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Comparison of ASHRAE Energy Standards for the Design of High-Performance Army Buildings

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Comparison of ASHRAE Energy Standards for the Design of High-Performance Army Buildings

USACE, NREL, PNNL

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Summary

The current Army policy for designing military facilities requires a balance between meeting both the Army's mission requirements and federal energy sustainability policies and statutes. To accomplish this, the Army adopted the 2009 version of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 189.1 (189.1-2009) as the standard for new facilities with the exception to site and renewable energy requirements. An updated version of 189.1 was published in 2011 (189.1-2011) and as a result, the U.S. Army Corps of Engineers (USACE) evaluated the design and cost impacts of adopting 189.1-2011 with the same noted exceptions. To accomplish this task, USACE prepared an annotated bibliography of applicable research studies and reports; completed a text-by-text comparison of the 189.1 versions; performed an energy evaluation based on several ASHRAE Standards of two Army facilities (Tactical Equipment Maintenance Facility [TEMF] and Brigade Headquarters [Bde HQ]) in six climate zones including a comparison to prototype commercial buildings; determined first cost and life-cycle cost of the two facilities by climate zone; and identified where overlap occurs between protocols by mapping 189.1-2011 to other federal requirements, including the Guiding Principles for Federal Leadership in High-Performance and Sustainable Buildings (HPSB GP)[1] and Leadership in Energy and Environmental Design (LEED).

USACE chose ASHRAE Standard 90.1-2007 (90.1-2007) as the baseline energy code to evaluate the energy consumption of the Army facilities; both versions of 189.1 reference a version of 90.1 with additional improvements added to energy systems and building components. The Army facilities evaluated were constructed in Fiscal Year 2007 and designed to meet the HPSB GP. In addition, 90.1-2004, as established in the Energy Policy Act 2005 (EPAct), was used to provide a beginning point for tracking the improvements in energy savings since 2007.

The basic question to be addressed by this study is: Should the Army adopt 189.1-2011 as the standard for new construction? To answer this question, several avenues of investigation and analysis were pursued. Below is a summary of these avenues and the conclusions reached:

- Does 189.1-2011 meet the HPSB GP?

  ASHRAE Standard 189.1-2011 would meet or exceed the HPSB GP guidance and requirements in all areas except energy and water efficiency. Particularly with regard to energy efficiency, following 189.1-2011 requirements results in a more energy-efficient baseline building than earlier versions of 90.1 and reduces the gap between the baseline energy performance and the requirements of the HPSB GP. In terms of water efficiency, meeting HPSB GP water-savings targets will depend on the number and type of fixtures subject to the prescriptive requirements in 189.1-2011. Meeting the 189.1-2011 requirements does not guarantee compliance with HPSB GP but does bring a building closer to meeting those targets. Because 189.1-2011 has a prescriptive approach and the HPSB GP has a performance-based approach, facilities may need to be evaluated by type and climate zones to verify compliance with HPSB GP requirements.

[1] Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings, Memorandum of Understanding (MOU), 06 Mar 06, and corresponding 12/1/2008 update, "High Performance and Sustainable Building Guidance." http://www.energystar.gov/ia/business/Guiding_Principles.pdf.

- What are the significant differences between 189.1-2009, 189.1-2011, and their referenced standards (i.e., 90.1-2007 and 90.1-2010, respectively)?

  ASHRAE Standard 189.1 is based largely on other ASHRAE Standards, including 62.1, 90.1, and 55, and aims to decrease whole building energy consumption and the impact a building has on the environment. While 189.1-2009 and 189.1-2011 are comparable in the topics addressed, 189.1-2011 is more detailed and includes additional requirements or exceptions than 189.1-2009, making it a more stringent option for green buildings.

  Based on the mapping exercise documented in Appendix B, 189.1-2009 requirements match 94 of the 131 (or 71 percent) of the 189.1-2011 sections evaluated. An additional 34 requirements in 189.1-2009 are similar to 189.1-2011 requirements, but are not an exact match. One additional section of 189.1-2011 is mentioned in 189.1-2009 but is not required or as specific as that in 189.1-2011. The two remaining sections are not mentioned in 189.1-2009. In many cases, 189.1-2009 requires compliance with previous versions of standards referenced in 189.1-2011, such as ASHRAE Standard 90.1.

  The greatest differences between 189.1-2009 and 189.1-2011 (based on a text-to-text comparison) were found in Section 7 (Energy Efficiency) and Section 8 (Indoor Environmental Quality). In particular, 189.1-2011 includes a significant number of energy-efficiency requirements not present in 189.1-2009.

- What is the difference in the energy savings modeled for two building types (i.e., TEMF and Bde HQ) across six climate zones?

  Tables S.1 and S.2 show the site energy use intensity (EUI) of the TEMF and Bde HQ, respectively, in the six climate zones studied (including plug and process loads). The percentage energy savings of 189.1-2011 compared to 90.1-2004 and 90.1-2007 are also shown.

Table S.1. Site EUI of TEMF in Six Climate Zones

Climate Zone	Location	90.1-2004	90.1-2007	189.1-2009	90.1-2010	189.1-2011	% Savings 189.1-2011 vs. 90.1-2007	% Savings 189.1-2011 vs. 189.1-2009
2A	Houston	50.2	46.6	44.7	41.8	40.9	12%	9%
3A	Memphis	57.0	52.3	50.5	47.9	47.1	10%	7%
3B	El Paso	52.6	47.8	46.2	43.5	42.7	11%	8%
4A	Baltimore	71.3	64.9	63.4	59.8	59.3	9%	7%
4C	Salem	63.0	57.8	56.6	53.5	53.1	8%	6%
5B	Boise	74.8	68.4	67.2	64.1	63.8	7%	5%

Table S.2. Site EUI of Bde HQ in Six Climate Zones

Climate Zone	Location	90.1-2004	90.1-2007	189.1-2009	90.1-2010	189.1-2011	% Savings 189.1-2011 vs. 90.1-2007	% Savings 189.1-2011 vs. 189.1-2009
2A	Houston	82.2	80.2	74.1	67.5	66.2	17%	11%
3A	Memphis	81.8	78.9	68.2	63.6	62.4	21%	9%
3B	El Paso	75.4	72.9	68.4	63.8	62.8	14%	8%
4A	Baltimore	85.6	81.5	67.8	64.0	63.2	22%	7%
4C	Salem	70.6	66.7	61.6	56.8	57.2	14%	7%
5B	Boise	77.8	74.8	65.8	62.1	61.3	18%	7%

Implementation of 189.1-2011 results in significant incremental energy savings as compared to 189.1-2009 for both facility types. Internal plug loads have a significant impact on the Bde HQ energy savings percentage because a large portion of the energy profile is dominated by the unregulated loads of the data center. In the TEMF, the fan energy and heating load are the dominant factors of the energy profile. The major impact of adopting 189.1-2011 would come from the increase in stringency of 90.1-2010. It could be argued that most of the savings in 189.1-2011 could be achieved by adopting 90.1-2010. However, 189.1-2011 includes site sustainability, water conservation, indoor air quality, and renewable energy requirements not included in 90.1-2010.

- How do the two facility types studied compare to prototype commercial office buildings?

  Table S.3 provides a summary of the EUI for the TEMF, Bde HQ, and four similar commercial buildings for 90.1-2010 (Thornton et al. 2010). This helps to put into perspective how these two Army facilities compare to similar commercial buildings in terms of energy use per square foot.

Table S.3. Comparison of EUI ASHRAE Standard-Compliant Buildings to Bde HQ and TEMF for ASHRAE 90.1-2010 (Average end-use for six climate zones studied)

Building Type EUI [kBtu/ft^2]	90.1-2010
Bde HQ	63.0
TEMF	54.8
Medium Office	35.8
Mid-Rise Apartment	39.5
Large Office	32.1
Warehouse	17.7

In terms of EUI, Army facilities are significantly different from the prototype commercial buildings used for comparison. This disparity exists because the Army facilities serve unique functions not found in typical commercial buildings. For example, the Bde HQ has an energy-intensive data center and the TEMF has unusually large outdoor air intakes to serve the vehicle repair bays. The requirements result in higher energy consumption compared to more straight forward commercial office buildings and warehouses.

- What is the first-cost difference if 189.1-2011 is adopted?

  Adoption of 189.1-2011 and application to the two Army building types results in a negligible (within estimating error) first-cost increase compared to 189.1-2009.

- Is 189.1-2011 life cycle-cost effective?

  The construction cost increase from 189.1-2009 and 189.1-2011 is negligible and within the estimating margin of error. The results of the life-cycle cost analysis (LCCA) show a similar result for the Bde HQ and TEMF in terms of the comparison between the two versions of 189.1. Relative to the baseline in the study, meeting the requirements of 189.1-2011 is life-cycle cost effective well within the 40-year payback period, results range between 6-15 years, for both facilities in all analyzed climate zones.

- What level of LEED Certification could Army projects achieve if 189.1-2011 was adopted?

  Compliance with 189.1-2011 could result in one of three levels of LEED Certification: Certified, Silver or Gold, depending on the level of LEED certification selected, the choices of which credits to pursue made by the project team, and the methods used in obtaining those credits.

- Should 189.1-2011 be adopted by the Army for new construction?

  ASHRAE 189.1 is a comprehensive standard that includes minimum requirements for energy, air quality, thermal comfort, water, materials, commissioning, and maintenance procedures and processes. ASHRAE 189.1 provides an integrated framework and foundation towards meeting the Army's goals of balancing mission, federal energy, and sustainability policies for military facilities.

  The additional detail, content changes, and new requirements found in 189.1-2011 make it a more stringent standard than 189.1-2009 for high-performance sustainable facilities. Based on the results from the energy models, implementation of 189.1-2011 yields significant incremental energy savings as compared to 189.1-2009.

  Compared to other commercial facilities, Army facilities are significantly different because they serve unique, mission-based functions not found in typical commercial buildings. These functions result in higher energy consumption compared to more straightforward commercial office buildings and warehouses. As a result, adjustments may be necessary to improve energy savings (e.g., reducing and controlling plug loads in Bde HQ or demand-control ventilation in the TEMF).

  Although meeting the 189.1 requirements does not guarantee compliance with the HPSB GP, it does bring the building closer to meeting those targets. With regard to LEED, compliance with 189.1 could result in LEED Certification from Certified to Gold, depending on the level of LEED certification selected, the choices of which credits to pursue made by the project team, and the methods used in obtaining those credits.

  Cost estimates indicate that the difference in cost between the two versions of 189.1 is within margin of error and considered negligible. The LCCA shows that, compared to the baseline, both the Bde HQ and TEMF yield a payback well within the 40-year payback period of each facility.

  Based on these findings, it is recommended that 189.1-2011 be adopted for new construction with the exceptions for site and renewable energy requirements as noted above. It is further recommend that the renewable energy requirements of ASHRAE 189.1-2011 be evaluated on a project by project basis.

  When applied to Army facilities, ASHRAE 189.1-2011 establishes a baseline and brings these facilities closer to meeting all additional federal requirements but will not meet them standing alone. Additional performance levels for energy, water, and Army-specific mission and life-safety requirements should be established to fully comply with all criteria.

