficiency kitchen equipment, exhaust hood and make-up air layout and design, and control strategies were recommended. The baseline and energy efficient building model assumptions are summarized in Table E.1 in Appendix E.

Exhaust air requirements are significantly reduced with the use of high-efficiency appliances and by changing the exhaust hood design and control. Adding side panels and installing close-proximity hoods reduces exhaust flow rates as well as the amount of air flowing through the make-up air unit. Control strategies to modulate flow based on temperature and particulates can also be used to drive down flow rates for both the exhaust and make-up air units. To further reduce energy consumption, all-electric kitchen equipment was also considered. Increased fan efficiencies and chiller COPs were also modeled, as well as reduced lighting power densities and increased daylighting with dimmable daylighting controls in the office, dining, and serving areas.

On the HVAC side of the DFAC, a number of EEMs were considered. Roof-top unit fans were modeled as VAV fans and compared to constant-volume fans as specified in the drawings provided by the Army. Fan efficiencies were also increased as well as cooling coil COPs, reaching a COP of 3.85.

Passive house insulation was recommended for climate zones 4A to 8A. With a tighter envelope construction, infiltration rates were reduced, which contributes to a reduction in heating and cooling loads to the space. Lowered exhaust and make-up air ventilation requirements were also recommended. This was achieved by using high-efficiency or all-electric kitchen equipment and exhaust hood design strategies. With efficient equipment, good hood design and the use of demand-control ventilation strategies, exhaust flow requirements can be significantly reduced.

4.1.2 Building Envelope

Studies have shown that significant reductions in energy use can be achieved by minimizing the impact of the external environment on the building heating and/or cooling loads. The building envelope is critical if the energy reduction targets of EISA 2007are to be achieved.

4.1.2.1 Passive House

While the current advanced buildings practice in the United States is based on ASHRAE 90.1 (2010) and ASHRAE 189.1 (2010), the most rigorous standards for building energy efficiency resulting in ultra-low energy buildings are the German Passivhaus standards.

Typical passive house characteristics for central European locations include the following:

- Airtight building shell ≤0.6 ACH @ 50 Pa pressure difference (~0.11 cfm/ft^2 of the building envelope area at 75 Pa pressure difference) measured by a blower-door test.
- Annual heat requirement ≤15 kWh/m^2/year (<4.75 kBtu/ft^2/yr)
- Primary Energy ≤120 kWh/m^2/yr (38.1 kBtu/ ft^2/yr)
- Window u-value ≤0.8 W/m^2/K (0.14 Btu/hr/ft^2/°F)
- Ventilation system with heat recovery with ≥75 percent efficiency and low electric consumption @ 0.45 Wh/m^3
- Thermal Bridge Free Construction ≤0.01 W/mK.

In addition to energy conservation, improved building insulation and airtightness result in a more stable room temperature between day and night, higher internal wall surface temperature in winter, and lower component internal wall temperature in summer, which improves occupant thermal comfort. Higher wall temperature in winter reduces the risk that mold or mildew may occur on the internal wall surfaces and improves the quality of life in a building.

Since 1996, more than 20,000 buildings meeting these standards were built and retrofitted around the world, primarily in Germany, Austria, and Switzerland, and they include residential and office buildings, kindergartens, and supermarkets. A great many of these buildings have been extensively monitored by the Passivhaus Institut in Darmstadt, Germany. The European Union Commission (EU Parliament resolution of 31 January 2008 on an Action Plan for Energy Efficiency) intends to require that all new buildings needing to be heated and/or cooled must be constructed to passive house or equivalent non-residential standards from 2011 onward.

ERDC-CERL researchers, in collaboration with Architekturbüro Zielke Passivhäuser and Passivhaus Institut, have developed an interpretation of passive house characteristics of the building envelope to be applied to U.S. construction specifics and all 15 DOE climate zones (see Table 1.1).

4.1.2.2 Insulation of Non-Transparent Building Components

Types of insulation materials used depend on construction practices, the climate, and other factors. Typical insulating materials used in the United States include wood-fiber boards, cellulose, foam glass, mineral wool, fiberglass, extruded polystyrene, expanded polystyrene, polyurethane boards, perlite, etc. The most commonly used materials are fiberglass (R-3.5 ft^{2}·°F·hr/(Btu·in)), expanded polystyrene (R-4 ft^{2}·°F·hr/(Btu·in)), and extruded polystyrene (R-5 ft^{2}·°F·hr/(Btu·in)). These low-cost materials are well suited for most new construction and retrofit situations. Table 4.1 shows insulation requirements (R-values) for walls and roof in different climate conditions resulted from this study compared to current Army requirements as well as requirements from the ASHRAE 90.1 (2010, 2007), ASHRAE 189.1, and the ASHRAE Advanced Energy Design Guides (http://www.ashrae.org/technology/page/938).

Recommended building insulation levels follow the passive house standard, which are noted in Table 4.1 Overhead door insulation levels were also increased to R-4 ft^{2}·hr·°F/Btu.

Table 4.1 Insulation Requirements (R-values). In order from most stringent to least stringent (ci = continuous insulation).

Climate Zone	1A Miami, FL	2A Houston, TX	2B Phoenix, AZ	3A Memphis, TN	3B El Paso, TX	3C San Francisco, CA	4A Baltimore, MD	4B Albuquerque, NM	4C Seattle, WA	5A Chicago, IL	5B Colorado Springs, CO	6A Burlington, VT	6B Helena, MT	7A Duluth, MN	8A Fairbanks, AK
Wall Insulation Passive Haus [R-value]	R-19 + R7.5ci	R-19 + R15ci	R-19 + R15ci	R-19 + R20ci	R-19 + R20ci	R-19 + R10ci	R-19 + R25ci	R-19 + R25ci	R-19 + R20ci	R-19 + R30ci	R-19 + R30ci	R-19 + R40ci	R-19 + R40ci	R-19 + R50ci	R-19 + R60ci
WBDG, Army Specs - Steel Framed Walls	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-12.5ci	R-13 + R-12.5ci	R-13 + R-12.5ci	R-13 + R-12.5ci	R-13 + R-18.8ci	R-13 + R-18.8ci	R-13 + R-18.8ci	R-13 + R-18.8ci
90.1 -2010 addenda bb - Steel Framed Walls	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-12.5ci	R-13 + R-12.5ci	R-13 + R-15.0ci	R-13 + R-15.0ci	R-13 + R-18.8ci	R-13 + R-18.8ci
189.1 -2009 - Steel Framed Walls	R-13 + R-5.0ci	R-13 + R-5.0ci	R-13 + R-5.0ci	R-13 + R-5.0ci	R-13 + R-5.0ci	R-13 + R-5.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci	R-13 + R-10.0ci
ASHRAE AEDG - Steel Framed Walls	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-3.8 c.i.	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-21.6 c.i.
90.1 -2007 - Steel Framed Walls	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-3.8 c.i.	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.
Roof Insulation Pasive Haus [R-value]	R-25	R-30	R-30	R-35	R-35	R-25	R-45	R-45	R-35	R-55	R-55	R-70	R-70	R-80	R-90
WBDG, Army Specs - Roofs Insulation DeckAbove	R-25	R-25	R-25	R-25	R-25	R-25	R-30	R-30	R-30	R-30	R-30	R-40	R-40	R-40	R-40
90.1 -2010 addenda bb - Roofs Insulation Above Deck	R-20	R-25	R-25	R-25	R-25	R-25	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-35	R-35
189.1-2009 - Roofs Insulation Above Deck	R-20	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-30	R-30	R-35	R-35
90.1 -2007 - Roofs Insulation Above Deck	R-15	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20
ASHRAE AEDG - Roofs Insulation Above Deck	R-15	R-15	R-15	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-30
Slab-On-Grade Floors (Unheated) Recommended	NR	NR	NR	R-10 for 24 in.	R-10 for 24 in.	NR	R-15 for 24 in.	R-15 for 24 in.	R-10 for 24 in.	R-20 for 24 in.	R-20 for 24 in.	R-20 for 48 in.	R-20 for 48 in.	R-20 for 24 in. + R-5 ci below	R-20 for 24 in. + R-5 ci below
WBDG, Army Specs - Unheated Slab-on-Grade Floor	NR	NR	NR	NR	NR	NR	R-15 for 24 in.	R-15 for 24 in.	R-15 for 24 in.	R-15 for 24 in.	R-15 for 24 in.	R-20 for 24 in.	R-20 for 24 in.	R-20 for 24 in.	R-20 for 48 in.
189.1-2009 - Unheated Slab-on-Grade Floor	NR	NR	NR	NR	NR	NR	R-10 for 24 in.	R-10 for 24 in.	R-10 for 24 in.	R-10 for 24 in.	R-10 for 24 in.	R-15 for 24 in.	R-15 for 24 in.	R-15 for 24 in. + R-5 ci below	R-20 for 24 in. + R-5 ci below
Slab-On-Grade Floors (Heated) Recommended	R-7.5 for 12in. + R-5 ci below	R-10 for 24in. + R-5 ci below	R-10 for 24in. + R-5 ci below	R-15 for 24in. + R-5 ci below	R-15 for 24in. + R-5 ci below	R-15 for 24in. + R-5 ci below	R-20 for 24in. + R-5 ci below	R-20 for 24in. + R-5 ci below	R-20 for 24in. + R-5 ci below	R-20 for 48in. + R-5 ci below	R-20 for 48in. + R-5 ci below	R-20 for 48in. + R-5 ci below	R-20 for 48in. + R-5 ci below	R-25 for 48in. + R-5 ci below	R-25 for 48in. + R-5 ci below
WBDG, Army Specs - Heated Slab-on-Grade Floor	R-7.5 for 12in.	R-10.0 for 24in.	R-10.0 for 24in.	R-15.0 for 24in.	R-15.0 for 24in.	R-15.0 for 24in.	R-20 for 24 in.	R-20 for 24 in.	R-20 for 24 in.	R-20 for 48 in.	R-20 for 48 in.	R-20 for 48 in.	R-20 for 48 in.	R-25 for 48 in.	R-25 for 48 in.
189.1-2009 - Heated Slab-on-Grade Floor	R-7.5 for 12in. + R-5 ci below	R-7.5 for 12in. + R-5 ci below	R-7.5 for 12in. + R-5 ci below	R-7.5 for 12in. + R-5 ci below	R-7.5 for 12in. + R-5 ci below	R-7.5 for 12in. + R-5 ci below	R-10.0 for 24in. + R-5 ci below	R-10.0 for 24in. + R-5 ci below	R-10.0 for 24in. + R-5 ci below	R-15.0 for 36in. + R-5 ci below	R-15.0 for 36in. + R-5 ci below	R-15.0 for 36in. + R-5 ci below	R-15.0 for 36in. + R-5 ci below	R-20.0 for 36in. + R-5 ci below	R-20.0 for 36in. + R-5 ci below

4.1.2.3 Windows

Windows play an important role in energy efficient buildings in two ways: first, they can reduce heat loss; second, they allow the sunlight to provide daylighting to naturally light the space. In addition, studies show that in a corporate facility, an effective daylighting scheme can improve employee productivity, health, and morale.[1] By using high-efficiency windows with heat-conserving glazing, it is possible to achieve low U-values with two low emissivity coatings and filled with either krypton or argon gas. In addition, the glazing has "warm edge" insulating glass spacers along with thermal breaks throughout the framing. This means that the surface temperature of the glass inside the room is comparable with the air temperature of the room itself. The amount of total solar gain with triple-glazed windows can be as high as 60 percent, depending on glazing and gas-filling. This requires the window frame to incorporate insulation and triple glazing. Ideally, thermal bridging ideally needs to be eliminated. The Army also has a security requirement for blast-resistant windows that needs to be accounted for when the window is selected.

Efficient blast-resistant window options listed in Table 4.2 by climate zone are recommended based on the climate-specific considerations with a low solar heat gain coefficient (SHGC) for warm climates and a higher value in cold climates. Table 4.2 lists requirements for window characteristics in different climate conditions resulting from this study compared to current Army requirements as well as requirements from ASHRAE 90.1 (2010, 2007), ASHRAE 189.1, and the ASHRAE Advanced Energy Guides. ERDC/CERL staff are researching triple-pane glass manufacturers who would have products that meet both current AT/FP blast-resistant and passive house requirements.

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[1] Edwards L and P Torcellini. 2002. "A Literature Review of the Effects of Natural Light on Building Occupants." [PDF]. NREL/TP-550-30769, pp. 4–6, National Renewable Energy Laboratory, Golden, Colorado. With direct reference to: Salares V and P Russell. 1996. "Low-E Windows: Lighting Considerations." "A Sustainable Energy Future: How do we get there from here?"

Table 4.2 Window Characteristics by Climate Zone (Units are US IP)

Windows	1A Miami, FL	2A Houston, TX	2B Phoenix, AZ	3A Memphis, TN	3B El Paso, TX	3C San Francisco, CA	4A Baltimore, MD	4B Albuquerque, NM	4C Seattle, WA	5A Chicago, IL	5B Colorado Springs, CO	6A Burlington, VT	6B Helena, MT	7A Duluth, MN	8A Fairbanks, AK
Passive Haus Window Specifications															
U-Value	0.26	0.26	0.26	0.26	0.26	0.26	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
SHGC	*0.25*	*0.25*	*0.25*	*0.39*	*0.39*	*0.39*	*0.39*	*0.39*	*0.39*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*
VT	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50	> 0.50
Army WBDG - Window Specifications															
U-Value	0.56	0.45	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.33	0.33
SHGC	*0.25*	*0.25*	*0.25*	*0.37*	*0.37*	*0.37*	*0.39*	*0.39*	*0.39*	*0.39*	*0.39*	*0.39*	*0.39*	*NR*	*NR*
VT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
ASHRAE 90.1-2010 Window Specifications															
U-Value	0.73	0.50	0.50	0.46	0.46	0.46	0.38	0.38	0.38	0.38	0.38	0.36	0.36	0.29	0.29
SHGC	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.30*	*0.30*	*0.30*	*0.30*	*0.30*	*0.35*	*0.35*	*0.40*	*0.40*
Min VT/ SHGC	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
ASHRAE 189.1 Window Specifications															
U-Value	1.2	0.75	0.75	0.55	0.55	0.55	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.35	0.35
SHGC	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.35*	*0.35*	*0.35*	*0.35*	*0.35*	*0.4*	*0.4*	*0.45*	*NR*
VT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
ASHRAE 90.1 -2007 Window Specifications															
U-Value	1.2	0.75	0.75	0.65	0.65	0.65	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.45	0.45
SHGC	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*NR*	*NR*
VT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

4.1.3 Infiltration

USACE Engineering Construction Bulletin (ECB) 29-2009 states that the air leakage rate of a building envelope shall not exceed 0.25 cfm/ft^2 at a pressure differential of 0.3 in. w.g. (75 Pa) for new and renovation construction projects. In 2010, more than 200 buildings were constructed and renovated to meet or exceed this requirement (achieving airtightness of 0.10 cfm/ft^2 or better was not uncommon) at no or minimum additional cost. Based on this experience and industry consensus, for this study the assumed level for airtightness was lowered to 0.15 cfm/ft^2 at a pressure differential of 0.3 in. w.g. (75 Pa). However, design teams are encouraged to analyze the infiltration rate for each building type and climate zone to achieve maximum energy savings. Table 4.3 lists the infiltration for the UEPH at these two leakage rates.

Table 4.3 UEPH Infiltration Leakage Rates

Infiltration	0.25 cfm/ft^2	0.15 cfm/ft^2
ACH at 0.3 in. w.g. (75 Pa)	2.98	1.79
ACH at 0.02 in. w.g. (5 Pa)	0.51	0.31
Excess ventilation flow at 0.02 in. w.g. (cfm @ 5 Pa)	5832	3499
Excess ventilation flow at 5 Pa (L/s)	2752	1651

The mechanical ventilation system pressurizes the building by providing outside air equal to the building exhaust plus the air leakage at 0.02 in. w.g. (5 Pa). Infiltration is often assumed to go to zero when buildings are pressurized. It was assumed that the average uncontrolled infiltration when the building is pressurized is reduced to 10 percent of the value calculated at 0.02 in. w.g. (5 Pa). The difference in the leakage rates between the two airtightness levels was accounted for in the outdoor ventilation rates for the baseline and energy efficient models.

4.1.4 Vestibules

Vestibules were included in the energy models for the UEPH and administrative areas of the Bde HQ and COF to help reduce the cooling, heating, and latent load into the space. Vestibules help reduce the infiltration losses (or gains) from wind and stack effect by creating an air lock entry.

Figure 4.2 shows the annual energy savings for U.S. office buildings with vestibules for different climate zones. The analysis was conducted under the International Energy Agency Energy Conservation in Buildings and Community Systems (IEA ECBCS) Annex 46 study (www.annex46.org).

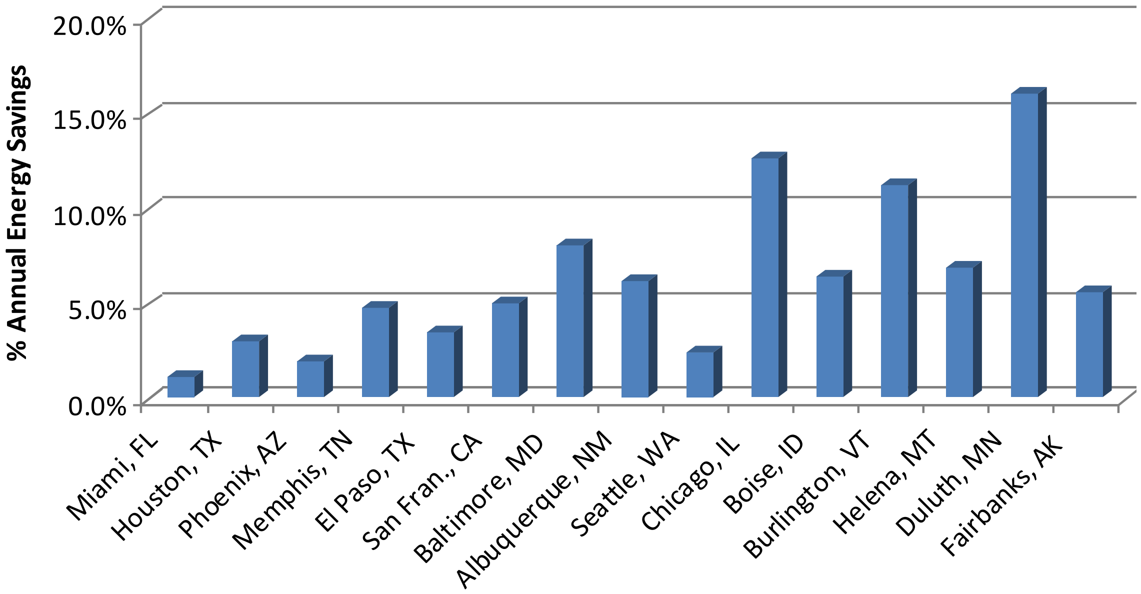


Figure 4.2 Estimated Annual Energy Savings for U.S. Office Buildings with Vestibules

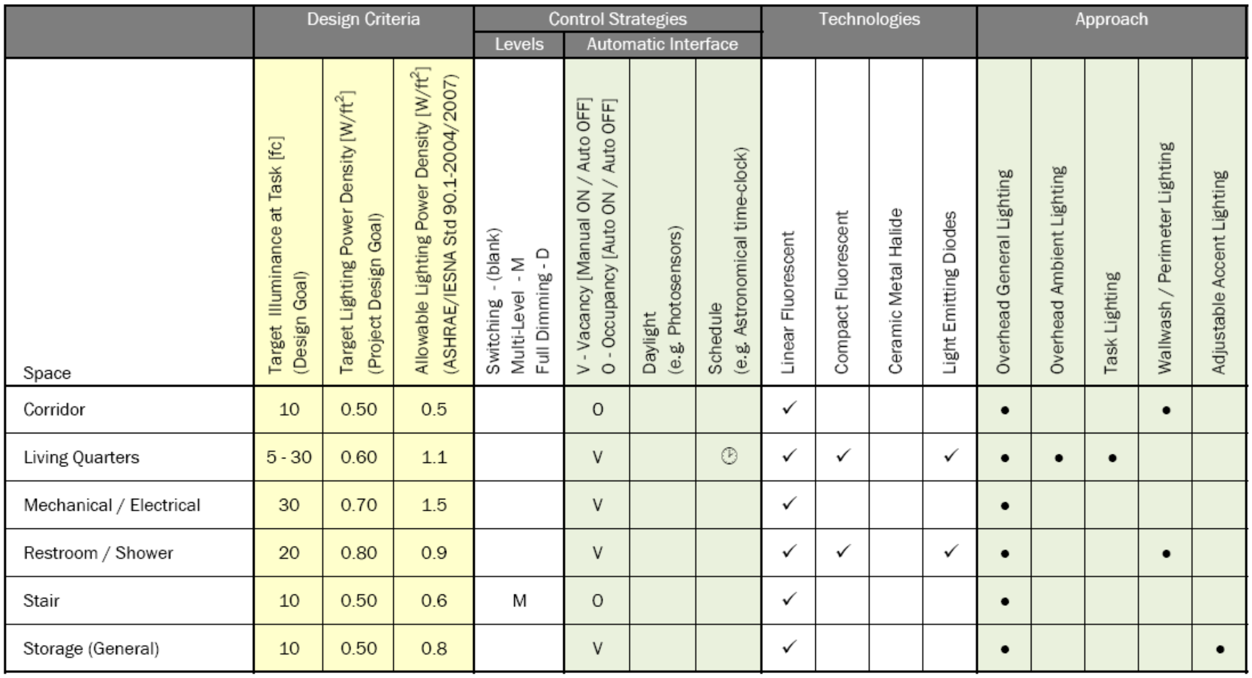
4.1.5 Lighting

Advanced lighting measures also play an important role in energy savings. Both interior and exterior lighting systems were examined during the study.

