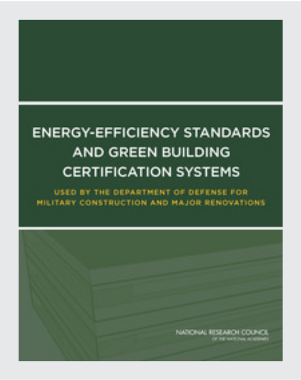


# Energy-Efficiency Standards and Green Building Certification Systems Used by the Department of Defense for Military Construction and Major Renovations (2013)

## DETAILS

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# ENERGY-EFFICIENCY STANDARDS AND GREEN BUILDING CERTIFICATION SYSTEMS

## USED BY THE DEPARTMENT OF DEFENSE FOR MILITARY CONSTRUCTION AND MAJOR RENOVATIONS

Committee to Evaluate Energy-Efficiency and Sustainability Standards
Used by the Department of Defense for Military Construction and Repair

Board on Infrastructure and the Constructed Environment
Division on Engineering and Physical Sciences

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**Staff**

LYNDA STANLEY, Study Director, Board on Infrastructure and the Constructed Environment (BICE)
HEATHER LOZOWSKI, Financial Associate, BICE
TERI THOROWGOOD, Administrative Coordinator, BICE

# Preface

The federal government operates a portfolio of almost one million facilities (429,000 buildings and 482,000 other structures) whose core purposes are to support the conduct of public policy, to help defend the national interest, and to provide services to the American public. How well federal facilities perform in terms of resource use (energy, water, materials, fossil fuels) and indoor environmental quality, and how much they cost to build, operate, and maintain, can support or hinder the ability of federal agencies to achieve their missions on a routine basis and during disasters. Federal facilities' performance and cost also have effects on the environment, the health and safety of building occupants, and on taxpayers. For these reasons, Congress has enacted laws and several presidential administrations have issued executive orders to improve the overall performance of federal facilities and to reduce the costs of operating them. Those mandates set performance objectives for high-performance federal buildings, also referred to as green buildings.

The U.S. Department of Defense (DOD), the military services—the U.S. Army, the U.S. Air Force, the U.S. Navy, the U.S. Marine Corps—and other DOD components together represent the largest single owner of facilities among all federal agencies. DOD components own and operate more than one-half million facilities (297,000 buildings and 211,000 additional structures) in the United States and abroad to support national defense-related activities.

To help meet congressional and executive mandates regarding high-performance federal facilities, DOD and the military services have been using building standards and green building certification systems to design and evaluate the performance of their buildings for more than a decade. Over time, DOD has modified its internal policies regarding the use of standards as knowledge about and experience with the design and operation of high-performance buildings has increased in both the public and private sectors.

Because DOD has invested and continues to invest billions of dollars in its facilities, the congressional defense committees want to ensure that DOD facilities are being operated efficiently in terms of cost and resource use. Section 2830 of the National Defense Authorization Act for Fiscal Year 2012 requires the Secretary of Defense to submit a report to the congressional defense committees with a cost-benefit analysis, return on investment, and long-term payback of specific energy-efficiency and sustainability standards used by DOD for military construction and renovation. The standards to be evaluated are American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 189.1-2011 for High-Performance Green Buildings, ASHRAE Energy Standard 90.1-2010, the Leadership in Energy and Environmental Design (LEED) green building certification system, and other American National Standards Institute-accredited standards, which include a version of the Green Globes green building certification system. DOD's report to the congressional defense committees must also include a copy of DOD's policy prescribing a comprehensive strategy for the pursuit of design and building standards across the department that include specific energy-efficiency standards and sustainable design attributes for military construction.

To provide independent, objective advice in developing DOD's response to Congress, the Deputy Undersecretary of Defense for Installations and Environment asked the National Research Council to establish an ad hoc committee of experts to complete three related tasks:

1. Conduct a literature review that synthesizes the state-of-the-knowledge about the costs and benefits, return on investment, and long-term payback of specified design standards related to sustainable buildings;
2. Evaluate a consultant-generated methodology and analysis of the cost-benefit, return on investment, and long-term payback for specified building design standards and evaluate the consultant's application of the methodology using empirical data from DOD buildings;
3. Identify potential factors and approaches that the DOD should consider in developing a comprehensive strategy for its entire portfolio of facilities that includes standards for energy-efficiency and sustainable design.

The Committee on Energy-Efficiency and Sustainability Standards Used by the Department of Defense for Military Construction and Repair included seven experts from government, industry, and academia. The committee held its first meeting at the end of June 2012 and was charged to complete its three related tasks within 6 months. The committee's report on those tasks is organized as follows:

- Chapter 1 sets the context for the congressional request, provides information on federal laws and mandates, identifies the committee's statement of task and related issues, and describes the committee's approach to that task.
- Chapter 2 describes factors related to the DOD operating environment that are relevant to the task, describes ASHRAE Standards 90.1-2010 and 189.1-2011 and the LEED and Green Globes green building certification systems, and identifies similarities and differences between the two systems.
- Chapter 3 provides background information on selected economic performance methods and measures, issues related to performance measurement of buildings, provides the committee's evaluation of the DOD consultant's report, and identifies issues related to the potential application of the consultant's analytical approach in the DOD operating environment.
- Chapter 4 summarizes the literature review conducted by the committee and the committee's conclusions.
- Chapter 5 presents the committee's findings from the literature search and its evaluation of the DOD consultant's report. Based on those findings and the committee members' expertise and experience, the committee identified five recommended approaches for DOD's consideration as it develops its comprehensive strategy and its response to Congress.

I personally consider it an honor and privilege to have served and worked with the other members of the committee, each a recognized expert in his or her field and each of whom volunteered their time and knowledge as a public service. As a team we appreciate the unwavering support and timely assistance of the NRC staff.

DOD has been a leader in adopting and adapting energy-efficiency and sustainability criteria and standards for buildings for more than 15 years. Given the relatively narrow scope of its tasks and the 6-month time frame, the committee could not highlight all of the programs and initiatives for improving the performance of facilities that are underway within DOD and the military services. The committee is aware, however, that those initiatives include comprehensive efforts to reduce the energy use of DOD installations, the development and testing of new building-related technologies, and the evaluation of the performance of its facilities, among many others. Nonetheless, in this report the committee has identified additional opportunities for DOD to lead the way in improving the performance of its buildings based on measured results of the actual outcomes of high-performance buildings. Through collaboration with other federal agencies, not-for-profit organizations, and the private sector, DOD can also take a leadership role in improving the knowledge and practices required to improve the performance of buildings throughout the United States. Through those and other efforts, DOD has a unique opportunity to lower the total cost of ownership of its facilities over the long term, to reduce environmental impacts, to improve the quality of life for the military and their families, and to benefit the entire nation.

Michael R. Johnson, *Chair*
Committee on Energy-Efficiency and Sustainability Standards
Used by the Department of Defense for Military Construction and Repair

# Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Stephen Berry, University of Chicago,
Bill Browning, Terrapin/Bright Green, LLC,
Marco Castaldi, City College of New York,
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Alan Washburn, U.S. Naval Postgraduate School, and
Richard Wright, National Institute of Standards and Technology (retired).

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Elizabeth M. Drake, Massachusetts Institute of Technology (retired). Appointed by the National Research Council, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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APPENDIXES

# Summary

Congress has an ongoing interest in ensuring that the 500,000 buildings and other structures owned and operated by the Department of Defense (DOD) are operated effectively in terms of cost and resource use. Section 2830 of the National Defense Authorization Act for fiscal year (FY) 2012 (NDAA 2012) requires the Secretary of Defense to submit a report to the congressional defense committees on the energy-efficiency and sustainability standards used by DOD for military construction and major renovations of buildings. DOD's report must include a cost-benefit analysis, return on investment, and long-term payback for the building standards and green building certification systems identified below:

(A) American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 189.1-2011 for the Design of High-Performance, Green Buildings Except Low-Rise Residential.
(B) ASHRAE Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential.
(C) Leadership in Energy and Environmental Design (LEED) Silver, Gold, and Platinum certification for green buildings, as well as the LEED Volume certification.
(D) Other American National Standards Institute (ANSI)-accredited standards.

DOD's report to the congressional defense committees must also include a copy of DOD policy prescribing a comprehensive strategy for the pursuit of design and building standards across the department that include specific energy-efficiency standards and sustainable design attributes for military construction based on the cost-benefit analysis, return on investment, and demonstrated payback required for the aforementioned building standards and green building certification systems.

## THE COMMITTEE'S TASK

To obtain independent, objective advice in developing its response to Section 2830 of NDAA 2012, the Deputy Undersecretary of Defense for Installations and Environment asked the National Research Council (NRC) to establish an ad hoc committee of experts to undertake three related tasks:

1. Conduct a literature review that synthesizes the state-of-the-knowledge about the costs and benefits, return on investment, and long-term payback of specified design standards related to sustainable buildings.
2. Evaluate a consultant-generated methodology and analysis of the cost-benefit, return on investment, and long-term payback for specified building design standards and evaluate the consultant's application of the methodology using empirical data from DOD buildings.
3. Identify potential factors and approaches that the DOD should consider in developing a comprehensive strategy for its entire portfolio of facilities that includes standards for energy efficiency and sustainable design.

The specified design standards to be evaluated are ASHRAE Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential; ASHRAE Standard 189.1-2011 for High-Performance Green Buildings Except Low-Rise Residential; LEED Silver, Gold, Platinum, and Volume certifications; and other ANSI-accredited standards such as Green Globes.

It became evident at the first committee meeting that the wording of task 2 was not clear in regard to the relationship between the NRC, DOD, and the consultant, or the work being undertaken by the consultant. For purposes of clarity, the committee notes that the consultant was hired directly by DOD under a separate contract and the consultant's report is contained in its entirety in Appendix C.

The DOD consultant's report developed an analytical approach that included a traditional benefit-cost analysis to calculate long-term benefits and costs, adjusted rate of return on investment, and payback of ASHRAE Standards 90.1-2010 and 189.1-2011 and of the LEED and Green Globes green building certification systems; sensitivity analyses using a range of scenarios that represented uncertainty in future conditions; and a test of the analytical approach using data from DOD buildings to identify issues that might arise if the approach were to be applied in the DOD operating environment.

The committee evaluated the cost-benefit and sensitivity analyses as outlined in task 2. Regarding the consultant's application of the methodology using empirical data from DOD buildings, it is important to note that the consultant's purpose was not to conduct a cost-benefit analysis for a sample of DOD buildings but to identify issues that might arise if the proposed analytical approach were to be used by DOD. Thus, the committee evaluated the potential application of the consultant's analytical approach to the DOD operating environment.

A clearer description of task 2 would read as follows:

> Evaluate a report developed under a separate contract by a DOD consultant that focuses on a methodology and analysis of the cost-benefit, return on investment, and long-term payback for specified building design standards and evaluate the potential application of the consultant's analytical approach to the DOD operating environment.

## HIGH-PERFORMANCE OR GREEN BUILDINGS

The Energy Independence and Security Act of 2007 (EISA 2007) defines the attributes of high-performance buildings, which include reductions of energy, water, material, and fossil fuel use, improved indoor environmental quality for occupants, improved worker productivity, and lower life-cycle costs when compared to baselines for building performance. The terms "green" and "sustainable" are often used interchangeably with high-performance buildings, but there are no standard definitions for those terms. In this report, *high performance* refers to buildings that are specifically called out as meeting the EISA standard. *Green* is a more inclusive term used to indicate buildings that are designed to be highly energy efficient, to meet green building certification systems, or to be otherwise regarded as sustainable. Buildings that are not described as high-performance or green are referred to as conventional buildings.

Building standards and green building certification systems have been developed by nonprofit organizations to provide a framework for the design and operation of high-performance and green buildings. Building standards typically establish minimum requirements for the design of one aspect of a building's performance (for example, energy). Green building certification systems, in contrast, take a "whole building" approach to design by accounting for the interrelationships among building design, materials, mechanical systems, technologies, and operating practices.

LEED, developed by the U.S. Green Building Council (USGBC), and Green Globes, licensed by the Green Building Initiative (GBI), are the green building certification systems most commonly used in the United States. EISA 2007 requires federal agencies to use a green building certification system for new construction and major renovations of buildings.

## ECONOMIC PERFORMANCE METHODS AND MEASURES

Several closely related methods and measures are used for determining the economic performance of buildings, building systems, and components. There are salient differences among the methods and measures that bear on their correct application and interpretation for evaluating the cost-effectiveness of DOD construction and renovation projects.

Benefit-cost analysis (BCA) is most often used to determine if a government program or investment can be justified on economic grounds. It entails assigning monetary values to societal benefits from the program/investment, as well as to assessing direct program/investment costs, all over a specified time horizon (e.g., 20 years), and finding the difference between benefits and costs as net present value (NPV) benefits. A positive NPV means that total benefits exceed total costs, and the program or other investment is cost-effective. BCA can also be used to make mutually exclusive choices among building design, systems, and components. The choice with the highest NPV benefits is preferred on economic grounds. Related additional economic performance measures—benefit-cost ratios, internal rates of return on investment, adjusted internal rates of return on investment—can be computed from the time-denominated cash flows of benefits and costs of BCA.

Payback refers to the time period at which initial investment is recovered. Payback measures do not include future savings that may occur after the initial investment is recovered. For that reason, payback measures are not appropriate for comparing the long-term economic effectiveness of buildings or projects, because the alternative with the shortest payback period may not be the alternative with the greatest NPV benefits or the greatest return on investment.

## COMPLEXITY OF THE TASK

The committee's completion of its three related tasks was complicated by the following factors:

- *Difficulty of measuring building performance objectively.* The research on high-performance or green buildings inherently incorporates some level of subjectivity because of the unique nature of buildings, diversity in baselines for comparison studies, and the lack of a standard protocol for research on this topic.

All buildings differ in terms of location, materials, design, size, function, technologies, operational practices, and other factors, which influence overall building performance. The diversity in building design and the multitude of factors that contribute to any building's performance make it difficult to isolate the specific factors that contribute to energy use, water use, or other performance measures.

There are no national baselines from which to measure the performance of multiple factors associated with high-performance or green buildings. Instead, some baselines have been developed to measure individual factors such as energy.

The Commercial Buildings Energy Consumption Survey (CBECS) is the only national data source for detailed characteristics and energy use of U.S. commercial buildings. EISA 2007 establishes the CBECS as a baseline within the definition of high-performance buildings. However, there are well-documented deficiencies in the CBECS database, as detailed in Chapter 3. There are no national databases for water use, operations and maintenance, indoor environmental quality, or worker productivity as it relates to buildings. Baselines for comparing those factors are typically developed differently for individual studies.

There is no standard protocol for conducting research on high-performance or green buildings, although some studies do use similar methodologies or evaluation methods. Together all of these factors hinder objective comparisons across studies and preclude definitive, fully documented findings. The subjectivity inherent in making comparisons across research studies instead requires judgments based on a "preponderance" of evidence.

- *Recent release of ASHRAE Standards 189.1-2011 and 90.1-2010 and the LEED Volume certification program.* Few, if any buildings have been built to the latest versions of the ASHRAE standards. The only information available about the expected performance of buildings constructed to those standards was based on the same design models used in their development. The LEED Volume certification is also a new program for which there is little documented experience thus far.
- *Continuous improvement of building standards and green building certification systems and related factors.* Building standards and green building certification systems are regularly updated to take into account new objectives, techniques, knowledge, and technologies for buildings. As a result, multiple versions of each exist. With a few exceptions, research studies do not identify the specific versions of the standards and certification systems under which the buildings studied were constructed. Instead, the research typically compares a sample of buildings that are defined as green to a sample of conventional buildings. Studies related to LEED-certified buildings typically include buildings constructed under different versions of LEED that meet a range of certification levels, so even these have great variability. All of those factors and the incorporation by reference of building standards such as ASHRAE 90.1 into green building certification systems create confounding factors for research studies, which hinder the attribution of specific benefits and costs to specific standards or certification systems.
- *Quantity and quality of the literature.* Although there are hundreds of publications related to high-performance or green buildings, relatively few are well-designed empirical studies. Of these, several focused specifically on LEED-certified buildings; none focused on Green Globes-certified buildings. The only data available on the actual performance of Green Globes-certified buildings were individual case studies.

Other factors that made the task more complex included issues related to qualitative and quantitative measurements of building performance, measured data versus modeled data for energy and water use, and the inclusion of a mix of building types in most empirical studies.

## THE COMMITTEE'S APPROACH

The committee focused on the main purposes of the statement of task but did not have time to conduct extensive additional investigations. Thus, the committee's report does not evaluate building standards or certification systems that were not specified, describe the various debates about the use of green building certification systems, or acknowledge the full array of initiatives that are underway at DOD. Such initiatives include approaches for reducing greenhouse gas emissions, and for net-zero-energy buildings.

For its evaluation of the research literature, the committee determined it would focus on studies that met the following criteria:

- *Time frame.* The committee relied on studies published in 2004 or later because the first studies evaluating the incremental costs of LEED-certified buildings were published in 2004. The first evaluations of a sample of at least six high-performance or green buildings in the United States were published in 2006.
- *Robustness.* The committee focused on studies with clearly stated objectives, a clearly defined methodology, findings based on empirical data, and a sample size of at least six buildings. Individual case studies were not evaluated because of the prevalence of bias, error, and chance.
- *Relevancy to the DOD operating environment*. DOD typically owns and operates buildings for 30 years or longer. Although the committee identified a number of robust, timely studies related to the market value, rental rates, vacancy rates, and appraised value of green buildings compared to conventional buildings, the committee did not evaluate those studies in detail because market factors typically are not relevant to the DOD operating environment.

Based on those criteria, the committee identified 25 studies that served as the basis for its findings. The studies are summarized in Chapters 2 and 4 and Appendix D.

In regard to the DOD consultant's report, the committee discussed the proposed methodology with the DOD consultant and representatives of ASHRAE, the USGBC, and GBI on June 28-29, 2012. The committee suggested changes to the methodology for the consultant's consideration. In September 2012, the committee received the consultant's final report, *Cost-Effectiveness Study of Various Sustainable Building Standards in Response to NDAA 2012 Section 2830 Requirements* for an in-depth evaluation (Slaughter, 2012; see Chapter 3 and Appendix C).

## FINDINGS

The committee's findings are based on the literature review, the evaluation of the DOD consultant's study, and the experience and expertise of its members. The findings are presented below with a brief explanation of the committee's rationale. Chapter 5 contains more detailed explanations of the rationale for the committee's findings and recommended approaches.

> **Finding 1: The committee did not identify any research studies that conducted a traditional benefit-cost analysis to determine the long-term net present value savings, return on investment, or long-term payback related to the use of ASHRAE Standard 90.1-2010, ASHRAE Standard 189.1-2011, and the LEED or Green Globes green building certification systems.**

Of the 25 studies that met the committee's criteria for time frame, robustness, and relevancy to the DOD operating environment, only two (Turner, 2006; Kats, 2010) provided some analyses of NPV benefits, return on investment, or payback associated with high-performance or green buildings. Those studies, however, did not evaluate the cost-effectiveness of the specific building standards or green building certification systems. Instead they looked at the cost-effectiveness of green buildings compared to conventional buildings.

**Finding 2: There is some limited evidence to indicate that provisions within ASHRAE Standard 189.1-2011 may need to be selectively adopted if use of this standard is to be cost-effective in the DOD operating environment.**

ASHRAE Standard 189.1-2011 contains mandatory requirements that limit the ability of DOD to adapt the standard to its operating environment. The foreword to ASHRAE 189.1-2011 states that "new provisions within the standard were not uniformly subjected to economic assessment" and that cost-benefit assessment was not a necessary criterion for acceptance of any given proposed change to the standard from the 2009 version. The study *Incremental Costs of Meeting ASHRAE Standard 189.1 at Air Force Facilities: An Evaluation of Four AF MILCON Projects* (LMI, 2011) and the committee's review of ASHRAE Standard 189.1-2011 identified some mandatory requirements that may not be cost effective or feasible in the DOD operating environment.

**Finding 3. Research studies indicate that the incremental costs to design and construct high-performance or green buildings typically range from 0 to 8 percent higher than the costs to design and construct conventional buildings, depending on the methodology used in the study and the type of building analyzed. The additional incremental costs to design and construct high-performance or green buildings are relatively small when compared to total life-cycle costs.**

Several studies focused on the incremental costs to design and construct high-performance or green buildings when compared to conventional buildings. Those studies used different methodologies to calculate the additional costs of design and construction and applied them to different types of buildings. The studies indicated that the additional first costs for high-performance or green buildings would typically range from 0 to 8 percent higher than the costs to design and construct conventional buildings, although the costs ranged up to 18 percent higher in a few instances. The study with the largest sample size indicated that, on average, the incremental first costs of green buildings were within 2 percent of the costs of conventional buildings,

Over the life cycle of a building, design and construction costs typically range from 5 to 10 percent of total costs, while operations and maintenance costs account for 60 to 80 percent of total costs. Thus, the additional incremental costs to design and construct high-performance or green buildings are relatively small when considered as part of total life-cycle costs.

**Finding 4: The analytical approach proposed by the DOD consultant has merit as a decision support tool in the DOD operating environment if appropriate and verifiable data are available for conducting benefit-cost and sensitivity analyses.**

The DOD consultant conducted a traditional benefit-cost analysis to calculate NPV benefits and adjusted rate of return on investment to determine the cost-effectiveness of the two ASHRAE Standards and the two green building certification systems. The consultant also conducted a payback analysis as required by NDAA 2012. The consultant's proposed analytical approach expanded on the traditional BCA to incorporate factors related to geographic location, climate conditions, and local factors for utility costs. Sensitivity analyses were also incorporated to test a range of scenarios that represented uncertain future conditions related to discount rates, water prices, and energy prices. To the committee's knowledge, those factors are not required by DOD or by other federal regulations. The committee believes that the consultant's analytical approach has merit as one of an array of decision support tools to be used by DOD for evaluating investments in new construction or major renovations.

However, the committee has significant concerns about the sources of data available and the application of those data in the consultant's analysis, including estimates of the incremental costs to design and construct high-performance or green buildings; those concerns are detailed in Chapters 3 and 5. As a consequence, the committee cannot support the consultant's findings related to the absolute NPV benefits calculated for the ASHRAE standards, LEED, or Green Globes.

**Finding 5: The evidence from the literature search indicates that high-performance or green buildings can result in significant reductions in energy use and water use. The cost savings associated with the reductions in energy and water use will vary by geographic region, by climate zone, and by building type.**

Thirteen of the 25 studies evaluated by the committee focused on measured actual energy use in buildings based on utility bills. All thirteen found that high-performance or green buildings, on average (i.e., over a group of buildings), used 5 to 30 percent less site energy than similar conventional buildings.

The six studies that provided some evaluation of water use found that high-performance or green buildings on average used 8 to 11 percent less water than conventional buildings.

Seven studies provided some analysis of the performance of buildings certified at different levels of LEED. They indicated that the majority of LEED-Silver and LEED-Gold and Platinum buildings studied used significantly less energy and less water than conventional buildings.

The long-term cost savings that can be achieved through reductions in energy and water use over the life cycle of buildings will depend, in part, on local utility prices and on heating and cooling loads related to climate zones. During the 30 or more years a DOD building is in use, those differences could be significant. Across a portfolio of facilities, local price factors may be an important consideration for DOD in determining which investments in military construction or major renovations will be the most cost-effective over the long term.

**Finding 6: Not every individual high-performance or green building achieved energy or water savings when compared to similar conventional buildings.**

Although high-performance or green buildings saved energy and water, on average, within a sample of green buildings, some individual buildings had significantly greater reductions than the average, and some did not perform as well as conventional buildings. Similarly, there were LEED-Silver and LEED-Gold-certified buildings that used more energy and more water than conventional buildings. The research studies speculated about reasons why this was so, but they did not provide sufficient evidence to draw generalizations regarding why some high-performance or green buildings significantly outperformed conventional buildings and why others did not, although building type was clearly a factor.

**Finding 7: In general, the quantities of energy and water used by a building once it is in operation are greater than the quantities of energy and water predicted by building design models, if these models are specifically created for compliance with LEED, Green Globes, or ASHRAE standards.**

All building standards and green building certification systems require that a building design meet or surpass an energy efficiency standard. In the case of LEED, Green Globes, and ASHRAE 189.1, this standard is ASHRAE/Illuminating Engineering Society of North America (IESNA) 90.1. An energy model created to be compared with the ASHRAE/IESNA 90.1 standard necessarily underestimates the energy use and the energy cost of the building once constructed and in operation. This is because (1) such models assume perfection in manufacturing, installation, and operation of buildings and their systems; and (2) such models do not include certain heat losses because they are too difficult to calculate.

Energy and water use should be predicted with an "actual use" model that takes into account factors not considered by the LEED, GBI, or ASHRAE design models. An "actual use" model starts with the model created for compliance with LEED, Green Globes, or with ASHRAE 189.1, and then incorporates real-life assumptions of manufacturing, installation, and operation. It also incorporates the three-dimensional heat losses.

An "actual use" model created during design can be significantly improved in its predictive value if it is updated with as-built/as-operated conditions. Imperfections during construction can be observed and incorporated in the model, change orders can be modeled as well, and variations in occupancy captured (e.g., different plug loads). An "actual use/as-built model" is best suited for use as a benchmark to assess whether the building performs as it should and to correct deficiencies in operation.

The difference between modeled energy or water use and actual energy or water use is important for facilities managers and other decision makers when communicating with other stakeholders. Using data from LEED, GBI, or ASHRAE design models in decision making or in communications can set unrealistically high expectations that cannot be met. Using data from an as-built model will provide more realistic performance data. However, conveying information based on measured energy or water use will provide the most realistic data for decision-making and will improve the credibility of facilities managers and decision makers with other stakeholders.

**Finding 8. DOD has the opportunity to continue to take a leadership role in improving the knowledge base about high-performance buildings, improving decision-support tools, and improving building models by collecting data on measured energy, water, and other resource use for its portfolio of buildings and by collaborating with others.**

The data currently available to support decision-making about investments in military construction and major renovation projects is inadequate. Under the Energy Performance Act of 2005, all federal buildings are required to be metered by FY 2012. Metered data for energy and water use can be used to improve decision support tools and processes, to establish baselines for conventional buildings, and to measure the performance of high-performance or green buildings against those baselines. DOD could work with the Department of Energy and others to improve the available knowledge and databases related to high-performance buildings, to the benefit of the federal government and society.

**Finding 9. Effective operation of high-performance buildings requires well-trained facilities managers.**

High-performance or green buildings incorporate new building design processes, new technologies, and new materials. Effective operation of high-performance buildings requires well-trained facilities managers who understand the interrelationships among building technologies, occupant behavior, and overall building performance, as recognized through the enactment of the Federal Buildings Personnel Training Act of 2010.

## RECOMMENDED APPROACHES FOR DOD'S CONSIDERATION

Decisions about investments related to new construction and major renovations of buildings at DOD installations are not reducible to a single decision rule (such as benefit-cost maximization), nor are facilities managers responsible to a single stakeholder. In fact, facilities managers must assess the relative merits of facilities improvement projects against performance with respect to multiple decision criteria and justify recommendations to stakeholder groups and governing bodies that hold different and sometimes conflicting priorities. Trade-offs are required for most building projects, including design and construction costs (i.e., first costs) versus operating and maintenance and deconstruction costs, resilience and flexibility factors versus worker productivity, and so forth.

Based on its findings and on its own expertise and experience with building standards and green building certification systems, the committee recommends that DOD consider the following approaches as it develops a comprehensive strategy for its entire portfolio of facilities to include standards for energy efficiency and sustainable design.

**Recommended Approach 1. Continue to require that new buildings or major renovations be designed to achieve a LEED-Silver or equivalent rating in order to meet the multiple objectives embedded in laws and mandates related to high-performance buildings.**

The preponderance of available evidence indicates that green building certification systems and their referenced building standards offer frameworks for reducing energy and water use in buildings, compared to design approaches and practices used for conventional buildings. They may also result in improved indoor environmental quality, improved worker productivity, and lower operations and maintenance costs, although the evidence is very limited. Green building certification systems can also help to establish explicit and traceable objectives for future building performance and a feedback loop to determine if the objectives were met.

The incremental costs to design and construct high-performance or green-certified buildings compared to conventional buildings is minimal compared to the total costs of a building over its life cycle. Over the 30 years or more that high-performance or green buildings are in use, the cost savings attributable to reduced energy use and reduced water use may be significantly greater than the incremental first costs of design and construction.

The limited evidence available indicates that the majority of LEED-Silver-certified buildings studied used significantly less energy and water than conventional buildings, although some LEED-Silver-certified buildings did not outperform conventional buildings. Based on the evidence and committee members' own experience with green building certification systems, the committee believes the most prudent course for DOD is to continue its current policy. At the same time, DOD should establish practices to evaluate the performance of its high-performance or green buildings to ensure that performance objectives are being met, to continuously improve performance, and to ensure that the measures required to reduce levels of energy and water use are cost-effective.

Because DOD has developed standard designs for the types of buildings it constructs most often, using the LEED-Volume certification program may be cost-effective, although as yet there is little experience with or documented evidence about the program. DOD should consider a pilot study to determine whether volume certifications will in fact be cost-effective.

**Recommended Approach 2. Retain flexibility to modify building standards and the application of green building certification systems in ways that are appropriate to the Department of Defense operating environment and mission.**

ASHRAE Standard 189.1-2011 contains many mandatory provisions that have not yet been evaluated for their cost-effectiveness. The committee recommends that DOD conduct pilot studies on specific provisions of the standard to determine their cost-effectiveness and their practicality in the DOD operating environment before adopting ASHRAE 189.1-2011 in its entirety. As experience with the various provisions emerges, DOD can determine which provisions of the standard are cost-effective and support DOD's mission and incorporate those provisions into DOD guidance documents when appropriate.

**Recommended Approach 3. Put policies and resources in place to measure the actual performance of the Department of Defense's high-performance, green, and conventional buildings to meet multiple objectives.**

Not every individual high-performance or green building will have significant energy and water savings even if it is certified at a LEED-Silver or equivalent rating. The committee recommends for all new construction and major renovations that DOD measure actual performance for 3 years or longer after initial occupancy and use the resulting information and lessons learned to further modify its policies if appropriate. This can be done because DOD meters all of its buildings. Data for conventional buildings should also be gathered to establish baselines for performance measurement.

It will be necessary to continue to use building models in the design stage to support decision making among alternatives. Building models can be improved over time such that predicted results are more closely aligned with actual results, as detailed in Chapter 5. As DOD's buildings are metered, DOD should gather data on the use of energy, water, and wastewater to establish baselines for conventional buildings and to determine how well high-performance or green buildings are performing in comparison to baselines and in comparison to predictions associated with design models.

DOD can continue to take a leadership role in improving the performance of all federal facilities, as well as all U.S. buildings, by collaborating with the Department of Energy, other federal agencies, nonprofit organizations, and others to improve national databases related to buildings and their performance and to improve the knowledge base related to the design, construction, and operation of high-performance facilities.

**Recommended Approach 4. Use investment approaches that analyze the total cost of ownership, a full range of benefits and costs, and uncertain future conditions as part of the decision-making process.**

The analytical approach developed by the DOD consultant could potentially be used by DOD to improve the basis for decisions about which investments will be most cost-effective across its portfolio of facilities. The proposed approach accounts for life-cycle costs, variations in geographic conditions, climate, type of building, and local cost factors. It also helps define upper and lower ranges of uncertainty for specific factors that are inherent with decision making about buildings that will be used for 30 years or longer. To use such an approach effectively, however, DOD will need to ensure that the data available for analysis are accurate and reliable.

**Recommended Approach 5: Specify and fund training appropriate for facilities managers to ensure the effective operation of high-performance buildings.**

Effective use of new technologies and new processes associated with high-performance buildings requires a workforce that is adequately trained to make decisions and implement them to maximum benefit. Facilities managers should have the skills and training necessary to understand the interaction of complex building systems and how to operate them effectively. Implementation of the Federal Building Personnel Training Act of 2010 should help to ensure that DOD facilities managers are certified in the required competencies and skills.

# 1

# Introduction

## CONTEXT

The Department of Defense (DOD), the military services—the U.S. Air Force, U.S. Army, U.S. Marines, and U.S. Navy—and other DOD components own and operate more than one-half million facilities (299,000 buildings and 211,000 additional structures) (GSA, 2012) in the United States and abroad. Those facilities support defense-related missions and programs by providing working and living environments for more than 2.3 million military and civilian employees (DOD, 2010) and the infrastructure required to support warfighting and peacekeeping activities. Most DOD structures are located on military installations that function much like small cities in terms of land mass, number and diversity of building types, and range of activities.

How well buildings perform in terms of energy and water use, indoor environmental quality, and total cost affects the capacity of DOD and the military services to achieve their missions on a routine basis and during disasters. Energy and water must be available to support the operations of the buildings used by DOD's civilian and military personnel and their families to support everyday functions and to provide for continuity of services in crisis situations. At the same time, funds spent to pay for energy, water, and buildings in general are funds that are not available to purchase weaponry and other equipment that is more directly associated with fulfillment of DOD's missions. Building performance also has effects on the environment, the health and safety of building occupants, the federal budget, and taxpayers. Overall, DOD and the military services spend approximately $15 billion annually to operate and maintain their buildings (GSA, 2012). Of this total, approximately $3.4 billion is spent on energy to power, heat, and cool buildings and equipment, including computers. The amount of energy used equals about 1 percent of the nation's site-delivered energy (Robyn, 2012). Finding ways to use less energy and water, and to operate its buildings more efficiently, can allow DOD to also operate more cost-effectively.

## FEDERAL LAWS AND MANDATES

Recognizing the magnitude of the investment in federal buildings and the effects of buildings on resource use and the environment,[1] Congress and several presidential administrations have enacted laws and issued executive orders to reduce the energy and water use of federal facilities, reduce operating costs, and reduce the total amount of square footage (overall footprint) owned and operated by federal agencies (Table 1.1). The laws and executive orders also include objectives for improving indoor environmental quality and worker productivity and objectives related to transportation and land use.

Each mandate calls for the use of a life-cycle perspective or life-cycle costing, establishes goals and objectives, and establishes baselines and performance measures for evaluating progress in achieving the goals. A life-cycle perspective requires evaluating a building's performance through several different phases: initial programming, design, and construction; occupancy/operations and maintenance; renewal; and decommissioning/demolition. A focus on the life-cycle costs of a building is important for effective decision-making, because once a building is in use, the investment made in operating, maintaining, repairing, and renewing it will be six to eight times greater than the design and construction costs (often referred to as first costs) (NRC 1998; 2012a).

The Energy Independence and Security Act of 2007 (EISA 2007; Public Law 110-40) defines a high-performance building as one that during its life cycle, as compared with similar buildings (as measured by Commercial Buildings Energy Consumption Survey (CBECS) data from the Energy Information Agency, has the following characteristics:

(A) Reduces energy, water, and material resource use;
(B) Improves indoor environmental quality, including reducing indoor pollution, improving thermal comfort, and improving lighting and acoustic environments that affect occupant health and productivity;
(C) Reduces negative impacts on the environment throughout the life cycle of the building, including air and water pollution and waste generation;
(D) Increases the use of environmentally preferable products, including bio-based, recycled content, and nontoxic products with lower life-cycle impacts;
(E) Increases reuse and recycling opportunities;
(F) Integrates systems in the building;
(G) Reduces the environmental and energy impacts of transportation through building location and site design that support a full range of transportation choices for users of the building; and
(H) Considers indoor and outdoor effects of the building on human health and the environment, including improvements in worker productivity, the life-cycle impacts of building materials and operations, and other factors considered to be appropriate.[2]

Executive Order 13423 requires that new federal buildings and major renovations comply with the Guiding Principles for Federal Leadership in High-Performance and Sustainable Buildings (see Appendix E).

Ever-increasing knowledge about the impacts of indoor environments on people and the impacts of buildings on the environment has led to new processes and tools for measuring and evaluating

[1] The federal government as a whole manages 399,000 buildings with a total square footage of 3.35 billion square feet and an additional 490,000 structures. The annual operating cost for these facilities is estimated at $31 billion (GSA, 2012).

[2] The terms *high-performance buildings*, *green buildings*, and *sustainable buildings* are often used interchangeably. In this report *high performance* refers to buildings specifically called out as meeting the EISA standard. *Green* is a more inclusive term used to indicate buildings that are designed to be highly energy efficient, to meet green building certification systems, or to be otherwise regarded as sustainable.

TABLE 1.1 Summary of Legislation, Executive Orders, and Department of Defense (DOD) Policies Applicable to High-Performance Buildings in DOD

| Drivers | Date | Description and Requirements |
|---|---|---|
| Energy Policy Act Public Law 109-58 | 2005 | Defines goals and standards for reducing energy use in existing and new federal buildings. Requires a 20% reduction in energy consumption by 2015, relative to a 2003 baseline. Sets an energy consumption target for new federal buildings of 30% below existing standards. Requires application of sustainable-design principles to new and replacement federal buildings. Establishes ENERGY STAR® labeling program. |
| Energy Independence and Security Act (EISA), Public Law 110-140 | 2007 | Establishes goals and criteria for high-performance green federal buildings. Increases the overall rate of required reduction in total energy consumption of federal buildings in each agency to 30% by 2015 (relative to 2003 baseline). Requires new buildings and major renovations to reach a 65% reduction in energy use by 2015 and zero-net energy use by 2030. Requires the identification and use of a green building certification system for new buildings and major renovations. Sets general water-conservation guidelines and storm-water runoff requirements for property development. |
| Federal Buildings Personnel Training Act of 2010, Public Law 111-308 | 2010 | Requires that General Services Administration (GSA) identify core competencies necessary for federal building personnel performing buildings operations and maintenance, energy management, safety, and design functions; including competencies related to building operations and maintenance, energy management, sustainability, water efficiency, safety, and building performance measures. Also requires GSA to identify appropriate training related to the competencies. |
| Executive Order 13423 | 2007 | Requires a 16% reduction in water use by agencies by 2015. Establishes as a basis for new construction the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (see Appendix E). All new construction and major renovations to comply with Guiding Principles and by fiscal year (FY) 2015 at least 15% of existing buildings to comply. |
| Executive Order 13514 | 2009 | Requires agencies to measure, manage, and reduce greenhouse gas emissions toward agency-defined targets, including:<br>• Reduce potable water use by 26% by 2020, relative to FY2007. Reduce other water use by 20% relative to FY2010.<br>• 50% recycling and waste diversion by 2015.<br>• 95% of all applicable contracts will meet sustainability requirements.<br>• Implementation of the 2030 net-zero-energy building requirement.<br>• Implementation of the storm-water provisions of the Energy Independence and Security Act of 2007, section 438. |
| Memorandum on Installation Energy Policy Goals for the Department of Defense (Philip W. Grone) | 2005 | 30% reduction of facility generated greenhouse gases by 2010 relative to 1990 base. Annual energy and water audits for 10% of the facilities on an installation. Water Management Plans with best management practices on 30% of its facilities by 2006, 50% by 2008 and 80% by 2010. Expansion of renewable energy use within its facilities with 5% goal by 2012 and 7.5% by 2013. |
| National Defense Authorization Act | 2007 | Requires that 25% of total DOD electricity come from renewable sources by 2025. |
| Memorandum on DOD Sustainable Buildings Policy (Dorothy Robyn) | 2010 | DOD components to design and build and certify as appropriate all new construction projects at a minimum to LEED-Silver (or equal). Beginning in FY2012 for projects in the planning stage, the sum of energy and water efficiency credits shall equal or exceed 40% of the points required for a LEED-Silver (or equal) rating. DOD components will design, execute, and certify major repair/renovation projects to be LEED-Silver, at a minimum, where appropriate. DOD components shall incorporate life-cycle and cost/benefit analysis into design decisions for new construction and renovation/repair projects. |

SOURCE: Adapted from Tylock et al. (2012).

how buildings perform throughout their life cycles. A distinguishing factor of high-performance or green buildings is a design philosophy that seeks to improve the performance of the building as a whole, taking into account the interrelationships of building materials, systems, and operating practices. Overall, the goal is to design and operate buildings that meet multiple objectives related to land use, transportation, energy and water efficiency, indoor environmental quality, and other factors. This is in contrast with more conventional design processes that typically treat building systems, materials, and other factors separately, which can result in suboptimal performance overall. At the same time, greater knowledge about buildings has also led to the development of new technologies that can reduce energy and water use, improve lighting, and improve the comfort of building occupants.

Recognizing that the effective design and operation of high-performance buildings requires well-trained and skilled facilities managers, Congress enacted the Federal Buildings Personnel Training Act of 2010. The act directs the administrator of the General Services Administration (GSA) to work with relevant professional societies and others to identify the core competencies necessary for federal personnel responsible for building operations and maintenance, energy management, sustainability, water efficiency, safety (including electrical safety, and building performance measures). The GSA is also charged with identifying certification programs, licenses, registrations, and other training programs to ensure that federal personnel can demonstrate the required competencies. A set of core competencies and associated training programs have been developed and are now posted at http://fmi.knowledgeportal.us/. The head of the GSA's Office of Federal High-Performance Green Buildings and the head of the Department of Energy's Office of Commercial High-Performance Green Buildings are also charged with developing a recommended curriculum relating to facility management and the operation of high-performance buildings.

## BUILDING STANDARDS AND GREEN BUILDING CERTIFICATION SYSTEMS

To aid in the design and efficient operation of high-performance or green buildings, nonprofit organizations have developed building standards and green building certification systems. Typically, building standards establish minimum requirements developed through consensus processes (for example, American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential). Building standards are designed to be adopted by state and local governments into their building codes.

Green building certification systems differ from building standards in that they typically take a "whole building" approach. They also provide a series of increasingly stringent levels of certification to measure the overall "greenness" of individual buildings, for example, how well they meet objectives for land use, water use, and other green building-related factors. Higher certification levels are achieved by the accumulation of a greater number of credits in specific categories, such as water and energy use. The level of "greenness" achieved is verified by an independent third-party entity. Certification programs have emerged "over the past 15 years as a way to differentiate environmental or socially preferable products from their conventional alternatives" (NRC, 2010, p. 3). Such systems are voluntary, not regulatory. Today, there are more than 12 separate green building certification systems used worldwide (IFMA, 2010).[3]

The two systems that are most commonly used in the United States and in the federal government are the U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED) and Green Globes, which is licensed by the Green Building Initiative (GBI). The LEED and

[3] In this report, only the LEED and Green Globes green building certification systems are discussed because they were the only two systems specifically identified in the statement of task.

Green Globes systems have both developed a series of certification levels. LEED levels include Certification, Silver, Gold, and Platinum. Green Globes' levels include one, two, three, and four green globes. Both systems have also developed different programs tailored to new construction/major renovations and existing buildings. LEED also has programs for different types of buildings and groups of buildings, and streamlined processes for the certification of 25 or more buildings of the same type (LEED Volume certification).

In practice, there is not a clear delineation between the use of building standards and green building certification systems. For example, ASHRAE 90.1 is incorporated by reference into ASHRAE 189.1, LEED, and Green Globes. ASHRAE Standard 189.1-2011, unlike most building standards, addresses the entire building and all of its systems. In addition, a version of the Green Globes certification system has been accredited by the American National Standards Institute (ANSI).

EISA 2007 required the Secretary of Energy, in consultation with the Administrator of the GSA and the Secretary of Defense, to identify a certification system and level for green buildings that the Secretary determines to be the most likely to encourage a comprehensive and environmentally sound approach to certification of green buildings. The level of certification to be identified was the "the highest level the secretary determines is appropriate above the minimum level required for certification under the system selected, and shall achieve results at least comparable to the system used by and highest level referenced by the General Services Administration as of the date of enactment of the Energy Independence and Security Act of 2007" (Section 433, D, III). The secretary may by rule allow federal agencies to develop internal certification processes, using certified professionals (Section 433, D, V). However, an agency using an internal certification system process must continue to obtain external certification by a third-party certifier for at least 5 percent of the total number of buildings certified annually by the agency. EISA 2007 also established a Federal Green Building Advisory Committee within the GSA and required that group to "identify and every 5 years reassess improved or higher rating standards" (Section 436, c).

DOD, similar to other federal agencies, must comply with laws and executive orders related to high-performance buildings. DOD has issued policies and guidance to help ensure compliance with those mandates among its components. Specifically, DOD's policy is that all new building design and construction and all major renovation projects should conform to the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (as outlined in Executive Order 13423) and must meet a LEED-Silver rating or equal at a minimum. Beginning in fiscal year (FY) 2012 for projects in the planning stage, the sum of energy and water efficiency credits must equal or exceed 40 percent of the points required for a LEED-Silver or equivalent rating.

## IMPETUS FOR THIS STUDY AND THE STATEMENT OF TASK

Given the magnitude of the investment in DOD facilities and their importance to the achievement of DOD's missions, the defense congressional committees have an ongoing interest in ensuring that those facilities are operated effectively in terms of resource use and cost. Section 2830 of the National Defense Authorization Act for 2012 (NDAA 2012) required the Secretary of Defense to submit a report to the congressional defense committees on the energy efficiency and sustainability standards used by DOD for military construction and repair. The report must include a cost-benefit analysis, return on investment, and long-term payback for the following building standards and green building certification systems:

(A) ASHRAE Standard 189.1-2011 for the Design of High-Performance, Green Buildings Except Low-Rise Residential;

(B) ASHRAE Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential;
(C) LEED Silver, Gold, and Platinum certification, as well as the LEED Volume certification; and
(D) Other ANSI-accredited standards.

DOD's report to the defense congressional committees must also include a copy of the DOD policy prescribing a comprehensive strategy for the pursuit of design and building standards across the department that include specific energy-efficiency standards and sustainable design attributes for military construction based on the cost-benefit analysis, return on investment, and demonstrated payback required for the aforementioned building standards and green building certification systems (subparagraphs A through D).

To obtain independent, objective advice in developing its response to Section 2830 of NDAA 2012, the Deputy Undersecretary of Defense for Installations and Environment asked the National Research Council (NRC) to establish an ad hoc committee of experts to undertake three related tasks:

1. Conduct a literature review that synthesizes the state-of-the-knowledge about the costs and benefits, return on investment, and long-term payback of specified design standards related to sustainable buildings;
2. Evaluate a consultant-generated methodology and analysis of the cost-benefit, return on investment, and long-term payback for specified building design standards and evaluate the consultant's application of the methodology using empirical data from DOD buildings;
3. Identify potential factors and approaches that the DOD should consider in developing a comprehensive strategy for its entire portfolio of facilities that includes standards for energy-efficiency and sustainable design.

The specified design standards to be evaluated are ASHRAE Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential; ASHRAE Standard 189.1-2011 for High-Performance Green Buildings Except Low-Rise Residential; LEED Silver, Gold, Platinum, and Volume Certifications; and other ANSI-accredited standards such as Green Globes.

It became evident at the first committee meeting that the wording of task 2 was not clear in regard to the relationship between the NRC, the DOD, and the consultant, or the work being undertaken by the consultant. For purposes of clarity, the committee notes that the consultant was hired directly by the DOD under a separate contract and the consultant's report is contained in its entirety in Appendix C.

The DOD consultant's report developed an analytical approach that included a traditional benefit-cost analysis to calculate long-term benefits and costs, adjusted rate of return on investment, and payback of ASHRAE Standards 90.1-2010 and 189.1-2011 and of the LEED and Green Globes green building certification systems; sensitivity analyses using a range of scenarios that represented uncertainty in future conditions; and a test of the analytical approach using data from DOD buildings to identify issues that might arise if the approach were to be applied in the DOD operating environment.

The committee evaluated the cost-benefit and sensitivity analyses as outlined in task 2. Regarding the consultant's application of the methodology using empirical data from DOD buildings, it is important to note that the consultant's purpose was not to conduct a cost-benefit analysis for a sample of DOD buildings but to identify issues that might arise if the proposed analytical approach were to be used by the DOD. Thus, the committee evaluated the potential application of the consultant's analytical approach to the DOD operating environment.

A clearer description of task 2 would read as follows:

> Evaluate a report developed under a separate contract by the DOD consultant that focuses on a methodology and analysis of the cost-benefit, return on investment, and long-term payback for specified building design standards, and evaluate the potential application of the consultant's analytical approach to the DOD operating environment.

## COMPLEXITY OF THE TASK

In June 2012 the NRC appointed a seven-member committee of experts from government, industry, and academia to fulfill the three related elements of the statement of task: the Committee to Evaluate Energy-Efficiency and Sustainability Standards Used by the Department of Defense for Military Construction and Repair. The committee members' expertise included architecture, engineering, construction, facilities management, engineering economics, energy efficiency, building codes and standards, life-cycle costing and assessment, the environment, green building certification systems, and sustainable design (see Appendix A). The committee's tasks of conducting a literature review and evaluating the DOD consultant's report were made more complex by several factors, as outlined below.

### Difficulty of Measuring Building Performance Objectively

The research on high-performance or green buildings inherently incorporates some level of subjectivity because of the unique nature of buildings, the diversity in baselines for comparison studies, and the lack of a standard protocol for research on this topic.

All buildings differ in terms of location, materials, design, size, function, technologies, operational practices, and other factors, which influence overall building performance. The diversity in building design and the multitude of factors that contribute to any building's performance make it difficult to isolate the specific factors that contribute to energy use, water use, or other performance measures.

There are no national baselines from which to measure the performance of the multiple factors associated with high-performance or green buildings. Commercial Buildings Energy Consumption Survey (CBECS) is the only national data source of detailed characteristics and energy use of U.S. commercial buildings. EISA 2007 establishes the CBECS as a baseline within the definition of high-performance buildings. However, there are deficiencies in the CBECS database that should be accounted for when generalizing the findings of studies using CBECS data, as detailed in Chapter 3.

There are no national databases for water use, for design and construction costs, operations and maintenance, indoor environmental quality, or worker productivity related to buildings. Baselines for comparing those factors are typically developed differently for individual studies.

Currently, there is no standard protocol for conducting research on high-performance buildings, although some studies do use similar methodologies or evaluation methods. The diversity in building design, the lack of standard definitions for green or conventional buildings, the diversity in baselines, and the lack of a standard research protocol all combine to hinder objective comparisons across studies and to preclude definitive, fully documented findings. The subjectivity inherent in making comparisons across research studies instead requires judgments based on a "preponderance" of evidence.

### Recent Release of ASHRAE Building Standards and LEED Volume Certification Program

NDAA 2012 specifically required an evaluation of the costs and benefits associated with the use of ASHRAE Standards 189.1-2011 and 90.1-2010. Given the recent release of those specific standards and the fact that most buildings require 2 to 5 years to design and construct, there are few if any existing buildings that conform to those versions of the standards. The only information available about the expected performance of buildings constructed to those versions of the standards was based on the same design models that were used in the development of the standards.

The NDAA also required an evaluation of the LEED Volume certification program. The LEED Volume certification program is a relatively new program developed for organizations that plan to certify at least 25 design and construction projects or existing buildings. The program is intended to reduce the time and costs involved with certifying 25 or more buildings by using streamlined processes. As with the ASHRAE standards, there is little experience with the program to date, which necessarily limited the committee's evaluation.

### Continuous Improvement of Building Standards and Green Building Certification Systems and Related Factors

Building standards and green building certification systems are regularly updated to take into account new objectives, techniques, knowledge, and technologies for buildings. As a result, multiple versions of each exist (such as ASHRAE standards 90.1-2001, 90.1-2004, and 90.1-2007 and LEED 1.0, 2.0, 2.2, and 3.0). Research studies that seek to analyze the performance of buildings constructed in accord with the standards or green building certification systems typically do not identify the specific versions of the standards and certification systems, but instead only refer to ASHRAE Standard 90.1 or LEED-certified buildings. Instead, the research typically compares buildings that are defined as green to a sample of conventional buildings. Studies related to LEED-certified buildings typically include buildings constructed under different versions of LEED and meeting a range of certification levels, so even these have great variability. Finally, the inclusion by reference of ASHRAE 90.1 into other building standards and green building certification systems is a confounding factor that makes it difficult to clearly distinguish which specific benefits and costs are attributable to a specific standard or certification system.

### Quality, Quantity, and Scope of the Literature

In its review of the literature on high-performance and green buildings, the committee identified hundreds of publications ranging from well-designed, empirical studies to individual case studies to opinion editorials. In some studies, building performance data were based on predictions using simulation models, while other studies presented data on the performance of actual buildings based on utility bills and post-occupancy surveys. Although some of the empirical studies analyzed LEED-certified buildings, none of the empirical studies used Green Globes-certified buildings in the sample. The only data available on the actual performance of Green Globes-certified buildings were individual case studies.

## THE COMMITTEE'S APPROACH

The committee met as a group in Washington, D.C., on June 28 and 29, 2012, and again on September 17 and 18, 2012. At both meetings the committee scheduled presentations from and discussions with DOD staff, the DOD consultant, and representatives of ASHRAE, the USGBC, and the GBI. The audience included representatives from DOD, the military services, other federal agencies, and from nonprofit organizations. Webinars were run to allow staff from DOD and the military services to participate remotely. Public comment sessions were scheduled to allow other interested groups to address the committee and submit written materials. Appendix B contains the list of meetings, invited speakers, and other parties who spoke during the public comment sessions. Between and after its meetings the committee members communicated with each other by e-mail and conference calls in order to complete their report.

The committee focused on the main purposes of the statement of task but did not have time to conduct extensive additional investigations. Thus, the committee's report does not evaluate building standards or certification systems that were not specified in the statement of task, describe the various debates about the use of green building certification systems, acknowledge the full array of initiatives underway at DOD, or assess how DOD is complying with various mandates. The committee is aware that federal agencies are using other ASTM building standards and possibly other green building certification systems, such as the Living Building Challenge. DOD's Sustainability Performance Plan for FY2011 (DOD, 2010) describes the many approaches that DOD and the military services have initiated to reduce their use of energy, water, and fossil fuels and to reduce their production of greenhouse gas emissions, as well as research and development of technologies and the testing of new technologies. The committee is also aware of the public dialog regarding whether it is more effective to have buildings certified by third parties or if self-certification is sufficient and also the controversies related to different materials and products allowed by the LEED and Green Globes green building certification systems. However, many of these issues were outside the scope of the committee's statement of task and, therefore, are not discussed in any detail in this report.

For the literature review, the committee established the following criteria related to time frame, robustness, and relevancy to determine which publications it would review in detail:

- *Time frame.* The committee relied on studies published in 2004 or later because the first studies evaluating the incremental costs to design and construct LEED-certified buildings were published in 2004. The first evaluations of a sample of at least six high-performance or green buildings in the United States were published in 2006.
- *Robustness.* The committee focused on studies with clearly stated objectives, a clearly defined methodology, findings based on empirical data, and a sample size of at least six buildings. The committee relied more heavily on those studies that reported measured results for energy (utility bills) or other factors (post-occupancy evaluations) than on studies that reported modeled or predicted results. A discussion of issues related to the use of measured data, as opposed to modeled data, is contained in Chapter 3.

The committee also relied more heavily on studies based on larger sample sizes and excluded individual case studies. Larger sample sizes can help to eliminate some factors of bias, error, and chance that are prevalent in individual case studies, although those factors may still be present.

- *Relevancy to the DOD operating environment.* The committee focused on those studies that were most relevant to the DOD operating environment. The research on high-performance or green buildings includes a number of reports that analyze the market and price effects of green versus conventional buildings in terms of rental rates, vacancy rates, turnover ratios, appraised value, and other factors. Those studies have value, particularly to private-sector owners and developers and to federal agencies such as the GSA, which acquires commercial building space for the use of other federal agencies. However, the committee chose not to review those studies in detail because market-related factors are not directly related to DOD, which typically owns and operates buildings for its own use for 30 years or longer.