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Acronyms and Abbreviations

ACF	Area Cost Factor
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
Bde HQ	Brigade Headquarters
BLCC/FEMP	Building Life-Cycle Cost/Federal Energy Management Program
cfm	Cubic Feet per Minute
CMU	Concrete Masonry Unit
COS	Center of Standardization
CRS	Condensate Recovery System
DCV	Demand-Control Ventilation
EMCS	Energy Management and Control System
EPAct	Energy Policy Act of 2005
EUI	Energy Use Intensity
ft^2	Square Foot (feet)
HPSB GP	High-Performance Sustainable Buildings Guiding Principles
HVAC	Heating, Ventilation, and Air-conditioning
IESNA	Illuminating Engineering Society of North America
LCCA	Life-cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
LPD	Lighting Power Density
LRD-ED-D-M	Louisville District Mechanical Engineering Department
MCACES	Micro-Computer Aided Cost Estimating Software
MILCON	Military Construction
NREL	National Renewable Energy Laboratory
PACES	Parametric Cost Engineering System
PEMB	Pre-Engineered Metal Building
PNNL	Pacific Northwest National Laboratory
SHGC	Solar Heat Gain Coefficient
SRI	Solar Reflectance Index
SSMR	Standing Seam Metal Roof
TEMF	Tactical Equipment Maintenance Facility
U-factor	Overall Heat Transfer Coefficient
USACE	U.S. Army Corps of Engineers

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1.0 Introduction and Explanation of Approach – Baseline Guiding Principle Building

The current Army policy for designing military facilities requires a balance between meeting both the Army's mission requirements and federal energy sustainability policies and statutes. To accomplish this, the Army adopted the 2009 version of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 189.1 (189.1-2009) as the standard for new facilities. ASHRAE Standard 189.1 (189.1) is a voluntary green building standard developed by key building-related industries through a consensus-based process. Standard 189.1 is comprehensive, including provisions for site sustainability, water conservation, indoor air quality, energy efficiency, building materials, commissioning, and operations and maintenance procedures and processes. An updated version of 189.1 was published in 2011 (189.1-2011) and has been evaluated (i.e., for design and cost impacts) by the U.S. Army Corps of Engineers (USACE). As part of its evaluation process, USACE completed an annotated bibliography of applicable research reports and studies (Appendix A); a text-by-text comparison of the 189.1 versions; performed an energy evaluation of two Army facilities (Tactical Equipment Maintenance Facility [TEMF] and Brigade Headquarters [Bde HQ]) in six climate zones; created energy models[1] comparing the two Army facilities to prototype commercial buildings; determined first cost and life-cycle cost of the two facilities by climate zone; and identified where overlap occurs between protocols by mapping 189.1-2011 to other federal requirements including the Guiding Principles for Federal Leadership in High-Performance and Sustainable Buildings (HPSB GP)[2] and Leadership in Energy and Environmental Design (LEED).

1.1 Baseline Energy Code

The goal of this analysis is to better understand the differences between 189.1-2009 and 189.1-2011 and the impacts of implementing 189.1-2011 on Army buildings. To ensure that energy modeling completed for this study was based on well-documented, vetted standards applicable to both Army facilities and similar commercial buildings, USACE selected ASHRAE Standard 90.1-2007 (90.1-2007) as the baseline energy code. ASHRAE Standard 90.1 represents the minimum code-compliant building in many jurisdictions and within the federal government; 90.1-2007 is referenced in 189.1-2009 and 90.1-2010 is referenced in 189.1-2011. In addition, ASHRAE Standard 90.1-2004 (90.1-2004), as established in the Energy Policy Act 2005 (EPAct), was used for several aspects of the analysis to provide a starting point for tracking the improvements in energy savings over time. It is also important to note that EPAct defines energy savings to be site energy as compared to source energy, which resulted in only site energy being evaluated in this study. Lastly, to comply with current Army policy, renewable energy systems were excluded from the analysis in connection with the Army facilities.

[1] Energy simulations were completed using EnergyPlus version 6.0 (DOE 2010).

[2] Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings, Memorandum of Understanding (MOU), 06 Mar 06, and corresponding 12/1/2008 update, "High Performance and Sustainable Building Guidance." http://www.energystar.gov/ia/business/Guiding_Principles.pdf.

1.2 Building Descriptions

The two Army facilities selected for this study were the Bde HQ and TEMF. Both facility types are constructed frequently by the Army. The Bde HQ, a hybrid of a government office building and a secure data center, was chosen because it most closely resembles a standard mid-sized commercial office building. A typical Bde HQ comprises administrative offices, special function rooms, classrooms, and/or a secure section. Within the Army, there are five different sizes of Bde HQs. The "large" size of the Bde HQ, which accommodates 122 to 156 personnel, was the subject of this study. The total square footage of the two-story building is 39,600 ft^2; 19,800 ft^2 on each floor. A secure data center on the first floor comprises a Brigade Operations Center, Network Operations Center, and Sensitive Compartmented Information Facility. The building is nominally occupied from 8 a.m. to 5 p.m., Monday through Friday.

A TEMF is a large-sized vehicle or equipment repair facility with administrative offices. The size of an Army TEMF is based on the type of equipment being maintained and repaired. These facilities are similar to large commercial vehicle repair facilities. The total square footage of the two-story building used in this study is 32,929 ft^2. The building is nominally occupied from 8 a.m. to 5 p.m., Monday through Friday. This facility type was selected because energy modeling based on 189.1-2009 had been completed in an earlier study for one climate zone (Carpio and Soulek 2011).

USACE selected buildings from six climate zones representing the locations of the majority of the Army installations across the United States and demonstrating a wide range of climatic conditions from hot and humid to cold and dry. These climate zones include 2A – Houston, TX; 3A – Memphis, TN; 3B – El Paso, TX; 4A – Baltimore, MD; 4C – Salem, NC; and 5B – Boise, ID.

1.3 Summary of Tasks

To better understand the differences between 189.1-2009 and 189.1-2011 and the impacts of implementing 189.1-2011 on Army buildings, the study was divided into several tasks. Section 2 describes the text-by-text ASHRAE comparison and energy modeling results. Section 3 discusses first-cost analysis, including methodology and results. Section 4 provides a life-cycle cost analysis (LCCA) and Section 5 describes the mapping exercise comparing 189.1-2011 to other mandates, protocols, and standards including HPSB GP and LEED. Conclusions are in Section 6 and references are in Section 7.

2.0 ASHRAE Standards Comparison and Energy Modeling: Results and Discussion

To capture the full impact of 189.1-2011 on Army facilities, USACE conducted a comparison of the text of 189.1-2009 and 189.1-2011 and the ASHRAE standards referenced therein. In addition, energy models were created for each of the Army facilities selected for the study. Section 2.1 discusses the comparison of ASHRAE standards. Section 2.2 describes the ASHRAE standard comparison results and impacts on various requirements. Section 2.3 shows the energy savings results for each building type in the six climate zones. Section 2.4 addresses the impacts based on geographical location and Section 2.5 describes the effect of plug and process loads. Section 2.6 is an evaluation of where the two facilities rank compared to other commercial buildings

2.1 Comparison of ASHRAE Standards

A text-by-text comparison of ASHRAE 189.1-2009 and 189.1-2011 and referenced sections of ASHRAE Standard 55-2004, 55-2010, 62.1-2007, 62.1-2010, 90.1-2007, and 90.1 2010 was completed. The results of the text-by-text comparison are included in Appendix C. The text comparison of 189.1 was used by energy modelers to input key differences between the standards and to identify energy savings.

Using the text-by-text comparison as a reference, USACE created energy models for both building types based on the prescriptive requirements of 189.1-2009, 189.1-2011, 90.1-2004, 90.1-2007, and 90.1-2010.

2.2 Comparison Results

In general, the major envelope; lighting; and heating, ventilation, and air-conditioning (HVAC) requirements remain constant between 189.1-2009 and 189.1-2011. The major differences between 189.1-2011 and 189.1-2009 come from the adoption of 90.1-2010 as the base standard in 189.1-2011 compared to 90.1-2007 as the base standard in 189.1-2009. Standard 90.1-2010 calls for a significant increase in stringency with regard to energy efficiency over 90.1-2007. When compared to 90.1-2004, the difference in energy savings represents a geometric increase from 90.1-2004 to 90.1-2010 as the standards became ever more restrictive.

2.2.1 Envelope Requirements

The insulation and fenestration requirements of 90.1-2007 and 90.1-2010 are the same and slightly more stringent than 90.1-2004. The two 189.1 standards (189.1-2009 and 189.1-2011) are equivalent to each other. However, the 189.1 requirements are more stringent than the 90.1 requirements. Requirements change by climate zone. In addition to insulation and fenestration, 90.1-2010, and, therefore, 189.1-2011, also includes requirements for air barriers, vestibules, fenestration orientation, and cool roofs, which are absent from 90.1-2007 and 189.1-2009.

2.2.2 Lighting Requirements

The interior and exterior lighting power density (LPD) requirements of 90.1-2010 are more stringent than 90.1-2007 and 90.1-2004. Both 189.1 standards reference the corresponding 90.1 LPDs but lower them by 10 percent. Occupancy sensor controls and other lighting controls are directly referenced in 189.1 from the corresponding 90.1 standard, except in few instances where the 189.1 standards impose a more stringent requirement. Daylighting controls are not required by 90.1-2004 or 90.1-2007, but are required in 90.1-2010, 189.1-2009, and 189.1-2011. Both 189.1 standards have more stringent daylighting control requirements than 90.1-2010.

2.2.3 Ventilation Requirements

Fan power requirements did not change between 90.1-2007 and 90.1-2010 but are reduced by 10 percent in both 189.1 standards over the comparable 90.1 standards. Demand-controlled ventilation is not required in the Bde HQ or the TEMF as neither facility type contains densely occupied spaces. Both versions of 90.1 and 189.1 reference a version of ASHRAE 62.1 for ventilation requirements; however, the requirements remain the same between the different versions of 62.1 so there is no impact on the

buildings. The main difference between the standards for ventilation is a ventilation reset requirement in 90.1-2010, and therefore in 189.1-2011, which is not required by earlier standards. This requirement significantly reduces outdoor air heating and cooling.

2.2.4 Heating and Cooling Equipment Requirements

For the TEMF, the HVAC equipment efficiencies are the same in 90.1-2007 and 90.1-2010[1] because of the particular equipment and equipment size; however, specific boiler efficiencies have changed between 90.1 2007 and 90.1-2010. The "EPAct Baseline" option was selected as opposed to the "Higher Efficiency/Energy Star" approach because the "EPAct Baseline" option represents the minimum prescriptive requirement for compliance. By using this approach, the 189.1 efficiencies match those required by the 90.1 standards. Therefore, all HVAC equipment efficiencies are the same for each energy model.

The Bde HQ uses a chiller and a boiler to supply cold and hot water to the air-handling equipment. The chiller load efficiency and the boiler efficiency are slightly more stringent in 90.1-2010 as compared to 90.1-2007 and 90.1-2004 (Thornton et al. 2011). For 189.1, because the EPAct Baseline path was adopted, the efficiencies are equal to the referenced 90.1 standard.

2.3 Energy Savings Results

2.3.1 TEMF

Figure 1 shows the average end-use consumption savings between the five standards. The energy savings for 90.1-2007 compared to those for 90.1-2004 are 8 percent on average, which is higher than the average (5 percent) determined for 15 prototype buildings in the Pacific Northwest National Laboratory's (PNNL's) 2011 study (Halverson et al. 2011a). An additional savings of 3 percent was seen with 189.1-2009 over 90.1-2007. The 90.1-2010 savings (16 percent) incorporate a number of improvements not found in 189.1-2009. ASHRAE 189.1-2011 improves on the requirements of 90.1-2010 as the base standard, and, as a result, saves slightly more energy than 90.1-2010.

Because only small HVAC equipment (i.e., small air-handling units for the office, consolidated bench, and tool room) is specified for the fully conditioned spaces in the TEMF, cooling efficiencies do not change between 90.1-2007 and 90.1-2010. However, they are lower for 90.1-2004. Thus, TEMF equipment efficiencies remain the same in all cases except for 90.1-2004. As seen in Figure 1, across all six climate zones the savings increase with each subsequent version of 189.1, culminating in savings of an average of 17 percent based on 189.1-2011 over 90.1-2004.

[1] The HVAC equipment specified for the TEMF fall within the types and sizes that do not change between the standards. This is because most of the HVAC equipment specified for heating and cooling consists of small rooftop units that serve office and consolidated bench areas. Larger HVAC equipment, which serves the repair bays and vehicle corridor, only requires heating if temperatures fall below 55°F. For that equipment, there is no cooling efficiency because there is no cooling coil. Heating efficiencies associated with the boiler remain at 80 percent across both 90.1 standards.