4.1.5.1 Interior

The UEPH lighting analysis was completed by Atelier Ten. The analysis focused on efficient lighting design and was based on an example of the control strategies in Table 4.4. The complete Atelier Ten report is found in Appendix F.

Table 4.4 Lighting Design by Atelier Ten

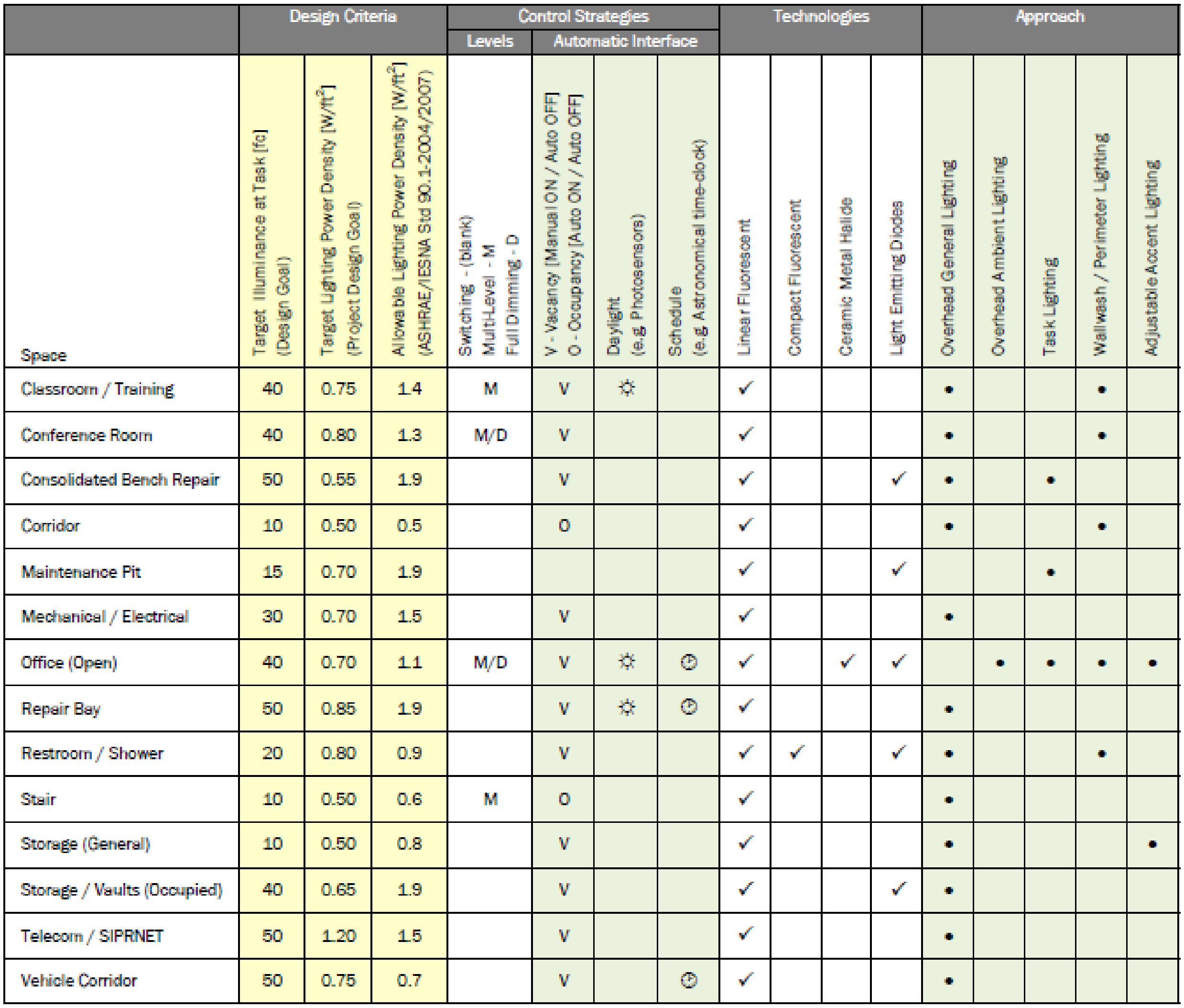


	Design Criteria			Control Strategies				Technologies				Approach				
				Levels	Automatic Interface											
Space	Target Illuminance at Task [fc] (Design Goal)	Target Lighting Power Density [W/ft^2] (Project Design Goal)	Allowable Lighting Power Density [W/ft^2] (ASHRAE/IESNA Std 90.1-2004/2007)	Switching - (blank) Multi-Level - M Full Dimming - D	V - Vacancy [Manual ON / Auto OFF] O - Occupancy [Auto ON / Auto OFF]	Daylight (e.g. Photosensors)	Schedule (e.g. Astronomical time-clock)	Linear Fluorescent	Compact Fluorescent	Ceramic Metal Halide	Light Emitting Diodes	Overhead General Lighting	Overhead Ambient Lighting	Task Lighting	Wallwash / Perimeter Lighting	Adjustable Accent Lighting
Corridor	10	0.50	0.5		O			✓				●			●	
Living Quarters	5 - 30	0.60	1.1		V		🕑	✓	✓		✓	●	●	●		
Mechanical / Electrical	30	0.70	1.5		V			✓				●				
Restroom / Shower	20	0.80	0.9		V			✓	✓		✓	●			●	
Stair	10	0.50	0.6	M	O			✓				●				
Storage (General)	10	0.50	0.8		V			✓				●				●

Lighting efficiency measures include lighting power density reductions with control strategies for each zone. Plug load power densities were assumed to be the same in all building models. An example is provided below in Table 4.5.

The lighting power density for Bde HQ was assumed to be the same as for a typical office building. For the baseline model, the lighting power density of 0.9 W/ft^2 was used. This value came from Savannah District for their standard for the Bde HQ. For the efficient model, the advanced lighting design specifications were supplied by Atelier Ten. When the spaces are averaged together, an overall value of 0.7 W/ft^2 is derived.

Table 4.5 TEMF Lighting Design by Atelier Ten. (Tables for other building types found in Appendix F – Atelier Ten Lighting Report)



	Design Criteria			Control Strategies				Technologies				Approach				
				Levels	Automatic Interface											
Space	Target Illuminance at Task [fc] (Design Goal)	Target Lighting Power Density [W/ft²] (Project Design Goal)	Allowable Lighting Power Density [W/ft²] (ASHRAE/IESNA Std 90.1-2004/2007)	Switching - (blank) Multi-Level - M Full Dimming - D	V - Vacancy [Manual ON / Auto OFF] O - Occupancy [Auto ON / Auto OFF]	Daylight (e.g Photosensors)	Schedule (e.g Astronomical time-clock)	Linear Fluorescent	Compact Fluorescent	Ceramic Metal Halide	Light Emitting Diodes	Overhead General Lighting	Overhead Ambient Lighting	Task Lighting	Wallwash / Perimeter Lighting	Adjustable Accent Lighting
Classroom / Training	40	0.75	1.4	M	V	☼		✓				•			•	
Conference Room	40	0.80	1.3	M/D	V			✓				•			•	
Consolidated Bench Repair	50	0.55	1.9		V			✓			✓	•		•		
Corridor	10	0.50	0.5		O			✓				•			•	
Maintenance Pit	15	0.70	1.9					✓			✓			•		
Mechanical / Electrical	30	0.70	1.5		V			✓				•				
Office (Open)	40	0.70	1.1	M/D	V	☼	⏲	✓		✓	✓		•	•	•	•
Repair Bay	50	0.85	1.9		V	☼	⏲	✓				•				
Restroom / Shower	20	0.80	0.9		V			✓	✓		✓	•			•	
Stair	10	0.50	0.6	M	O			✓				•				
Storage (General)	10	0.50	0.8		V			✓				•				•
Storage / Vaults (Occupied)	40	0.65	1.9		V			✓			✓	•				
Telecom / SIPRNET	50	1.20	1.5		V			✓				•				
Vehicle Corridor	50	0.75	0.7		V		⏲	✓				•				

4.1.5.2 Exterior Lighting

Light-emitting diode (LED) parking area lights were recommended to be substituted for what had been the standard exterior lighting for the five building types. However, exterior lighting was not modeled. Exterior lighting studies in recent years have showcased the use and advantages of LED lighting in terms of long-term energy savings and O&M cost due to their longer life cycles. Based on this information, the decision was made to include them in the cost estimation for each building type.

4.1.6 Onsite Renewable Energy

4.1.6.1 Transpired Solar Collectors

A transpired solar collector (TSC) preheats ventilation air by drawing make-up air through perforated steel or aluminum cladding that is warmed by solar radiation. The TSC is typically attached to the south façade of a building, with an air gap between the existing wall and the TSC cladding. The TSC is dark-colored to absorb the maximum amount of solar radiation. Air is drawn through the small holes in the wall and heated at the same time.

TSCs provide a cost-effective and energy efficient solution for preheating ventilation air, and have been recommended for buildings located in climate zones 2A to 8A. Energy savings are most significant in climate zones 3A to 7A, and the technology works particularly well for the COF and TEMF building types that have spaces of large volume that only require minimally conditioned ventilation air. The types of space that benefit from this technology the most are the readiness bay modules in the COF and the repair bays in the TEMF.

4.1.6.2 Solar Water Heating

The "Sustainable Design and Development Policy Update," dated October 27, 2010 from the Assistant Secretary of the Army – Installations, Energy, and Environment, mandates that beginning in FY13 "all new construction projects with an average daily non-industrial hot water requirement of 50 gallons or more, and located in an area shown on the NREL solar radiation maps (http://www.nrel.gov/gis/solar.html) as receiving an annual average of 4 $kWh/m^2/day$ or more will be designed to provide a minimum of 30 percent of the facility's hot water demand by solar water heating." EISA 2007, Section 523, has a similar requirement for all new Federal buildings in all locations if cost-effective.

In the United States, different types of solar water heating systems are available for use in stand-alone buildings. Different design guidelines are available from NREL and ASHRAE for small size systems. These systems are usually complex given their size and application.

For this study, solar hot water was deemed feasible for UEPH, but based on the 30 percent renewable energy requirement; the TEMF and DFAC may also be candidates for solar hot water that is life-cycle cost effective. Energy savings were modeled and part of the cost estimates for those building types.

4.1.7 Plug Loads

The modeling supported the findings of the previous EPACT study for each of the building types that plug loads are a major source of energy usage, particularly in the UEPH, Bde HQ, and DFAC. Reducing the plug loads in these building types may be the only way to meet EISA 2007 requirements. For example, in UEPH, the fraction of the total power consumed by plug loads increased from 29 percent in the baseline model to 43 percent in the low-energy model. This would be indicative of all buildings where the overall energy usage is reduced without reducing the plug loads. The potential EEMs common to the five building types are as follows:

- Use high-efficiency LED computer monitors.
- Replace all desktop computers (100 W each) with laptop computers (30 W each).
- Change computer power settings to "standby when idle for 15 minutes."
- Implement the use of standby switching devices.

- Eliminate personal printers, copiers, fax machines, and scanners. Replace them with one or two multi-function print stations.
- If vending machines are in the building, use a load-managing device and de-lamp them.
- Turn miscellaneous electronics off when they are not being used or during unoccupied hours.
- Investigate more efficient task lighting, such as LED task lighting per work station.

All plug load appliances and equipment are not created equal in terms of energy usage. A prioritized list should be developed that results in the greatest energy savings for least cost increase.

4.1.7.1 UEPH

In the UEPH, the bedroom was assumed to have a computer, stereo, television, and other smaller electronic devices for a plug load density of 1.67 W/ft^2. Each kitchen contains a refrigerator and an electric range. The refrigerator was assumed to be efficient with an average power consumption of 76 W, and the range was assumed to have a peak power of 1,500 W. Three loads per occupant per week or 48 loads/day were assumed. ENERGY STAR® commercial washing machines use approximately 20 gallons of water per load and 0.60 kWh of electricity per load. The dryers were assumed to use 1.5 kWh of electricity per load. All internal loads were operated on the schedules shown in Table A.5 in Appendix A.

4.1.7.2 TEMF

There is no metered data and very little information about plug load equipment associated with the TEMF. Because this information was not available, plug load EEMs were not considered in this study and assumed power densities remained the same in all models. However, some EEMs could be considered in future analysis, especially in areas such as the office/administrative area.

4.1.7.3 COF

There is very little detailed information about the plug and process loads in COF buildings, and assumptions have to be made in order to include them in the models. Using engineering judgment, equipment power densities were assumed and are listed by zone in Tables C.8 through C.15 in Appendix A.

4.1.7.4 Bde HQ

Plug loads were modeled differently for the office spaces and the data center. For the office spaces baseline model the plug loads were supplied by the Savannah District COS for their standard design averaged at 1.7 W/ft^2. Using ENERGY STAR® equipment reduces the office plug loads to 1.35 W/ft^2. Further equipment reductions were made in office spaces using Consortium for Energy Efficiency (CEE) Tier 3 equipment reduced the office plug loads to 1.20 W/ft^2 for the final efficient model. The CEE Tier 1 is aligned with the ENERGY STAR® specification and represents performance that will realize energy savings and greenhouse gas reductions on a national basis. CEE Tier 2 and Tier 3 help distinguish equipment that is super-efficient and are often the basis for building-critical levels of demand reduction using these higher performing products.

The plug loads in the data center include all of the server racks, computer stations, and other electrical equipment. The loads were calculated based on the information provided in the standard brigade design specification (USACE Savannah 2010). The data center loads are recognized to be peak nameplate values only. The data center loads were simulated at 5.3 W/ft^2. The data center loads were not reduced for the efficient model due to lack of information for currently available advanced data center equipment. Further internal load reduction in the data center is possible when information on advanced server equipment becomes available from the U.S. Environmental Protection Agency (EPA) or CEE. All internal loads were operated on the schedules shown in Table D.4 in Appendix D.

4.1.7.5 DFAC

Plug and process loads for commercial kitchens are very large and have a significant impact on the HVAC and overall building energy use. The 2007 DOE Buildings Energy Data Book estimates that the cooking and refrigeration loads in a typical “Food Service” building is approximately 45 percent of the total energy use (DOE 2007). Significantly reducing the energy consumption associated with kitchen equipment is a challenging task, but a number of energy efficiency measures can be implemented.

The process loads associated with food preparation, serving, and cleaning for this model were estimated by Architectural Energy Corporation and Fisher Nickel, Inc. The Army supplied the kitchen layout, equipment specification sheets, a 21-day menu, and the number of meals served per day. The cooking energy for each piece of equipment was estimated for each space based on the menus, and aggregated schedules were created for each space including warm-up and idle times.

Based upon the current kitchen design, best-in-class high-efficiency gas and electric kitchen equipment was recommended, along with two alternative choices. The use of high-efficiency equipment also reduces exhaust and make-up air requirements, especially when paired with proper exhaust hood design, layout, and flow controls that are part of the ventilation system.

Going a step further, an all-electric kitchen equipment design was considered. The all-electric scenario also positions the facility to be able to operate using 100 percent renewable energy as opposed to having to convert gas appliances and equipment at a later date and increased cost. Plug loads are found in Table E.2 in Appendix E.

4.2 Water

Water use, technically seen as a sustainability measure, was modeled in terms of hot water usage. This section addresses interior potable water, including hot water, and exterior non-potable. The goals for the study were a 30 percent reduction in water usage and 50 percent reduction in wastewater.

4.2.1 Interior Potable

In the UEPH, water-use reduction can be achieved through the use of water-conserving fixtures. These include high-efficiency toilets (HETs), dual-flush toilets, composting toilets, low-flow lavatories, low-flow showers, and low-flow kitchen sinks. (See TechNotes for HETs and low-flow fixtures.)

The reduction rates are comparisons between the baseline model and three design proposals. The baseline model uses conventional water fixtures, whereas the design proposals use various water-conserving fixtures. All calculations evaluate annual wastewater volumes from fixtures.

Various assumptions were made with regard to occupancy, flow rates, and daily usage in order to compute the overall annual volume of water consumption. The baseline calculations use conventional fixtures. Conventional fixture flow rates were based on the values from the 2009 *LEED Reference Guide for Green Building Design and Construction* (USGBC 2009). The design calculations use various types of low-flow fixtures.

Daily uses were based on the 2009 *LEED Reference Guide for Building Design and Construction* for each occupant type. Values for soldiers were based on the resident occupant type for most instances. The calculations determine an approximate annual volume of water consumption. Volumes are determined based on the different occupants and their respective usage in that building.

4.2.2 Exterior – Non-Potable

No potable water was used for irrigation in conformance with current Army requirements. Stormwater measures that use captured gray water for irrigation and other purposes are described in Section 5.3.1. Reuse of interior potable water potentially for boot washing or other uses was researched and installation of "purple" pipe was part of the buildings' cost estimates.

4.3 Other Sustainability

A number of sustainability features were examined as part of the study. These measures were also included in the cost estimating.

4.3.1 Stormwater

Stormwater quantity control aims to limit the disturbance of natural movement, distribution, and quality of water. This can be achieved through various techniques that reduce impervious cover, increase filtration, and reduce pollution in water runoff.[2]

EISA 2007 Section 438 requires Federal projects with a footprint over 5,000 ft^2 to "maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow." The project footprint includes all hard, horizontal surfaces and areas of land disturbed by the project development. This includes the building area, roads, parking lots, and sidewalks.[3] The Deputy Under Secretary of Defense (Installations and Environment) memorandum, effective January 2010, directs DoD components to implement EISA 2007 Section 438 using LID techniques in accordance with the methodology described below.[4]

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[2] LEED Reference Guide for Green Building Design and Construction. 2009. U.S. Green Building Council. Washington, D.C. p. 91.

[3] United States Environmental Protection Agency. Office of Water. Low Impact Development (LID): A literature review. EPA-841-B-00-005. October 2005. P. 1-4.

[4] United States Environmental Protection Agency. Office of Water. Low Impact Development (LID): A literature review. EPA-841-B-00-005. October 2005. P. 1-4.

LID practices fall into three main categories: infiltration, storage and reuse, and evapotranspiration (ET). ET is the process of evaporation, sublimation, and transpiration of water from the earth's surface as summarized in Table 4.6.

Table 4.6 Low Impact Development Techniques

Infiltration	Storage & Reuse	Evapotranspiration
Bioretention	Rain Barrels	Biorention
Vegetated Swales	Cisterns	Vegetated Swales
Permeable Pavement	Disconnected Downspouts	Vegetated Roofs
Sub-Surface Retention		
Vegetated Roofs		

All of these techniques were investigated and cost estimates were developed where applicable for each of the five building types in this study. Several of these techniques are site-specific, which resulted in assumptions being made in terms of what measures would be used most frequently. (See TechNotes for LID techniques.)

4.3.2 Enhanced Commissioning

Enhanced commissioning was driven by LEED 2009. The estimate considered the items listed below.

- Prior to the start of the construction documents phase, designate an independent Commissioning Authority (CxA) to lead, review, and oversee the completion of all commissioning process activities.
- The CxA shall conduct two commissioning design reviews of the Owner's Project Requirements (OPR), Basis of Design (BOD), and design documents prior to mid-construction documents phase and back-check the review comments in the subsequent design submission.
- The CxA shall review contractor submittals applicable to systems being commissioned for compliance with the OPR and BOD. This review shall be concurrent with A&E reviews and submitted to the design team and the owner.
- Verify that the requirements for training operating personnel and building occupants are completed.
- Develop a systems manual that provides future operating staff the information needed to understand and optimally operate the commissioned systems.
- Ensure the involvement by the CxA in reviewing building operation within 10 months after substantial completion with O&M staff and occupants. Include a plan for resolution of outstanding commissioning-related issues.

4.3.3 Measurement and Verification

Measurement and verification (M&V) is part of ASHRAE 189.1 and LEED 2009. While LEED requires a plan for measurement and verification, ASHRAE 189.1 has more detailed requirements, which include the use of meters for various systems. This study acknowledged both of these sources and included M&V in the cost estimate for the building types.

At the Installations level, IMCOM is currently leading Phase I of a major metering project. During this phase, all buildings that are over 29,000 ft^2 or exceed $35,000 a year in utility costs will be required to be metered. Phase II of the program includes development of a Metered Building Energy Conservation Strategy that will capture and manage the resulting data. Metering is expected to be completed by the end of 2012.

4.3.4 Daylighting

LEED 2009 requires the determination of a building's "regularly occupied" space for calculating the following three indoor environmental quality (IEQ) credits:

1. IEQcr5: Indoor Chemical and Pollutant Source Control
2. IEQcr8.1: Daylight and Views—Daylight
3. IEQcr8.2: Daylight and Views—Views.

Regularly occupied space is defined as areas where occupants are seated or stand as they work inside a building. In residential applications such as the barracks, these areas include all spaces except bathrooms, utility areas, closets, or other storage rooms.[5] Regularly occupied spaces were calculated for each of the five building types based on drawings for their standard designs. Techniques and systems related to daylighting include the following:

- use of passive lighting ceiling systems (e.g. light shelves) that "stretch" light into spaces with no direct daylight exposure
- louvers and overhangs (to act as shading devices)
- daylight sensors (to minimize use of powered light fixtures in areas with free light sources)
- daylighting software (to predict and analyze how daylighting will affect the building and when electrical lighting can be dimmed or turned off)
- fiber optics (to act as a hybrid solar lighting system by bringing daylighting into the building via fiber-optic fibers, without requiring large penetrations in the building envelope as a skylight or window would)

TechNotes are available for daylight sensors and light shelves (see Section 5.6.2), and the Atelier Ten Lighting Report in Appendix F contains tables with daylighting values for the different building types.