To evaluate the DOD consultant's report, the committee reviewed a paper outlining the consultant's proposed methodology prior to its first meeting. On June 28, 2012, the consultant discussed the proposed methodology with the committee in greater detail. The committee also heard from representatives of ASHRAE, the USGBC, and GBI, who were invited to express concerns that they had about the methodology (they had been provided the same paper as the committee prior to the meeting). On June 29, 2012, the committee provided its comments to the consultant in open session regarding changes that the consultant should consider incorporating into the methodology before embarking on data collection.

At the second meeting in September 2012, the committee was briefed on the consultant's final methodology, analysis, and findings. The committee received the consultant's final report at the end of September for an in-depth evaluation. The consultant's report as it was submitted to the committee is contained in Appendix C.

As a group, the committee developed findings based on the synthesis of the results from the 25 studies reviewed as part of the literature search. Because of the large variation in these studies in terms of sample sizes, building types, baselines, methodologies, and information included, and the confounding factors inherent in research related to high-performance or green buildings, the committee relied on the "preponderance" of evidence to develop its findings.

The committee evaluated the DOD consultant's report and based its findings on the expertise and experience of its own members and on the literature search. The committee's recommended approaches for DOD's consideration as DOD develops its comprehensive strategy for the pursuit of design and building standards, including those for energy efficiency and sustainability, are based on the findings related to the literature review, the evaluation of the DOD consultant's report, and the committee members' expertise and experience.

# 2

# The DOD Operating Environment, Building Standards, and Green Building Certification Systems

This chapter provides background information about the Department of Defense (DOD) operating environment, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standards 90.1-2010 and 189.1-2011, the Leadership in Energy and Environmental Design (LEED) and Green Globes green building certification systems, and similarities and differences between the LEED and Green Globes systems.

## THE DOD OPERATING ENVIRONMENT

DOD and the military services own and operate almost 500,000 buildings and other structures in support of their various defense-related missions. Typically, hundreds of individual structures are co-located on increasingly large and complex military installations. Those installations are located throughout the United States and the world and are subject to a wide range of geographic and climatic conditions. The majority of DOD facilities are more than 40 years old. Current budget issues are expected to curtail the construction of new buildings in the foreseeable future. The majority of buildings that will be used by DOD in 2030 and beyond likely already exist. Thus, the majority of future DOD investments in military construction will likely be spent on upgrades to or renovations of existing buildings.

As noted in Chapter 1, facilities managers at permanent military installations are required to meet an array of legislative and policy mandates related to high-performance buildings, including specific targets to reduce the use of energy, water, and fossil fuels. Facilities managers must also ensure that facilities meet standards for security and for continuity of operations during emergency situations. In addition to new technologies related to high-performance buildings, DOD facilities may incorporate additional security-related technologies, which require well-trained staff if such technologies are to perform optimally.

DOD and other federal agencies are required by the Energy Independence and Security Act of 2007 (EISA 2007) to reduce their total energy consumption by 30 percent by 2015 relative to 2005 levels. To determine how well it is progressing toward this goal, DOD measures its energy use in terms of energy intensity (Btus per gross square foot of conditioned space) (DOD, 2010). Executive Order 13423 also required agencies to reduce their water intensity (gallons per square foot) by 2 percent each year through fiscal year (FY) 2015, for a total of 16 percent reduction below water consumption in 2007. Federal agencies must also ensure that 15 percent of the existing federal capital asset building inventory of each agency incorporates the sustainable practices outlined in "Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings" (hereinafter called the Guiding Principles; reprinted in Appendix E) by the end of FY 2015. The Guiding Principles are the following:

1. Employ Integrated Design Principles;
2. Optimize Energy Performance;
3. Protect and Conserve Water;
4. Enhance Indoor Environmental Quality; and
5. Reduce Environmental Impact of Materials.

To meet the various mandates, DOD has undertaken a wide-ranging set of activities to make their facilities more sustainable, as outlined in the Department of Defense Strategic Sustainability Performance Plan for FY 2011 (DOD, 2010). These activities address issues such as renewable energy, the vulnerability of the electrical grid, chemicals of environmental concern, water resources management, the reduction of greenhouse gas emissions, and the research and development of new technologies. Some initiatives relate to individual buildings, such as those aimed at developing net-zero-energy buildings by 2030. Others take advantage of the size and single ownership of DOD installations, which allows for large-scale, systems-based approaches involving both infrastructure systems and clusters of buildings and the use of technologies such as district energy systems, combined heat and power (co-generation) plants, geothermal conditioning systems, water capture and reuse, and others. Larger-scale planning for energy systems and for the use of renewable sources of energy also has implications for resiliency during disasters, which is a primary consideration for the 24/7 operations of DOD.

Mandates related to federal high-performance buildings call for the use of a life-cycle perspective or life-cycle costing. A life-cycle perspective involves consideration of all phases of a building's life cycle: programming/planning, design, construction, operations, maintenance and repair, retrofit, and demolition or deconstruction (Figure 2.1).

Life-cycle costing for buildings focuses on the integrated costs and performance of all building components, from planning through construction, through operations, repairs, replacements, and renovations, through disposal.

Federal agencies began using green building certification systems when those systems were being developed and tested in the late 1990s (Wang et al., 2012). The 2003 report *The Federal Commitment to Green Building: Experiences and Expectations* (OFEE, 2003) noted that the Office of Management and Budget's Circular A-11 encouraged agencies to incorporate ENERGY STAR®[1] or LEED into designs for new buildings and major renovations. In 2003, nine federal agencies, including the General Services Administration (GSA), the Navy, and the Air Force, were using LEED or a similar system for new projects; eight federal buildings were LEED certified and 60 additional federal buildings were undergoing LEED certification (OFEE, 2003).

The Army took a different approach, developing a self-assessment tool called the Sustainable Project Rating Tool (SPiRiT) to help installations and designers quantify and measure the sustainability of infrastructure projects and military construction and repair projects. SPiRiT was first published in

[1]ENERGY STAR® is a voluntary labeling program designed to identify and promote energy efficient products to reduce greenhouse gas emissions. More information is available at http://www.energystar.gov.

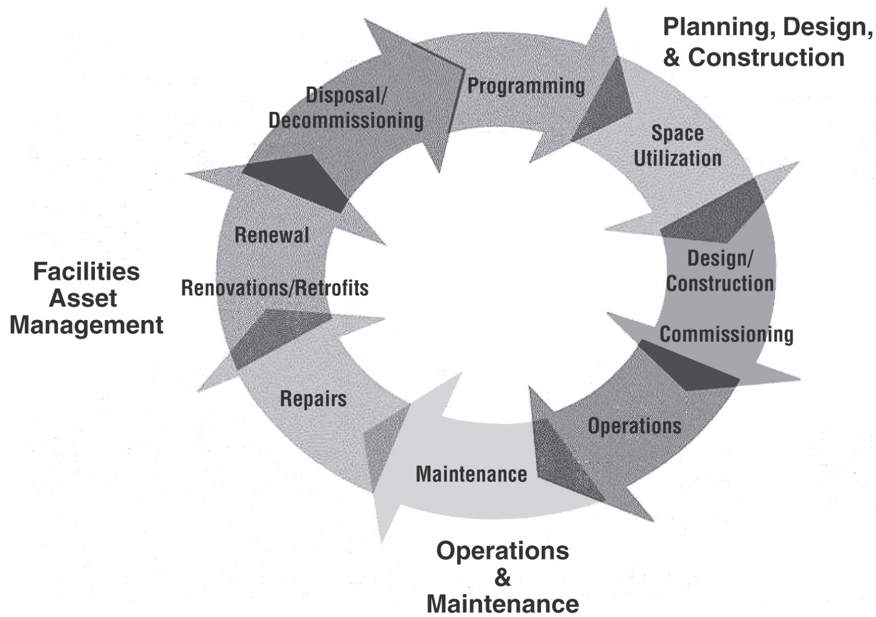


FIGURE 2.1 Facilities asset management life-cycle model. SOURCE: NRC (2008), adapted from APPA (2003). Courtesy of APPA, Federal Facilities Council, Holder Construction Company, International Facility Management Association, and National Association of State Facilities Administrators. Reprinted with permission.

2001, and the Army used it for more than 5 years. A 2006 report, *Implementation of the U.S. Green Building Council's LEED as the Army's Green Building Rating System,* compared and evaluated SPiRiT to LEED-New Construction (LEED-NC). The report recommended the adoption of LEED-NC without modification or supplement, with an initial target rating of LEED-Silver for a 1-year probationary period (Schneider and Stumpf, 2006). The Army subsequently adopted LEED-NC as its green building certification standard.

As of August, 2011, 40 federal buildings were Green Globes-certified (most by the Department of Veterans Affairs), and 519 federal buildings were LEED-certified (Wang et al., 2012).

## ASHRAE STANDARDS

Building standards, in general, serve as technical references and guidelines for architects, engineers, and others for designing and constructing buildings and building systems to achieve certain objectives. ASHRAE is an international technical society for individuals and organizations interested in heating, ventilation, air-conditioning, and refrigerating systems for buildings. Founded in 1894, ASHRAE develops standards for building systems through a consensus-driven process involving building code officials, design professionals, building users, academics, manufacturers, building owners, consumers, contractors, and others. ASHRAE standards are not legally enforceable, stand-alone documents. They are designed to be integrated into building codes.[2]

[2] The International Code Council standards, in contrast, are written to be legally enforceable and include code enforcement language.

### ASHRAE Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential Buildings

Standard 90.1-2010 establishes minimum energy efficiency requirements for buildings (other than low-rise residential buildings) for design, construction, and a plan for operation and maintenance and for utilization of onsite, renewable energy sources (ASHRAE, 2010).

Standard 90.1 was first issued in 1975, and revised editions were published in 1980, 1989, and 1999 using the American National Standards Institute (ANSI) and ASHRAE periodic maintenance procedures (ASHRAE, 2010). As technology advances accelerated and energy prices increased, the ASHRAE board of directors voted to place the standard on continuous maintenance so that the standard could be updated several times each year through the publication of approved addenda to the standard. The standard is published in its entirety every 3 years (as in 2004, 2007, and 2010); a new version is planned for 2013 (Thornton et al., 2011).

In 2007, the U.S. Department of Energy, as part of its Advanced Codes Initiative, signed a memorandum of understanding with ASHRAE to develop advanced commercial building standards and codes. The first step was a commitment that Standard 90.1-2010 would lead to a 30 percent energy savings compared to Standard 90.1-2004; this was the first time that an energy goal was set for developing the new edition of the standard (Thornton et al., 2011). Other significant changes in the 2010 version were the following:

- The scope was expanded so that 90.1-2010 covers receptacles and process loads (for example, data centers).
- Building envelope requirements became more stringent.
- Most interior lighting power densities were lowered; additional occupancy sensing controls and mandatory daylighting requirements were added for specific types of space.
- Most energy efficiency requirements were made more stringent.
- Modeling requirements (for example, for LEED certification) were clarified and expanded.

At the time of the printing of the standard, energy cost savings were estimated at 23.4 percent, and energy use savings (quantities) were estimated at 24.8 percent when compared to Standard 90.1-2007 (ASHRAE, 2010).

### ASHRAE Standard 189.1-2011 for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings

ASHRAE Standard 189.1 was created through a collaborative effort involving ASHRAE, the U.S. Green Building Council (USGBC), and the Illuminating Society of North America. It was written in code-intended (mandatory and enforceable) language to allow for ready adoption by code officials. The standard was first published in 2009 and was updated in 2011[3] (ASHRAE, 2011).

Standard 189.1 addresses site sustainability, water use efficiency, energy use efficiency, indoor environmental quality, and the building's impact on the atmosphere, materials, and resources. All mandatory requirements must be met along with those of either the prescriptive or performance path; there is some flexibility in the form of alternative paths and exceptions (VanGeem and Lorenz, 2011). Provisions in the 2011 version that differed from the 2009 version included, but were not limited to, the following:

[3] Even though it was originally developed independently, ASHRAE 189.1 has been accepted as an alternate compliance path to the International Green Construction Code (IgCC). Any entity (municipality, government agency, private developer, and so forth) may decide to adopt the standard whether or not their local code has integrated the IgCC.

- Reference to ASHRAE Energy Standard 90.1-2010 rather than Standard 90.1-2007.
- Prescribed onsite renewable energy must be based on roof area rather than conditioned space area, and the renewable energy requirement for multiple-story buildings exceeds the requirement for single-story buildings.

The foreword to ASHRAE Standard 189.1-2011 for high-performance green buildings states the following:

> New provisions within the standard were not uniformly subjected to economic assessment. Cost-benefit assessment, while an important consideration in general, was not a necessary criterion for acceptance of any given proposed change to the standard. The development of an economic threshold value associated with the environmental benefit of each provision falls outside the scope of this standard (ASHRAE, 2011, p. 2).

A 2011 study by the Logistics Management Institute (LMI, 2011) sought to determine the incremental upfront construction cost to the Air Force (AF) of adhering to ASHRAE Standard 189.1-2009 (not version 2011). Their purpose was to identify aspects of 189.1-2009 that could be included in Air Force Construction Criteria. Case studies for four different types of facilities in four different climate zones were conducted. Among LMI's findings were the following:

- Because AF buildings already are constructed to meet the Guiding Principles for High-Performance and Sustainable Buildings and meet at least LEED-Silver requirements and other federal sustainable building requirements, the added initial cost of meeting ASHRAE 189.1-2009 as a percentage of total building construction costs was 1 to 2.8 percent for three of the building types (fitness center, hangar, dormitory) and 7.1 percent for the fourth type (weather agency headquarters). The higher costs associated with the weather agency headquarters were attributed to the requirement for onsite renewable energy (LMI, 2011).
- Some of the requirements listed in ASHRAE Standard 189.1-2009 would require fundamental changes to the implementation of the AF energy and metering programs.
- One part of the standard requires being able to reduce a building's energy demand by 10 percent at peak load times. However, if an AF building provides mission-critical functions, the building would be excepted from base-wide load-shedding management.
- The standard required that electricity, gas, and water meters have remote reading capability. The AF required advanced meters for new construction, but it had ordered a strategic pause in connecting new meters to existing remote meter reading systems due to security concerns and the pursuit of a standardized platform.
- The AF at that time did not have the ability to manage the data collected by the meters (or sub-meters on some systems).
- Some of the requirements overlap with what the AF is already doing; others, like renewable energy, drive a very large capital investment that may not align with the AF corporate renewable energy strategy, and still others may be in conflict with how individual programs are implemented in the AF.
- The Army took exception to the renewable energy requirement because it makes more sense for military bases to use their size and footprint to tackle that problem rather than looking at individual building applications, where the numbers simply are not life-cycle cost-effective.

Members of the committee reviewed ASHRAE Standard 189.1-2011 in detail. Some provisions were identified that could potentially prove problematic in the DOD operating environment, as follows:

- *Heat island effect reduction.* The standard LEED criteria are maintained, but walls are added into the calculation, which could restrict aesthetic design choices for opaque wall surfaces.
- *Renewable power space allocation.* As a mandatory requirement, space and pathways need to be allocated, based on roof area, for renewable power generation (Single story: 20 $kWh/m^2$, Multi-story: 32 $kWh/m^2$), which will present difficulties in rooftop space allocation where mechanical space allocation is at a premium.
- *Minimum side lighting.* All classrooms and office spaces must have a required level of daylighting. The calculation is similar to the LEED EQc8.1 credit and may be difficult to satisfy, especially for larger floor plate buildings. This is both a prescriptive and performance requirement under 189.1-2011 and may not be feasible for some types of buildings. It is not labeled as mandatory, but in effect it is mandatory, since the 100 percent threshold must be met with either prescriptive or performance methodology.
- *Maximum waste generation.* It is a mandatory requirement that a project may generate a maximum of 42 $yd^3$ or 12,000 lbs of waste (recycled and landfilled/incinerated) per 10,000 $ft^2$ building area. Based on information from completed commercial projects gathered by one committee member, the combination of landfill and recycled waste surpasses this requirement by a factor of 10 to 40. This threshold may be difficult to achieve for many projects.
- *Indoor air quality management before occupancy.* A building flush-out or air quality testing is similar to LEED EQc3.2, but in Standard 189.1-2011 it is a mandatory requirement. Either option could prove to be impractical to implement, given logistical and scheduling concerns for a project.
- *Plans for operation.* The development of at least five separate plans for operation of a building is a mandatory requirement: high-performance building operation plan, maintenance plan, service life plan, green cleaning plan, and transportation management plan. Developing these plans will require additional staff time. To be beneficial, the plans will need to be consistently implemented and monitored throughout a building's life cycle.

## GREEN BUILDING CERTIFICATION SYSTEMS

Green building certification systems are a relatively new concept when compared to building standards. Worldwide, at least 12 different certification or assessment systems have been developed around the environmental and energy impacts of buildings. The first green building certification system was created in the United Kingdom in 1990 and named the Building Research Establishment Environmental Assessment Method (BREEAM). In the United States, the USGBC's LEED certification system was released in 1998. The Green Building Initiative (GBI) launched Green Globes in the U.S. market in 2005 by adapting the Canadian version of BREEAM (Smith et al., 2006).

Green building certification systems are intended to provide a framework through which building professionals and owners can design and construct buildings that meet performance objectives for land use, transportation, energy and water efficiency, indoor environmental quality, and other factors. They are different from most building standards in that they:

- Provide a verifiable method and framework to help professionals design, construct and renovate buildings and manage property in a more sustainable way.
- Document progress toward a design or operational performance target.
- Document the design and operations outcomes and/or strategies that are being used in a building.

Currently 1.6 million square feet of building space are being certified worldwide under LEED each day. Nearly 50,000 projects are currently participating in LEED, comprising more than 8.9 billion square feet of construction space in more than 130 countries (USGBC, 2012). In the United States and Canada, 3,700 buildings have been certified by Green Globes (Stover, 2012).

## Leadership in Energy and Environmental Design

The USGBC was co-founded by David Gottfried and Michael Italiano in 1993. They invited members of environmental design, real estate, academic, governmental, and business communities to shape the development of standards to guide construction projects, to improve performance, and help design and build structures that are more environmentally sensitive and sustainable.

An initial certification program, LEED 1.0, was launched in 1998 (Smith et al., 2006). It was followed by versions 2.0 in 2000, 2.1 in 2002, and 2.2 in 2005. A system of 69 credits was incorporated in the LEED framework, and the credit structure was updated with each version. LEED 3.0, published in 2009, redistributed the points to better reflect consensus priorities about the relative importance of environmental issues. The scoring regime was modified to create a new 100-point rating system that included 4 bonus credits for sensitivity for locally or regionally important features and 6 credits for innovation in design. A new version of LEED was developed during 2012, but the USGBC has delayed its consensus ballot on LEED 2012 until June 1, 2013.

Several steps are required to earn LEED certification for new construction, major renovations, and existing buildings. The basic framework involves registration, application, submission, review, and certification. Owners or developers who seek to achieve LEED certification of a project must develop building strategies early in the process in order to satisfy a set of established prerequisites. Each of the four levels of certification (Certified, Silver, Gold, Platinum) requires satisfying a different number of earned points which are awarded as a cumulative total for each performance category in the rating. For the base level of Certified, a project must earn 40-49 points out of 100 points; Silver, 50-59 points; Gold, 60-79 points; and Platinum, 80+. Currently, there is a cost of $900 to $1,200 to register projects; the cost of certification varies by project size (USGBC, 2012).

The possible points for each of the categories for LEED-NC under version 3.0 provide a sense of how efforts for the priorities are rewarded: sustainable sites (26 points); water efficiency (10 points); energy and atmosphere (35 points); materials and resources (14 points); and indoor environmental quality (15 points). There is the potential to achieve 10 bonus points through innovative design (6 points) and regional priority (4 points) (Smith et al., 2006; USGBC, 2012).

The USGBC has also developed a set of programs tailored to different building types and different numbers of buildings. They include LEED-NC, LEED-EB (existing buildings operations and maintenance), Core and Shell Development, Commercial Interiors, Retail, Homes, Schools, Healthcare, LEED for Neighborhood Development (which may include entire neighborhoods or portions of neighborhoods), and LEED Volume certification (for organizations planning to certify at least 25 new buildings or existing buildings seeking certification of their operations and maintenance).

The LEED Volume certification program is intended to streamline the certification process for organizations that plan to certify at least 25 projects. The three-step process requires (1) registering a building prototype; (2) precertification of the prototype; and (3) ongoing certification of individual buildings as they are constructed. The program is intended to reduce costs to participants by taking advantage of uniformity in building design, construction, and operational practices and managerial uniformity within an organization in order to forgo the need for a full review of every project seeking LEED certification

(USGBC, 2012). The intent is to allow owners or developers of 25 or more projects to achieve LEED certification for their projects faster and at a lower cost than through individual in-depth reviews.

The Green Building Certification Institute (GBCI), established in January 2008, administers project certification for commercial and institutional buildings and tenant spaces for the LEED green building certification system and manages the USGBC's professional credentialing program (Air Quality Sciences, 2009; GBCI, 2012). GBCI is an ANSI-accredited standards development organization.

## Green Globes

Green Globes is a building environmental certification program that is based on the U.K. BREEAM and the related Canadian BREEAM system. The U.K. BREEAM was introduced in 1990 and claims to be:

> The world's foremost environmental assessment method and rating system for buildings, with 200,000 buildings with certified BREEAM assessment ratings and over a million registered for assessment since it was first launched in 1990 (BREEAM, 2012, p. 1).

BREEAM continues to be developed, with the most recent version released in 2008. The Building Research Establishment (BRE) continues to work to export the standard to different countries and to harmonize the certification requirements with those in other countries. For example, BRE signed a memorandum of understanding to work with the French CSTB (Centre scientifique et technique du bâtiment) to develop a pan-European building environmental assessment method.

The Canadian BREEAM was introduced in 1996 by the Canadian Standards Association (Green Globes, 2012). It was renamed Green Globes in 2000 and moved to an online assessment and rating process. For existing buildings, it is now overseen in Canada by the Building Owners and Managers Association (BOMA), while new construction standards are overseen by ECD Energy and Environment Canada Ltd. (a private, for-profit company).

In the United States, the GBI, a nonprofit organization, has owned the license for use of the Green Globes certification system since 2004. The GBI originally worked with the National Association of Home Builders on certifications but has expanded to include commercial and governmental buildings included in the Green Globes system. Initially, the conversion of the Canadian certification system to application in the United States involved changes to measurement units, regulatory references, and the number of certification categories.

GBI became an ANSI-accredited standards development organization and developed ANSI/GBI 01-2010, Green Building Assessment Protocol for Commercial Buildings, which is derived from, but is not the same as, the Green Globes green building certification system. The ANSI standards development process was led by a technical committee comprised of expert individuals and organizations and involved extensive consultation and consensus building.

The Green Globes certification system is similar to LEED in that the assessment is based on award of points for different building characteristics. Different point scales exist for different types of buildings. Programs have been developed for existing buildings (Green Globes Continual Improvement of Existing Buildings [CIEB]) and for new construction (Green Globes for New Construction) (Air Quality Sciences, 2009). Table 2.1 illustrates the division of points for new construction along with the points received for an example building (the Wisconsin Electrical Employees Benefit Fund Office). The Green Globes certification has four different levels (represented by one to four green globes) with 35-54 percent for one globe, 55-69 percent for two globes, 70-84 percent for three globes, and 85-100 percent for four

TABLE 2.1 Possible Green Globe Points for New Construction and Points Received for an Example Building

| Assessment Area | Points Possible | Example Building |
|---|---|---|
| Energy | 380 | 228 |
| Water | 85 | 28 |
| Resources | 100 | 34 |
| Emissions | 70 | 36 |
| Indoor environment | 200 | 124 |
| Project management | 50 | 45 |
| Site | 115 | 45 |
| Total | 1,000 | 550 |

SOURCE: Green Globes (2012).

globes. Thus, the example building in Table 2.1 achieved more than 55 percent of the points possible and certification at the level of two green globes.

The Green Globes certification is based upon a Web-based, interactive questionnaire and a third-party onsite assessment. The third-party assessment can also include review of compliance with Executive Order 13423, Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings. In addition, Green Globes life-cycle assessment credit calculator is offered to help architects and engineers understand various life-cycle environmental impacts of building assemblies (Air Quality Sciences, 2009).

## SIMILARITIES AND DIFFERENCES BETWEEN THE LEED AND GREEN GLOBES GREEN BUILDING CERTIFICATION SYSTEMS

A 2006 report published by the University of Minnesota found that "given their common roots and similar goals . . . more similarities than differences exist" between the two systems (Smith et al., 2006, p. 2). Nonetheless, the authors concluded that noteworthy differences in process and content remain. The two systems attach differing values to certain aspects of green building, expressed by moderately dissimilar point allocations, especially at the lower levels of assessment.

For example, LEED requires a minimum performance level in categories such as energy use, erosion control, and indoor air quality, among others, while similar action in Green Globes earns points toward certification. Different strategies of point allocations translate into trade-offs between flexibility and prescription between the two systems (Smith et al., 2006).

Bryan and Skopek (2008) attempted to compare the environmental attributes of the LEED-NC and the Green Globes-New Construction systems by looking at seven dual-certified buildings and their official submission summaries. They noted that the two systems addressed slightly different levels of detail but had a similar rating nomenclature, as shown in Table 2.2. (It is important to note that Bryan and Skopek reviewed LEED when it was still a 69-point system, not the current 100-point system.)

The authors found that although both systems were similar in regards to the number of credits and point assignments to each category, LEED had six categories while Green Globes had seven. In addition, LEED had an innovative and design process category, while Green Globes had a category for project management (Bryan and Skopek, 2008).

TABLE 2.2 A Comparison of the Four Levels of Certification that Are Used by Green Globes and Leadership in Energy and Environmental Design

| LEED | Green Globes |
|---|---|
| Certified—26 to 32 points (>37%) | One Globe (>35%) |
| Silver—33 to 38 points (>47%) | Two Globes (>55%) |
| Gold—39 to 51 points (>56%) | Three Globes (>70%) |
| Platinum—52 to 69 points (>75%) | Four Globes (>85%) |

SOURCE: Bryan and Skopek (2008).

Other differences included incorporation of life-cycle emissions data (including the supply chain for production of resource inputs) by Green Globes. Green Globes also accepted four different forest certification systems, while LEED accepted only one forest certification system.[4]

Wang et al. (2012) prepared a review of three green building certification systems (LEED, Green Globes, and the Living Building Challenge) for the GSA in accord with EISA 2007. EISA required a review of the systems every 5 years to identify and reassess improved or higher ratings. EISA identified criteria to be used in reviewing the certification systems; however, the cost-effectiveness of the rating systems was not a criterion.

Wang et al. reviewed the systems as they aligned with 27 federal requirements related to new high-performance green buildings and 28 requirements related to existing buildings. The authors found that for new buildings, the Green Globes-NC system aligned with 25 of the 27 federal requirements, while LEED-NC aligned with 20 of the 27 requirements. For existing buildings, Green Globes CIEB aligned with 22 of 28 federal requirements, while LEED-EB aligned with 27 of the 28 requirements (Wang et al., 2012). The authors also stated that

> None of the systems discussed in this report ensures that a building will meet Federal sustainable design requirements (once certified), or that the building will perform optimally. Federal sector high-performance sustainable design and operations requirements can be met without the use of a green building certification system. At the same time, certification systems have been identified as useful tools by users when they are documenting, tracking, and reporting a building's progress toward the Federal requirements. The determination of which, if any, certification system to use depends on the user's goals (p. ii).

[4]At both meetings of the NRC Committee on Energy-Efficiency and Sustainability Standards Used by the DOD for Military Construction and Repair, representatives of several different organizations submitted comments on this issue and others related to the credit systems used in LEED and Green Globes as they relate to forest certification (see Appendix B). The committee considered this issue to be outside the scope of the statement of task.

# 3

# The Committee's Evaluation of the DOD Consultant's Report

The Committee on Energy-Efficiency and Sustainability Standards Used by the Department of Defense for Military Construction and Repair was tasked to evaluate a report produced by a Department of Defense (DOD) consultant under a separate contract. The consultant's report, *Cost-Effectiveness Study of Various Sustainable Building Standards in Response to NDAA 2012 Section 2830 Requirements* (Slaughter, 2012; reprinted in Appendix C), analyzed the benefit-cost, return on investment, and long-term payback of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards 90.1-2010 and 189.1-2011 and of the Leadership in Energy and Environmental Design (LEED) and Green Globes green building certification systems. The report also identified issues that might arise if the same analytical approach were applied in the DOD operating environment and provided recommendations to DOD regarding considerations for development of its comprehensive strategy.

As noted in Chapter 1, the committee reviewed a paper outlining the DOD consultant's proposed analytical approach prior to the committee's first meeting. The committee provided its comments to the consultant in open session at the first meeting regarding changes that the consultant should consider incorporating into the approach before embarking on data collection.

At its second meeting, the committee was briefed on the consultant's final methodology, analysis, and findings. The committee later received the consultant's final report for an in-depth evaluation. The consultant's final report as it was presented to the committee is contained in Appendix C.

To provide context for the consultant's analytical approach and the committee's evaluation of that approach, Chapter 3 first describes closely related methods and measures for assessing the economic performance of buildings. Although the terms are sometimes used interchangeably in informal discussions, there are salient differences among the methods and measures that bear on their correct application and interpretation for evaluating DOD construction and renovation decisions. A discussion on issues related to the actual measurement of building performance in terms of energy, water, indoor environmental quality, and other factors follows. The remaining sections of this chapter describe the DOD consultant's analytical approach for determining the cost-effectiveness of the relevant building standards and green building certification systems. This chapter concludes with the committee's evaluation of the consultant's methodology, analysis, and issues related to the potential application of the analytical approach in the DOD operating environment.

## DEFINITION AND USE OF SELECTED ECONOMIC PERFORMANCE METHODS AND MEASURES

Life-Cycle Cost Analysis (LCCA), Cost-Effectiveness Analysis (CEA), and Benefit-Cost Analysis (BCA) are three methods for measuring the economic performance of buildings.[1] The definitions and appropriate use of those analytical methods are described below.

### Life-Cycle Cost Analysis

LCCA takes into account all costs associated with a structure, system, or component over its defined life cycle or over the specific time horizon of the decision maker. Life-cycle costs (LCC) typically include those incurred during the acquisition phase, utilization phase, and disposal phase. The acquisition phase may include such costs as those for research and development, conceptual design, detailed design and development, construction and/or production, and installation. The utilization phase may include costs of energy and other resources and labor costs for operation, maintenance, repair, and replacements. The disposal phase may include demolition costs incurred at the end of the life cycle or end of the user's time horizon and may also entail positive resale, recycle, or scrap value, which is treated as a negative cost in the LCCA formulation.

LCCA is an appropriate method for selecting among possible alternatives that all meet performance requirements and differ primarily in their life-cycle costs. Other factors being the same, the alternative with the lowest LCC is the preferred choice. The purpose of LCCA is to base the choice among mutually exclusive alternatives on a broader, longer-term view of costs, rather than on first costs alone (such as acquisition, design, and construction costs). The analysis brings costs of each of the alternatives to a net present value (NPV) to allow the alternatives to be compared on a common basis. (If benefits also differ somewhat among alternatives, these can be incorporated as negative costs in the LCCA formulation, or a subjective trade-off can be made among alternatives, taking into account both their comparative life-cycle costs and their performance differences.) ASTM International (formerly known as the American Society for Testing and Materials) has developed a Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems (ASTM E917-05, 2010).

The U.S. Office of Management and Budget (OMB) prescribes discount rates for use in performing both cost-effectiveness analysis and benefit-cost analysis of federal investments: real discount rates for federal CEA—and, therefore, LCCA—vary by time period, and the rate for a 30-year time horizon is currently 2.0 percent. [2]

### Cost-Effectiveness Analysis

CEA encompasses LCCA, but is somewhat broader in scope. It is an approach for comparing alternatives that meet or exceed the desired level of performance or benefits and differ primarily in their comparative costs. CEA can be used to compare alternatives that differ in both their cost and performance

[1] Life-Cycle Assessment is an analytical method for measuring the environmental impacts of buildings. Although important, it is not part of this study or the DOD consultant's report because Section 2830 of the National Defense Authorization Act of 2012 and the statement of task specifically focused on economic/financial measures.

[2] Federal discount rates are available at http://www.whitehouse.gov/omb/circulars_a094/a94_appx-c.

to ensure that additions to costs are economically worthwhile. For example, the choice among alternative designs that vary in cost and also are associated with differing morbidity incidence rates might be assisted by computing not only the LCCs of the alternatives, but also the incremental cost of achieving improved health outcomes.

### Benefit-Cost Analysis

BCA is an approach most often used to determine if a government program or investment can be justified on economic grounds. It entails assigning monetary values to societal benefits and costs from the program/investment and assessing direct program/investment costs, all over a specified time horizon, and finding the difference between benefits and costs as NPV benefits. A positive NPV (greater than 1) means that total benefits exceed total costs, and the program or other investment is cost-effective.

BCA can also be used to make mutually exclusive choices among building and facilities design, systems, and components. In this application, the choice with the highest NPV is preferred on economic grounds. Related, additional economic performance measures can be computed from the time-denominated cash flows of benefits and costs of BCA. These include benefit-cost ratios, internal rates of return on investment, and the closely related concept of adjusted internal rates of return on investment. ASTM International has developed the standard practices Measuring Benefit to Cost and Savings to Investment Ratios for Buildings and Building Systems (E964-06, 2010) and Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems (E1057-06, 2010).

Caution is advised, however, in using the measures of benefit-cost ratios and rates of return measures computed on total benefits and costs for choosing among mutually exclusive alternatives. The problem is that ratios and the rates of return based on total benefits and costs begin to fall before the optimal choice is found. To avoid this problem, ratio and rate of return measures should be applied incrementally when used to guide selection among mutually exclusive choices. If the incremental ratio is greater than 1 or the incremental rate of return is greater than the minimum required rate of return (as indicated in federal analysis by the OMB-specified discount rate), moving to that increment is deemed cost-effective.

### Choosing among LCCA, CEA, and BCA

Making mutually exclusive choices among alternatives with similar benefits—such as the design or choice of systems or components for a given building or facility—is usually conducted with LCCA and CEA, using the associated federally prescribed discount rates. In contrast, assessing whether a given government program or investment has been worthwhile or is projected to be worthwhile is usually conducted with BCA, using its associated federally prescribed discount rate. In cases where the analysis of building systems and facilities has been expanded to include multiple categories of benefits, in addition to costs, the BCA approach may be required, but it should be used in the mode of comparing alternatives, with use of the CEA-appropriate federal discount rate. In addition, care must be taken to apply ratio and rate of return metrics incrementally when used for choosing among alternative building/facilities designs, systems, and components.

### Payback

Section 2830 of the National Defense Authorization Act of 2012 (NDAA 2012) and the committee's statement of task require the calculation of payback.[3] Simple payback is the time period at which initial

[3]Although payback and internal rate of return are sometimes used interchangeably, the terms and their purposes are very different.

investment (the incremental cost) is recovered, ignoring the time value of money. Discounted payback is the time period at which initial investment is recovered, taking into account the time value of money. Neither simple nor discounted payback includes future savings that may occur after the initial investment is recovered. Payback measures are not appropriate for comparing the long-term economic effectiveness of buildings or projects, because the alternative with the shortest payback period may not be the alternative with the greatest NPV benefits or return on investment. ASTM International has also developed the standard practice Measuring Payback in Investments in Buildings and Building Systems (E1074-09).

## ISSUES RELATED TO THE MEASUREMENT OF BUILDING PERFORMANCE

The actual measurement of the multiple factors that affect building performance and cost is not straightforward. Measurement issues include those related to quantitative and qualitative factors, the establishment of baselines, and the use of measured or modeled data, as described below.

### Quantitative and Qualitative Measurement

There are multiple benefits and costs associated with high-performance or green buildings that can be measured in various ways. Typically, it is easiest, and most objective, to measure quantitatively direct resources such as energy and water. Meters can measure the amounts of energy and water used, and utility bills can provide cost information. In the case of energy, however, the results will depend on whether site or source energy is being measured: site energy is energy measured at the meter, whereas source energy includes both onsite energy and offsite energy losses associated with the generation and distribution of energy. The distinction between site energy and source energy is significant, and the choice to measure one or the other can lead to very different findings.

Quantifying benefits can also be complicated by the fact that facility investments generate both direct and indirect benefits and costs. The direct costs of high-performance or green buildings are borne by building developers and owners, who also may receive the direct benefits of their investments. Indirect benefits accrue to building occupants, to the surrounding community, and to society at large, although those groups may not directly contribute to the costs. Providers of displaced building technologies and systems may experience indirect cost in terms of loss of sales. A federal benefit-cost analysis typically takes a broad perspective, including both direct and indirect effects.

### Baselines

Baselines for measuring "whole building performance" are not available and would be difficult to develop because of the uniqueness inherent in every building. As a consequence, measuring differences between high-performance or green buildings and conventional buildings is problematic. The most objective way to conduct comparison studies is to use a reference (prototype) building and then measure the incremental costs and benefits associated with the green alternatives. This type of baseline development is used in the DOD consultant's study evaluated later in this chapter.

Many building energy-related studies rely on the database and characteristics of the national building stock produced through the Commercial Buildings Energy Consumption Survey (CBECS). CBECS is the only national data source of detailed characteristics and energy use of U.S. commercial buildings. It is cited in the definition for federal high-performance buildings as a baseline for comparative studies.

However, there are deficiencies in the CBECS data that should be taken into account when generalizing the findings of studies using CBECS data. The 2012 National Research Council study *Effective*

*Tracking of Building Energy Use: Improving the Commercial Buildings and Residential Energy Consumption Surveys* found that the two priority concerns for researchers using this database are timeliness and frequency of the data and gaps in the data. The authors of the CBECS-related study concluded that the frequency of the survey does not meet data users' needs well, and the amount of time it takes to collect, process, and release the data collected by the surveys is too long. More importantly, "the sample sizes are too small to produce data that meet quality and confidentiality thresholds" (NRC, 2012, p. 2). In addition,

> The current CBECS sample design is best suited for producing descriptive statistics for larger geographical divisions, such as the entire country or census division levels. The relatively small sample sizes, in combination with strict quality control and confidentiality protections, severely limit the amount of data that can be released from the survey. This in turn limits, in terms of both geography and complexity, the analyses that can be conducted based on the data" (NRC, 2012, p. 3).

There are no national databases for water use in buildings or for operations and maintenance costs. Studies that look at those factors typically develop baselines from a variety of industry publications, including publications by the Building Owners and Managers Association and the International Facility Management Association.

### Measured Data Versus Modeled Data for Energy and Water Use

All building standards and green building certification systems require that a building design meet or surpass an energy efficiency standard. In the case of LEED, Green Globes, and ASHRAE 189.1, this standard is ASHRAE/IESNA 90.1.

An energy model created to be compared with the ASHRAE/IESNA 90.1 standard necessarily underestimates the energy use and the energy cost of the building once it is constructed and in operation. There are two primary reasons for this. First, the energy model that embodies the ASHRAE standard assumes perfection in manufacturing, installation, and operation. The assumption of perfection is necessary. For instance, the standard can require a certain insulation level, but it cannot control for installation problems, such as rips and compression due to piping. The standard can require a certain chiller efficiency, but the standard cannot control for suboptimal installation or for suboptimal operation. Since the energy model for the ASHRAE standard assumes perfection, the energy model for the proposed design also must assume perfection for the comparison to be useful.

Second, certain heat losses are not included in the ASHRAE 90.1 calculations, because at this time they are too difficult to calculate by most practitioners. Therefore these effects are not included in the design calculations. For instance, the three-dimensional heat loss effect that occurs at the intersection between slab edge and wall creates a significant heat loss that is not captured by either the ASHRAE standard or by the design model.

The same types of issues that are relevant for modeled and measured energy use also apply to modeled and measured water use.

## DESCRIPTION OF THE DOD CONSULTANT'S ANALYTICAL APPROACH

For the *Cost-Effectiveness Study* report (Slaughter, 2012), the DOD consultant developed an analytical approach composed of the following elements:

- A traditional benefit-cost analysis to calculate long-term benefits and costs (expressed as net present value savings), adjusted rate of return on investment, and payback of ASHRAE standards 90.1-2010 and 189.1-2011 and of the LEED and Green Globes green building certification systems. The analyses were conducted for two different building prototypes and five different geographic locations and climate zones.

- Sensitivity analyses to assess the long-term benefits and costs of the same ASHRAE standards and green building certification systems for a range of scenarios that represented uncertainty in future conditions. The scenarios differed in terms of discount rates, time periods, and escalation rates for energy and water costs.

The DOD consultant also conducted a test of the analytical approach, working with staff from DOD headquarters and military installations and using data from DOD buildings. The purpose was to identify issues that might arise if the approach were to be applied in the DOD operating environment.

More detailed information about the analytical approach used to determine the cost-effectiveness of the building standards and green building certification systems, as well as issues related to the application of that approach in the DOD operating environment follows. The page numbers in parentheses refer to the DOD consultant's report (Slaughter, 2012), which is reprinted in Appendix C.

## Traditional Benefit-Cost Analysis of ASHRAE Standards and Green Building Certification Systems

To analyze the benefits and costs (in terms of NPV benefits) that would result from the use of ASHRAE Standards 90.1-2010 and 189.1-2011 and the LEED and Green Globes certification systems, the DOD consultant first created baseline models. The models provided a baseline against which to compare the relative incremental benefits and costs of the standards and green building certification systems. The consultant then collected data for the incremental benefits and costs associated with the ASHRAE standards, LEED, and Green Globes and compared those to the prototype baselines. Three categories of costs were analyzed: investment costs (incremental cost for constructing the building in addition to major repair/replacement costs), energy costs, and water costs.[4]

### Creating the Baselines

To establish a common basis for calculating NPV benefits for the ASHRAE standards and the green building certification systems, the consultant used two building prototype models from a protocol developed by the Department of Energy (DOE) (Deru et al., 2011). The base models chosen were the "medium office" and "small hotel" models, which are commonly built by commercial firms. The prototypes also roughly correspond to DOD administrative buildings and its barracks and military dormitories, respectively, which was an important factor in testing the application of the analytical approach in the DOD operating environment.

The characteristics of the medium office prototype are shown in Figure 3.1 and Table 3.1. The characteristics of the small hotel prototype are shown in Figure 3.2 and Table 3.2.

To help determine the cost-effectiveness of the ASHRAE standards, LEED, and Green Globes under different geographic and climatic conditions, the DOD consultant analyzed the two prototype buildings in five geographic regions and climate zones across the continental United States: Miami, Florida; Phoenix, Arizona; Memphis, Tennessee; Baltimore, Maryland; and Helena, Montana (shown in Figure 3.3 and described in Table 3.3). The locations were chosen to represent the heating and cooling loads and local

[4] The consultant attempted to collect data for several additional categories—operations and maintenance costs, solid waste disposal costs, hazardous waste disposal costs, and landscaping/maintenance—but was unable to do so within the given time frame.

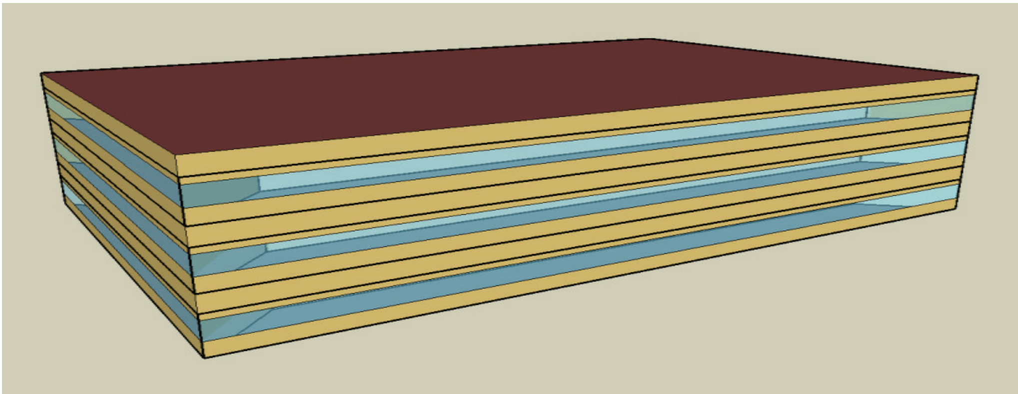

FIGURE 3.1 Axonometric view of medium office prototype. SOURCE: Thornton et al. (2011).

TABLE 3.1 Building Details for Medium Office Prototype

| Building | Medium Office |
|---|---|
| **Form** | |
| Total floor area (sq. feet) | 53,600 $ft^2$ (163.8′ × 109.2′) |
| Aspect ratio | 1.5 |
| Number of floors | 3 |
| Window fraction (wall-to-wall ratio) | (Window dimensions: 163.8 ft × 4.29 ft on the long side of façade, 109.2 ft × 4.29 ft on the short side of the façade), Average Total: 33% |
| Window locations | Window ribbons: 4.29 ft high, around building perimeter each floor |
| Floor to floor height (feet) | 13′ |
| **Details** | |
| Occupancy | 268 people |
| Orientation | Long axis orientation East/West |
| Requirements: | |
| Parking area | 86,832.00 $ft^2$ |
| Exterior doors | 5.36 $ft^2$ |
| Façade | 4,154.00 $ft^2$ |
| **Architecture—Fixed across all prototypes** | |
| Superstructure | (Not specified) Structural steel frame |
| Substructure | (Not specified) Column footings, strip footings for slab |
| Floor deck | (Not specified) Sheet metal decking, topping slab |
| Orientation | Long axis orientation East/West |
| Fuel mix | Gas, electricity |
| Foundation slab | 8″ concrete slab |
| Interior partitions | 2×4 stud (nonloadbearing, uninsulated) |
| Plug load | 0.75 W/$ft^2$ (guestrooms) |
| Elevator | 2 hydraulic (16,055 W) |

continued

TABLE 3.1 Continued

| Building | Medium Office |
|---|---|
| **Change by location, certification level** | |
| Windows | Window ribbons—4.29 ft high, around building perimeter each floor |
| Skylight | None |
| Ceiling | 4″ plenum |
| HVAC | Gas furnace with packaged AC, VAV with electric heat coil |
| Hot water | Natural gas, 260 gal tank |
| Lighting | 1 W/ft$^2$ (guestrooms) |
| Exterior lighting | 14,385 W |
| Flooring | Carpet |
| Interior finishes | (Not specified) |
| Exterior walls | Steel frame (2×4 16″ o.c.), 4″ stucco, 5/8″ gypsum board, insulation, 5/8″ gypsum |
| Roof | Membrane, insulation, metal decking |
| Floor slab | (Not specified) Insulation |

SOURCE: Thornton et al. (2011); see Slaughter (2012, p. 161).

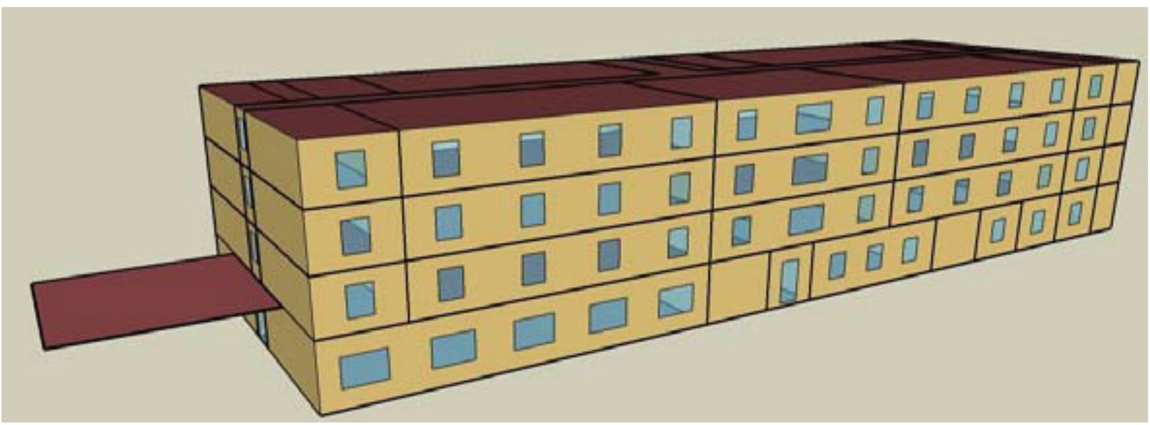

FIGURE 3.2 Axonometric view of small hotel prototype. SOURCE: Thornton et al. (2011).

TABLE 3.2 Building Details for Small Hotel Prototype

| Building | Small Hotel |
|---|---|
| **Form** | |
| Total floor area (sq. feet) | 43,200 ft$^2$ (180′ × 60′) |
| Aspect ratio | 3 |
| Number of floors | 4 |
| Window fraction (wall-to-wall ratio) | South: 3.1%, East: 11.4%, North: 4.0%, West: 15.2%, Average Total: 10.9% |
| Window locations | One per guest room (4′ x 5′) |
| Floor to floor height (feet) | Ground floor: 13 ft; Upper floors: 9 ft |

*continued*

TABLE 3.2 Continued

| Building | Small Hotel |
|---|---|
| **Details** | |
| Occupancy | 259 people |
| Orientation | Long axis orientation North/South |
| Requirements: | |
| Parking area | 33,680 ft$^2$ |
| Exterior doors | 31.22 ft$^2$ |
| Façade | 3,819 ft$^2$ |
| **Architecture—Fixed across all prototypes** | |
| Superstructure | (Not specified) Structural steel frame |
| Substructure | (Not specified) Column footings, strip footings for slab |
| Floor deck | (Not specified) Sheet metal decking, topping slab |
| Orientation | Long axis orientation North/South |
| Fuel mix | Gas, electricity |
| Foundation slab | 6″ concrete slab |
| Interior partitions | 2×4 stud (nonloadbearing, uninsulated) |
| Plug load | 1.11 W/ft$^2$ (guestrooms) |
| Elevator | 2 hydraulic (16.055 W) |
| **Change by location, certification level** | |
| Windows | 4′ x 5′ (1 per guestroom) |
| Skylight | None |
| Ceiling | No plenum |
| HVAC | PTAC (packaged terminal air conditioner) with electric resistance heating in each guestroom; gas furnace with packaged AC (split system with DX cooling) for public spaces; electric cabinet heaters for storage areas and stairs |
| Hot water | 2 natural gas (200 gal tank for guestrooms, 100 gal tank for laundry) |
| Lighting | 1.11 W/ft$^2$ (guestrooms) |
| Exterior lighting | 13.030 W |
| Flooring | Carpet |
| Interior finishes | (Not specified) |
| Exterior walls | Steel frame (2×4 16″ o.c.) 1″ stucco, 5/8″ gypsum board, insulation, 5/8″ gypsum |
| Roof | Membrane, insulation, metal decking |
| Floor slab | (Not specified) Insulation |

SOURCE: Thornton et al. (2011); see Slaughter (2012, p. 160).

factor prices that influence economic efficiency calculations (p. 95). DOD has large installations in each of the five geographic areas and climate zones chosen for analysis.

To establish a baseline for each of the building prototypes in each location, costs were calculated as follows:

- Construction costs for the baseline buildings were calculated using industry averages as published in RS Means Square Foot Calculator for April 2012 (p. 111).
- Energy use (quantities of building and site energy used) for each building prototype was generated using EnergyPlus software following ASHRAE 90.1-2004 (p. 111). Unit costs for electricity and natural gas were based on monthly statistics published by the DOE's Energy Information Administration (EIA). Total energy costs were calculated by multiplying the quantities by the unit costs (p. 112).

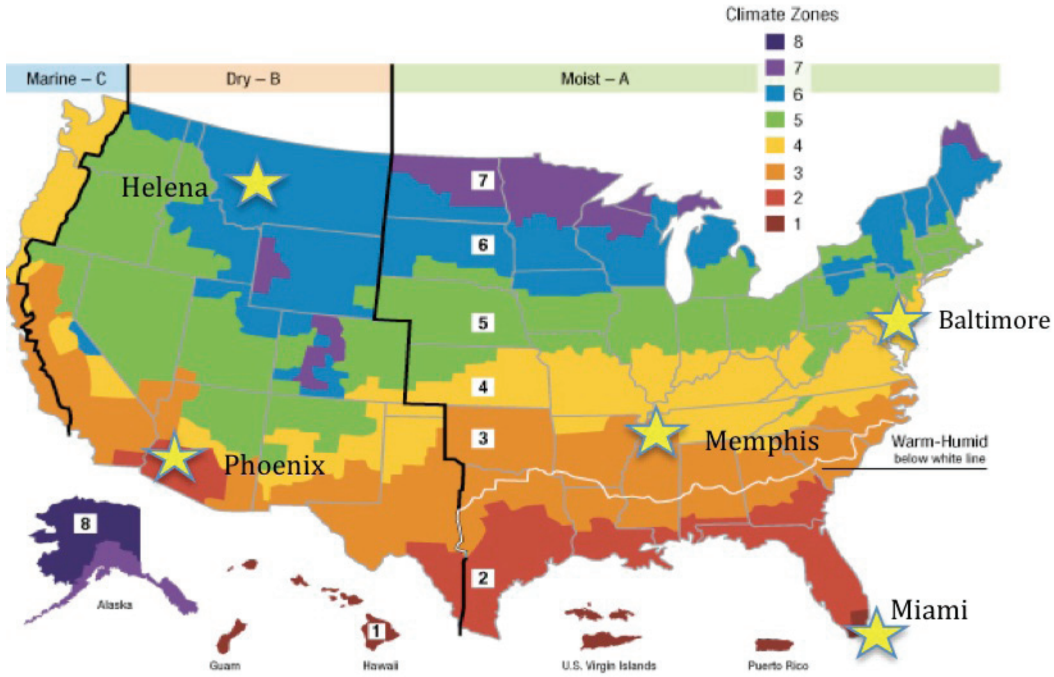


FIGURE 3.3 U.S. climate zone map developed by the Department of Energy.

TABLE 3.3 Selected Locations as Characterized by the Department of Defense Consultant

| Location | Climate Zone | Region | Climate Temperature | Climate Humidity | Market Type |
|---|---|---|---|---|---|
| Miami | 1 | Southeast | Hot | Wet | Large urban |
| Phoenix | 2 | Southwest | Hot | Dry | Medium urban |
| Memphis | 3 | Central | Medium | Medium | Medium urban |
| Baltimore | 4 | Northeast/Mid-Atlantic | Medium | Wet | Large urban |
| Helena | 6 | Northwest | Cool | Dry | Small urban/rural |

SOURCE: Slaughter (2012), p. 109.

- Water use (quantities) was based on current usage rates as reported by industry sources (p. 111). Local unit costs for water supply were based on public data sources, including municipal agencies and publications (p. 111). Total water costs were calculated by multiplying the quantities by the local unit costs (p. 112).

For the benefit-cost analysis of the ASHRAE standards and the green building certification systems the following factors were used:

- *Discount rate:* 2 percent (consistent with OMB guidance for fiscal year 2013).
- *Time period:* 40 years (consistent with the Energy Independence and Security Act of 2007).

- *Price escalation rates:*
  — Energy price escalation rate (eE): 0.5 percent per year.
  — Water price escalation rate (eW): 2.0 percent per year (p. 104).

The consultant based the energy price escalation rates on the rates reported annually by DOE's EIA. Energy escalation rates were calculated using an annual equivalent escalation rate. The consultant based the water price escalation rate on an analysis of the Consumer Price Index, which uses 1982-1984 as the base time period. The consultant calculated that the national average increase for water and sewer prices had been approximately 5 percent per year. The DOD consultant's study used an annual escalation rate of 2 percent, which was characterized as conservative, as an estimate of expected water price increases.