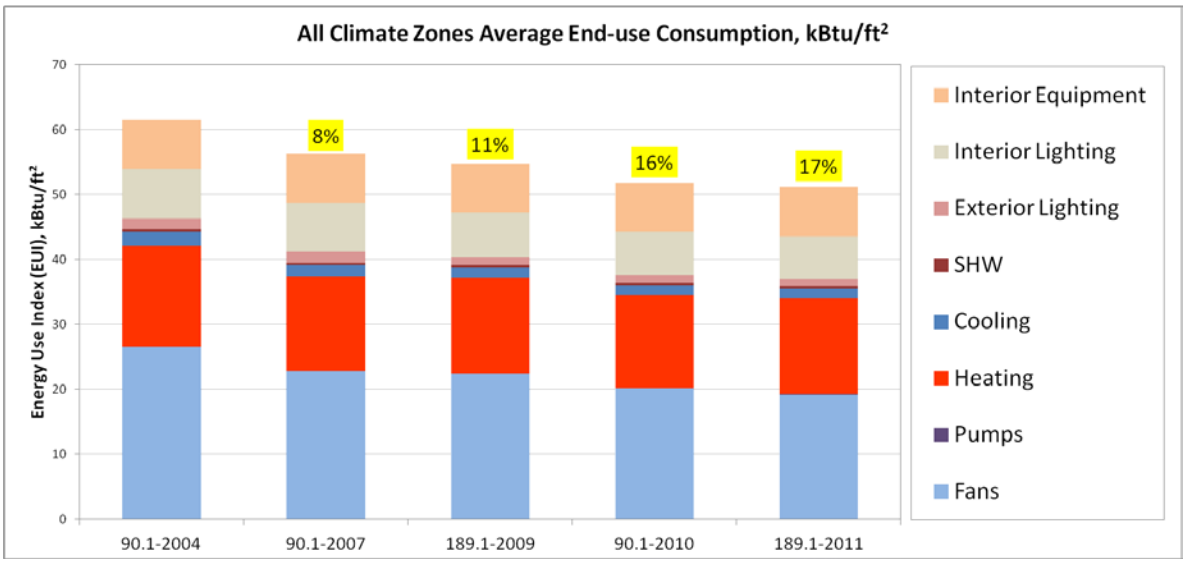

Figure 1. TEMF – All Climate Zones Average End-Use Consumption (kBtu/ft^2) (the percent change noted at the top of each column is in comparison to 90.1-2004)

It is important to note that for the TEMF, building energy is dominated by ventilation and heating loads. These loads are due to the high ventilation flow rates specified by 62.1 (1.5 cfm/ft^2) for automotive maintenance and repair areas. To meet minimum compliance with ASHRAE standards, this ventilation rate was applied to the large volumetric areas of the repair bays and vehicle corridor during occupied hours. The repair bays and vehicle corridor are also minimally conditioned (heated) to 55°F. Cooling is not called for in the design, which explains why the heating energy greatly surpasses the cooling energy in TEMF buildings.

2.3.2 Bde HQ

Figure 2 shows the EUI (kBtu/ft^2) of the Bde HQ building for the five standards averaged across the six selected climate locations. The savings percentages reflect the reduction in EUI of each standard compared to 90.1-2004. The energy savings of 90.1-2007 are small (4 percent) compared to those under 90.1-2004. However, the energy savings of 189.1-2009 are large (14 percent) compared to those under 90.1-2007. ASHRAE 90.1-2010 incorporates a number of improvements not found in 189.1-2009, resulting in an energy savings of 20 percent compared to 90.1-2004. ASHRAE 189.1-2011 uses 90.1-2010 as its reference standard and, as a result, saves slightly more energy than 90.1-2010.

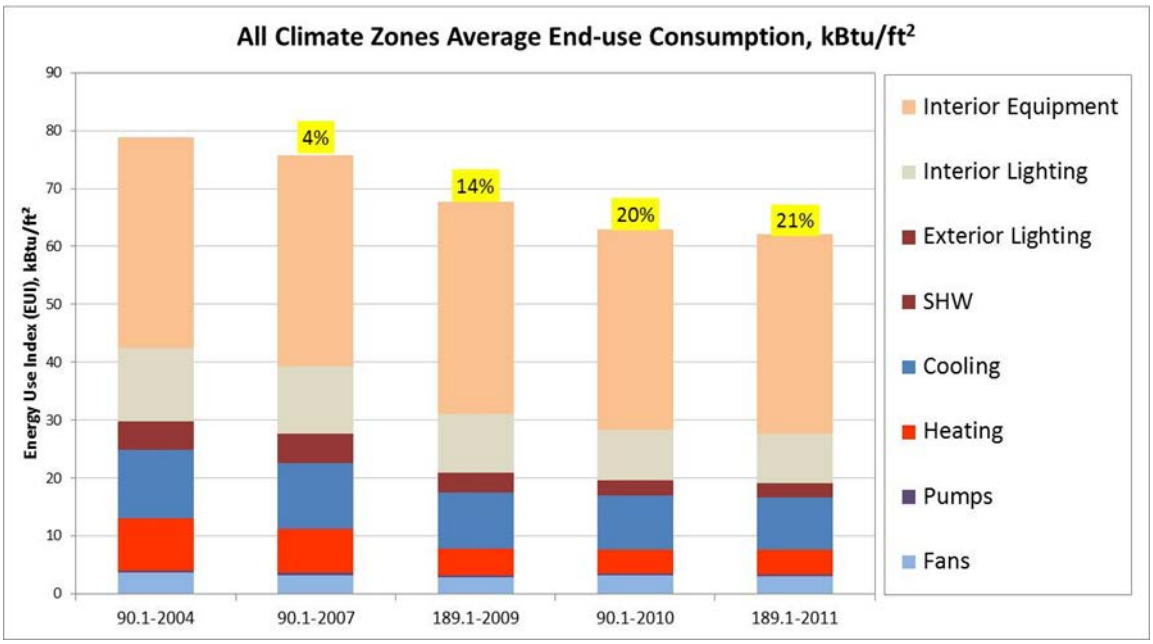

Figure 2. Bde HQ – All Climate Zones Average End-Use Consumption (kBtu/ft^2) (the percent change noted at the top of each column is in comparison to 90.1-2004)

2.4 Impact of Building Location

2.4.1 TEMF

Figure 3 shows the EUI (kBtu/ft^2) of the TEMF for 189.1-2011 in each climate zone. The percentages listed in Figure 3 show the energy consumption savings by climate zone for 189.1-2011 compared to 90.1-2007 (e.g., 90.1-2007 EUI for Houston is 47 while the corresponding 189.1-2011 EUI is 41, yielding an energy savings of 12 percent). The repair bays and vehicle corridor account for 66 percent of the volume of the TEMF and are minimally conditioned (heated to 55°F). Therefore, the different standards do not have a large effect on whole building energy use. However, the energy savings do change between the standards. The greatest energy savings were associated with 189.1-2011, which ranged from 7 to 12 percent savings over 90.1-2007 across climate zones. From Figure 1, the average end-use consumption reduction for all climate zones is 9 percent between 189.1-2011 and 90.1-2007. Larger savings are indicated in warmer climate zones and the largest savings are indicated in climate zone 2A (Houston, TX).

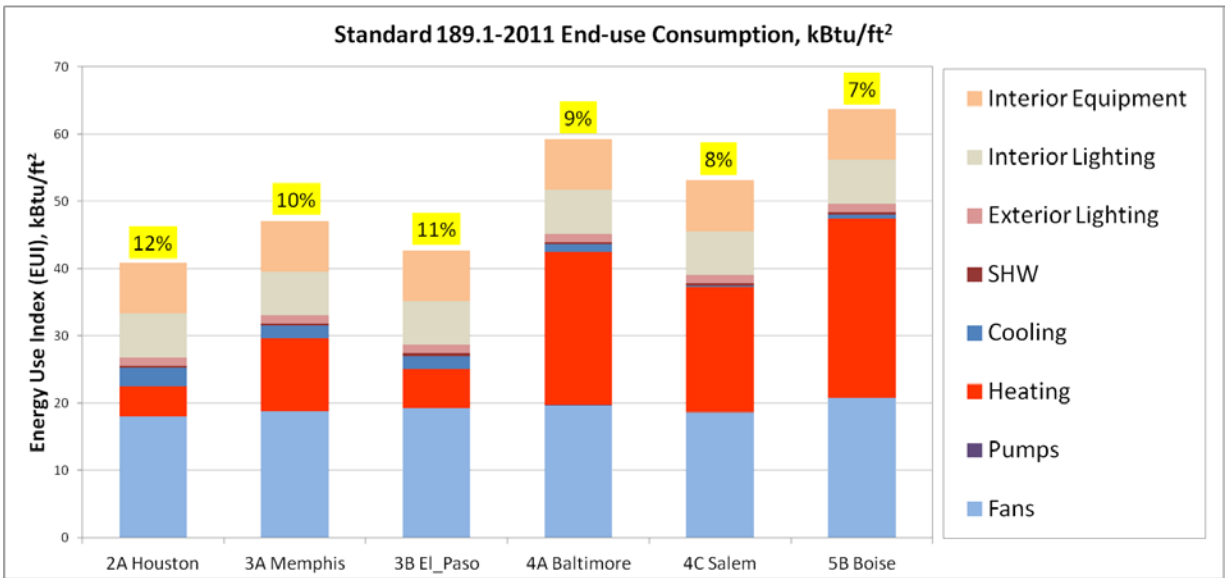

Figure 3. TEMF – Energy Consumption Savings Compared to 90.1-2007 by Climate Zone

2.4.2 Bde HQ

Figure 4 shows the EUI (kBtu/ft^2) of the Bde HQ building for Standard 189.1-2011 in each climate zone. The savings percentage at the top of each bar indicates the energy savings of 189.1-2011 in that climate zone compared to 90.1-2007 (e.g., 90.1-2007 EUI for Houston is 80 while the corresponding 189.1-2011 EUI is 66, yielding an energy savings of 17 percent). The data center energy consumption is the dominant load in the Bde HQ building. The whole building energy savings are highest for Baltimore (26 percent) and lowest in El Paso (17 percent) for 189.1-2011 compared to 90.1-2007.

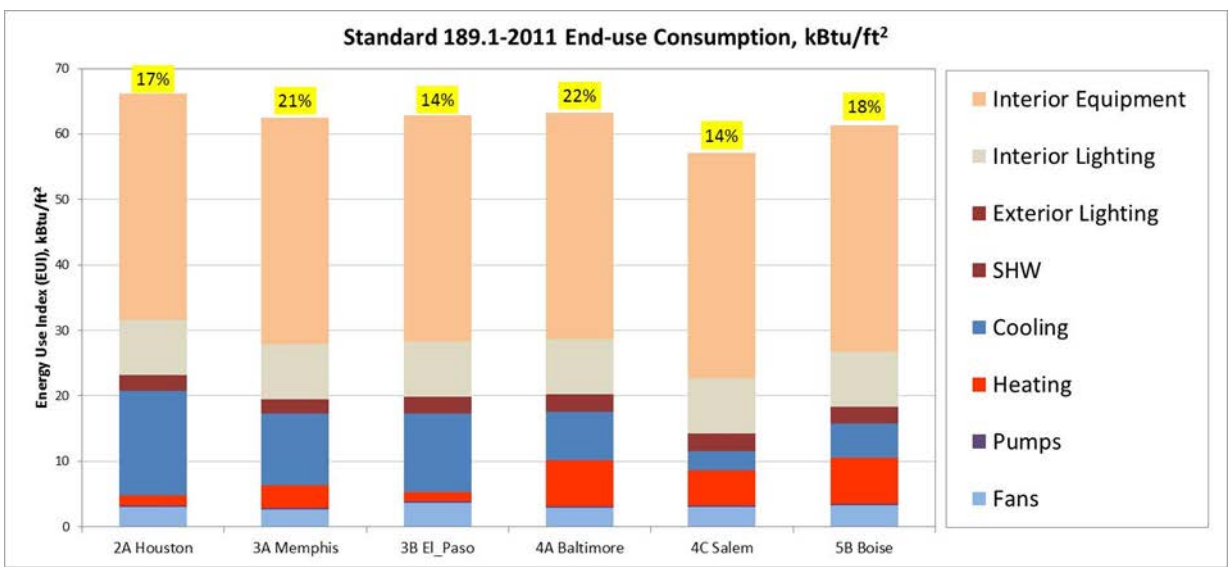

Figure 4. Bde HQ – Energy Consumption Savings Compared to 90.1-2007 by Climate Zone

2.5 Impact of Plug and Process Loads

ASHRAE standards do not regulate plug or process loads. Plug and process loads are usually outside of the scope of new Army facility construction projects. However, as buildings become more efficient, plug and process loads become equally important in terms of the amount of energy used.