4.3.4.1 UEPH

Skylights and light tubes were included in the UEPH with one skylight or light tube per module. Thirty-eight solar tubes direct additional lighting to the second and third floors. The exact locations and required floor area were not determined for this study. It may be possible to use the floor area from mechanical closets for light tubes when some of the HVAC system packages do not require mechanical rooms within the occupied space.

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[5] LEED Reference Guide for Green Building Design and Construction, 2009.

4.3.4.2 TEMF

The door, window, and skylight sizes and distribution within the repair bays are the same in all energy models, with a skylight-to-floor-area (SFA) fraction of 4 percent. However, daylighting recommendations for the office and consolidated bench areas include an increase in the SFA fraction to 3 percent and an increase in vertical glazing by 50 percent. Dimmable daylighting controls to off with a 500 lux setpoint are also recommended for all daylit areas. Fenestration details are also listed in Table B.3 in Appendix B.

4.3.4.3 COF

Daylighting controls were not included in the baseline model. In the energy efficient model, dimmable daylighting controls to off with a 500 lux setpoint were recommended for all daylit areas. The SFA fraction was also increased to 3 percent over the readiness bays, platoon offices, mezzanine corridor, and storage space. The 3 percent SFA follows recommendations found in the *The ASHRAE 30 % Advanced Energy Design Guide for Small Retail Buildings* (http://www.ashrae.org/technology/page/938). Fenestration details are listed in Tables C.2 and C.3 in Appendix C.

4.3.4.4 Bde HQ

The Bde HQ standard design failed to successfully incorporate a sufficient daylighting scheme into the building. The distance from one exterior wall to the opposite exceeds 60 ft, which is the pre-determined maximum distance that allows for daylighting penetration[6]. Therefore, the calculated interior spaces did not receive sufficient daylight. Consequently, this particular design could not receive LEED credit for daylighting. Several strategies, including narrowing the building's footprint and using reflective finishes on surfaces, could have enabled the building to achieve the daylighting credit. Fenestration details are listed in Tables D2 and D3 in Appendix D.

4.3.4.5 DFAC

Currently, the standard DFAC design provides sufficient daylighting to the dining area, but the kitchen/preparation area and the dishwashing area lack daylighting. The standard design features clerestories and skylights in the dining area. Notably, the DFAC is a single-story building; therefore, the use of light tubes or additional skylights would provide enough natural light into spaces that are currently lacking daylighting. Fenestration details are listed in Tables E.3 and E.4 in Appendix E.

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[6] (Lechner, N. 2009. Heating, Cooling, Lighting. Hoboken, New Jersey: John Wiley & Sons, Inc. P 380).

5.0 Outputs and Results

Following analysis of the regulatory drivers and potential strategies, energy modeling of selected packages of energy efficient features was conducted. The goal was to meet the EISA 2007 target for 2015 of a 65 percent energy reduction based on 2003 CBECS data that was also life-cycle cost effective and considered other factors such as O&M impacts.

5.1 Energy Savings

Modeling was completed for each baseline building plus additional EEM packages for all 15 climate zones. Cost estimates for the baseline building and selected Low Energy Packages were also completed for climate zones based on the location of buildings in the FY13 construction program list. Appendices A through E include more detailed figures, tables, and cost estimates for each building type.

Low Energy Packages for all building types included increased exterior insulation, daylighting and daylighting controls, DOAS HVAC systems, improved pumps and fans, pressurization and make-up air, and top-tier ENERGY STAR® appliances and products. In addition, features such as solar hot water and transpired solar collectors were examined where appropriate.

5.1.1 UEPH

For the UEPH, the “Other Lodging” category was chosen from the CBECS, because it was determined to be the closest match to the UEPH facility. As will be seen from the results in this section and subsequent building types, CBECS building categories and their related EUIs are not directly comparable to the five Army building types that were analyzed. This directly affects whether a building meets or falls short of the EISA 2007 targets for 2015. Annual EUI for each climate zone was determined from the CBECS data and compared to the energy baseline for the designed building. The target EUI is 35 percent of the CBECS values, or a 65 percent increase in efficiency, which is a very aggressive target from the EISA 2007 legislation.

The simulated results for the energy efficient designs including the envelope, infiltration, lighting, equipment, and HVAC energy conservation measures are shown in tables and figures below with the cumulative percent savings compared to the baseline building (B) EUI for each EEM package (P1–P13). In the tables and figures below, the “Baseline Building” or “B” is the base building model from each of the COS standard designs (baseline building assumptions are listed in each building appendix [A–E]). Each EEM or Low Energy Package is applied cumulatively to the baseline B, starting with P1 (e.g., lighting load and electric power load density reduction for UEPH), then P2, P3, and finally P4. Package P4 is considered the baseline high-performance or low-energy package for each building and is called “Low Energy Package 1.” Then, EEMs 5–13 are applied individually or in combination to P4 to compare the different HVAC alternatives. The results for each building are shown for both site and source. The source results are necessary for EISA 2007 compliance. The site results are shown for direct comparison to CBECS data.

Table 5.1 Site Energy Use Intensities (EUIs) for Each Energy Efficiency Measure (EEM) Package. (Package 4 [P4], circled in red, is considered the baseline low-energy building.)

Site Energy Totals with Plug Loads [kBtu/ft2]	2003 CBECS Other Lodging	CBECS Site Budget	Baseline Building	Low Energy Package 1												
			B	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1A Miami	68	24	69	52	46	39	37	37	35	36	36	35	34	37	34	30
2A Houston	69	24	69	56	47	40	38	37	36	37	36	35	34	38	35	31
2B Phoenix	67	23	64	49	42	37	35	34	32	34	32	31	30	35	31	26
3A Memphis	68	24	72	61	50	43	41	37	39	39	36	36	34	38	35	31
3B El Paso	64	22	63	50	44	38	36	34	35	35	33	33	31	36	33	28
3C San Francisco	58	20	59	49	42	38	35	34	35	34	33	34	33	36	33	30
4A Baltimore	75	26	77	68	53	46	43	38	42	42	36	37	35	40	38	33
4B Albuquerque	66	23	69	58	48	42	40	35	38	38	34	34	33	39	35	30
4C Seattle	68	24	69	63	49	43	40	36	40	39	34	36	34	37	35	32
5A Chicago	84	29	84	77	59	51	48	39	47	46	38	39	37	40	37	35
5B Colorado Springs	73	26	75	65	54	47	44	37	43	42	36	36	35	41	38	32
6A Burlington	97	34	88	82	62	54	50	40	50	48	39	39	38	43	40	36
6B Helena	86	30	84	77	59	51	48	38	47	46	37	38	37	42	39	34
7A Duluth	105	37	98	93	70	60	56	42	55	54	41	42	41	45	43	39
8A Fairbanks	135	47	122	119	87	74	69	50	69	67	49	50	49	47	45	47

B	Baseline Energy Budget
P1	Lighting Load and Electric Power Load Density Reduction from 1.67 W/ft^2 to 0.835 W/ft^2 applied to B
P2	Passiv haus insulation specification; increased insulation and air tightness, reduce OA pressurization air to 65CFM due to air tightness with P1-B
P3	Increase chiller and boiler efficiencies and all variable high efficiency pumps and fans with P2-B
P4	Reduce hot water with 1.5gpm shower heads with P3-B
P5	Energy recovery ventilation (ERV) with P4
P6	Indirect evaporative pre-cooling with P4
P7	Radiant heating and cooling with P4
P8	ERV and radiant with P4
P9	ERV and indirect evaporative pre-cooling with P4
P10	ERV, indirect evaporative pre-cooling and radiant heating and cooling with P4
P11	Ground source heat pump (GSHP) and ERV with P4
P12	Reduction in equiment loads (0.5W/ft2) with premium equipment in soldiers rooms; added to P11
P13	Reduction in equiment loads (0.5W/ft2) with premium equipment in soldiers rooms, Added to P10

Table 5.2 Source EUI for Each EEM Package. (P4, circled in red, is considered the baseline low-energy building.)

Source Energy Totals with Plug Loads [kBtu/ft2]	2003 CBECS Other Lodging	CBECS Source Budget	Baseline Building	Low Energy Package 1												
			B	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1A Miami	191	73	209	151	133	113	111	110	103	108	108	103	99	111	99	87
2A Houston	169	68	195	143	124	108	106	104	99	102	101	98	95	108	97	83
2B Phoenix	168	68	186	132	115	101	100	96	89	95	92	88	84	101	89	72
3A Memphis	161	62	188	138	120	106	103	99	99	99	96	95	91	106	95	80
3B El Paso	143	60	171	119	107	97	95	92	90	91	89	88	84	100	88	72
3C San Francisco	141	52	152	107	98	91	88	87	88	85	84	87	84	95	85	73
4A Baltimore	164	62	183	138	117	105	102	96	99	98	93	93	90	108	98	79
4B Albuquerque	155	57	170	121	108	99	96	91	92	92	87	88	84	104	92	73
4C Seattle	148	56	162	120	104	96	93	88	92	90	85	88	85	97	87	74
5A Chicago	170	65	187	143	121	109	105	96	103	101	93	94	90	104	94	80
5B Colorado Springs	158	59	172	125	111	102	99	91	96	95	88	90	86	106	95	75
6A Burlington	180	71	186	144	121	109	105	95	104	102	92	93	90	111	101	80
6B Helena	166	64	179	136	115	105	102	92	100	98	89	91	87	108	97	77
7A Duluth	185	72	193	153	126	114	110	96	109	106	93	95	92	116	106	82
8A Fairbanks	217	83	215	178	142	127	123	102	122	119	100	102	99	117	107	90

Table 5.3 shows the incremental percent savings for each as it is added to the previous package. The baseline Low Energy Package consists of packages, P1 through P4, applied to the baseline energy model,

B. Packages P5, P8–11 appear to achieve the best results based on the energy modeling information, because they show the highest energy savings percentages. Low Energy Packages P12 and P13 are not considered in the final analysis because they assume that there is a further reduction in equipment loads in the soldier's rooms.

Table 5.3 Site Cumulative Percent Savings. (The red box indicates what is considered as the baseline Low Energy Package P4. The columns to the right show the incremental percent savings compared to the P4 package.)

UEPH	Incremental % Savings (Site)												
	P1-B	P2-P1	P3-P2	P4-P3	P5-P4	P6-P4	P7-P4	P8-P4	P9-P4	P10-P4	P11-P4	P12-P4	P13-P4
1A Miami	-25%	-11%	-15%	-4%	-1%	-7%	-3%	-3%	-7%	-10%	0%	-10%	-19%
2A Houston	-19%	-16%	-14%	-5%	-4%	-5%	-3%	-7%	-8%	-12%	-1%	-10%	-20%
2B Phoenix	-23%	-14%	-13%	-5%	-4%	-10%	-4%	-7%	-11%	-15%	0%	-10%	-25%
3A Memphis	-16%	-18%	-13%	-6%	-9%	-4%	-4%	-12%	-12%	-15%	-5%	-13%	-23%
3B El Paso	-21%	-13%	-12%	-6%	-6%	-4%	-4%	-9%	-10%	-13%	-1%	-10%	-23%
3C San Francisco	-16%	-14%	-10%	-8%	-3%	-1%	-3%	-6%	-4%	-7%	3%	-6%	-15%
4A Baltimore	-11%	-22%	-13%	-7%	-13%	-2%	-4%	-16%	-15%	-19%	-7%	-13%	-25%
4B Albuquerque	-16%	-17%	-12%	-7%	-11%	-3%	-3%	-14%	-14%	-17%	-2%	-10%	-25%
4C Seattle	-9%	-22%	-11%	-8%	-11%	-1%	-4%	-14%	-11%	-15%	-7%	-13%	-21%
5A Chicago	-9%	-23%	-13%	-7%	-18%	-1%	-3%	-21%	-19%	-22%	-17%	-22%	-28%
5B Colorado Springs	-13%	-18%	-12%	-7%	-16%	-1%	-3%	-18%	-17%	-19%	-7%	-13%	-26%
6A Burlington	-7%	-25%	-13%	-7%	-20%	-1%	-3%	-23%	-21%	-24%	-14%	-19%	-28%
6B Helena	-8%	-23%	-13%	-7%	-20%	-1%	-3%	-22%	-21%	-23%	-12%	-18%	-29%
7A Duluth	-5%	-25%	-14%	-7%	-24%	0%	-3%	-26%	-24%	-26%	-18%	-22%	-30%
8A Fairbanks	-2%	-27%	-15%	-6%	-28%	0%	-2%	-29%	-28%	-30%	-32%	-34%	-32%
Avg % Savings	-13%	-19%	-13%	-6%	-13%	-3%	-3%	-15%	-15%	-18%	-8%	-15%	-25%

After reviewing the data with the COSs and cost estimators, packages 5, 8 and 11 were selected in addition to the baseline Low Energy Package 4 for full cost estimates. These selections were made based on possible issues with maintenance of newer technologies and a high first cost or lack of availability of systems to be supplied by three or more vendors.

As can be seen from Figure 5.1 below, the initial EEMs show good source energy improvement and the selected packages for closer evaluation are indicated (P5, P8, and P11). Even with all of these technologies applied the targets could not be achieved, and only when internal loads are reduced further do we start seeing further improvements. Another interesting result is that when source fuels are calculated, the savings from GSHPs (P11) are not as good as expected because most of the advantages are negated when the source fuels for electricity generation are considered. In other words, GSHPs inherently need electricity to operate, and a large percentage of the electricity generation in the United States is from fossil-fuel-based power plants.

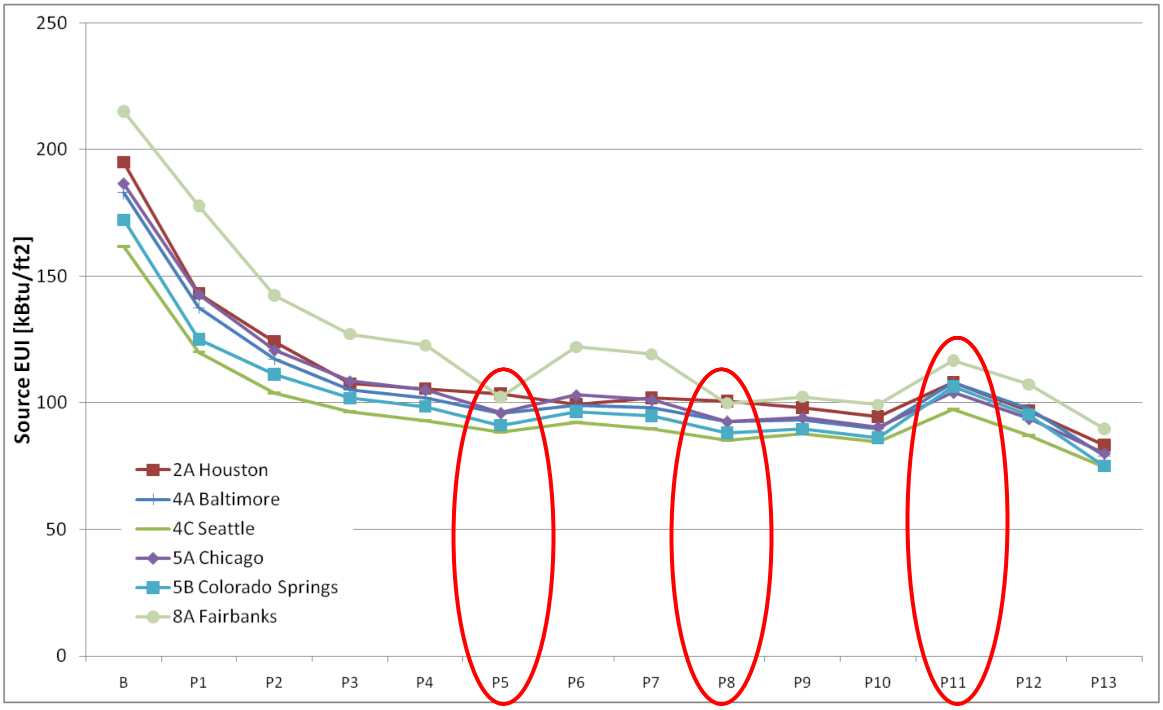

Figure 5.1 UEPH Source Energy Use Intensities by EEM Package (P5, P8, and P11, circled in red, show packages that were chosen for cost estimation in addition to baseline package P4)

In addition to the energy packages that were evaluated, 30 percent of the hot water demand was supplied with solar hot water heaters. Table 5.4 below shows the site energy savings results with the solar hot water added to the Low Energy Packages that were evaluated for the UEPH facility. There is a slight improvement to get closer to the targeted 65 percent energy values. For simplification purposes, P4, P5, P8, and P11 are renamed Low Energy Package 1–4 in the tables that follow.

Table 5.4 Description of Low Energy Packages for the UEPH

UEPH	Energy Efficiency Measures
Low Energy Package 1 (P1-P4)	• Passive house insulation, windows– applied to whole building. • Reduced infiltration rates from 0.4 cfm/ft^2 to 0.15 cfm/ft^2 • Reduced lighting power densities • High efficiency fixtures to reduce hot water demand includes: 0.5-gpm flow faucets, 1.5-gpm flow shower heads • Cool roofs in climates 1-5 and window shading • Increased vertical glazing size by 50%, increased skylight-to-floor area (SFA) fraction to 3% • Advanced HVAC system: o Dedicated outside air system (DOAS) for ventilation, o Improved chiller and boiler efficiencies, o All variable high-efficiency pumps and fans, o Pressurization and make-up air, o Condenser heat recovery for DOAS o Separate ventilation for living area and laundry facilities • Solar hot water system included • Top tier ENERGY STAR® appliances
Low Energy Package 2 (P5)	• Same as Low Energy Package 1 plus adding total energy recovery (ERV) unit at 80% effectiveness
Low Energy Package 3 (P8)	• Same as Low Energy Package 2 with ceiling radiant heating and cooling added (radiant mat is installed in the ceiling)
Low Energy Package 4 (P11)	• Same as Low Energy Package 2 except replace high-efficiency chiller and boiler with a ground-source heat pump system

Table 5.5 UEPH Cumulative Site Energy Savings of Each Low Energy Package Compared to the Baseline EUI

Site Energy Savings Compared to Baseline [%]	Low Energy Package 1	Low Energy Package 2	Low Energy Package 3	Low Energy Package 4
1A Miami	37%	49%	50%	48%
2A Houston	37%	50%	52%	49%
2B Phoenix	39%	51%	52%	49%
3A Memphis	37%	53%	54%	51%
3B El Paso	38%	51%	53%	48%
3C San Francisco	37%	48%	49%	44%
4A Baltimore	37%	56%	57%	52%
4B Albuquerque	38%	54%	56%	49%
4C Seattle	37%	53%	55%	51%
5A Chicago	36%	58%	60%	54%
5B Colorado Springs	37%	56%	58%	51%
6A Burlington	37%	60%	61%	56%
6B Helena	37%	59%	61%	55%
7A Duluth	36%	62%	63%	58%
8A Fairbanks	36%	64%	65%	66%

Based on the cost estimates that were completed and the energy savings that resulted from the modeling analysis, Low Energy Package 3 was selected as the lowest energy and most cost-effective package (see Section 5.5 for LCCA analysis results). Table 5.6 compares the Low Energy Package 3 site EUI to the CBECS 2003 targets for the Other Lodging category. Four of the 15 climate zones reach or are within 5 percent of the CBECS targets (noted in red). When comparing the CBECS source energy targets to the low-energy model, the percentage difference is not as high as in the CBECS site EUI comparison. It is important to note again that the CBECS 2003 category that was chosen may not match well to the UEPH facility in terms of energy consumption data.

Table 5.6 UEPH Site Energy Savings of Low Energy Package 3 Compared to the 2003 CBECS Baseline Category (Other Lodging)

Site Energy Savings Compared to CBECS [kBtu/ft2]	2003 CBECS Site EUI (Other Lodging)	65% Reduction - CBECS 2003 Target EUI [kBtu/ft2]	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	68	24	35	49%
2A Houston	69	24	33	51%
2B Phoenix	67	23	30	55%
3A Memphis	68	24	33	51%
3B El Paso	64	22	30	53%
3C San Francisco	58	20	30	49%
4A Baltimore	75	26	33	56%
4B Albuquerque	66	23	31	54%
4C Seattle	68	24	31	55%
5A Chicago	84	29	34	59%
5B Colorado Springs	73	26	32	57%
6A Burlington	97	34	34	64%
6B Helena	86	30	33	62%
7A Duluth	105	37	37	65%
8A Fairbanks	135	47	43	68%

Table 5.7 UEPH Source Energy Savings of Low Energy Package 3 Compared to the 2003 CBECS Baseline Category (Other Lodging)

Source Energy Savings Compared to CBECS [kBtu/ft2]	2003 CBECS Source EUI (Other Lodging)	65% Reduction - CBECS 2003 Target EUI [kBtu/ft2]	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	191	67	106	44%
2A Houston	169	59	99	42%
2B Phoenix	168	59	91	46%
3A Memphis	161	56	93	42%
3B El Paso	143	50	86	39%
3C San Francisco	141	49	82	42%
4A Baltimore	164	58	90	45%
4B Albuquerque	155	54	85	45%
4C Seattle	148	52	82	44%
5A Chicago	170	59	90	47%
5B Colorado Springs	158	55	85	46%
6A Burlington	180	63	88	51%
6B Helena	166	58	85	49%
7A Duluth	185	65	89	52%
8A Fairbanks	217	76	96	56%

To investigate further how to reach the EISA 2007 targets, Figure 5.2 below plots the same results as Table 5.6, but also includes the breakdown of the components that make up the total building energy consumption. Although improvements have been made with the low-energy model toward meeting the EISA 2007 goals, this breakdown shows that without considering further internal load reduction, the EISA 2007 targets cannot be met. Even buildings with low internal energy loads can end up being dominated by internal loads when built or retrofitted to passive house requirements and using advanced "low-energy" systems to satisfy remaining heating and cooling needs. The remaining energy requirements will be dominated by electrical power needs for lighting, appliances, and internal processes, and by domestic hot water needs or the "mission" of the building.