### Data Sources for the Calculation of NPV Benefits

The data required to calculate the incremental benefits and costs that would be realized by use of the ASHRAE standards, LEED, and Green Globes, in comparison to the baseline prototypes, came from several sources. Data on energy use and water use were provided by representatives of ASHRAE, the USGBC, and the GBI. Investment/construction costs were calculated by the consultant using (1) R.S. Means data for the total construction cost of the prototypical, baseline buildings and (2) total construction costs for actual buildings, provided by the USGBC and the GBI for a sample of their projects. The USGBC and GBI data, like the R.S. Means data, referred to the total construction costs of buildings. Because those cost data did not refer solely to incremental costs specific to energy-saving or water-saving building features, the consultant's calculation of cost differences between the baseline prototypes and the LEED-certified and Green Globes-certified projects probably include costs that are not related to energy, water, or other green systems.

For the analysis of the ASHRAE standards, the ASHRAE staff provided energy use information for both building prototypes in all five locations. Water use data were also provided for ASHRAE 189.1-2011. The data submitted by ASHRAE in all cases were generated from building models, because buildings have yet to be constructed and operated to standards 90.1-2010 or 189.1-2011. Thus, the same data were used in the DOD consultant's analysis of NPV benefits as were used in the development of the standards.

To calculate incremental construction costs for ASHRAE Standard 189.1-2011, which requires onsite energy generation, the consultant included incremental costs for energy generation units in the construction cost, and the onsite energy was used to offset the energy used by the building (p. 114).

For the analysis of both green building certification systems, the data for energy and water use were obtained from actual buildings certified under those systems. Energy use and water use data for 25 LEED-certified buildings were provided by the USGBC staff. The GBI staff provided energy use and water use data for 11 Green Globes-certified buildings. The LEED sample included buildings certified at the Certified, Silver, Gold, and Platinum levels (p. 116). The Green Globes sample included buildings certified at one, two, three, and four green globes (p. 117).

The data for incremental construction costs for both samples were estimated by the consultant using a variety of sources, because applications for certification by LEED and Green Globes do not require the owner or developer to include incremental construction costs.

For the benefit-cost analysis of the LEED certification system, the consultant worked with staff from the USGBC to obtain incremental construction cost data for 20 projects. Incremental construction cost data for five additional LEED-certified buildings were estimated by the consultant based on public data sources (including press releases, articles, and other public data sources) (p. 114).

The incremental construction costs for the buildings in the LEED and Green Globes samples were in many cases assumed to include all project costs, specifically construction costs plus related architect, engineering, and construction management fees. The consultant stated that those fees often average 35 percent of the total project costs according to R.S. Means and other industry sources. Therefore, for the analysis, the consultant reduced total project costs for the LEED and Green Globes buildings by 35 percent to exclude those fees (p. 115). The consultant also noted that insufficient data were provided to identify any particular technical cost drivers (such as unusual site conditions, structural requirements, or special equipment) or other factors that influence construction costs (such as local market conditions) independent of expected performance levels.

In summary, for the analyses of energy use and water use related to the ASHRAE standards, the consultant used data from building models that were similar to the prototype buildings (medium office and small hotel), not data from actual buildings. For the LEED and Green Globes analyses of energy use and water use, data from actual buildings were available, and those actual buildings were similar in function to the prototype buildings (medium office and small hotel).

Data for incremental construction costs were not available for the 25 LEED buildings or for the 11 Green Globes buildings that were analyzed. Instead, the consultant compared the total actual construction cost of those buildings against the total construction cost for the prototypes, which was calculated from R.S. Means square foot data (after adjusting for design/management fees).

## Sensitivity Analysis for Uncertain Future Conditions

The second element of the consultant's analytical approach were sensitivity analyses to calculate NPV benefits of the ASHRAE standards, LEED, and Green Globes for a range of scenarios that represent uncertain future conditions. For the different scenarios, the discount rate, time period, and price escalation rates for energy and water costs were varied to create a range of NPV benefits.

As noted by the consultant, traditional calculations of NPV benefits provide a single point estimate given specific input variables (i.e., time period, discount rate, and escalation rates). The sensitivity analyses provided upper and lower bounds for the point estimate by calculating a range of NPV benefits given the uncertainties for external factors such as capital markets, energy prices, and water prices (p. 104). Table 3.4 summarizes the key factors that were used for the NPV calculations for the scenarios developed and defined by the consultant.

In distinguishing the Economic High Growth Scenario from the Economic Low Growth Scenario, the consultant explained that

> When the economy is growing slowly, there are fewer opportunities for capital investment and the discount rate declines. When the economy is growing more quickly, more opportunities for higher yields for capital investment increase the discount rate. Therefore, the "Economic High Growth" scenario in this study includes a discount rate of 3 percent, which is equal to the OMB real discount rate in 2007 and which could be expected to occur within the study period of 40 years. The "Economic Slow Growth" scenario includes a discount rate of 1.5 percent, which could occur in the future if economic activity (and opportunities for investment) limits the alternatives for higher yield investments (p. 106).

For the analyses of ASHRAE standards 90.1-2010 and 189.1-2011 and the LEED and Green Globes certification systems, the consultant calculated NPV benefits, adjusted rate of return on investment, and payback for those standards and systems in relation to the two baseline prototype buildings in five locations.

TABLE 3.4 Factors Used in Benefit-Cost and Sensitivity Analyses

| Scenario | Real Discount Rate (percent) | Time Period (years) | Energy Annual Escalation Rate (eE) (percent) | Water Annual Escalation Rate (eW)(percent) |
|---|---|---|---|---|
| Long-term Benefit-Cost | 2.0[a] | 40 | 0.5[b] | 2.0 |
| Short-term Benefit-Cost | 1.7[a] | 20 | 0.5[b] | 2.0 |
| Economic High Growth | 3.0 | 20, 40 | 0.5[b] | 0 |
| Economic Slow Growth | 1.5 | 20, 40 | 2.0 | 4.0 |

NOTE: eE = Energy (annual) escalation rates, excluding inflation; eW = Water (annual) escalation rates, excluding inflation (p. 16). Any systematic effort to include inflation would not change the results as long as inflation is consistently excluded from all factors.

[a] OMB Real Discount Rates, fiscal year 2013.

[b] Annual equivalent of Energy Information Administration/Federal Energy Management Program energy price escalations.

SOURCE: Slaughter (2012, p. 105).

The Building Life-Cycle Cost (BLCC) program[5] developed by the National Institute of Standards and Technology was used to calculate net present value savings, adjusted rate of return on investment, and payback for all of the analyses. The BLCC program is updated annually to incorporate the current OMB discount rates and the annual energy price escalations provided by the EIA (pp. 104 and 121).

### Application of the Analytical Approach to the DOD Operating Environment

The DOD consultant also tested the analytical approach to identify issues that might arise if the approach were to be applied in the DOD operating environment. The consultant worked with staff from DOD headquarters and staff from the military services at both headquarters and installations to gather data on several categories of costs, including energy, water, operations and maintenance, solid waste disposal, and hazardous waste disposal. Traditional benefit-cost and sensitivity analyses were conducted in the same manner as for the ASHRAE standards and green building certification systems, but this time data were used from DOD buildings. Based on the test case analysis, the consultant identified four general categories of issues associated with the application of the proposed approach for analyzing the cost-effectiveness of building design alternatives within the DOD operating environment, as follows:

- The timing of economic efficiency analyses for decision support on project planning, design and implementation, particularly in the context of current authorization and appropriation processes and legislative mandates;
- Data collection and baseline development;
- Use of the analytical approach to track actual performance of buildings relative to expected benefits; and
- Industry and market factors influencing the long-term economic efficiency of DOD military construction and renovation (p. 156).

### Timing of Economic Efficiency Analyses for Decision Support

DOD currently requires an economic efficiency analysis as part of Form 1391 for the initiation of the military construction authorization process for individual building construction projects (p. 154).

[5] See http://www1.eere.energy.gov/femp/information/download_blcc.html.

The consultant stated that the analytical approach would be best applied across a portfolio of projects at the earliest stages, for budgeting and planning, rather than on individual projects at the authorization stage. The consultant proposed that the approach could also be effectively applied during design development and implementation in the choice of specific building characteristics (p. 154), although existing DOD processes may need to be refined. Such refinements would include the following elements in the earliest stages of project planning and scope development through detailed design and implementation:

- Recognition of uncertainty with respect to future conditions, costs, and opportunities;
- Clear specification of inputs and outcomes to provide a basis to measure actual performance and to revise assumptions;
- Clear delineation of exogenous factors (e.g., market trends, potential disruptions) and analysis of potential impacts to provide a basis for robust risk mitigation; and
- Flexibility to evaluate new conditions, opportunities, inputs, and outcomes to provide a means to rapidly and effectively improve performance and cost-efficiency (p. 154).

### Data Collection and Baseline Development

The DOD consultant stated that the proposed analytical approach requires credible and verifiable data related to incremental construction costs; major repair/replacement costs; and operations, maintenance, and repair costs over the life of a facility. It may also require additional data collection and an explicit process to assess the performance of building systems, components, equipment, and materials relative to the actual capture of expected benefits to inform design, procurement, and implementation processes. The consultant stated that those data would need to be grounded in the local market, incorporating local construction costs (and available skill levels) and local factor unit prices (e.g., energy, water, municipal and hazardous waste, and costs for operations and maintenance, cleaning, and landscaping), as well as potential future price escalation. Those types of data could provide critical information related to uncertainty in future conditions needed for strategic decision-making and risk mitigation at the installation level and for specific facilities (p. 154).

The consultant also stated that the analytical approach would require the definition of appropriate baselines if useful and empirically verifiable results are to be obtained from the economic efficiency analysis. This is because the calculation of NPV benefits requires a specific base case against which to compare the relative incremental costs and benefits among alternatives (p. 155).

### Use of the Analytical Approach to Track Actual Performance of Buildings Relative to the Expected Benefits

The DOD consultant stated that the economic efficiency analysis and the related data collection could be used to track actual performance of buildings relative to their expected benefits. As DOD meters its facilities, data on energy and water use and related costs could be used to evaluate specific buildings, systems, or building types for additional real-time operational refinement and commissioning to meet the expected high-performance levels. Those data could also be used for annual reporting requirements, monitoring the cost savings for given investments, and measuring progress in achieving legislative mandates (p. 155).

### Industry and Market Factors

The DOD consultant stated that further research is needed to determine the extent to which industry development as a whole may reduce initial investment costs and improve the capture of expected benefits from high-performance facilities (pp. 157-158). The consultant noted that anecdotal evidence indicated that the capabilities (learning curve) and capacities (market development) needed to design and construct high-performance buildings have developed rapidly across the architecture, engineering, and construction industry (p. 157), and these capabilities may lead to greater economic efficiency. Specifically, a study by Urban Catalyst Associates (2010) asserted that "costs for green buildings continue to decrease as materials become standard and practitioners become more proficient in new technologies" (p. 157).

The "learning curve" (in economic terms) refers to the rate of progress to achieve a stable production rate given the introduction of new processes, systems, and/or materials and may encompass both "labor learning" for specific skills and "organizational learning" to reflect the development and implementation of effective management practices of the new processes, systems, and/or materials (p. 157).

Market development was associated with achieving economies of scale, where the marginal cost to produce each unit decreases as the number of units increase (p. 157).

The consultant identified five factors that may specifically influence the incremental construction costs for high-performance buildings, as follows:

- Learning curve and market development for manufacturers of high-performance equipment, materials, and systems, which may reduce their unit price costs;
- Learning curve and capacity development for designers of high-performance buildings, which improves decision making and reduces the time required to plan, design, and manage such facilities; and
- Learning curve, skill development, and organizational capacity development by general and specialty contractors, which improve the quality and reduce the time required to construct or renovate high-performance facilities. (p. 157)

Incremental construction costs as well as long-term operations and maintenance costs may be reduced through learning curve and capacity development, as follows:

- Within owner organizations, which can improve the decision making during planning and design and improve operations management over time; and
- For facilities managers, which can improve decision making during planning and design through integrated project teams, and improve the capture of benefits during operations and maintenance (p. 158).

## COMMITTEE'S EVALUATION OF THE DOD CONSULTANT'S ANALYTICAL APPROACH

The committee's evaluation of the DOD consultant's analytical approach is comprised of three topics: the consultant's methodology, data sources and the application of those data, and the applicability of the methodology to the DOD operating environment.

### Consultant's Methodology

The long-term benefit-cost analysis used by the DOD consultant to calculate NPV benefits and adjusted rate of return demonstrated the appropriate use of a traditional benefit-cost analysis. Payback was a required element to respond to Section 2830 of NDAA 2012, and the consultant also appropriately conducted a payback analysis.

The consultant's methodology incorporated an analysis of NPV benefits that would result from investments in similar building types in different locations and climatic conditions. Sensitivity analyses were incorporated to test a range of scenarios that represented uncertain future conditions related to discount rates and water and energy prices. To the committee's knowledge, analyses for different locations and climate zones and sensitivity analysis for uncertain future conditions are not currently required by DOD or other federal regulations when decisions are being made about building investments. The committee believes that the consultant's analytical approach has merit as one of an array of decision support tools to be used by DOD for evaluating investments in new construction or major renovations of buildings.

The cost categories of data that the consultant sought to measure—incremental construction, energy, water, operations and maintenance, solid waste, and hazardous waste—are appropriate to the DOD operating environment. The categories are reflective of the multiple objectives associated with high-performance buildings, as defined by Energy Independence and Security Act of 2007. To the committee's knowledge, DOD and other federal agencies do not typically measure all of these categories, perhaps because industry baselines have not been established.

The committee is aware that DOD has already instituted policies and practices to reduce its overall energy use, to improve its energy security, and reduce its reliance on outside sources for energy supply during routine and crisis situations. The issues of water supply, water use, and water cost are almost certain to become increasingly important considerations for DOD, with several areas of the country already experiencing water shortages and escalating prices. Operations and maintenance costs account for the majority of life-cycle costs associated with buildings and are critical to cost-effectiveness calculations.

The baseline prototype buildings and the BLCC program used by the consultant are both public data sources that are available to DOD, the military services, and other federal agencies and could potentially serve as a basis for more widespread, collaborative benchmarking of facility performance within and across federal agencies.

### Data Sources and Application of Data

The committee has significant concerns about the sources of data available for the DOD consultant's analyses and the application of those data. The committee recognizes that the consultant had to complete the analysis in less than 4 months and had to rely on data-gathering methods that might not have been used if more time were available; the consultant did, in fact, identify some shortcomings of the data used in the analyses and stated that verifiable, reliable data are required for an effective analysis. Nonetheless, the committee is obligated to point out the shortcomings of the data that were analyzed and their likely effects on the results of the consultant's analyses.

First, actual incremental construction cost data for both LEED-certified and Green Globes-certified buildings were not available; those certification systems do not require that type of information. To generate the incremental construction cost data, which are essential to calculations of NPV benefits, the consultant used two methods. The total cost of a building that is not LEED-certified or Green Globes-certified (a baseline building) was calculated using square foot data gathered from R.S. Means. For the LEED-certified and Green Globes-certified buildings, the consultant used the actual costs of construction for entire buildings, which were then adjusted based on an assumption that 35 percent of the project costs were attributable to architect and engineering fees and other costs. The committee notes that for the purpose of calculating the cost of energy, water, and green systems, the R.S. Means square foot data cannot be directly compared to the cost of actual buildings, because the R.S. Means data make assumptions about building configurations, while actual buildings have specifics. There can be many differences between an actual building and a prototypical building used by R.S. Means in the square foot tabulations that are not attributable to water, energy, or green systems. If the specifics of the actual building are unknown, the comparison can be significantly skewed.

Second, to conduct the analyses of cost effectiveness for ASHRAE standards 189.1-2011 and 90.1-2010, the data provided by ASHRAE were the same data used in the models run for the development of those standards. The source of the data, therefore, did not allow for an independent verification of the cost-effectiveness of those standards. Given the recent release of those standards, there are few if any buildings that have actually been built to those standards, and no actual measured data were available to test the accuracy of the predictions of the models. The committee was particularly concerned about the estimated NPV benefits attributable to water savings associated with ASHRAE 189.1-2011, which the committee believes would be very difficult to achieve absent extraordinary measures that may not be cost effective for DOD. As buildings are constructed and operated in accord with the ASHRAE standards, validation of actual building performance will become possible.

Third, the consultant used estimated data assembled by ASHRAE staff for the ASHRAE standards analysis. The consultant used a combination of data from actual buildings and estimated data (R.S. Means square foot data) for the analysis of the green building certification systems. The use of data from such different sources makes it difficult to compare the cost-effectiveness of the ASHRAE standards to the cost-effectiveness of the LEED and Green Globes green building certification systems.

The lack of actual incremental cost data calls into question the consultant's findings related to incremental costs, and, therefore, it calls into question the consultant's findings related to NPV benefits. Several of the studies analyzed in the committee's review of the literature (Chapter 4) indicate that the incremental construction costs for LEED-certified buildings are significantly lower than the incremental construction costs estimated by the DOD consultant. The NPV benefits calculated by the consultant would likely have been higher if the consultant had used the average incremental construction costs from those studies.

Therefore, the committee cannot support the *absolute* net present values calculated by the DOD consultant for ASHRAE standards 90.1-2010 or 189.1-2011 or for the LEED and Green Globes green building certification systems.

### Applicability of the Consultant's Analytical Approach to the DOD Operating Environment

The DOD consultant proposed an analytical approach for use by DOD in making investment decisions for the construction and renovation of buildings today, understanding that future conditions for the value of money, the cost of energy and water, and the cost of solid and hazardous waste disposal is uncertain. The approach recognizes the importance of economic efficiency as one factor in decision making and recognizes that DOD owns and operates most of its facilities for 30 years or longer. It also recognizes that total net savings resulting from an investment will vary by the type of building, by time period, by location and climatic condition, and by the price of resources and services. The proposed approach could potentially be useful as part of an array of decision support tools to be used by DOD. However, as clearly presented by the consultant and reiterated by the committee, effective use of the approach first requires clearly established baselines and accurate, reliable data for the various analyses and may require other refinements to DOD processes and practices.

Gathering and analyzing data related to the costs of energy and water use, operations and maintenance, and hazardous and solid waste disposal for DOD's portfolio of existing and new facilities could provide a valuable base of information when making decisions about building-related investments. However, to use such data effectively for benefit-cost analyses across the military services and other

DOD components, DOD would first need to develop standard baselines for prototype buildings, standard definitions related to what should or should not be included in each category, standards for calculating quantities and costs of resources, and a standard protocol for gathering data. Personnel deployments may also affect energy use, water use, and other building-related factors. Effective tracking of those types of effects would also require standards and protocols that could be used consistently across the military services.

To implement this type of approach, it will be particularly important to have in place clearly established baselines for prototype buildings commonly constructed or renovated by DOD that can be used by all DOD components. Effective use of the baselines will require credible and verifiable data related to construction costs, energy use, water use, operations and maintenance costs, and other factors, such as solid and hazardous waste disposal, that could have effects on DOD's mission, operating environment, and budget.

# 4

# Benefits and Costs Associated with High-Performance or Green Buildings: Summary of the Literature Review

The Committee on Energy-Efficiency and Sustainability Standards Used by the Department of Defense for Military Construction and Repair was tasked to conduct a literature review that synthesizes the state-of-the-knowledge about the costs and benefits, return on investment, and long-term payback of specified American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) design standards and green building certification systems. The committee identified numerous publications, ranging from studies with clearly outlined design objectives and methodologies and empirical information, to individual case studies and opinion editorials. In Chapters 1 and 3, the committee identified factors that made its task more complex. Additional factors became apparent as the committee reviewed the literature, as outlined below.

- *Baselines and definitions.* As noted in Chapter 3, baselines for measuring the energy and water use and operations and maintenance costs for buildings are limited, and it is difficult to quantify the benefits and costs of those factors. The equally important but more difficult to quantify effects, such as worker health, productivity, and well being, are typically treated qualitatively, although quantitative measures are sometimes developed for these factors. Typically information about indoor environmental quality (IEQ),[1] which relates to health, well being, and productivity, is gathered through surveys of building occupants, introducing a level of subjectivity that is not present when resources are monitored through engineered systems.

There are no national baselines for measuring occupant satisfaction with indoor environmental quality or for measuring worker productivity related to building design. Standard survey forms to collect data from building users have been developed by the Center for the Built Environment (CBE) at the University of California, Berkeley, and the Usable Buildings Trust in the United Kingdom.[2] Data gathered from the CBE surveys have been collected in a single database from which baselines can be developed for comparative studies. As of October 2009, the CBE database included 51,000 individual

[1] Indoor environmental quality typically refers to factors such as temperature, humidity, ventilation, lighting, and noise.
[2] See http://www.usablebuildings.co.uk.

responses from occupants of 475 buildings (CBE, 2012). As of 2011, the Usable Buildings database contained surveys of occupants of 500 buildings in 17 countries (Baird et al., 2012).

Studies on high-performance or green buildings use a wide range of definitions to describe the criteria/attributes of the buildings being evaluated. In some studies, green buildings are defined as Leadership in Energy and Environmental Design (LEED)-certified. In others, the green building sample may include a mix of LEED-certified buildings, LEED-registered buildings, buildings receiving industry awards, and buildings designed with energy efficiency as an objective. This variance in definitions, like the variance in baselines, makes it difficult to objectively compare the results of one study to another.

- *Types of buildings and sizes.* Each of the studies reviewed included a variety of building types in the sample sets for green buildings, ranging from office buildings to schools, hospitals, and laboratories to courthouses. Different building types and different building sizes incorporate different types of mechanical and other systems to meet differing needs in terms of hours of operation (24/7 or weekdays only), use, intensity of use, number of floors, and other factors. Generalizing findings across a mix of building types and sizes introduces another set of confounding factors that prevent an apples-to-apples comparison across studies.

Given those factors, the factors identified in Chapters 1 and 3, and a 6-month time frame to complete its work, the committee determined it would need to focus solely on the main purposes of the statement of task. For its evaluation of the research literature, the committee determined that it would rely on studies that met the following criteria:

- *Time frame.* The committee relied on studies published in 2004 or later because the first studies evaluating the incremental costs of LEED-certified buildings were published in 2004. The first evaluations of a sample of at least six high-performance or green buildings were published in 2006.
- *Robustness.* The committee focused on studies with clearly stated objectives, a clearly defined methodology, findings based on empirical data, and a sample size of at least six buildings. The committee relied more heavily on those studies that reported measured results for energy (utility bills) than on modeled or predicted results, because the committee believes that data from actual buildings will be more reflective of the type of results that DOD can expect from its high-performance buildings.

Because the number of green buildings is increasing each year, more recent studies can incorporate larger sample sizes from which to make comparisons. Larger sample sizes can help to eliminate some factors of bias, error, and chance that are prevalent in individual case studies, although such factors may still be present.

- *Relevance to the DOD operating environment.* The research literature on high-performance and green buildings includes a number of reports that analyze the market and price effects of LEED or ENERGY STAR®[3]-certified buildings (primarily office buildings) compared to conventional buildings in terms of rental rates, vacancy rates, turnover ratios, appraised value, and other factors (Miller et al., 2008; Chappell and Corps, 2009; Dermisi, 2009; Fuerst, 2009; Fuerst and McAllister, 2008; Fuerst et al., 2010; Conlan and Glavis, 2012; Eicholz et al., 2009, 2011). These studies are of value, particularly to the private sector and to federal agencies such as the General Services Administration (GSA), which secures commercial space for other agencies. However, because DOD primarily owns and operates its facilities for 30 years or longer, the committee did not analyze these studies in detail, because market-related factors such as rental premiums and appraised value are not directly relevant to the DOD operating

[3] ENERGY STAR® is a labeling program for energy-efficient building-related products and equipment. It is not a green building certification system.

environment. The committee instead relied on studies that focused on energy and water use, indoor environmental quality, and other factors that DOD is required to address through the Energy Independence and Security Act of 2007 and other mandates.

## OVERVIEW OF FINDINGS FROM THE STUDIES ANALYZED

The committee did not identify any studies that conducted a traditional benefit-cost analysis to determine the long-term net present value savings, return on investment, or long-term payback related to the use of ASHRAE standards 90.1-2010 and 189.1-2011 and the LEED or Green Globes green building certification systems. Only two studies (Turner, 2006; Kats, 2010) compared the performance of green buildings (defined differently) to conventional buildings (different baselines) and assigned some measure of net present value (NPV) to different categories of costs and benefits.

The committee also did not identify any studies that analyzed the performance of samples of six or more Green Globes-certified buildings; the only evaluations of the performance of Green Globes-certified buildings were individual case studies.

The data cited for the 25 studies that met the committee's criteria are not universally unique; that is, some studies evaluated all or portions of the same data sets. For example, one of the most robust studies of green buildings conducted to date is *Energy Performance of LEED for New Construction Buildings* (Turner and Frankel, 2008). Turner and Frankel gave other researchers access to their data set for green buildings. Thus, studies published by Newsham et al. (2009) and by Scofield (2009a, 2009b) used the same data set but applied different analytical tests and arrived at different conclusions. In a different instance, Fowler and Rauch (2008) analyzed 12 green buildings owned and operated by the GSA. Fowler et al. (2010) reanalyzed the original 12 buildings, updated the available data, and also included 10 additional GSA green buildings in their analysis.

For the ease of the reader, the findings from the 25 studies are organized by specific topic area—energy use, water use, operations and maintenance costs, indoor environmental quality and productivity, and incremental costs to design and construct high-performance buildings. Where studies are cited more than once, the first reference includes some basic information about the sample size, definitions, methodology, and other factors. This information is not repeated if the study is cited multiple times. Table 4.1 contains summary information about the studies cited. They are arranged in the order that they first appear in Chapter 4. More detailed information about each of the studies is contained in Appendix D.

## ENERGY USE

Sixteen studies focused solely or in part on the site energy use in high-performance or green buildings. They are organized below into three categories: studies of energy use in commercial buildings; studies of energy use in federal buildings; and regional studies of energy use.

The majority of the studies measured energy use intensity (EUI), typically calculated by taking the total energy consumed in 1 year (measured in kBtu) and divided by total building floor area to compare the performance of green to conventional buildings. Most studies measured site energy, although a few measured source energy. Measurement of source energy brings into play issues and policies related to the reduction of greenhouse gas emissions, which is beyond the scope of the committee's statement of task. For that reason, the committee reports study results in terms of site energy.

TABLE 4.1 Studies Evaluated and Some of Their Characteristics

| Authors and Study Title | Characteristics of High-Performance or Green Building Sample | Variables Measured | Methodology |
|---|---|---|---|
| Torcellini et al. (2006) *Lessons Learned from Case Studies of Six High-Performance Buildings* | Six high-performance buildings defined as designed to achieve aggressive energy goals; buildings constructed between 1996 and 2005; six building types; a range of locations | Net source energy used; net site energy used (both measured as energy use intensity (EUI); energy costs | Monitored six buildings intensively over a 4-year period; gathered at least 1 year of energy use and costs for each building; compared actual costs to baseline energy models for the buildings and to energy-code compliant baseline buildings |
| Diamond et al. (2006) *Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings* | 21 LEED-NC buildings certified between 2001 and 2005; 14 federal and 7 non-federal; 8 office, 4 laboratories, 1 library, 3 multifamily, 4 mixed use, 1 education | Baseline energy modeled; design energy modeled; actual energy use, all expressed as EUI; ENERGY STAR® scores (illustrative); LEED energy-efficiency-related points | Compared the actual site energy use of 18 of the 21 buildings, based on utility bills, to the baseline energy and design energy models submitted for the LEED certification process; also compared simulated whole building energy to actual billed energy |
| Turner and Frankel (2008) *Energy Performance of LEED® for New Construction Buildings* | 121 LEED-NC-certified buildings; 100 buildings classified as "medium energy use activities" (office and similar); 21 buildings as "high energy use activities" (data centers, laboratories, and similar) | Site energy (EUI) actual, modeled for total sample and subsets of sample, including office (35 buildings) and LEED certification levels (Certified, Silver, Gold/Platinum; also collected data on occupant satisfaction | Compared the actual site energy use of 121 LEED-certified buildings to CBECS national averages, ENERGY STAR® ratings, and LEED baseline energy models; evaluated energy use of medium-energy-use buildings, high-energy-use buildings, 35 office buildings, and for buildings at different LEED certification levels |
| Newsham et al. (2009) *Do LEED-certified buildings save energy? Yes, but . . .* | 100 LEED-certified buildings categorized as "medium energy use activities"; same data subset as Turner and Frankel (2008) | Site energy (EUI) actual, modeled; site energy use for buildings certified as LEED-certified, LEED-Silver, and LEED-Gold/Platinum | Reanalyzed a data set from Turner and Frankel (2008), applying *t*-tests and other statistical measures to provide more rigor; individually matched LEED-certified buildings in data set to similar non-LEED-certified buildings in the CBECS database |
| Scofield (2009a) *A Re-Examination of the NBI LEED Building Energy Consumption Study* | 100 LEED-certified buildings categorized as "medium energy use activities"; same data subset as Turner and Frankel (2008) and Newsham et al. (2009) | Site energy use; source energy use; energy use by LEED certification level | Defined mean EUI differently than two other studies; measured source energy as well as site energy and conducted statistical tests |

*continued*

TABLE 4.1 Continued

| Authors and Study Title | Characteristics of High-Performance or Green Building Sample | Variables Measured | Methodology |
|---|---|---|---|
| Scofield (2009b) *Do LEED-Certified Buildings Save Energy? Not Really* | 35 LEED-certified office buildings; same subset of data used by Turner and Frankel (2008) | Site energy; source energy | Weighted EUI of each building by its gross square feet; used different averaging methods than other studies |
| Kats (2010) *Greening Our Built World: Costs, Benefits, and Strategies* | 170 green buildings of a wide range of types, located in 33 states and 8 countries; green buildings defined as LEED-certified, anticipating LEED certification or certified under another similar system (none certified under Green Globes) | Incremental costs of green design and construction; energy use and costs; water use and costs; data reported for all buildings in sample and by LEED-certification level | Conducted benefit-cost analysis and payback analyses for energy use and water use of green versus conventional buildings; data for green buildings primarily based on models, not actual measured data |
| Fowler and Rauch (2008) *Assessing Green Building Performance: A Post Occupancy Evaluation of 12 GSA Buildings* | 12 General Services Administration (GSA) buildings designed to be LEED-certified or otherwise designated green; 6 office, 4 courthouses, 2 combination office/courthouse | Site energy use, water use, operating costs, occupant satisfaction | Measured energy use based on utility bills and compared to CBECS national and regional averages and GSA baselines; measured water use based on utility bills and compared to a derived baseline for domestic water use; compared operating costs to industry sources; distributed CBE survey to measure occupant satisfaction |
| Fowler et al. (2010) *Re-Assessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings* | Updated data for 12 GSA green buildings studies by Fowler and Rauch (2008); expanded data set to include 10 additional GSA green buildings; total sample included 8 courthouses, 12 office buildings, and 2 mixed office/courthouse | Same measures as Fowler and Rauch (2008) | Same methodology as Fowler and Rauch (2008); also provided analyses of a subset of 15 LEED-certified buildings by certification level (Certified, Silver, Gold/Platinum) |
| Menassa et al. (2012) *Energy Consumption Evaluation of U.S. Navy LEED-Certified Buildings* | 11 Naval Facilities Engineering Command (NAVFAC) buildings LEED-certified by 2008, included 3 LEED-certified, 5 LEED-Silver, 3 LEED-Gold buildings; 1 drill hall, 3 maintenance facilities, 1 laboratory, 1 child care center, 2 barracks, 1 golf course clubhouse, 2 administration buildings | Site energy use for 11 buildings; water use for 9 buildings (2 LEED-certified, 4 LEED-Silver, 3 LEED-Gold) | Compared measured site and water use for the LEED-certified buildings to measured energy and water use for 11 similar NAVFAC buildings that were not LEED-certified |

*continued*

TABLE 4.1 Continued

| Authors and Study Title | Characteristics of High-Performance or Green Building Sample | Variables Measured | Methodology |
|---|---|---|---|
| Turner (2006) *LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report* | 11 LEED-certified buildings in the Pacific Northwest; sample included 7 offices or libraries and 4 multi-family buildings; 3 LEED-NC-certified, 4 LEED-NC-Silver, 3 LEED-NC-Gold, 1 LEED-EB-Gold | Site energy use; indoor water use; NPV benefits for energy and water; occupant satisfaction | Compared actual energy use (utility bills) and water use to three baselines: initial model projections, baseline approximate to code, and ENERGY STAR® median; NPV calculations assumed a 25-year time period, discount rate of 3 percent, and utility rate increases equal to rate of inflation |
| Baylon and Storm (2008) *Comparison of Commercial LEED Buildings and Non-LEED Buildings within the 2002-2004 Pacific Northwest Commercial Building Stock* | 24 LEED-certified buildings constructed between 2002 and 2005 in the Pacific Northwest. 8 different building types; most buildings had been occupied at least 2 years | Site energy use (EUI) | Compared the characteristics of the LEED-certified buildings to a larger sample of contemporary buildings built to local standard codes; characteristics studied included lighting, HVAC systems, building envelope, glazing, and control systems |
| Sacari et al. (2007) *Green Buildings in Massachusetts: Comparison Between Actual and Predicted Energy Performance* | 19 new or renovated green buildings in Massachusetts, including 12 green schools and 6 other buildings that were LEED-certified | Site energy use | Compared actual site energy use in the green buildings to the energy use predicted by design models and to energy use in buildings constructed to Massachusetts code |
| Widener (2009) *Regional Green Building Case Study Project: A Post-Occupancy Study of LEED Projects in Illinois* | 25 LEED-certified projects in Illinois including projects certified under a variety of LEED programs; at least 6 different building types; most certified under LEED versions 2.0 or 2.1 | Site energy use (EUI); greenhouse gas emissions; water use (indoor and outdoor); commute transportation; construction and operating costs; green premium, health and other benefits; occupant comfort | Compared data for the LEED-certified projects to three other data sets/baselines: Turner and Frankel (2008), CBECs national averages, and ENERGY STAR®; single data element that was mandatory for inclusion in the sample was post-occupancy measured energy use |

continued

TABLE 4.1 Continued

| Authors and Study Title | Characteristics of High-Performance or Green Building Sample | Variables Measured | Methodology |
|---|---|---|---|
| Oates and Sullivan (2012) *Postoccupancy Energy Consumption Survey of Arizona's LEED New Construction Population* | 25 LEED-NC-certified buildings in Arizona; 7 building types certified under LEED versions 2.0, 2.1, and 2.2; all had been in operation at least 1 year as of October 2009; sample broken into 19 buildings with medium energy intensity (offices and similar) and 6 buildings of high energy intensity (laboratories) | Site energy (EUI); source energy (EUI) | Actual energy performance of the LEED-certified buildings was compared to national averages from the CBECs database; CBECS data normalized to match the gross square feet weights for each building type in the LEED sample |
| Leonardo Academy (2008) *The Economics of LEED for Existing Buildings for Individual Buildings* | 11 to 13 buildings certified under LEED-EB program as of 2007 | LEED-EB certification costs; operating costs | Gathered data from building owners on costs to certify buildings under the LEED-EB program (13 buildings); collected data on operating costs for 11 buildings and compared them to industry sources |
| Abbaszadeh et al. (2006) *Occupant Satisfaction with Indoor Environmental Quality in Green Buildings* | 21 green office buildings of which 15 were LEED-certified and 6 had received green or energy efficiency awards | Overall occupant satisfaction; thermal comfort, air quality, lighting, and acoustics/noise | Surveyed occupants of green buildings directly using questionnaire developed by CBE; compared results to remaining buildings in CBE database (conventional) |
| Miller et al. (2009) *Green Buildings and Productivity* | 154 buildings that were LEED-certified or had an ENERGY STAR® label; located across the country | Productivity measured as sick days and self-reported productivity percentage after moving into a green building | Conducted a survey of more than 2,000 tenants in 154 buildings; also calculated the economic impacts of those tenants who claimed an increase in productivity (report summarized a literature review as well) |
| Baird et al. (2012) *A Comparison of the Performance of Sustainable Buildings with Conventional Buildings from the Point of View of the Users* | 31 sustainably designed commercial or institutional buildings located in 11 countries; occupied by 15 to 350 staff; 15 office, 10 education, 4 laboratories, 2 mixed use | Occupant satisfaction overall; occupant satisfaction with temperature, lighting, and acoustics/noise | Distributed a questionnaire developed for the Buildings In Use (BIU) studies to 2,035 tenants in 31 green buildings; compared results to data for occupants in 109 conventionally designed buildings from the BIU database that had been surveyed during a similar time period |

*continued*

TABLE 4.1 Continued

| Authors and Study Title | Characteristics of High-Performance or Green Building Sample | Variables Measured | Methodology |
|---|---|---|---|
| Matthiessen and Morris (2004) *Costing Green: A Comprehensive Cost Database and Budgeting Methodology* | 45 LEED-seeking buildings from the database of the Davis Langdon Company | Incremental construction costs of green buildings | Compared the construction costs of 45 LEED-seeking buildings to the construction costs of 93 non-LEED-seeking buildings; all costs were normalized for time and location to ensure consistency for the comparisons |
| Matthiessen and Morris (2007) *Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in Light of Increased Market Adoption* | 83 buildings seeking LEED certification under versions 2.1 and 2.2; building types included academic classrooms, laboratories, libraries, community centers, and ambulatory care facilities | Incremental construction costs of green buildings | Compared the construction costs of 83 LEED-seeking buildings to the construction costs of 138 non-LEED-seeking buildings; all costs were normalized for time and location to ensure consistency for the comparisons |
| Steven Winter Associates (2004) *GSA LEED Cost Study* | Study undertaken to estimate the costs to develop green federal buildings using LEED 2.1; examined a 5-story courthouse and a mid-rise federal office building | Incremental construction costs for federal courthouses and office buildings | Individual LEED credit assessments and cost estimates were completed for six different scenarios to create a cost range for LEED-certified, LEED-Silver, and LEED-Gold levels |
| Indian Health Service (IHS) (2006) *LEED Cost Evaluation Study* | Study undertaken to evaluate potential cost impacts of achieving LEED-NC and LEED-NC-Silver certification on IHS facilities | Incremental construction costs for hospitals and other healthcare-related buildings | Evaluated initial capital cost investments and life-cycle costs (20-year period); LEED credits were evaluated against standard practices of the IHS as outlined in the IHS design guide |
| Caprio and Soulek (2011) *MILCON Energy Efficiency and Sustainability Study of Five Types of Army Building* | Five standard building types most commonly constructed by the U.S. Army: barracks, tactical equipment and maintenance facility, government office and other public assembly, brigade headquarters, and dining facility | Incremental construction costs; total energy use (modeled) | Study undertaken to identify incremental construction costs for building energy efficiency enhancements intended to meet federal mandates |

NOTE: HVAC = heating, ventilation, and air-conditioning.

## Studies of Energy Use in Commercial Buildings

Torcellini et al. (2006) conducted field evaluations over a 4-year period for six high-performance buildings of different types and in different geographic areas. High-performance buildings were defined as those that were designed to meet energy-savings goals ranging from 40 percent better than energy-code-compliant buildings to net-zero-energy buildings. All used innovative technologies and a whole building design process to look at the interrelationships of each building's technologies, materials, and design. The researchers compared source and site energy performance (at least 1 year of measured performance) and the energy costs of each of the buildings to energy-code-compliant base-case buildings. They found that the six high-performance buildings used between 25 percent and 79 percent less site energy than the baseline buildings. Site energy costs were 12 to 67 percent lower than the energy costs for the baseline buildings. The variability in energy cost savings was attributed to differences in utility rate structures, fuel types, and peak demand profiles, among other factors.

Diamond et al. (2006) measured the actual energy use of 21 LEED-certified buildings (utility bills for the first year of operation) against the energy use predicted by the energy-use baseline and design models submitted for the same buildings for LEED certification. For the 18 buildings in the sample for which the researchers had both simulated whole building energy use and actual purchased energy data, the actual energy use was 28 percent lower than for the baseline model. However, there was significant variation among individual buildings, with some being more energy efficient than predicted and some being less efficient. For a subset of nine federal buildings, the actual energy use was lower than the modeled use.

Turner and Frankel (2008) reviewed the post-occupancy energy performance of 121 LEED-New Construction (LEED-NC)-certified buildings, of which 100 were classified as "medium energy use activities" and defined as buildings that had EUIs in a range similar to office buildings. (Total EUI was derived by summing the purchased energy for all fuel types.) Twenty-one buildings were classified as "high-energy use activities," which included buildings with very high process loads, such as laboratories, data centers, and recreation facilities. Most of the analyses in the report focused on the 100 medium-energy-use buildings. Within the 100-building sample, at least eight building types were included, and office was the predominant use. Thirty-eight of those buildings were certified as LEED-NC-certified; 35 as LEED-NC-Silver; and 27 as LEED-NC-Gold or -Platinum.

The report compared measured energy use (1 full year of post-occupancy energy use) to several different benchmarks, including CBECS national averages, ENERGY STAR® ratings, and modeled energy performance predictions provided as part of the submittals for LEED certification. They found that for all 121 LEED-certified buildings, the median measured site EUI was 24 percent lower than the CBECS national average (as of 2003) for all commercial building stock. For 35 office buildings in the LEED-certified sample, the average energy use was 33 percent lower than the CBECS national average for office buildings. The authors found that project types classified as high-energy-use activities with high process loads, such as laboratories, were problematic, because the energy use of high-energy-use building types is not well understood by designers.

Within the sample of 100 medium-energy-use activities, Turner and Frankel found that LEED-NC-certified buildings used 26 percent less site energy than the CBECS national average, LEED-NC-Silver buildings used 32 percent less energy, and LEED-NC-Gold/Platinum-certified buildings used 44 percent less energy on average than the CBECS national average. The authors also compared the actual energy use in the LEED-certified buildings to the energy use predicted by baseline and design models submitted for the buildings as part of the LEED certification process. In this instance, measured energy use for the buildings was 28 percent less on average than the energy baseline models (most used ASHRAE Standard 90.1-1999) and 25 percent less on average than the levels predicted by the design models. However, the energy use for more than half of the projects deviated by more than 25 percent from design projections, with 30 percent significantly better and 25 percent significantly worse.

For all but the warm-to-hot zones, LEED-NC buildings used significantly less energy than the CBECS national average, with median LEED EUIs 36 to 49 percent lower than the CBECS average for those zones. For the warm-to-hot zones, the median LEED EUI was virtually the same as CBECS. The authors stated that "the current variability between predicted and measured performance has significant implications for the accuracy of prospective life-cycle cost valuations for any given building" (Turner and Frankel, 2008, p. 5).

Newsham et al. (2009) re-analyzed the data used in Turner and Frankel (2008) for the 100 LEED-NC buildings categorized as "medium energy use activities." They employed a range of statistical tests to improve the rigor of the analysis. In the tests, Newsham et al. sought to pair each LEED building with a single matched building from the CBECS database. Newsham et al. noted that a limitation of the Turner and Frankel study was that the comparisons to the CBECS data were somewhat crude:

> The median EUI of all LEED buildings was compared to the mean EUI of all CBECS buildings, by activity type, thus confounding two different metrics of central tendency. Little specific account was made of differences in the two datasets related to climate zone, building size, or building age (Newsham et al., 2009, p. 5).

Nonetheless, Newsham et al. found that:

- No matter the basis of comparison, the LEED-certified buildings used statistically significant less energy per floor area than the CBECS averages. On average, the LEED-certified buildings used 18 to 39 percent less energy per floor area.
- Twenty-eight to 35 percent of LEED-certified buildings used more energy per floor area than their individually matched buildings from the CBECS database.
- There was no statistically significant relationship between LEED-NC certification level and energy use intensity or percent energy saved versus the baseline. LEED-NC-Silver buildings did not exhibit better energy performance than LEED-NC-certified buildings and LEED-NC-Gold/Platinum buildings did not exhibit better energy performance than LEED-NC-Silver buildings. This finding was the opposite of the finding from the Turner and Frankel (2008) study.

Scofield published two separate papers that reanalyzed subsets of the Turner and Frankel data (Scofield, 2009a, b). In both cases, Scofield's major focus was source energy, although he also analyzed site energy. Turner and Frankel (2008) and Newsham et al. (2009) used site energy only.

In the report *A Re-examination of the NBI LEED Building Energy Consumption Study* (Scofield, 2009a), Scofield pointed out Turner and Frankel's comparison of the mean of one distribution to the median of another and stated that "to compare the mean of one with the median of the other introduces bias by compensating for skew in only one distribution" (Scofield, 2009a, p. 765). Scofield also defined mean energy intensity differently, using a gross square foot averaging method, and conducted statistical tests of the data for several subsets of the Turner and Frankel database. Scofield compared data from some of the LEED-certified buildings to the CBECS database and also to a subset of buildings from CBECS constructed between 2000 and 2003. His conclusions included the following:

- LEED-certified medium-energy-use buildings, on average, used 10 percent less site energy but no less source (or primary) energy than did comparable conventional buildings, whether restricted to new vintage (constructed between 2000 and 2003) or not.

- LEED-NC-certified buildings used slightly more site energy than the CBECS comparison group, while LEED-Silver and LEED-Gold or -Platinum buildings used 23 percent and 31 percent less site energy, respectively, than the CBECS comparison group.
- LEED office buildings used 17 percent less site energy than that of the CBECS comparison group of all vintages; there was no significant reduction in primary (source) energy use relative to non-LEED office buildings.

The paper "Do LEED-certified buildings save energy? Not really. . ." (Scofield, 2009b) was written as a direct rebuttal to Newsham et al. Scofield reanalyzed data from Turner and Frankel (2008) for a subset of 35 LEED-certified office buildings. Scofield weighted the energy intensity of each building in the LEED sample by its gross square footage, which he stated was exactly equal to the total energy use by all buildings divided by their total gross square feet. In doing so, Scofield pointed out that different averaging methods would yield different means and different conclusions. Nonetheless, Scofield found that:

- LEED-NC-certified office buildings used, on average, 10 to 17 percent less site energy than comparable non-LEED buildings.
- LEED-certified commercial buildings, on average, show no significant primary energy savings over comparable non-LEED buildings.
- Smaller LEED office buildings had relatively lower purchased EUI (relative to non-LEED), while larger LEED office buildings showed less savings in comparison to non-LEED buildings.

Kats (2010) analyzed data for 170 green buildings representing of a wide range of building types located in 33 states and 8 countries. The primary emphasis of this study was on the financial benefits and costs of green buildings in comparison to conventional buildings. Data related to the incremental costs of green construction, energy use and water use, and other measures were gathered directly from building owners, architects, and developers. The results of the survey were synthesized with the findings from other studies to develop estimates of the NPV of benefits and costs. Other studies used in the synthesis included surveys, case studies, and market research.

The buildings in the sample were completed between 1998 and 2009. Green buildings were defined as those that were LEED-certified or anticipating LEED certification or certification under another similar rating system. Approximately 15 percent of the 170 buildings were certified under systems such as the Massachusetts green schools guidelines, Enterprise Green Communities, or the Green Guide for Healthcare Facilities.

Reported reductions in energy use for the green buildings were measured as EUI and largely based on computer design and baseline models submitted as part of the LEED certification process, not on actual measured energy use (utility bills) for the buildings. Kats (2010) reported that the buildings in the data set had projected reductions in energy use, from less than 10 percent to more than 100 percent (meaning that the building generated more power than it used), with a median reduction of 34 percent. However, Kats also noted that even within a single building type and region, green and conventional buildings showed a wide range of energy intensities depending on factors such as building design, mechanical systems and appliances, operations and maintenance practices, and occupancy.

For the benefit-cost analyses to calculate NPV benefits, Kats used a time period of 20 years, a discount rate of 7 percent, and assumed annual inflation rates of 2 percent, and used the median savings of 34 percent for the green buildings comparison. Kats calculated that the NPV of 20 years of energy savings in a typical green building ranged from $4 per square foot to $16 per square foot, depending on building type and LEED level of certification. Kats found that "when compared with an ASHRAE 90.1 baseline building, LEED-certified buildings in the data set reported median savings of 23 percent; for Silver, the figure was 31 percent; for Gold, 40 percent; and for Platinum, 50 percent" (Kats, 2010, p. 16).

## Studies of Energy Use in Federal Buildings

Fowler and Rauch (2008) looked at 12 green buildings owned by GSA located in half of its national regions. The sample included seven LEED-certified buildings, one LEED-registered building, one building constructed to meet the Living Building Challenge, and three buildings designed to achieve energy efficiency. The building sample included six office buildings, four courthouses, and two combination office/courthouse buildings. Fowler and Rauch measured the actual energy use of these buildings based on utility bills. They found that on average the 12 GSA green buildings used 29 percent less energy than the CBECS national average, 29 percent less energy than the CBECS regional average, and 14 percent less energy than the GSA energy goal for its portfolio of facilities.

In 2010, Fowler et al. studied 22 green buildings in the GSA's portfolio. The sample included updated data from the 12 buildings included in the 2008 study and 10 additional GSA LEED-certified buildings. In all, the study included 8 courthouses, 12 federal buildings (office space), and 2 courthouse/federal buildings. Thirteen of the buildings were LEED-certified, three were LEED-registered (one of these buildings did not specify the proposed level of certification), while the others emphasized energy efficiency during the design phase. The methodology used was generally the same. Fowler et al. found that energy use in the 22 GSA green buildings, on average, was 25 percent lower than the CBECS national average, 18 percent lower than CBECS regional averages, and 10 percent lower than GSA regional averages for fiscal year (FY) 2009.

Data were available for 15 LEED-certified buildings. For five of the seven LEED-Silver buildings, energy use was lower for all three baselines (CBECS regional, GSA target, GSA regional). The energy use in two LEED-Silver buildings was higher than the CBECS regional average. The LEED-Gold buildings used consistently less energy than the baseline for all buildings.

Menassa et al. (2012) looked at the energy use of 11 buildings operated by the Naval Facilities Engineering Command (NAVFAC) that had achieved various levels of LEED certification (three Certified, five Silver, three Gold) by 2008. The study compared the site energy of the LEED-certified buildings to 11 NAVFAC buildings of similar size, function, and location that were not LEED-certified. Menassa et al. found that 7 of 11 LEED-certified buildings reduced their electricity use when compared to their non-LEED-certified counterparts, with reductions ranging from 3 to 60 percent less electricity. However, 4 of the 11 NAVFAC LEED-certified buildings used more energy than their non-LEED counterparts, ranging from 11 to 200 percent more energy. Four of five LEED-Silver buildings used 3 to 49 percent less energy than their non-LEED counterparts, while one LEED-Silver building used 128 percent more energy than its non-LEED counterpart. Two of the three LEED-Gold-certified buildings used 6 percent and 15 percent less energy than their non-LEED counterparts, while the third used twice as much energy as its non-LEED counterpart. Only 3 of the 11 NAVFAC LEED-certified buildings used less energy than the CBECS national average.

## Regional Studies of Energy Use

Turner (2006) looked at measured energy usage (at least 1 year of utility bills) of 11 LEED-certified buildings (three building types) in relation to initial modeling predictions and to a baseline approximate to code in the Pacific Northwest. Energy was measured as per conditioned square feet, and savings estimates were made by comparing actual energy to the energy use predicted by models. Turner found that all of the buildings used less energy than the baseline approximate to code, averaging nearly 40 percent below that baseline. Nine of the eleven buildings achieved energy savings when compared to a baseline similar building in the region. The author calculated NPV benefits for energy assuming a 25-year time period, a discount rate of 3 percent, constant use of energy, and energy price increases at the rate of inflation. Based on those parameters, Turner estimated that the cost savings per year for energy for the LEED-certified buildings would range from $0 to $26 per square foot, with an average savings of $2 per square foot when compared to the regional median.

In the Turner study, four LEED-NC-Silver buildings used 39 to 57 percent less energy than their approximate to code baseline model. The two LEED-NC-Gold buildings for which data were available used 43 to 86 percent less energy than the baseline approximate to code. For the four LEED-NC-Silver buildings, Turner estimated that the long-term cost savings would be $7 to $26 per square foot; for the three LEED-Gold buildings the savings would range from $0 to $8 per square foot.

Baylon and Storm (2008) compared the actual site energy performance of 24 LEED-certified buildings in the Pacific Northwest to the actual site energy performance of a larger sample of contemporary buildings constructed to local codes. Most of the buildings in the study had been occupied for at least 2 years. The LEED buildings in the sample saved 12 percent more energy than the comparison group. The authors noted that energy codes in Washington and Oregon were more stringent than ASHRAE 90.1-1999, which was the basis for LEED at that time.

Sacari et al. (2007) compared the predicted energy use (estimated during the preconstruction, design phase) to the actual energy use (utility bills for electricity and natural gas) in 19 new or renovated green buildings in Massachusetts compared to buildings designed to the Massachusetts baseline building code. The sample included 12 schools and 7 other buildings. Sacari et al. found that most of the green buildings were consuming less energy than a building designed to Massachusetts baseline code, although they were also consuming 40 percent more energy on average than predicted by design models.

Widener (2009) analyzed the post-occupancy performance and costs and benefits of 25 LEED-certified projects in Illinois. Most projects were certified under LEED versions 2.0 and 2.1. The sample included more than six building types certified under different LEED programs (e.g., LEED-NC, LEED-CI) and at all LEED certification levels. All projects provided at least 1 year of post-occupancy energy use; 17 of the 25 projects provided "whole project energy use data," where complete energy data were provided. The performance of all the LEED-certified buildings was compared to three other data sets: the Turner and Frankel study published in 2008; the 2003 CBECS; and ENERGY STAR®. Widener found that the 17 LEED-certified projects for which complete energy data were available used 5 percent less energy than the CBECS comparison group. Widener also noted that there was a large variation in the energy performance among projects.

Oates and Sullivan (2012) conducted post-occupancy energy consumption surveys for 25 LEED-NC buildings in Arizona. The sample included various types of buildings that had been certified under LEED versions 2.0, 2.1, and 2.2 and that had been in operation for at least 1 year as of October 2009. Actual energy performance of those buildings as measured by EUI for source and site energy was compared to CBECS data. The CBECS data were normalized to match the gross square feet weights for each building type in the LEED sample. The LEED building sample was also characterized by medium energy intensity (19) and high energy intensity (6) structures. The authors noted that two buildings accounted for 40 percent of the total data set's gross square footage and 51 percent of the gross square footage in the medium energy intensity subset.

The authors found that the 19 medium-energy-intensity LEED-certified buildings used 13 percent less energy than the CBECS comparison group. (The high-energy-intensity subset was not analyzed, because the sample size was too small.) Of the 19 buildings (both medium- and high-energy-intensity use) with design and baseline model simulations, only one used less energy than had been predicted in the design case, and only four used less energy than the baseline simulation.

## WATER USE

Six of the studies cited under energy use also studied water use. No studies were identified that focused only on water use in high-performance or green buildings.

Kats (2010) looked at 170 green buildings across the country. Of these, 119 reported projected reductions (from models) in indoor potable water use when compared to conventional buildings. The reductions ranged from 0 percent to more than 80 percent, with a median of 39 percent. Kats also found that water savings generally increased with LEED level of certification. Kats estimated the NPV benefits of water savings in typical green buildings ranged from $.50 per square foot to $2 per square foot, depending on building type and LEED level of certification.

Fowler and Rauch (2008) measured water use for 12 GSA green buildings. They established a baseline for domestic water use as the base load revealed from monthly water use data. Given these estimates, the average water use for the GSA green buildings was 3 percent less than the baseline.