2.5.1 TEMF

As illustrated by comparing Figure 1 to Figure 5, TEMF plug loads are not a significant load when compared to ventilation fan energy and heating energy. Plug load densities were represented as typical loads for office spaces, work benches, and automotive repair facilities. The whole building energy savings, including plug loads, were 8 to 17 percent across climate zones. When plug loads are not considered, whole building energy savings increase to 10 to 19 percent on average across all climate zones.

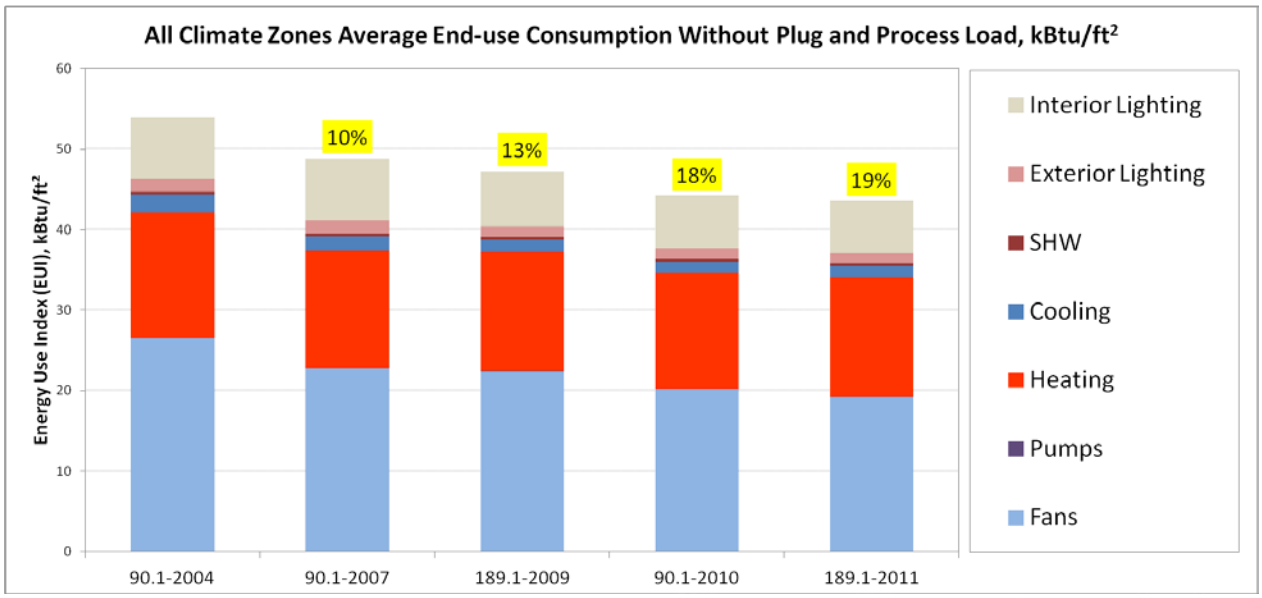

Figure 5. TEMF – Average End-Use Consumption (kBtu/ft^2) after Removing Plug and Process Loads (the percent change noted at the top of each column is in comparison to 90.1-2004)

2.5.2 Bde HQ

Figure 6 shows the EUI (kBtu/ft^2) of the Bde HQ building averaged across the six selected climate zones excluding plug loads (see Figure 2 for comparison). The whole building energy savings, including plug loads, were 4 to 21 percent across all climate zones. When plug loads are not considered, whole building energy savings increases to 7 to 35 percent across climate zones.

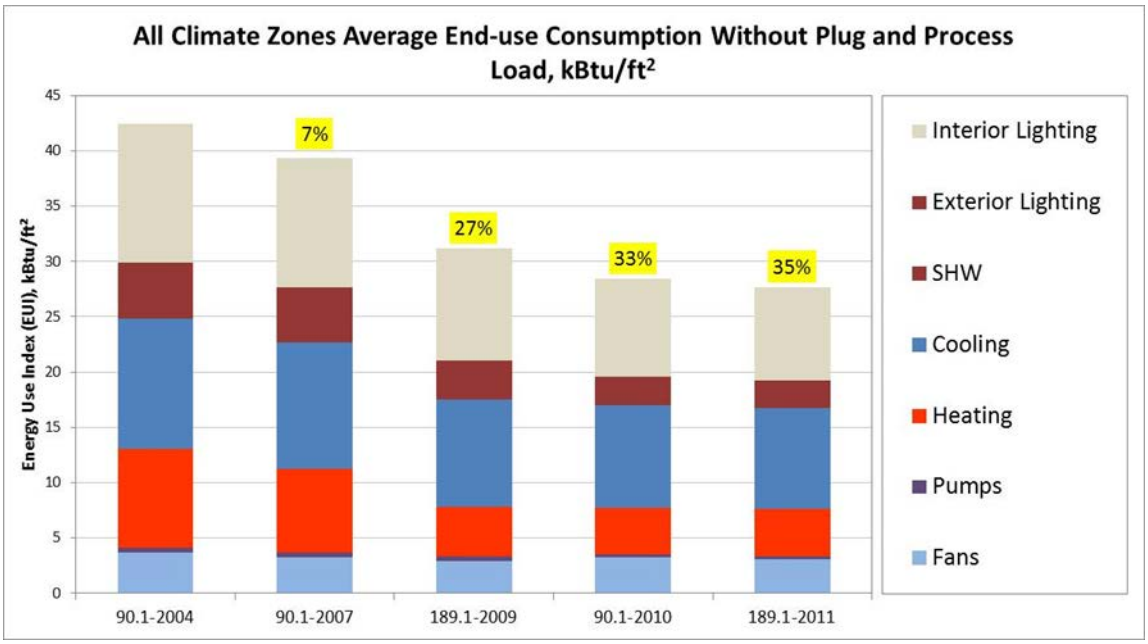

Figure 6. Bde HQ – Average End-Use Consumption (kBtu/ft^2) after Removing Plug and Process Loads (the percent change noted at the top of each column is in comparison to 90.1-2004)

2.6 Comparison to Commercial Buildings

Table 1 and Figure 7 compare the EUI of the Bde HQ and the TEMF buildings with that of buildings analyzed previously in Thornton et al. (2011). Prototype buildings included a large office, a medium office, a warehouse, and a mid-rise apartment building. The office buildings and warehouse referenced in Thornton et al. (2011) were the closest building types available to the Bde HQ and TEMF. A prototype mid-rise apartment building was included to provide an additional data point in terms of energy use and because it most closely resembles another Army building type, Unaccompanied Enlisted Personnel Housing (UEPH) or barracks. ASHRAE 90.1-2010 was used as a baseline for the comparison to commercial buildings because it was the only data available for all building types.

The EUI of the TEMF is much higher than the prototype warehouse building because of the vehicle maintenance shops and the high outdoor air requirements in the TEMF building. However, when comparing the TEMF to a standard automotive repair facility, the most significant difference is the high ventilation rate required to eliminate health-threatening contaminants found in large diesel vehicle engine exhaust. As mentioned in Section 2.2.3, the high ventilation rates cause the fan and heating energy (during winter months) to be extremely high. In addition, the TEMF has architecturally programmatic differences from standard vehicle maintenance facilities that influence energy consumption. The TEMF has a large office space on a separate floor and does not include customer waiting areas. This contrast may account for differences in lighting power densities and plug loads (e.g., televisions, cash registers, and small refrigerators).

As previously discussed, the Bde HQ is dominated by internal loads typical of medium-sized office buildings. However, it also incorporates a data center, which is usually found in much larger office buildings but was absent from the prototype office buildings in Thornton et al. (2011). The data center presents a larger than usual internal load and is the single largest consumption among different end-uses.

The data center dilutes the energy savings because its energy use is not regulated by ASHRAE 90.1 or 189.1. This difference explains why the EUI is significantly higher for the Bde HQ than for the two prototype office buildings.

Table 1. EUI Comparison between PNNL Prototype Buildings, Bde HQ and TEMF

Building	2A Houston	3A Memphis	3B El Paso	4A Baltimore	4C Salem	5B Boise	Average
Bde HQ	67.5	63.6	63.8	64.0	56.8	62.1	63.0
TEMF	44.7	50.5	46.2	63.4	56.6	67.2	54.8
Medium office	38.1	36.1	34.1	36.9	33.2	36.1	35.8
Large office	34.5	33.0	30.3	33.4	29.4	31.8	32.1
Warehouse	13.7	16.4	15.4	20.5	18.8	21.2	17.7
Mid-rise apartment	37.8	38.8	36.4	42.5	39.1	42.6	39.5

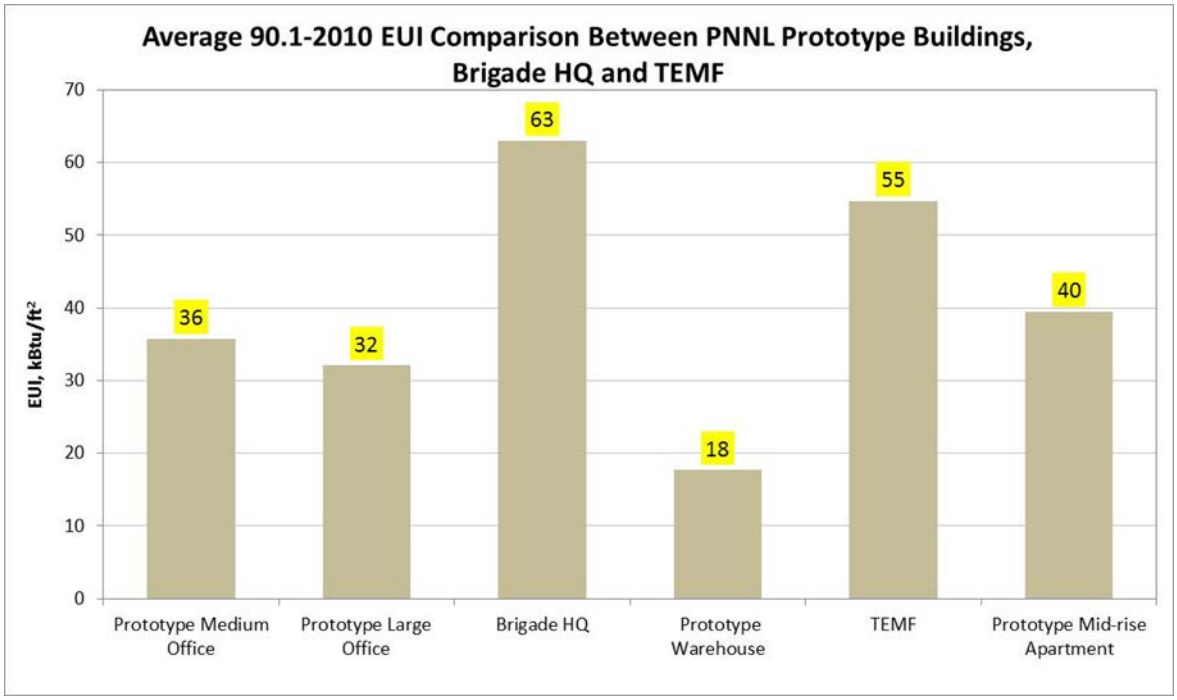

Figure 7. Average End-Use EUI Comparison between Army and Prototype Buildings for Six Climate Zones

3.0 Results of First-Cost Analysis and Discussion

The USACE Louisville District was tasked to perform the cost impact for this study related to energy and sustainability standards for the TEMF and the Bde HQ facilities. These facilities were studied in the same six climatic zones used for energy modeling to examine the cost impacts of complying with both versions of 189.1 versus 90.1-2007. The criteria of each standard was interpreted and applied to both facilities in each climate zone by the relevant design disciplines. The requirements were identified and applicable

changes were made to standard facility designs. These changes were then estimated to establish the cost impact for comparison.