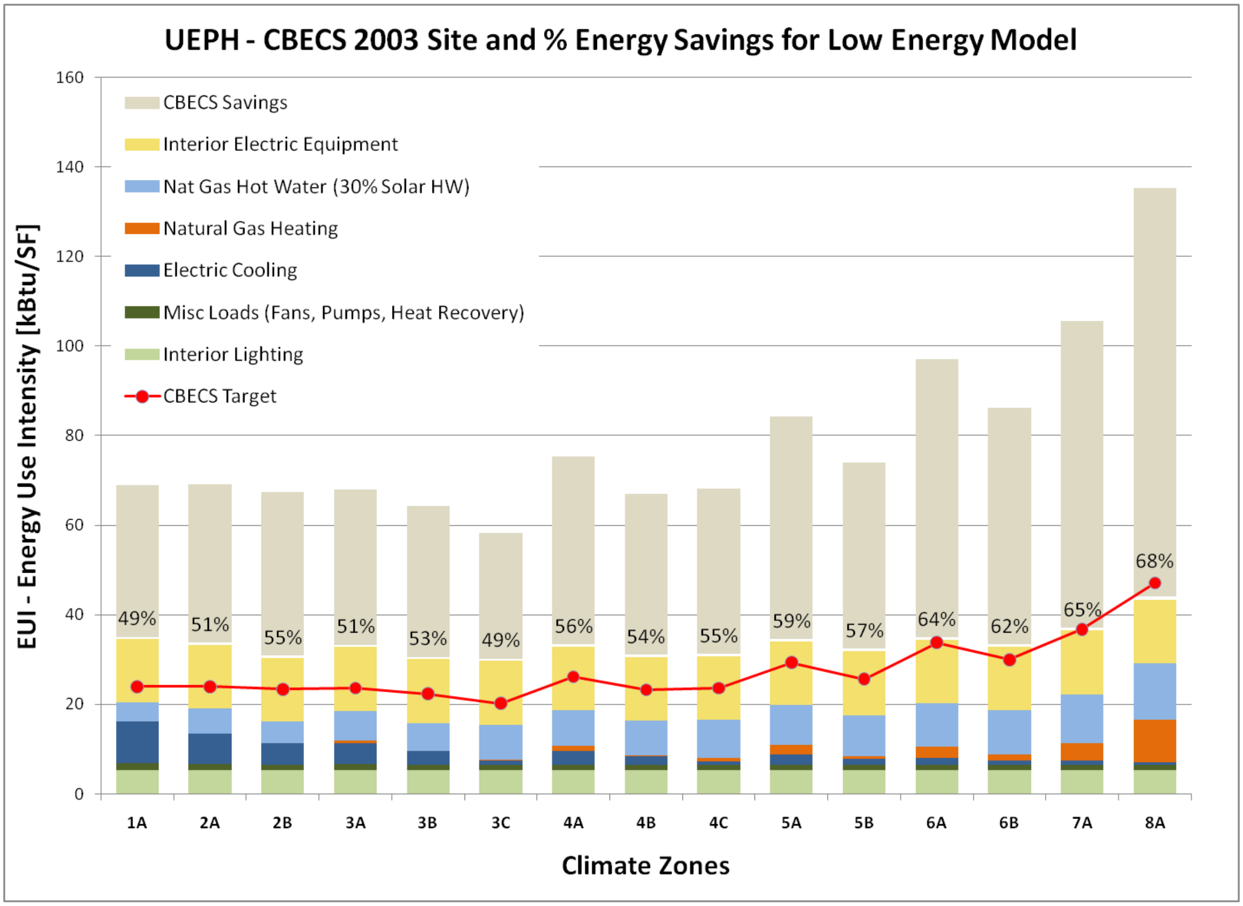

Figure 5.2 UEPH Percent Low Energy Package 3 with Comparison to EISA 2007 Targets (Site Energy)

Table 5.8 breaks down the site baseline building component energy for the UEPH by climate zone and shows that the interior lights, interior equipment/plug loads, and natural gas hot water make up from 50 percent to 86 percent of the load, varying by climate zone.

Table 5.8 Baseline UEPH (Site Energy)

Site Energy [kBtu/ft2]	Electric Cooling	Interior Lights	Interior Equipment	Electric Fans, Pumps	Natural Gas Heating	Natural Gas Hot Water	Total
1A Miami	22.9	11.2	22.4	3.2	0.1	9.1	68.8
2A Houston	17.0	11.2	22.4	2.2	3.2	12.1	68.9
2B Phoenix	15.5	11.2	22.4	2.4	1.3	10.4	63.8
3A Memphis	12.6	11.2	22.4	2.3	8.5	14.4	71.8
3B El Paso	9.4	11.2	22.4	2.2	4.2	13.6	63.5
3C San Francisco	3.5	11.2	22.4	2.1	2.4	16.9	58.6
4A Baltimore	8.5	11.2	22.4	2.2	14.9	17.2	76.9
4B Albuquerque	6.3	11.2	22.4	2.4	9.5	16.8	69.0
4C Seattle	3.1	11.2	22.4	2.1	11.3	18.4	68.8
5A Chicago	6.7	11.2	22.4	2.2	22.2	19.2	84.3
5B Colorado Springs	4.4	11.2	22.4	2.4	15.0	19.7	75.4
6A Burlington	4.7	11.2	22.4	2.1	26.7	21.0	88.4
6B Helena	3.4	11.2	22.4	2.3	22.9	21.2	83.8
7A Duluth	3.2	11.2	22.4	2.1	35.1	23.7	98.1
8A Fairbanks	2.0	11.2	22.4	2.2	57.0	27.1	122.1

Table 5.9 shows that even after the improved lighting design, reducing hot water consumption with low-flow shower heads and improving the interior equipment/plug loads by almost 50 percent , a significant percentage of interior equipment/plug load remains. With EISA 2007, total energy is now considered. This is unlike EPACT 2005, Section 109, where the plug loads were considered unregulated. Now they are a significant part of the challenge posed by EISA 2007 requirements.

Table 5.9 Energy Efficient UEPH (Site Energy)

Site Energy [kBtu/ft2]	Electric Cooling	Interior Lights	Interior Equipment	Electric Fans, Pumps	Natural Gas Heating	Natural Gas Hot Water	Total
1A Miami	9.3	5.4	14.2	1.5	0.0	4.2	34.6
2A Houston	6.7	5.4	14.2	1.4	0.1	5.6	33.3
2B Phoenix	4.8	5.4	14.2	1.2	0.0	4.8	30.4
3A Memphis	4.7	5.4	14.2	1.2	0.7	6.6	32.8
3B El Paso	3.0	5.4	14.2	1.1	0.1	6.3	30.1
3C San Francisco	1.1	5.4	14.2	1.0	0.2	7.8	29.7
4A Baltimore	3.1	5.4	14.2	1.2	1.0	8.0	32.8
4B Albuquerque	2.0	5.4	14.2	1.1	0.2	7.8	30.6
4C Seattle	0.9	5.4	14.2	1.1	0.7	8.5	30.7
5A Chicago	2.4	5.4	14.2	1.1	2.1	8.9	34.1
5B Colorado Springs	1.4	5.4	14.2	1.1	0.6	9.1	31.8
6A Burlington	1.6	5.4	14.2	1.1	2.4	9.7	34.4
6B Helena	1.1	5.4	14.2	1.1	1.4	9.8	32.9
7A Duluth	1.1	5.4	14.2	1.1	3.8	11.0	36.5
8A Fairbanks	0.6	5.4	14.2	1.1	9.5	12.5	43.3

Figure 5.3 further illustrates the point of how much the interior equipment/plug load percentage increases from the baseline building to the low-energy building in climate zone 4A.

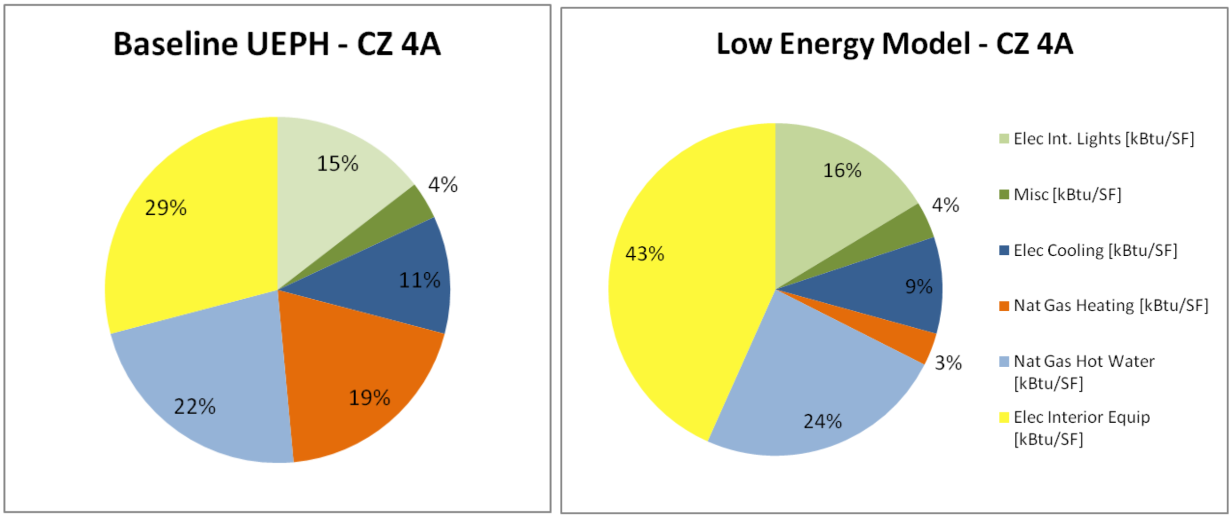

Figure 5.3 Percentage of Energy Loads – Baseline and Low-Energy Model for UEPH in Climate Zone 4A

5.1.2 TEMF

For the TEMF, the “Other Service” category was chosen from CBECS data. Annual energy use intensity for each climate zone was determined from the CBECS data and compared to the energy baseline for the designed building. The EEMs considered for the TEMF were analyzed in a fashion similar to the UEPH. EEMs with the highest energy savings were chosen to be included in a Low Energy Package for each climate zone. Three iterations of Low Energy Packages followed, exploring the effects of adding TSCs to the south façade of the building, radiant floors in the repair bays and vehicle corridor, and a combination of both. Economizers were not modeled because the air handling units (AHUs) for the repair bays are dedicated to bringing 100 percent outside air and only minimally condition the air to 55 °F. A description of the four packages is found in Table 5.10 below.

Table 5.10 Description of Low Energy Packages for the TEMF

TEMF	Energy Efficiency Measures
Low Energy Package 1	• Increased daylighting and reduced lighting power density • Passive House insulation for climate zones 3A, 3B, 4A-8A • VAV fans, increased fan and HVAC efficiency, reduced ventilation in repair bays and vehicle corridor, transfer air from office to repair bays • Cool roofs for climate zones 1-5
Low Energy Package 2	• Low Energy Package 1 plus the installation of TSCs on south façade
Low Energy Package 3	• Low Energy Package 1 plus the installation of radiant floors in the repair bays and vehicle corridor
Low Energy Package 4	• Low Energy Package 1 plus the installation of both TSCs on the south façade and radiant floors in the repair bays and vehicle corridor

Results showing EUI and percent savings are presented in Table 5.11and Table 5.12 below. Baseline modeling assumptions were taken from the drawings for the Vehicle Maintenance Shop 7th Transportation Battalion PN-20807, FY10 for Fort Bragg, North Carolina.

Table 5.11 TEMF Site EUI for Each Low Energy Package

Site Energy [kBtu/ft2]	Baseline	Low Energy Package 1	Low Energy Package 2	Low Energy Package 3	Low Energy Package 4
1A Miami	27	15	15	16	16
2A Houston	33	20	19	20	19
2B Phoenix	31	19	19	20	19
3A Memphis	41	21	20	22	20
3B El Paso	36	19	19	19	19
3C San Francisco	32	18	18	17	16
4A Baltimore	55	25	23	25	23
4B Albuquerque	46	21	20	21	20
4C Seattle	51	23	21	23	22
5A Chicago	68	29	27	29	27
5B Colorado Springs	58	25	22	25	22
6A Burlington	78	33	30	33	30
6B Helena	74	31	28	30	28
7A Duluth	94	40	35	39	35
8A Fairbanks	138	63	59	59	56

Table 5.12 Site Energy Savings of Each Low Energy Package Compared to the TEMF Baseline EUI

Site Energy Savings Compared to Baseline [%]	Low Energy Package 1	Low Energy Package 2	Low Energy Package 3	Low Energy Package 4
1A Miami	43%	43%	38%	39%
2A Houston	39%	41%	40%	42%
2B Phoenix	39%	40%	37%	39%
3A Memphis	48%	51%	48%	51%
3B El Paso	46%	48%	46%	48%
3C San Francisco	43%	45%	47%	49%
4A Baltimore	55%	59%	55%	58%
4B Albuquerque	54%	58%	54%	57%
4C Seattle	55%	58%	55%	57%
5A Chicago	57%	61%	57%	60%
5B Colorado Springs	56%	62%	56%	61%
6A Burlington	58%	62%	58%	62%
6B Helena	59%	63%	59%	62%
7A Duluth	58%	63%	59%	63%
8A Fairbanks	55%	57%	57%	59%

The highlighted packages in Table 5.12 were chosen as recommended low-energy packages for each climate zone. The recommendations were based upon the level of energy savings and a rough assumption on cost for TSCs and radiant floors. Achieving the highest amount of energy savings was the goal for this project. However, for climate zones 4A through 7A, the decision to install radiant floors along with TSCs was made to increase occupant comfort in the repair bays and vehicle corridor, even though the option shows slightly lower energy savings when compared to Low Energy Package 2. It is also important to note that passive house insulation levels are not recommended for all climate zones. Climate zones 1A though 2B and 3C did not show significant savings from the specified passive house insulation levels, and thus the measure was excluded from the respective low-energy model packages. However, it is recommended that that a more detailed analysis investigating insulation levels, cost, and energy savings be conducted to fine-tune and optimize the level of insulation needed for each climate zone.

Table 5.13 compares the Low Energy Package site EUI to the CBECS 2003 targets for the Other Repair Service category. Fourteen out of the 15 climate zones meet the CBECS site targets (noted in red).

Table 5.13 TEMF Site Energy Savings of Low Energy Package Models to CBECS 2003 "Other Service" Data

Site Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Site Energy EUI (Other Service)	65% Reduction - CBECS 2003 Target EUI [kBtu/ft2]	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	85	30	15	82%
2A Houston	84	29	19	77%
2B Phoenix	82	29	19	77%
3A Memphis	84	29	21	75%
3B El Paso	79	28	19	76%
3C San Francisco	76	27	16	79%
4A Baltimore	93	33	24	74%
4B Albuquerque	83	29	21	75%
4C Seattle	86	30	23	73%
5A Chicago	100	35	29	71%
5B Colorado Springs	90	32	24	73%
6A Burlington	111	39	33	70%
6B Helena	101	35	30	70%
7A Duluth	119	42	39	67%
8A Fairbanks	158	55	63	60%

The source EUI for the recommended Low Energy Packages per climate zone was compared to source energy data from CBECS 2003 for "Other Service" building types to meet EISA 2007 requirements. This comparison is shown in Table 5.13. All 15 climate zones reach or are within 5 percent of the CBECS targets (noted in red).

Table 5.14 TEMF Source Energy Savings of Low Energy Package Models to CBECS 2003 "Other Service" Data

Source Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Source Energy EUI (Other Service)	65% Reduction - CBECS 2003 Target EUI [kBtu/ft2]	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	325	71	49	85%
2A Houston	198	65	54	73%
2B Phoenix	208	53	56	73%
3A Memphis	180	56	59	67%
3B El Paso	158	51	58	63%
3C San Francisco	160	48	46	71%
4A Baltimore	187	57	59	68%
4B Albuquerque	182	40	56	69%
4C Seattle	172	41	56	68%
5A Chicago	207	58	61	71%
5B Colorado Springs	201	56	57	72%
6A Burlington	226	66	63	72%
6B Helena	218	52	62	72%
7A Duluth	242	63	67	72%
8A Fairbanks	317	79	91	71%

5.1.3 COF

For the COF, the “Government Office” and “Other Public Assembly” categories were chosen from 2003 CBECS data. Government Office represented the administrative office space portion of the COF and Other Public Assembly represented the readiness bays. The EEMs considered for the COF were analyzed individually, and the EEMs with the highest energy savings were chosen to be included in a low-energy “package” for each climate zone. This follows the same path as the UEPH and TEMF analyses. Reduced lighting power density, increased daylighting, control strategies for lighting and daylighting, and passive house insulation levels were recommended for each climate zone. High-efficiency HVAC equipment and VAV fans were also recommended for each climate zone, as well as “cool roof” construction for climate zones 1A through 3B.

For the readiness bays alone, energy recovery ventilators were recommended for climate zones 1A, 2A, 3A, and 3C to 4B. DOASs, energy recovery ventilators and fan coils were recommended for climate zones 2B and 3B, and indirect evaporative cooling was recommended for climate zones 4C to 8A. Lastly, an alternative construction design was also explored for the readiness bays, which reduced the volume of conditioned air in each module. Energy savings from this efficiency measure was significant, ranging between 16 percent and 34 percent for the readiness bays alone. However, a drastic change in the design of these modules may conflict with current Army regulations on building form and geometry, and it is recommended that this efficiency measure be examined in more depth.

The administration building followed the same HVAC efficiency measures as those considered for the Bde HQ study, because the buildings are similar in form and function. These efficiency measures include energy recovery ventilators for climate zones 1A to 4B, and indirect evaporative cooling for 4C to 8A. The Low Energy Packages considered in this study are summarized below in Table 5.8.

Table 5.15 Description of Low Energy Packages for the COF

COF	Energy Efficiency Measures
Low Energy Package 1	• **Readiness bays only:** o Increased daylighting, daylighting and occupancy controls, and reduced lighting power density o Passive House insulation for all climate zones o Cool roof for climate zones 1A-3B o VAV fans, increased fan and HVAC efficiency o ERV in climate zones 1A, 2A, 3A, 3C-4B o IDEC in climate zones 4C-8A, o DOAS, ERV, and fan coils in climate zones 2B and 3B • **Administration Building follows Bde HQ measures**
Low Energy Package 2	• **Whole building – Low Energy Package 1 with the following applied to the administration building:** o Increased daylighting, daylighting and occupancy controls, and reduced lighting power density o VAV fans, increased fan and HVAC efficiency o ERV in climate zones 1A-4B o IDEC in climate zones 4C-8A
Low Energy Package 3	• **Whole Building:** o Low Energy Package 2 with a reduced air volume alternate construction applied to the readiness bays

Three low-energy packages were modeled and compared to baseline building models for all 15 climate zones. Low Energy Package 1 includes EEMs for the readiness bays alone, and was compared to a baseline building model consisting of just the readiness bays. The approach to isolate the readiness bays was chosen so that design options for these modules could be examined and optimized without the influence of the administration building. Low Energy Packages 2 and 3 include EEMs for the entire building, including both the administration building and the readiness bays. Table 5.16 compares the Low Energy Packages with the baseline building models.

The baseline building envelope features were modeled as steel frame wall construction, roof insulation entirely above deck, and door and fenestration types from ASHRAE 90.1-2007. Recommended building insulation levels follow the passive house standard and are noted in Table 4.1. With passive house insulation values, infiltration rates were assumed to fall from 0.4 cfm/ft^2 to 0.15 cfm/ft^2 throughout the building. Results showing EUI and percent savings are presented in Tables 5.16 and Table 5.17 below.

Table 5.16 COF Site EUI for Each Low Energy Package

Site Energy [kBtu/ft2]	Baseline	Baseline - Readiness Bays Only	Low Energy Package 1 - Readiness Bays Only	Low Energy Package 2 - Whole Building	Low Energy Package 3 - Whole Building w/Alternate Construction
1A Miami	58	47	27	29	23
2A Houston	62	53	26	30	24
2B Phoenix	60	48	32	35	29
3A Memphis	72	60	26	30	25
3B El Paso	59	48	31	34	29
3C San Francisco	54	43	20	25	21
4A Baltimore	78	70	25	29	25
4B Albuquerque	67	57	21	26	21
4C Seattle	68	57	21	26	23
5A Chicago	94	83	24	29	25
5B Colorado Springs	79	69	20	25	21
6A Burlington	103	92	24	29	25
6B Helena	94	83	22	27	23
7A Duluth	117	108	24	30	26
8A Fairbanks	163	152	32	37	33

Table 5.17 COF Site Energy Savings of Each Low Energy Package Compared to the Baseline EUI

Site Energy Savings Compared to Baseline [%]	Low Energy Package 1 - Readiness Bays Only	Low Energy Package 2 - Whole Building	Low Energy Package 3 - Whole Building w/Alternate Construction Applied to Repair Bays
1A Miami	43%	50%	60%
2A Houston	51%	52%	61%
2B Phoenix	34%	42%	52%
3A Memphis	57%	58%	65%
3B El Paso	36%	42%	50%
3C San Francisco	53%	54%	61%
4A Baltimore	65%	62%	68%
4B Albuquerque	63%	62%	69%
4C Seattle	63%	62%	67%
5A Chicago	71%	69%	73%
5B Colorado Springs	70%	68%	73%
6A Burlington	74%	72%	76%
6B Helena	73%	71%	75%
7A Duluth	77%	75%	78%
8A Fairbanks	79%	77%	80%

The readiness bays were modeled separately from the whole building design (which includes the readiness bays and the administration building) because the administration building is similar in form and function to the Bde HQ, and studies have already been conducted to optimize the Bde HQ design. Tables 5.16 and 5.17 presents results for three packages. The change in construction to the readiness bays as modeled in EnergyPlus is shown in Figure 4.1. The results show that significant energy savings can be achieved by any of the three packages that were modeled.