Fowler et al. (2010) measured water use for 22 GSA green buildings and found that two-thirds of the buildings used less water than the GSA baseline, with the average being 11 percent lower. Of the 6 buildings with higher water use than the baseline, 5 had cooling towers or evaporative cooling, 2 had exterior fountains in a hot, dry climate, and 3 had non-typical operating schedules. For 5 of the 7 LEED-Silver buildings, water use was below the national and regional averages and the GSA baseline. Two LEED-Silver buildings (one with a cooling tower and one with evaporative cooling) had significantly higher water use than the average. Two of the 3 LEED-Gold buildings performed better than the baselines, but one used significantly more water than the baselines in both the 2008 and 2010 studies.

Menassa et al. (2012) found that 7 of 9 LEED-certified buildings used by NAVFAC reduced their water consumption by more than 15 percent when compared to NAVFAC non-LEED-certified similar buildings. Four of the LEED-certified buildings reduced their water use by 50 to 75 percent. Seven of 9 LEED-certified buildings reduced their water consumption between 18 and 72 percent. For the 4 LEED-Silver buildings for which water data were available, water use was 18 to 61 percent lower than their non-LEED counterparts. Two of the 3 LEED-Gold-certified buildings showed water savings of 56 and 60 percent, while the third used 90 percent more than its non-LEED counterpart.

Turner (2006) compared actual water use to modeled water use and to baseline code buildings in the Pacific Northwest. When compared to the baseline code buildings, 4 of the 7 buildings were using 8 percent less water. For the 7 buildings for which water use projections (models) were available, 6 buildings used at least slightly more water than projected.

Widener (2009) collected data on water use for 12 LEED-certified projects in Illinois. Widener found a wide range in annual water use and attributed it to individual project size, principal activity, and occupancy.

## OPERATIONS AND MAINTENANCE COSTS

The committee identified three studies that attempted to compare operations and maintenance costs for high-performance or green buildings to other baselines.[4]

[4] A study by Miller et al. (2010) looked at operations and maintenance costs for ENERGY STAR® buildings and was not reviewed by the committee because the Energy Star labeling program was not included as part of the statement of task.

A 2008 study by the Leonardo Academy measured operating costs for 11 buildings certified under the LEED-Existing Buildings (EB) program, each of which had a significant component of office space (Leonardo Academy, 2008). Operating costs included cleaning expenses, repair and maintenance expenses, roads/grounds expenses, security expenses, and administrative and utility expenses. Data for the LEED-EB-certified buildings were collected and compared to the operating costs in BOMA's (Building Owners and Managers Association) *Experience Exchange Report,* an industry standard. The authors found that "in all categories of operating costs, more than 50% of the LEED-EB buildings have expenses less than the BOMA average for the region. Total expenses per square foot of the LEED-EB buildings are less than the BOMA average for 7 of the 11 buildings" (p. 21).

Fowler and Rauch (2008) calculated aggregate operating costs for 12 GSA green buildings and compared those costs to industry baselines. The baselines were developed from a number of sources, including data from BOMA and the International Facility Management Association (IFMA). Aggregate operating costs included water and energy utilities, general maintenance, grounds maintenance, waste and recycling, and janitorial costs. They found that, on average, aggregate operating costs were 13 percent lower than average costs than the industry baselines. However, several of the buildings had consistently higher operating costs in each category.

Fowler et al. (2010) analyzed operating costs for 22 GSA green buildings using the same definition of operating cost as Fowler and Rauch (2008). Fowler et al. found that, on average, aggregate operating costs were 19 percent lower for the green buildings than the baseline. Aggregate operating costs for 17 of the buildings were 2 to 53 percent lower than the industry baselines. Five of the 22 buildings had higher aggregate operating costs than the baselines, ranging from 1 to 27 percent higher.

## INDOOR ENVIRONMENTAL QUALITY AND WORKER PRODUCTIVITY

The committee identified five studies that met its criteria for time frame, robustness, and relevancy, and that compared IEQ and the health and productivity of workers in high-performance or green buildings to that of workers in conventional buildings.[5] It should be noted that a body of well-designed, empirical studies evaluating various factors related to IEQ in all buildings is available. However, in keeping with its narrow focus on the statement of task, the committee evaluated only studies specifically related to IEQ and high-performance or green buildings.

Abbaszadeh et al. (2006) looked at the satisfaction of occupants in green buildings compared to the satisfaction of occupants in conventional buildings, using information from the CBE database. They compared surveys from occupants in 21 green buildings (15 were LEED-certified and 6 additional buildings were reported as green, based on the receipt of national or local green building or energy efficiency awards) to CBE surveys from occupants in conventional buildings.

The study focused on occupant satisfaction with thermal comfort, air quality, lighting, and acoustics. The authors noted that "self-reported productivity scores follow the same pattern as those of satisfaction—productivity scores are high where satisfaction is high and low where satisfaction scores are low" (Abbaszadeh et al., 2006, p. 366). Other findings included the following:

- On average, occupants in LEED-certified green buildings were more satisfied than occupants of conventional buildings when it came to thermal comfort, air quality, and overall satisfaction with workspace and building.
- The mean satisfaction score in LEED-rated/green buildings was significantly higher than that for conventional buildings (1.47 versus 0.93).

[5] Three additional studies, Birkenfeld et al. (2011), Singh et al. (2009), and Cook (2005), analyzed only one or two buildings each, and for that reason were not included in the review of studies by the committee.

- Occupants in LEED-rated/green buildings were more satisfied with thermal comfort compared to occupants in conventional buildings (0.36 versus –0.16) and more satisfied with air quality in their workspace (1.14 versus 0.21).
- Even when considering only conventional buildings that were less than 15 years old, the mean satisfaction score with air quality was significantly higher for LEED-rated/green buildings (1.14 versus 0.52).
- When including only buildings 15 years old or newer in the conventional category, no statistically significant relationship was found for the IEQ categories of lighting and acoustics.

Fowler and Rauch (2008) used the CBE questionnaire to survey the occupants of 12 GSA green buildings. All of the green buildings scored above the CBE median for general occupant satisfaction, with the average being 22 percent higher than the CBE median.

Fowler et al. (2010) assessed 22 GSA green buildings and also used the CBE questionnaire. They found that, on average, occupant satisfaction with the green buildings in general was 27 percent higher than the CBE baseline, except for lighting, where it was the same as the baseline.

Miller et al. (2009) conducted a survey of 154 buildings that were deemed green by virtue of either an ENERGY STAR® label or LEED certification (any level) to determine if green buildings provided more productive environments. They gathered data for sick days and self-reported productivity percentages from building occupants who had moved to a new green building. Some 534 tenant responses were collected from buildings located across the United States. They found that 55 percent of the respondents agreed or strongly agreed that employees in green buildings were more productive, while 45 percent suggested no change. They also found that 45 percent of the respondents agreed that workers were taking fewer sick days than before moving to a green building, while 45 percent found it was the same as before, and 10 percent reported more sick days (the 10 percent were all in ENERGY STAR®-labeled buildings).

Baird et al. (2012) sought to determine whether there were any significant differences in the users' perceptions of a range of factors concerned with the operation, environmental conditions, control, and degree of satisfaction between sustainable and conventionally designed buildings.

The set of sustainably designed buildings (defined as either recipients of national awards for sustainable design or highly rated in terms of their country's buildings sustainability rating tool(s) or had pioneered some aspect of green architecture) included 31 commercial and institutional buildings (at least six different building types) located in 11 different countries. Surveys were gathered from 2,035 occupants. The survey questionnaire and baselines for comparison were from the Buildings in Use (BIU) database. The comparison sample of 109 conventionally designed buildings was compiled from the BIU database and included buildings that had been surveyed during a similar time period as the sustainable buildings were surveyed. Baird et al. (2012) found the following:

- An overall improvement in temperature and air quality in sustainably designed buildings was statistically significant. The sustainable buildings were perceived to be colder on average in winter but much the same (still on the hot side) in summer, whereas their air was perceived to be both fresher and less smelly year round.
- Lighting also showed a considerable and statistically significant improvement in the sustainably designed buildings when compared to the conventional buildings.
- No significant difference for noise was found in the sustainable buildings compared to the conventional buildings. There was a perception of slightly too much noise from various internal sources (e.g., conversations, telephones) in both samples.
- For the sustainable buildings, all of the factors in the satisfaction category showed a significant improvement over the conventional buildings. Occupants of sustainable buildings perceived

> that they were 4 percent more productive than did occupants of conventional buildings. The improvement in perceived health among occupants in sustainable buildings (4.25) in comparison to occupants in conventionally designed buildings (3.29) was also statistically significant.

Widener (2009) found that most of the 21 LEED-certified projects in Illinois were not tracking health-related benefits. Survey results related to occupant overall satisfaction with building comfort (light level, noise, temperature, air quality/ventilation) were available for 11 LEED-certified projects. Widener found that, overall, occupant satisfaction was high, with the highest-rated categories being lighting and air quality/ventilation. The lowest-rated category was temperature.

## INCREMENTAL COSTS TO DESIGN AND CONSTRUCT HIGH-PERFORMANCE BUILDINGS

Studies that seek to compare the difference in design and construction costs, the so-called first costs, or the "green premium," between high-performance or green and conventional buildings typically discuss four different types of costs: (1) the baseline costs of the project itself; (2) the marginal capital costs of some (but not all) green improvements to the project itself, such as more expensive technologies or materials, which may be offset by savings in other systems; (3) the soft costs associated with additional documentation, analysis, and evaluation, such as energy modeling; and (4) the direct costs associated with third-party certification. Those studies, however, use different methods to define the comparison group. The different methods result in different types of findings. Some studies are specific in evaluating the cost of individual green strategies on a given building, in effect using a hypothetical baseline model for the self-same building, much as energy models do. Studies conducted for the GSA and the Indian Health Service (IHS) to look at the cost differential between LEED-certified and non-LEED-certified buildings used this approach (SWA, 2004; IHS, 2006). Caprio and Soulek (2011) looked at the cost-effectiveness of various energy efficiency improvements in Army standard designs. Others reference building budgets, asking whether the green project cost more than budgeted or anticipated for the conentional equivalent; Kats (2010) used this approach. Two studies by Mattheissen and Morris (2004, 2007) used the population approach, aiming to identify whether the population of green buildings was distinguished by cost when compared to the building stock in general. The latter approach is typically used in valuation studies that identify whether green buildings sell or lease for more than the building stock in general. The different methods for calculating incremental construction costs are valid, but should not be combined.

Matthiessen and Morris (2004) undertook a study with the goal of comparing construction costs of buildings where LEED certification was a primary goal to the costs of similar buildings where LEED was not considered during design. The authors studied 93 non-LEED-seeking and 45 LEED-seeking buildings for which data were gathered from the database of the Davis Langdon Company. All costs were normalized for time and location to ensure consistency for the comparisons. Among their conclusions were the following:

- Many projects achieve sustainable design within their initial budget or with very small supplemental funding, suggesting that owners are finding ways to incorporate project goals and values, regardless of budget, by making choices.
- There was no statistically significant difference [in cost per square foot] between the LEED-seeking and the non-LEED seeking buildings. The cost per square foot for the LEED-seeking buildings was scattered throughout the range of costs for all buildings studied, with no apparent pattern to the distribution.

A second report using the Davis Langdon database (Matthiessen and Morris, 2007) compared the construction costs of 83 buildings seeking LEED 2.1 and 2.2 New Construction certification to 138 non-LEED-seeking buildings (the samples included five different building types). Findings from the study were the following:

- Many projects were achieving LEED certification within their budgets and in the same cost range as non-LEED-seeking projects.
- While there appeared to be a general perception that sustainable design features added to the overall cost of the building, the data did not show a significant difference in the average costs of LEED-seeking and non-LEED-seeking buildings.

Kats (2010) found that the owners or owner's representatives of 170 green buildings reported the median additional cost was 1.5 percent more to build a green building compared to a conventional building. The large majority of green building owners reported additional incremental costs between 0 and 4 percent, although the total range was 0 to 18 percent. The author concluded that most green buildings cost slightly more than similar conventional buildings to construct. Generally, the higher the certification level, the greater the cost premium, but all LEED levels could be achieved for minimal additional cost.

Three studies looked at the incremental costs associated with energy efficiency or LEED certification of federal buildings. Stephen Winter Associates (SWA, 2004) provided a detailed and structured review of both the capital and soft cost implications of achieving Certified, Silver, or Gold LEED ratings for the two building types most commonly constructed by the GSA: a five-story courthouse and a mid-rise federal office building. The study indicated that there was an inherent degree of variability to LEED construction cost impacts. However, the authors concluded that many Silver-certified projects could be built at a cost that was within 4 percent of the cost for a similar non-LEED-certified courthouse or office building, as well as occasional LEED-Gold-certified projects.

The IHS conducted a study (IHS, 2006) to evaluate the potential cost impacts of achieving a LEED-certified or a LEED-Silver certification on its facilities, which are primarily hospitals and other healthcare-related buildings. Among the study findings were the following:

- Initial capital construction costs (design and construction) would require a 1 to 3 percent increase in the budget to meet the Certification level and a 3.5 to 7.6 percent increase in the budget to meet LEED-Silver certification.
- Energy savings over 20 years of operation have the potential to significantly mitigate the initial capital cost impacts. Given the potential margin of error inherent in these types of calculations and the uncertainty of future energy prices, life-cycle cost savings may completely offset or even exceed initial capital costs.

Caprio and Soulek (2011) sought to determine the difference in initial investment (incremental construction costs) for building energy-efficiency enhancements intended to meet federal mandates. Benefit-cost analyses were conducted for the U.S. Army's new construction standard designs for FY 2013 for the five most commonly constructed Army building types. The results were based on total energy use and were modeled, not measured. The authors noted that 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. They concluded, however, that (1) significant energy savings were possible for all climates, and (2) buildings achieving 25 to 35 percent energy savings would yield the maximum energy savings for the lowest cost. For buildings achieving 35 to 60 percent energy savings, each increment of energy saved came at an increasingly higher cost (plug load reduction, small-scale renewable energy, building orientation, site-specific design).

Widener (2009) found wide variation among the 15 Illinois LEED-certified projects that submitted information on construction costs. Widener concluded that similar to conventional buildings, the variation in construction costs for the LEED-certified buildings may be attributed to principal building activity and the individual project's goals and specifications.

The Kats (2010) finding that the median premium is 1.5 percent, as compared to a notional budget, is not incompatible with the IHS finding that adding green features to a reference conventional building results in a premium of 1 to 8 percent, nor is it incompatible with the Matthiessen and Morris (2004) finding that there was no statistically significant difference between the LEED-seeking and non-LEED-seeking buildings.

## CONCLUSIONS

The committee did not identify any research studies that met its criteria and that conducted a traditional benefit-cost analysis to determine the long-term net present value savings, return on investment, or long-term payback related to the use of ASHRAE standards 90.1-2010 or 189.1-2011, the LEED or Green Globes green building certification systems, or the LEED Volume certification program.

The committee did identify 15 studies that compared the energy use of high-performance or green buildings to conventional buildings. Those studies incorporated different methods, baselines, types of buildings, and sample sizes; some applied to large areas of the country, and some were specific to regions or states. Despite these variations, the 13 studies that measured actual energy used (not modeled energy) found that high-performance or green buildings, on average, used 5 to 30 percent less site energy than conventional buildings.

There was also some evidence that high-performance or green buildings used less water than conventional buildings, with average water-use reductions in the range of 8 to 11 percent.

On a building-by-building basis, however, not all green buildings achieved energy or water savings in comparison to conventional buildings. Because there was significant variability within sample sets in terms of the types, numbers, and locations of buildings, the committee could not determine with certainty why individual buildings succeeded or failed to meet the average. For those studies that looked at buildings certified at different levels of LEED, the evidence that is available is inconclusive regarding whether LEED-Silver-certified buildings outperformed LEED-certified buildings, or whether LEED-Gold buildings outperformed LEED-Silver buildings.

There was also suggestive evidence that operations and maintenance costs may be lower for green buildings, but the very limited sample size leaves the analysis results outside the range of certainty. The three studies evaluated all included utility costs (energy and water) in operating costs, so it is not possible to determine how significant the other factors were in total operating costs.

Additionally, there was suggestive evidence that high-performance buildings result in improvements in some aspects of indoor environmental quality (air quality, thermal comfort, and overall satisfaction with workspace).

Regarding the differences in costs to design and construct green buildings in comparison to conventional buildings, the studies reviewed used different methods to identify those costs. The results from the studies indicated that design and construction cost (variously defined) would range from 0 to 8 percent higher for green versus conventional buildings, depending on the method used to calculate the costs and the type of building.

# 5

# Findings and Recommended Approaches for DOD's Consideration

The Committee on Energy-Efficiency and Sustainability Standards Used by the Department of Defense for Military Construction and Repair was tasked to conduct a literature review (Appendix D) and evaluate a Department of Defense (DOD) consultant's report (Slaughter, 2012; reprinted in Appendix C) to help determine the long-term economic benefits of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standards 90.1-2010 and 189.1-2011, the U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED), and the Green Globes green building certification systems. Based on its findings, the committee was also tasked to recommend approaches for DOD's consideration as part of DOD's comprehensive strategy for improving the sustainability of its portfolio of facilities.

The first green building certification system implemented in the United States, the USGBC's LEED system was introduced in 1998. DOD and other federal agencies were early adopters of LEED and other green building certification systems as a tool to help design buildings to limit their environmental impact. Legal requirements for the use of green building certification systems, to meet goals for multiple objectives related to high-performance buildings and for the training of federal building managers, were subsequently enacted through the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007, and the Federal Buildings Personnel Training Act of 2010. As of fiscal year (FY) 2012, the federal government as a whole had 550 buildings certified under LEED, Green Globes, or other green building certification systems in a total portfolio of 429,000 buildings.

The first empirical studies to evaluate the performance of buildings designed to be highly energy efficient or buildings certified under a green building certification system in the United States were published in 2006 (Torcellini et al.; Diamond et al.; Turner). The first study evaluating a sample size of more than 100 green buildings was published in 2008 (Turner and Frankel). The largest study to date that focused on factors relevant to the DOD operating environment included 170 buildings (Kats, 2010).

In conducting its literature review, the committee identified 25 studies that met its criteria for timeframe, robustness, and relevancy to the DOD operating environment. Most included a wide range of building types within the samples of green or high-performance buildings and focused on the reduction of energy and water use or improvements in indoor environmental quality. The baselines for comparison of high-performance or green buildings to conventional buildings varied, as did the factors evaluated, the methodologies used, and the locations of buildings. None of the studies focused on the long-term cost-effectiveness attributable to the use of building standards or green building certification systems.

Because there is not yet a significant body of objective, research-based evidence available on the topic of the performance of high-performance or green buildings, the committee's evaluation of the literature review was not straightforward. The green building movement is a relatively recent phenomenon, and so the lack of a standard research protocol, variations in definitions and baselines, limited sample sizes, and the inclusion of many building types were not unexpected. Development of a body of empirical research for any building-related topic takes many years: it typically takes at least 5 years to program, design, and construct a building, which will then be operated for 30 years or longer. Over decades of use, a building's performance will change as building systems age, through wear and tear, and through changes in occupancy and equipment. How much performance changes depends on the quality of the design and construction, operation and maintenance practices, climate zones, and other factors.

For these reasons and others, as outlined in Chapters 1 through 4, the committee relied on the "preponderance" of evidence from the literature review, its evaluation of the DOD consultant's report, and its members' own experience and expertise in developing its findings and recommended approaches, which are presented below.

## FINDINGS

**Finding 1. The committee did not identify any research studies that conducted a traditional benefit –cost analysis to determine the long-term net present value savings, return on investment, or long-term payback related to the use of ASHRAE Standard 90.1-2010, ASHRAE Standard 189.1-2011, and the LEED or Green Globes green building certification systems.**

Of the 25 studies that met the committee's criteria for time frame, robustness, and relevancy to the DOD operating environment, only two (Turner, 2006; Kats, 2010) provided some analyses of net present value (NPV) benefits, return on investment, or payback associated with high-performance and green buildings. Those studies, however, did not evaluate the cost-effectiveness of the specific building standards or green building certification systems. Instead, they looked at the cost-effectiveness of green buildings compared to conventional buildings.

The DOD consultant's report did conduct a traditional benefit-cost analysis for the specified building standards and green building certification systems. However, the committee had significant concerns about the data used for the analyses and the application of those data, such that it could not support the absolute NPV benefits calculated by the DOD consultant for the ASHRAE standards, LEED, or Green Globes.

**Finding 2. There is some limited evidence to indicate that provisions within ASHRAE Standard 189.1-2011 may need to be selectively adopted if use of this standard is to be cost-effective in the DOD operating environment.**

ASHRAE Standard 189.1-2011 contains mandatory requirements that limit the ability of DOD to adapt the standard to its operating environment. The foreword to ASHRAE 189.1-2011 states that "new provisions within the standard were not uniformly subjected to economic assessment" (p. 1) and that cost-benefit assessment was not a necessary criterion for acceptance of any given proposed change to the standard from the 2009 version.

The Logistics Management Institute study *Incremental Costs of Meeting ASHRAE Standard 189.1 at Air Force Facilities* (LMI, 2011) and this committee's review of ASHRAE 189.1-2011 identified some mandatory requirements that may not be cost-effective or feasible in the DOD operating environment. Among those are requirements related to renewable energy, remote metering systems, peak load shedding, and maximum waste generation. Provisions for heat island reduction, minimum side lighting, indoor environmental quality management before occupancy, and the consistent implementation of operations plans could also prove problematic for design choices and in building operations.

**Finding 3. Research studies indicate that the incremental costs to design and construct high-performance or green buildings typically range from 0 to 8 percent higher than the costs to design and construct conventional buildings, depending on the methodology used in the study and the type of building analyzed. The additional incremental costs to design and construct high-performance or green buildings are relatively small when compared to total life-cycle costs.**

Several studies focused on the incremental costs to design and construct high-performance or green buildings when compared to conventional buildings. Those studies used different methodologies to calculate the additional costs of design and construction and applied them to different types of buildings. The studies indicated that the additional first costs for high-performance or green buildings would typically range from 0 to 8 percent higher than the costs to design and construct conventional buildings, although the costs ranged up to 18 percent higher in a few instances. The study with the largest sample size indicated that, on average, the incremental first costs of green buildings are within 2 percent of the costs of conventional buildings.

During the life cycle of a building, design and construction costs typically range from 5 to 10 percent of total costs, while operations and maintenance costs account for 60 to 80 percent of total costs. Thus the additional incremental costs to design and construct high-performance or green buildings are relatively small when considered as part of total life-cycle costs. If the additional up-front investment in a building results in long-term savings in energy, water, and other resources, as indicated by an NPV greater than 1, then the investment would be cost-effective.

**Finding 4. The analytical approach proposed by the DOD consultant has merit as a decision support tool in the DOD operating environment if appropriate and verifiable data are available for conducting benefit-cost and sensitivity analyses.**

The DOD consultant conducted a traditional benefit-cost analysis to calculate NPV benefits and adjusted rate of return on investment to determine the cost-effectiveness of the two ASHRAE standards and the two green building certification systems. The consultant also conducted a payback analysis as required by the National Defense Authorization Act of 2012. The consultant's proposed analytical approach expanded on the traditional benefit-cost analysis to incorporate factors related to geographic location, climate conditions, and local factors for utility costs. Sensitivity analyses were also incorporated to test a range of scenarios that represented uncertain future conditions related to discount rates, water prices, and energy prices. To the committee's knowledge, those factors are not required by DOD or by other federal regulations. The committee believes that the consultant's analytical approach has merit as one of an array of decision support tools to be used by DOD for evaluating investments in new construction or major renovations.

However, the committee has significant concerns about the sources of data available and the application of those data in the consultant's NPV calculations, including estimates of the incremental costs to design and construct high-performance or green buildings. Actual incremental construction cost data for both LEED-certified and Green Globes-certified buildings were not available. To generate the incremental construction cost data, which are essential to calculations of NPV benefits, the consultant used two methods. The total cost of a building that is not LEED-certified or Green Globes-certified (a baseline building) was calculated using square foot data gathered from R.S. Means. For the LEED-certified and Green Globes-certified buildings, the consultant used the actual costs of construction for entire buildings, which were then adjusted based on an assumption that 35 percent of the project costs were attributable to architect and engineering fees and other costs. The committee notes that for the purpose of calculating the cost of energy, water, and green systems, the R.S. Means square foot data cannot be directly compared to the cost of actual buildings, because the R.S. Means data make assumptions about building configurations, while actual buildings have specifics. There can be many differences between an actual building and a prototypical building used by R.S. Means in the square foot tabulations that are not attributable to water, energy, or green systems. If the specifics of the actual building are unknown, the comparison can be significantly skewed.

Second, to conduct the analyses of cost-effectiveness for ASHRAE standards 189.1-2011 and 90.1-2010, the data provided by ASHRAE were the same data used in the models run for the development of those standards. The source of the data, therefore, did not allow for an independent verification of the cost-effectiveness of those standards.

The committee was particularly concerned about the estimated NPV benefits attributable to water savings associated with ASHRAE 189.1-2011, which the committee believes would be very difficult to achieve absent extraordinary measures that may not be cost-effective for DOD.

Third, the consultant used estimated data assembled by ASHRAE staff for the ASHRAE standards analysis. The consultant used a combination of data from actual buildings and estimated data (R.S. Means square foot data) for the analysis of the green building certification systems. The use of data from such different sources makes it difficult to compare the cost-effectiveness of the ASHRAE standards to the cost-effectiveness of the LEED and Green Globes green building certification systems.

The lack of actual incremental cost data calls into question the consultant's calculations for incremental costs and, therefore, it calls into question the consultant's findings related to NPV benefits. As noted in Finding 3, the studies analyzed in the committee's review of the literature indicate that the incremental construction costs for LEED-certified buildings are significantly lower than the incremental construction costs estimated by the DOD consultant. The NPV benefits calculated by the DOD consultant would likely have been higher if the consultant had used the average incremental construction costs from those studies.

As a consequence, the committee cannot support the consultant's findings related to the absolute NPV benefits calculated for the ASHRAE standards, LEED, or Green Globes.

**Finding 5. The evidence from the literature search indicates that high-performance or green buildings can result in significant reductions in energy use and water use. The cost savings associated with the reductions in energy and water use will vary by geographic region, by climate zone, and by building type.**

Thirteen of the 25 studies evaluated focused on measured actual energy use in buildings based on utility bills. Despite a wide variation in baselines, sample sizes, types of buildings, methodologies, and geographic distributions, all 13 studies found that high-performance or green buildings, on average (i.e., over a group of buildings), used 5 to 30 percent less site energy than similar conventional buildings.

The six studies that provided some evaluation of water use found that high-performance or green buildings on average used 8 to 11 percent less water than conventional buildings.

Seven studies provided some analysis of the performance of buildings certified at different levels of LEED. They indicated that the majority of LEED-Silver, Gold, or Platinum buildings studied used significantly less energy and less water than conventional buildings.

The long-term cost savings that can be achieved through reductions in energy and water use over the life cycle of buildings will depend, in part, on local utility prices and on heating and cooling loads related to climate zones. Five studies focused on buildings in specific regions or states (Pacific Northwest [2], Massachusetts, Illinois, and Arizona). In these studies, energy use reductions attributed to green buildings when compared to conventional buildings ranged from 5 to 40 percent. During the 30 or more years a DOD building is in use, those differences could be significant. Across a portfolio of facilities, local price factors may be an important consideration for DOD in determining which investments in military construction or major renovations will be the most cost-effective over the long term.

**Finding 6. Not every individual high-performance or green building achieved energy or water savings when compared to similar conventional buildings.**

Although high-performance or green buildings saved energy and water, on average, across a sample of green buildings, some individual buildings had significantly greater reductions than the average, and some did not perform as well as conventional buildings. Similarly, there were LEED-Silver and LEED-Gold buildings that used more energy and more water than conventional buildings. The research studies speculated about reasons why this was so but did not provide sufficient evidence to draw generalizations regarding why some high-performance or green buildings significantly outperformed conventional buildings and why others did not, although building type was clearly a factor. Another factor was the type of technologies employed to reduce energy or water use.

**Finding 7. In general, the quantities of energy and water used by a building once it is in operation are greater than the quantities of energy and water predicted by building design models, if these models are specifically created for compliance with LEED, Green Globes, or ASHRAE standards.**

All building standards and green building certification systems require that a building design meet or surpass an energy efficiency standard. In the case of LEED, Green Globes, and ASHRAE 189.1, this standard is ASHRAE/IESNA 90.1. An energy model created to be compared with the ASHRAE/IESNA 90.1 standard necessarily underestimates the energy use and the energy cost of the building once it is constructed and in operation. This is because (1) such models assume perfection in manufacturing, installation, and operation of buildings and their systems; and (2) such models do not include certain heat losses, because they are too difficult to calculate.

Energy and water use should be predicted with an "actual use" model that takes into account factors not considered by the LEED, Green Building Initiative (GBI), or ASHRAE design models. An "actual use" model starts with the model created for compliance with LEED, Green Globes, or with ASHRAE 189.1, and then incorporates real-life assumptions of manufacturing, installation, and operation. It also incorporates the three-dimensional heat losses.

An "actual use" model created during design can be significantly improved in its predictive value if it is updated with as-built/as-operated conditions. Imperfections during construction can be observed and incorporated in the model, change orders can be modeled as well, and variations in occupancy captured (e.g., different plug loads). An "actual use/as-built model" is best suited for use as a benchmark to assess whether the building performs as it should and to correct deficiencies in operation.

The difference between modeled energy or water use and actual energy or water use is important for facilities managers and other decision makers when communicating with other stakeholders. Using data from LEED, GBI, or ASHRAE design models in decision making or in communications can set unrealistically high expectations that cannot be met. Using data from an as-built model will provide more realistic performance data. However, conveying information based on measured energy or water use will provide the most realistic data for decision-making and will improve the credibility of facilities managers and decision makers with other stakeholders.

**Finding 8. DOD has the opportunity to continue to take a leadership role in improving the knowledge base about high-performance buildings, improving decision-support tools, and improving building models by collecting data on measured energy, water, and other resource use for its portfolio of buildings and by collaborating with others.**

The data currently available to support decision-making about investments in military construction and major renovation projects are inadequate. Under the Energy Performance Act of 2005, all federal buildings are required to be metered by FY2012. Metered data for energy and water use can be used to improve decision support tools and processes, establish baselines for conventional buildings, and measure the performance of high-performance or green buildings against those baselines. DOD could work with the Department of Energy (DOE) and others to improve the available knowledge and databases related to high-performance buildings to the benefit of the federal government and society.

**Finding 9. Effective operation of high-performance buildings requires well-trained facilities managers.**

High-performance or green buildings incorporate new building design processes, new technologies, and new materials. Effective operation of high-performance buildings requires well-trained facilities managers who understand the interrelationships among building technologies, occupant behavior, and overall building performance, as recognized through the enactment of the Federal Buildings Personnel Training Act of 2010.

The actual performance of green buildings also depends on the actions of building occupants, who can easily undermine effective building operations by bringing in additional appliances and equipment, by leaving computers and lights on, and similar practices. Facilities managers need to understand the human aspect of building performance as well as the engineering aspects.

## RECOMMENDED APPROACHES FOR DOD'S CONSIDERATION

Decisions about investments related to new construction and major renovations of buildings at DOD installations are not reducible to a single decision rule (such as benefit-cost maximization), nor are facilities managers responsible to a single stakeholder. In fact, facilities managers must assess the relative merits of facilities improvement projects against performance with respect to multiple decision criteria and justify recommendations to stakeholder groups and governing bodies that hold different, and sometimes conflicting, priorities. Trade-offs are required for most building projects: design and construction costs (i.e., first costs) versus operating and maintenance and deconstruction costs, resilience and flexibility factors versus worker productivity, and so forth.

Based on its findings and on its own expertise and experience with building standards and green building certification systems, the committee recommends that DOD consider the following approaches as it develops a comprehensive strategy for its entire portfolio of facilities to include standards for energy efficiency and sustainable design.

**Recommended Approach 1. Continue to require that new buildings or major renovations be designed to achieve a LEED-Silver or equivalent rating in order to meet the multiple objectives embedded in laws and mandates related to high-performance buildings.**

The preponderance of available evidence indicates that green building certification systems and their referenced building standards offer frameworks for reducing energy and water use in buildings, compared to design approaches and practices used for conventional buildings. They may also result in improved indoor environmental quality, improved worker productivity, and lower operations and maintenance costs, although the evidence related to those factors has only begun to emerge. Green building certification systems can also help to establish explicit and traceable objectives for future building performance and a feedback loop to determine if the objectives were met.

The incremental costs to design and construct high-performance or green-certified buildings compared to conventional buildings is minimal compared to the total costs of a building over its life cycle. Over the 30 years or more that high-performance or green buildings are in use, the cost savings attributable to reduced energy use and reduced water use may be significantly greater than the incremental first costs of design and construction. If the calculated NPV benefits are greater than 1 when incremental costs, energy costs, and water costs are included, then the use of building standards and green building rating systems will be cost-effective.

The limited evidence available indicates that the majority of LEED-Silver-certified buildings studied used less energy and water than conventional buildings, although some LEED-Silver-certified buildings did not outperform conventional buildings. Based on the preponderance of available evidence and committee members' own experience with green building certification systems, the committee believes the most prudent course for DOD is to continue its current policy requiring new buildings and major renovations to meet a LEED-Silver or equivalent rating. At the same time, DOD should have standards and practices in place to evaluate the performance of its high-performance or green buildings across all of its components. Standard evaluation practices can help to ensure that building-related performance objectives are being met, to continuously improve performance, and to ensure that the measures taken to reduce levels of energy and water use are cost-effective. The lessons learned through evaluations should be shared among DOD components so that best practices can be identified and incorporated into standard designs.

Because DOD has developed standard designs for the types of buildings it constructs most often, using the LEED-Volume certification program may be cost-effective, although as yet there is little experience with or documented evidence about the program. DOD should consider a pilot study to determine whether volume certifications will, in fact, be cost-effective.

**Recommended Approach 2. Retain flexibility to modify building standards and the application of green building certification systems in ways that are appropriate to the Department of Defense operating environment and mission.**

ASHRAE Standard 189.1-2011 contains many mandatory provisions that have not yet been evaluated for their cost-effectiveness. The committee recommends that DOD conduct pilot studies on specific provisions of the standard to determine their cost-effectiveness and their practicality in the DOD operating environment before adopting ASHRAE 189.1-2011 in its entirety. As experience with the various provisions emerges, DOD can determine which provisions of the standard are cost effective and support DOD's mission and incorporate those provisions into DOD guidance documents or standard designs when appropriate.

**Recommended Approach 3. Put policies and resources in place to measure the actual performance of Department of Defense's high-performance, green, and conventional buildings to meet multiple objectives.**

Not every individual high-performance or green building will have significant energy and water savings, even if it is certified at a LEED-Silver or equivalent rating. The committee recommends that for all new construction and major renovations that DOD measure actual performance for 3 years or longer after initial occupancy and use the resulting information and lessons learned to further modify its policies, if appropriate. This can be done, because DOD meters all of its buildings. Data for conventional buildings should also be gathered to establish baselines for performance measurement.

It will be necessary to continue to use building models in the design stage to support decision-making among alternatives. Building models can be improved over time such that predicted results are more closely aligned with actual results.

During design, the actual energy use of a building can only be predicted with an "actual use" model. This actual use model starts with the model created for compliance with LEED, Green Globes, or with ASHRAE 189.1, but it goes further, by incorporating real-life assumptions of manufacturing, installation, and operation and three-dimensional heat losses.

An actual use model created during design can be significantly improved in its predictive value if it is updated with as-built/as-operated conditions. Imperfections during construction can be observed and incorporated in the model, change orders can be modeled as well, and variations in occupancy captured (e.g., different plug loads). An "actual use/as-built model" is best suited for use as a benchmark to assess whether the building performs as it should and to correct deficiencies in operation. If data on actual building performance are not available (e.g., for ASHRAE 189.1-2011) or in instances where a new design is being evaluated, the managers should require actual use energy models that are developed by modifying the standard-complying models through the introduction of the real-life factors discussed above.

When DOD facilities managers and decision-makers are considering investments in high-performance buildings, the performance of those buildings will not operate under ideal conditions, but will instead depend on the as-built design and will be influenced by occupant behavior. Relying on data based on actual building performance, as opposed to predicted performance, should help to minimize gaps in expectations about how new or renovated buildings will perform and support the credibility of facilities managers and others when making the case for building investments.

As DOD's buildings are metered, DOD should gather data on the use of energy, water, and wastewater to establish baselines for conventional buildings and to determine how well green buildings are performing in comparison to baselines and in comparison to predictions associated with design models. Where building performance falls well below expectations, DOD should examine the reasons why and determine if the causes are systematic. Where appropriate, best practices should be incorporated into standard building designs, and failed practices should be avoided.

DOD can continue to take a leadership role in improving the performance of all federal facilities, as well as all U.S. buildings, by collaborating with DOE, other federal agencies, nonprofit organizations, and others to improve national databases related to buildings and their performance and to improve the knowledge base related to the design, construction, and operation of high-performance facilities.

**Recommended Approach 4. Use investment approaches that analyze the total cost of ownership, a full range of benefits and costs, and uncertain future conditions as part of the decision-making process.**

The analytical approach developed by the DOD consultant could potentially be used by DOD to improve the basis for decisions about which investments will be most cost-effective across its portfolio of facilities. The proposed approach accounts for life-cycle costs, variations in geographic conditions, climate, type of building, and local cost factors. It also helps define upper and lower ranges of uncertainty for specific factors. Uncertainty is inherent in decision making about buildings that will be used for 30 years or longer. To use such an approach effectively, however, DOD will need to ensure that the data available to conduct the analysis are accurate and reliable.

**Recommended Approach 5. Specify and fund training appropriate for facilities managers to ensure the effective operation of high-performance buildings.**

Effective use of new technologies and new processes associated with high-performance buildings requires a workforce that is adequately trained to make decisions and implement them to maximum benefit. Facilities managers should have the skills and training necessary to understand the interaction of complex building systems and how to operate them effectively. Implementation of the Federal Building Personnel Training Act of 2010 should help to ensure that DOD facilities managers are certified in the required competencies and skills.

Facilities managers also need to understand how the behavior of occupants can affect effective facility operations and, in turn, how facility performance can affect occupants' health and productivity. Training is needed to help facilities managers identify strategies that can be used to create a better understanding by occupants of how their behavior affects indoor environmental quality, energy use, and other factors.

# 6

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# Appendixes

# A

# Biosketches of Committee Members

MICHAEL R. JOHNSON, *Chair,* is the associate vice chancellor for facilities at University of Arkansas and teaches in the Department of Civil Engineering. He was elected to the National Academy of Engineering in 2010 "for leadership and achievements in U.S. Naval construction management and projects throughout the world." Admiral Johnson joined the university with experience as a civil engineer and with an extensive career in the U.S. military. His academic credentials include a bachelor's degree in civil engineering from the University of Colorado, a bachelor's degree in business/economics from Chapman College, and master's degrees in public works and civil engineering from the University of Pittsburgh. After more than 33 years of service, Admiral Johnson retired from the U.S. Navy as rear admiral in the Civil Engineer Corps in 2004. As commander of the Naval Facilities Engineering Command and chief of civil engineers, he directed the worldwide operations of the Navy's global engineering organization, managing more than 14,000 civilian and military personnel and a multi-billion-dollar budget. As chief of civil engineers, he was responsible for the community management of almost 40,000 military and civilian personnel. Admiral Johnson has held leadership positions in the Atlantic and Southwest Divisions of the Navy. He also served as director of Shore Installation Management on the staff of the commander in chief, U.S. Atlantic Fleet.

PAUL FISETTE is an associate dean of the College of Natural Sciences at the University of Massachusetts, Amherst. Previous to his current position he served as head of the Department of Environmental Conservation and as director of the Building and Construction Technology Program. He is currently a professor of building and construction technology and a professor of architecture. Mr. Fisette's research and professional focus involve the performance of building systems, energy-efficient construction, sustainable building practices, and the performance of building materials. His primary interest is green building, which involves the sustainable integration of natural and built environments, and he has taught a variety of courses that focus on the performance of structures, materials, and construction practices. He is expert in how moisture moves and influences buildings and the health of building occupants. Mr. Fisette has authored more than 200 published works regarding building science and construction technology, including "Analysis of LEED and BREEAM Assessment Methods for Educational Institutions." Prior to joining the University of Massachusetts, Mr. Fisette owned and operated a general contracting business and was senior editor with *Progressive Builder Magazine,* covering technical information and innovations of interest to residential building firms. He was a member of the National Research Council's (NRC's) Board on Infrastructure and the Constructed Environment (BICE) for 6 years, served on the Committee to Evaluate the Health and Productivity Benefits of Green Schools and the Committee to Review and Assess the Partnership for Advancing Technology in Housing Program, and he currently serves on a National Academies expert panel to evaluate energy efficiency and sustainability standards used by the Department of Defense for its portfolio of 500,000 buildings and facilities. He is contributing editor with *The Journal of Light Construction* and a member of the National Institute of Building Science, and has served on a variety of editorial and professional advisory boards. His current projects include the performance and durability of building systems, energy-efficient construction, and sustainable development and resource efficiency.

CHRIS HENDRICKSON is the Duquesne Light Company University Professor of Engineering at Carnegie Mellon University and co-director of the Green Design Institute and editor-in-chief of *Journal of Transportation Engineering* of the American Society of Civil Engineering (ASCE). He was elected to the National Academy of Engineering in 2011 "for leadership and contributions in transportation and green design engineering." His research, teaching, and consulting are in the general area of engineering planning and management, including design for the environment, project management, transportation systems, finance, and computer applications. Current research projects include life-cycle assessment methods (especially based on economic input/output tables such as eiolca.net), assessment of alternative construction materials, economic and environmental implications of Ecommerce, product takeback planning, and infrastructure for alternative fuels. He has co-authored three textbooks, *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach* (2005), *Project Management for Construction* (1989), and *Transportation Investment and Pricing Principles* (1984), and two monographs, *Knowledge Based Process Planning for Construction and Manufacturing* (1989) and *Concurrent Computer Integrated Building Design* (1994). In addition, he has published numerous articles in the professional literature. Mr. Hendrickson is a distinguished member of ASCE, an emeritus member of the Transportation Research Board, and a fellow of the American Association for the Advancement of Science. He has been the recipient of the 2002 ASCE Turner Lecture Award, the 2002 Fenves Systems Research Award, the 1994 Frank M. Masters Transportation Engineering Award, the Outstanding Professor of the Year Award of the ASCE Pittsburgh Section (1990), the ASCE Walter L. Huber Civil Engineering Research Award (1989), the Benjamin Richard Teare Teaching Award (1987), and a Rhodes Scholarship (1973).

ROSALIE RUEGG is the managing director of TIA Consulting, Inc., a firm that assembles, directs, and participates in research teams to conduct impact and process evaluations of science and technology investments. Ms. Ruegg has more than 35 years of evaluative experience working with scientists, engineers, and company leaders. Prior positions include serving as director of the Economic Assessment Office of the Advanced Technology Program; senior economist in the Applied Mathematics Laboratory of the National Institute of Standards and Technology (NIST); and financial economist with the Federal Reserve Board of Governors. Her publications include a chapter in *Handbook on the Theory and Practice of Program Evaluation* (2012); "New Benefit-Cost Methodology for Evaluating Renewable and Energy Efficient Programs of the U.S. Department of Energy," *Environmental Economics and Investment Assessment* (2010); "Tracing from Applied Research Programs to Downstream Innovations" in *Research Evaluation* (2011); *A Toolkit for Evaluating Public R&D Investment* (2003); *Quantitative Methods of*

*Research Evaluations Used by the US Federal Government* (with D. Hicks et al., 2002); and *Building Economics: Theory and Practice* (1990). Ms. Ruegg has received the Department of Commerce's medals, the Wellington Award for contributions in the field of engineering economics, the American Evaluation Association's Outstanding Publication in Evaluation Award, and he was named Distinguished Alumnus of NIST. She holds degrees in economics from the University of North Carolina (B.A., with honors) and the University of Maryland (M.A., Woodrow Wilson Fellow), an M.B.A. (specialty in finance) from American University, a professional certification from Georgetown University, and executive training from the U.S. Federal Executive Institute and Harvard University.

MAXINE L. SAVITZ is the retired general manager of Technology Partnerships, Honeywell, Inc. She has managed large research and development (R&D) programs in the federal government and in the private sector. Some of the positions that she has held include the following: chief, Buildings Conservation Policy Research, Federal Energy Administration; professional manager, Research Applied to National Needs, National Science Foundation; division director, Buildings and Industrial Conservation, Energy Research and Development Administration; deputy assistant secretary for conservation, U.S. Department of Energy; president, Lighting Research Institute, and general manager, Ceramic Components, Allied-Signal, Inc. (now Honeywell). Dr. Savitz has extensive technical experience in the areas of materials, fuel cells, batteries and other storage devices, energy efficiency, and R&D management. She was elected to the National Academy of Engineering (NAE) in 1992 "for technical developments contributing to national initiatives in energy conservation and energy efficiency" and currently serves as vice president of the NAE. She has been, or is serving as, a member of numerous public- and private-sector boards, including the National Science Board, the Secretary of Energy Advisory Board, the American Council for an Energy Efficient Economy, and the Draper Laboratory. She has served on many energy-related and other NRC committees. She has a Ph.D. in organic chemistry from the Massachusetts Institute of Technology.

THOMAS P. SEAGER is the senior sustainability scientist for the Global Institute of Sustainability and a professor and the Lincoln Fellow of Ethics and Sustainability in the School of Sustainable Engineering and the Built Environment at Arizona State University. Dr. Seager conducts research related to environmental decision analysis and the life-cycle environmental impacts of alternative energy technologies. His work combines life-cycle assessment of emerging energy technologies with cutting-edge analytic tools in stochastic multi-criteria decision analysis to form a novel basis for analysis of energy issues. He is pioneering a new approach called anticipatory life-cycle assessment that combines laboratory and pilot-scale experimentation with technology forecasting to improve the developmental trajectory of novel energy technologies with respect to the environment. This approach has been applied to a permanent military base in the context of conflicting policy or stakeholder perspectives and prioritizing the need for more information and making investment decisions. Dr. Seager previously taught at the Rochester Institute of Technology and Purdue University. He earned a Ph.D. in civil and environmental engineering from Clarkson University.

ADRIAN TULUCA is a registered architect with more than 25 years of experience in energy-efficient design, aided by modeling, testing, and monitoring. He is a principal of Viridian Energy and Environmental, a Vidaris company. Mr. Tuluca has analyzed all building types, including the more typical (offices, housing, and schools) and the less common (zoos, airports). Examples of his work include large buildings, such as the Bank of America Headquarters and Hearst Headquarters, medium ones such as several New York City schools, and small projects such as a 5,000-square-foot educational shed in a park. His team has performed modeling for more than 100 million square feet of facility space, from pre-design through post-occupancy, and has studied issues such as energy use, light, airflow, and thermal bridging and has performed evaluations of thermal characteristics of facades and heating, ventilation, and air-conditioning systems. He has also led post-occupancy testing and monitoring, which help verify the effectiveness of the energy model. Mr. Tuluca has contributed to various codes and standards, including the New York State Energy Code, the New York State Green Building Tax Credit, and the ASHRAE Standard 90.1. He has studied the relationship between code compliance, LEED compliance, and actual performance of buildings. He is the lead author of *Energy Efficient Design and Construction for Commercial Buildings* (1997). He holds a master's degree in architecture from Romania and an M.S. in architecture technology from Columbia University.

# B

# Committee Meetings, Briefings, and Public Comment

## JUNE 28-29, 2012, COMMITTEE MEETING

### Briefings

Dorothy Robyn, Deputy Under Secretary of Defense for Installations and Environment
Sarah Slaughter, Consultant to the Department of Defense
Merle McBride, Senior Research Associate, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
Claire Ramspeck, Director of Technology, ASHRAE
Christopher Pyke, Vice President, Research, U.S. Green Building Council
Kevin Stover, Facilities Engineer Consultant, Green Building Initiative

### Public Comment

David Karmol, International Code Council
Karyn Schmidt, American Chemistry Council
Kevin Morrow, National Association of Home Builders
Meg Waltner, Natural Resources Defense Council

## SEPTEMBER 17-18, 2012, COMMITTEE MEETING

### Briefings

Maureen Sullivan, Office of the Deputy Under Secretary of Defense for Installations and Environment
Sarah Slaughter, Consultant to the Department of Defense
Erin Shaffer, Vice President, Federal Outreach, Green Building Initiative
Dr. Donald Colliver, Presidential Member, ASHRAE

Claire Ramspeck, Director of Technology, ASHRAE
Melissa Gallagher-Rogers, LEED AP, U.S. Green Building Council

**Public Comment**

Meg Waltner, Natural Resources Defense Council
Catherine L. Phillips**.** Vice President, Sustainable Forestry, Weyerhaeuser
Jeff Bradley, American Wood Council

# C

# Consultant's Report: Cost Effectiveness Study of Various Sustainable Building Standards in Response to NDAA 2012 Section 2830 Requirements

This appendix reproduces substantially (with minor reformatting) as submitted, a study prepared by Sarah Slaughter for the Committee to Evaluate Energy-Efficiency and Sustainability Standards Used by the Department of Defense for Military Construction and Repair, dated September 10, 2012. Note that in the reproduced report's table of contents, the page numbers reflect the pagination that applies for inclusion in the current report, rather than the page numbers of the submitted report.

# COST EFFECTIVENESS STUDY OF VARIOUS SUSTAINABLE BUILDING STANDARDS IN RESPONSE TO NDAA 2012 SECTION 2830 REQUIREMENTS

PREPARED BY:
Dr. Sarah Slaughter

DATE:
September 10, 2012

PURPOSE:
National Research Council
Committee to Evaluate Energy-Efficiency and Sustainability Standards Used
by the Department of Defense for Military Construction and Repair

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## OVERVIEW

In the NDAA 2012 Section 2830(a), Congress required the Department of Defense to submit a report that includes a cost-benefit analysis, return on investment, and long-term payback for specific building standards and rating systems (ASHRAE 189.1 and 90.1, LEED Silver, Gold, and Platinum, and other ANSI accredited standards such as Green Globes). It also required the DOD to provide a policy prescribing a comprehensive strategy for the cost-effective pursuit of design and building standards that include specific energy-efficient standards and sustainable design attributes based on those findings.

At the request of the Office of the Secretary of Defense for Installations and Environment, the National Research Council (NRC) appointed an ad hoc committee to review the literature on the state-of-the-knowledge about the economic efficiency of sustainable buildings, to evaluate a consultant-generated methodology and analysis of the economic efficiency of the specified building design standards, and to identify potential factors and approaches that the DOD should consider in developing a comprehensive strategy for its entire portfolio of facilities that includes standards for energy-efficiency and sustainable design.

This report outlines the methodology and findings by the consultant to analyze the cost-benefit, return on investment, and long-term payback for the specified building design standards and ratings systems. The second part of the study tested the applicability of the analytical tools to DOD facilities going forward, as input to the DOD comprehensive strategy.

The consultant developed and applied the methodology for this study building on existing research, methods, best practices, and tools to analyze the economic efficiency of the specified building standards and rating systems and to provide input into the development of the DOD comprehensive strategy. The methodology was developed to address robustness, validity, and replicability of the analysis of the specific building design standards and rating systems, and to ensure applicability to DOD facilities. The methodology (described in the Methodology section of this report) consists of the following elements:

1. **Economic Efficiency Analysis**: This study follows standard economic analysis methodologies and data collection approaches to calculate long-term cost-benefits (Present Value Net Savings), return on investment, and payback, as required in the NDAA 2012 Section 2830. The study developed an analytical approach to assess the long-term cost-benefits of alternatives for a range of scenarios that represent uncertain future conditions. This approach was applied using a set of tools developed specifically for this study to provide sensitivity analyses of the results under different scenarios, specifically for variations in the discount rate, time period, and price escalation rates for energy and water costs.

   This study also utilized the NIST Building Life-Cycle Cost (BLCC) software to calculate present value net savings, (adjusted) rate of return on investment, and payback.

2. **Prototype Buildings and Locations**: This study established a common basis on which to calculate the long-term cost-benefits, return on investment, and payback using prototype buildings and selected locations to represent the heating and cooling loads and local factor prices that influence the economic efficiency calculations. Specifically, this study utilized the results and characteristics of two building prototype models from the Department of Energy (DOE) Pacific Northwest National Laboratory (PNNL) study that are most applicable to DOD facilities, specifically the “medium office” and “small hotel” models (corresponding to administrative buildings and barracks, respectively). This study also utilized a subset of five locations from the DOE PNNL set of 15 locations that reflect the diversity of geographic regions across the continental US to create the baseline prototype buildings.

3. **Benefit and Cost Categories**: This study includes existing reporting categories for DOD under the Annual Energy Management Report to Congress and other reports for the analysis of costs and benefits for high performance buildings. The benefit-cost categories are: Investment (initial investment and major repair/replacement costs); Operations, Maintenance, and Repair (OM&R) costs, including: Energy use (building and supporting/site facilities); Water use (building and supporting/site facilities); Solid waste (municipal and hazardous); and Building/site O&M (general, cleaning, and landscaping).

The strategy for data collection addressed the issues of validity and accuracy of the results. In discussions with staff from ASHRAE, Green Building Initiative, and the US Green Building Council, the cost and benefit data for the analysis of the specified building rating systems (Green Globes and LEED) was developed using data from actual certified commercial/private projects that are similar to (and brought into conformance with) the characteristics of the selected prototype buildings (i.e., medium office and small hotel) and selected locations. The ASHRAE standards data were generated using the PNNL building models for the two prototype buildings in the selected locations.

Separately, and in parallel with the analysis of the specified standards and rating systems, the consultant worked with DOD installation, HQ, construction agent and OSD teams to test the applicability of the analytical approach, process, and tools to DOD military construction and renovation.

## SUMMARY OF RESULTS

In direct response to the NDAA 2012 Section 2830, to provide a cost-benefit analysis, return on investment and long-term payback for the specified design standards, this study analyzed the (Present Value) Net Savings, (Adjusted) Rate of Return on Investment, and Payback in accordance with the Office of Management and Budget (OMB) Circular A-94 Revised (1992). These potential Net Savings can also be viewed as the potential future additional costs that may be incurred for these building types and locations under these scenarios.

The Results section of this report provides the Net Savings for the Long-Term Cost-Benefit with the sensitivity analysis, as well as the Rate of Return on Investment and Payback, for each specified standard and rating systems using the two building types (i.e., residential and office) and five locations that represent the variety of climate conditions and markets across the continental U.S. Specifically, this study analyzed the economic efficiency of buildings built under the guidance of: ASHRAE Standards 90.1-2010 and 189.1-2011; LEED Silver, Gold and Platinum Certifications; and Green Globes One, Two, Three and Four Certifications.

The results of the analysis in this study indicate that the building standards and rating systems provide buildings that are economically efficient depending on building type and location. Specifically, the Long-term Cost-Benefit analysis of ASHRAE Standard 90.1-2010 provided significant Net Savings in energy reductions for both building types and in all 5 locations. ASHRAE Standard 189.1-2011 provided greater Net Savings than 90.1-2010 across all locations for both building types in both energy and water cost reductions. In particular, the water cost reductions equaled approximately 50% of the Annual Savings across the building types and locations. ASHRAE 189.1-2011 also includes the requirement for on-site energy generation, and these incremental initial construction costs were included, and the on-site energy was used to offset the building energy used, so the overall building energy reductions were greater for 189.1-2011 than for 90.1-2010.