3.1 Estimating Methodology

Each building was estimated in detail using Micro-Computer Aided Cost Estimating Software (MCACES) V4.1. Estimates were based on those in the Military Construction (MILCON) Energy Efficiency and Sustainability Study of Five Types of Army Buildings, July 2011 (Carpio and Soulek, 2011), and modified per the requirements for each building and climate zone to establish a construction cost. The use of an estimating framework with modifications allowed a simple "delta" approach to be used to establish the cost impact of complying with the newer standards.

The methodology used for the cost estimates considered the following criteria:

- The prescriptive option, not the performance option, of 189.1 was used.
- Many requirements (e.g., lower lighting power densities) were already implemented within current designs in an attempt to achieve LEED® Silver design goals.
- The material Area Cost Factor (ACF) from the approved data set for Parametric Cost Engineering System (PACES) 1.0 software was used to address local material cost fluctuations.
- The appropriate local Davis-Bacon wage decision[1] was used to reflect the local labor market.
- State designations for contractors were based on the locale to appropriately capture payroll tax and insurance effects for each trade.
- Contractors were assigned, as appropriate, to task items with specific markups, rather than using a general prime/sub relationship.
- The RS Means 2010 Unit Price Book[2] was used in conjunction with vendor pricing on major mechanical equipment.
- An additional material adjustment factor of 10 percent was applied to material costs only to address historical cost inflation according to Engineering News Record data[3] from the period of January 2010 to October 2012, thus making material costs current.
- No escalation or construction schedules were applied due to the theoretical nature of the study.
- Design costs were not included in the cost estimates.
- Vendor pricing for major mechanical equipment was obtained where possible. Because it was impractical to obtain vendor pricing for every possible combination in the study, a simple regression was used to establish costs for components that fell between provided cost data at the extremes of the equipment size/efficiency range and several points in between.

[1] Accessed from http://www.wdol.gov/dba.aspx
[2] USACE database within MII software based on the RS Means cost books data and additional data compiled by USACE
[3] USACE spreadsheet that tracks historic ENR cost index trend data, particularly January 2010 and November 2012

This costing exercise does not include the design labor. While some material costs are associated with implementing the electrical changes required by 189.1, the design labor would be indirectly related to the cost increase because some material costs cancel others out. For example, greater effort, and therefore, a higher design cost, may be required at lower lighting levels to ensure even and adequate illumination while maintaining required power densities. Similarly, other requirements indicate higher labor cost while not necessarily adding significantly to material costs. However, it is important to note that by using a standard design approach, the design cost should only be incurred once rather than for each individual building.

In addition, this exercise was specific to the designs provided as part of this study. The results would vary if changes were made based on project team decisions in electrical or other system costs or if other design approaches were taken. Based on these particular designs, electrical costs are relatively low compared to other design disciplines.

3.2 Costing Results

All new federal facilities are required to be designed to meet EPAct energy savings requirements. The Army has chosen to meet EPAct by using 189.1-2009 with modifications. In this study, for costing, 90.1-2007 was used as the baseline because 90.1 and 189.1 are standards with prescriptive requirements, as opposed to EPAct requirements that use performance-based parameters. Using a baseline with EPAct performance-based requirements would produce results open to multiple interpretations and potential uncertainty.

3.2.1 TEMF Costing Results

For TEMF, compliance with 189.1-2009 versus 90.1-2007 comes at an overall project cost increase of 1.7 percent on average, with values falling between -1.3 and 4.1 percent depending on climate zone (see Table 2). By comparison, compliance with 189.1-2011 versus 90.1-2010 is slightly less at 1.5 percent cost increase on average, with values varying between -1.2 and 3.8 percent depending on climate zone. Cost differences between the 189.1-2009 and 189.1-2011 standards are negligible (0.2 percent) and well within estimating error.

Comparing only primary facility cost which includes everything within 5 ft of the building footprint, an average increase of 3.7 percent was observed compared to 90.1-2007, due to more stringent insulation and lighting requirements. Comparing the cost of supporting facilities, located within the boundaries of the site but beyond 5-ft from the building, an average of -0.7 percent was observed, primarily due to decreased underground storm water detention capacity.[1]

[1] In general, within the 5-ft line is primary, outside is supporting. However, major mechanical equipment and/or the yard, even if not located inside the 5-ft line, often is considered primary. Though some exceptions exist, but the 5-ft line gives the best idea of what is meant by the division.

In this case, supporting facilities are really just site work. In the case of the TEMF, the majority is heavy concrete paving. In the case of the Bde HQ, the majority is landscaping and parking. The Bde HQ has more landscaping and less parking; the opposite is true for the TEMF. In addition, each facility has some utility development (e.g., electrical, water, sewer, gas).

Table 2. TEMF Primary and Supporting Facilities Construction Costs

TEMF Construction Cost	Type	ASHRAE 90.1 (2007) Compliant	ASHRAE 189.1 (2009) Compliant	Δ% Compared to 90.1-2007	ASHRAE 189.1 (2011) Compliant	Δ% Compared to 90.1-2007
Houston, TX 2A	Primary	$5,694,751	$5,884,439	3.3%	$5,863,027	3.0%
	Support	$4,976,748	$4,909,840	-1.3%	$4,915,255	-1.2%
Memphis, TN 3A	Primary	$6,037,809	$6,238,276	3.3%	$6,211,747	2.9%
	Support	$5,161,874	$5,108,677	-1.0%	$5,114,196	-0.9%
El Paso, TX 3B	Primary	$5,112,766	$5,298,270	3.6%	$5,276,930	3.2%
	Support	$4,728,740	$4,738,875	0.2%	$4,743,555	0.3%
Baltimore, MD 4A	Primary	$6,850,712	$7,118,830	3.9%	$7,097,023	3.6%
	Support	$5,802,975	$5,726,160	-1.3%	$5,733,285	-1.2%
Salem, OR 4C	Primary	$7,117,050	$7,412,271	4.1%	$7,390,550	3.8%
	Support	$6,027,471	$6,022,431	-0.1%	$6,030,384	0.0%
Boise, ID 5B	Primary	$6,637,212	$6,898,933	3.9%	$6,876,305	3.6%
	Support	$5,553,065	$5,511,273	-0.8%	$5,517,688	-0.6%
Average	Primary	$6,241,717	$6,475,170	3.7%	$6,452,597	3.4%
	Support	$5,375,146	$5,336,209	-0.7%	$5,342,394	-0.6%
Total Average	Both	$11,616,862	$11,811,379	1.7%	$11,794,991	1.5%

The breakdown for the TEMF by climate zone generally shows the same relationships among systems (see Appendix D). More stringent building envelope requirements in terms of insulation and sunshades result in an average cost increase of 5.9 percent. In addition, HVAC and electrical costs result in average increases of 2 to 3 percent and 14.5 to 16.9 percent, respectively. Further, the added cost of the condensate recovery system is small, but higher than in the Bde HQ due to the layout and pumping requirements.

Paving costs are higher for the TEMF due to the large amounts of pervious concrete needed to satisfy the stormwater requirements of 189.1-2011. This increase ranges between 0.6 and 2.2 percent, except for in El Paso, where annual rainfall is so low that pavement changes are not required.

Stormwater storage capacity requirements for the 189.1-2011 compliant building result in a significant cost reduction which drives a decrease in the supporting facilities cost. Landscaping requirements for the 189.1-2011 compliant building result in a minimal overall impact due to the small planted area surrounding the TEMF. The Bde HQ has a much larger planted area, amplifying the overall effect.

3.2.2 Bde HQ Costing Results

As with the TEMF, Bde HQ compliance with 189.1-2009 versus 90.1-2007 comes at a small average overall project cost increase (2.7 percent) (see Table 3). Costs associated with 189.1-2011 and 90.1-2007 are essentially the same, with values varying between 2.4 and 3.1 percent. Therefore, the cost increases between 189.1-2009 and 189.1-2011 are negligible. Analogous to the TEMF in terms of the primary facility costs, there is an increase on average of 2.4 percent. Supporting facility costs increase 3.7 percent, on average, due primarily to landscaping requirements.

Table 3. Bde HQ Primary and Supporting Facilities Construction Costs

Bde HQ Construction Cost	Type	ASHRAE 90.1 (2007) Compliant	ASHRAE 189.1 (2009) Compliant	Δ% Compared to	ASHRAE 189.1 (2011) Compliant	Δ% Compared to
Houston, TX 2A	Primary	$7,963,589	$8,156,896	2.4%	$8,176,124	2.7%
	Support	$2,391,495	$2,504,481	4.7%	$2,504,481	4.7%
Memphis, TN 3A	Primary	$4,996,360	$5,185,817	3.8%	$5,176,878	3.6%
	Support	$1,298,273	$1,430,135	10.2%	$1,430,135	10.2%
El Paso, TX 3B	Primary	$7,429,442	$7,614,767	2.5%	$7,611,417	2.4%
	Support	$2,225,108	$2,271,537	2.1%	$2,271,537	2.1%
Baltimore, MD 4A	Primary	$9,327,901	$9,557,863	2.5%	$9,554,059	2.4%
	Support	$2,811,536	$2,941,990	4.6%	$2,941,990	4.6%
Salem, OR 4C	Primary	$9,646,806	$9,869,347	2.3%	$9,859,946	2.2%
	Support	$3,121,864	$3,244,213	3.9%	$3,244,213	3.9%
Boise, ID 5B	Primary	$9.032,469	$9,242,668	2.3%	$9,234,390	2.2%
	Support	$2,711,233	$2,799,737	3.3%	$2,799,737	3.3%
Average	Primary	$7,872,820	$8,271,226	2.6%	$8,268,802	2.6%
	Support	$2,426,585	$2,532,016	4.8%	$2,532,016	4.8%
Total Average	Both	$10,299,404	$10,803,242	3.7%	$10,800,818	3.7%

As noted in the TEMF results, breakdowns for each climate zone generally show the same relationships among systems (Appendix D provides the cost breakdown for the Bde HQ and TEMF by climate zone). A minor decrease in plumbing cost is observed in Bde HQ facilities due to lower capacity water heaters; no new plumbing standards were indicated for TEMF. Minor changes in HVAC costs are due to slight fluctuations in equipment capacity. A notable increase in electrical costs is present in all climate zones due to lighting control and monitoring requirements. The cost of the electrical upgrades are offset in part by cost reductions due to smaller HVAC equipment feeds, disconnects, etc. where equipment was downsized. The impact of the condensate recovery system is smaller in the case of the Bde HQ due to the simple gravity-fed design and close proximity of the air-handling units. Further, requirements for pervious pavement can result in modest cost increases and requirements for native plantings can result in significant cost increases.

4.0 Life-Cycle Cost Analysis

An LCCA was performed for the TEMF and Bde HQ using Building Life-Cycle Cost/Federal Energy Management Program (BLCC/FEMP) life cycle software, which complies with the federal life-cycle costing guidelines as described in NIST Handbook 135, Life-Cycle Costing Manual for the FEMP.