To complete a comparison between the low-energy buildings and the CBECS 2003 building, a new CBECS-equivalent value was necessary because the administration building and readiness bays have different EUIs. A blended or mixed CBECS EUI value was calculated assuming a 50-50 mix of the two building types. The new source EUIs were calculated by applying conversion factors (3.35 for electricity and 1.05 for gas) to each portion of site electricity and site gas of the whole building baseline model. Table 5.18 shows the site CBECs EUI values for each building type plus the new hybrid site and source values, as well as the breakdown of electricity and gas of the baseline whole building for each climate zone.

Table 5.18 COF Site and Source Whole Building CBECS Values

				Whole Building Site Energy		
CBECS Values for Whole Building EUI Calculation [kBtu/ft2]	**CBECS 2003 Site Energy EUI Government Office**	**CBECS 2003 Site Energy EUI Other Public Assembly**	**CBECS 2003 Site New Whole Building**	**% Electricity**	**% Gas**	**New Source Values for**
1A Miami	73	40	56	78%	22%	160
2A Houston	75	40	57	63%	37%	143
2B Phoenix	73	38	56	71%	29%	149
3A Memphis	71	39	55	51%	49%	122
3B El Paso	66	37	52	57%	43%	121
3C San Francisco	65	36	50	46%	54%	106
4A Baltimore	79	43	61	38%	62%	118
4B Albuquerque	68	39	53	45%	55%	111
4C Seattle	72	40	56	36%	64%	105
5A Chicago	85	47	66	34%	66%	121
5B Colorado Springs	73	42	57	37%	63%	109
6A Burlington	94	52	73	29%	71%	125
6B Helena	83	47	65	32%	68%	116
7A Duluth	98	56	77	24%	76%	123
8A Fairbanks	133	74	104	21%	79%	159

The source EUI for the lowest energy package (package 3) per climate zone was compared to the new blended CBECS EUIs. This comparison is shown in Table 5.19. None of the 15 climate zones reaches or is within 5 percent of the CBECS targets.

Table 5.19 COF Source Energy Savings of Low Energy Package Whole Building Models Compared to the Blended CBECS 2003 EUIs

Source Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Source Energy EUI ((Whole Building - Government Office + Other Public	65% Reduction - CBECS 2003 Target EUI	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	160	56	74	54%
2A Houston	143	50	69	52%
2B Phoenix	149	52	80	46%
3A Memphis	122	43	69	44%
3B El Paso	121	42	72	41%
3C San Francisco	106	37	54	49%
4A Baltimore	118	41	64	46%
4B Albuquerque	111	39	56	50%
4C Seattle	105	37	51	51%
5A Chicago	121	42	62	49%
5B Colorado Springs	109	38	52	52%
6A Burlington	125	44	58	54%
6B Helena	116	41	54	54%
7A Duluth	123	43	57	54%
8A Fairbanks	159	55	64	60%

5.1.4 Bde HQ

For the Bde HQ, the “Government Office” category was chosen from the 2003 CBECS data. Annual EUI for each climate zone was determined from the CBECS data and compared to the energy baseline for the designed building. This theoretical study was designed to give guidance on the direction and limitations for this building type. It showed that the internal loads are very important to address and will limit the building designer’s ability to meet the EISA 2007 requirements. The source of the fuels to produce the energy is also very important and ultimately will need a mix of efficient generation.

It is noteworthy to mention that predicted energy savings strongly depend upon the climate and building orientation, and will vary for specific building design. However, implementation of developed energy budgets and sets of technologies included in the prescriptive path, and allowed to streamline and reduce the cost of facility design and construction process, will ensure that newly constructed facilities comply with the intent of EPACT 2005 and EISA 2007 without jeopardizing the facilities’ functional quality.

Addition of the passive house insulation package and airtightness specifications reduces the loads on the HVAC systems and reduces the impact for the type of system selected. Therefore, the HVAC system can be selected using multiple criteria with energy efficiency gains along with ease of O&M and installation preference.

With this study, the targets are based on source fuels, not on site energy consumption. This changes the benefits of the different HVAC and plant technologies selected. When looking just at site energy, GSHPs can look like an attractive selection until you take into account the regional source fuels. When the calculation is made back to the source fuels, many of the gains of using GSHPs are negated and in some locations they use more source fuel.

The simulated results for the Bde HQ energy efficient designs, including the envelope, infiltration, lighting, equipment, and HVAC EEMs, are shown in the tables below with the cumulative percentage savings for each Low Energy Package. In Table 5.20, Low Energy Packages P1–P3 are applied cumulatively to the baseline building until Package P4, which is considered the standard high-performance or low-energy building (P1-P4). Then, Low Energy Packages P5–P13 are applied to P4 to compare the different HVAC alternatives in the same way as the UEPH. The results are shown for both site and source, where the source results are necessary for EISA 2007 compliance. The site results are shown for direct comparison to CBECS data.

Table 5.20 Site Bde HQ Results

Site Energy Totals with Plug Loads [kBtu/ft2]	2003 CBECS Government Office	CBECS Site Budget	Baseline Building	Low Energy Package 1												
			B	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1A Miami	73	26	61	58	48	45	37	36	35	44	44	44	38	44	35	33
2A Houston	75	26	55	52	44	39	33	33	32	40	40	40	35	40	33	30
2B Phoenix	73	26	67	64	54	45	37	37	27	38	38	37	35	37	33	31
3A Memphis	71	25	54	52	46	37	32	31	31	38	38	38	34	37	32	29
3B El Paso	66	23	47	45	38	34	30	30	26	35	35	34	32	32	31	29
3C San Francisco	65	23	38	36	30	28	27	27	26	32	33	32	32	32	30	26
4A Baltimore	79	28	54	52	47	33	30	29	29	36	35	36	32	34	31	28
4B Albuquerque	68	24	50	48	42	32	29	29	26	33	33	33	31	30	31	28
4C Seattle	72	25	42	41	37	28	26	26	26	32	32	32	32	30	30	26
5A Chicago	85	30	59	57	53	34	30	29	30	36	35	36	32	33	31	28
5B Colorado Springs	73	26	50	49	44	31	28	28	26	33	32	33	30	29	30	28
6A Burlington	94	33	60	58	55	33	30	27	29	36	33	36	31	32	30	27
6B Helena	83	29	56	55	51	31	29	27	27	34	32	34	30	29	30	27
7A Duluth	98	34	67	65	63	34	31	28	31	36	33	36	31	31	31	27
8A Fairbanks	133	47	88	87	85	43	37	31	36	41	35	41	34	33	32	29

B	Baseline Energy Budget
P1	Lighting Load and Electric Power Load Density Reduction from 1.67 W/ft^2 to 0.835 W/ft^2 applied to B
P2	Reduced Electric Power Load Density from 1.7 W/ft^2 to 1.2 W/ft^2 in the Office Areas average for all spaces
P3	Passive Haus Specification; Increased Insulation, Advanced Windows and Air Tightness, reduce OA pressurization air due to air tightness
P4	Efficient VAV Sys: Increase Chiller and Boiler Efficiencies and all variable high efficiency pumps and fans.
P5	Energy Recovery [ERV] and VAV with P4
P6	Indirect evaporative pre-cooling (IDEC) and VAV with P4
P7	Dedicated Outdoor Air System (DOAS) with P4
P8	DOAS and ERV with P4
P9	DOAS and IDEC with P4
P10	DOAS, IDEC and radiant heating and cooling with V4
P11	DOAS, ERV and free cooling chiller with P4
P12	DOAS, ERV and Ground Source Heat Pump (GSHP) with P4
P13	GSHP, ERV and VAV with P4

Table 5.21 Site Bde HQ Cumulative Results

Bde HQ	Cumulative % Savings (Site)												
	P1-B	P2-P1	P3-P2	P4-P3	P5-P4	P6-P4	P7-P4	P8-P4	P9-P4	P10-P4	P11-P4	P12-P4	P13-P4
1A Miami	-5%	-21%	-26%	-38%	-40%	-42%	-27%	-27%	-28%	-38%	-27%	-43%	-46%
2A Houston	-4%	-19%	-29%	-39%	-40%	-42%	-26%	-26%	-28%	-35%	-28%	-40%	-45%
2B Phoenix	-4%	-18%	-33%	-44%	-45%	-59%	-43%	-43%	-45%	-48%	-45%	-50%	-54%
3A Memphis	-4%	-16%	-33%	-41%	-43%	-44%	-29%	-30%	-30%	-37%	-33%	-41%	-47%
3B El Paso	-5%	-20%	-28%	-36%	-37%	-44%	-26%	-26%	-27%	-31%	-31%	-33%	-39%
3C San Francisco	-5%	-23%	-26%	-30%	-28%	-33%	-16%	-14%	-16%	-18%	-17%	-21%	-31%
4A Baltimore	-3%	-13%	-38%	-44%	-46%	-46%	-33%	-35%	-33%	-40%	-38%	-42%	-48%
4B Albuquerque	-4%	-16%	-35%	-41%	-41%	-48%	-33%	-34%	-33%	-38%	-39%	-38%	-44%
4C Seattle	-3%	-13%	-35%	-38%	-39%	-39%	-24%	-25%	-24%	-24%	-29%	-30%	-39%
5A Chicago	-2%	-10%	-42%	-48%	-51%	-49%	-38%	-41%	-38%	-45%	-44%	-48%	-52%
5B Colorado Springs	-3%	-13%	-39%	-44%	-45%	-48%	-34%	-37%	-35%	-40%	-42%	-40%	-45%
6A Burlington	-2%	-8%	-45%	-50%	-54%	-51%	-40%	-44%	-40%	-48%	-47%	-49%	-54%
6B Helena	-2%	-9%	-44%	-49%	-51%	-52%	-39%	-43%	-40%	-46%	-48%	-46%	-51%
7A Duluth	-2%	-6%	-48%	-54%	-58%	-54%	-45%	-51%	-45%	-53%	-53%	-54%	-59%
8A Fairbanks	-1%	-3%	-51%	-58%	-64%	-59%	-53%	-60%	-53%	-61%	-62%	-64%	-67%
Avg % Savings	-3%	-14%	-37%	-44%	-46%	-47%	-34%	-36%	-34%	-40%	-39%	-43%	-48%

As can be seen from Table 5.21, the initial Low Energy Packages show good improvement and the selected packages for closer evaluation were P5, P6, and P13. Even with all of these EEMs applied to the individual building, the targets could not be achieved.

Table 5.22 Source Energy Use Intensities for Each EEM Package with Cumulative Percent Savings

Bde HQ	Cumulative % Savings (Source)												
	P1-B	P2-P1	P3-P2	P4-P3	P5-P4	P6-P4	P7-P4	P8-P4	P9-P4	P10-P4	P11-P4	P12-P4	P13-P4
1A Miami	-5%	-21%	-26%	-38%	-40%	-42%	-27%	-27%	-28%	-38%	-27%	-43%	-46%
2A Houston	-5%	-21%	-28%	-38%	-39%	-41%	-25%	-25%	-26%	-34%	-26%	-39%	-44%
2B Phoenix	-4%	-19%	-32%	-44%	-44%	-59%	-43%	-42%	-45%	-48%	-45%	-50%	-54%
3A Memphis	-4%	-20%	-29%	-38%	-39%	-41%	-26%	-25%	-27%	-33%	-28%	-37%	-43%
3B El Paso	-5%	-23%	-27%	-34%	-35%	-43%	-25%	-24%	-26%	-30%	-30%	-32%	-37%
3C San Francisco	-6%	-25%	-25%	-29%	-27%	-32%	-14%	-12%	-15%	-16%	-16%	-19%	-30%
4A Baltimore	-4%	-20%	-31%	-37%	-38%	-40%	-25%	-25%	-25%	-31%	-28%	-33%	-40%
4B Albuquerque	-5%	-22%	-30%	-37%	-36%	-45%	-28%	-29%	-29%	-32%	-34%	-33%	-39%
4C Seattle	-5%	-21%	-29%	-32%	-32%	-33%	-17%	-16%	-17%	-17%	-21%	-21%	-31%
5A Chicago	-4%	-19%	-33%	-39%	-40%	-40%	-27%	-27%	-27%	-33%	-30%	-34%	-40%
5B Colorado Springs	-5%	-21%	-31%	-36%	-36%	-42%	-26%	-27%	-26%	-30%	-33%	-30%	-36%
6A Burlington	-4%	-18%	-34%	-39%	-40%	-40%	-26%	-28%	-27%	-32%	-31%	-32%	-39%
6B Helena	-4%	-19%	-34%	-38%	-38%	-42%	-27%	-29%	-28%	-32%	-35%	-31%	-38%
7A Duluth	-4%	-16%	-37%	-41%	-43%	-41%	-29%	-31%	-30%	-35%	-35%	-33%	-40%
8A Fairbanks	-3%	-13%	-40%	-45%	-48%	-46%	-37%	-41%	-37%	-43%	-44%	-39%	-45%
Avg % Savings	-5%	-20%	-31%	-38%	-38%	-42%	-27%	-27%	-28%	-32%	-31%	-34%	-40%

An interesting result is that when source fuels are calculated for the EEMs, the savings from GSHPs are not good as expected because many of the advantages are not there when the source fuels for electricity generation are considered.

The Bde HQ is a mixed-use building composed of an office building portion and a data center. CBECS only has EUI values for an office building. The data center represents approximately 17.5 percent of the total area. CBECS only has EUI values for an office building. If an EUI existed in CBECS for a data center, that value would be have been used for that percentage of the building. In this case, the decision was made to make the other 82.5% of the building comply and then use the same EEM's for the data center portion assuming that it would be the best possible path for that part of the building as well. As a result, data center specific EEMs were not developed since the office portion represents the dominant portion of the building's area.

For a more direct comparison and to account for the data center portion of the Bde HQ building, the simulation results were broken out into a data center in addition to the administrative office section. The data center section is labeled NOC/BOC/SCIF. As can be seen in Table 5.23, the NOC/BOC/SCIF EUIs are much higher than the EUIs from the "Government Office" CBECS category. This presents an added challenge to meeting EISA 2007 targets.

Table 5.23 Source Results for NOC/BOC/SCIF

Source Energy Totals with Plug Loads [kBtu/ft2]	2003 CBECS Government Office	CBECS Source Budget	Baseline Building	Low Energy Package 1												
			B	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1A Miami	203	85	553	546	546	530	470	471	463	497	499	495	421	499	491	490
2A Houston	198	85	510	504	504	493	445	449	438	489	491	488	415	478	474	458
2B Phoenix	193	84	603	594	594	572	497	514	411	472	475	471	411	463	478	470
3A Memphis	183	76	483	477	477	468	429	435	421	488	490	488	413	463	466	437
3B El Paso	160	74	471	465	465	462	426	433	394	464	467	464	403	440	462	439
3C San Francisco	163	73	441	435	435	440	410	448	400	448	451	447	400	446	451	424
4A Baltimore	188	78	449	444	444	440	410	417	403	478	479	478	407	441	459	421
4B Albuquerque	170	72	482	475	475	475	434	449	388	452	454	451	400	422	455	427
4C Seattle	168	73	404	399	399	403	387	397	382	447	449	447	395	427	449	401
5A Chicago	185	77	437	431	431	428	403	410	398	477	477	477	405	432	456	412
5B Colorado Springs	170	72	449	443	443	445	415	430	380	449	450	448	398	413	452	414
6A Burlington	194	81	420	414	414	413	393	400	388	466	465	466	400	419	452	404
6B Helena	178	74	429	423	423	425	401	416	373	452	452	452	398	409	450	402
7A Duluth	193	77	409	404	404	403	387	393	384	462	461	461	398	410	451	396
8A Fairbanks	228	91	407	402	402	406	389	399	376	449	447	449	394	398	446	390

Table 5.24 and Table 5.25 show the site and source results of combining the administrative office section of the Bde HQ and the NOC/BOC/SCIF section. The results for the combined or hybrid building are not as good as the office building alone because now the high internal loads due to the NOC/BOC/SCIF or data center are accounted for.

Table 5.24 Site Results for Combined Office and NOC/BOC/SCIF

Site Energy Totals with Plug Loads [kBtu/ft2]	2003 CBECS Government Office	CBECS Site Budget	Baseline Building	Low Energy Package 1												
			B	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1A Miami	73	26	83	81	76	72	61	60	59	71	71	70	56	71	56	56
2A Houston	75	26	75	73	69	64	55	56	54	66	66	66	54	65	54	52
2B Phoenix	73	26	91	89	83	75	63	64	47	63	63	62	53	61	54	52
3A Memphis	71	25	72	71	67	59	53	53	51	64	63	64	53	61	52	49
3B El Paso	66	23	66	64	60	57	51	52	45	59	59	59	51	56	52	49
3C San Francisco	65	23	55	53	49	49	46	50	44	56	56	56	50	55	50	46
4A Baltimore	79	28	70	69	66	54	49	50	48	61	60	60	52	57	51	47
4B Albuquerque	68	24	68	66	63	56	51	52	43	57	56	57	50	52	51	47
4C Seattle	72	25	56	55	52	46	44	45	43	55	55	55	49	52	49	44
5A Chicago	85	30	73	72	70	54	49	49	48	60	59	60	52	55	51	46
5B Colorado Springs	73	26	66	64	61	52	48	49	43	56	55	56	50	51	51	46
6A Burlington	94	33	73	72	70	51	47	47	46	59	57	59	50	53	50	45
6B Helena	83	29	69	68	66	50	47	47	43	57	55	57	50	50	50	45
7A Duluth	98	34	78	77	75	51	47	46	47	58	56	58	50	51	50	45
8A Fairbanks	133	47	97	96	95	59	52	48	51	60	55	60	52	51	50	45

Table 5.25 Source Results for Combined Office and NOC/BOC/SCIF

Source Energy Totals with Plug Loads [kBtu/ft2]	2003 CBECS Government Office	CBECS Source Budget	Baseline Building	Low Energy Package 1												
			B	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1A Miami	203	85	278	271	252	239	202	200	195	237	236	234	185	237	188	185
2A Houston	198	85	246	239	223	211	183	184	177	219	219	217	180	216	179	172
2B Phoenix	193	84	302	294	274	249	208	212	157	208	209	205	177	204	180	173
3A Memphis	183	76	230	224	209	196	174	176	167	210	210	209	177	203	174	163
3B El Paso	160	74	214	208	193	188	169	172	149	196	197	195	170	187	173	164
3C San Francisco	163	73	179	174	159	164	152	165	147	184	186	184	167	184	166	152
4A Baltimore	188	78	210	205	192	177	161	164	156	198	198	197	171	187	169	156
4B Albuquerque	170	72	214	209	194	185	167	173	143	186	186	186	167	174	170	156
4C Seattle	168	73	173	168	156	151	144	150	141	181	181	181	161	172	164	146
5A Chicago	185	77	208	203	190	171	158	160	154	194	193	193	169	181	167	153
5B Colorado Springs	170	72	198	192	179	170	157	162	140	182	182	182	164	167	168	151
6A Burlington	194	81	198	193	181	162	151	153	148	187	186	187	165	172	165	149
6B Helena	178	74	195	190	178	161	151	156	139	182	181	182	164	165	166	148
7A Duluth	193	77	197	193	182	157	148	149	146	184	181	183	163	166	165	147
8A Fairbanks	228	91	215	211	201	163	152	151	147	179	174	179	162	160	166	149

After reviewing the data with the COS for the Bde HQ and cost estimators, P5, P6, and P13 were selected in addition to the baseline Low Energy Package 4 for full cost estimates. Following the same methodology for the other buildings, these selections were made based on balancing good energy savings results with possible issues with maintenance of newer technologies and a high first cost or lack of availability of systems to be supplied by three or more vendors. For simplification purposes, P4, P5, P6, and P13 are renamed Low Energy Package 1–4 in the tables that follow.

Table 5.26 Description of Low Energy Packages for the Brigade Headquarters (Bde HQ)

Bde HQ	Energy Efficiency Measures
Low Energy Package 1 (P1-P4)	• Passive house insulation, windows– applied to whole building. Reduced infiltration rates from 0.4 cfm/ft^2 to 0.15 cfm/ft^2 Reduced lighting power densities • High efficiency fixtures to reduce hot water demand includes: 0.5-gpm flow faucets, 1.5-gpm flow shower heads Advanced HVAC system: o Dedicated outside air system (DOAS) for ventilation, o Improved chiller and boiler efficiencies, o All variable high-efficiency pumps and fans, o Pressurization and make-up air, o Condenser heat recovery for DOAS o Separate ventilation for living area and laundry facilities
Low Energy Package 2 (P5)	• Same as Low Energy Package 1 plus adding total energy recovery (ERV) unit at 80% effectiveness
Low Energy Package 3 (P6)	• Same as Low Energy Package 2 with indirect evaporative cooling (IDEC)
Low Energy Package 4 (P13)	• Same as Low Energy Package 2 except replace high-efficiency chiller and boiler with a ground-source heat pump system

The source EUI for the lowest energy package (lowest of the four packages) per climate zone was compared to the 2003 CBECS EUIs for "Government Office" category. None of the 15 climate zones reaches or is within 5 percent of the CBECS targets. Buildings with high internal energy loads are dominate by internal loads when built or retrofitted to passive house requirements. These buildings use advanced "low-energy" systems to satisfy remaining heating and cooling needs. This same phenomenon happens to low internal load buildings as well. Therefore, we see that both the administrative office portion and the NOC/BOC/SCIF portion end up being internal load dominated. The remaining energy requirements will be dominated by electrical power needs for lighting, appliances and internal processes, and by domestic hot water needs. Table 5.27 summarizes the improvements made towards EISA 2007 goals and shows that without considering further internal load reduction, the EISA 2007 targets cannot be met for the full building.