Buildings built under the guidance of the LEED rating system (Silver, Gold and Platinum Certification levels) and the Green Globes rating system (One, Two, Three and Four Globes certification levels) are economically efficient depending on building type and location, and are highly sensitive to the incremental initial construction cost. The LEED Volume Certification program could further increase cost-effectiveness through pre-approval of standardized designs and management procedures, and coordinated procurement programs. In addition, the recent DOD guidance (2010) specifying that 40% of all points in those rating systems must be in energy and water categories will increase the economic efficiency (as measured in this study) of DOD buildings using these rating systems. It must be noted, however, that these results are highly dependent on the data provided for these data samples, particularly the reported initial construction costs.

The sensitivity analysis incorporated variations in energy and water price escalations, as well as the cost of capital (represented by the discount rate). The results indicate that Net Savings for the specified buildings standards and rating systems would increase significantly with annual price escalations of 2% for energy and 4% for water and wastewater, which has been experienced in some locations of the US. The building standards and rating systems could reduce the vulnerability of DOD installations to price shocks—and increase cost-effectiveness—by reducing the use of these resources. The sensitivity analysis results also indicate that, even if the prices for energy and water decrease and the cost of capital increases (represented by a discount rate of 3%), most facilities built under the guidance of the standards and rating systems remain economically efficient.

## INPUT FOR DOD COMPREHENSIVE STRATEGY

This study recognizes that the core purpose of military construction and renovation is to provide high performance facilities that are effective and efficient. Specifically, the results of this study and the application of the analytical approach can be used to identify opportunities to improve effectiveness and efficiency, such as to reduce the resource usage (and the related burden on neighboring communities), reduce vulnerabilities to price increases, and increase overall resiliency by reducing the "baseload" resource requirements under normal and extreme conditions. The primary objective of this study is to ensure the usefulness of the analytical approach and results to aid decision-making for strategic investments in DOD capital facility assets.

The results of the economic evaluation of the building standards and rating systems presented in this report have direct applicability to the development of the DOD comprehensive strategy for cost-effective military construction and renovation. This study highlighted opportunities for cost-effective high performance buildings built under the guidance of the specified standards and rating systems for different building types, specifically for a residential facility and an office building, in both energy and water usage. It also examined the potential economic value in different locations that represent the variety of climate zones and urban/rural markets across the U.S., incorporating local factor unit prices and conditions that affect cost-efficiency. The sensitivity analysis provides insight into the variability of cost-effectiveness, in particular, potential escalation of energy and water prices and changes in the cost of money (as represented by the discount rate).

The implication of the results of the economic evaluation of the specified building standard and rating systems for the DOD comprehensive strategy for cost-effective military construction is that ASHRAE 189.1-2011 (which includes ASHRAE 90.1-2010 by reference) would likely provide economically efficient high performance military facilities. The voluntary ratings systems of LEED and Green Globes can provide important guidance for overall high performance facilities (including attributes not measured in this study) as well as third party verification, and buildings certified under these rating systems would be cost-efficient if the incremental initial investment costs are within a margin (in these samples, if the incremental initial investment cost is less than 20% of the baseline investment cost) and the annual savings are sufficient to offset that incremental cost.

It must be noted, however, that those results are highly sensitive to the heating and cooling loads for different climate zones and to the local factor unit prices. Consideration of specific choices associated with the application of those standards for design development and implementation should be evaluated grounded in the specific local context.

The second portion of this study tested the applicability of the analytical approach, process and tools developed for this research to military construction and renovation projects going forward, as further input for the DOD comprehensive strategy. The results from example applications of the analytical approach using empirical data from actual DOD buildings were reviewed with staff from the selected installations, HQ, construction agents, and the Office of the Secretary of Defense. The exercise provided important feedback for the potential application of the economic efficiency evaluation process for DOD military and construction going forward.

In particular, the discussion raised certain challenges and opportunities associated with economic efficiency evaluations. First, the analytical approach of economic efficiency analysis would be most effectively applied across a portfolio of projects—with respect to the overall installation requirements—that increase mission effectiveness and economic efficiency. Second, the application of an economic efficiency analysis requires access to credible and verifiable data on the initial investment costs, major repair/replacement costs, and operations, maintenance and repair costs over the expected life of the facility. The DOD components, installations and construction agents are initiating specific programs to collect information on energy and sustainability performance for capital facility assets, including both the expected and actual performance of the facilities. The effective use of an economic efficiency analysis approach may require additional data collection to aid decision-making. Finally, further research is needed to determine the extent to which industry development as a whole may increase the cost-effectiveness of military construction and repair.

The Department of Defense has incorporated life cycle cost analysis into all military construction and renovation projects, and the DOD components have launched several initiatives to incorporate economic assessment into decision making for military construction and renovation. This study provides the results of the economic evaluation of the specified building standards and rating systems, and the applicability of the analytical approach, as input into the development of the DOD comprehensive strategy going forward.

## SCOPE AND BACKGROUND

### DEPARTMENT OF DEFENSE POLICY ON SUSTAINABLE FACILITIES

Recognizing the significant role of buildings in solving national issues such as energy independence and security, and the opportunity for federal leadership, Congress and two Presidential administrations have enacted laws and issued Executive Orders directing federal agencies to develop high-performance, energy efficient, and sustainable federal buildings. To implement these mandates, federal departments and agencies have issued policies for sustainable building design.

The Department of Defense (DOD) and its components manage more than 500,000 buildings and structures worldwide, containing more than 2.1 billion total square feet of space. The annual energy budget for these facilities is more than $4 billion. The DOD's Sustainable Building Policy includes supplementary information (October 2010) that specifies that:

1. All new building design and construction shall conform to the Guiding Principles in the High Performance and Sustainable Buildings Memorandum of Understanding.

2. DOD components will design, build, and certify as appropriate, all new construction projects, at a minimum, to the Silver level of the Leadership in Energy and Environmental Design (LEED) green building rating system (or equal). Beginning in FY12 for projects in the planning stage, the sum of energy and water efficiency credits shall equal or exceed 40 percent of the points required for a LEED Silver (or equal) rating; this highlights the importance of pursuing additional energy- and water-related credits in areas such as cool roofs and day lighting.
3. All repair/renovation projects in existing buildings shall also conform to the Guiding Principles where they apply. The DOD components will design, execute and certify major repair/renovation projects to be LEED Silver, at a minimum, where appropriate.
4. Reducing total cost of ownership is intrinsic to sustainable buildings. The DOD components shall incorporate life cycle and cost/benefit analysis into design decisions for new construction and renovation/repair projects.[1]

Concerns have been raised in Congress that DOD buildings conforming to this policy may not be cost effective or achieving federal mandates for energy efficiency. In response to these concerns, the National Defense Authorization Act (NDAA) for Fiscal Year 2012, Section 2830, requires the Department of Defense (DOD) to submit a report to the congressional defense committees on energy efficiency and sustainability standards used by the DOD for military construction and repair. The report must include a cost-benefit analysis, return on investment, and long-term payback for the following building design standards:

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 189.1-2011 for the Design of High-Performance, Green Buildings Except Low-Rise Residential Buildings
- ASHRAE Energy Standard 90.1-2010 for Buildings Except Low-Rise Residential
- Leadership in Energy and Environmental Design (LEED) Silver, Gold, Platinum, and Volume Certifications
- Other American National Standards Institute (ANSI) accredited standards, such as Green Globes.

The report must also include a copy of the DOD policy prescribing a comprehensive strategy for the pursuit of design and building standards that include specific energy-efficient standards and sustainable design attributes based on the cost-benefit analysis, return on investment, and demonstrated payback for the aforementioned building design standards.

## DEFINITION OF TASK

At the request of the Office of the Secretary of Defense for Installations and Environment, an ad hoc committee was appointed by the National Research Council (NRC) to: (1) evaluate the completeness, accuracy, and relevance of a literature review that synthesizes the state-of-the-knowledge about the costs and benefits, return on investment, and long-term payback of specified design standards related to sustainable buildings; (2) evaluate a consultant-generated methodology and analysis of the cost-benefit, return on investment, and long-term payback for the specified building standards and rating systems in NDAA 2012 Section 2830, and the test for the potential applicability of the analytical approach to military construction and renovation using empirical data

[1] Dorothy Robyn (2010). "Department of Defense Sustainable Buildings Policy." Office of the Secretary of Defense, Deputy Under Secretary of Defense (Installations & Environment).

from DOD buildings; and (3) identify potential factors and approaches that the DOD should consider in developing a comprehensive strategy for its entire portfolio of facilities that includes standards for energy-efficiency and sustainable design.

The consultant, working with the Office of the Secretary of Defense and the military components, and in conjunction with representatives of the organizations for the specified standards and rating systems organizations, developed a methodology for: 1) analyzing the cost-benefit, return on investment, and long-term payback achievable using sustainable building standards specified in the NDAA 2012 Section 2830 using an example building; and 2) gathering and analyzing empirical data from DOD buildings to evaluate the cost benefit, return on investment, and long-term payback achievable using sustainable building standards specified in the NDAA 2012 Section 2830.

The consultant then gathered and analyzed example building data to calculate the cost-benefit, return on investment, and long-term payback achievable using sustainable building standards specified in the NDAA 2012 Section 2830. The methodology for this study is described in the following section, followed by the results of the analysis for the specified building standards and rating systems.

The consultant also worked with the DOD installation, HQ, and construction agent teams to gather and analyze empirical data from selected DOD buildings to demonstrate the methodology to determine the cost-benefit, return on investment, and long-term payback achievable using the referenced sustainability standards. The final chapter provides potential factors and approaches that the DOD should consider in developing a comprehensive strategy for military construction and renovation that includes standards for energy efficiency and sustainable design.

## METHODOLOGY FOR ECONOMIC EVALUATION OF SPECIFIED RATING SYSTEMS AND STANDARDS AND DEVELOPMENT OF ANALYTICAL TOOLS

The consultant developed and applied the methodology building on existing research, methods, best practices, and existing tools to analyze the economic efficiency of the specified building standards and rating systems and to provide input into the development of the DOD comprehensive strategy. The methodology was developed to address robustness, validity, and replicability of the analysis of the specific building design standards and rating systems, and to ensure applicability to DOD facilities. The methodology consists of the following elements:

1) **Economic Efficiency Analysis**: This study follows standard economic analysis methodologies and data collection approaches to calculate long-term cost-benefits (Present Value Net Savings), return on investment, and payback, as required in the NDAA 2012 Section 2830. The study developed an analytical approach to assess the long-term cost-benefits of alternatives for a range of scenarios that represent uncertain future conditions. This approach was applied using a set of tools developed specifically for this study to provide sensitivity analyses of the results under different scenarios, specifically for variations in the discount rate, time period, and price escalation rates for energy and water costs. This study also utilized the NIST Building Life-Cycle Cost (BLCC) software to calculate present value net savings, (adjusted) rate of return on investment, and payback.
2) **Prototype Buildings and Locations**: This study established a common basis on which to calculate the long-term cost-benefits, return on investment, and payback using prototype buildings and selected locations to represent the heating and cooling loads and local factor prices that influence the economic efficiency calculations. Specifically,

this study utilized the results and characteristics of two building prototype models from the Department of Energy (DOE) Pacific Northwest National Laboratory (PNNL) study that are most applicable to DOD facilities, specifically the "medium office" and "small hotel" models (i.e., corresponding to administrative buildings and barracks, respectively). This study also utilized a subset of five locations from the DOE PNNL set of 15 locations that reflect the diversity of geographic regions across the continental US to create the baseline prototype buildings.

3) **Benefit and Cost Categories**: This study includes existing reporting categories for DOD under the Annual Energy Management Report to Congress and other reports for the analysis of costs and benefits for high performance buildings. The benefit-cost categories are:
   a. Investment (initial investment and major repair/replacement costs;
   b. Operations, Maintenance, and Repair (OM&R) costs, including:
      i. Energy use (facility and supporting/site facilities);
      ii. Water use (facility and supporting/site facilities);
      iii. Solid waste (municipal and hazardous); and
      iv. Building/site O&M (general, cleaning, and landscaping).

The strategy for data collection addressed the issues of validity and accuracy of the results. In discussions with staff from ASHRAE, the Green Building Initiative, and the US Green Building Council, the data for the analysis of the specified building rating systems (Green Globes and LEED) were provided based on actual certified commercial/private projects that are similar to (and brought into conformance with) the characteristics of the selected prototype buildings (i.e., medium office and small hotel) and locations. In discussions with the staff from ASHRAE, the data for the analysis of the specific building standards were generated using the PNNL building models for the two prototype buildings in the selected locations.

## ECONOMIC EFFICIENCY ANALYSIS

This study analyzed the economic efficiency of the specified building standards and rating systems in accordance with the Office of Management and Budget (OMB) Circular A-94 Revised (1992), which provides "general guidance for conducting benefit-cost and cost-effectiveness analyses." (Appendix E refers to legislative requirements for life cycle cost analysis.) OMB Circular A-94 provides the following definitions:

- Benefit-Cost Analysis—A systematic quantitative method of assessing the desirability of government projects or policies when it is important to take a long view of future effects and a broad view of possible side-effects.
- Cost-Effectiveness—A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective.[2]

National Institute of Standards and Technology (NIST) *Life-Cycle Costing Manual for the Federal Energy Management Program* (1996) defines life cycle cost analysis (LCCA) as

> An economic method of project evaluation in which all costs arising from owning, operating, maintaining, and ultimately disposing of a project are considered to be potentially important in that decision. LCCA is particularly suitable for the evaluation of building design

[2] Office of Management and Budget (1992). *Circular A-94 Appendix A, Definitions of Terms,* Revised.

> alternatives that satisfy a required level of building performance (including occupant comfort, safety, adherence to building codes and engineering standards, system reliability, and even aesthetic considerations), but that may have different initial investment costs; different operating, maintenance, and repair (OM&R) costs (including energy and water usage); and possibly difference lives. However, LCCA can be applied to any capital investment decision in which higher initial costs are traded for reduced future cost obligations. LCCA provides a significantly better assessment of the long-term cost effectiveness of a project than alternative economic methods that focus only on first costs or on operating-related costs in the short run.[3]

The NDAA 2012 Section 2830(b) required a report that includes a cost-benefit analysis, return on investment, and long-term payback, which are calculated in this study using (Present Value) Net Savings, (Adjusted) Rate of Return on Investment, and Payback. The Net Savings method can be used when benefits occur primarily from future operational benefits (such as energy and water cost savings), relative to a specific base case. The National Institute of Standards and Technology (NIST) guidance states:

> It is not necessary to include all project-related costs in a life-cycle costing analysis of project alternatives. Only those costs that are **relevant** to the decision [for the alternatives] and **significant** in amount are needed to make a valid investment decision. Costs are relevant to the decision when they change from alternative to alternative. [4] (*Emphasis in original*)

The economic efficiency analysis of Net Savings requires a ***specific base case*** against which to compare the relative **incremental** costs and benefits of alternatives. The Net Savings are calculated as the differences in costs between the base case and the alternative(s). The objective of these calculations is to bring future costs and benefits into current year values for direct comparison.

The definitions and equations used for this analysis are:

- **(Present Value) Net Savings**: Comparison of the total costs of ownership, operation, and maintenance over the defined study period (N) among two or more alternatives. The time-adjusted costs are subtracted from the time-adjusted savings, where the discount rate (d) represents foregone opportunities in the market for investment. If the Net Savings are greater than zero, the investment is economically efficient and higher Net Savings indicates better economic efficiency.
    - General Equation: $NS = \Sigma(B_t - C_t)/(1 + d)^t$
        - Variables:
            - NS = Net Savings
            - $B_t$, $C_t$ = Benefits, Costs at time t
            - t = 0 to N
            - N = Study Period
            - d = Discount rate
    - For Annual Savings with expected price escalation:
      $NS = A_0*[(1 + e)/(d - e)][1 - ((1 + e)/(1 + d))^N]$

[3] National Institute of Standards and Technology (1996). *Life-Cycle Costing Manual for the Federal Energy Management Program,* NIST Handbook 135, Washington, DC, p. 4-1.

[4] National Institute of Standards and Technology (1996). *Life-Cycle Costing Manual for the Federal Energy Management Program,* NIST Handbook 135, Washington, DC, p. 4-1.

        - Variables
            - NS = Net Savings
            - $A_0$ = annually recurring cost at base-date price
            - d = discount rate
            - e = escalation rate
            - N = Study Period

- **(Adjusted) Rate of Return on Investment:** Annual yield from a project over the study period (N), taking into account the reinvestment of interim savings at the discount rate (d). If the ARROI is greater than the discount rate (d), the investment is economically efficient and higher ARROI (relative to the same discount rate) indicates better economic efficiency for independent projects.

    - ARROI=$((1 + d)*SIR^{1/N}) - 1$
        - Variables:
            - SIR (Savings-to-Investment Ratio)=(NS – I)/I
            - I = Incremental Investment associated with alternative
            - d = discount rate
            - N = Study Period

- **Payback:** Time period at which initial investment is recovered, as a measure of capital liquidity. Simple payback does not include time-adjusted costs or benefits, and is the time when the summation of the expected annual savings equals the original investment; discounted payback includes time-adjusted annual savings, and is the time when the summation of the time-adjusted savings equals the original investment. While payback does indicate how quickly the original investment is recovered through annual savings, it cannot be used to compare the economic efficiency for projects, since it does not include all of the savings expected over the study period. The alternative with the shortest Payback period is not necessarily the alternative with the highest Net Savings or ARROI.

    - Simple PB = t = $(I/A_0)$
        - Variables:
            - t = 0 to N
            - N = Study Period
            - I = Incremental Investment associated with alternative
            - $A_0$ = annually recurring cost at base-date price

    - Discounted PB = t when $\Sigma(B_t - C_t)/(1 + d)^t = I$
        - Variables:
            - t = 0 to N
            - N = Study Period
            - I = Incremental Investment associated with alternative
            - $B_t$, $C_t$ = Benefits, Costs at time t
            - d = Discount rate

## STUDY METHODOLOGY FOR ECONOMIC EFFICIENCY ANALYSIS

This study analyzed the economic efficiency in accord with federal legislation and guidance. As required under OMB Circular A-94 Appendix C, the study utilized the current **real** discount rates for FY2013,[5] which are based on Treasury Notes and Bonds of specified maturities. The real discount rate excludes the inflation premium. (Please see Appendix A for recent OMB real discount rates from 2007-2012.) This study also utilized the Study Period of 40 years, in conformance with the requirement in the Energy Independence and Security Act (EISA) for the maximum study period.

Energy and water price escalation is a critical factor in long-term cost-benefit analysis, and is particularly relevant to this analysis of the specified building standards and rating systems. The US Energy Information Administration (EIA) annually provides projected energy prices for a thirty year time period in conformance with the Federal Energy Management Program (FEMP), which is incorporated by reference in federal government guidance for life cycle cost analysis. While EIA provides energy escalation rates for each year, this study uses the annual equivalent escalation rate of 0.5%.

The water price escalation rate used in this analysis is based on an analysis of the Consumer Price Index, which reports price increases using 1982-1984 as the base year (Appendix A). The CPI national average annual increase for water and sewer prices has been almost 5% between 1982 and 2012. These price increases are often due to increased operating costs, required investments in system upgrades, or local shortages. The CPI includes the effects of inflation, which is estimated to have averaged approximately 1% between 1982 and 2012.[6] This study uses an annual water escalation rate of 2% as a conservative estimate of expected water price increases.

For this study, the Long-term cost-benefit used throughout this report is defined as:

**Discount rate:** 2.0%
**Study Period:** 40 years
**Price escalation rates:**
- **Energy price escalation (eE)**: 0.5%
- **Water price escalation (eW)**: 2%

This study developed an analytical approach to assess the long-term cost-benefits of alternatives for a range of scenarios that represent uncertain future conditions. This approach was applied using a set of tools specifically developed for this study to analyze the sensitivity of the results to different scenarios.

The analytical approach provides additional insight to aid decision-making under uncertainty. Traditional calculations of Net Savings provide a single "point estimate" given specific input variables (i.e., Study Period, discount rate, and escalation rate). The analytical approach developed in this study provides the context for that "point estimate" by calculating the feasible range of Net Savings outcomes given the unknowns for external factors (for instance, capital markets and energy or water price escalation). The sensitivity analysis in this study calculates the upper and lower bounds of the values for Net Savings for an alternative under different conditions, creating a region of feasible outcomes (Table 1).

[5] Office of Management and Budget, Memorandum M-12-06, "2012 Discount Rates for OMB Circular No. A-94," January 3, 2012. (http://www.whitehouse.gov/sites/default/files/omb/memoranda/2012/m-12-06.pdf).
[6] U.S. Department of Commerce, Consumer Price Index, Inflation Calculator, 2012.

Table 1: Sensitivity Analysis Scenarios

| Scenarios | Real Discount Rates | Study Period | Energy Annual Escalation Rates (eE) | Water Annual Escalation Rates (eW) |
|---|---|---|---|---|
| Long-term Cost-Benefit | 2.0%[1] | 40 | 0.5%[2] | 2% |
| Short-Term Cost-Benefit | 1.7%[1] | 20 | 0.5%[2] | 2% |
| "Economic High Growth" | 3% | 20, 40 | 0.5%[2] | 0% |
| "Economic Slow Growth" | 1.5% | 20, 40 | 2% | 4% |

[1] OMB Real Discount Rates FY2013.
[2]Annual equivalent of EIA/FEMP energy price escalations
eE = Energy (Annual) Escalation Rates, excluding inflation
eW = Water (Annual) Escalation Rates, excluding inflation.

### Sensitivity Analysis on Study Period

The Study Period selected for any life cycle cost analysis reflects the expected useful life of the investment (i.e., capital facility asset), the investor's time horizon, or other factors.[7] Since the average building lifespan is the U.S. is over 50 years,[8] the EISA increase of the Study Period to 40 years reflects the federal government's long time horizon for capital facility assets.

The sensitivity analysis in this study includes the range from 20 to 40 years to reflect relatively recent changes in federal legislation related to life cycle cost analysis. Specifically, the Energy Independence and Security Act (EISA, 2007) extended the maximum study period for economic efficiency analysis to 40 years from the previous 25-year study period (Section 441). Therefore, the Long Term Cost-Benefit analysis in this study uses the 40-year Study Period, and the sensitivity analysis includes the 20-year Study Period (related to the OMB real discount rate for 20 years).

Longer study periods extend the time period over which benefits and costs are calculated. As a result, the Net Savings for 40 years is greater than the Net Savings for 20 years when there are net savings that accumulate over the longer time period. Alternatives that were not economically efficient at 20 years may be economically efficient at 40 years if the future benefits continue to accumulate at a sufficient rate. However, facilities with short expected lifespans (e.g., temporary facilities) should use a Study Period related to the expected usage period.

### Sensitivity Analysis on Discount Rate

A second area of uncertainty in future conditions is the "opportunity cost of capital," represented by the discount rate. The Office of Management and Budget (OMB) annually updates the real and nominal discount rates to be used for cost-effectiveness studies of federal capital investments, which are based on the interest rates for Treasury Notes of different maturity dates.

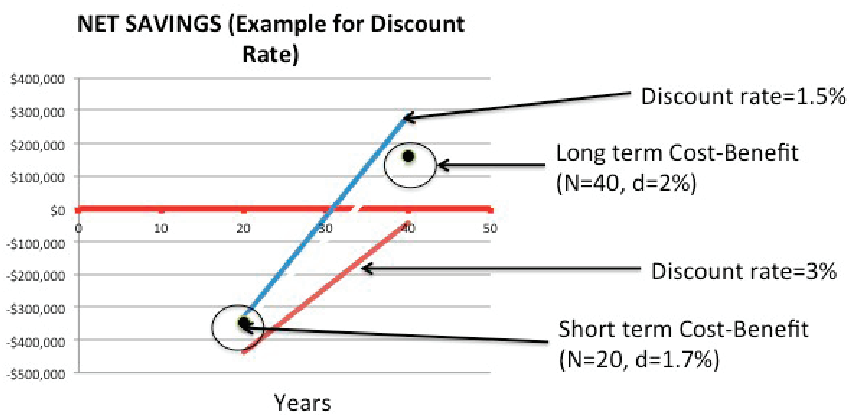
[7] National Institute of Standards and Technology (1996). *Life-Cycle Costing Manual for the Federal Energy Management Program,* NIST Handbook 135, Washington, DC, p. 2-8, 2-9.

[8] US Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Program, *2008 Buildings Energy Data Book*, pages 3-12.

The OMB real discount rates have declined from a high of 8% in 1982 to 2% in 2012 (Appendix A). When the economy is growing slowly, there are fewer opportunities for capital investment and the discount rate declines. When the economy is growing more quickly, more opportunities for higher yields for capital investment increase the discount rate. Therefore, the "Economic High Growth" scenario in this study includes a discount rate of 3%, which is equal to the OMB real discount rate in 2007 and which could be expected to occur within the Study Period of 40 years. The "Economic Slow Growth" scenario includes a discount rate of 1.5%, which could occur in the future if economic activity (and opportunities for investment) limits the alternatives for higher yield investments.

The higher discount rate, which represents more opportunity in the market for higher returns, means that an alternative has to perform better to be economically efficient. The lower discount rate, which represents less opportunity in the capital market, reduces the economic efficiency boundary—that is, an alternative that was not economically efficient at 8% (in 1982) may be economically efficient at 2% (in 2012). In the example below (Figure 1), the Net Savings in the Long-term Cost-Benefit scenario is great than 0 and therefore economically efficient, but is not economically efficient when the discount rate is 3% or when the Study Period is 20 years. It is, however, economically efficient when the discount rate is 1.5% and the Study Period is 30 to 40 years.

Figure 1: Example of Sensitivity Analysis for Time Period and Discount Rate



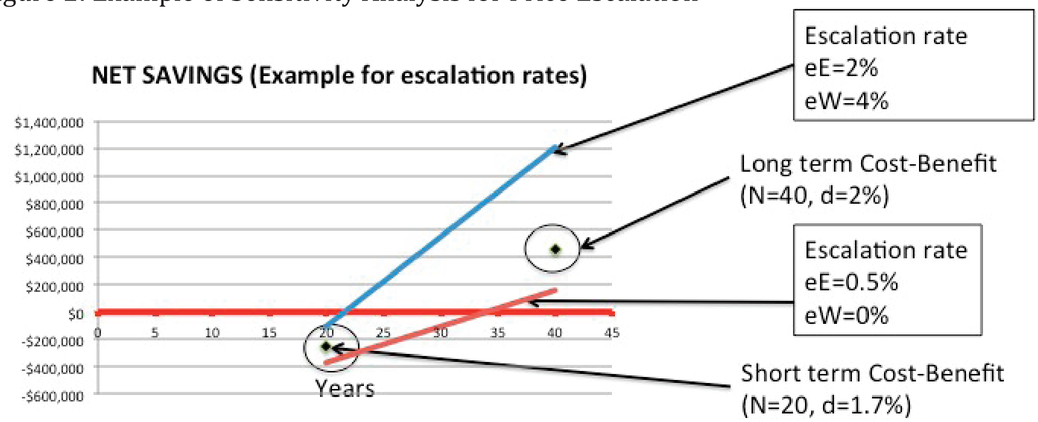

## Sensitivity Analysis on Factor Price Escalation

Another major area of uncertainty related to this study is future prices for municipal utilities (such as electricity, natural gas, water and sewage) over the next 20-40 years. Analysis of the Consumer Price Index (Appendix A) indicates that the average annual increase for energy costs has increased by approximately 2-4% between 1982 and 2012 (depending on energy fuel source) and the CPI average annual increase for water and sewer prices has been almost 5% over that time period.

Therefore, the estimated 2% annual price escalation for water included in the scenario analysis could be considered a conservative estimate of the future value of water cost reductions, and the 4% annual price escalation in the "Economic Slow Growth" scenario could better represent rate of increase in the future of water and wastewater prices. The DOE EIA FEMP estimated energy price escalation is approximately 0.5% over 40 years (varying annually based on the energy price model), and the 2% annual price escalation for energy in the "Economic Slow Growth" scenario represents potential significant future energy price increases. In the sample below (Figure 2), the

Net Savings (representing avoided future costs) increase significantly with the higher energy and water/wastewater escalation rates. Even with the lower energy and water prices, the alternative is economically efficient for a Study Period of just over 30 to 40 years.

Figure 2: Example of Sensitivity Analysis for Price Escalation




For this report, the variations in both the discount rates and prices escalations are combined in the scenarios and represented as the feasible range of Net Savings for a specific alternative under a range of conditions (Figure 3).

The analytical approach, to calculate a feasible range of values for Net Savings given uncertain future conditions, is applied using a set of tools developed specifically for this study (Figure 4). The tools provide a standardized approach to collect and organize data and to automate the calculation of the measures of economic efficiency. Since the scope of this study required comparing the results of the analysis of the specified building standards and rating systems across two building types and five locations, the set of tools also provides a means to view and compare the results across the portfolio of alternatives.

This study also used the latest version of Building Life Cycle Cost (BLCC) software program from the National Institute of Standards and Technology (NIST) to calculate Net Savings, (Adjusted) Rate of Return on Investment, and Payback for the specified building standards and rating systems.[9] The BLCC software is updated annually by NIST to incorporate the current OMB discount rates and the annual energy price escalations provided by the Department of Energy (DOE) Energy Information Administration (EIA) in accord with the Federal Energy Management Program (FEMP). BLCC also includes the default values for calculating values for MILCON projects (specifically the mid-year discount approach). The program also computes projected energy savings and projected emissions reductions.

[9] The BLCC software is available for download through http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc.

Figure 3: Net Savings—Boundary Area from Sensitivity Analysis

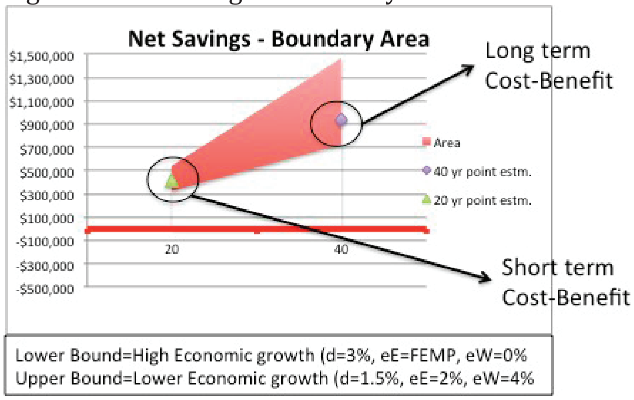
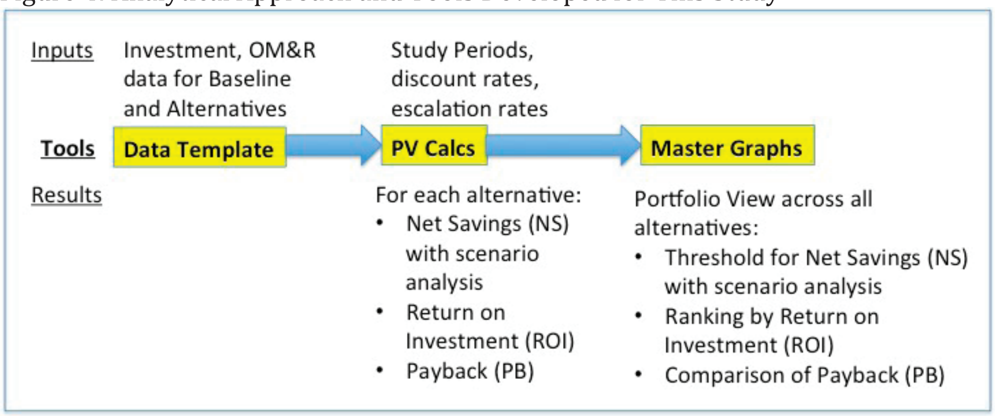



Figure 4: Analytical Approach and Tools Developed for This Study




## STUDY METHODOLOGY USING PROTOTYPE BUILDINGS AND CLIMATE ZONES

This study established a common basis on which to calculate the long-term cost-benefits, return on investment, and payback using prototype buildings and selected locations to represent the heating and cooling loads and local factor prices that influence the economic efficiency calculations for different locations across the continental U.S.

Specifically, this study utilized the results and characteristics of the selected prototype building models developed by Pacific Northwest National Lab (PNNL) as part of the Department Energy (DOE) Commercial Building Initiative. The selected reference buildings are the "medium office" prototype (which corresponds to military administrative buildings) and the "small hotel" prototype (which corresponds to barracks and military dormitories). These models are publicly available and incorporate the versions of ASHRAE 90.1 (specifically 90.1-2004, 90.1-2007, and 90.1-2010), and the *EnergyPlus* results are publicly available for these building prototypes and locations. Use of the existing PNNL models builds upon previous research to improve replicability and robustness of the results, and to expedite this study.

The ASHRAE 90.1-2004 version of the two prototype building models was used as the baseline for this study because it is specified as the basis for improved building performance in the Energy Policy Act (2005) and the Energy Independence and Security Act (EISA) (Table 2).

(Appendix B provides the descriptions of the "medium office" and "small hotel" prototype building characteristics.)

The locations were selected to represent the diversity of conditions that drive cost effectiveness for high performance buildings across the US, including heating/cooling loads and local design and construction market characteristics. The locations were selected to represent regions of the US, climate zones and conditions, and size of the design/construction market (Table 3 and Figure 5).

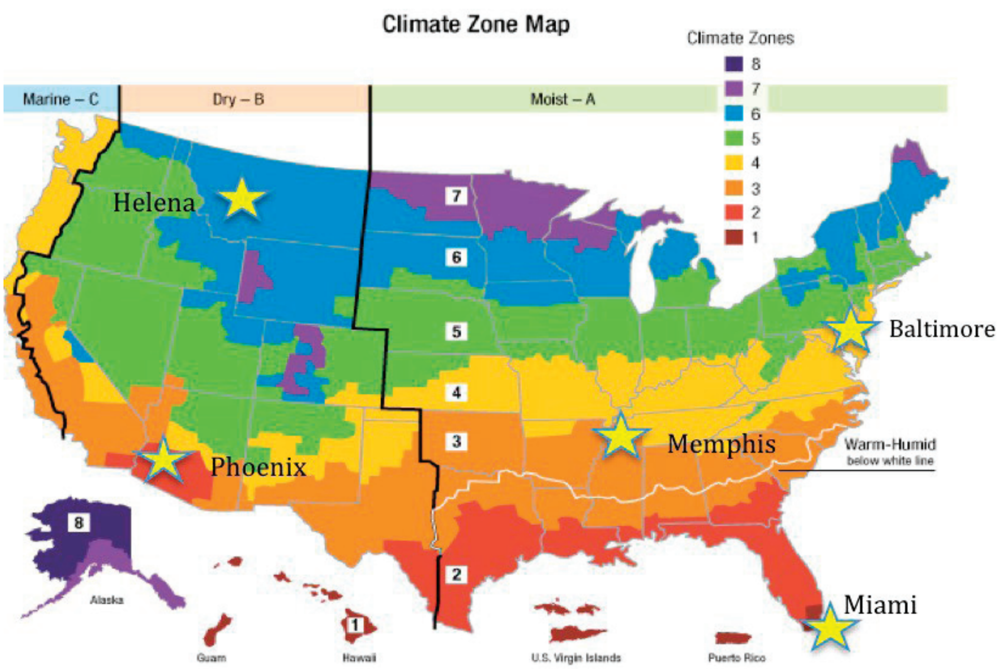
Table 2: Selected PNNL Prototype Buildings and Climate Zones

| Prototype building type (2) | Locations/ Climate Zones (5) |
|---|---|
| Medium Office (similar to administration buildings)<br>Small Hotel (similar to barracks) | 1A Miami<br>2B Phoenix<br>3A Memphis<br>4A Baltimore<br>6B Helena |

Table 3: Selected Locations by Characteristics

| Location | Climate Zone | Region | Climate Temp | Humidity | Market Type |
|---|---|---|---|---|---|
| Miami | 1 | Southeast | Hot | Wet | Large urban |
| Phoenix | 2 | Southwest | Hot | Dry | Medium urban |
| Memphis | 3 | Central | Medium | Medium | Medium urban |
| Baltimore | 4 | Northeast/Mid-Atlantic | Medium | Wet | Large urban |
| Helena | 6 | Northwest | Cool | Dry | Small urban/rural |

Figure 5: Locations for the Study



## STUDY METHODOLOGY FOR BENEFIT AND COST CATEGORIES

The study focused on benefit-cost categories that directly relate to financial outcomes. The primary focus of the benefit-cost categories are the measures on which the Department of Defense is required to report annually in the DOD Annual Energy Management Report (Appendix F).

> DoD provides an annual facilities energy management report detailing its energy goals, plans to meet those goals, and progress to date. This report, directed by DoD instruction 4170.11, meets the requirements of multiple statutes and executive orders. Annual contents may vary depending on adjustments made by the interested congressional committees in appropriations and authorization language. DoD transmits this report to the Congress, the Executive Office of the President, and to the Department of Energy.[10]

These categories include energy use, water use, and reduction of solid waste (including municipal and hazardous waste). In addition, the categories include measures of operations and maintenance (O&M) costs that could be expected to be affected by high performance building attributes (Table 4). (See Appendix C for definitions.)

Table 4: Benefit-Cost Categories

| Investment Costs | Operations, Maintenance, and Repair (OM&R) Costs |
|---|---|
| • Initial Investment<br>• Major Repair and Replacement Costs | *Current Reporting Requirements*<br>• Building energy<br>• Supporting Facilities/Site energy<br>• Building water supply<br>• Building waste water (disposal)<br>• Supporting Facilities/Site water<br>• Municipal (nonhazardous) solid waste<br>• Hazardous waste<br>*Expected Sustainable Outcomes*<br>• Building/site operations and maintenance (O&M)<br>• Building cleaning<br>• Landscaping |

The benefit-cost categories under "Expected Sustainable Outcomes" have been mentioned in the literature that examines the expected outcomes from high performance buildings approaches.[11] For instance, "Building and site operations and maintenance (O&M)" would include general labor, material and equipment for the operations and maintenance of the building and grounds, which may increase with the addition of complex equipment or may decrease with continuous monitoring equipment. Improved durability of materials may reduce cleaning costs (i.e., labor, equipment and materials) or special materials may require special cleaning activities and thereby increase costs. Specific landscaping approaches, such as low-water landscaping, could eliminate mowing and other related landscaping costs or may require additional plant maintenance for protection of indigenous plantings.

Other potential benefits associated with high performance facilities may include measures of occupant health, safety, and well-being; however, there is currently insufficient evidence to

[10] See http://www.acq.osd.mil/ie/energy/energymgmt_report/main.shtml.

[11] National Research Council (2011). *Achieving High Performance Federal Facilities: Strategies and Approaches for Transformational Change*. The National Academies Press, Washington, DC.

calculate explicit financial outcomes from these attributes, and so they were not included in this study.

## STUDY METHODOLOGY FOR DATA COLLECTION FOR PROTOTYPE BUILDINGS

The Net Savings approach requires a baseline against which to compare the alternatives to calculate the financial value of the costs and benefits of the alternatives. In this study, the baseline prototype buildings use the characteristics of the PNNL building prototypes ("Medium office" and "Small hotel") and specific locations on which to compile data for the benefit-cost categories (see Table 5) for each location using public data sources and local unit prices.

The initial investment costs for each prototype building in each location was calculated using R.S. Means *Square Foot Cost Estimator* in that location with April 2012 cost data, modified to reflect the specific technical characteristics of the prototype buildings. The R.S. Means cost-estimating system is an industry standard, and is often viewed as generally over-estimating construction costs. However, given the generalized description of the prototype buildings (from the PNNL building prototypes), it was not feasible to generate more detailed cost-estimates.

Table 5: Construction Cost Estimates (Cost/square foot) for Prototype Buildings in Each Location

| Location | Office ($/sf) | Hotel ($/sf) |
|---|---|---|
| Miami | $112.91 | $116.90 |
| Phoenix | $111.39 | $115.23 |
| Memphis | $107.36 | $111.70 |
| Baltimore | $117.03 | $115.53 |
| Helena | $110.90 | $119.74 |

The unit quantities for each OM&R category for each baseline prototype building were generated to represent standard current building performance related to the ASHRAE 90.1-2004 levels as established in the Energy Policy Act (2005) and the Energy Independence and Security Act (2007). Specifically, the energy use for each building prototype in each location for both building and site (exterior) energy were generated from the PNNL building models (using *EnergyPlus*) following ASHRAE 90.1-2004.

Water use for each building type was calculated using current usage rates as reported by industry sources. Likewise, municipal solid waste and hazardous waste quantities were estimated based on current industry reported rates. It must be noted, however, that the definitions of "hazardous waste" for office and hotel buildings are usually categorized under "household hazardous waste" (rather than industrial hazardous waste) and include such items as paints, cleaning materials, batteries, hydraulic fluids, oils, and pesticides.[12] (Appendix D includes the quantity and cost data for the Baseline Office and Baseline Small Hotel for all five locations.)

Total costs for the energy, water, and solid waste categories for each prototype building in each location were calculated using the quantities (as defined above) multiplied by the local factor unit prices. Energy prices for electricity and natural gas were established using the U.S. Energy Information Administration (EIA) monthly statistics, based on current prices.[13] Energy prices fluctuate significantly by month and by year, and these prices should be taken as representative of

[12] Environmental Protection Agency, Household Hazardous Wastes, http://www.epa.gov/osw/conserve/materials/hhw.htm.

[13] U.S. Energy Information Administration, Form EIA-826, "Monthly Electric Sales and Revenue Report with State Distributions Report" and "Monthly Natural Gas Prices" for April 2012.

current market conditions. Local water prices for water supply (potable water) and wastewater (water disposal) were determined through public data sources, including municipal agencies and publications. Local municipal solid waste and hazardous waste costs were determined through municipal agency publications and published rates (Table 6 and Appendix D, with data source references).

Table 6: Factor Unit Prices in Each Location

| Location | Electricity ($/kwh) | Natural Gas ($/ft3) | Water ($/gal) | Wastewater ($/gal) | Municipal Solid Waste ($/ton) | Hazardous Waste ($/ton) | Renewable Energy Credit ($/kwh) |
|---|---|---|---|---|---|---|---|
| Miami | $0.0980 | $10.28 | $0.0041 | $0.0059 | $62.59 | $114.18 | $0.09 |
| Phoenix | $0.0921 | $9.68 | $0.0018 | $0.0017 | $38.25 | $10.00 | $0.09 |
| Memphis | $0.0989 | $8.66 | $0.0027 | $0.0020 | $22.00 | $15.00 | $0.09 |
| Baltimore | $0.1060 | $11.11 | $0.0032 | $0.0041 | $80.00 | $80.00 | $0.09 |
| Helena | $0.0906 | $7.99 | $0.0035 | $0.0028 | $70.75 | $75.00 | $0.09 |

Building operations and maintenance (O&M) costs (general labor, materials and equipment) were estimated based on cost per building area (i.e., square foot) using industry averages for similar building types (i.e., office and small hotel). These estimates provide a general approximate range of costs; however, actual O&M costs would be directly related to the condition, complexity, and specific requirements for an actual building.

Cleaning and landscaping costs were also estimated based on cost per building area (i.e., square foot) using industry averages for similar building types. Data sources for these costs most often focus on a specific market segment (such as education buildings) and may not capture the full range of costs associated with these activities for other market segments.

The consultant provided the benefit-cost data for the baseline buildings to the participating organizations (ASHRAE, Green Building Initiative, and the U.S. Green Building Council) for each building type and location. In several instances, the professional staff and professionals associated with those organizations offered suggestions for improvement and refinement (such as recent empirical studies and data sources). Where applicable, the data from these references were included in the revised baselines.

## STUDY METHODOLOGY FOR DATA COLLECTION FOR STANDARDS AND RATINGS SYSTEMS

The strategy for data collection addressed the issues of validity and accuracy of the results. To ensure comparability across the standards and rating systems, this study used the characteristics of the prototype buildings (i.e., “medium office” and “small hotel”) in the 5 selected locations.

In discussions with the staff of ASHRAE, Green Building Initiative, and the US Green Building Council, those organizations agreed to provide detailed cost and benefit data for the prototype buildings in locations that were similar to or near the selected locations. (As noted earlier, the selected locations represent 5 climate zones, and a range of urban and non-urban markets.)

- ASHRAE agreed to provide energy and water usage data generated using building models, since the recent release of these standards precludes the possibility of obtaining data from a sufficiently large sample of actual buildings to provide valid results. The building models utilized the PNNL prototype buildings (i.e., “medium office” and “small hotel”).

- The Green Building Initiative (GBI) and the US Green Building Council (USGBC) agreed to provide energy and/or water usage data based on actual buildings certified under their (respective) rating systems. The actual buildings selected by GBI and USGBC were similar to the selected prototype buildings (i.e. office and hotel/dormitory) and are commercially or privately owned facilities.

The advantages of this approach are:

1) Certification submissions for the rating programs require reporting in the benefit and cost categories (particularly for expected energy and water usage);
2) The reported data is assumed to be valid and accurate, and is verified by a third party affiliated with each organization; and
3) The selected certified building projects represent current capabilities of “expert users” of the rating system.

### *Data Requirements*

The organizations were provided with a data template for each building type for each location, in which to provide the initial investment costs (i.e., construction costs), and quantities of expected energy and water use, generation of solid waste, and other related amounts. The requested materials included, for each building type (small hotel and medium office), location, and standard or sustainable building rating level, specification of:

- **Differences in** components, systems, and materials (compared to the ASHRAE 90.1 2004 baseline);
- Associated **differences in** initial investment and major repair/replacement costs (compared to the provided baseline prototype buildings);
- Associated **differences in** operations, maintenance and repair (OM&R) costs, including energy, water, solid waste, and O&M costs for each location (compared to the provided baseline prototype buildings).

## ASHRAE Standards Data: Building Models

The data for the ASHRAE Standards 189.1-2011 and 90.1-2010 for each location and each building type were generated using the PNNL building models for “small hotel” and “medium office” for compared to the ASHRAE 90.1-2004 baseline (Table 7). (The recent release of these standards precludes the possibility of obtaining data from a sufficiently large sample of actual buildings to provide valid results.) The building characteristics for the Std. 90.1 and 189.1 buildings are the same as the 90.1-2004 baseline buildings. The characteristics that do change by climate zone would be the thermal performance of the envelope measures (R-values) and the HVAC equipment efficiencies. (Appendix G provides a detailed description of the ASHRAE methodology for generating the data for each building type in each location.)

ASHRAE provided energy performance data for each building type in each location for Standard 90.1-2010, and energy and water performance data for each building type in each location for Standard 189.1-2011 (Table 8). No data was provided for expected solid waste (municipal or hazardous) or operations and maintenance (general, cleaning or landscaping) quantities or costs, so these costs were not included in this analysis. ASHRAE 189.1-2011 also includes a requirement for on-site energy generation. The initial investment costs for these energy generation units were included in the construction cost, and the on-site energy was used to offset the energy used by the building.

Table 7: ASHRAE Data Sample

| Building Types | Locations | Standards |
|---|---|---|
| Office | 5 | 90.1-2010, 189.1-2011 |
| Small Hotel | 5 | 90.1-2010, 189.1-2011 |

Table 8: ASHRAE Data: Energy and Water Performance by Building Type and Standard

| Building Type | Standard | Average Building Energy[1] Reduction | Average Site Energy Reduction | Average Building Water Reduction | Average Site Water Reduction | Number with On-site Energy | Total Buildings |
|---|---|---|---|---|---|---|---|
| Hotel | 90.1-2010 | 11% | 31% | 0% | 0% | 0 | 5 |
| | 189.1- | 24% | 35% | 48% | 97% | 5 | 5 |
| Office | 90.1-2010 | 21% | 64% | 0% | 0% | 0 | 5 |
| | 189.1- | 26% | 63% | 88% | 91% | 5 | 5 |

[1] Average Building Energy Reduction calculated as percentage of energy cost savings.

**LEED Data: Certified Buildings from US Green Building Council (USGBC)**

The US Green Building Council (USGBC) provided energy and water performance data for 72 LEED-certified office buildings and 55 LEED-certified hotels, dormitories, or multi-unit residential buildings that were certified under the LEED rating system for new construction. The LEED certification system requires certain levels of energy and water performance as prerequisites and specifically provides points for improved performance levels, which are included in the submitted certification materials. The LEED reporting requirements do not include investment costs (i.e., construction costs). No data was provided for projected solid waste (municipal or hazardous) or operations and maintenance (general, cleaning or landscaping) quantities or costs, so these costs were not included in this analysis.

The data provided by USGBC did not include building construction cost, but subsequent communications with the staff at USGBC provided construction cost data on 20 projects; public data sources (including press releases, articles, and other public data sources) provided construction cost data for the other five projects in this sample.

The resulting sample is 25 LEED-certified buildings (defined by available construction cost data, and energy and/or water performance data) (Table 9), which are similar to the characteristics of the prototype buildings. USGBC provided the location for each building, which was then used to map it to its relevant climate zone. The climate zone for each sample building was then used to assign each building to the selected relevant location for this study. (Buildings in climate zones 5 and higher were assigned to the Helena location, which is in climate zone 6.)

The LEED certification submission materials include expected energy and water performance (for instance, percentage of energy use reduction compared to ASHRAE 90.1-2004), and these data were provided for the 25 buildings in the sample, which were then used to adjust the relevant quantities in comparison to the baseline prototype building for that location (Table

10). The resulting energy and water quantities for each building in the LEED sample were then used with the local factor unit costs for each location to calculate the projected savings compared to the baseline prototype building.

Table 9: USGBC LEED Sample by Location, Building Type, and Certification Level

| Location | Hotel | Office | Total |
|---|---|---|---|
| Baltimore | 2 Silver<br>1 Gold | 1 Silver<br>3 Gold<br>1 Platinum | 8 |
| Helena | 1 Platinum | 1 Silver<br>3 Gold<br>1 Platinum | 6 |
| Memphis | 2 Gold<br>1 Platinum | 3 Silver<br>1 Gold<br>1 Platinum | 8 |
| Miami | 1 Silver | 0 | 1 |
| Phoenix | 1 Silver | 1 Silver | 2 |
| **Total** | **9** | **16** | **25** |

Table 10: LEED Data: Energy and Water Performance Data by Building Type and Certification Level

| Building Type | Certification Level | Average Energy Reduction | Average Building Water Reduction | Average Site Water Reduction | Number with Onsite Energy | Total |
|---|---|---|---|---|---|---|
| Hotel | Silver | -24% | -31% | -100% | 2 | 4 |
| | Gold | -21% | -27% | -83% | 1 | 3 |
| | Platinum | -42% | -30% | -75% | 1 | 2 |
| Office | Silver | -30% | -28% | -46% | | 6 |
| | Gold | -31% | -30% | -79% | | 7 |
| | Platinum | -37% | -30% | -100% | 2 | 3 |
| **Total Sample** | | **-30%** | **-29%** | **-78%** | **6** | **25** |

The "investment costs" of the sample of LEED buildings (that is, the construction costs as identified through USGBC communications and public sources) were in many cases assumed to include all project costs, specifically construction costs plus related architect, engineering, and construction management fees (but excluding land purchase costs). According to R.S. Means and other industry sources, these fees often average 35% of the total project costs. Therefore, the total project costs in those cases were reduced by 35% to exclude these fees and to focus on actual construction costs.

Unfortunately, insufficient data was provided to identify any particular technical cost drivers for the LEED sample of projects (such as unusual site conditions, structural requirements, or special equipment) or other factors that influence construction costs (such as local market conditions) independent of expected performance levels. As a result, there is a high degree of variation among the reported construction costs for the LEED buildings (Table 11). Therefore, the initial investment costs for some of the LEED projects were over 2 times the investment costs for the baseline prototype buildings.

Notably, in three cases (2 hotels, 1 office), the LEED construction cost was less than the specific baseline prototype building's construction cost in that location. In these cases, the analysis of economic efficiency is clear, since these high performance buildings are obtained at no incremental initial cost—that is, all of the benefits are captured without requiring additional investments.

It is not possible in this study, given the relatively small size of the sample and the short time frame, to draw conclusions on relative trends in construction cost for LEED buildings, but previous studies have likewise found high variation in construction costs independent of expected building performance.[14]

Therefore, this study will use the construction costs provided for these LEED projects, with the caveat that this data has not been independently verified and may include costs related to specific technical or special function requirements that are not related to this study.

Table 11: LEED Silver, Gold, Platinum Buildings: Construction Cost Variation

| Building Type | Minimum Cost per square foot | Maximum Cost per square foot | Standard Deviation of Cost per square foot | Average Cost per square foot | Sample Size |
|---|---|---|---|---|---|
| Hotel | $96.01 | $259.68 | $48.36 | $134.65 | 9 |
| Office | $97.47 | $279.64 | $62.47 | $179.54 | 16 |
| Total Sample | $96.01 | $279.64 | $60.85 | $163.38 | 25 |

**Green Globes Data: Certified Buildings from Green Building Initiative (GBI)**

The Green Building Initiative (GBI) provided data on expected energy and/or water performance for 13 Green Globes-certified buildings that were certified under the Green Globes rating system for new construction. The Green Globes certification does not require specific energy or water performance as a prerequisite, and does not have specific reporting requirements for expected energy or water savings or other benefits. The Green Globes reporting requirements do not include investment cost (i.e., construction cost). No data was provided for projected solid waste (municipal or hazardous) or operations and maintenance (general, cleaning or landscaping) quantities or costs. Therefore, these costs were not included in this analysis.

The data provided by GBI did not include building construction cost for any of the 13 Green Globes-certified buildings. Public data sources (including press releases, articles, and other public data sources) provided construction cost data for 11 projects.

The resulting sample is 11 Green Globes-certified buildings (defined by available construction cost data, and energy and/or water performance data) (Table 12), which are similar to the characteristics of the prototype buildings. GBI provided the location for each building, which was then use to map it to its relevant climate zone. The climate zone for each sample building was then used to assign each building to the selected relevant location for this study. (Buildings in climate zones 5 and higher were assigned to the Helena location, which is in climate zone 6.)

GBI provided expected energy and water performance data for the buildings in the sample (such as expected energy use reduction), which were then used to adjust the relevant quantities in

[14] David Langdon (2004). *Costing Green: A Comprehensive Cost Database and Budgeting Methodology,* pp. 18-23, which found a "large variation in costs of buildings, even within the same building program category."

comparison to the baseline prototype building for that location (Table 13). The resulting energy and water quantities for each building in the Green Globes sample were then used with the local factor unit costs for each location to calculate the projected savings compared to the baseline prototype building.

The "investment costs" of the sample buildings (as identified through public sources) in many cases was assumed to include all project costs, specifically construction costs plus related architect, engineering, and construction management fees (excluding land purchase costs). According to R.S. Means and other industry sources, these fees often average 35% of the total project costs. Therefore, the total projects costs in those cases were reduced by 35% to exclude these fees and to focus on projected actual construction costs.