As discussed in the previous section, the construction cost increase from 189.1-2009 and 189.1-2011 is negligible and within the estimating margin of error. The results of the LCCA show a similar result for the Bde HQ and the TEMF in terms of the comparison between the two versions of 189.1. Relative to the baseline in the study, meeting the requirements of 189.1-2011 is life-cycle cost effective well within the 40-year payback period, results range between 6-15 years, for both facilities in all of the climate zones (Appendix E).

Additional factors influenced these results, including maintenance costs and low energy costs available to Army installations but not generally available to the commercial sector in the same geographic area. The

assumption is that the maintenance cost element is a function of investment cost (1 percent or less of total) on an annual basis.

5.0 Comparing 189.1-2011 to other Mandates, Policies, and Standards

To better understand the impact of 189.1-2011 on Army facilities, a mapping exercise (Appendix B) was completed to determine how 189.1-2011 compared with HPSB GP and other mandates, policies, and standards (MPS), including LEED-2009. To facilitate the mapping exercise, 189.1-2011 requirements were first separated into the following section topics: site sustainability; water use efficiency; energy efficiency; indoor environmental quality; the building's impact on the atmosphere, materials, and resources; and construction and plans for operation. Individual requirements within those sections were then listed to assist in identifying corresponding requirements in the MPS. An Excel spreadsheet was used to track the mapping. The MPS was reviewed and the corresponding requirement (if located) was placed under an Excel tab for the appropriate 189.1-2011 section. In addition, a ranking and corresponding notes column was generated. The ranking column includes a visual graphic depicting the level of compliance with 189.1-2011 that would be obtained if the MPS requirement was met.

5.1 189.1 Compared to HPSB GP

Although there is topical alignment between 189.1-2011 and the HPSB GP, a more detailed comparison of requirements revealed several incongruities between the documents. In many cases, the HPSB GP includes minimal and high level (e.g., site sustainability) guidelines, while 189.1-2011 includes specific and comprehensive requirements. As a result, compliance with 189.1-2011 would meet or exceed HPSB GP for site sustainability; indoor environmental quality; impact on the atmosphere, materials, and resources; and construction plans for operation.

However, HPSB GP for water efficiency and energy efficiency are focused on meeting energy-reduction goals relative to a baseline, while 189.1-2011 requirements in these areas are more prescriptive in terms of the equipment and systems employed. Although the energy- and water-reduction goals in the HPSB GP would likely be achieved by complying with 189.1-2011, a more detailed quantitative comparison, factoring in building type and location, would be necessary for a definitive conclusion. For example, in terms of water efficiency, meeting HPSB GP water-savings targets will depend on the number and type of fixtures that are subject to the prescriptive requirements in 189.1-2011.

With regard to energy efficiency, the overall guidance and goal of the HPSB GP is to reduce energy use by 30 percent compared to the baseline building performance rating per 90.1-2007. ASHRAE 189.1-2011significantly reduces the gap between earlier versions of ASHRAE Standard 90.1 and the requirements of HPSB GP. However, the manner in which a building meets the 30 percent energy-reduction goal (relative to 90.1-2007) is not explicitly prescribed in the HPSB GP.

5.2 189.1 Compared to LEED

LEED is a voluntary program that allows a project to select credits from several subject areas (e.g., energy, water). Points associated with the credits are awarded upon successful completion of the certification process. Because LEED permits a project to select specific subject areas for certification,

there is no guarantee that credits will be obtained in any specific subject area. In addition, credits can be obtained in various ways, not all of which are equal in compliance with the 189.1-2011.

In other words, where you end with this analysis depends on where you start. Analyzing LEED as compared to 189.1-2011, yields different conclusions than if you begin by basing your analysis on 189.1-2011 and then compare to LEED. To put it another way, it is easy to show where the two systems are not equivalent, but difficult, if not impossible in most cases, to show exactly where they are equivalent. This is compounded by certification/documentation issues. While it is possible to say that the two are "close enough," concluding that there is complete equivalence would be inaccurate. As such, a conclusion that a 189.1-2011 compliant building is equivalent to a specific level of LEED certification is dubious, whereas a 189.1-2011 compliant building may be comparable to a LEED building across a range of certification levels.

Therefore, the level of compliance with 189.1-2011 is heavily dependent on the level of LEED certification selected, the choices of which credits to pursue made by the project team, and the methods used in obtaining those credits.

5.2.1 LEED Certification

The mapping exercise determined that 28 of the 131 189.1-2011 sections align or "match" with LEED requirements. An additional 60 requirements in 189.1-2011 are similar to LEED requirements, but are not an exact match and therefore not equivalent to LEED requirements and, as a result, 189.1-2011 requirements may or may not be met. In many cases, LEED requires compliance with previous versions of standards referenced in 189.1-2011, such as ASHRAE Standard 90.1, and the differences between the referenced documents may or may not effect compliance with 189.1-2011. A total of 15 additional sections of 189.1-2011 are mentioned in LEED, but not required or as specific as those in 189.1-2011. The 28 remaining sections are not mentioned in LEED. Upon analysis of these similarities and differences, potential LEED Certification for a 189.1-2011 building was determined to range from Certified to Gold.

6.0 Conclusions

Several questions were posed to determine whether the Army should adopt 189.1-2011 as its standard for new construction. These questions included:

- Does 189.1-2011 meet the HPSB GP?
- What are the significant differences between 189.1-2009 and 189.1-2011 and their referenced standards (i.e., 90.1-2007 and 90.1-2010, respectively)?
- What is the difference in the energy savings modeled for two building types (i.e., TEMF and Bde HQ) across six climate zones?
- How do the two facilities studied compare to prototype commercial office buildings?
- What is the first-cost difference if 189.1-2011 is adopted?
- Is 189.1-2011 life cycle cost effective?

- What level of LEED Certification would Army projects achieve if 189.1-2011 were adopted?

These questions are answered as follows:

Does 189.1-2011 meet the HPSB GP?

ASHRAE Standard 189.1-2011 would meet or exceed the HPSB GP guidance and requirements in all areas except energy and water efficiency. Particularly with regard to energy efficiency, following 189.1-2011 requirements results in a more energy-efficient baseline building than earlier versions of 90.1 and reduces the gap between the baseline energy performance and the requirements of the HPSB GP. In terms of water efficiency, meeting HPSB GP water-savings targets will depend on the number and type of fixtures subject to the prescriptive requirements in 189.1-2011. Meeting the 189.1-2011 requirements does not guarantee compliance with HPSB GP but does bring a building closer to meeting those targets. Because 189.1-2011 has a prescriptive approach and the HPSB GP has a performance-based approach, facilities may need to be evaluated by type and climate zones to verify compliance with HPSB GP requirements.

Conclusion: 189.1-2011 would meet or exceed the HPSB GP guidance and requirements in all areas except water efficiency and energy efficiency. Because 189.1-2011 has a prescriptive approach and HPSB GP has a performance-based approach, facilities may need to be evaluated by type and climate zones to verify compliance with the energy and water HPSB GP requirements. Meeting the 189.1-2011 requirements does not guarantee compliance with HPSB GP but does bring the building closer to meeting those targets.

What are the significant differences between 189.1-2009, 189.1-2011, and their referenced standards (i.e., 90.1-2007 and 90.1-2010, respectively)?

ASHRAE Standard 189.1 is based largely on other ASHRAE Standards, including 62.1, 90.1, and 55, and aims to decrease whole building energy consumption and the impact a building has on the environment. While 189.1-2009 and 189.1-2011 are comparable in the topics addressed, 189.1-2011 is more detailed and includes additional requirements or exceptions than 189.1-2009, making it a more stringent option for green buildings.

Based on the mapping exercise found in Appendix B, 189.1-2009 requirements match 94 of the 131 (or 71 percent) of the 189.1-2011 sections evaluated. An additional 34 requirements in 189.1-2009 are similar to 189.1-2011 requirements, but are not an exact match. One additional section of 189.1-2011 is mentioned in 189.1-2009 but is not required or as specific as that in 189.1-2011. The two remaining sections are not mentioned in 189.1-2009. In many cases, 189.1-2009 requires compliance with previous versions of standards referenced in 189.1-2011, such as ASHRAE Standard 90.1.

The greatest differences between 189.1-2009 and 189.1-2011 (based on a text-to-text comparison) were found in Section 7 (Energy Efficiency) and Section 8 (Indoor Environmental Quality). In particular, 189.1-2011 includes a significant number of energy-efficiency requirements not present in 189.1-2009.

The most significant changes to Section 7 include the requirements added to the prescriptive option of 189.1-2011 for onsite renewable energy systems, lighting power allowance, and occupancy sensors. Exceptions were added in 189.1-2011 for HVAC economizers and zone controls. Occupancy sensor

controls, automatic controls for lighting in daylight zones, and an annual energy cost for the performance option in 189.1-2009 were incorporated in the update to 90.1-2010.

In Section 8, additional prescriptive requirements or exceptions were added to 189.1-2011 for sidelighting, mandatory provisions for particulate matter, and open space shading. In addition, the performance option requirement for usable illuminance in office spaces and classrooms changed from 189.1-2009.

Further, minor changes were made to Section 5 (Site Sustainability), Section 6 (Water Use Efficiency), Section 9 (The Building's Impact on the Atmosphere, Materials, and Resources), and Section 10 (Construction and Plans for Operation).

The text-by-text differences between versions of 189.1 would be incomplete without an analysis of the underlying referenced 90.1 documents and the impact of those changes on new construction. An understanding of all four of these standards results in a clear distinction between the impact of adopting 189.1-2011 and simply adopting 90.1-2010.

For example, the major envelope, lighting, and HVAC requirements of both 189.1 standards remain constant, but the underlying 90.1 requirements for each version have important differences. A significant increase in energy savings (%) is indicated between 90.1-2010 and 90.1-2007. In addition, an increase in energy savings (%) is indicated between 90.1-2007 and 90.1-2004. The difference in energy savings represents a geometric increase from 90.1-2004 to 90.1-2010 as the standards subsequently become more restrictive. The 189.1 envelope requirements are more stringent than those found in 90.1. ASHRAE 90.1-2010 includes requirements for air barriers, vestibules, fenestration orientation, and cool roofs not included in 90.1-2007. Further, the interior and exterior LPD requirements of 90.1-2010 are more stringent than those of 90.1-2007 or 90.1-2004. Both 189.1 standards reference the corresponding 90.1 LPDs but lower them by 10 percent. Occupancy sensor controls and other lighting controls are taken from corresponding 90.1 standards, except in a few cases where 189.1 standards impose more stringent requirements.

Daylighting controls are not required by 90.1-2004 or 90.1-2007, but are required in 90.1-2010 and both 189 standards. Both 189.1 standards have more stringent daylighting control requirements than 90.1-2010.

Conclusion: 90.1-2010 requirements are more stringent than previous versions of the standard and 189.1-2011 (which includes 90.1-2010 by reference) has some significant differences from 189.1-2009, particularly in Section 7 (Energy Efficiency) and Section 8 (Indoor Environmental Quality).

What is the difference in the energy savings modeled for two building types (i.e., TEMF and Bde HQ) across six climate zones?

For the TEMF, the energy savings of 90.1-2007 compared to 90.1-2004 on average are 8 percent, which is higher than the average (5 percent) determined for 15 prototype buildings in PNNL's 2011 study (Thornton et al. 2011). An additional savings of 3 percent was seen with 189.1-2009 over 90.1-2007. The 90.1-2010 savings compared to 90.1-2007 (8 percent) incorporate a number of improvements not found in 189.1-2009. ASHRAE 189.1-2011 builds on 90.1-2010 as its base reference standard, and as a result saves slightly more energy than 90.1-2010 on its own.