Table 5.27 Source Energy Savings of Low Energy Package Models to 2003 CBECS Government Office Data

Source Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Source Energy EUI (Government Office)	65% Reduction - CBECS 2003 Target EUI [kBtu/ft2]	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	203	71	185	9%
2A Houston	198	69	172	13%
2B Phoenix	193	68	157	19%
3A Memphis	183	64	163	11%
3B El Paso	160	56	149	7%
3C San Francisco	163	57	147	10%
4A Baltimore	188	66	156	17%
4B Albuquerque	170	59	143	16%
4C Seattle	168	59	141	16%
5A Chicago	185	65	153	17%
5B Colorado Springs	170	59	140	18%
6A Burlington	194	68	148	24%
6B Helena	178	62	139	22%
7A Duluth	193	68	146	24%
8A Fairbanks	228	80	147	35%

The results are much better when removing the NOC/BOC/SCIF section from the Bde HQ building. Table 5.28 shows that even though EISA 2007 targets cannot be met even when the administrative office results are broken out the results are much closer to the 65 percent target.

Table 5.28 Bde HQ Office Source Energy Savings of Low Energy Package Models to 2003 CBECS Government Office Data

Source Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Source Energy EUI (Government Office)	65% Reduction - CBECS 2003 Target EUI [kBtu/ft2]	Low Energy Model EUI [kBtu/ft2]	% Difference of Low Energy from CBECS 2003
1A Miami	203	71	108	47%
2A Houston	198	69	99	50%
2B Phoenix	193	68	90	53%
3A Memphis	183	64	95	48%
3B El Paso	160	56	86	47%
3C San Francisco	163	57	84	49%
4A Baltimore	188	66	91	52%
4B Albuquerque	170	59	83	51%
4C Seattle	168	59	82	51%
5A Chicago	185	65	91	51%
5B Colorado Springs	170	59	82	52%
6A Burlington	194	68	88	55%
6B Helena	178	62	83	54%
7A Duluth	193	68	86	55%
8A Fairbanks	228	80	90	61%

With EISA 2007, the total energy usage (building plus plug loads) of the building is now considered unlike EPACT 2005 where the plug loads were considered unregulated. Including plug loads in the energy usage calculations creates a significant energy usage that may be outside the control of the designers and constructors of the building. This is illustrated in the comparison of the combined office and NOC/BOC/SCIF and just the office section, which shows that the plug loads are the most significant and uncontrolled percentage of the total energy consumed. The building envelope and HVAC systems efficiency gains will reach a theoretical minimum with the largest percentage remaining in the building due to the "mission" of the building: lighting, equipment, and domestic hot water usage. The next steps will to look at understanding these loads and make further energy efficiency increases and reductions in these areas.

5.1.5 DFAC

For the DFAC, the "Fast Food" category was chosen from 2003 CBECS data. Annual energy use intensity for each climate zone was determined from the CBECS data and compared to the energy baseline for the designed building.

The EEMs considered for the DFAC were analyzed individually, and EEMs with the highest energy savings were chosen to be included in a Low Energy Package for each climate zone. Reduced lighting power density, daylighting, and control strategies for both lighting and daylighting were recommended for each climate zone, along with passive house insulation for climate zones 4A through 8A. Efficiency upgrades in the HVAC system were also recommended, as well as a number of EEMs associated with the kitchen equipment. A set of best-in-class, high-efficiency kitchen equipment upgrades were paired with exhaust hood design and control options to reduce cooking, fan, and HVAC energy. Demand control ventilation (DCV) on the make-up air units (MAUs) were also explored, as well as an all-electric kitchen equipment option. Each Low Energy Package is summarized below in Table 5.29.

Table 5.29 Summary of Low Energy Packages for the DFAC

DFAC	EEMs
Low Energy Package 1	• Increased daylighting, daylighting and occupancy controls, and reduced lighting power density • Passive House insulation for climate zones 4A-8A • VAV fans, increased fan and HVAC efficiency, reduced exhaust hood ventilation • High efficiency kitchen equipment
Low Energy Package 2	• Package 1 with demand control ventilation on make-up air units
Low Energy Package 3	• Package 1 with all-electric, high-efficiency kitchen equipment
Low Energy Package 4	• Package 3 with demand control ventilation on make-up air units

Results showing EUI and percent savings are presented in Table 5.30 and Table 5.31 below.

Table 5.30 DFAC Site Energy Use Intensity for Each Low Energy Package

Site Energy [kBtu/ft2]	Baseline	Low Energy Package 1	Low Energy Package 2	Low Energy Package 3	Low Energy Package 4
1A Miami	354	272	268	227	221
2A Houston	373	297	287	256	243
2B Phoenix	363	287	277	248	235
3A Memphis	394	322	307	286	267
3B El Paso	369	297	284	259	243
3C San Francisco	359	297	281	257	239
4A Baltimore	428	356	336	323	297
4B Albuquerque	396	327	309	292	270
4C Seattle	402	337	316	304	278
5A Chicago	468	391	365	362	329
5B Colorado Springs	430	355	333	319	294
6A Burlington	509	425	393	399	359
6B Helena	481	399	369	369	335
7A Duluth	566	472	433	451	403
8A Fairbanks	730	606	547	593	525

Table 5.31 DFAC Site Energy Savings of Each Low Energy Package Compared to the Baseline EUI

Site Energy Savings Compared to Baseline [%]	Baseline [kBtu/ft2]	Low Energy Package 1	Low Energy Package 2	Low Energy Package 3	Low Energy Package 4
1A Miami	354	23%	24%	36%	38%
2A Houston	373	21%	23%	31%	35%
2B Phoenix	363	21%	24%	32%	35%
3A Memphis	394	18%	22%	27%	32%
3B El Paso	369	19%	23%	30%	34%
3C San Francisco	359	17%	22%	28%	33%
4A Baltimore	428	17%	22%	24%	31%
4B Albuquerque	396	17%	22%	26%	32%
4C Seattle	402	16%	21%	24%	31%
5A Chicago	468	17%	22%	23%	30%
5B Colorado Springs	430	18%	23%	26%	32%
6A Burlington	509	17%	23%	22%	29%
6B Helena	481	17%	23%	23%	30%
7A Duluth	566	17%	23%	20%	29%
8A Fairbanks	730	17%	25%	19%	28%

The highlighted packages in Table 5.31 were chosen as recommended energy packages per climate zone. For each case, the highest level of energy savings was associated with the packages including all-electric kitchen equipment and aggressive exhaust flow rate reduction strategies. Because plug and process loads make up a significant portion of the total building energy use, it is important to consider high-efficiency kitchen designs for these facilities. The all-electric kitchen equipment design also positions the facility to have the option to operate using 100 percent renewable energy.

Table 5.32 and Table 5.33 compare Low Energy Packages 2 and 4 site and source EUIs to the CBECS 2003 EUI targets for the “Fast Food” category. All of the low-energy model values fail to reach or get within 5 percent of the site and source CBECS targets. This illustrates the problem with selecting “Fast Food” as a building category to compare to a DFAC. Even though there was a significant decrease in energy consumption for the low-energy model compared to the baseline building, when comparing the low-energy model values to the fast food facility, the source values do not come close to meeting the targets.

Table 5.32 DFAC Site Energy Savings of Low Energy Package Models to CBECS 2003 Fast Food Data

Site Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Site Energy EUI (Fast Food)	65% Reduction - CBECS 2003 Target EUI	Low Energy Model Package 2	All Electric Low-Energy Model Package 4	Package 2: %Difference from CBECS 2003	Package 4: %Difference from CBECS 2003
1A Miami	377	132	268	221	29%	41%
2A Houston	387	135	287	243	26%	37%
2B Phoenix	380	133	277	235	27%	38%
3A Memphis	396	139	307	267	22%	33%
3B El Paso	381	133	284	243	26%	36%
3C San Francisco	370	130	281	239	24%	35%
4A Baltimore	430	151	336	297	22%	31%
4B Albuquerque	400	140	309	270	23%	32%
4C Seattle	406	142	316	278	22%	32%
5A Chicago	463	162	365	329	21%	29%
5B Colorado Springs	426	149	333	294	22%	31%
6A Burlington	503	176	393	359	22%	29%
6B Helena	467	163	369	335	21%	28%
7A Duluth	540	189	433	403	20%	25%
8A Fairbanks	669	234	547	525	18%	22%

Table 5.33 DFAC Source Energy Savings of Low Energy Package Models to CBECS 2003 Fast Food Data

Source Energy Savings Compared to Baseline [kBtu/ft2]	CBECS 2003 Source Energy EUI (Fast Food)	65% Reduction - CBECS 2003 Target EUI	Package 2: Low-Energy Model	Package 4: All Electric Low-Energy Model	Package 2: %Difference from CBECS 2003	Package 4: %Difference from CBECS 2003
1A Miami	1244	435	768	722	38%	42%
2A Houston	1212	424	752	721	38%	40%
2B Phoenix	1187	416	737	713	38%	40%
3A Memphis	1175	411	746	728	37%	38%
3B El Paso	1032	361	717	699	31%	32%
3C San Francisco	1161	406	677	669	42%	42%
4A Baltimore	1067	373	764	753	28%	29%
4B Albuquerque	1221	427	724	716	41%	41%
4C Seattle	1159	406	711	710	39%	39%
5A Chicago	1142	400	782	780	32%	32%
5B Colorado Springs	1256	440	754	748	40%	40%
6A Burlington	1188	416	800	805	33%	32%
6B Helena	1311	459	778	782	41%	40%
7A Duluth	1242	435	832	848	33%	32%
8A Fairbanks	1348	472	939	974	30%	28%

5.2 Square Footage Impact

Increased insulation levels on the exterior of the buildings to meet passive house requirements resulted in a direct impact on square footage. Most of the building types across the range of climate zones were shown to have an increase in gross square footage.

The tables below list increases in scope based on insulation being added to the exterior of the buildings.

- Note that the thickness of brick and the airspace is at least 0.35 ft. If the buildings that use brick were to replace the brick with an Exterior Insulation Finishing System rather than add to buildings material there would be no increase in scope for climate zones 1A through 6B.
- The UEPH does not have an overall building plan. It is difficult to establish the perimeter of the entire building, and layout may affect the scope. Depending on the enhanced HVAC package selected, the mechanical closets may not be required. This could reduce the scope by 9 ft2 per closet. For 112 soldiers there would be 56 closets freeing up 504 ft^2—that is as long as the closet space is not used for light tube space.
- 3C is not an error. This is the number derived from the climate zone information.

Table 5.34 UEPH Insulation Square Footage Impact

UEPH The UEPH is a three story building with each floor the same size. The perimeter of the building is 550 LF per floor. Perimeter of the upper floor is 1100 LF.					
Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	206
2B	1.5	3.0	1.5	0.13	206
3A	1.5	4.0	2.5	0.21	344
3B	1.5	4.0	2.5	0.21	344
3C	1.5	2.0	0.5	0.04	69
4A	1.5	5.0	3.5	0.29	481
4B	2.5	5.0	2.5	0.21	344
4C	2.5	4.0	1.5	0.13	206
5A	2.5	6.0	3.5	0.29	481
5B	2.5	6.0	3.5	0.29	481
6A	4.0	8.0	4.0	0.33	550
6B	4.0	8.0	4.0	0.33	550
7A	4.0	10.0	6.0	0.50	825
8A	4.0	12.0	8.0	0.67	1100

Table 5.35 TEMF Insulation Square Footage Impact

TEMF

The TEMF is a two story building. The majority of the scope is on the first floor. The ground floor has a perimeter of 830 LF. The second floor only covers a portion of the first floor. The second floor has 260 LF of exterior perimeter.

Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	136
2B	1.5	3.0	1.5	0.13	136
3A	1.5	4.0	2.5	0.21	227
3B	1.5	4.0	2.5	0.21	227
3C	1.5	2.0	0.5	0.04	45
4A	1.5	5.0	3.5	0.29	318
4B	2.5	5.0	2.5	0.21	227
4C	2.5	4.0	1.5	0.13	136
5A	2.5	6.0	3.5	0.29	318
5B	2.5	6.0	3.5	0.29	318
6A	4.0	8.0	4.0	0.33	363
6B	4.0	8.0	4.0	0.33	363
7A	4.0	10.0	6.0	0.50	545
8A	4.0	12.0	8.0	0.67	727

Table 5.36 COF Administrative Building A Insulation Square Footage Impact

COF Admin Building A

The COF Admin is a two-story building. Each floor is the same size, perimeter per floor is 388 LF.

Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	97
2B	1.5	3.0	1.5	0.13	97
3A	1.5	4.0	2.5	0.21	162
3B	1.5	4.0	2.5	0.21	162
3C	1.5	2.0	0.5	0.04	32
4A	1.5	5.0	3.5	0.29	226
4B	2.5	5.0	2.5	0.21	162
4C	2.5	4.0	1.5	0.13	97
5A	2.5	6.0	3.5	0.29	226
5B	2.5	6.0	3.5	0.29	226
6A	4.0	8.0	4.0	0.33	259
6B	4.0	8.0	4.0	0.33	259
7A	4.0	10.0	6.0	0.50	388
8A	4.0	12.0	8.0	0.67	517

Table 5.37 COF Readiness Building B Insulation Square Footage Impact

COF Readiness Building B

The COF readiness building is a partial two-story building. The majority of the scope is on the first floor. The ground floor has a perimeter of 918 LF. The second floor is a mezzanine and does not affect the perimeter.

Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	115
2B	1.5	3.0	1.5	0.13	115
3A	1.5	4.0	2.5	0.21	191
3B	1.5	4.0	2.5	0.21	191
3C	1.5	2.0	0.5	0.04	38
4A	1.5	5.0	3.5	0.29	268
4B	2.5	5.0	2.5	0.21	191
4C	2.5	4.0	1.5	0.13	115
5A	2.5	6.0	3.5	0.29	268
5B	2.5	6.0	3.5	0.29	268
6A	4.0	8.0	4.0	0.33	306
6B	4.0	8.0	4.0	0.33	306
7A	4.0	10.0	6.0	0.50	459
8A	4.0	12.0	8.0	0.67	612

Table 5.38 COF Readiness Building C Insulation Square Footage Impact

COF Readiness Building C

The COF readiness building is a partial two-story building. The majority of the scope is on the first floor. The ground floor has a perimeter of 904 LF. The second floor is a mezzanine and does not affect the perimeter.

Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	113
2B	1.5	3.0	1.5	0.13	113
3A	1.5	4.0	2.5	0.21	188
3B	1.5	4.0	2.5	0.21	188
3C	1.5	2.0	0.5	0.04	38
4A	1.5	5.0	3.5	0.29	264
4B	2.5	5.0	2.5	0.21	188
4C	2.5	4.0	1.5	0.13	113
5A	2.5	6.0	3.5	0.29	264
5B	2.5	6.0	3.5	0.29	264
6A	4.0	8.0	4.0	0.33	301
6B	4.0	8.0	4.0	0.33	301
7A	4.0	10.0	6.0	0.50	452
8A	4.0	12.0	8.0	0.67	603

Table 5.39 Bde HQ Insulation Square Footage Impact

Bde HQ

The BDE is a two story building. Each floor is the same size, perimeter per floor is 570 LF.

Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	143
2B	1.5	3.0	1.5	0.13	143
3A	1.5	4.0	2.5	0.21	238
3B	1.5	4.0	2.5	0.21	238
3C	1.5	2.0	0.5	0.04	48
4A	1.5	5.0	3.5	0.29	333
4B	2.5	5.0	2.5	0.21	238
4C	2.5	4.0	1.5	0.13	143
5A	2.5	6.0	3.5	0.29	333
5B	2.5	6.0	3.5	0.29	333
6A	4.0	8.0	4.0	0.33	380
6B	4.0	8.0	4.0	0.33	380
7A	4.0	10.0	6.0	0.50	570
8A	4.0	12.0	8.0	0.67	760

Table 5.40 DFAC Insulation Square Footage Impact

DFAC

The DFAC is a single story building. The perimeter of the building is 550 LF per floor.

Climate Zone	Continuous base building insulation of XPS in inches thick	Passive house continuous insulation of XPS in inches thick	Additional wall thickness in inches	Additional wall thickness in feet	Total increase of scope of ground floor and upper floors
1A	1.5	1.5	0.0	0.00	0
2A	1.5	3.0	1.5	0.13	118
2B	1.5	3.0	1.5	0.13	118
3A	1.5	4.0	2.5	0.21	197
3B	1.5	4.0	2.5	0.21	197
3C	1.5	2.0	0.5	0.04	39
4A	1.5	5.0	3.5	0.29	276
4B	2.5	5.0	2.5	0.21	197
4C	2.5	4.0	1.5	0.13	118
5A	2.5	6.0	3.5	0.29	276
5B	2.5	6.0	3.5	0.29	276
6A	4.0	8.0	4.0	0.33	316
6B	4.0	8.0	4.0	0.33	316
7A	4.0	10.0	6.0	0.50	474
8A	4.0	12.0	8.0	0.67	631

5.3 Water Savings

The UEPH peak washing machine use per floor is assumed to be four loads per hour or 80 gal/hr of 120 °F hot water, which is approximately 53 gal/hr from a 140 °F storage tank. Hot water usage from shower is at 105 °F with from a 140 °F storage tank and assumes 30 to 35 gal/person/day for hot water use, with a subset of 20 gal/person/day for shower with a 2.0-gpm shower head and 5 gal of miscellaneous use in the kitchen and bathroom. The efficient building assumes a 1.5-gpm shower head that reduces the shower hot water usage.

Flush fixtures include water closets and urinals. Three different design options were proposed. The first used low-flow water closets and non-water urinals; the second called for composting toilets and non-water urinals; the third called for dual-flush toilets and non-water urinals. Figure 5.4 summarizes the comparison between the baseline design and the three proposed water-savings options for the UEPH.

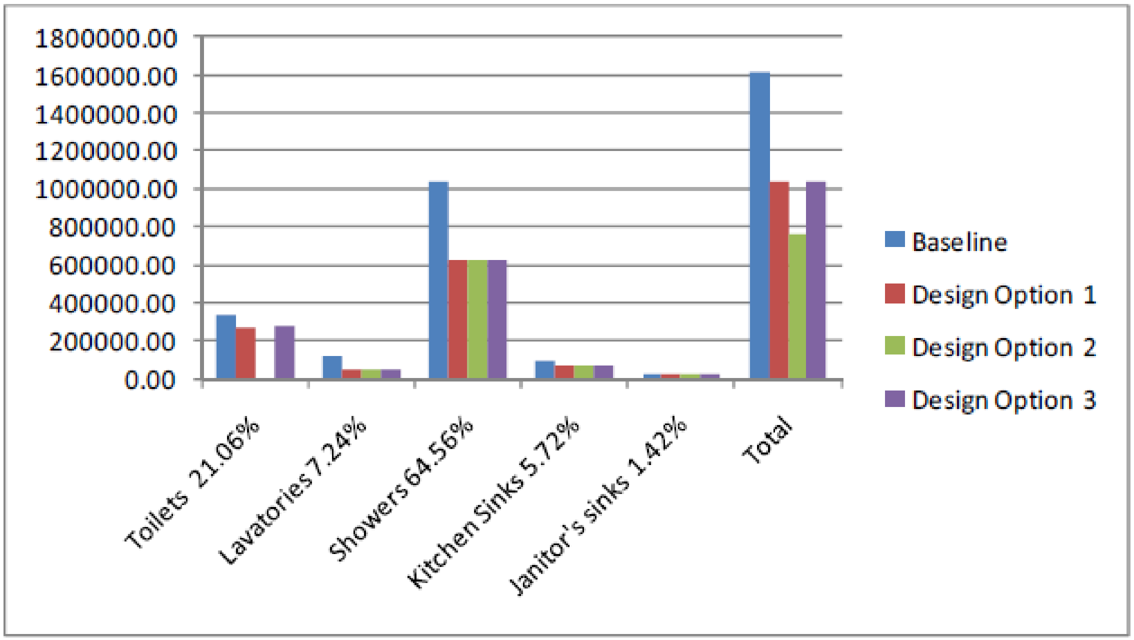

Figure 5.4 UEPH Water Consumption (Gallons)

The TEMF includes specialty equipment that contributes to the overall water consumption that was not accounted for in the water conservation analysis. For the COF, the toilets are the largest consumers of water. Water usage of toilets is dramatically reduced by using water-conserving fixtures. Like most office buildings, a Bde HQ consumes a minimal amount of domestic hot water. Hot water consumption was assumed to be 1.0 gal/person/day. The usage profile was taken from a typical office building schedule. The hot water supply temperature was set at 140 °F with a mixed water temperature at the tap of 105°F. The domestic water heating system in the baseline building models uses an 80 percent efficient boiler and the energy efficient models use a 95 percent efficient boiler. Figure 5.5 through Figure 5.7 summarize the comparison between the baseline design and the three proposed water savings options for the TEMF, COF, and Bde HQ.