Table 12: GBI Green Globes Sample by Location, Building Type, and Certification Level

| Location | Hotel | Office | Total |
|---|---|---|---|
| Baltimore | 1 One Globe<br>1 Two Globes | 1 Two Globes<br>1 Four Globes | 4 |
| Helena | 1 One Globe<br>1 Two Globes | 0 | 2 |
| Memphis | 1 One Globe | 2 Three Globes<br>1 Four Globes | 4 |
| Miami | 0 | 0 | 0 |
| Phoenix | 0 | 1 Two Globes | 1 |
| **Total** | **5** | **6** | **11** |

Table 13: Green Globes Data: Energy and Water Performance Data by Building Type and Certification Level

| Building Type | Certification Level | Average Energy Reduction | Average Building Water Reduction | Total |
|---|---|---|---|---|
| Hotel | One | 4% | 25% | 3 |
| | Two | 25% | 43% | 2 |
| Office | Two | 12% | 38% | 2 |
| | Three | 35% | 84% | 2 |
| | Four | 40% | 62% | 2 |
| **Total Sample** | | **21%** | **48%** | **11** |

Unfortunately, insufficient data was provided to identify any particular technical cost drivers for the projects (such as unusual site conditions, structural requirements, or special equipment) or other factors that influence construction costs (such as local market conditions) independent of expected performance levels. As a result, there is a high degree of variation among the reported construction costs for this sample of 11 actual buildings that received Green Globes certification (Table 14). Therefore, the initial investment costs for some of the Green Globes projects was over 2 times the investment costs for the baseline prototype buildings.

It is not possible in this study, given the relatively small size of the sample and the short time frame, to draw conclusions on relative trends in construction cost for Green Globes buildings.

Therefore, this study will use the construction costs provided for these Green Globes projects, with the caveat that this data has not been independently verified and may include costs related to specific technical or special function requirements that are not related to this study.

Table 14: Green Globes One, Two, Three and Four Globes: Construction Cost Variation

| Building Type | Minimum Cost per square foot | Maximum Cost per square foot | Standard Deviation of Cost per square foot | Average Cost per square foot | Sample Size |
|---|---|---|---|---|---|
| Hotel | $127.00 | $244.00 | $49.43 | $163.80 | 5 |
| Office | $109.00 | $235.00 | $47.85 | $149.17 | 6 |
| Total Sample | $109.00 | $244.00 | $46.70 | $155.82 | 11 |

## RESULTS OF ECONOMIC EFFICIENCY EVALUATION OF SPECIFIED BUILDING STANDARDS AND RATING SYSTEMS

In the NDAA 2012 Section 2830(a), Congress required the Department of Defense to submit a report that includes a cost-benefit analysis, return on investment, and long-term payback for specific building standards and rating systems (ASHRAE 189.1 and 90.1, LEED Silver, Gold, and Platinum, and other ANSI accredited standards such as Green Globes). The objective is to determine if buildings built under the guidance of these building standards and rating systems are economically efficient.

The analysis results include Net Savings, (Adjusted) Rate of Return on Investment, and Payback for the recent “green” buildings compared to the baseline (e.g., ASHRAE 90.1-2004) to calculate Long-term Cost-Benefit as well as the results of the sensitivity analysis for study period, discount rates, and price escalation rates (Table 15).

Table 15: Summary Definitions of Terms

| Measure | Definition |
|---|---|
| Net Savings | Time-adjusted costs are subtracted from the time-adjusted savings, where the discount rate (d) represents foregone opportunities in the market for investment. If the Net Savings are greater than zero, the investment is economically efficient and higher Net Savings indicates better economic efficiency. |
| (Adjusted) Rate of Return on Investment | Annual yield from a project over the study period (N), taking into account the reinvestment of interim savings at the discount rate (d). If the ARROI is greater than the discount rate (d), the investment is economically efficient and higher ARROI (relative to the same discount rate) indicates better economic efficiency for independent projects. |
| Payback | Payback is the time period in which initial investment is recovered, as a measure of capital liquidity. Simple Payback is the time when the summation of the expected annual savings equals the original investment; Discounted payback is the time when the summation of the time-adjusted annual savings equals the original investment. |

## ASHRAE 90.1-2010—ECONOMIC EFFICIENCY RESULTS ACROSS BUILDING TYPES AND LOCATIONS

The stated purpose of ASHRAE 90.1-2010 *Energy Standards for Buildings Except Low-Rise Residential Buildings* is:

> To provide minimum requirements for the energy-efficient design of buildings except low-rise residential buildings, for:
> - Design, construction, and a plan for operation and maintenance, and
> - Utilization of on-site, renewable energy resources.[15]

The Pacific Northwest National Laboratory (PNNL) worked with ASHRAE during the development of Standard 90.1-2010, providing technical and analytical support under the Department of Energy (DOE) Building Energy Codes Program (BECP).

> In 2007, as part of its Advanced Codes Initiative, DOE signed a memorandum of understanding (MOU) with ASHRAE to develop advanced commercial standards and included an agreement that 90.1-2010 would result in 30% energy savings relative to 90.1-2004. This MOU initiated the effort by BECP and ASHRAE which culminated in the release of 90.1-2010 in October 2010. This signed MOU introduced a new element and significant challenges for developing 90.1-2010. For the first time in the history of Standard 90.1, an energy goal was established for developing the new edition, 90.1-2010.[16]

The PNNL technical and analytical support included modeling building energy performance using *EnergyPlus* models and parameterized cost curves to incorporate cost efficiency considerations.

For this study, the economic efficiency analysis for Standard 90.1-2010 focused on the energy performance in the five specific locations, for the two building types (which are a subset of the PNNL locations and building types), using **actual local energy costs** rather than national energy cost curves (as used in the PNNL study). This analysis calculated the Net Savings and other economic efficiency measures using the energy cost savings relative to the incremental construction costs (i.e., incremental initial investment costs) compared to the baseline prototype buildings.

As noted in the Methodology Section of this report, ASHRAE provided the benefit-cost data, specifically investment costs and projected energy usage (building and site), based on building models (not actual buildings), since the standard was only recently passed and has not been accepted by many jurisdictions or applied to actual projects. No data was provided for ASHRAE 90.1-2010 related to quantities of water, solid waste or O&M expected usage, which were therefore excluded from this analysis.

### Long-Term Cost-Benefit

The Net Savings for both building types in all five locations are greater than zero, indicating that 90.1-2010 provides economically efficient results (Figure 6, with NS>0 denoted as red line at x-axis). There are differences in the Net Savings between the building types; for instance, the Net

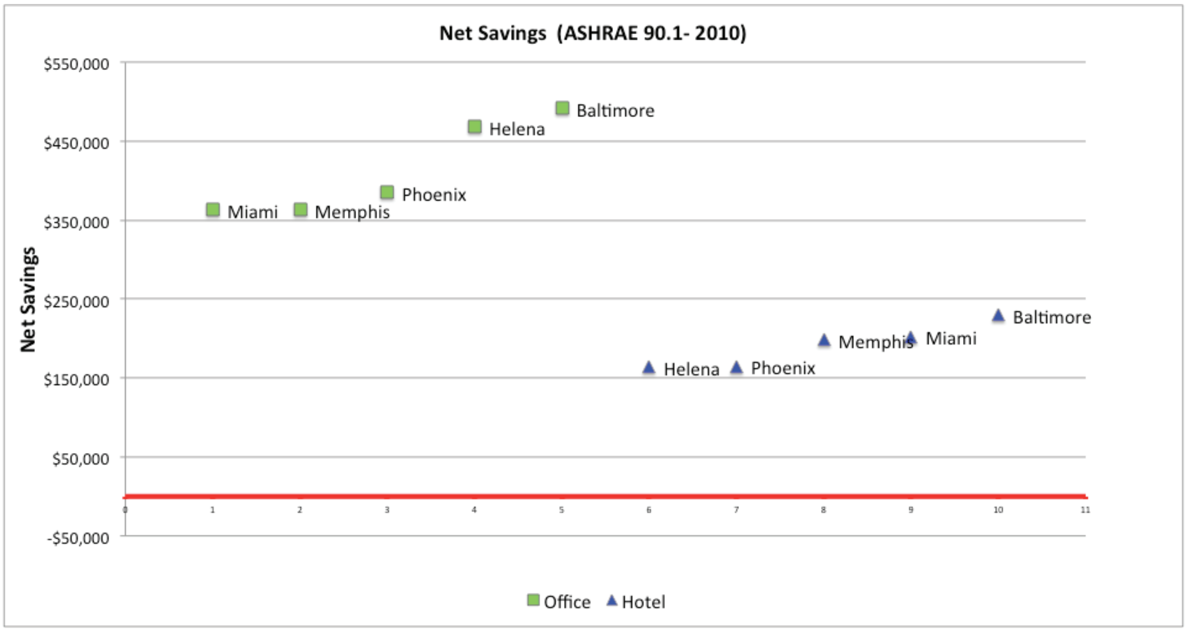
[15] American Society for Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE), Standards—titles and scopes (http://www.ashrae.org/standards-research-technology/standards-guidelines/titles-purposes-and-scopes#90-1).

[16] Thornton, BA et al., *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-201,* Pacific Northwest National Laboratory, May 2011, p. iii.

Savings for Offices in all locations are higher than those for the Hotels. There are also differences by location; for example, the Net Savings are the highest in Baltimore (for both building types), which has the highest energy costs for both electricity and natural gas.

The Net Savings results for the hotel buildings tend to cluster together at approximately $200,000, driven by the energy loads associated with the laundry facilities (electricity and natural gas). Baltimore Hotel had the highest Net Savings, followed by Miami, Memphis, Phoenix and Helena Hotels. For office buildings, while Baltimore Office has the highest Net Savings, the second highest Net Savings is the Helena Office, which has the second highest reduction in annual energy use under ASHRAE 90.1-2010.

Figure 6: ASHRAE 90.1-2010 Long-term Cost-Benefit: Net Savings for All Building Types, All Locations



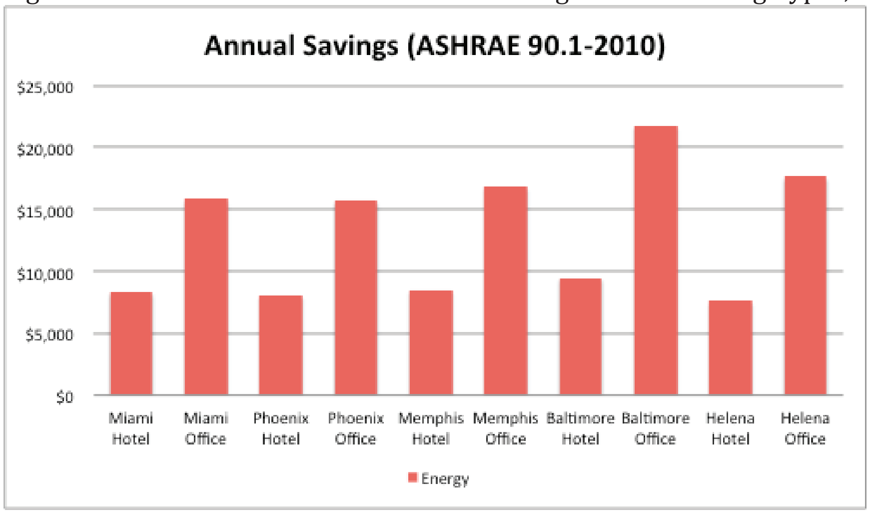

NOTE: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

The ASHRAE 90.1-2010 Net Savings differential between offices and hotels is driven by the fact that the Annual Net Savings, specifically energy use, for the office buildings decreases more, proportionately, than the energy use in the hotels decreases (Figure 7). Specifically, the energy loads modeled in *EnergyPlus* include the plug loads of the laundry equipment, which includes Energy Star-rated equipment, but does not decrease as much as the overall Office energy loads (which also include expected plug loads). Therefore, the Annual Net Savings for Offices are greater than the Annual Net Savings for Hotels.

The differences in Annual Net Savings by building type and location also indicate the relative importance of both heating/cooling loads (as indicated by the climate zone) and local factor prices for electricity and natural gas. As mentioned in the Methodology section of this report, the energy prices (i.e., electricity and natural gas) were the highest in Baltimore, followed by Helena. The Annual Net Savings, then reflect the energy quantity reductions as well as the total value of those reductions based on the local market price. The summation of those annual savings over the 40-year Study Period (discounted to present value) leads to higher Net Savings.

The sensitivity analysis on Net Savings provides additional insight into the potential savings associated with buildings built under the guidance of ASHRAE 90.1-2010 in different climate conditions and local markets. The Long-term Cost-Benefit for the 40-year Study Period (Figure 6 and Table 16, middle column) represents the expected Net Savings with the current OMB discount rate of 2% and the energy price escalation as per the EIA/FEMP energy price models. The maximum potential Net Savings (for the Economic Slow Growth scenario) range across locations from approximately $600,000 to $800,000 for offices and approximately $270,000 to $370,000 for hotels.

Figure 7: ASHRAE 90.1-2010 Annual Net Savings for All Building Types, All Locations




The sensitivity analysis represents the potential benefits that could be captured by buildings built under the guidance of ASHRAE 90.1-2010 under different conditions. That is, if energy prices escalate at 2%, the Net Savings over the 40 years would increase by over 50%. These potential future Net Savings under this scenario could also be viewed as the potential future additional costs that will be incurred if a building does not follow ASHRAE 90.1-2010. For instance, if energy prices increase in future years, an office building may see its additional energy costs (which could have been avoided under ASHRAE 90.1-2010) almost double in some locations.

The minimum potential Net Savings (presented in the Economic High Growth scenario) is still well above the threshold of Net Savings=0, ranging across locations from approximately $280,000 to $390,000 for offices and from $127,000 to $185,000 for hotels. Therefore, even if energy prices stay constant (in real dollars, which is less than the EIA/FEMP energy price projections) and if the cost of money increases (represented as the discount rate, d, increasing to 3%), these buildings built under the guidance of 90.1-2010 will still be economically efficient.

These potential future opportunities for Net Savings under different conditions can be graphically represented with the example of the Baltimore Office and Hotel (Figure 8). Within the Study Period range of 20 to 40 years, the Net Savings > 0 for both building types, indicating that ASHRAE 90.1-2010 is economically efficient for the scenarios under consideration. The potential Net Savings for the Baltimore office is approximately twice as high as the potential Net Savings for the Baltimore hotel. In addition, the Net Savings increase significantly from 20 years to 40 years as the savings accumulate. The other selected locations show similar patterns for the sensitivity analysis for Net Savings for both building types.

Table 16: ASHRAE 90.1-2010 Sensitivity Analysis for Net Savings: 40-Year Study Period

**Office**

| | Economic High Growth | Long-term Cost Benefit | Economic Slow Growth |
|---|---|---|---|
| Baltimore | $388,067 | $492,480 | $804,844 |
| Helena | $384,661 | $469,281 | $722,430 |
| Phoenix | $309,485 | $385,025 | $611,009 |
| Memphis | $282,272 | $363,154 | $605,119 |
| Miami | $286,924 | $363,064 | $590,841 |

**Hotel**

| | Economic High Growth | Long-term Cost Benefit | Economic Slow Growth |
|---|---|---|---|
| Baltimore | $184,755 | $230,370 | $366,831 |
| Miami | $162,691 | $202,848 | $322,984 |
| Memphis | $157,803 | $198,650 | $320,848 |
| Phoenix | $162,691 | $165,060 | $280,885 |
| Helena | $127,401 | $163,839 | $272,846 |

Economic High Growth when d=3%, eE=0.5%, eW=0%
Long-term Cost Benefit when d=2%, eE=0.5%, eW=2%
Economic Slow Growth when d=1.5%, eE=2%, eW=4%

Figure 8: ASHRAE 90.1-2010 Sensitivity Analysis for Net Savings: Baltimore

**Office** **Hotel**


Lower Bound=Economic High Growth (d=3%, eE=FEMP, eW=0%)
Upper Bound=Economic Slow Growth (d=1.5%, eE=2%, eW=4%)

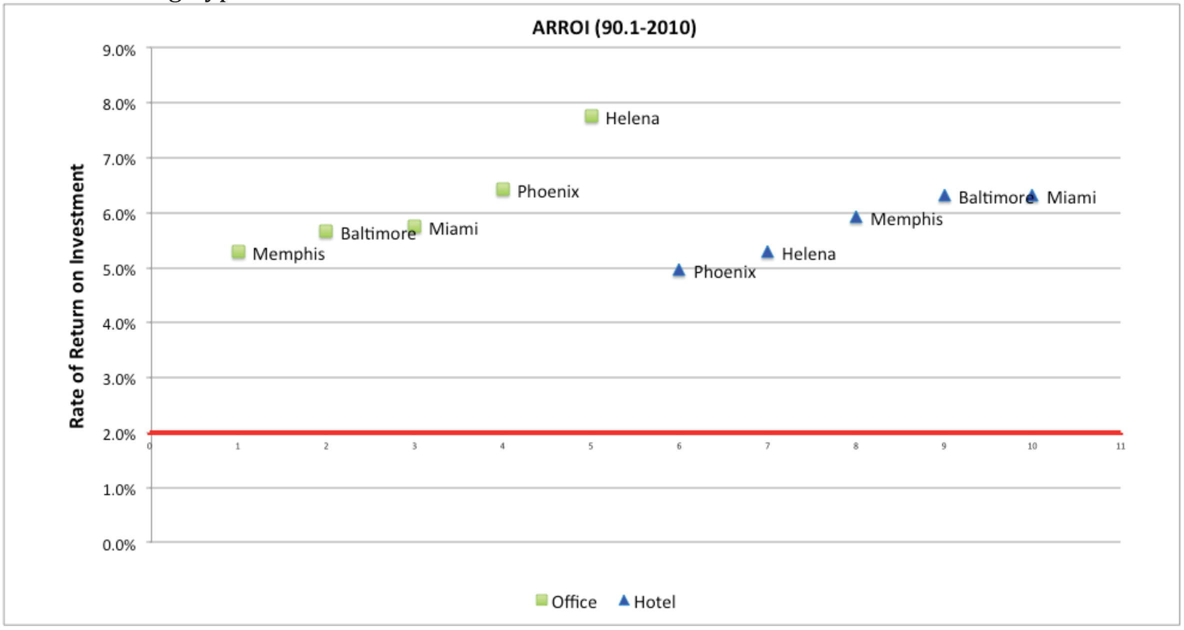
## Rate of Return on Investment

The (Adjusted) Rate of Return on Investment (ARROI) for the ASHRAE 90.1-2010 buildings in all locations and all building types is greater than the discount rate (2%), indicating that ASHRAE 90.1-2010 is economically efficient (Figure 9). The ARROI ranges from approximately 5% to 8% across the building types and locations, which is 2-4 times higher than the current investment returns (that is, the current returns on long-term US Treasury Notes, as denoted by the OMB real discount rate of 2%). Therefore, investments in buildings following the guidance of ASHRAE 90.1-2010 would be better than most investments currently available to the US federal government on the market.

ARROI is particularly appropriate for ranking independent projects to evaluate the relative return on specific levels of investment. The ranking of the office projects indicates that Helena has a higher return on investment (at almost 8%) than Baltimore (at 5.7%), which is driven by the relatively lower investment required in Helena than in Baltimore with approximately similar overall Net Savings. Therefore, the Helena Office would be a better investment than the Baltimore Office, but both investments perform better than the current default option (that is, US Treasury Notes at 2%).

In contrast, the Baltimore and Miami Hotels have higher ARROIs than the hotels in the other locations, and indeed better than the offices in Baltimore, Miami and Memphis. The savings achieved in these cases, relative to the investments required, provides a better overall return.

Figure 9: ASHRAE 90.1-2010 Long-term Cost-Benefit: Adjusted Rate of Return on Investment (ROI) for All Building Types, All Locations

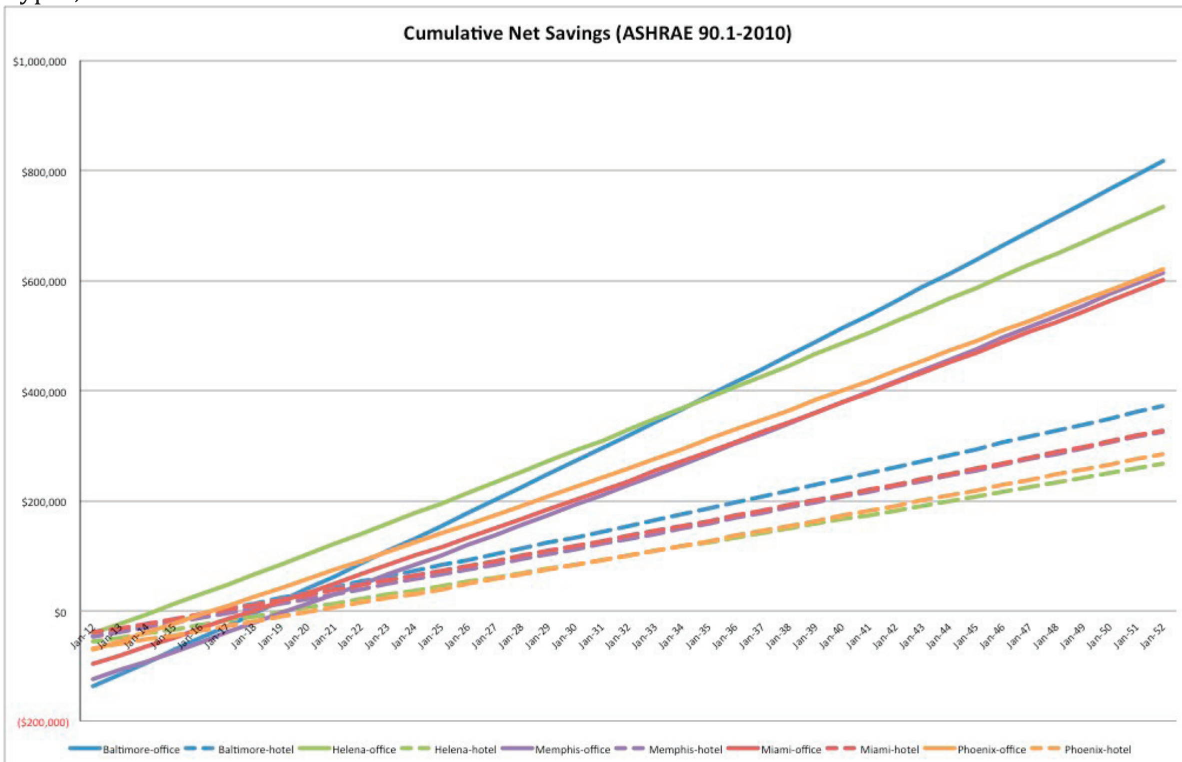



Note: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

## Payback

The Simple Payback for ASHRAE 90.1-2010 buildings range between 3 and just over 9 years, indicating that the liquidity of the investment is fairly high, since that time period is less than a quarter of the total Study Period of 40 years. The Cumulative Annual Net Savings for each building in each location indicates the time at which the accumulating savings equal the initial investment (that is, when the lines cross the x-axis) (Figure 10). It should be noted that the majority of the savings accumulate after the payback period, and the building with the shortest payback does not have the highest Net Savings.

Figure 10: ASHRAE 90.1-2010 Simple Payback through Cumulative Annual Savings: All Building Types, All Locations




## Summary Results for ASHRAE 90.1-2010

For the two building types (Medium Office and Small Hotel) and five locations considered in this analysis, buildings built under the guidance of ASHRAE 90.1-2010 would yield cost-efficient results under a range of conditions. For the Long-term Cost-Benefit analysis, the Net Savings for all buildings and all locations is greater than the threshold of NS=0 (Table 17). In addition, the Adjusted Rate of Return on Investment (ARROI) is greater than the threshold of 2% (current return on long-term US Treasury Notes, as reported by OMB for FY13). These investments recoup the incremental initial investment amount in less than a quarter of the total Study Period of 40 years (i.e., Simple Payback), indicating relatively high liquidity.

The sensitivity analysis of Net Savings addresses the robustness of these results under different conditions, specifically changes in the discount rate (from 1.5% to 3%) and changes in factor price escalation (specifically energy price escalation from 0.5% to 2%). In those conditions, considering the Long-term Cost-Benefit, all building types and all locations analyzed in this study would be economically efficient investments.

Table 17: ASHRAE 90.1-2010 Long-term Cost-Benefit Analysis: Summary of Net Savings, ROI and Payback for All Building Types, All Locations

| ASHRAE 90.1 | | | | | |
|---|---|---|---|---|---|
| Location | Building Type | Net Savings | ARROI | Simple Payback | Discounted Payback |
| Miami | Hotel | $202,848 | 6.32% | 5.7 | 6 |
| Baltimore | Hotel | $230,370 | 6.32% | 5.7 | 6 |
| Memphis | Hotel | $198,650 | 5.93% | 6.6 | 7 |
| Helena | Hotel | $163,839 | 5.30% | 8.4 | 10 |
| Phoenix | Hotel | $165,060 | 4.97% | 9.5 | 11 |
| Helena | Office | $469,281 | 7.76% | 3.3 | 4 |
| Phoenix | Office | $385,025 | 6.42% | 5.5 | 6 |
| Miami | Office | $363,064 | 5.75% | 7.1 | 8 |
| Baltimore | Office | $492,480 | 5.66% | 7.3 | 8 |
| Memphis | Office | $363,154 | 5.29% | 8.4 | 9 |

Long-term Cost Benefit when N=40, d=2%, eE=0.5%, eW=2%

## ASHRAE 189.1-2011—ECONOMIC EFFICIENCY RESULTS ACROSS BUILDING TYPES AND LOCATIONS

ASHRAE 189.1-2011 Standard for the Design of High Performance Green Buildings Except Low-Rise Residential Buildings was developed through a collaborative effort with ASHRAE, the US Green Building Council (USGBC), and the Illuminating Engineering Society of North America (IES). It explicitly references the current version of 90.1-2010 (*Energy Standards for Buildings Except Low-Rise Residential Buildings*) and is accepted as a compliance option of the International Green Construction Code. ASHRAE Standard 189.1-2011 is "written in code-intended (mandatory and enforceable) language so that it may be readily referenced or adopted by enforcement authorities to provide the minimum acceptable level of design criteria specifically for high performance green buildings within their jurisdiction."[17]

The ASHRAE stated purpose of Standard 189.1-2011 is:

> To provide minimum requirements for the siting, design, construction and plan for operation of high-performance green buildings to:
> (a) Balance environmental responsibility, resource efficiency, occupant comfort and well being, and community sensitivity, and
> (b) Support the goal of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
>
> 2. SCOPE:
> 2.1 This standard provides minimum criteria that:
> (a) Apply to the following elements of building projects:
> New buildings and their systems.
> New portions of buildings and their systems.
> New systems and equipment in existing buildings.
> (b) Address site sustainability, water use efficiency, energy efficiency, indoor environmental quality (IEQ), and the building's impact on the atmosphere, materials and resources."[18]

[17] ASHRAE/ANSI/USGBC/IES Standard 189.1-2011, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*, 2011, p. 2.

[18] American Society for Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE), Standards—titles and scopes (http://www.ashrae.org/standards-research-technology/standards-guidelines/titles-purposes-and-scopes#189-1).

The analysis of economic efficiency of ASHRAE 189.1-2011 for this study focused on the energy and water performance in the five specific locations for the building types, using actual local energy, water, and wastewater unit costs for each location. This analysis calculated the Net Savings, Adjusted Rate of Return on Investment, and Payback using the energy, water and wastewater cost savings relative to the incremental construction costs (i.e., incremental initial investment costs) compared to the baseline prototype buildings.

As noted in the Methodology section of this report, ASHRAE provided the benefit-cost data, specifically the investment costs and projected energy usage (building and site), water usage (building and site) and waste water disposal based on building models (not actual buildings), since the standard was only recently passed and has not been accepted by many jurisdictions or applied to actual projects. No data was provided for quantities related to solid waste or O&M costs, which were therefore excluded from this analysis.

## Long-Term Cost-Benefit

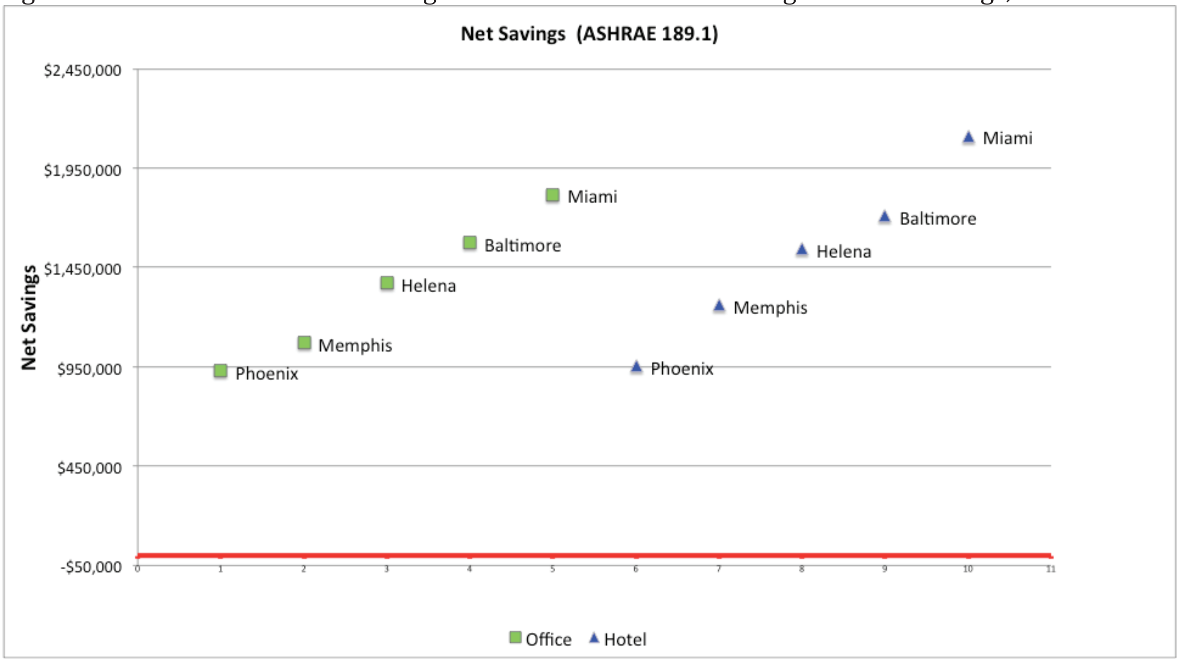
The Net Savings for both building types in all five locations are greater than zero, indicating that ASHRAE 189.1-2011 provides economically efficient results (Figure 11). There are differences in the Net Savings between the building types; for instance, the Net Savings for Hotels in each location is higher than the Net Savings for the Offices. There are also differences by location; for example, the Net Savings are the highest in Miami (for both building types), which has the highest water and wastewater disposal costs compared to all other locations. Baltimore, which has the second highest water and wastewater disposal costs, had the second highest Net Savings for both Office and Hotel.

The Net Savings results for the building types follow a similar sequence by location. For the hotels, the improvements in both energy and water performance for the building, particularly the laundry facilities (i.e., electricity, natural gas, water and wastewater disposal), provide significant savings, which is slightly higher than the savings for the office buildings, with the combination of energy performance improvements and water efficiency improvements (for both the building and the site).

The ASHRAE 189.1-2011 Net Savings are driven by both the reduction in quantities of resource usage (i.e., energy and water) and local factor unit prices, as seen in the Annual Net Savings by building type and location (Figure 12). As can be clearly seen, the water savings in many locations is more than half of the total Annual Net Savings. The differences in local prices and heating/cooling loads determine the relative savings in each location; for instance, Miami water unit costs are approximately 2 times higher than water unit costs in Phoenix, and Miami wastewater disposal costs are approximately 3 times higher than Phoenix wastewater disposal costs, which is reflected in the differential in expected savings in the two locations. The reduction in water usage was higher for Hotels than Offices because of the laundry facilities included in the Hotels. The Annual Net Savings, then, reflect the energy and water reductions as well as the total value of those reductions based on the local market price. The summation of those annual savings over the 40-year Study Period (discounted to present value) leads to higher Net Savings.

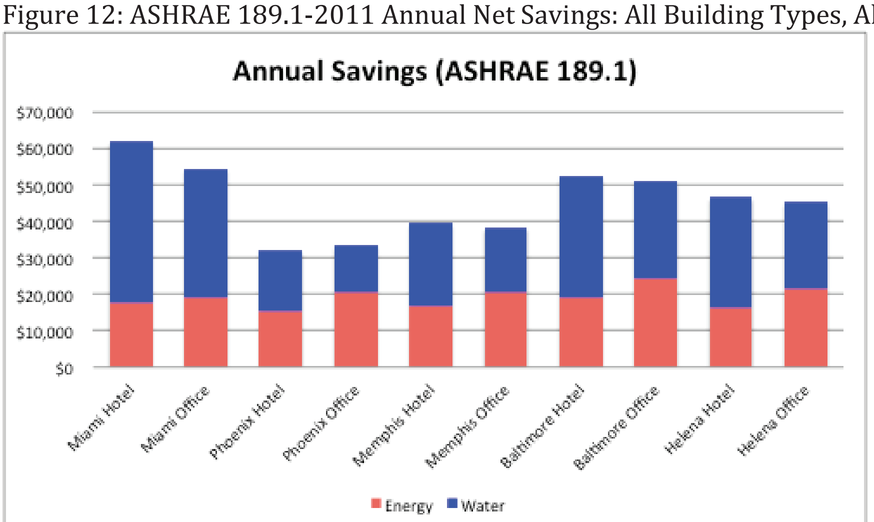
ASHRAE 189.1-2011 also includes a requirement for on-site energy generation. As noted in the Methodology section of this report, the initial investment costs for these energy generation units were included in the construction costs, and the on-site energy was used to offset the energy used by the building. The resulting overall energy usage for the building, therefore, is less than the energy usage under ASHRAE 90.1-2010, and the savings are greater compared to the baseline prototype building.

Figure 11: ASHRAE 189.1-2011 Long-term Cost-Benefit: Net Savings for All Buildings, All Locations




Note: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

Figure 12: ASHRAE 189.1-2011 Annual Net Savings: All Building Types, All Locations




The sensitivity analysis on Net Savings provides additional insight into the potential savings associated with buildings built under the guidance of ASHRAE 189.1-2011 in different climate conditions and local markets. The Long-term Cost-Benefit for the 40-year Study Period (Figure 11 and Table 18, middle column) represents the expected Net Savings with the current OMB discount rate of 2% and energy price escalation as per the EIA/FEMP energy price models, with water escalation at 2%. The maximum potential Net Savings (for the Economic Slow Growth scenario) range across locations from approximately $1.6 million to $3 million for the offices and hotels.

The sensitivity analysis represents the potential benefits that could be captured by buildings built under the guidance of ASHRAE 189.1-2011 under different conditions. That is, if energy prices escalate at 2% and water prices escalate at 4%, the Net Savings over the 40 years would increase by over 60%. These potential future Net Savings under this scenario could also be viewed as the potential future additional costs that will be incurred if a building does not follow ASHRAE 189.1-2011. For instance, if energy and water prices increase in future years, an office building may see its additional energy and water costs (which could have been avoided under ASHRAE 189.1-2011) almost double in some locations.

The minimum potential Net Savings (presented in the Economic High Growth scenario) is well above the threshold of Net Savings=0, ranging from approximately $600,000 to over $1 million for all building types in all locations. Therefore, even if energy prices stay constant (in real dollars, which is less than the EIA/FEMP energy price projections) and if water prices remain constant (in real prices, which is well below the current rate of 4% calculated from the Consumer Price Index and excluding inflation) and if the cost of money increases (represented by the discount rate, d, at 3%), these buildings built under the guidance of ASHRAE 189.1-2011 would still be economically efficient.

Both energy and water price escalation rates are included in the sensitivity analysis, and the potential future opportunities for Net Savings under different conditions can be graphically represented with the example of the Miami Office and Hotel (Figure 13). Within the Study Period range of 20 to 40 years, the Net Savings > 0 for both building types, indicating that ASHRAE 189.1-2011 is economically efficient for the scenarios under consideration. The potential Net Savings for the Miami Hotel is approximately $1 million greater than for the Miami Office in the Economic Slow Growth scenario, which is particularly affected by the higher water savings for the hotels (associated with the laundry facilities) coupled with the 4% water price escalation. In addition, the Net Savings increase significantly from 20 years to 40 years as the savings accumulate. The other locations show similar patterns for the sensitivity analysis for Net Savings for both building types.

Table 18: ASHRAE 189.1-2011 Sensitivity Analysis for Net Savings: 40-Year Study Period

**Office**

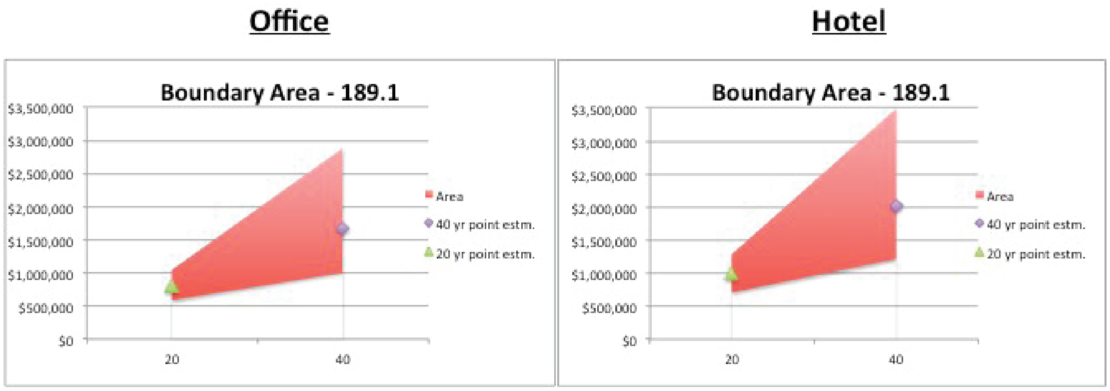
| | **Economic High Growth** | **Long-term Cost Benefit** | **Economic Slow Growth** |
|---|---|---|---|
| Baltimore | $1,011,139 | $1,575,111 | $2,678,681 |
| Helena | $868,552 | $1,372,045 | $2,355,767 |
| Memphis | $675,239 | $1,072,111 | $1,869,869 |
| Miami | $1,130,615 | $1,816,753 | $3,094,444 |
| Phoenix | $616,903 | $929,611 | $1,585,968 |

**Hotel**

| | **Economic High Growth** | **Long-term Cost Benefit** | **Economic Slow Growth** |
|---|---|---|---|
| Baltimore | $1,060,558 | $1,708,479 | $2,921,874 |
| Helena | $956,131 | $1,541,898 | $2,632,495 |
| Memphis | $801,719 | $1,261,566 | $2,143,359 |
| Miami | $1,286,096 | $2,111,338 | $3,615,835 |
| Phoenix | $606,956 | $955,630 | $1,640,788 |

Economic High Growth when d=3%, eE=0.5%, eW=0%
Long-term Cost Benefit when d=2%, eE=0.5%, eW=2%
Economic Slow Growth when d=1.5%, eE=2%, eW=4%

Figure 13: ASHRAE 189.1-2011 Sensitivity Analysis for Net Savings: Miami




Lower Bound=Economic High Growth (d=3%, eE=FEMP, eW=0%)
Upper Bound=Economic Slow Growth (d=1.5%, eE=2%, eW=4%)

**Rate of Return on Investment**

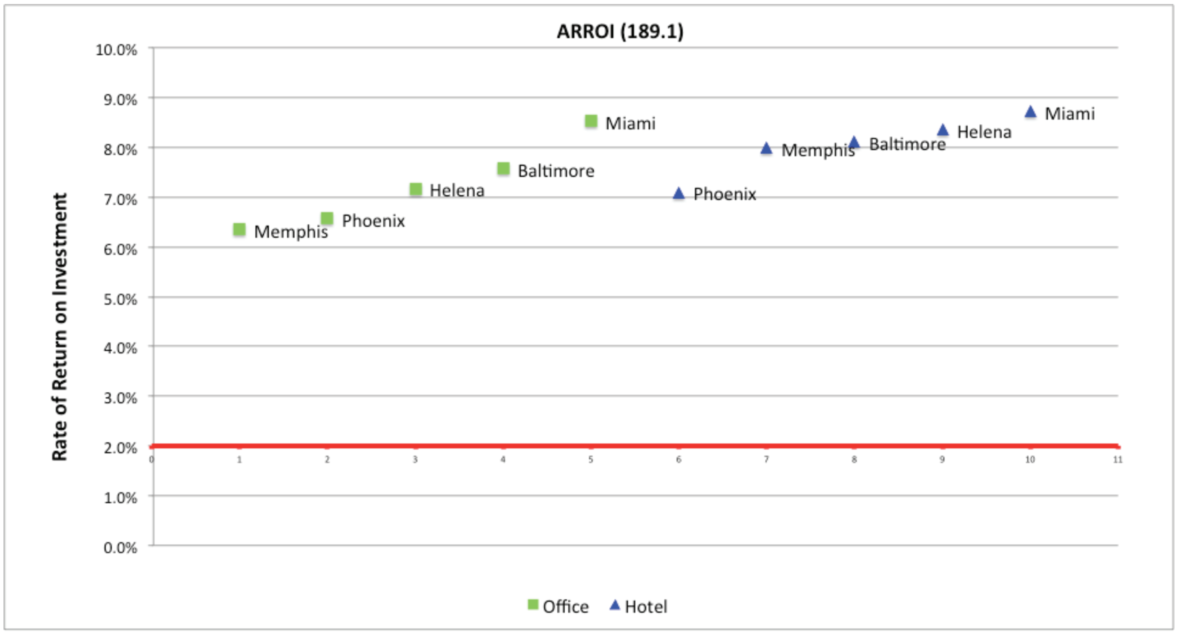
The (Adjusted) Rate of Return on Investment (ARROI) for the ASHRAE 189.1-2011 buildings in all locations and all building types is greater than the discount rate (2%), indicating that ASHRAE 90.1-2010 is economically efficient (Figure 14). The ARROI ranges from approximately 6% to 9% across the building types and locations, which is 3-4 times higher than the current investment returns (that is, the current returns on long-term US Treasury Notes, as denoted by the OMB real discount rate of 2%). Therefore, investments in buildings following the guidance of ASHRAE 189.1-2011 would be better than most investments currently available to the US federal government on the market.

ARROI is particularly appropriate for ranking independent projects to evaluate the relative return on specific levels of investment. The ranking of the office projects indicates that Miami Hotel and Miami Office have the highest returns on investments (over 8%), which are greater than the returns for the Phoenix Office and Hotel at approximately 7%, which are driven by the much lower water/wastewater costs in Phoenix. While the Baltimore Hotel had a higher Net Savings than Helena, the lower relative investment costs for the Helena Hotel gave it a higher ARROI. Therefore, the Helena Hotel would be a better investment than the Baltimore Hotel, but both investments perform better than the current default option (that is, US Treasury Notes at 2%).

**Payback**

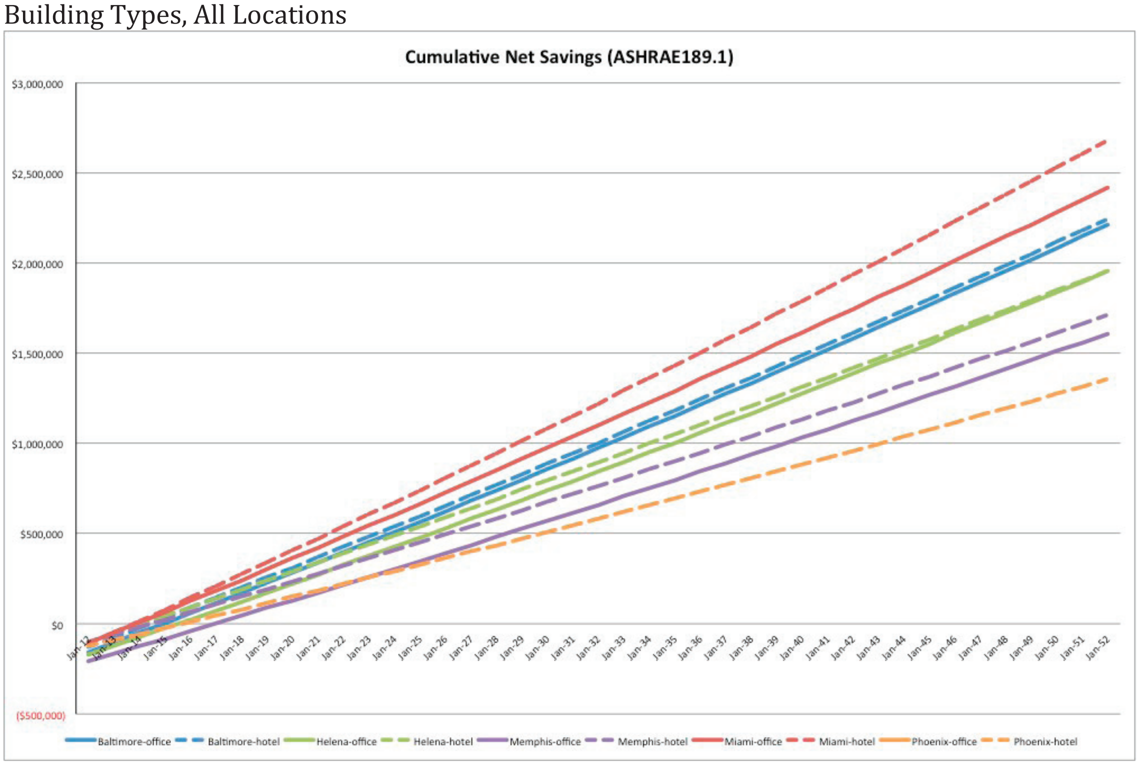
The Simple Payback for ASHRAE 189.1-2011 buildings range between 3 and 7.5 years, indicating that the liquidity of the investment is fairly high, since that time period is less than a quarter of the total Study Period of 40 years (Figure 15). The Cumulative Annual Net Savings for each building in each location indicates the time at which the accumulating savings equal the initial investment (that is, the lines cross the x-axis). In general, the payback is shorter for the hotels than the offices in each location, but the payback time periods differ significantly across locations, based on local factor prices and relative energy and water savings. For instance, the Miami Office and Miami Hotel have a Simple Payback time of just over 3 years and have the highest Net Savings, while the Helena Hotel has a Simple Payback time of 3.4 years but a lower overall Net Savings.

Figure 14: ASHRAE 189.1-2011 Long-term Cost-Benefit: Adjusted Rate of Return on Investment (ROI) for All Building Types, All Locations




Note: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

Figure 15: ASHRAE 189.1-2011 Simple Payback through Cumulative Annual Net Savings: All Building Types, All Locations



## Summary Results for ASHRAE 189.1-2011

For the two building types (Medium Office and Small Hotel) and five locations considered in this analysis, buildings built under the guidance of ASHRAE 189.1-2011 would yield cost-efficient results under a range of conditions. For the Long-term Cost-Benefit analysis, the Net Savings for all buildings and all locations is greater than the threshold of NS=0 (Table 19).

In addition, the Adjusted Rate of Return on Investment (ARROI) is greater than the threshold of 2% (current return on long-term US Treasury Notes, as reported by OMB for FY13). These investments recoup the initial investment amount in less than a quarter of the total Study Period of 40 years, indicating relatively high liquidity.

The sensitivity analysis of Net Savings addresses the robustness of these results under different conditions, specifically changes in the discount rate (from 1.5% to 3%) and changes in factor price escalation (specifically energy price escalation from 0.5% to 2%). In those conditions, considering the Long-term Cost-Benefit, all building types and all locations are economically efficient investments.

Table 19: ASHRAE 189.1-2011 Net Savings, ROI and Payback: All Building Types, All Locations (Long-term Cost-Benefit)

| ASHRAE 189.1 | | | | | |
|---|---|---|---|---|---|
| Location | Building Type | Net Savings | ARROI | Simple Payback | Discounted Payback |
| Miami | Hotel | $2,111,338 | 8.7% | 2.9 | 3 |
| Helena | Hotel | $1,541,898 | 8.4% | 3.2 | 4 |
| Baltimore | Hotel | $1,708,479 | 8.1% | 3.5 | 4 |
| Memphis | Hotel | $1,261,566 | 8.0% | 3.6 | 4 |
| Phoenix | Hotel | $955,630 | 7.1% | 5.0 | 6 |
| Miami | Office | $1,816,753 | 8.5% | 3.0 | 4 |
| Baltimore | Office | $1,575,111 | 7.6% | 4.2 | 5 |
| Helena | Office | $1,372,045 | 7.2% | 4.9 | 6 |
| Phoenix | Office | $929,611 | 6.6% | 5.8 | 7 |
| Memphis | Office | $1,072,111 | 6.3% | 6.5 | 7 |

Long-term Cost Benefit when N=40, d=2%, eE=0.5%, eW=2%

## LEED—ECONOMIC EFFICIENCY RESULTS ACROSS BUILDING TYPES AND LOCATIONS

The U.S. Green Building Council developed the Leadership in Energy and Environmental Design (LEED) in 2000. LEED is a voluntary rating system that uses credits that are weighted to reflect potential environmental impacts and responsiveness to regional issues. Each project must meet the prerequisites for certain levels of performance and obtain sufficient credit points to be certified at the different levels (i.e., Certified, Silver, Gold, and Platinum).

> LEED certification provides independent, third-party verification that a building or community was designed and built using strategies aimed at achieving high performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality. . . . LEED-certified buildings are designed to:
>
> - Lower operating costs and increase asset value
> - Reduce waste sent to landfills
> - Conserve energy and water
> - Be healthier and safer for occupants

- Reduce harmful greenhouse gas emissions
- Qualify for tax rebates, zoning allowances and other incentives in hundreds of cities

Moreover, an organization's participation in the voluntary and technically rigorous LEED process demonstrates leadership, innovation, environmental stewardship and social responsibility.[19]

The analysis of the economic efficiency of LEED Silver, Gold and Platinum certification levels (as specified in the NDAA 2012) used the five selected locations and two building types (medium office and small hotel) to establish the baseline against which to compare the actual building data received from USGBC.

As noted in the Methodology section of this report, USGBC provided the expected energy savings, building water savings, site (landscape) water savings, and on-site renewable energy generation reported by 25 projects in the LEED submission materials for certification. No data is currently collected in the LEED certification process related to expected reductions in solid waste (municipal or hazardous) or operations and maintenance (general labor and equipment, cleaning, and landscaping), and therefore no data was provided, so these measures were then excluded from the analysis.

This analysis calculated the Net Savings and other economic efficiency measures using the energy and water costs relative to the incremental construction costs (incremental initial investment costs) compared to the baseline prototype buildings. The investment cost data (i.e., construction costs) were obtained by USGBC from communications with the project team and/or from public data sources. Unfortunately, insufficient data was provided to identify any particular technical cost drivers for the projects (such as unusual site conditions, structural requirements, or special equipment) or other factors that influence construction costs (such as local market conditions) independent of expected performance levels.

As a result, there is a high degree of variation among the reported construction costs for the LEED buildings (Table 20). [Note: Construction cost per square foot for the baseline prototype buildings, as estimated from RS Means, ranged from $111 to 120/sf for the hotels and $110 to 117/sf for the offices.] Therefore, the initial investment costs for some of the LEED projects was over 2 times the investment costs for the baseline prototype buildings.

Notably, in three cases (2 hotels, 1 office), the LEED construction cost was less than the specific baseline prototype building's construction cost in that location. In these cases, the analysis of economic efficiency is clear, since these high performance buildings are obtained at no incremental initial cost—that is, all of the benefits are captured without requiring additional investments.

It is not possible in this study, given the relatively small size of the sample and the short time frame, to draw conclusions on relative trends in construction cost for LEED buildings, but previous studies have likewise found high variation in construction costs independent of expected building performance.[20]

Therefore, this study will use the construction costs provided for these LEED projects, with the caveat that this data has not been independently verified and may include costs related to specific technical or special function requirements that are not related to this study.

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[19] USGBC, "What LEED Delivers" (http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1990).

[20] David Langdon (2004). *Costing Green: A Comprehensive Cost Database and Budgeting Methodology,* pp. 18-23, which found a "large variation in costs of buildings, even within the same building program category."

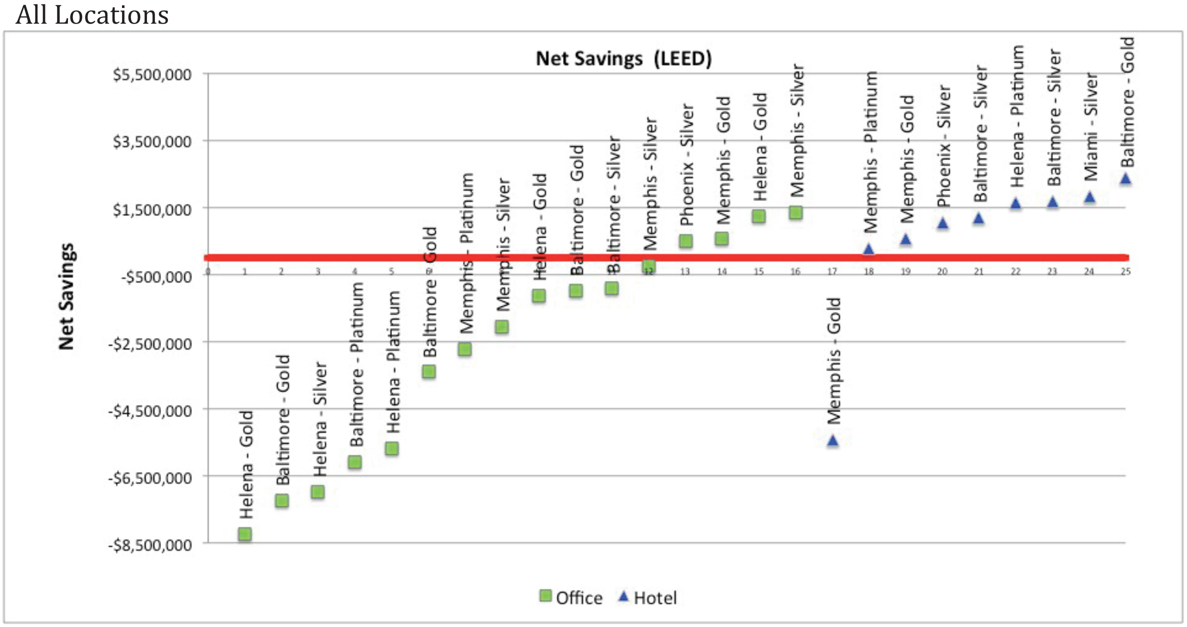
Table 20: LEED Silver, Gold, Platinum Buildings: Construction Cost Variation

| Building Type | Minimum Cost per square foot | Maximum Cost per square foot | Standard Deviation of Cost per square foot | Average Cost per square foot | Sample Size |
|---|---|---|---|---|---|
| Hotel | $96.01 | $259.68 | $48.36 | $134.65 | 9 |
| Office | $97.47 | $279.64 | $62.47 | $179.54 | 16 |
| Total Sample | $96.01 | $279.64 | $60.85 | $163.38 | 25 |

## Long-Term Cost-Benefit

The Net Savings for the 89% of hotel buildings and 25% of the office buildings (48% of the total sample) across the five locations are greater than zero, indicating that LEED provides economically efficient results (Figure 16). There are differences in the Net Savings between the building types; for instance, the Net Savings for the Hotels in this sample generally tend to be higher than the Net Savings for the Offices in this sample. There are also differences by location; the office buildings in climate zones 4-7 (represented by Baltimore, MD and Helena, MT) were more likely to have extremely high construction costs that overshadowed the benefits from energy and water savings for those buildings.