For the Bde HQ, the energy savings of 90.1-2007 (4 percent) compared to 90.1-2004 is in line with the average determined for 15 prototype buildings (5 percent) in PNNL (Halverson et al. 2011a). Some new requirements, which were to be incorporated into 90.1-2010, were adopted by 189.1-2009. As a result, relative to 90.1-2004, the savings based on 189.1-2009 are large (14 percent) when compared to 90.1-2007 (4 percent). The 90.1-2010 savings (20 percent) compared to 90.1-2004 incorporate a number of improvements not found in 189.1-2009. ASHRAE 189.1-2011 uses 90.1-2010 as its base standard, and saves slightly more energy than 90.1-2007 (21 percent).

Depending on the type of facility and the energy load profile, plug and process loads may play a critical role in the amount of energy that can be saved since no ASHRAE standards regulate plug or process loads (i.e., unregulated loads). In the TEMF, the fan energy and heating load are the dominant factors of the energy profile. Plug load densities were represented as typical loads for office spaces, work benches, and automotive repair facilities. For the TEMF, the whole building energy savings found, including plug and process loads, was 8 to 17 percent across climate zones. When plug and process loads are not considered, whole building energy savings increases to 10 to 19 percent across climate zones.

In the Bde HQ, the dominant factor is the data center. Data centers are a 24–7 load and require mechanical cooling even during winter months. In the Bde HQ, the whole building energy savings found, including plug loads, was 4 to 21 percent across climate zones. When plug loads are not considered whole building energy savings increases to 7 to 35 percent across climate zones.

Table 4 and Table 5 show the site EUI of the TEMF and Bde HQ, respectively, in the six climate zones studied (including plug and process loads). The percentage energy savings of 189.1-2011 compared to 90.1-2004 and 90.1-2007 are also shown.

Table 4. Site EUI of TEMF in Six Climate Zones

Climate Zone	Location	90.1-2004	90.1-2007	189.1-2009	90.1-2010	189.1-2011	% Savings 189.1-2011 vs. 90.1-2007	% Savings 189.1-2011 vs. 189.1-2009
2A	Houston	50.2	46.6	44.7	41.8	40.9	12%	9%
3A	Memphis	57.0	52.3	50.5	47.9	47.1	10%	7%
3B	El Paso	52.6	47.8	46.2	43.5	42.7	11%	8%
4A	Baltimore	71.3	64.9	63.4	59.8	59.3	9%	7%
4C	Salem	63.0	57.8	56.6	53.5	53.1	8%	6%
5B	Boise	74.8	68.4	67.2	64.1	63.8	7%	5%

Table 5. Site EUI of Bde HQ in Six Climate Zones

Climate Zone	Location	90.1-2004	90.1-2007	189.1-2009	90.1-2010	189.1-2011	% Savings 189.1-2011 vs. 90.1-2007	% Savings 189.1-2011 vs. 189.1-2009
2A	Houston	82.2	80.2	74.1	67.5	66.2	17%	11%
3A	Memphis	81.8	78.9	68.2	63.6	62.4	21%	9%
3B	El Paso	75.4	72.9	68.4	63.8	62.8	14%	8%
4A	Baltimore	85.6	81.5	67.8	64.0	63.2	22%	7%
4C	Salem	70.6	66.7	61.6	56.8	57.2	14%	7%
5B	Boise	77.8	74.8	65.8	62.1	61.3	18%	7%

Conclusion: Implementation of 189.1-2011 results in significant incremental energy savings as compared to 189.1-2009 for both facility types. Internal plug loads have a significant impact on the Bde HQ energy savings percentage because a large portion of the energy profile is dominated by the unregulated loads of the data center, whereas in the TEMF, the fan energy and heating load are the dominant factors of the energy profile. The major impact of adopting 189.1-2011 would come from the increase in stringency of 90.1-2010. It could be argued that most of the savings in 189.1-2011 could be achieved by adopting 90.1-2010. However, 189.1-2011 includes site sustainability, water conservation, indoor air quality, and renewable energy requirements not included in 90.1-2010.

How do the two facility types studied compare to prototype commercial office buildings?

Table 6 provides a summary of the EUI for the TEMF, Bde HQ, and four similar commercial buildings for 90.1-2010 (Thornton et al. 2010). This helps to put into perspective how these two Army facilities compare to similar commercial buildings in terms of energy use per square foot.

Table 6. Comparison of EUI ASHRAE Standard-Compliant Buildings to Bde HQ and TEMF for ASHRAE 90.1-2010 (Average end-use for six climate zones studied)

Building Type EUI [kBtu/ft^2]	90.1-2010
Bde HQ	63.0
TEMF	54.8
Medium Office	35.8
Mid-Rise Apartment	39.5
Large Office	32.1
Warehouse	17.7

The EUI of the TEMF is much higher than the prototype warehouse building because of the vehicle maintenance shops and the high outdoor air requirements in the TEMF building. However, when comparing the TEMF to a standard automotive repair facility, the most significant difference is the high ventilation rates required to eliminate health-threatening contaminants found in large diesel vehicle engine exhaust. In addition, the high ventilation rates cause the fan energy and heating energy (during winter months) to be extremely high. Further, the TEMF has architecturally programmatic differences from standard vehicle maintenance facilities that influence the energy consumption of the facility. The TEMF has a large office space on a separate floor and does not include customer waiting areas. This contrast may account for differences in lighting power densities and plug loads (e.g., televisions, cash registers, and small refrigerators).

The Bde HQ building is dominated by internal loads typical of medium-sized office buildings. However, it also incorporates a data center, which is usually found in much larger office buildings but was absent from the prototype office buildings in the PNNL study (Thornton et al. 2011). The data center presents a larger than usual internal load and is the single largest consumption among different end-uses. The data center dilutes the energy savings percentage because its energy use is not regulated by ASHRAE 90.1 or 189.1 standards. This is the reason the EUI is significantly higher for the Bde HQ than the two prototype office buildings.

Conclusion: In terms of EUI, Army facilities are significantly different from the prototype commercial buildings used for comparison. This disparity exists because the Army facilities serve unique functions not found in typical commercial buildings. The requirements from these functions result in higher energy consumption compared to more straightforward commercial office buildings and warehouses.

What is the first-cost difference if 189.1-2011 is adopted?

For the TEMF, compliance with 189.1-2009 versus 90.1-2007 comes at an overall project cost increase of 1.7 percent on average, with values falling between -1.3 and 4.1 percent depending on climate zone. Comparatively, compliance with 189.1-2011 versus 90.1-2010 is slightly less at a cost increase of 1.5 percent cost average, with values falling between -1.2 and 3.8 percent. The cost differences between the 189.1-2009 and 2011 Standards are negligible (0.2 percent).

Comparing only the primary facility cost, there is an increase on average of 3.7 percent due to more stringent insulation and lighting requirements. For the supporting facility, there is an average decrease of 0.7 percent, due primarily to decreased underground stormwater detention capacity.

As with the TEMF, the Bde HQ (189.1-2009 versus 90.1-2007) comes at a small average overall project cost increase of 2.7 percent. Compliance with 189.1-2011 versus 90.1-2007 is essentially the same, with values varying between 2.4 and 3.1 percent. Therefore, the cost increases between 189.1-2009 and 2011 are negligible. Analogous to the TEMF in terms of the primary facility costs, there is an increase on average of 2.4 percent. The supporting facility costs increase 3.7 percent, on average, due primarily to landscaping requirements.

Conclusion: Adoption of 189.1-2011 and application to the two Army building types results in a negligible (within estimating error) first-cost increase.

Is 189.1-2011 life cycle cost effective?

The construction cost increase from 189.1-2009 and 189.1-2011 is negligible and within the estimating margin of error. The results of the LCCA show a similar result for the Bde HQ and the TEMF in terms of the comparison between the two versions of 189.1. Relative to the baseline in the study, meeting the requirements of 189.1-2011 is life-cycle cost effective within the 40-year payback period for both facilities in all of the analyzed climate zones.

Conclusion: Adoption of 189.1-2011 is life-cycle cost effective within an acceptable and conservative margin of error.

What level of LEED Certification would Army projects achieve if 189.1-2011 were adopted?

In addition to the mapping exercise, a previous mapping exercise for the MILCON Energy Study that looked at how multiple mandates, policies, and standards compared to LEED was updated with 189.1-2011 requirements and a tally of possible LEED points was calculated. It is estimated that by fulfilling the requirements of 189.1-2011, a project will achieve, at a minimum, the equivalent of LEED Certified and up to the equivalent of LEED Gold. The total points achieved and, therefore, the level of compliance with 189.1-2011 is heavily dependent on the level of LEED certification selected, the choices of which credits to pursue made by the project team, and the methods used in obtaining those credits.

Conclusion: Compliance with 189.1-2011 could result in LEED Certification from Certified to Gold, depending on the level of LEED certification selected, the choices of which credits to pursue made by the project team, and the methods used in obtaining those credits.

Overall Summary and Conclusion:

- ASHRAE 189.1 is a comprehensive standard that includes minimum requirements for energy, air quality, thermal comfort, water, materials, commissioning, and maintenance procedures and processes. ASHRAE 189.1 provides an integrated framework and foundation towards meeting the Army's goals of balancing mission, federal energy, and sustainability policies for military facilities.
- The additional detail, content changes, and new requirements found in 189.1-2011 make it a more stringent standard than 189.1-2009 for high-performance sustainable facilities. Based on the results from the energy models, implementation of 189.1-2011 yields significant incremental energy savings as compared to 189.1-2009. The major impact of adopting 189.1-2011 comes from the reduction in energy consumption required by 90.1-2010. It could be argued that most of the savings in 189.1-2011 could be achieved by adopting 90.1-2010. However, 189.1-2011 includes site sustainability, water conservation, indoor air quality, and renewable energy requirements not included in 90.1-2010.
- Compared to other commercial facilities, Army facilities are significantly different because they serve unique, mission-based functions not found in typical commercial buildings. These functions result in higher energy consumption compared to more straightforward commercial office buildings and warehouses. As a result, adjustments may be necessary to improve energy savings (e.g., reducing and controlling plug loads in Bde HQ or demand-control ventilation in the TEMF).
- Although meeting the 189.1 requirements does not guarantee compliance with the HPSB GP, it does bring the building closer to meeting those targets. With regard to LEED, compliance with 189.1 could result in LEED Certification from Certified to Gold, depending on the level of LEED certification selected, the choices of which credits to pursue made by the project team, and the methods used in obtaining those credits.
- Cost estimates indicate that the difference in cost between the two versions of 189.1 is within margin of error and considered negligible. The LCCA shows that, compared to the baseline, both the Bde HQ and TEMF yield a payback within the 40-year payback period of each facility.
- Based on these findings, it is recommended that 189.1-2011 be adopted for new construction with the exceptions for site and renewable energy requirements as noted above. It is further recommend that the renewable energy requirements of ASHRAE 189.1-2011 be evaluated on a project by project basis.

  When applied to Army facilities, ASHRAE 189.1-2011 establishes a baseline and brings these facilities closer to meeting all additional federal requirements but will not meet them standing alone. Additional performance levels for energy, water, and Army-specific mission and life-safety requirements should be established to fully comply with all criteria.

7.0 References

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2007. *Energy Standard for Buildings*. ASHRAE 90.1-2007, Atlanta, Georgia.

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2010. *Energy Standard for Buildings*. ASHRAE 90.1-2010, Atlanta, Georgia.

ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2009. *Standard for the Design of High-Performance, Green Buildings Except Low-Rise Residential Buildings*. ASHRAE 189.1-2009, Atlanta, Georgia.

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

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2007. *Ventilation for Acceptable Indoor Air Quality*. ASHRAE 62.1-2007, Atlanta, Georgia.

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2010. *Ventilation for Acceptable Indoor Air Quality*. ASHRAE 62.1-2010, Atlanta, Georgia.

Carpio DM and AB Soulek. 2011. Military Construction (MILCON) Energy Efficiency and Sustainability Study of Five Types of Army Buildings, U.S. Army Corps of Engineers.