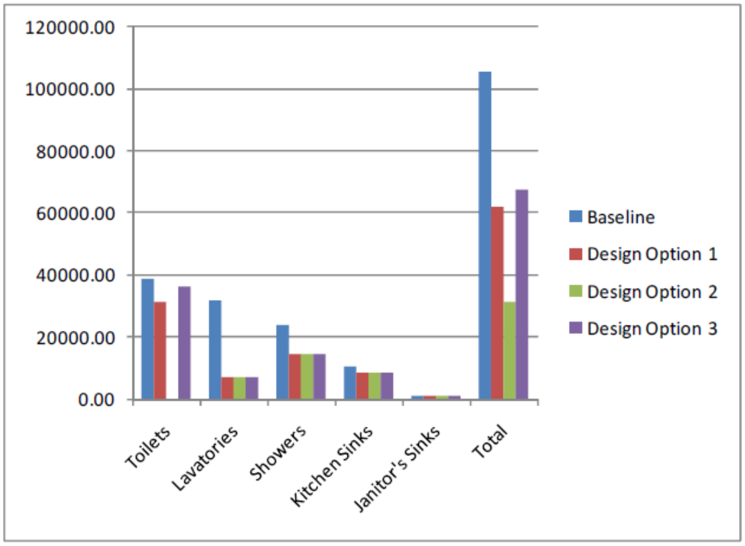

Figure 5.5 TEMF Water Consumption (Gallons)

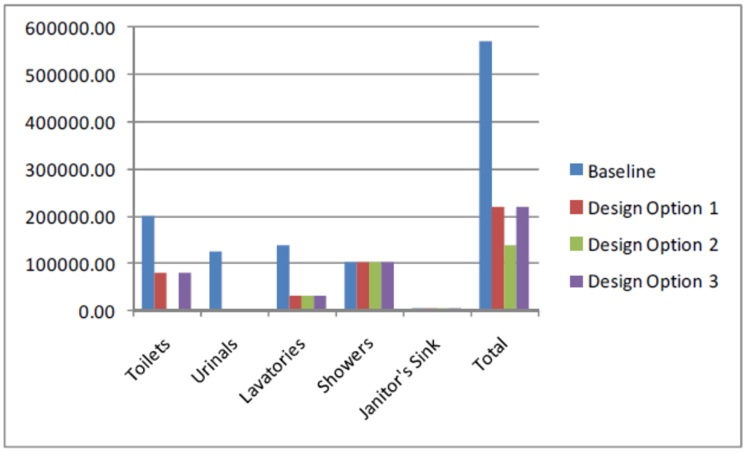

Figure 5.6 COF Water Consumption (Gallons)

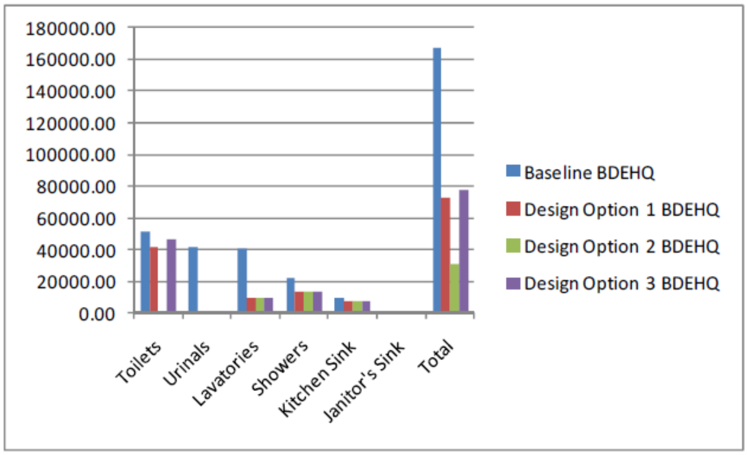

Figure 5.7 Bde HQ Water Consumption (Gallons)

Although kitchen equipment in the DFAC consumes the majority of the water, only flush and flow fixtures were addressed in the water-reduction calculations. It is assumed that with the high-efficiency equipment in the Low Energy Packages there will be water savings in addition to the savings that were calculated. Figure 5.8 below summarizes a comparison of the baseline design and three design options.

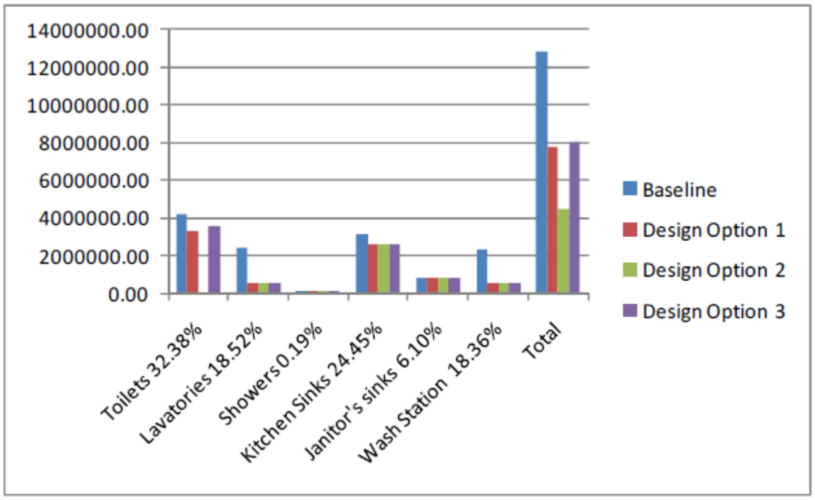

Figure 5.8 DFAC Water Consumption (Gallons)

The goals of 30 percent water reduction and 50 percent wastewater reduction were expected to be achieved based on the results of the study. Annual volume water savings for all five buildings are summarized in Table 5.41.

Table 5.41 Summary of Annual Water Consumption Volumes for UEPH, TEMF, COF, Bde HQ, and DFAC

UEPH	Gallons	Savings
Baseline		
Flush Fixtures	339,888	
Flow Fixtures	1,274,222	
Total	1,614,110	
Flush Fixtures		
Option 1	271,910	20.0%
Option 2	-	100.0%
Option 3	276,013	18.8%
Flow Fixtures	765,923	39.9%
Total Water Savings		
Option 1	1,037,834	35.7%
Option 2	765,923	52.5%
Option 3	1,041,936	35.4%

TEMF	Gallons	Savings
Baseline		
Flush Fixtures	72,044	
Flow Fixtures	72,285	
Total	144,329	
Flush Fixtures		
Option 1	31,027	56.9%
Option 2	-	100.0%
Option 3	36,214	49.7%
Flow Fixtures	36,448	49.6%
Total Water Savings		
Option 1	67,475	53.2%
Option 2	36,448	74.7%
Option 3	72,662	49.7%

COF	Gallons	Savings
Baseline		
Flush Fixtures	324,380	
Flow Fixtures	245,540	
Total	569,920	
Flush Fixtures		
Option 1	159,744	50.8%
Option 2	-	100.0%
Option 3	178,830	44.9%
Flow Fixtures	98,003	60.1%
Total Water Savings		
Option 1	257,747	54.8%
Option 2	98,003	82.8%
Option 3	276,833	51.4%

Bde HQ	Gallons	Savings
Baseline		
Flush Fixtures	93,800	
Flow Fixtures	72,406	
Total	166,206	
Flush Fixtures		
Option 1	41,440	55.8%
Option 2	-	100.0%
Option 3	46,550	50.4%
Flow Fixtures	31,259	56.8%
Total Water Savings		
Option 1	72,699	56.3%
Option 2	31,259	81.2%
Option 3	77,809	53.2%

DFAC	Gallons	Savings
Baseline		
Flush Fixtures	5,890,662	
Flow Fixtures	8,692,099	
Total	14,582,761	
Flush Fixtures		
Option 1	3,330,201	43.5%
Option 2	-	100.0%
Option 3	3,583,497	39.2%
Flow Fixtures	4,436,709	49.0%
Total Water Savings		
Option 1	7,766,910	46.7%
Option 2	4,436,709	69.6%
Option 3	8,020,206	45.0%

5.4 Summary of Cost Estimates

The estimates use a “unit cost for bill of quantities” approach and assigned a unit cost to each of the facility components. The estimates were made based on the following work breakdown structure:

- Substructure
- Interior Construction
- HVAC
- Equipment
- Superstructure
- Interior Finishes
- Fire Protection
- Special Construction

- Exterior Closure
- Conveying Systems
- Electric Power and Lighting
- Roofing
- Plumbing
- Electrical Systems

Quantities were available from the Adapt Build-level construction drawings. As a result, the construction components in question could be identified.

The estimates were tailored to their respective locations. Taxes, markups, and libraries were selected as appropriate. Ideally, this would be done for all the facilities in all the climate zones for multiple HVAC systems; however, doing all the estimates that way was not practical. The estimates were revised to reflect a non-specific location. Taxes, markups, and labor rates were removed or replaced with national averages. To adjust for location, a direct cost markup similar to an area cost factor was included for labor, equipment, material, and subcontractor bid costs. As a result, the estimates were reasonably close to the original standard design while allowing it to be quickly adjusted for use in other locations by applying an Area Cost Factor (ACF) in line with the Army Programming Accounting Execution System (PAX) newsletter system.

Each of the facilities was estimated using an ACF of 1.0. At this stage the estimated project is at a neutral location, based on construction design drawings incorporating the most recent standards criteria and requirement solutions, with enough detail to identify construction component quantities.

Project estimates were compared to estimates developed using a programmatic method. The Army Detailed Cost Estimating System (MII) file estimates adjusted for location by adjustments to the direct costs were returning results similar to programmed projects using the PAX newsletter system.

The nonspecific subcontractor markup would not be as accurate as a specific subcontractor markup, but the benefit of identifying individual subcontractors would be of no significant benefit to the overall subcontractor cost. Using the latest PAX area cost factor to mark up direct cost, mark up of material and labor is an acceptable method of estimating construction at different locations. Design cost was 4 percent in all cases.

The Energy Analysis package identified EEMs that required modifications to the construction components. In addition to the EEMs, sustainable practices are included. As a rule, the construction method or design was not altered by the estimator. Only in the case of the foundation of the UEPH did the COS identify a construction change from the standard. The COF also had, in addition to the true standard scenario, a second study completed where the volume of the readiness module was reduced by removing the mezzanine and replacing it with an increased single-level building footprint.

The building envelope is one of the significant cost impacts due to the quantity of additional material. The change of construction in the foundation of the UEPH is a significant factor in the UEPH results. Items that are not due to the EEM but are in the package because of sustainability make it difficult to draw the line in the cost comparisons based on what features make the buildings more energy efficient.

The insulation of the buildings required adjustments based on a comparison of the existing constructed value to the amount of insulation needed to meet passive house standards. In some cases, this is straightforward. For example, the current design indicates 6 in., while in a given climate zone the additional insulation might be 8 in. A recommendation would be to allow for an increase to the gross square footage of a building in order to allow for increased envelope insulation for improved energy conservation.

The insulating value requirement of the building's envelope is the reason for the cost of replacing double-pane with triple-pane windows. The lighting plan and the daylighting requirements share the cost of additional window area. As a result, attributing the cost of this item is difficult to separate out between the insulation, lighting reduction, and additional sustainability practices EEMs. The estimate results report this as a single item cost titled, "Increased Window Efficiency."

The EEM package identified the changes to the lighting plan in general terms. The estimator contacted vendors in developing the new lighting plan estimate.

At most, four packages per facility type were selected from the many available mechanical systems. The mechanical systems with the most likely benefit were selected to be estimated. Some equipment was resized based on the reduced loads. This information was calculated and provided in addition to the EEM package. A variety and combination of elements and systems were required. Items such as equipment sizes, higher efficiency components, energy recovery, indirect evaporative cooling, transpired solar collectors, radiant flooring, radiant ceiling, and ground source heat pump are items in the packages. The mechanical estimator contacted vendors for major component costs.

The construction drawings provided enough information to quantify plumbing items and the estimate provided enough detail to identify the plumbing fixtures and replacement with the higher efficiency fixtures. The delta between the fixtures was relatively easy to document and attribute to a sustainable cost.

Some items were not included in the original standard design and since they did not replace another system, their costs were added to the total baseline costs of the project. These added items include rainwater harvesting, enhanced commissioning, and measurement and verification.

Rainwater harvesting is not only new to the project, it is also under discussion as to whether it should be included in the building or supporting facilities costs in the programming document (DD1391). The system captures water from the roof, channels it to a tank, filters it, pumps it out, and distributes it into the building as a secondary plumbing system. In the estimates, the rainwater harvesting system is included in the building cost.

Enhanced commissioning is a new initial contract cost to the standard and continues 10 months beyond the buildings completion date. The enhanced commissioning cost was established by providing resources to each of the tasks identified in LEED 2009 for new construction.

M&V is a new initial contract cost to the standard and continues beyond the buildings completion date. The M&V estimate includes metering equipment, collection of the data on a regular basis throughout the year, evaluating the data, and revising the energy model using the collected data.

The cost estimates for the five building types are summarized in Tables 5.42 through 5.46 below.

Table 5.42 UEPH Cost Estimate Summary

UEPH	Climate Zone	**Baseline Building Contract Cost**	**Low E Package 1**				**Low E Package 2**			
			Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Shafter	1	$18,209,585	$19,902,998	$1,693,413	9.30%	37%	$19,957,568	$1,747,983	9.60%	49%
Fort Hood	2A	$7,585,822	$8,393,139	$807,317	10.64%	37%	$8,416,563	$830,741	10.95%	50%
Fort Bliss	3B	$8,986,431	$9,889,334	$902,903	10.05%	38%	$9,917,134	$930,703	10.36%	51%
Fort Campbell	4A	$8,597,669	$9,514,315	$916,646	10.66%	37%	$9,540,056	$942,387	10.96%	56%
Fort Lewis	4C	$10,242,658	$11,262,589	$1,019,931	9.96%	37%	$11,293,220	$1,050,562	10.26%	53%
Fort Wainwright	8	$18,080,550	$20,982,214	$2,901,664	16.05%	36%	$21,103,771	$3,023,221	16.72%	64%
			Low E Package 3				**Low E Package 4**			
	Climate Zone		Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Shafter	1		$19,062,512	$852,927	4.68%	50%	$22,100,105	$3,890,520	21.37%	48%
Fort Hood	2A		$8,031,414	$445,592	5.87%	52%	$9,333,535	$1,747,713	23.04%	49%
Fort Bliss	3B		$9,382,468	$396,037	4.41%	53%	$11,009,837	$2,023,406	22.52%	48%
Fort Campbell	4A		$9,044,995	$447,326	5.20%	57%	$10,551,818	$1,954,149	22.73%	52%
Fort Lewis	4C		$10,704,097	$461,439	4.51%	55%	$12,497,217	$2,254,559	22.01%	51%
Fort Wainwright	8		$20,087,958	$2,007,408	11.10%	65%	$23,159,854	$5,079,304	28.09%	66%

Table 5.43TEMF Cost Estimate Summary

TEMF	Climate Zone	**Baseline Building Contract Cost**	**Low E Package 1**				**Low E Package 2**			
			Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Bliss	3B	$7,529,077	$8,027,764	$498,687	6.62%	46%	$8,120,106	$591,029	7.85%	48%
Fort Campbell	4A	$6,969,882	$7,470,428	$500,546	7.18%	55%	$7,555,930	$586,048	8.41%	59%
Fort Lewis	4C	$8,302,808	$8,888,652	$585,844	7.06%	55%	$8,990,399	$687,591	8.28%	58%
Fort Carson	5B	$7,610,110	$8,210,887	$600,777	7.89%	56%	$8,304,084	$693,974	9.12%	62%
			Low E Package 3				**Low E Package 4**			
			Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Bliss	3B		$8,119,395	$590,318	7.84%	46%	$8,211,736	$682,659	9.07%	48%
Fort Campbell	4A		$7,555,271	$585,389	8.40%	55%	$7,640,773	$670,891	9.63%	58%
Fort Lewis	4C		$8,989,615	$686,807	8.27%	55%	$9,091,362	$788,554	9.50%	57%
Fort Carson	5B		$8,303,366	$693,256	9.11%	56%	$8,396,562	$786,452	10.33%	61%

Table 5.44 Bde HQ Cost Estimate Summary

Bde HQ			Low E Package 1				Low E Package 2			
	Climate Zone	Baseline Building Contract Cost	Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Campbell	4A	$8,535,728	$8,965,589	$429,861	5.0%	44%	$9,410,513	$874,785	10.2%	46%
Fort Lewis	4C	$10,122,092	$10,609,301	$487,209	4.8%	38%	$11,138,760	$1,016,668	10.0%	39%
Fort Drum	6A	$9,894,934	$10,575,485	$680,551	6.9%	50%	$11,087,147	$1,192,213	12.0%	54%
Fort Wainwright	8	$18,362,721	$20,142,153	$1,779,432	9.7%	58%	$21,094,290	$2,731,569	14.9%	64%
			Low E Package 3				Low E Package 4			
			Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Campbell	4A		$9,646,657	$1,110,929	13.0%	46%	$9,781,123	$1,245,395	14.6%	48%
Fort Lewis	4C		$11,419,771	$1,297,679	12.8%	39%	$11,592,301	$1,470,209	14.5%	39%
Fort Drum	6A		$11,358,713	$1,463,779	14.8%	51%	$11,516,438	$1,621,504	16.4%	54%
Fort Wainwright	8		$21,599,637	$3,236,916	17.6%	59%	$21,868,796	$3,506,075	19.1%	67%

Table 5.45 COF Administrative Building Cost Estimate Summary

COF			Low E Package 1				Low E Package 3			
Admin A + Readiness B + Readiness C	Climate Zone	Baseline Building Contract Cost	Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Shafter	1	$30,909,084	$33,334,464	$2,425,380	7.8%	43%	$33,295,314	$2,386,230	7.7%	60%
Fort Campbell	4A	$14,631,260	NA	NA	NA	65%	$16,254,649	$1,623,389	11.1%	68%
Fort Lewis	4C	$17,309,882	NA	NA	NA	63%	$19,335,410	$2,025,528	11.7%	67%
Fort Carson	5B	$15,923,121	$18,159,680	$2,236,559	14.0%	70%	$18,198,947	$2,275,826	14.3%	73%
Fort Drum	6A	$16,995,154	NA	NA	NA	74%	$19,688,509	$2,693,355	15.8%	76%
Fort Richardson	7A	$26,632,969	$31,493,361	$4,860,392	18.2%	77%	$31,886,041	$5,253,072	19.7%	78%

Table 5.46 DFAC Cost Estimate Summary

DFAC			Low E Package 2				Low E Package 4			
	Climate Zone	Baseline Building Contract Cost	Revised Cost	Cost Increase	% Increase	Energy Savings	Revised Cost	Cost Increase	% Increase	Energy Savings
Fort Wainwright	8	$9,749,134	$10,179,126	$429,992	4.4%	25%	$9,944,342	$195,208	2.0%	28%

5.5 Life-Cycle Cost Analysis

The installations that were selected for this analysis were based on the locations where the majority of projects were located in the FY13 program list. Energy and water use were taken directly from the energy models and investment costs were taken from cost estimates. Energy savings were based on the low-energy model compared to the baseline building model.

Life-cycle cost analysis was performed for UEPH (Fort Bliss and Fort Campbell) and TEMF (Fort Carson and Fort Campbell). The analysis met the requirements of 10 CFR 436 by using the BLCC program developed by NIST.

Assumptions for the analysis included the following:

- A 40-year life cycle was used.
- All capital investment amounts and energy savings were based on the cost estimates and energy modeling results from this study.
- Current Dollar Analysis with a 4 percent nominal discount rate (provided by the BLCC software) for operations, maintenance, and repair (OM&R) and utility costs. Initial Capital Investment was held constant with the provided cost estimate.
- The BLCC program used the DOE escalation factor for utility costs.
- For water consumption, we assumed constant usage throughout seasons. Water usage split 50/50 between summer and winter.
- Residual factor: 0 percent
- Cost adjustment factor: 0.97 percent
- Annual rate of increase annual OM&R: 4 percent
- We assumed an even distribution of total project cost between a 2-year period (April 2011 – April 2013) for cost phasing of initial costs.
- Routine Annually Recurring OM&R Costs: Assumed $100,000 per year. One percent of the Total Project Cost did not provide a constant when comparing energy savings versus total project cost.
- We assumed that the building systems maintenance is generally the same for all packages on a level-of-effort basis. This was one of the decision factors in selecting Low Energy Packages.
- For the UEPH, non-recurring facility maintenance was not taken into account in the analysis.
- For the TEMF, windows (skylight) were the only system identified to not have a useful life for the entire analysis period. Cost equals material plus installation ($62,120.02).

An assumption to keep O&M constant for the baseline building and Low Energy Packages was made for two reasons. First, good historical operations and maintenance data were not available for any of the buildings studied. Second, part of the technology selection process was to pick the energy systems that would not severely affect the current O&M staff at the installations. Utility rate information for specific installations that was used in the LCCA was provided by the Huntsville COS and is listed in Table 5.47**Error! Reference source not found.** This cost is lower than would be the case in other parts of the country.

Table 5.47 Utility Rate Information for Army Installations

		Rate ($)/Unit			Annual Demand Charge (%)
Climate Zone	Installation	Electricity (Mbtu)	Gas (Mbtu)	Water (gal)	Electricity
3B	Fort Bliss	14.43	6.38	0.006	0.52
4A	Fort Campbell	19.66	6.98	0.0023	0.5
4C	Fort Lewis	14.65	8.14	0.0021	0.1

5B	Fort Carson	14.36	6.26	0.003	0

The LCCA results show the dependency on building type and location. Not all buildings will have the same payback period because they have different EUIs and vary in how much electricity versus gas is consumed. Building locations will also factor into the LCCA because energy savings differ for each climate zone. In addition, utility rates play a big part because some locations have a much lower utility rate based on how the energy is generated in each particular region. The LCCA results (Table 5.48 through Table 5.51) show that three of the four buildings that were analyzed had various Low Energy Package options with net present values (NPVs) that were less than the baseline building alternative NPV. The TEMF at Fort Carson (climate zone 5B) was the only building where the NPV was not less than the baseline alternative. One reason for this is that the cost of the passive house insulation ($249,350) was about a third of the overall cost increase for the four low-energy alternatives. Design teams are encouraged to analyze each building in each climate zone to fine-tune the EEMs and find the right balance between energy savings and cost effectiveness.