Figure 16: LEED Long-term Cost-Benefit: Net Savings for All Buildings, All Certification Levels, and All Locations



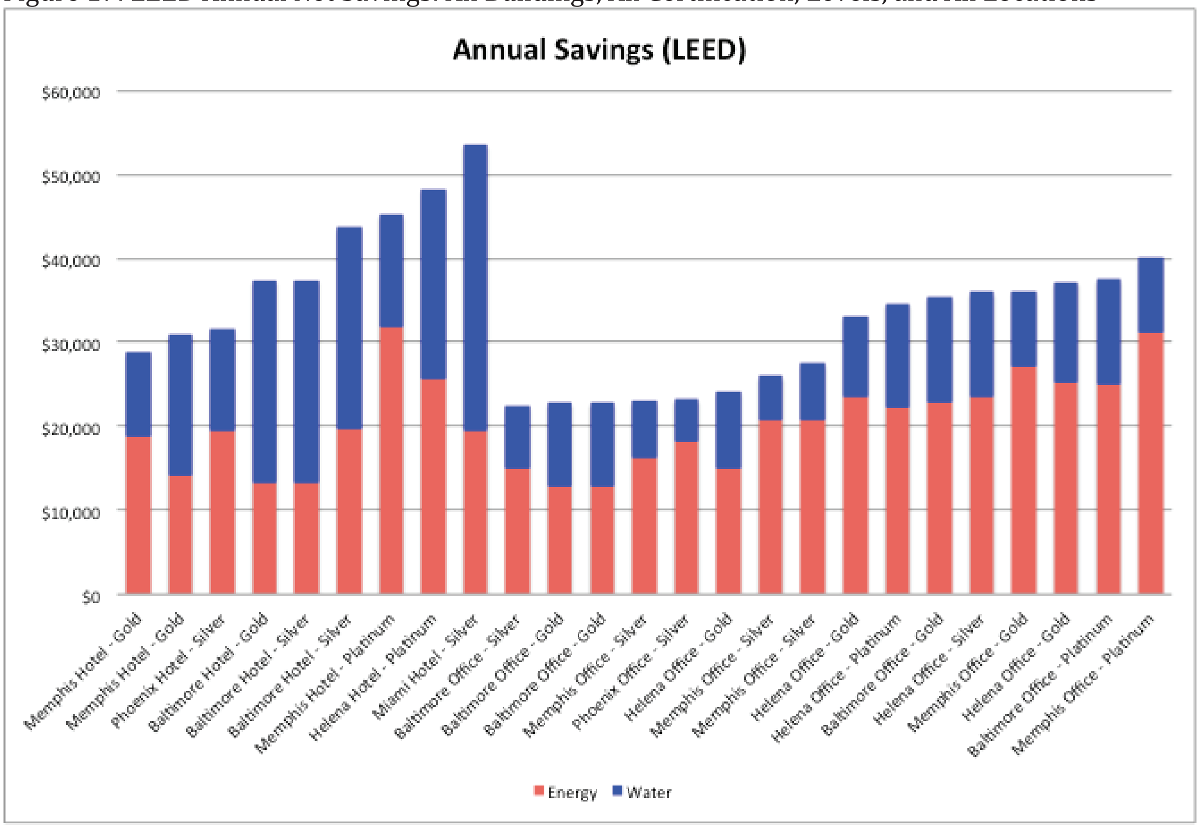

Note: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%

The LEED Net Savings are driven by the high initial investment costs (discussed above). The Net Savings are calculated using the reduction in the quantities of resources (i.e., energy and water) together with the local factor prices, as can be seen in the Annual Net Savings (Figure 17). In this sample, the water savings for the hotels is often more than half of the Annual Net Savings.

The differences in local prices determine the relative savings in each location; for instance, Miami has highest water and wastewater disposal costs, and Baltimore has the highest energy costs, and these relative factor unit prices increase the value of those reductions for those locations. The reduction in water usage was higher for the Hotels than for Offices, possibly influenced by changes in related facilities (such as laundry facilities).

Six LEED buildings included on-site renewable energy generation, ranging from 3-12% renewable energy (measured as an offset of energy costs in LEED certification materials). As noted in the Methodology section of this report, it is assumed that the initial investment costs for these energy generation units were included in the construction costs, and the on-site energy was used to offset the energy used by the building. The resulting lower overall energy usage for those building, therefore, provided greater energy savings compared to the baseline prototype buildings.

Figure 17: LEED Annual Net Savings: All Buildings, All Certification, Levels, and All Locations




It must be noted that, with this range of Annual Net Savings (between approximately $20,000 to $50,000 a year), it would be expected that the LEED projects would be economically efficient. From this limited sample of 25 LEED projects, it appears that buildings with incremental initial investment costs less than 20% of the baseline prototype buildings have Net Savings greater than the threshold (NS>0). If the incremental initial investments cost is equal to or greater than 20% of the baseline prototype building's investment cost, it is difficult—but not impossible—for the Net Savings to be positive (Table 21). For example, the Memphis Hotel-Platinum's incremental initial investment cost is 25% greater than the baseline investment, but the expected Annual Net Savings provide sufficient value over the 40-year Study Period for positive Net Savings. In all other cases where the costs are greater than 20%, however, the additional initial investment costs lead to negative Net Savings—and therefore an inefficient economic investment.

Table 21: LEED Incremental Investment Cost to Net Savings Comparison

| Location | Building Type | Certification | %increase $/sf from Baseline | Net Savings |
|---|---|---|---|---|
| Baltimore | Hotel | Gold | 80% | $2,389,476 |
| Memphis | Office | Silver | 91% | $1,360,692 |
| Baltimore | Hotel | Silver | 94% | $1,677,037 |
| Helena | Office | Gold | 100% | $1,229,819 |
| Helena | Hotel | Platinum | 100% | $1,653,282 |
| Phoenix | Hotel | Silver | 101% | $1,037,229 |
| Miami | Hotel | Silver | 104% | $1,814,791 |
| Phoenix | Office | Silver | 104% | $496,401 |
| Baltimore | Hotel | Silver | 107% | $1,196,059 |
| Memphis | Office | Gold | 111% | $552,849 |
| Memphis | Hotel | Gold | 111% | $575,051 |
| Memphis | Office | Silver | 120% | ($247,195) |
| Memphis | Hotel | Platinum | 125% | $279,066 |
| Baltimore | Office | Silver | 126% | ($899,960) |
| Baltimore | Office | Gold | 134% | ($975,804) |
| Helena | Office | Gold | 138% | ($1,144,800) |
| Memphis | Office | Silver | 149% | ($2,059,962) |
| Baltimore | Office | Gold | 168% | ($3,405,806) |
| Memphis | Office | Platinum | 170% | ($2,733,037) |
| Helena | Office | Platinum | 215% | ($5,678,077) |
| Baltimore | Office | Platinum | 217% | ($6,077,130) |
| Baltimore | Office | Gold | 229% | ($7,248,508) |
| Memphis | Hotel | Gold | 232% | ($5,426,645) |
| Helena | Office | Silver | 237% | ($6,968,371) |
| Helena | Office | Gold | 252% | ($8,229,571) |

Note: Net Savings for Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

The sensitivity analysis on Net Savings provides additional insight into the potential savings associated with LEED buildings in different climate conditions and market conditions. The Long-term Cost-Benefit for the 40-year Study Period (Figure 16 and Table 22, middle column) represents the expected Net Savings with the current OMB discount rate of 2% and the energy price escalation as per the EIA/FEMP energy price models, with water/wastewater price escalation at 2%.

The maximum potential Net Savings (for the Economic Slow Growth scenario) yields positive Net Savings for 52% of the LEED buildings, indicating that even if some of these buildings are not currently economically efficient, they may yield positive Net Savings if energy and/or water prices increase significantly (Table 22).

The sensitivity analysis represents the potential benefits that could be captured by LEED-certified buildings under different conditions. That is, if energy and water prices escalate at 2% and 4% respectively, the Net Savings over the 40 years for some buildings could increase by over 50%. These potential future Net Savings under this scenario could also be viewed as the potential future additional costs that will be incurred if a building does not implement energy and/or water savings options.

The sensitivity analysis provides additional insight into the potential future benefits under different conditions. For the Phoenix Office and Hotel (Figure 18), the Net Savings >0 within the Study Period range of 20 to 40 years for both building types, indicating that they are economically efficient investments for the scenarios under consideration. The potential Net Savings for the Hotel is more than twice the Net Savings for the Office, and these savings increase rapidly over the time period as the savings accumulate.

Table 22: LEED Silver, Gold and Platinum Sensitivity Analysis for Net Savings: 40-Year Study Period

**Office**

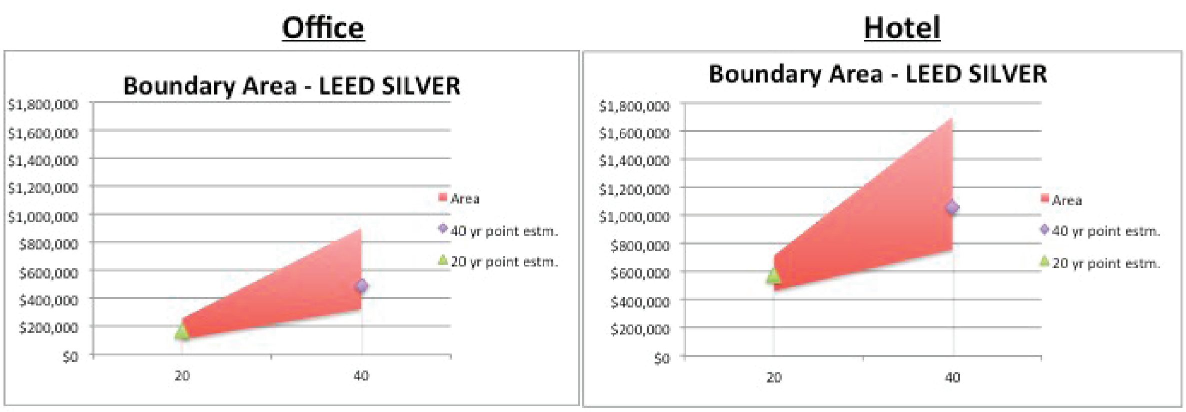
| | Certification | Economic High Growth | Long-term Cost Benefit | Economic Slow Growth |
|---|---|---|---|---|
| Helena | Gold | $906,930 | $1,229,819 | $1,932,998 |
| Memphis | Silver | $1,172,613 | $1,360,692 | $1,807,745 |
| Memphis | Gold | $271,553 | $552,849 | $1,197,664 |
| Phoenix | Silver | $324,822 | $496,401 | $900,244 |
| Memphis | Silver | -$461,343 | -$247,195 | $243,827 |
| Baltimore | Gold | -$1,297,010 | -$975,804 | -$290,360 |
| Baltimore | Silver | -$1,096,446 | -$899,960 | -$474,253 |
| Helena | Gold | -$1,420,797 | -$1,144,800 | -$532,064 |
| Memphis | Silver | -$2,252,494 | -$2,059,962 | -$1,633,805 |
| Memphis | Platinum | -$3,033,246 | -$2,733,037 | -$2,031,640 |
| Baltimore | Gold | -$3,678,948 | -$3,405,806 | -$2,864,316 |
| Helena | Platinum | -$5,995,463 | -$5,678,077 | -$5,003,881 |
| Baltimore | Platinum | -$6,408,657 | -$6,077,130 | -$5,360,807 |
| Helena | Silver | -$7,292,151 | -$6,968,371 | -$6,275,045 |
| Baltimore | Gold | -$7,488,512 | -$7,248,508 | -$6,749,437 |
| Helena | Gold | -$8,455,474 | -$8,229,571 | -$7,754,162 |

**Hotel**

| | Certification | Economic High Growth | Long-term Cost Benefit | Economic Slow Growth |
|---|---|---|---|---|
| Baltimore | Gold | $1,918,456 | $2,389,476 | $3,267,553 |
| Miami | Silver | $1,145,054 | $1,814,791 | $3,066,637 |
| Helena | Platinum | $1,148,340 | $1,653,282 | $2,665,954 |
| Baltimore | Silver | $1,205,997 | $1,677,037 | $2,555,172 |
| Baltimore | Silver | $694,750 | $1,196,059 | $2,164,747 |
| Phoenix | Silver | $737,235 | $1,037,229 | $1,664,572 |
| Memphis | Gold | $222,152 | $575,051 | $1,258,564 |
| Memphis | Platinum | -$100,635 | $279,066 | $1,118,906 |
| Memphis | Gold | -$5,687,539 | -$5,426,645 | -$4,869,220 |

Economic High Growth when d=3%, eE=0.5%, eW=0%
Long-term Cost Benefit when d=2%, eE=0.5%, eW=2%
Economic Slow Growth when d=1.5%, eE=2%, eW=4%

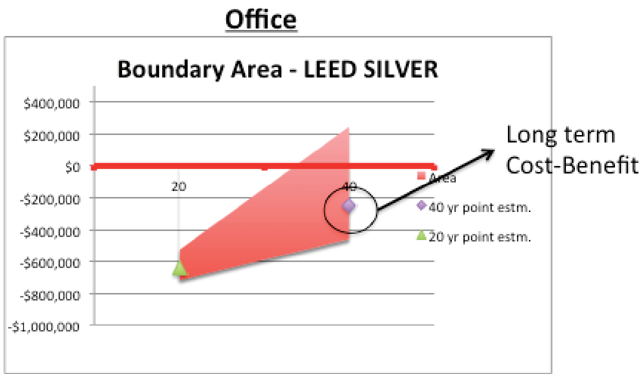
Figure 18: LEED Sensitivity Analysis for Net Savings: Phoenix




Lower Bound=Economic High Growth (d=3%, eE=FEMP, eW=0%)
Upper Bound=Economic Slow Growth (d=1.5%, eE=2%, eW=4%)

The potential future opportunities for Net Savings under different conditions can be graphically represented with the example of the Memphis Office–Silver (Figure 19). In this example, it can be noted that even though the Net Savings are less than 0 for the Long-term Cost-Benefit, a portion of the boundary area that represents the feasible range of Net Savings is above the threshold, indicating that the investment could provide economically efficient results in the future under certain conditions—specifically, with energy and water price escalation at 2% and 4% respectively, and decreasing cost of money (represented by the discount rate, d, at 1.5%).

Figure 19: LEED Sensitivity Analysis for Net Savings: Memphis Office–Silver




Lower Bound=Economic High Growth (d=3%, eE=FEMP, eW=0%)
Upper Bound=Economic Slow Growth (d=1.5%, eE=2%, eW=4%)
Long-term Cost-Benefit (N=40, d=2%, eE=FEMP, eW=2%)

## Rate of Return on Investment

The (Adjusted) Rate of Return on Investment (ARROI) is particularly appropriate for ranking independent projects that have Net Savings greater than 0 to evaluate the relative return on specific levels of investment. (ARROI cannot be calculated for projects with Net Savings<0.) For the three (3) LEED buildings that have initial investment costs less than the baseline prototype buildings' initial investment costs (i.e., the Baltimore Hotel-Gold, Baltimore Hotel-Silver, and Memphis Office-Silver), the ARROI is essentially infinite—that is, there is no incremental investment cost, and investments in these projects would be the strongest investment options.

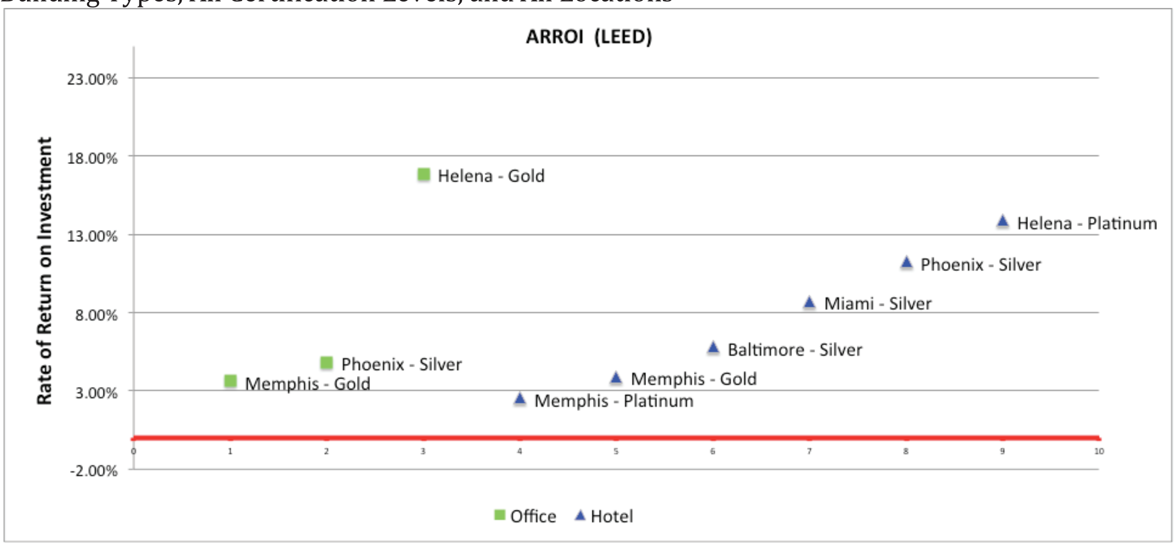
For the other nine (9) LEED projects with positive Net Savings, the ARROI is greater than the discount rate (2%), indicating economically efficient investments (Figure 20). The ARROI ranges from approximately 3% to 17%, which is 1.5 to 8 times higher than the current investment returns (that is, the current returns on long-term US Treasury Notes, as denoted by the OMB real discount rate of 2%). Therefore, investments in these buildings would be better than most investments currently available to the US federal government on the market.

The Helena Office–Gold has the highest return on investment, and also had the highest Net Savings. The Phoenix Office–Silver had a slightly lower Net Savings than the Memphis Office–Gold, but required a lower incremental initial investment, and is therefore a better investment given the return on investment. For the Hotels, the Helena Hotel–Platinum has the highest return on investment, even though it had a slightly lower Net Savings than Miami Hotel–Silver, which is driven by the relatively lower investment required for the benefits obtained. (As noted above, the Baltimore Hotel–Gold, Baltimore Hotel–Silver, and Memphis Office–Silver with high Net Savings had no incremental initial investment cost and therefore do not appear on this chart.) Therefore, the Helena Hotel–Platinum would be a better investment than the Miami Hotel–Silver, but both investments would perform significantly better than the current default option (i.e., Treasury Notes at 2%).

## Payback

Simple Payback provides a measure of relative liquidity of an investment, and for the 3 LEED projects with initial investment costs less than the baseline prototype buildings' initial investment costs, the liquidity is immediate—that is, the Cumulative Annual Net Savings are greater than 0 as soon as these buildings are occupied. (Note: For projects with Net Savings <0, the Payback Period is greater than the Study Period, and is not presented here.) The Cumulative Annual Net Savings for each of these buildings indicates the time at which the accumulating savings equal the incremental initial investment (that is, when the line crosses the x-axis) (Figure 21). For the remaining nine (9) LEED projects with Net Savings >0, the Simple Payback time periods range between less than a year to just over 25 years, indicating that while the liquidity for some investments are fairly high (being significantly less than the Study Period of 40 years), other investments provide significant overall Net Savings but the liquidity is not high.

Figure 20: LEED Long-term Cost-Benefit: Adjusted Rate of Return on Investment (ROI) for All Building Types, All Certification Levels, and All Locations

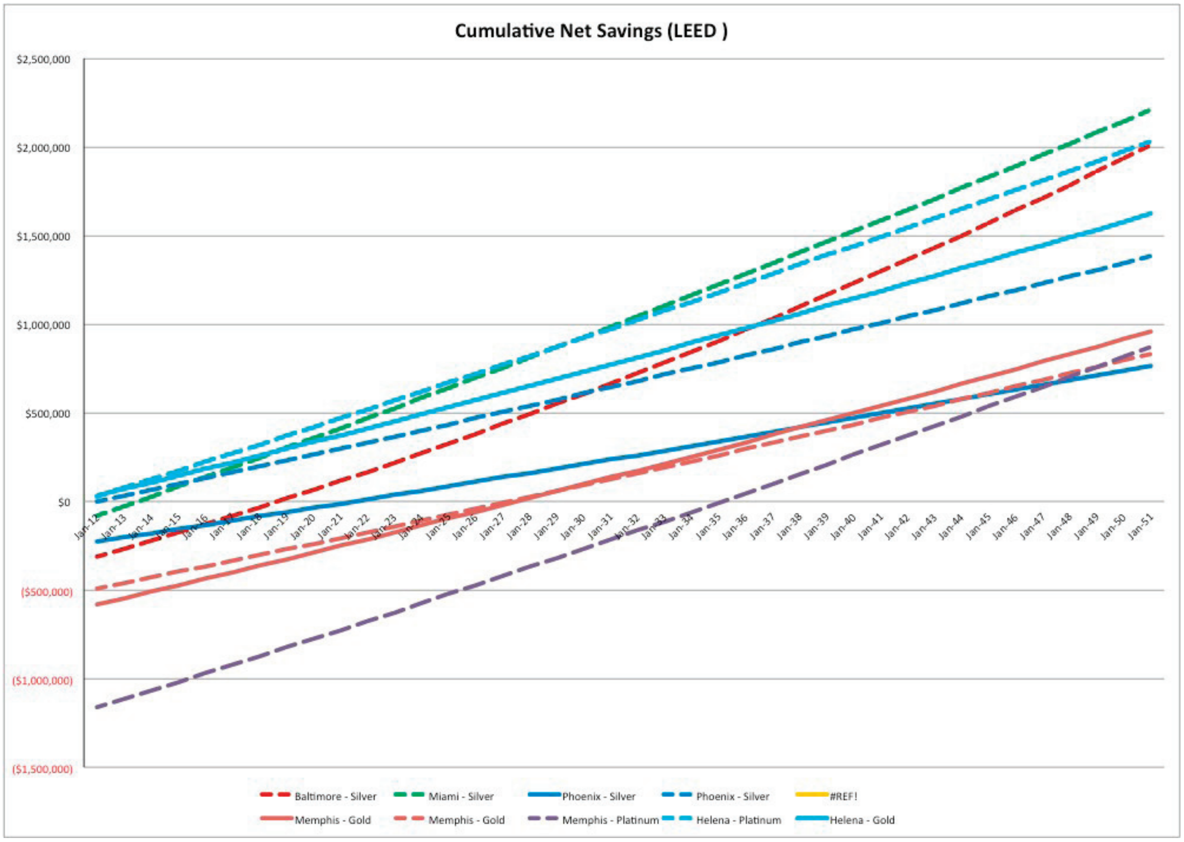



Note: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

## Summary Results for LEED

For this sample of 25 buildings that have been certified by the USGBC at the level of Silver, Gold and Platinum, which represent the two building types (Office and Hotel), the majority of these buildings (52%) provide economically efficient investment opportunities under certain conditions, examined within the context of the five selected locations for this study. Three projects have initial investment costs that are less than the baseline prototype buildings, and therefore provide benefits without additional costs (Table 23).

Figure 21: LEED Simple Payback through Cumulative Net Savings: All Building Types for All Locations




Nine additional buildings provide positive Net Savings in the Long-Term Cost-Benefit scenario, and an additional project (Memphis Office–Silver) provides positive Net Savings under the Economic Slow Growth scenario (Study Period of 40 years, with energy escalation at 2%, water escalation at 4%, and the discount rate at 1.5%). For these buildings, the Adjusted Rate of Return on Investment (ARROI) is greater than the threshold of 2% (current return on long-term US Treasury Notes, as reported by OMB for FY13). Six of these projects recoup the incremental initial investment amount in less than one quarter of the total Study Period of 40 years (i.e., Simple Payback), indicating relatively high liquidity.

The sensitivity analysis of Net Savings addresses the robustness of these results under different conditions, specifically changes in the discount rate (from 1.5% to 3%) and changes in factor price escalation (specifically, energy price escalation from FEMP estimates (~0.5%) to 2%, and water price escalation from 0% to 4%). In those conditions, considering the long-term benefit at 40 years, 52% of the buildings would be economically efficient investments.

Table 23: LEED Long-term Cost-Benefit Analysis: Summary of Net Savings, ROI, and Payback for All Building Types, All Certification Levels, and All Locations

| **LEED Projects** | | | | | | |
|---|---|---|---|---|---|---|
| **Location** | **Building Type** | **Certification** | **Net Savings** | **ARROI** | **Simple Payback** | **Discounted Payback** |
| Baltimore | Hotel | Gold | $2,389,476 | NA | NA | NA |
| Baltimore | Hotel | Silver | $1,677,037 | NA | NA | NA |
| Helena | Hotel | Platinum | $1,653,282 | 13.9% | 0.4 | 1 |
| Phoenix | Hotel | Silver | $1,037,229 | 11.2% | 1.1 | 2 |
| Miami | Hotel | Silver | $1,814,791 | 8.7% | 2.9 | 3 |
| Baltimore | Hotel | Silver | $1,196,059 | 5.8% | 8.2 | 9 |
| Memphis | Hotel | Gold | $575,051 | 3.9% | 16.9 | 18 |
| Memphis | Hotel | Platinum | $279,066 | 2.5% | 26.8 | 28 |
| Memphis | Hotel | Gold | ($5,426,645) | ROI<0 | PB>40 | PB>40 |
| Memphis | Office | Silver | $1,360,692 | NA | NA | NA |
| Helena | Office | Gold | $1,229,819 | 16.9% | 0.1 | 1 |
| Memphis | Office | Gold | $552,849 | 3.6% | 17.1 | 19 |
| Phoenix | Office | Silver | $496,401 | 4.8% | 10.7 | 12 |
| Memphis | Office | Silver | ($247,195) | 1.4% | PB>40 | PB>40 |
| Baltimore | Office | Silver | ($899,960) | 0.0% | PB>40 | PB>40 |
| Baltimore | Office | Gold | ($975,804) | 0.5% | PB>40 | PB>40 |
| Helena | Office | Gold | ($1,144,800) | 0.2% | PB>40 | PB>40 |
| Memphis | Office | Silver | ($2,059,962) | ROI<0 | PB>40 | PB>40 |
| Memphis | Office | Platinum | ($2,733,037) | ROI<0 | PB>40 | PB>40 |
| Baltimore | Office | Gold | ($3,405,806) | ROI<0 | PB>40 | PB>40 |
| Helena | Office | Platinum | ($5,678,077) | ROI<0 | PB>40 | PB>40 |
| Baltimore | Office | Platinum | ($6,077,130) | ROI<0 | PB>40 | PB>40 |
| Helena | Office | Silver | ($6,968,371) | ROI<0 | PB>40 | PB>40 |
| Baltimore | Office | Gold | ($7,248,508) | ROI<0 | PB>40 | PB>40 |
| Helena | Office | Gold | ($8,229,571) | ROI<0 | PB>40 | PB>40 |

Long-term Cost Benefit when N=40, d=2%, eE=0.5%, eW=2%
NA = Not applicable, since no incremental initial investment cost

## GREEN GLOBES—ECONOMIC EFFICIENCY RESULTS ACROSS BUILDING TYPES AND LOCATIONS

The Green Building Initiative (GBI) launched the Green Globes certification program in 2004 under a licensing agreement with the Canadian Green Globes® program. That program was based on the BREEAM Canada program for existing buildings that was developed by the Canada Standards Association, which in turn was based on the BREEAM program developed in the UK in 1990 by the Building Research Establishment (BRE). For the U.S. program, GBI modified the Canadian Green Globes, including adding a third-party assessment process.

The Green Globes certification is a voluntary rating system that uses credits that are weighted to reflect potential environmental impacts.

> The Green Globes software tools and ratings/certification system use a recognized and proven assessment protocol to comprehensively assess environmental impacts on a 1,000 point scale in multiple categories [including energy, water, resources, emissions, indoor environment, project management, and site]… Those buildings that achieve 35% or more of the 1,000 points possible in the Green Globes rating system are eligible candidates for a certification of one, two, three, or four Green Globes.
>
> The Green Globes system provides higher levels of achievement based on the number of points a building acquires…. After achieving a minimum threshold of 35% of the 1,000 total points in the preliminary self-evaluation, new and existing buildings are eligible to seek a Green Globes certification and rating for their environmental sustainability and achievements. The process utilizes third-party assessors with expertise in green building design, engineering, construction and facility operations. These professionals interface with project teams and building owners to review documentation and conduct onsite building tours. Green Globes rating and certification is attainable for a wide range of commercial and government buildings, and enables building owners to credibly market their environmental responsibility to shareholders, tenants, and their community."[21]

The analysis of the economic efficiency of the Green Globes certification levels (One, Two, Three and Four Globes) used the five selected locations and two building types (medium office and small hotel) to establish the baseline prototype buildings against which to compare the actual building data received from GBI.

As noted in the Methodology section of this report, GBI provided the expected energy and water savings for 11 projects based on communications with project teams, since these expected savings are not required as part of the Green Globes reporting requirements. No data is currently collected in the Green Globes certification process related to expected reductions in solid waste (municipal or hazardous) or operations and maintenance costs (general labor and equipment, cleaning, or landscaping), and therefore no data was provided by GBI for this study, so those benefit-cost categories were excluded from this analysis.

This analysis calculated the Net Savings and other economic efficiency measures using the energy and water costs relative to the incremental construction costs (initial investment costs) compared to the baseline prototype buildings. The investment cost data (i.e., construction costs) were obtained from public data sources.

Unfortunately, insufficient data was provided to identify any particular technical cost drivers for the projects (such as unusual site conditions, structural requirements, or special equipment) or other factors that influence construction costs (such as local market conditions) independent of expected performance levels.

As a result, there is a high degree of variation among the reported construction costs for this sample of 11 actual buildings that received Green Globes certification (Table 24). [Note: Construction cost per square foot for the baseline prototype buildings, as estimated from RS Means, ranged from $111 to 120/sf for the hotels and $110 to 117/sf for the offices.] Therefore, the initial investment costs for some of the Green Globes projects was over 2 times the investment costs for the baseline prototype buildings.

It is not possible in this study, given the relatively small size of the sample and the short time frame, to draw conclusions on relative trends in construction cost for Green Globes buildings.

Therefore, this study will use the construction costs provided for these Green Globes projects, with the caveat that this data has not been independently verified and may include costs related to specific technical or special function requirements that are not related to this study.

[21] The Green Building Initiative, Green Globes Overview (http://www.thegbi.org/green-globes/).

Table 24: Green Globes One, Two, Three and Four Globes: Construction Cost Variation

| Building Type | Minimum Cost per square foot | Maximum Cost per square foot | Standard Deviation of Cost per square foot | Average Cost per square foot | Sample Size |
|---|---|---|---|---|---|
| Hotel | $127.00 | $244.00 | $163.80 | $49.43 | 5 |
| Office | $109.00 | $235.00 | $149.17 | $47.85 | 6 |
| Total Sample | $109.00 | $244.00 | $155.82 | $46.70 | 11 |

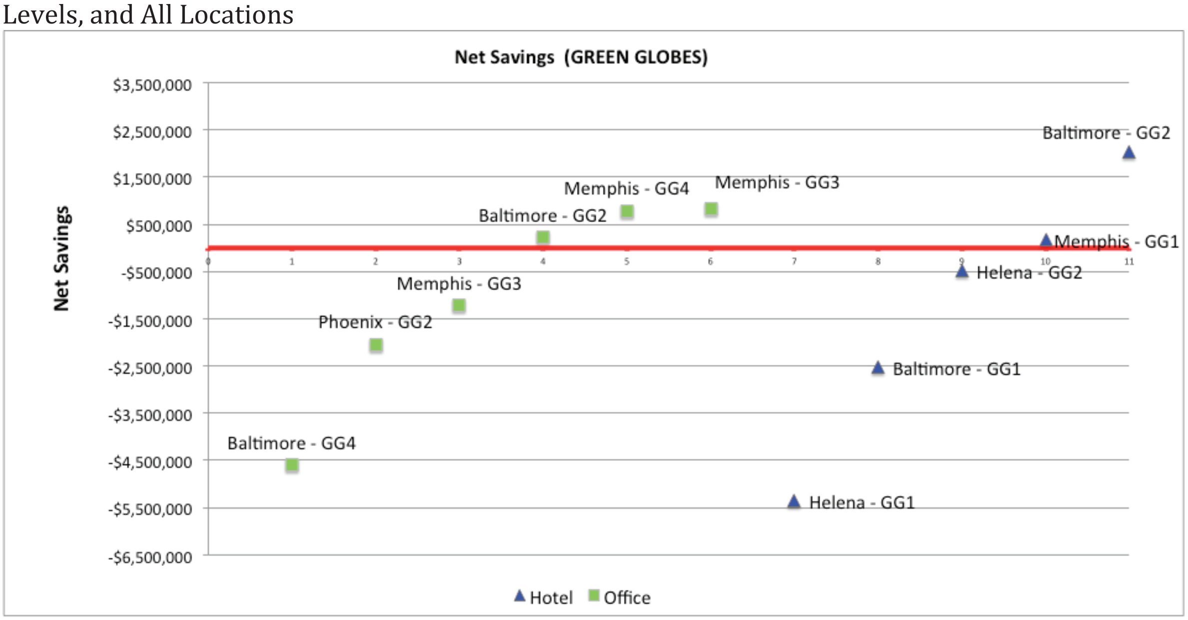
## Long-Term Cost-Benefit

The Net Savings for the 20% of hotel buildings and 50% of the office buildings (45% of the sample) across the five locations are greater than zero, indicating that Green Globes provides economically efficient results (Figure 22). There do not appear to be significant differences in the Net Savings between the building types; however, this sample of 11 buildings is too small upon which to draw any significant conclusions on potential trends in Green Globes certified projects.

The Green Globes Net Savings are driven by the high initial investment costs (discussed above). The Net Savings are calculated using the reduction in the quantities of resources (energy and water) together with the local factor prices, balanced against the incremental initial investment costs. The Annual Net Savings for the Green Globes buildings range from approximately $500 to over $80,000 compared to the baseline prototype buildings (Figure 23). In this sample of the 11 Green Globes buildings, four projects had water savings that equaled over 50% of the Annual Net Savings.

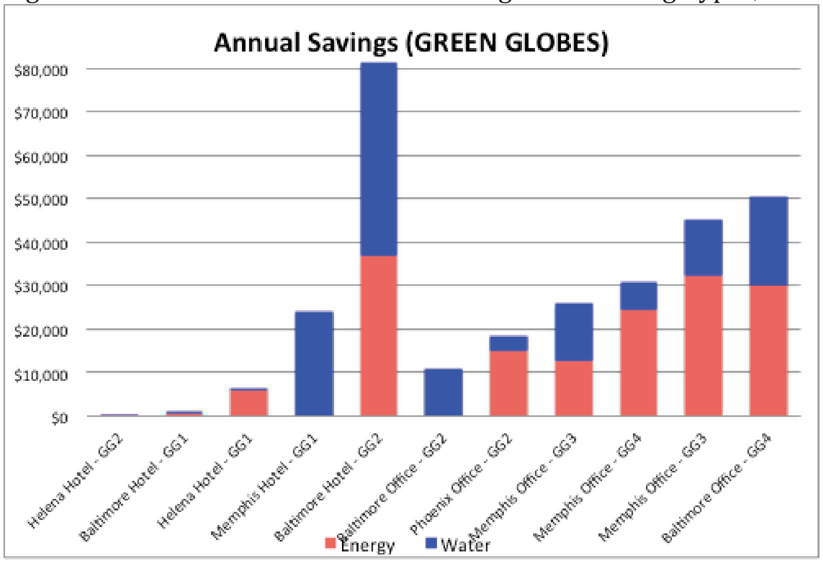
The differences in local factor prices determines the relative savings in each locations; for instance, Baltimore has the highest energy prices, and the second highest wastewater disposal costs, and those factor unit prices increase the value of those reductions for those locations.

Figure 22: Green Globes Long-term Cost-Benefit: Net Savings for All Buildings, All Certification Levels, and All Locations




Note: Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

Figure 23: Green Globes Annual Net Savings: All Building Types, All Locations




It should be noted that for the projects with Annual Net Savings over $20,000 a year, it would be expected that these Green Globes projects would be economically efficient. From this limited sample of 11 Green Globes projects, it appears that most of the buildings with incremental initial investments costs less than 20% of the baseline prototype buildings have Net Savings greater than the threshold (NS>0). If the incremental initial investment costs are greater than 20% of the baseline prototype building's investment cost—or if the Annual Net Savings are small—the Net Savings will likely be negative, and therefore an inefficient economic investment (Table 25).

The sensitivity analysis on Net Savings provides additional insight into the potential savings associated with Green Globes buildings in different climate conditions and market conditions. The Long-term Cost-Benefit for the 40-year Study Period (Figure 22 and Table 26, middle column) represents the expected Net Savings under the current OMB discount rate of 2% and energy price escalation as per the EIA/FEMP energy price models, with water price escalation at 2%.

Table 25: Green Globes Incremental Investment Cost to Net Savings Comparison

| Location | Building Type | Certification | %increase $/sf from Baseline | Net Savings |
|---|---|---|---|---|
| Memphis | Office | Green Globes 3 | 102% | $821,071 |
| Baltimore | Office | Green Globes 2 | 103% | $218,994 |
| Memphis | Office | Green Globes 4 | 103% | $790,045 |
| Helena | Hotel | Green Globes 2 | 110% | ($477,481) |
| Baltimore | Hotel | Green Globes 2 | 116% | $2,046,430 |
| Memphis | Hotel | Green Globes 1 | 116% | $180,633 |
| Phoenix | Office | Green Globes 2 | 144% | ($2,041,132) |
| Memphis | Office | Green Globes 3 | 147% | ($1,223,329) |
| Baltimore | Hotel | Green Globes 1 | 149% | ($2,516,575) |
| Baltimore | Office | Green Globes 4 | 201% | ($4,597,574) |
| Helena | Hotel | Green Globes 1 | 211% | ($5,348,579) |

Note: Net Savings for Long-term Cost-Benefit when N=40, d=2%, eE=0.5%, eW=2%.

Table 26: Green Globes Sensitivity Analysis for Net Savings: 40-Year Study Period

Office

| | Certification | Economic High Growth | Long-term Cost Benefit | Economic Slow Growth |
|---|---|---|---|---|
| Memphis | GG3 | $538,901 | $821,071 | $1,378,116 |
| Memphis | GG4 | $567,160 | $790,045 | $1,320,114 |
| Baltimore | GG2 | $36,796 | $218,994 | $526,315 |
| Memphis | GG3 | -$1,598,778 | -$1,223,329 | -$387,235 |
| Phoenix | GG2 | -$2,174,136 | -$2,041,132 | -$1,722,805 |
| Baltimore | GG4 | -$5,089,888 | -$4,597,574 | -$3,578,645 |

Hotel

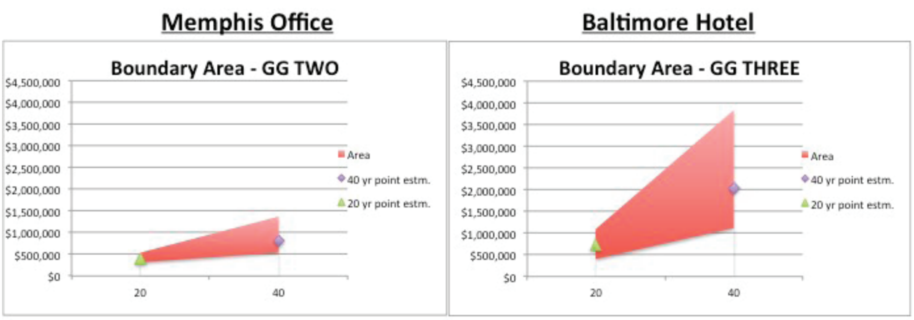
| | Certification | Economic High Growth | Long-term Cost Benefit | Economic Slow Growth |
|---|---|---|---|---|
| Baltimore | GG2 | $1,122,300 | $2,046,430 | $3,837,527 |
| Memphis | GG1 | -$229,449 | $180,633 | $872,277 |
| Helena | GG2 | -$485,065 | -$477,481 | -$464,666 |
| Baltimore | GG1 | -$2,529,019 | -$2,516,575 | -$2,490,938 |
| Helena | GG1 | -$5,385,541 | -$5,348,579 | -$5,247,877 |

Economic High Growth when d=3%, eE=0.5%, eW=0%
Long-term Cost Benefit when d=2%, eE=0.5%, eW=2%
Economic Slow Growth when d=1.5%, eE=2%, eW=4%

The sensitivity analysis represents the potential benefits that could be captured by these buildings under different conditions. That is, if energy and water prices escalate at 2% and 4% respectively (for the Economic Slow Growth scenario), the Net Savings for several buildings in this sample could increase by over 50% and, in some cases, almost double. These potential future Net Savings under this scenario could also be viewed as the potential future additional costs that will be incurred if a building does not implement energy and/or water saving options.

The sensitivity analysis provides additional insight into the range and conditions of potential future Net Savings (Figure 24). For the Memphis Office and Baltimore Hotel, the Net Savings are great than 0 within the Study Period of 20-40 years, indicating that these buildings are economically efficient for the scenarios under consideration. The potential Net Savings for the Baltimore Hotel is considerably greater than the potential Net Savings for the Memphis Office, and these savings increase rapidly over the time period, particularly related to the water price escalation.

Figure 24: Green Globes Sensitivity Analysis for Net Savings: Memphis Office and Baltimore Hotel



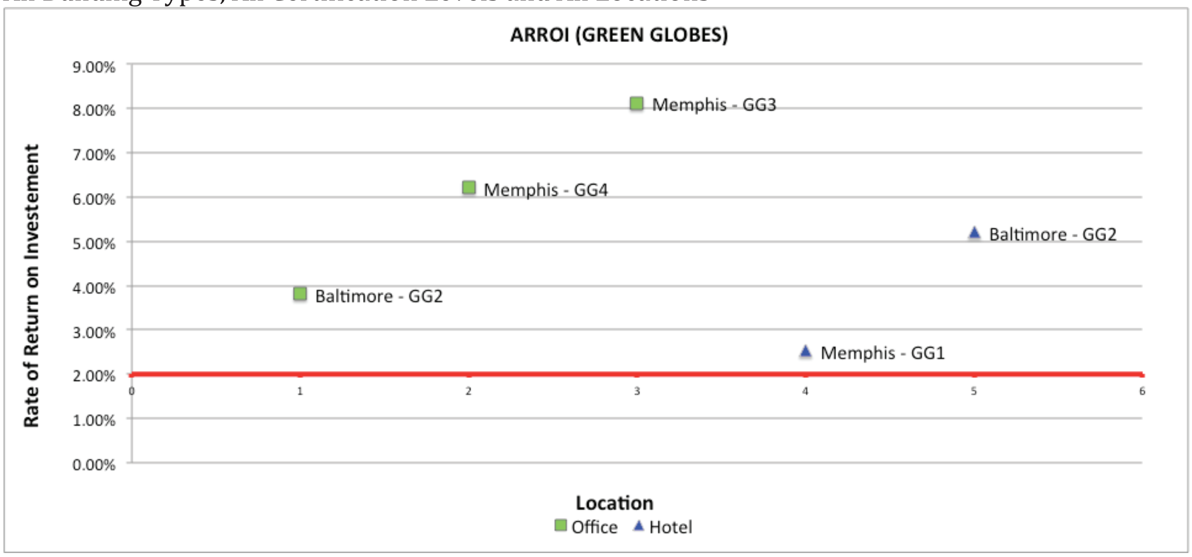

Lower Bound=Economic High Growth (d=3%, eE=FEMP, eW=0%)
Upper Bound=Economic Slow Growth (d=1.5%, eE=2%, eW=4%)

## Rate of Return on Investment

The (Adjusted) Rate of Return on Investment (ARROI) is particularly appropriate for ranking independent projects that have Net Savings greater than 0 to evaluate the relative return on specific levels of investment. (ARROI cannot be calculated for projects with Net Savings<0.) For the five (5) Green Globes projects with positive Net Savings, the ARROI is greater than the discount rate (2%), indicating economically efficient investments (Figure 25). The ARROI ranges from approximately 2.5% to 8%, which is higher than the current investment returns (that is, the current returns on long-term US Treasury Notes, as denoted by the OMB real discount rate of 2%). Therefore, investments in these buildings would be better than most investments currently available to the US federal government on the market.

The Memphis Office-Green Globes Three has the highest return on investment of the five buildings, even though it had a lower Net Savings than the Baltimore Hotel–GG2. Because it had a lower incremental initial investment cost, it is therefore a better return on the investment. All of these projects would perform better than the current default option (i.e., Treasury Notes at 2%).

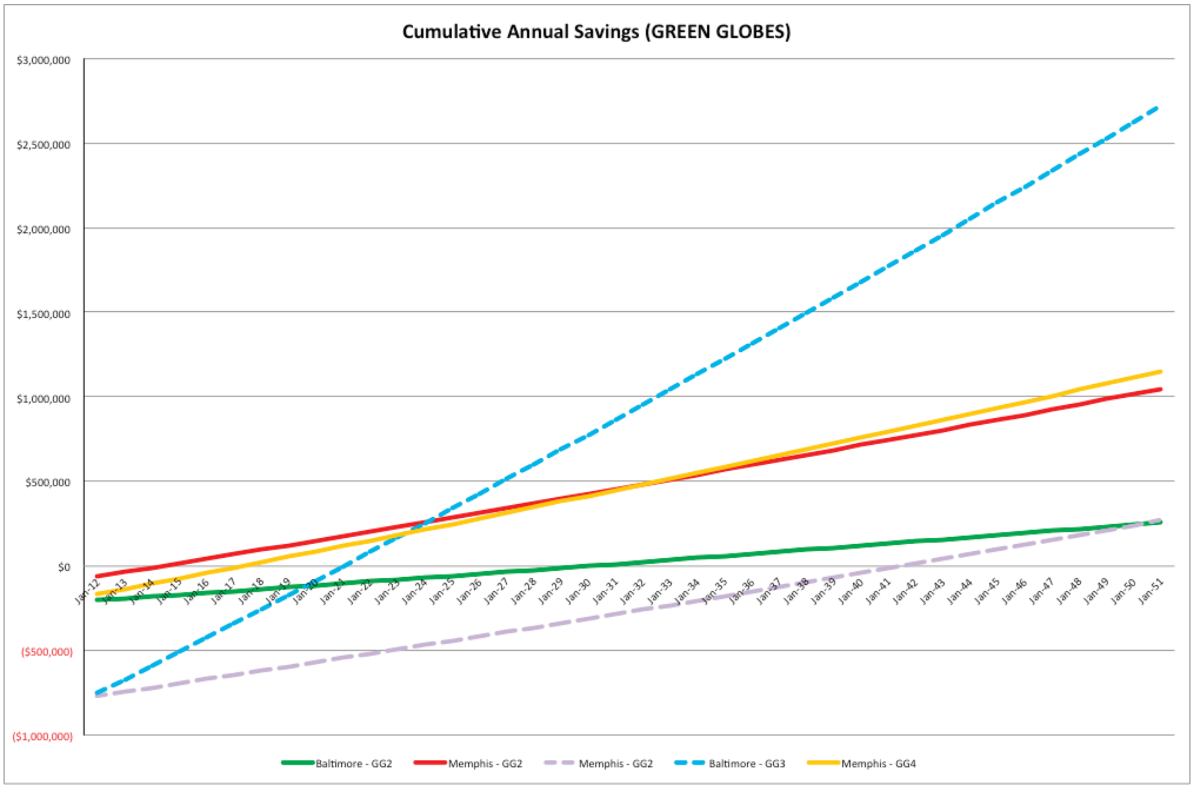
Figure 25: Green Globes Long-term Cost-Benefit: Adjusted Rate of Return on Investment (ROI) for All Building Types, All Certification Levels and All Locations




## Payback

Simple Payback provides a measure of relative liquidity of an investment. (Note: For projects with Net Savings <0, the Payback Period is greater than the Study Period, and is not presented here.) The Cumulative Annual Net Savings for each of the five (5) Green Globes buildings with NS>0 indicates the time at which the accumulating savings equal the incremental initial investment (that is, when the line crosses the x-axis) (Figure 26). For these buildings, the Simple Payback time periods range between 3 years to just over 32 years, indicating that while the liquidity for some investments are fairly high (being significantly less than the Study Period of 40 years), other investments provide significant overall Net Savings but the liquidity is not high.

Figure 26: Green Globes Simple Payback through Cumulative Annual Savings: All Building Types, All Locations




**Summary Results for Green Globes**

For this sample of 11 buildings that have been certified by the Green Building Initiative (GBI) at the level of One, Two, Three or Four Globes, which represent the two building types (Office and Hotel), five buildings (45% of the sample) provide economically efficient investment opportunities under certain conditions, examined within the context of the five selected locations for this study (Table 27).

For these buildings, the Adjusted Rate of Return on Investment (ARROI) is greater than the threshold of 2% (current return on long-term US Treasury Notes, as reported by OMB for FY13), and three of these projects recoup the incremental initial investment amount in less than one quarter of the total Study Period of 40 years (i.e., Simple Payback), indicating relatively high liquidity.

The sensitivity analysis of Net Savings addresses the robustness of these results under different conditions, specifically changes in the discount rate (from 1.5% to 3%) and changes in factor price escalation (specifically, energy price escalation from FEMP estimates (~0.5%) to 2%, and water price escalation from 0% to 4%). In those conditions, considering the long-term benefit at 40 years, 45% of the buildings would be economically efficient investments.

Table 27: Green Globes Long-term Cost-Benefit Analysis: Summary of Net Savings, ROI, and Payback for All Building Types, All Certification Levels, and All Locations

| Green Globes | | | | | | |
|---|---|---|---|---|---|---|
| Location | Building Type | Certification | Net Savings | ARROI | Simple Payback | Discounted Payback |
| Baltimore | Hotel | Green Globes 2 | $2,046,430 | 5.2% | 10.2 | 11 |
| Memphis | Hotel | Green Globes 1 | $180,633 | 2.5% | 32.6 | 34 |
| Helena | Hotel | Green Globes 2 | ($477,481) | ROI<0 | PB>40 | PB>40 |
| Baltimore | Hotel | Green Globes 1 | ($2,516,575) | ROI<0 | PB>40 | PB>40 |
| Helena | Hotel | Green Globes 1 | ($5,348,579) | ROI<0 | PB>40 | PB>40 |
| Memphis | Office | Green Globes 3 | $821,071 | 8.1% | 3.4 | 4 |
| Memphis | Office | Green Globes 4 | $790,045 | 6.2% | 6.3 | 7 |
| Baltimore | Office | Green Globes 2 | $218,994 | 3.8% | 19.7 | 21 |
| Memphis | Office | Green Globes 3 | ($1,223,329) | 0.5% | PB>40 | PB>40 |
| Phoenix | Office | Green Globes 2 | ($2,041,132) | ROI<0 | PB>40 | PB>40 |
| Baltimore | Office | Green Globes 4 | ($4,597,574) | ROI<0 | PB>40 | PB>40 |

Long-term Cost Benefit when N=40, d=2%, eE=0.5%, eW=2%

## SUMMARY OF RESULTS OF ECONOMIC EFFICIENCY EVALUATION

This study analyzed the economic efficiency of buildings built under the guidance of the ASHRAE Standards 90.1-2010 and 189.1-2011 for two building types (office, hotel) and five (5) locations representing the variety of climate and market conditions across the U.S. using building models. (The recent release of these standards precludes the use of actual building data, as described in the Methodology section of this report.) These ASHRAE building standards offer the opportunity to significantly reduce energy and water use (and related costs) in DOD facilities. As mentioned in earlier, Standard 90.1-2010 was developed explicitly to achieve the 30% energy improvement specified in the Energy Independence and Security Act (2007).

The results of the analysis in this study indicate that those standards are economically efficient across all five locations for both building types. The Long-term Cost-Benefit analysis of ASHRAE Standard 90.1-2010 provided significant Net Savings in energy reductions, equaling approximately $400,000 for offices and $200,000 for hotels over the 40-year Study Period. The (Adjusted) Rate of Return on Investment was between 5-8% across the building types and locations, and the payback time period was between 3 and 10 years, depending on the location and building type.

The sensitivity analysis results indicate that, if the cost of energy escalated at higher rates than currently projected by the US Energy Information Administration (that is, at 2% annual escalation), the potential Net Savings could increase up to $800,000 for offices and up to $400,000 for hotels over the 40-year Study Period.

The Long-term Cost-Benefit analysis of ASHRAE Standard 189.1-2011 provided greater Net Savings than 90.1-2010, in both energy and water cost reductions. In particular, the water cost reductions equaled approximately 50% of the Annual Savings across the building types and locations. ASHRAE 189.1-2011 also includes the requirement for on-site energy generation, and these incremental initial construction costs were included, and the on-site energy was used to offset the building energy used, so the overall building energy reductions were greater for 189.1-2011 than for 90.1-2010. The Net Savings for both offices and hotels were between $1-2 million over the 40-year Study Period, and the (Adjusted) Rate of Return on Investment were between 7-9% across the building types and locations. The payback time period was between 3 and 6 years, depending on the location and building type.

The sensitivity analysis results for ASHRAE 189.1-2011 also indicate that, even if water prices remained constant (in real dollars) and the cost of money increased (discount rate raised to 3%), these buildings would remain cost-effective. In addition, if energy and water prices increased significantly (2% and 4% respectively), the potential Net Savings could increase to $2-4 million over the 40-year Study Period.

These potential Net Savings can also be viewed as the potential future additional costs that may be incurred for these building types and locations under different scenarios. This analysis examines specifically those costs that could have been avoided for these buildings if they were built under the guidance of these building standards.

This study analyzed the economic efficiency of buildings built under the guidance of the Leadership in Energy and Environmental Design (LEED) for two building types (office, hotel) and five (5) locations representing the variety of climate and market conditions across the U.S. using data from 25 LEED-certified buildings. (The Methodology section of this report describes the specific data provided by the US Green Building Council.) LEED, as a voluntary building rating systems, offers the opportunity to improve overall building performance, including attributes that were not assessed for financial implications in this study. For example, this study did not consider the economic implications of improvements in occupant health, safety, and well-being, since the empirical basis for those financial impacts have not been established. It also did not calculate the spill-over effects that could be associated with programs focused on local procurement of materials, equipment, and systems, including the development of the local economy, since these financial implications have not been empirically verified.

The analysis results in this study indicate that buildings built under the guidance of the LEED rating systems are economically efficient depending on building type and location, and are highly sensitive to the initial construction cost. This sample of 25 LEED-certified buildings provides insight into the cost-effectiveness of the rating system, but is not large enough to make conclusions on trends in LEED-certified buildings. Specifically, insufficient information was obtained relating to the cost drivers for the initial investment cost (i.e., construction cost); the costs used in this analysis may include items to meet specific technical or special functional requirements that are not related to this study (as discussed in the Results section of this report).

Three buildings in this sample had construction costs that were lower than the baseline prototype building and therefore provided the value of energy and water cost savings with no incremental cost increase. Nine additional buildings had Net Savings ranging from $400,000 to $2.4 million over the 40-year Study Period, with (Adjusted) Rate of Return on Investment of between 3-14%, and payback time periods from less than a year to 25 years, depending on the building type and location.

The sensitivity analysis for these LEED buildings indicate that, if energy and water prices increased significantly (2% and 4% respectively), the potential Net Savings could increase to $1-3 million over the 40-year Study Period. In addition, the sensitivity analysis indicates that an additional building that was not economically efficient with moderate energy and water price escalation (at 0.5% and 2% respectively) would become economically efficient if those prices increased significantly.

The remaining 12 buildings in this sample (48% of the total) had incremental initial investment costs over 20% higher than the baseline building prototype and had NS<0. Even though the average Annual Savings for the sample was over $30,000, the Net Savings for these buildings were not above the threshold value for cost effectiveness (that is, Net Savings need to be greater than zero), since the accumulation of savings over the 40-year Study Period was insufficient to offset the incremental initial investment cost. (In cases where the Net Savings is negative, it is not possible to compute return on investment, and the payback period is always beyond the designated study period.)