Energy Policy Act of 2005 (EPAct 2005). Public Law 109-58. 08 Aug 05, U.S. Government Printing Office.

Halverson M, B Liu, E Richman, and D Winiarski. 2011a. *ANSI/ASHRAE/IESNA Standard 90.1-2007 Final Determination Quantitative Analysis*, Pacific Northwest National Laboratory/US Department of Energy, May 2011, PNNL-20456..

Halverson M, B Liu, M Rosenberg. 2011b. *ANSI/ASHRAE/IESNA Standard 90.1-2010 Final Determination Quantitative Analysis*, Pacific Northwest National Laboratory/US Department of Energy, October 2011, PNNL-20882.

Thornton BA, W Wang, H Cho, B Liu, MI Rosenberg, Y Xie, VV Mendon, EE Richman, J Zhang, and RA Athayle. 2011. *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*. Pacific Northwest National Laboratory/U.S. Department of Energy: 370 pp.

Appendix A

Bibliography

To assist the modelers and cost estimators in both framing and addressing questions related to the cost-effectiveness of ASHRAE Standard 189.1-2011 for the U.S. Army Corps of Engineers (USACE) building stock, Pacific Northwest National Laboratory developed an annotated bibliography of related studies, reports, and articles on the topic. A literature search was conducted to capture literature from the past ten years that addressed "green" buildings and high-performance energy-efficient buildings, as well as reports related to commercial building efficiency and sustainability standards and rating systems.

The key findings of approximately 90 studies/reports were summarized and categorized in terms of their relevancy to the cost-effectiveness of high-performing buildings and the USACE building stock. Specifically, the literature was characterized and evaluated in terms of the following criteria:

- Applicability to the USACE and federal government building stock
- Applicability to Standard 189.1-2009 and 2011 criteria
- Substance of data and methodology (conclusions and findings based on empirical data and sound methodology rather than anecdotes and opinions)
- Transparency and accessibility (is data and process presented in a manner that one could confirm and apply appropriately to other questions/situations?)
- Timeliness (are the findings outdated or still relevant?).

Approximately 24 of the studies/reports were ranked as being highly relevant to addressing the questions related to cost-effectiveness in terms of the above described criteria. An effort was made to identify patterns and relationships among study results, including any sources of agreement or disagreement among results.

File can be found here: http://mrsi.usace.army.mil/sustain/SitePages/PolicyToolsReferences.aspx

Appendix B

Mapping the Differences between the Standards

There are numerous mandates, policies, and standards (MPS) in effect that can be confusing and difficult to understand, particularly when compared to each other. To address this issue, a mapping exercise was completed that answers the following questions:

If a currently available MPS is met by a facility, how will the facility be impacted if American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) 189.1-2011 becomes the baseline?

Concurrently, will 189.1-2011 requirements be achieved by complying with the requirements of a current MPS?

To facilitate the mapping exercise, AHSRAE 189.1-2011 requirements were separated into section topics and individual requirements within those sections were listed to assist in identifying corresponding MPS requirements. In addition, a ranking and corresponding notes column was generated. The ranking column includes a visual graphic depicting the level of compliance of the MPS with ASHRAE 189.1-2011. The following is a description of the graphic used:

● *Solid circle*: The MPS requirement meets or exceeds the 189.1-2011 requirement.

◑ *Half-filled circle*: The MPS requirement is patterned after, but does not fully match, the 189.1-2011 requirement ***or*** at least a portion of the 189.1-2011 requirement is met.

○ *Open circle*: There is a loose association or general relationship of the MPS requirement to 189.1-2011 requirement. The MPS either cannot achieve 189.1-2011 compliance by complying with MPS (1st priority) or it is unclear whether achieving MPS compliance will result in compliance with 189.1-2011 (2nd priority). The MPS requirement may also be listed as a best practice.

Blank: The MPS does not mention the 189.1-2011 requirement or similar best practice.

Results of the comparison study vary by MPS. In general, 189.1-2009, United Facilities Criteria 1-200-02, Sustainable Design and Development Policy, Engineering Construction Bulletins, and Leadership in Energy and Environmental Design (LEED) NC-2009 (in no particular order) were the most comparable to ASHRAE 189.1-2011. In many instances, compliance was difficult to determine because the MPS referenced another document that was not included in this study. The first tab of the Excel mapping spreadsheet includes the title of the 189.1-2011 requirement section header and the graphical rank of each MPS.

In addition to the mapping exercise, a previous mapping exercise MILCON Energy Study that looked at how multiple MPS compared to LEED NC-2009 was updated with 189.1-2011 requirements and a tally of possible LEED points was calculated. It is estimated that by fulfilling the requirements of 189.1-2011, a project will achieve, at a minimum, the equivalent of LEED Certified (solid circles only) and up to the equivalent of LEED Gold (sum of solid and half circles).

File can be found here: http://mrsi.usace.army.mil/sustain/SitePages/PolicyToolsReferences.aspx

Appendix C

Text-by-Text Comparison of ASHRAE Standard 189.1 Versions

A text-by-text comparison of the 2009 and 2011 versions of American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 189.1 was performed and compiled into an Excel spreadsheet format. Due to copyright issues, the text-by-text comparison is only available to USACE personnel at the link provided below and is not publicly available. The study was conducted in two phases: the first phase developed a comparison of the text of the two 189.1 documents to identify the changes that were made to the 2011 version; the second phase was an assessment of the text of select ASHRAE standards referenced in both versions of 189.1. It was necessary to conduct a text-by-text comparison of the referenced standards to fully understand the transition to 189.1-2011 as many are updated versions of documents referenced by 189.1-2009.

C.1 ASHRAE 189.1

The text-by-text comparison of the 2009 and 2011 versions of 189.1 was performed on Section 3, Sections 5 through 10; and Section 11: Normative References. A text-by-text comparison was completed and all of the changes that occurred between 189.1-2009 and 189.1-2011 were indicated for each of the sections considered in this study. Results are as follows:

- Section 3 (Definitions): Several definitions were added and significant changes to the definition of daylight area and invasive plants were made in 189.1-2011.
- Section 5 (Site Sustainability): Minor changes included text rewording, a minor deletion of text from 189.1-2009, and the addition of requirements and exceptions in 189.1-2011. Most notably, requirements pertaining to Plants (5.3.4) and the Mitigation of Transportation Impacts (5.3.5) were added to 189.1-2011.
- Section 6 (Water Use Efficiency): Minor changes were found, mostly rewording for clarification.
- Section 7 (Energy Efficiency): Changes include a modification in the mandatory provisions for onsite renewable energy systems (7.3.2). Additional requirements for the prescriptive option were added to ASHRAE 189.1-2011 for onsite renewable energy systems (7.4.1.1); exhaust air energy recovery (7.4.3.6); automatic control of HVAC and lights in hotel/motel guest rooms (7.4.3.9); lighting power allowance (7.4.6.1); occupancy sensors (7.4.6.4); controls for exterior sign lighting (7.4.6.5); and computer servers, integral LED lamps, and commercial griddles and ovens (7.4.7). Exceptions were added to 189.1-2011 for building envelope permanent projections (7.4.2.5); HVAC economizers (7.4.3.3) and zone controls (7.4.3.4); and automatic control of HVAC and lights in hotel/motel guest rooms (7.4.3.9). Requirements for vestibules (7.4.2.7); duct and plenum leakage (7.4.3.3); HVAC controls (7.4.3.7); pipe insulation (7.4.3.11); occupancy sensor controls (7.4.6.2); automatic controls for lighting in daylight zones (7.4.6.5); controls for outdoor lighting (7.4.6.7); and annual energy cost for the performance option (7.5.2) were deleted from 189.1-2009. Less significant text changes, including rewording for clarification also occurred throughout Section 7.

- Section 8 (Indoor Environmental Quality): Additional prescriptive requirements or exceptions were added to 189.1-2011 for sidelighting (8.4.1.1) and open space shading (8.4.1.2); Mandatory provisions for particulate matter were added as well. In addition, the performance option requirement for usable illuminance in office spaces and classrooms (8.5.1.1) changed. Less significant text changes, including rewording for clarification also occurred throughout Section 8.
- Section 9 (The Building's Impact on the Atmosphere, Materials, and Resources): Minor changes were found, mostly rewording for clarification.
- Section 10 (Construction and Plans for Operation): Minor changes were found, mainly rewording for clarification. In 189.1-2011, fenestration control systems were added to the list of systems that must have acceptance testing (10.3.1.1.3) and be commissioned (10.3.1.2.4).

C.2 Referenced Standards

Differences identified between versions of Section 11 (Normative References) in the 189.1 standards were used to initiate the second phase of the study—the comparison of the referenced ASHRAE standards. Three of the ASHRAE standards referenced in 189.1-2009 have an updated version that is referenced in 189.1-2011:

- 55-2004, including addendum e to 55-2010
- 62.1-2007, including addendum i to 62.1-2010
- 90.1-2007 to 90.1-2010.

Changes that occurred between the versions of the ASHRAE standards were identified using a side-by-side comparison of the text from each document. When comparing the referenced portions of 55-2004 and 55-2010, significant changes were identified in Sections 6.1, "Design," and 6.2, "Documentation." Significant changes were also found in Section 5 (Systems and Equipment) and Section 6 (Procedures) of 62.1-2007 and 62.1-2010. Minor changes in Section 8 (Operations and Maintenance) and Section 4 (Outdoor Air Quality) between the two versions of 62.1 occurred as well.

The majority of the differences between versions of a referenced standard occurred in 90.1-2007 and 90.1-2010. Significant changes were found in the Mandatory Provisions (5.4) of Section 5 (Building Envelope). Similarly, the Mandatory Provisions (6.4) of Section 6 (Heating, Ventilation, and Air Conditioning) and requirements for the Prescriptive Path (6.5) also changed considerably. Minor differences in the Simplified Approach Option for HVAC Systems (6.3) were noted as well. The general description (8.1) and Mandatory Provisions (8.4) of Section 8 (Power) had significant changes, as well as the general description (9.1), Mandatory Provisions (9.4), Building Area Method Compliance Path (9.5), and Alternative Compliance Path: Space-by-Space Method (9.6), and Submittals (9.7) portions of Section 9 (Lighting). Section 10 (Other Equipment) had significant changes to the Mandatory Provisions (10.4).

C.3 Summary

Minor changes were made to Section 5 (Site Sustainability), Section 6 (Water Use Efficiency), Section 9 (The Building's Impact on the Atmosphere, Materials, and Resources), and Section 10 (Construction and

Plans for Operation). The greatest changes were in Section 7 (Energy Efficiency) and Section 8 (Indoor Environmental Quality). The changes in Section 7 in particular represent a significant increase in energy-efficiency requirements as compared to 189.1-2011 and 90.1-2007.

C.4 References

ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2004. *Thermal Environmental Conditions for Human Occupancy*. ASHRAE 55-2004, Atlanta, Georgia.

ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2010. *Thermal Environmental Conditions for Human Occupancy*. ASHRAE 55-2010, Atlanta, Georgia.

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2007. *Ventilation for Acceptable Indoor Air Quality*. ASHRAE 62.1-2007, Atlanta, Georgia.

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2010. *Ventilation for Acceptable Indoor Air Quality*. ASHRAE 62.1-2010, Atlanta, Georgia.

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File is located here: http://mrsi.usace.army.mil/sustain/SitePages/Internal.aspx and has limited access

Appendix D – Cost Estimation Methodology:

http://mrsi.usace.army.mil/sustain/Policy%20Tools%20%20References%20Documents/Appendix%20D%20Cost%20Estimating%20Methodology.pdf

Appendix E – Life-Cycle Cost Estimating Details:

http://mrsi.usace.army.mil/sustain/Policy%20Tools%20%20References%20Documents/Appendix%20E%20Life-Cycle%20Cost%20Analysis.pdf