Table 5.48 Fort Bliss Net Present Value of Life-Cycle Costs – UEPH

UEPH - Net Present Value of Life Cycle Costs					
Fort Bliss (El Paso)	**Baseline**	**Low Energy Package 1**	**Low Energy Package 2**	**Low Energy Package 3**	**Low Energy Package 4**
Investment cost	$ 9,117,135	$ 9,746,942	$ 9,774,742	$ 9,240,076	$ 10,867,445
Operations and Maintenance	$ 3,800,000	$ 3,800,000	$ 3,800,000	$ 3,800,000	$ 3,800,000
Utility costs	$ 1,578,166	$ 912,336	$ 886,539	$ 860,763	$ 943,413
Replacement costs	$ -	$ -	$ -	$ -	$ -
Total NPV LCC:	$ 14,495,301	$ 14,459,278	$ 14,461,281	$ 13,900,839	$ 15,610,858
LCC Savings:	$ -	$ 36,023	$ 34,020	$ 594,462	$ (1,115,557)
Simple Payback Period (Years)		18.72	18.82	3.39	54.58

Table 5.49 Fort Campbell Net Present Value of Life-Cycle Costs – UEPH

UEPH - Net Present Value of Life Cycle Costs					
Fort Campbell (Baltimore)	**Baseline**	**Low Energy Package 1**	**Low Energy Package 2**	**Low Energy Package 3**	**Low Energy Package 4**
Investment cost	$ 8,718,690	$ 9,361,512	$ 9,387,253	$ 8,852,191	$ 10,399,015
Operations and Maintenance	$ 3,800,000	$ 3,800,000	$ 3,800,000	$ 3,800,000	$ 3,800,000
Utility costs	$ 1,952,823	$ 1,075,392	$ 1,015,216	$ 1,003,991	$ 1,139,731
Replacement costs	$ -	$ -	$ -	$ -	$ -
Total NPV LCC:	$ 14,471,513	$ 14,236,904	$ 14,202,469	$ 13,656,182	$ 15,338,746
LCC Savings:	$ -	$ 234,609	$ 269,044	$ 815,331	$ (867,233)
Simple Payback Period (Years)		14.50	14.11	2.78	40.90

Table 5.50 Fort Carson Net Present Value of Life-Cycle Costs – TEMF

TEMF - Net Present Value of Life Cycle Costs					
Fort Carson (Colorado Springs)	**Baseline**	**Low Energy Package 1**	**Low Energy Package 2**	**Low Energy Package 3**	**Low Energy Package 4**
Investment cost	$ 7,743,244	$ 8,101,952	$ 8,195,149	$ 8,194,431	$ 8,287,627
Operations and Maintenance	$ 3,799,309	$ 3,799,309	$ 3,799,309	$ 3,799,309	$ 3,799,309
Utility costs	$ 451,916	$ 220,010	$ 199,072	$ 213,293	$ 196,999
Replacement costs	$ 62,106	$ 62,106	$ 62,106	$ 62,106	$ 62,106
Total NPV LCC:	$ 12,056,575	$ 12,183,377	$ 12,255,636	$ 12,269,139	$ 12,346,041
LCC Savings:	$ -	$ (126,802)	$ (199,061)	$ (212,564)	$ (289,466)
Simple Payback Period (Years)	-	30.61	35.37	37.42	42.27

Table 5.51 Fort Campbell Net Present Value of Life-Cycle Costs – TEMF

TEMF - Net Present Value of Life Cycle Costs					
Fort Campbell (Baltimore)	**Baseline**	**Low Energy Package 1**	**Low Energy Package 2**	**Low Energy Package 3**	**Low Energy Package 4**
Investment cost	$ 7,073,200	$ 7,353,554	$ 7,439,056	$ 7,438,397	$ 7,523,899
Operations and Maintenance	$ 3,800,000	$ 3,800,000	$ 3,800,000	$ 3,800,000	$ 3,800,000
Utility costs	$ 812,503	$ 442,204	$ 419,401	$ 419,595	$ 406,448
Replacement costs	$ 62,120	$ 62,120	$ 62,120	$ 62,120	$ 62,120
Total NPV LCC:	$ 11,747,823	$ 11,657,878	$ 11,720,577	$ 11,720,112	$ 11,792,467
LCC Savings:	$ -	$ 89,945	$ 27,246	$ 27,711	$ (44,644)
Simple Payback Period (Years)	-	14.98	18.42	18.40	21.97

5.6 Progress Toward Other Mandates

ERDC-CERL staff conducted an analysis to ensure that all five building types would be able to achieve LEED Silver certification. LEED scorecards were completed and an analysis of credits was conducted to determine which credits should be pursued.

5.6.1 ASHRAE 189.1

This was not a study of ASHRAE 189.1 and the recent Army policy requiring compliance with ASHRAE 189.1 was not in effect when this study began. Therefore, this is not a comprehensive analysis, rather it is intended to “red flag” sections of ASHRAE 189.1 that may need further evaluation during the design of these buildings; e.g., some of the sections of ASHRAE 189.1 can only be evaluated based on the building site. However, in terms of ASHRAE 189.1, there is a high level of confidence from this study that using the measures described above the five building types would meet or exceed the ASHRAE 90.1-2007 energy goal of a 30 percent reduction in energy use. It is important to note that there are examples where this study exceeded the prescriptive values found in ASHRAE 189.1, such as improved insulation levels, a lower air infiltration rate, greater HVAC equipment efficiencies, and lighting concepts and strategies that exceeded the minimum requirements of the ASHRAE standard.

In terms of formatting, as is true in the “Mapping to LEED” tool described in Section 5.6.3, in general, a full circle indicates compliance with ASHRAE 189.1 requirements; a half circle indicates some but not all ASHRAE 189.1 requirements are met, and an empty circle indicates that 1) the relevant information to determine if the design specs complied could not be found, or 2) there is a loose association with the ASHRAE 189.1 requirements. Running notes are found in the second, more detailed tab of the Excel spreadsheet.

5.6.2 TechNotes

"TechNotes" were developed to provide summary technology information for DoD designers, cost engineers, and installation personnel. Each TechNote includes a description of the technology or design strategy, potential specific products, a summary of the requirements the strategy could affect, supplemental specification language or resources, and a case study emphasizing the technology.

Case in point, the topic of roofing material choices that meet both design goals and environmental and energy goals has been a design challenge in recent years. The "Heat Island Roof" TechNote includes information regarding roofing materials and colors that may assist installation and design teams with that decision. The 'Heat Island Roof' TechNote also provides an example of the expected content for the TechNotes. TechNotes can be found at the following web link: http://mrsi.usace.army.mil/cos/TechNotes/Forms/AllItems.aspx

Additional TechNotes organized by general categories are posted for the following topics:

- HVAC
  - Desiccant HVAC
  - Overhead Radiant Heating
  - Radiant Floor Heating – Commercial
  - Radiant Floor Heating and Cooling – Residential
  - Ground Source Heat Pumps
- Renewables
  - Solar Collector Wall
  - Solar Hot Water
- Water
  - Dual Flush Toilets
  - High Efficiency Toilets
  - Low-Flow Showerheads
  - Ultra Low Flow Faucets
- Lighting
  - LED – Parking Lot
  - Light Pollution Reduction
- Daylighting
  - Dimming Photosensor
  - Light Shelf
  - Light Tubes
  - Sunlight Tracking

- Miscellaneous
  - Appliances
  - Enhanced Commissioning
  - Heat Island – Roof
  - Permeable Pavement
  - Reflective Paints

Another 20 TechNotes will be added to this page once their initial technical review has been completed. O&M TechNotes for O&M staff and one-page summary TechNotes for building occupants will also be developed. Additional feedback on the technical content and/or requests for additional topics for new TechNotes should be sent to Daniel.Carpio@usace.army.mil.

5.6.3 Mapping to LEED

The research team reviewed current mandates, policies, and standards (MPS) and compared them to LEED 2009 in an effort to illustrate potentially attainable levels of LEED certification from meeting current requirements. The following documents were evaluated in comparison to LEED 2009:

- Energy Policy Act of 2005 (EPACT)
- Energy Independence and Security Act of 2007 (EISA)
- Executive Order (EO) 13423
- EO 13514
- High Performance and Sustainable Buildings Guiding Principles (HPSB GP) Final (dated 12/1/08)
- Army Memorandum: Sustainable Design and Development Policy Update (SDD Policy, dated 10/27/10)
- Other policies and mandates, including Unified Facilities Criteria (UFC), Unified Facilities Guide Specifications (UFGS), and U.S. Codes of Federal Regulations (CFRs)
- Army Engineering and Construction Bulletins (ECBs)
- ASHRAE 189.1.

The requirements listed in each document were compared to the relevant LEED credit to determine whether meeting the requirements would result in achieving points under LEED. If the MPS requirements were equal to or more stringent than the requirements to achieve the LEED points, and complying with the MPS would result in achieving the LEED points, a black circle was placed next to the corresponding LEED credit.

If the MPS requirements were patterned after the requirements to achieve LEED points, but are either less stringent or dependent on specific site or building systems, and complying with the MPS may or may not result in achieving the LEED points, a half circle was placed next to the corresponding LEED credit. For example, the MPS may require 70 percent of regularly occupied spaces to have lighting controls, but providing lighting controls to 90 percent of building occupants is required to achieve LEED points.

If the MPS requirements were loosely related or had a general relationship to the requirements to achieve LEED points, but either could not achieve the LEED points by complying with the MPS or it was unclear whether complying with the MPS would result in achieving the LEED points, a white or empty circle was placed next to the corresponding LEED credit. Best practices that are encouraged but not required by the MPS also fall under this category.

If the MPS did not include any requirements that related to a LEED credit, the space next to the corresponding LEED credit was left blank.

6.0 Recommendations for Implementation

This section discusses three major areas: cost estimating, barriers, and recommendations. The impact of the modeling results for new energy and sustainability features on the original baseline/standard design buildings became clear during cost estimating. During the course of the study, a number of barriers or constraints had to be overcome. A list of recommendations is provided as a summary of lessons learned.

6.1 Costs

The cost increases for the recommended Low Energy Packages for the five building types ranged from 2 percent to 10 percent with an average cost increase of 6 to 8 percent. This study performed a life-cycle cost for two buildings (baseline building plus four Low Energy Packages) in three climate zones. Three of the four building combinations had multiple Low Energy Packages that were life-cycle cost effective. The one building (four Low Energy Packages) that was not life-cycle cost effective was due to the increased cost for additional insulation without a proportionate increase in energy savings. Adding renewables to individual buildings to bring them above the 65 percent energy reduction target would be cost prohibitive. In terms of renewables, the cost is over six times higher than the current investment in EEMs in today’s dollars. Renewables should be considered as a centralized resource either for clusters of buildings or as completely offsite, e.g., large, ground-based solar arrays. Energy costs vary by season and region and the DoD should take advantage of cost effective renewable energy technology during peak demand periods, avoiding the most expensive fossil fuel based resources and their associated environmental externalities.

As an example of this approach, numerous innovations in solar thermal technologies in recent years have resulted in cost-effective large-scale systems including integrated solar supported heating networks. Such systems may be cost-effective for clusters of Army buildings containing, for example, barracks, dining facilities, gyms, child-development centers, and swimming pools. Similar opportunities exist on large hospital campuses, family housing complexes, etc.

The Central Solar Water Heating Systems – Design Guide (draft available from ERDC/CERL) is the first attempt to develop recommendations for optimal and reliable configurations of solar water heating systems in different climates along with design specifications, planning principles, and guidelines for such systems serving building clusters with significant usage of domestic hot water (DHW) operating in combination with central heating systems. Designers of new Army construction projects should first consider implementing larger centralized solar water heating systems in accordance with the Design Guide referenced above before designing a small individual building solar water heating system to meet the Sustainable Design Policy and EISA 2007 requirements discussed above.

6.2 Barriers

The final savings determination was difficult because there is no clearly defined baseline for these Army building types within CBECS. In other words, these buildings do not have equivalent categories within CBECS. Assumptions and compromises had to be made in terms of category selection and EUI figures used.

There was also initial confusion about the different energy baselines found in ASHRAE standards (modeled building energy) and EISA 2007 (measured building and plug load energy). This created an “apples to oranges” scenario that cannot be easily resolved.

Because of the uncertain baseline, the focus became one of creating the most efficient building within the constraints of the analysis rather than trying to create an exact match with what were basically arbitrary CBECS targets. Modeling and calculations were done, however, to provide results in terms of EISA 2007 and CBECS requirements.

The study was able to show the energy effectiveness of a range of efficiency measures. However, the study was not able to show the cost-effectiveness of individual measures, nor was it able to optimize the designs for the highest energy performance at the lowest costs. This typically is done early in the design phase.

The issue of how to address the impact of plug loads was also a barrier. As can be seen from the building energy reduction results, the increased cost only takes the buildings up to a certain point in terms of energy efficiency unless and until plug loads are reduced. In other words, the buildings are as energy efficient as possible while remaining life-cycle cost-effective and would meet the 65 percent energy reduction target in a number of climate zones and for the building types if proportionately high plug loads are not considered. Because controlling the plug loads was not within the scope of the project, all the study could do was highlight the impact on energy usage.

Other challenges included a lengthy and difficult contracting process between USACE and the DOE Laboratories (a Memorandum of Understanding is now in place that makes this process easier), unavailability of new technologies with three U.S. manufacturers (e.g., triple-pane windows that meet AT/FP blast-resistance requirements), and ASHRAE 189.1 becoming an Army requirement during the course of the study.

6.3 Recommendations

To implement the results of this study, a number of efforts are needed. These include the following:

- Tools, protocols, and guidance –
  - Develop tools that will help COSs, Army Installations staff, general contractors, A&Es, trades, and occupants to understand what needs to be done to design, implement, operate, maintain, and properly use the technologies and packages that were analyzed in this study. These would need to include tools such as additional TechNotes, guide specifications, UFCs, and training materials.
  - Develop protocols that will ensure performance targets are met for individual projects that are building type and site specific
  - In cooperation with the COSs, develop guidance about how to achieve a truly integrated design regardless of building type.

- Technical assistance –
    - Provide technical assistance as needed to the COSs to determine what changes need to be made to the standard designs to achieve maximum, life-cycle cost-effective energy efficient buildings
    - Review mission and quality of life requirements that affect high plug loads for some building types, implement changes, as appropriate.
    - Work with master planners to redesign the location of several types of buildings and multiple usages for a single building or connected complex of buildings, e.g., barracks, to take maximum advantage of shared resources. Evaluate energy savings for various options and institute changes.
- Additional research –
    - Complete the cost optimization for each of the energy efficiency packages.
    - Ensure compliance with ASHRAE 189.1 and the results of this study.
    - Conduct a study of other technologies in combination with current practices in some climate zones for the five building types that could produce similar energy savings to those found in this study.
    - Evaluate these study results in terms of major renovations that will be conducted within the next 5 years of specific types of buildings in specific climate zones, e.g., VOLAR barracks.
    - Coordinate work with DOE commercial building projects and research.
- Procurement –
    - Procure only top-tier ENERGY STAR® appliances and equipment or appliances and equipment that can be shown to be in the top 10 percent in terms of energy efficiency where an ENERGY STAR labeling program is unavailable.
    - Develop industry partnerships for specific technologies and products to ensure availability and lower cost over time.

7.0 Summary of Findings

Fully integrated design is a requirement and not an option with high-efficiency buildings. All subject matter experts, including the commissioning agent and O&M staff, need to be involved from the earliest stages of the project. If this is not done, much time is wasted passing the design back and forth for changes and systems, particularly HVAC systems, are not designed to their maximum efficiency to work with exterior insulation levels, roofing materials, etc.

Enhanced commissioning is a particularly important part of integrated design to ensure that design, installation, and startup of systems are done correctly and M&V is important to verify modeling results. Many of the mechanical systems will only operate properly within a narrow set of parameters. Once operating outside of those parameters for extended periods of time, systems will either not function efficiently or fail to function at all.

Cost optimization needs to be completed for all energy models that were a part of this study and should ideally be completed at the early stages of a project. It is important to complete cost optimization early so that the highest energy efficiencies can be determined.

There is no single, “silver bullet” answer for these buildings. Climate zone, building site conditions, and other factors play major roles in building performance. When buildings are designed to be minimally energy efficient, it is relatively easy to use a “one size fits all” prescriptive approach because the results in terms of energy efficiency are not a factor. With these buildings, the burden is on the designers to take a performance-based rule set and apply it to an individual building by defining strategies that result in achieving overall energy reduction targets.

While this study focused on passive house approaches and technologies, these should not be the prescribed path for the design team to take when it comes to incorporating measures into standard designs. For example, climate zone 1A may not be found to be appropriate for passive house measures based on actual experience due to concerns over moisture/humidity control. Climate zone 5A may achieve much better results. Another example, it may not be optimal to design triple-pane windows on all four walls of a building if further study and modeling reveal that it is not appropriate on the north side of the building or if a taller building or landscaping shades one or more sides of the building and two-pane, low-e windows can be used with little or no impact on energy performance. In this example, it would be beneficial to also take a look at the window U-value to maintain an acceptable occupant thermal comfort and not just the solar heat gain.

It is expected that for some buildings in some climate zones, current practices or current practices with relatively few changes, will result in achieving the performance targets. In other buildings and climate zones, real innovation will be needed to achieve the same results. In the future, to meet ever more stringent energy targets on the path to net zero energy, buildings will need to be:

- Grouped together to take advantage of larger, more energy efficient technologies. This will allow for the sharing of resources between buildings, e.g., waste heat in a cogeneration facility.
- Combined into one building for multiple life/work purposes (e.g., UEPH on the upper floors, DFAC on the main floor of a barracks complex, and a COF either on the first floor or in the basement of the barracks complex).

- Evaluated using additional criteria, e.g, some buildings or locations are optimal for minimizing energy demands and should be the preferred ones for upgrades. For example those located below a hill outside of the prevailing wind have much less exposure to the elements and could have a better orientation for renewable technologies like roof top solar.
- Evaluated to determine if full use is being made of the thermal mass of the structure.

Reducing the plug loads to a level that would achieve the targeted EISA-2007 energy reduction goal by 2015 would require a reevaluation of mission and quality of life requirements for some standard designs. For example:

- UEPH – Prescribe the types of electronic equipment that soldiers can put in their modules; e.g., LED TVs only of a maximum size—no plasma TVs, LED computer screens only, limit kitchen appliances to a microwave, centralized laundry facilities—no in-module facilities, two person modules versus one person.
- Bde HQ – Procure only LED computer screens; limit the number per person; procure only top-tier ENERGY STAR® central processing units, laptops, and related/support equipment; mandate and enforce a low maximum wattage usage per person.
- DFAC – Change the menu to eliminate or minimize the need for high-energy-usage kitchen appliances and equipment. Extend the meal periods over a longer period of time to reduce the peak demand loads currently needed by kitchen appliances and equipment.

When it is determined that technologies need further development/improvement, the Army should work with industry directly to make the changes so improved or new products can be brought to market by leveraging the buying power of all of the armed services.

In addition, lessons learned from operators of large portfolios of buildings with similar use to the DOD could offer some very practical and cost effective insights into the payback of various options within specific regions. Many large real estate firms that have taken over BRAC and other facilities and transformed them into profitable and energy efficient installations should be consulted and site visits conducted to see how this “reuse” has progressed and why landowners elected to invest in different building improvements to achieve their financial and other ownership objectives to determine if the private sector done better than existing DOD installations in making progress toward similar goals in the last 5-10 years.

O&M staff must be properly trained on new systems and technologies or high-efficiency buildings will quickly become less efficient or worse than buildings constructed in the past. Occupant behavior needs to change. Whether it is turning off lights when not in use, properly using operable windows or not blocking HVAC vents, occupants determine the ultimate efficiency of a building. Changing these behavior patterns through education and training is essential to the long-term goal of having a net zero installation. Education also needs to be provided to USACE COSs, Army Installations staff, general contractors, A&Es, and trades on new features, technologies, systems and approaches.

This study’s results need to be integrated into ASHRAE 189.1 requirements. Meeting EISA 2007 energy targets is important, but other requirements also now need to be met. This study was already in progress when ASHRAE 189.1 became an Army requirement. More work is needed to ensure compliance.

8.0 References

American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). 2004, 2007. *Ventilation for Acceptable Indoor Air Quality*. Standard 62.1, Atlanta, Georgia.

American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). 2010. Standard for Design of High-Performance Green Buildings Except Low-Rise Residential Buildings.

Standard 189.1, Atlanta, Georgia.

American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). 2004, 2007, 2010. *Energy Standard for Design for Buildings Except Low-Rise Residential Buildings*. Standard 90.1, Atlanta, Georgia.

Deru M, K Field, D Studer, K Benne, B Griffith, P Torcellini, B Liu, M Halverson, D Winiarski, M Rosenberg, M Yazdanian, J Huang, and D Crawley. 2011. *U.S. Department of Energy Commercial Reference Building Models of the National Building Stock*. NREL/TP-5500-46861, National Renewable Energy Laboratory Golden, Colorado.

Energy Independence and Security Act of 2007, Public Law 110-140 (December 19, 2007).

Energy Policy Act of 2005, Public Law 109-58 (August 8, 2005).

Executive Order (EO) 13423, *Strengthening Federal Environmental, Energy, and Transportation Management* (January 29, 2007).

Fossil Fuel-Generated Energy Consumption Reduction for New Federal Buildings and Major Renovations of Federal Buildings, 10 CFR Part 433 and 435, Vol. 75 , No. 199, October 15, 2010

U.S. Army Corps of Engineers (USACE). 2009. *Building Air Tightness Requirement*. USACE Engineering Construction Bulletin (ECB) 29-2009, Wahsington, D.C.

U.S. Department of Energy (DOE). 2010. *EnergyPlus*, version 5.0. Washington, D.C.

U.S. Green Building Council (USGBC). 2009. *LEED Reference Guide for Green Building Design and Construction*. Washington, D.C.