Based on the results of the analysis in this study for this sample of 25 actual buildings, LEED-certified buildings provide significant Annual Savings, and are cost-efficient when the incremental initial investment costs do not exceed 20% of the baseline investment costs. In addition, the recent DOD guidance (2010) specifying that 40% of all points in those rating systems must be in energy and water categories will increase the economic efficiency (as measured in this study) of DOD buildings using this rating system. It must be noted, however, that these results are highly dependent on the data provided for this set of 25 buildings, particularly the reported initial construction costs.

This study also analyzed the economic efficiency of buildings built under the guidance of the Green Globes rating system for two building types (office, hotel) and five (5) locations representing the variety of climate and market conditions across the U.S. using data from 11 Green Globes-certified buildings. (The Methodology section of this report describes the specific data provided by the Green Building Initiative.) Green Globes, as a voluntary building rating systems, offers the opportunity to improve overall building performance, including attributes that were not assessed for financial implications in this study. For example, this study did not consider the economic implications of improvements in occupant health, safety, and well-being, since the empirical basis for those financial impacts have not been established.

The analysis results in this study indicate that buildings built under the guidance of the Green Globes rating systems are economically efficient depending on building type and location, and are highly sensitive to the initial construction cost. This sample of 11 actual Green Globes-certified buildings provides insight into the cost-effectiveness of the rating system, but is not large enough to make conclusions on trends in Green Globes-certified buildings. Specifically, insufficient information was obtained relating to the cost drivers for the initial investment cost (i.e., construction cost); the costs used in this analysis may include items to meet specific technical or special functional requirements that are not related to this study.

Five buildings in this sample had Net Savings ranging from $200,000 to $2 million over the 40-year Study Period, with (Adjusted) Rate of Return on Investment of between 3-8%, and payback time periods from 3 to 33 years, depending on the building type and location. The sensitivity analysis for these Green Globes buildings indicate that, if energy and water prices increased significantly (2% and 4% respectively), the potential Net Savings could increase to $0.5-4 million over the 40-year Study Period.

The remaining 6 buildings in this sample (55% of the total) had incremental initial investment costs over 20% higher than the baseline building prototype and had NS<0. Even though the average Annual Savings for the sample was over $25,000, the Net Savings for these buildings were not above the threshold value for cost effectiveness (that is, Net Savings need to be greater than zero), since the accumulation of savings over the 40-year Study Period was insufficient to offset the incremental initial investment cost. (In cases where the Net Savings is negative, it is not possible to compute return on investment, and the payback period is always beyond the designated study period.)

Based on the results of the analysis in this study for this sample of 11 actual buildings, Green Globes-certified buildings provide sizeable Annual Savings, and are cost-efficient when the incremental initial investment costs do not exceed 20% of the baseline investment costs. In addition, the recent DOD guidance (2010) specifying that 40% of all points in those rating systems must be in energy and water categories will increase the economic efficiency (as measured in this study) of DOD buildings using this rating system. It must be noted, however, that these results are highly dependent on the data provided for this set of 11 buildings, particularly the reported initial construction costs.

## APPLICABILITY OF COST EFFECTIVENESS STUDY TO DOD MILITARY CONSTRUCTION AND RENOVATION

The National Defense Authorization Act (NDAA) 2012 Section 4830(a)(3) requires the Department of Defense to provide a "policy prescribing a comprehensive strategy for the pursuit of design and building standards across the Department of Defense that include specific energy-efficient standards and sustainable design attributes for military construction based on the cost-benefit analysis return on investment, and demonstrated payback."[22]

The results of the economic evaluation of the building standards and rating systems presented in this report have direct applicability to the development of the DOD comprehensive strategy for cost-effective military construction and renovation. The study highlighted opportunities for cost-effective high performance buildings built under the guidance of the specified standards and rating systems for different building types, specifically for a residential facility and an office building, in both energy and water usage. It also examined the potential economic value in different locations that represent the variety of climate zones and urban/rural markets across the U.S., incorporating local factor unit prices and conditions that affect cost-efficiency. The sensitivity analysis provides insight into the variability of cost-effectiveness, in particular, potential escalation of energy and water prices and changes in the cost of money (as represented by the discount rate).

In addition, the second portion of this study tested the applicability of the analytical approach, process and tools developed for this research to military construction and renovation projects going forward, as further input for the DOD comprehensive strategy. The results from these example applications of the analytical approach using empirical data from actual DOD buildings were reviewed with staff from the selected installations, HQ, construction agents, and the Office of the Secretary of Defense. The exercise provided important feedback for the potential application of the economic efficiency evaluation process for DOD military construction.

This study recognizes that the core purpose of military construction and renovation is to provide high performance facilities that are effective and efficient. Specifically, the results of this study and the application of the analytical approach can be used to identify opportunities to improve effectiveness and efficiency, such as to reduce the resource usage (and the related burden on neighboring communities), reduce vulnerabilities to price increases, and increase overall resiliency by reducing the "baseload" resource requirements under normal and extreme conditions. The primary objective is to ensure the usefulness of the approach to aid decision-making for strategic investments in DOD capital facility assets.

## IMPLICATIONS OF ECONOMIC EFFICIENCY EVALUATION FOR MILITARY CONSTRUCTION AND RENOVATION INVESTMENTS

The findings from the economic evaluation of the specified building standards and rating systems indicate opportunities to improve the effectiveness and economic efficiency of military construction and renovation, as input into the DOD comprehensive strategy. The Department of Defense (DOD) and its components manage more than 500,000 buildings and structures worldwide, containing more than 2.1 billion total square feet of space. The annual energy budget for these facilities is more than $4 billion. Spending on military construction, family housing, BRAC, and related programs in FY 2010 was $23.3 billion, and was $13 billion in FY2012 (with wind-down of the BRAC program).

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[22] National Defense Authorization Act 2012, Section 4830(a)(3).

The Department of Defense has incorporated life cycle cost analysis into all construction projects. Form 1391, which is used to initiate the authorization process for military construction projects, requires a life cycle cost analysis. The DOD's Sustainable Building Policy includes supplementary information (October 2010), which requires that, beginning in FY12, 40% of all credits for a LEED-Silver (or equivalent) rating will be associated with energy and water credits. It also includes the specification that since "reducing total cost of ownership is intrinsic to sustainable buildings […] The DOD components shall incorporate life cycle and cost/benefit analysis into design decisions for new construction and renovation/repair projects."[23]

In addition, DOD components have been developing tools and testing approaches to address these areas, including:

- A recent Air Force briefing described the development of a "Sustainability Measurement Tool" that includes life cycle cost analysis and the "Sustainability Return on Investment" (SROI) system developed by HDR Decision Economics.[24]
- The Navy has developed an "eROI tool" that includes life cycle cost analysis as well as other priorities (such as minimize shore energy consumption and provide reliable energy to critical infrastructure). [25]
- Army Corps of Engineers has developed an "Energy and Sustainability checklist" (based on a Navy checklist) to track compliance with federal mandates, and other performance measures.
- DOD-wide program on Total Ownership Costs to "maintain or improve current readiness while reducing operations and support costs."[26]

The results of the analysis in this study indicate that the building standards and rating systems provide buildings that are economically efficient depending on building type and location. Specifically, the Long-term Cost-Benefit analysis of ASHRAE Standard 90.1-2010 provided significant Net Savings in energy reductions for both building types and in all 5 locations. ASHRAE Standard 189.1-2011 provided greater Net Savings than 90.1-2010 across all locations for both building types in both energy and water cost reductions. In particular, the water cost reductions equaled approximately 50% of the Annual Savings across the building types and locations. ASHRAE 189.1-2011 also includes the requirement for on-site energy generation, and these incremental initial construction costs were included, and the on-site energy was used to offset the building energy used, so the overall building energy reductions were greater for 189.1-2011 than for 90.1-2010.

Buildings built under the guidance of the LEED rating system (Silver, Gold and Platinum Certification levels) and the Green Globes rating system (One, Two, Three and Four Globes certification levels) are economically efficient depending on building type and location, and are highly sensitive to the incremental initial construction cost. The LEED Volume Certification program could further increase cost-effectiveness through pre-approval of standardized designs and management procedures, and coordinated procurement programs. In addition, the recent DOD guidance (2010) specifying that 40% of all points in those rating systems must be in energy and water categories will increase the economic efficiency (as measured in this study) of DOD buildings

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[23] Office of the Secretary of Defense, Deputy Under Secretary of Defense (Installations & Environment) Dorothy Robyn (2010). "Department of Defense Sustainable Buildings Policy Memorandum."

[24] HDR Decision Economics (2012). "Sustainability Measurement Tool."

[25] CAPT Burgess, Operations Officer, NAVFAC (2011). "Mid-Atlantic Energy Programs."

[26] Office of the Under Secretary of Defense (Comptroller) (2011). *Department of Defense Efficiency Initiatives: FY 2012 Budget Estimates*, and 1997 memorandum referenced in (http://www.almc.army.mil/alog/issues/JanFeb99/MS368.htm).

using this rating system. It must be noted, however, that these results are highly dependent on the data provided for these data samples, particularly the reported initial construction costs.

The sensitivity analysis incorporated variations in energy and water price escalations, as well as the cost of capital (represented by the discount rate). The results indicate that Net Savings for the specified buildings standards and rating systems would increase significantly with annual price escalations of 2% for energy and 4% for water and wastewater, which has been experienced in some locations of the US. The building standards and rating systems could reduce the vulnerability of DOD installations to price shocks—and increase cost-effectiveness—by reducing the use of these resources. The sensitivity analysis results also indicate that, even if the prices for energy and water decrease and the cost of capital increases (represented by a discount rate of 3%), most facilities built under the guidance of the standards and rating systems remain economically efficient.

The implication of these results for the DOD comprehensive strategy for cost-effective military construction is that ASHRAE 189.1-2011 (which includes ASHRAE 90.1-2010 by reference) would generally provide economically efficient high performance military facilities. The voluntary ratings systems of LEED and Green Globes can provide important guidance for overall high performance facilities (including attributes not measured in this study) as well as third party verification, and buildings certified under these rating systems would be cost-efficient if the incremental initial investment costs are within a margin (in these sample, 20% over the baseline building cost) and the annual savings are sufficient to offset that incremental cost.

It must be noted, however, that those results are highly sensitive to the heating and cooling loads for different climate zones **and to the local factor unit prices.** Consideration of specific choices associated with the application of those standards for design development and implementation should be evaluated grounded in the specific local context.

## APPLICABILITY OF ANALYTICAL FRAMEWORK FOR DOD MILITARY CONSTRUCTION

Separately, and in parallel with the economic evaluation of the specified standards and rating systems, the consultant worked with the DOD components (Air Force, Army, Navy/Marines) and selected installations' teams to test and demonstrate the analytical approach and tools developed in this study. This study analyzed empirical data from recent DOD buildings using the analytical approach and tools, working with the DOD components, construction agents, and selected installations. The results from the example application of the analytical approach and tools were reviewed with staff from the selected installations, HQ, construction agents, and the Office of the Secretary of Defense as input into the comprehensive strategy, as requested in the NDAA Section 2830.

The approach developed in this research study is designed to help decision-makers explicitly define uncertainties in the economy and local markets (e.g., discount rates and factor price escalations) and to identify potential financial opportunities and risks. The objective is to aid prudent investments in military construction and renovation that mitigate those risks and achieve expected performance levels. The methodology and tools developed in this research study, and as tested for applicability to DOD military facilities, can be used to compare:

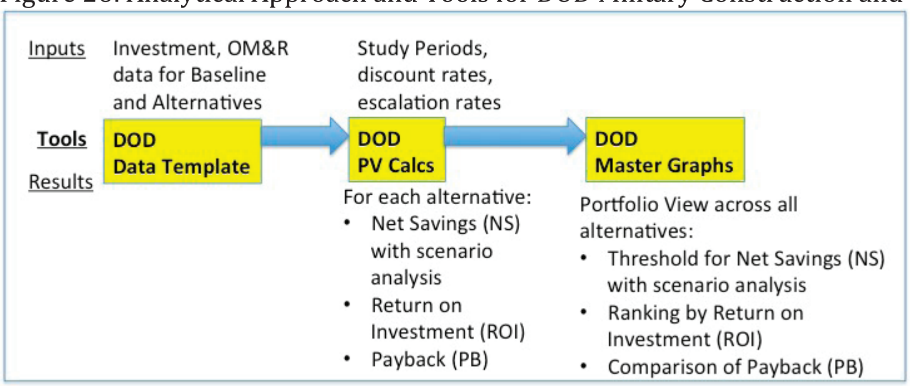
- High performance buildings to "standard" buildings (i.e., not high performance) to continue to assess the economic effectiveness of high performance buildings;
- Expected to Actual performance of high performance buildings to track performance and refine future investment decisions;
- Design alternatives for a planned capital investment to evaluate the relative economic effectiveness of each option;

- An independent set of building projects across a portfolio (such as for an installation or component) to establish a rational funding priority list based on expected economic performance.

The consultant provided materials and met with the staff from the selected installations, HQ, construction agents, and Office of Secretary of Defense to demonstrate and test the applicability of the analysis methodology developed in this study to actual DOD projects, and to obtain feedback on the applicability of the analytical approach and tools as input to the development of the DOD comprehensive strategy. Using the DOD Data Template provided by the consultant, the DOD components and selected installations collected data on recent DOD facilities, which were then using the tools developed in this research (Figure 26). The results included:

- Net Savings, Rate of Return on Investment, and Payback using the current OMB real discount rate (d=2%) and study period (N=40 years) for recent actual DOD buildings compared to the identified baseline buildings;
- Sensitivity analysis of the results relative to the minimum and maximum discount rates, time periods, and factor unit price escalations (i.e., energy and water).

Figure 26: Analytical Approach and Tools for DOD Military Construction and Renovation




The exercise provided important feedback for the potential application of the economic efficiency evaluation process for DOD military and construction going forward. In particular, the discussion raises certain challenges and opportunities associated with economic efficiency evaluations in the following areas:

- Timing of economic efficiency analysis for decision support on project planning, design, and implementation, particularly in the context of current authorization and appropriation processes, as well as existing legislative mandates;
- Current data collection and analysis processes at the installation, component, and DOD level, related to legislative requirements for reporting, and current management processes for strategic investment in DOD capital facility assets;
- Industry and market factors influencing the long-term economic efficiency of DOD military construction and renovation.

## Timing of Economic Efficiency Analysis for Decision Support

As mentioned previously, the DOD requires an economic efficiency analysis with Form 1391 for the initiation of the military construction authorization process. At the moment, the authorization and appropriation processes for DOD military construction and renovation tend to focus more on individual projects than on a strategic level portfolio management approach.

The analytical approach of economic efficiency analysis would be best applied across a portfolio of projects at the earliest stages, for budgeting and planning, rather than on single projects just at the authorization stage. It could also be effectively applied during design development and implementation, in the choice of specific building characteristics—with respect to the overall installation requirements—that increase mission effectiveness and economic efficiency. In addition, the increased focus on capital investment for sustainment and renewal of existing facilities could best be accomplished across the portfolio of potential opportunities, within the context of mission effectiveness for installations, rather than on single projects.

For the economic efficiency analysis to be used effectively in decision-making, the early project planning and scope development through detailed design development and implementation would include:

- Recognition of uncertainty with respect to future conditions, costs, and opportunities, which is particularly relevant for durable capital facility assets;
- Clear specification of inputs and outcomes, which provide a critical basis to measure actual performance and correct assumptions;
- Clear delineation of exogenous factors (e.g., market trends, potential disruptions) and analysis of potential impacts, which provides a basis for robust risk mitigation;
- Flexibility to evaluate new conditions, opportunities, inputs and outcomes, which provide a means to rapidly and effectively improve performance and cost efficiency.

Therefore, the effective implementation of an economic evaluation approach may require refinement to the existing processes.

## Current DOD Data Collection for Strategic Investment in DOD Capital Facility Assets

The application of an economic efficiency analysis requires access to credible and verifiable data on the initial investment costs, major repair/replacement costs, and operations, maintenance and repair costs over the expected life of the facility. The DOD components, installations and construction agents are initiating specific programs to collect information on energy and sustainability performance for capital facility assets, including both the expected and actual performance of the facilities. The effective use of an economic efficiency analysis approach may require additional data collection, as well as clear delineation of the process to collect, refresh, maintain, and disseminate the data effectively to aid decision-making. It may also require an explicit process to assess the performance of building systems, components, equipment and materials relative to the actual capture of expected benefits, to inform design, procurement, and implementation processes going forward.

In particular, this data should be grounded in the local market, incorporating local construction costs (and available skill levels) and local factor unit prices (e.g., energy, water, municipal and hazardous waste, and costs for O&M, cleaning, and landscaping), as well as potential future price escalation. This approach provides critical information related to uncertainty in future conditions relevant for strategic decision making and risk mitigation at the installation level as well as for specific military facilities.

The definition of the appropriate base case is critical for obtaining useful and empirically verifiable results from the economic efficiency analysis. The economic efficiency analysis of Net Savings requires a ***specific base case*** against which to compare the relative **incremental** costs and benefits of alternatives. The Net Savings are calculated as the differences in costs between the baseline and the alternative(s). The baseline for DOD military construction and renovation should reflect the current market equivalent building **relative to the benefits/costs analyzed** for the specific location under consideration.

DOD components and construction agents could compile a "library" of useful baseline building cases from previous similar DOD facilities projects or through other reference sources. Specifically, the benefit-cost data for the baseline building cases could be obtained through:

1) Values for expected energy performance from the *EnergyPlus* 90.1-2004 model (often used as the basis for LEED certification submissions) for specific projects;
2) Actual performance data (energy, water, solid waste, and O&M) from existing buildings;
3) Related public data sources and references on comparable buildings;
4) Reductive analysis of current building designs, with the extraction of specific building systems, components, and equipment related to the specific benefits and costs being evaluated.

In compiling the baseline building cases, the models used during planning and design (including *EnergyPlus*) could be utilized during commissioning and operation to reflect actual facility usage. For instance, the original energy models can be rerun with actual occupancy loads and schedules, as opposed to the expected levels, to recalibrate the projected energy usage under current conditions. These refinements can provide a verifiable baseline for tracking building performance, as well as improve planning and design for subsequent similar buildings.

These baseline building cases could be used to expedite design development through the explicit consideration of effectiveness and economic efficiency. In particular, they could be used throughout bid review and project management to enable decision-making on the selection of building systems, components, equipment and materials through the explicit identification of expected benefits and costs and resultant relative economic efficiency, and the opportunity to mitigate risks (e.g., price escalation).

This study highlighted the differences in opportunities for costs and benefits for different building types, specifically for a residential facility and an office building, in both energy and water usage. For example, the office buildings provide more opportunities for energy-savings, given their higher use per square foot of energy and their (relatively) lower usage per square foot of water, while the residential facilities have relatively higher water usage (particularly with the inclusion of the laundry facilities) and thereby offer greater opportunities for water savings. Further data collection related to specific DOD military facility types could identify specific opportunities for reducing OM&R costs related to facility-specific resource use and therefore increase economic efficiency in military construction and renovation going forward.

The economic efficiency analysis, and the related data collection, can be also used to track actual performance relative to the expected benefits. As the energy and water monitoring systems installed on DOD installations come into effective use, the data on resource usage (and related cost) can be used to evaluate specific buildings, systems, or building types for additional real-time operational refinement and commissioning to meet the expected high performance levels. The data can also be used to monitor the cost savings for given investments, and progress in achieving legislative mandates, in required annual reports.

This study highlighted the differences among locations—including heating/cooling degree days (by climate zone) and local factor unit prices. For example, locations with higher cooling loads (such as Miami) also have higher electric loads (primarily used for air conditioning equipment), while locations with higher heating loads (such as Helena) have higher natural gas loads. Since the costs of these energy sources differ significantly by location—and fluctuate on a monthly basis—the economic impact of specific strategies to reduce these energy usage categories should be calculated with respect to the specific location to assess opportunities for net savings. In addition, the volatility of energy costs can be usefully incorporated into the economic efficiency analysis to mitigate vulnerability to price shocks.

In the same way, water and wastewater prices differed significantly by location, and may increase rapidly in a short time period. Among the five locations in this study, the unit costs for water differed by a factor of 2, and the wastewater disposal costs differed by a factor of almost 3. Further, several of the locations were predicting a rapid increase in water and wastewater rates.[27] Therefore, future economic efficiency analyses should explicitly incorporate consideration of local water and wastewater disposal costs, and the potential of significant future price escalations.

The cost-benefit categories of solid and hazardous waste were included in this study, and the analysis of factor unit prices for the 5 locations found a high differential among the locations, with a factor of 4 difference in solid waste disposal costs, and a factor of over 7 difference in hazardous waste disposal costs (although there is some difference in the definition of hazardous waste across the municipalities). Several of the DOD facilities analyzed in this exercise reported significant reductions in municipal and/or hazardous waste that provided substantial cost savings. Additional monitoring of reductions in solid waste would provide a means to incorporate these savings into the economic evaluations, and could have a significant impact on the relative economic efficiency of different facility alternatives and operations programs.

The cost-benefit categories of O&M (general), cleaning and landscaping were also included in this study. These costs could be expected to decrease with improvements in sustainable building systems and materials, and savings in these cost categories could have major cost implications, since these cost expenditures are often several times higher than expenditures for energy and water. Several DOD facilities analyzed in this exercise reported 1-5% reductions in O&M costs that provided moderate cost savings. Additional monitoring and assessment of O&M costs would provide a means to incorporate these savings into the economic evaluations, and could have a significant impact on the relative economic efficiency of different facility alternatives as well as potential operations programs.

The current data collection initiatives being developed by the DOD component, construction agent, and installation teams can provide critical capabilities to incorporate effective economic evaluations into decision making for military construction and renovation, with specific attention to local conditions and factor prices as well as potential changes over time. These approaches can improve the effectiveness and efficiency of military high performance facilities at the installation, command, and service level, as well as for the individual facilities.

## Industry and Market Factors for Long-Term Cost Efficiency of Military Construction and Renovation

As noted earlier, the DOD expends over $10 billion a year in military construction and repair and is the largest single real property holder in the US and indeed in the world.[28] As such, it has an important role to "demand pull" improvements and cost reductions from the industry. A

[27] Baltimore Brew, "City water, sewer rates expected to jump 9 percent," (http://www.baltimorebrew.com/2011/05/18/your-water-sewer-bill-expect-over-1000-a-year/).

[28] Deputy Secretary of Defense (Ashton Carter) (2012). "Energy Security and Innovation." (http://www.defense.gov/pubs/pdfs/Energy_Security_and_Innovation_based_on_remarks_given_at_Georgia_Tech_04DB.pdf).

recent National Academies report found that "Federal agencies can use their purchasing power to drive the market demand for sustainable products and services."[29]

Anecdotal evidence indicates that the capabilities and capacities across the industries that support high performance facilities have developed rapidly over the last ten years. A recent study on sustainable buildings in Michigan asserts that "costs for green buildings continue to decrease as materials become standard and practitioners become more proficient in new technologies."[30] Further research is needed to determine the extent to which industry development as a whole may reduce initial investment costs and improve the capture of expected benefits from high performance facilities.

Several factors may be driving the market as a whole, and may significantly increase the economic efficiency of high performance buildings in general, and for DOD military construction and renovation specifically.

The "learning curve" (in economic terms) refers the rate of progress to achieve a stable production rate given the introduction of new processes, systems and/or materials. These learning curves often encompass both "labor learning" (for specific skills) as well as "organizational learning" to reflect the development and implementation of effective management practices of the new processes, systems, and/or materials.[31]

Market development is associated with achieving economies of scale, where the marginal cost to produce each unit decreases as the number of units increase. Recent research has started to explore the potential trends in economies of scale in the production of energy efficient equipment.[32] Indeed, the LEED Volume Certification program explicitly recognizes the economies of scale in the certification of large numbers of similar projects, as a means to "streamline" the design and certification process while achieving the expected levels of high performance.

These factors (learning curves and market development) may affect different segments of the value-adding chain in the industries that support the design, construction, operation, and renovation of high performance buildings. For instance, three factors may specifically influence the initial investment costs for high performance facilities:

- Learning curve and market development for manufacturers of high performance equipment, materials and systems, which reduce the unit prices for initial investment;
- Learning curve and capacity development for designers (architects and engineers) of high performance facilities, which improve decision making and reduce the time required to plan, design, and manage high performance facility projects;
- Learning curve, skill development, and organizational capacity development by general and specialty contractors, which improve the quality and reduce the time required to construct or renovate high performance facilities.

Two related factors may both reduce the incremental initial investment costs and increase the capture of expected benefits from high performance facilities:

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[29] National Academies Press (2011). *Achieving High-Performance Federal Facilities: Strategies and Approaches for Transformational Change,* p. 7.

[30] Urban Catalyst Associates (2010). *Building Green for the Future: Case Studies in Sustainable development in Michigan,* p. 3. (http://www.epa.gov/P3/success/michigan.pdf).

[31] L.E. Yelle (1979), "The Learning Curve: A historical review and comprehensive survey," *Decision Sciences*, Vol 10, Issue 2, pp. 302-328. (http://tuvalu.santafe.edu/~bn/reading_group/Yelle.pdf).

[32] Jardot et al. (2009), "Effects of economies of scale and experience on the costs of energy-efficient technologies: A case study of electric motors," ECEEE Conference Proceedings (http://www.eceee.org/conference_proceedings/eceee/2009/Panel_5/5.389).

- Learning curve and capacity development within owner organizations, which improve the decision making during planning and design, and improve operations management over time;
- Learning curve and capacity development for facilities managers, which can improve decision making during planning and design through integrated project teams, and improve the capture of benefits during operations and maintenance.

At this point, however, there is insufficient data available to make recommendations on these topics, but they offer the opportunity to further increase the cost-effectiveness of high performance facilities as the industries that support high performance facilities continue to develop. Further research is needed to determine the extent to which industry development as a whole may increase the cost-effectiveness of military construction and repair.

## APPENDIX A: SENSITIVITY ANALYSIS DATA

Table A.1: Price Escalation 2010-2011 and Equivalent Annual Escalation for Energy, Water/Sewer, and Municipal Waste

| Expenditure Category | 2011 Annual Average (CPI) | Percent change from 2010 to 2011 | Equivalent Annual Escalation Rate (1982-2011) [a] |
|---|---|---|---|
| Housing—Fuel oil | 367.804 | 30.0% | 4.4% |
| Housing—Propane, kerosene, and firewood | 348.050 | 8.6% | 4.2% |
| Housing—electricity | 196.737 | 1.9% | 2.3% |
| Housing—Utility (piped) gas service | 184.334 | -2.8% | 2.0% |
| Housing—Water and sewer services | 402.868 | 5.8% | 4.8% |
| Housing—Garbage and trash collection | 395.091 | 2.8% | 4.7% |

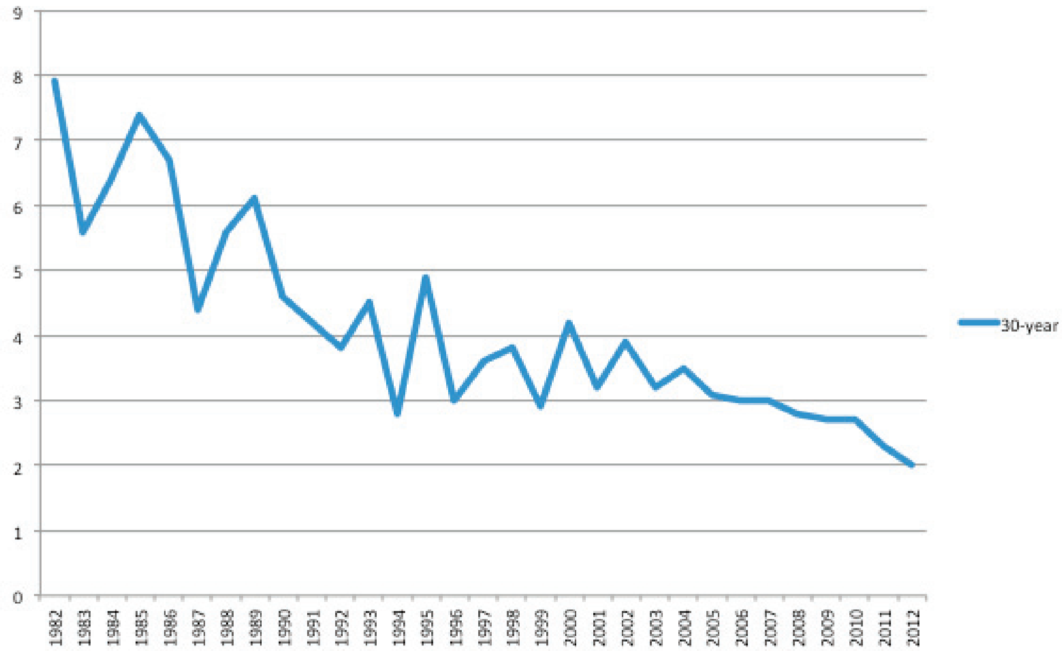
Source: Table 3A. Consumer Price Index for all Urban Consumers (CPI-U): U.S. city average, detailed expenditure categories, 2011. CPI establishes 1982-84=100.
[a] Calculated from CPI.

Table A.2: (OMB) Discount Rate for Cost-effectiveness 2007-2012

| Year | 20-year | 30-year |
|---|---|---|
| 2007 | 3.0% | 3.0% |
| 2008 | 2.8% | 2.8% |
| 2009 | 2.7% | 2.7% |
| 2010 | 2.7% | 2.7% |
| 2011 | 2.1% | 2.3% |
| 2012 | 1.7% | 2.0% |

Source: Office of Management and Budget (OMB) Circular A-94, Appendix C.

Figure A.1: OMB Real Discount Rate – 30-year.




## APPENDIX B: PROTOTYPE BUILDINGS—CHARACTERISTICS

The Department of Energy (DOE) Building Energy Code Program (BECP) reviews the technical and economic basis for updates to model energy codes and standards. DOE contracted with the Pacific Northwest National Laboratory (PNNL) to analyze the energy and cost savings of ASHRAE Standard 90.1-2010 compared to ASHRAE 90.1 2004 to provide technical and economic analysis support, utilizing the *EnergyPlus* simulation framework and sixteen prototype building types (Table 2). The objective was to ensure that ASHRAE 90.1-2010 achieved the goal of reducing energy use by 30% compared to ASHRAE 90.1-2004, as specified in the Energy Policy Act (EPAct) and the Energy Independence and Security Act (EISA).[33]

The U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) with PNNL used the same climate zones (and approximate locations) to analyze five buildings types (Unaccompanied Enlisted Personnel Housing, Tactical Equipment Maintenance Facility, Brigade HQ, Company Operations Facility, and Dining Facility). The objective was to "investigate current building features and construction methods and materials to optimize energy reduction and sustainability."[34]

[33] Pacific Northwest National Laboratory (2011). *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010,* NTIS, PNNL-20405.

[34] U.S. Army Corps of Engineers (2011). *MILCON Energy Efficiency and Sustainability Study of Five Types of*

Table B.1: DOE PNNL Prototype Buildings, Locations/Climate Zones

| Prototype building type (16) | Locations/Climate Zones (15) |
|---|---|
| Office (small, medium, large) | 1A Miami |
| Retail (stand-alone, strip mall) | 2A Houston, 2B Phoenix |
| School (primary, secondary) | 3A Memphis, 3B El Paso, 3C San Francisco |
| Healthcare (outpatient, hospital) | 4A Baltimore, 4B Albuquerque |
| Hotel (small, large) | 5A Chicago, 5B Boise |
| Warehouse | 6A Burlington, 6B Helena |
| Restaurant (quick, full-service) | 7 Duluth |
| Apartment (mid-rise, high-rise) | 8 Fairbanks |

Source: DOE EERE Building Energy Codes Program, 90.1 Prototype Building Models (http://www.energycodes.gov/commercial/901models/).

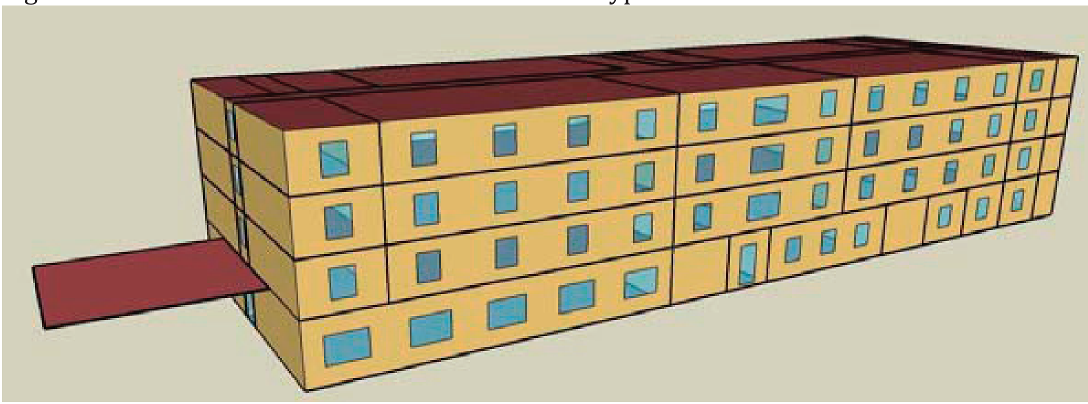
## SMALL HOTEL

The small hotel design came out of the (PNNL) study. All of the attributes from the construction type, form, space configuration and size of the guest rooms were adapted from a Hampton Inn prototype floor plan.

Table B.2: Building Details for Small Hotel

| | Building | Small Hotel |
|---|---|---|
| **Form** | | |
| | *Total Floor Area (sq feet)* | 43,200 (180' x 60') |
| | *Aspect Ratio* | 3 |
| | *Number of Floors* | 4 |
| | *Window Fraction (Window-to-Wall Ratio)* | South: 3.1%, East: 11.4%, North: 4.0%, West: 15.2%<br>Average Total: 10.9% |
| | *Window Locations* | One per guest room (4' x 5') |
| | *Floor to floor height (feet)* | Ground floor: 11 ft<br>Upper floors: 9 ft |
| **Details** | | |
| | *Occupancy* | 259 People |
| | *Orientation* | Long axis orientation North/South |
| | *Requirements:* | |
| | *Parking Area* | 33,680 ft2 |
| | *Exterior Doors* | 31.22 ft2 |
| | *Façade* | 3,819 ft2 |
| **Architecture- Fixed across all Prototypes** | | |
| | *Superstructure* | (Not specified) Structural Steel Frame |
| | *Substructure* | (Not specified) Column Footings, strip footings for slab |
| | *Floor Deck* | (Not specified) Sheet metal decking, topping slab |
| | *Foundation Slab* | 6" concrete slab |
| | *Interior Partitions* | 2x4 stud (nonloadbearing, uninsulated) |
| | *Plug Load* | 1.11 W/ft2 (guestrooms) |
| | *Elevator* | 2 Hydraulic (16.055 W) |
| | *Orientation* | Long axis orientation North/South |
| | *Fuel Mix* | Gas, Electricity |
| **Change by location, certification level** | | |
| | *Windows* | 4'x5' (1 per guestroom) |
| | *Skylight* | None |
| | *Ceiling* | No Plenum |
| | *HVAC* | PTAC (Packaged Terminal Air Conditioner) with electric resistance heating in each guestroom; gas furnace with packaged AC (split system with DX cooling) for public spaces; electric cabinet heaters for storage areas and stairs |
| | *Exterior Walls* | Steel frame (2x4 16"o.c.), 1" stucco, 5/8" gypsum board, insulation, 5/8" gypsum |
| | *Roof* | Membrane, insulation, metal decking |
| | *Floor Slab* | (Not specified) Insulation |
| | *Hot Water* | 2 natural gas (200 gal tank for guestrooms, 100 gal tank for laundry) |
| | *Lighting* | 1.11 W/ft2 (guestrooms) |
| | *Exterior Lighting* | 13.030 W |
| | *Flooring* | Carpet |
| | *Interior Finishes* | (Not specified) |

Figure B.1: Axonometric View of Small Hotel Prototype



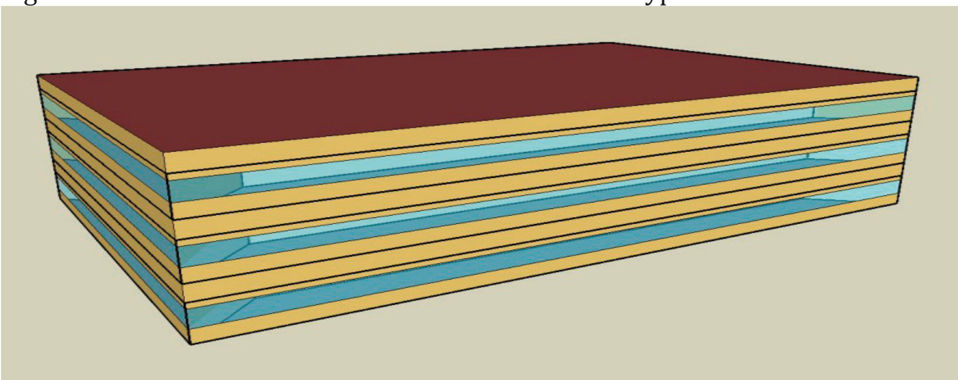
## MEDIUM OFFICE

The medium office design came out of the (PNNL) study. All of the attributes from the form, space configuration, construction type and floor plan are based on the specification of the medium size office schematics.

Table B.3: Building Details for Medium Office

| | Building | Medium Office |
|---|---|---|
| **Form** | | |
| | *Total Floor Area (sq feet)* | 53,600 ft2 (163.8' x 109.2') |
| | *Aspect Ratio* | 1.5 |
| | *Number of Floors* | 3 |
| | *Window Fraction (Window-to-Wall Ratio)* | (Window Dimensions: 163.8 ft x 4.29 ft on the long side of facade 109.2 ft x 4.29 ft on the short side of the façade) Average Total: 33% |
| | *Window Locations* | Window ribbons – 4.29 ft. high, around building perimeter each floor |
| | *Floor to floor height (feet)* | 13' |
| **Details** | | |
| | *Occupancy* | 268 People |
| | *Orientation* | Long axis orientation East/West |
| | *Requirements:* | |
| | *Parking Area* | 86,832.00 ft2 |
| | *Exterior Doors* | 5.36 ft2 |
| | *Façade* | 4,154.00 ft2 |
| **Architecture- Fixed across all Prototypes** | | |
| | *Superstructure* | (Not specified) Structural Steel Frame |
| | *Substructure* | (Not specified) Column Footings, strip footings for slab |
| | *Floor Deck* | (Not specified) Sheet metal decking, topping slab |
| | *Orientation* | Long axis orientation East/West |
| | *Fuel Mix* | Gas, Electricity |
| | *Foundation Slab* | 8" concrete slab |
| | *Interior Partitions* | 2x4 stud (nonloadbearing, uninsulated) |
| | *Plug Load* | 0.75 W/ft2 (guestrooms) |
| | *Elevator* | 2 Hydraulic (16,055 W) |
| **Change by location, certification level** | | |
| | *Windows* | Window ribbons – 4.29 ft. high, around building perimeter each floor |
| | *Skylight* | None |
| | *Ceiling* | 4" plenum |
| | *HVAC* | Gas furnace with packaged AC, VAV with electric reheat coil |
| | *Hot Water* | Natural gas, 260 gal tank |
| | *Lighting* | 1 W/ft2 (guestrooms) |
| | *Exterior Lighting* | 14,385 W |
| | *Flooring* | Carpet |
| | *Interior Finishes* | (Not specified) |
| | *Exterior Walls* | Steel frame (2x4 16"o.c.), .4" stucco, 5/8" gypsum board, insulation, 5/8" gypsum |
| | *Roof* | Membrane, insulation, metal decking |
| | *Floor Slab* | (Not specified) Insulation |

Figure B.2: Axonometric View of Medium Office Prototype



## APPENDIX C: DEFINITIONS OF BENEFIT-COST CATEGORIES

1. Initial Investment Cost—total building cost for completed facility approved for occupancy (excludes land acquisition); cost per square foot.
2. Major Repair and Replacement Costs—costs related to repair or replacement of major equipment within the study period, with identified timing for replacement.
3. Building energy—for lighting, heating/cooling/ventilation, security, sensing/controls, building equipment (e.g., elevators). Excludes plug and process loads (e.g., computers).
   - 3.1 Energy Source—electricity, distillate fuel oil (#1, #2), residual fuel oil (#4, #5, #6), natural gas, liquefied petroleum gas, coal, other (PV, wind, etc.).
   - 3.2 Annual consumption—total energy use; energy use by occupant, energy use by square foot.
   - 3.3 Local Cost—Price/kWh for electricity, Mcf for natural gas, Mbtu for other fuel types and rate schedule (residential, commercial, industrial).
4. Supporting Facilities (Site) energy—for landscape/site lighting, security, sensing/controls, site equipment (e.g., transformers).
   - 4.1 Energy Source—electricity, distillate fuel oil (#1, #2), residual fuel oil (#4, #5, #6), natural gas, liquefied petroleum gas, coal, other (PV, wind, etc.).
   - 4.2 Annual consumption—total energy use; energy use by square foot.
   - 4.3 Local Cost—Price/kWh for electricity, Mcf for natural gas, Mbtu for other fuel types and rate schedule (residential, commercial, industrial).
5. Building water use—for building systems (e.g., cooling) and fixtures/appliances.
   - 5.1 Water source—municipal, on-site well, rainwater harvesting, wastewater re-use, other.
   - 5.2 Annual water usage (summer, winter)—total water use; water use by occupant, water use by square foot.
   - 5.3 Local Cost—Price/gallon
6. Building wastewater (water disposal)—from building systems (e.g., cooling) and fixtures/appliances.
   - 6.1 Water treatment—municipal, on-site septic, wastewater re-use, other.
   - 6.2 Annual water usage (summer, winter)—total water use; water use by occupant, water use by square foot.
   - 6.3 Local Cost—Price/gallon.
7. Supporting Facilities (Site) water supply—for landscaping and related exterior water uses.
   - 7.1 Water source—municipal, on-site well, rainwater harvesting, wastewater re-use, other.
   - 7.2 Annual water usage (summer, winter)—total water use; water use by square foot.
   - 7.3 Local Cost—Price/gallon.

8. Municipal (Nonhazardous) Waste—solid waste haul and tip costs.
   8.1 Annual waste generated—total cost or weight; waste by occupant, waste by square foot.
   8.2 Local Cost—Price/ton.
9. Hazardous Waste—hazardous waste material handling and disposal (e.g., hydraulic fluid, pesticides, etc.).
   9.1 Annual hazardous waste generated—total cost or weight; waste by occupant, water by square foot.
   9.2 Local Cost—Price/ton.
10. Building/site O&M-Labor (personnel daily supervision for operations, maintenance, repair), materials, equipment.
    10.1 Annual O&M costs—total cost; cost by occupant, cost by square foot.
    10.2 Local Cost—Price/square foot or total annual cost.
11. Building Cleaning—includes labor, cleaning materials and equipment.
    11.1 Annual cleaning costs—total cost; by occupant, cost by square foot.
    11.2 Local Cost—Price/square foot or total annual cost.
12. Landscaping—includes labor, equipment and materials for cutting/mowing, raking, planting, pruning, tending, etc.
    12.1 Annual Landscaping costs—total cost; cost by occupant, cost by square foot.
    12.2 Local Cost—Price/square foot or total annual cost.

# APPENDIX D: BASELINE PROTOTYPE BUILDINGS RESOURCE USAGE AND FACTOR UNIT PRICES BY LOCATION

Table D.1: Benefit-Cost Data for Baseline Buildings: Quantities

| | Baseline Building Data | | |
|---|---|---|---|
| Benefit-Cost Category | Office | Hotel | References |
| Energy | | | DOE EERE Building Energy Codes Program, 90.1 Prototype Building Models, http://www.energycodes.gov/commercial/90 1models/ |
| Building water | 62 gal/sf/yr | 165 gal/sf/yr (includes laundry) | Office: http://www.seco.cpa.state.tx.us/SECO_Water_ Standards_2002.pdf<br>Hotel: http://coloradowaterwise.org/Resources/Doc uments/ICI_toolkit/docs/Brendle%20Group% 20and%20CWW%20ICI%20Benchmarking%2 0Study.pdf |
| Landscape water | 30 gal/sf/yr | 60 gal/sf/yr | Office: http://www.seco.cpa.state.tx.us/SECO_Water_ Standards_2002.pdf<br>Hotel: http://www.watertechonline.com/municipal-industrial/article/finding-hidden-water |
| Municipal solid waste | 0.00178 tons/sf/yr | 0.000712 ton/sf/yr | http://www.wastecare.com/usefulinfo/Waste _Generated_by_Industry.htm |
| Hazardous waste | 0.005 ton/sf/yr | 0.000007 ton/sf/yr | http://www.sustainability.umd.edu/document s/2010_Sustainability_Metrics_Report.pdf<br>http://www.epa.gov/region9/waste/solid/ho use.html |
| Building/ site O&M | $3.00/sf/yr | $3.00/sf/yr | FM Benchmark 6/19/2012, http://www.fmbenchmarking.com/ |
| Building Cleaning | $2.50/sf/yr | $2.50/sf/yr | FM Benchmark 6/19/2012, http://www.fmbenchmarking.com/ |
| Landscaping | $0.28/sf/yr | $0.28/sf/yr | 2008 M&O Study, http://asumag.com/Maintenance/2008M&OC ostStudy.pdf |

Table D.2: Factor Unit Prices By Location

| Location | Electricity ($/kwh)[1] | Natural Gas ($/ft3)[1] | Water ($/gal)[2] | Wastewater ($/gal)[3] | Municipal Solid Waste ($/ton) | Hazardous Waste ($/ton)[9] | Renewable Energy Credit ($/kwh)[10] |
|---|---|---|---|---|---|---|---|
| Miami | $0.0980 | $10.28 | $0.0041 | $0.0059 | 62.59 [7] | $114.18 | $0.09 |
| Phoenix | $0.0921 | $9.68 | $0.0018 | $0.0017 | 38.25 [8] | $10.00 | $0.09 |
| Memphis | $0.0989 | $8.66 | $0.0027 | $0.0020 | 22.00 [6] | $15.00 | $0.09 |
| Baltimore | $0.1060 | $11.11 | $0.0032 | $0.0041 | 80.00 [4] | $80.00 | $0.09 |
| Helena | $0.0906 | $7.99 | $0.0035 | $0.0028 | 70.75 [5] | $75.00 | $0.09 |

[1] DOE EIA, April 2012
[2] Local water utility rates, June 2012
[3] The Price of Wastewater: A Comparison of Sewar Rates in 30 U.S. cities – Circle of Blue WaterNews, August 20
[4] Baltimore County, MD Public Works – Refuse Disposal/FAQs
[5] Helena Transfer Station Fees
[6] A Citizen's Guide to a Cleaner Memphis
[7] Miami-Dade County – Department of Solid Waste Management Schedule of Disposal Fees Oct. 2011
[8] City of Phoenix – Disposal Facility Fees, 2012
[9] Army Corps State Taxes and Fees for Hazardous Waste Disposal
[10] estimated based on PG&E PPA Nov. 2010 @ $0.09/kWh

## APPENDIX E: FEDERAL STATUTES FOR LIFE CYCLE COST ANALYSIS

Federal capital projects are required to conduct life-cycle cost analysis under the National Energy Conservation Policy Act (1978), the Federal Energy Management Improvement Act (1988), the Energy Policy Act (2005), and the Energy Independence and Security Act (2007), which are specified in the Office of Management and Budget (OMB) Circular A-94 and the Code of Federal Regulations, Title 10, Part 436, Subpart A (10 CFR 436A). The Energy Independence and Security Act (EISA), Section 432, 4(B) further specifies that each energy manager may "bundle individual measure of varying paybacks together into combined projects."

OMB Circular A-94 Appendix C is updated annually with the nominal and real discount rates to be used for cost-effectiveness studies of federal capital investments.

The Federal Energy Management Program (FEMP) is applicable to renewable energy, energy conservation, and water conservation projects in all federal buildings. Each year, FEMP provides the applicable discount rate to be used to assess those projects, with the discount rate set by statute (10 CFR 436) at a minimum of 3% and a maximum of 10%. In addition, the Department of Energy (DOE) Energy Information Administration (EIA) provides thirty-year forecasts of energy prices.

The National Institute of Standards and Technology (NIST) incorporates the OMB and FEMP discount rates, and the energy indices based on the DOE EIA forecasts into the Annual Supplement to NIST Handbook 135, Life-Cycle Costing Manual for the Federal Energy Management Program. NIST also provides the NIST Building Life-Cycle Cost (BLCC) software program, which incorporates the annual updates. (The BLCC software is available for download available through http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc).

# APPENDIX F: REFERENCES FOR FEDERAL REPORTING REQUIREMENTS FOR BENEFIT-COST CATEGORIES

The Federal Energy Management Program (FEMP) requires the Department of Defense to provide an Annual Energy Management Report (AEMR) to Congress, which "enables the Department to track and report progress against facility energy goals required by several relevant legislative statues, executive orders, and internal DOD directives. "[35] The DOD is also required to report subject to other legislative requirements, including 10 USC Section 2925, and 10 USC Section 2911(e). Recent AEMR performance measures are listed in Table F.1.

Table F.1: Annual Energy Management Report—Outcome Measures

| Measures |
| --- |
| Facilities energy use (electricity, natural gas, fuel oil, coal, purchased steam, LPG/Propane and renewables) |
| Energy intensity level (BTU/area) Renewable energy use Renewable energy potential |
| On-site energy production during grid outages |
| Water intensity (gallons/area) Potable water use |
| Industrial, landscaping and agriculture water consumption |
| Metering of electricity use |
| Non-tactical fleet vehicle fuel consumption |
| Progress on Federal Building Energy Efficiency Standards—30% more energy efficient than ASHRAE 90.1-2004 standard |
| Waste prevention (hazardous, nonhazardous) |
| Electronics stewardship |

# APPENDIX G: ASHRAE DATA GENERATION METHODOLOGY

ASHRAE Standards 90.1-2010 and 189.1-2011 First Costs

Prepared By: Merle McBride, Ph.D., P.E., ASHRAE Member

Date: August 8, 2012

Prepared for: ASHRAE in support of the NDAA 2013 Section 2830(a) in which Congress required the Department of Defense to submit a report, in part, on the economics of ASHRAE Standards 90.1-2010 and 189.1-2011.

## ACRONYMS

| | |
| --- | --- |
| AEDG | Advanced Energy Design Guide |
| DOE | U.S. Department of Energy |
| FC | first cost |

[35] Office of the Deputy Under Secretary of Defense (Installations and Environment) (2011). *Department of Defense Annual Energy Management Report Fiscal Year 2010,* p. 9.

| | |
|---|---|
| HVAC | heating, ventilating and air-conditioning |
| Int. Ltg. | interior lighting |
| kWh | kilowatt hour |
| LPD | lighting power density |
| Mcf | thousands of cubic feet |
| NREL | National Renewable Energy Laboratory |
| PPL | plug and process loads |
| PNNL | Pacific Northwest National Laboratory |
| PV | photovoltaic |
| SWH | service water heating |
| TSD | technical support document |
| VAV | variable air volume |

## FIGURES



## TABLES



## ASHRAE STANDARD 90.1-2010 AND STANDARD 189.1-2011 FIRST COSTS

### 1.0 Introduction

In support of the ASHRAE energy standards development process the U.S. Department of Energy (DOE) provides technical resources through the Pacific Northwest National Laboratory (PNNL) to assist in the development of the criteria and periodic updates on the energy savings progress. Then, once the standard is finalized, PNNL determines the energy savings of the new standard relative to a baseline standard(s). Evaluation of the final standard is a very time consuming process and consequently follows publication of the standard by a significant time lag. This is the current situation for both Standards 90.1-2010 and 189.1-2011. The first costs and final energy savings will be formally documented but the analysis and results are not currently available for use in this project.

Recognizing that the final reports for Standards 90.1-2010 and 189.1-2011 were not available, the challenge was to estimate the first costs using information contained in currently published reports. These first costs are understood to be approximate. This report presents the methodology used to develop the first costs and the final results. It is critical to understand that the calculation of the first costs is based on the energy savings. Thus, this report contains the annual energy savings as well as the first costs.

## 2.0 Objective

The objective of this analysis was to determine the first costs for ASHRAE Standards 90.1-2010 and 189.1-2011 relative to the baseline ASHRAE Standard 90.1-2004.

## 3.0 Background

The first costs for ASHRAE Standards 90.1-2010 and 189.1-2011 had not been previously calculated and reported so they have to be derived from the data that was readily available. The Technical Support Documents developed in support of the ASHRAE Advanced Energy Design Guides from PNNL for the medium office building (Thornton, 2009) and highway lodging (Jiang) provided the only first cost data for each city. However, neither of these reports contained all of the individual energy results which were needed in order to determine the first costs. Mike Rosenberg, from PNNL, was contacted and provided the EnergyPlus simulation results which contained the required energy information.

## 4.0 Representative Cities

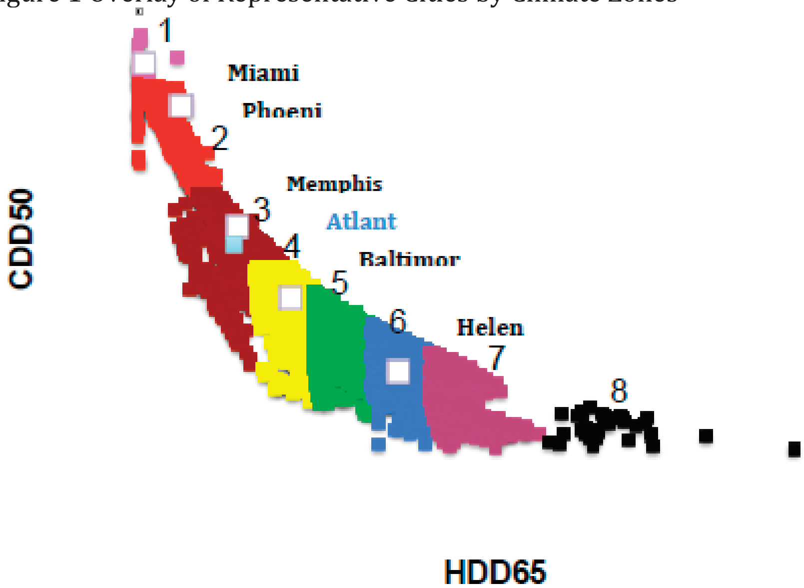
All of the analysis was intended to use the same representative five cities, see Table 1. However, in some of the reports Memphis was replaced with Atlanta.

Figure 1 is an overlay of the representative cities in their climate zones. Each climate zone is shown as a separate color. The representative cities are shown as a white square while Atlanta is a blue square. In general the representative cities are centrally located within the climate zones. The climatic conditions for Atlanta are very close to Memphis so applying the data for Atlanta to Memphis was assumed to be appropriate.

Table 1 Representative Cities

| CZ | City | HDD65 | CDD50 |
|---|---|---|---|
| 1 | Miami | 200 | 9474 |
| 2 | Phoenix | 1350 | 8425 |
| 3 | Memphis | 3082 | 5467 |
| 3 | Atlanta | 2991 | 5038 |
| 4 | Baltimore | 4704 | 3709 |
| 6 | Helena | 8031 | 1922 |

Figure 1 Overlay of Representative Cities by Climate Zones




## 5.0 Supporting Documents

Multiple reports have been previously completed which contain energy saving results in some form, either for individual cities and building types or weighted averages by climate zone or a national average, see Table 2. The information in these reports was used to estimate the first costs and annual energy savings for Standards 90.1-2010 and 189.1-2011.

Table 2 Sources of Information

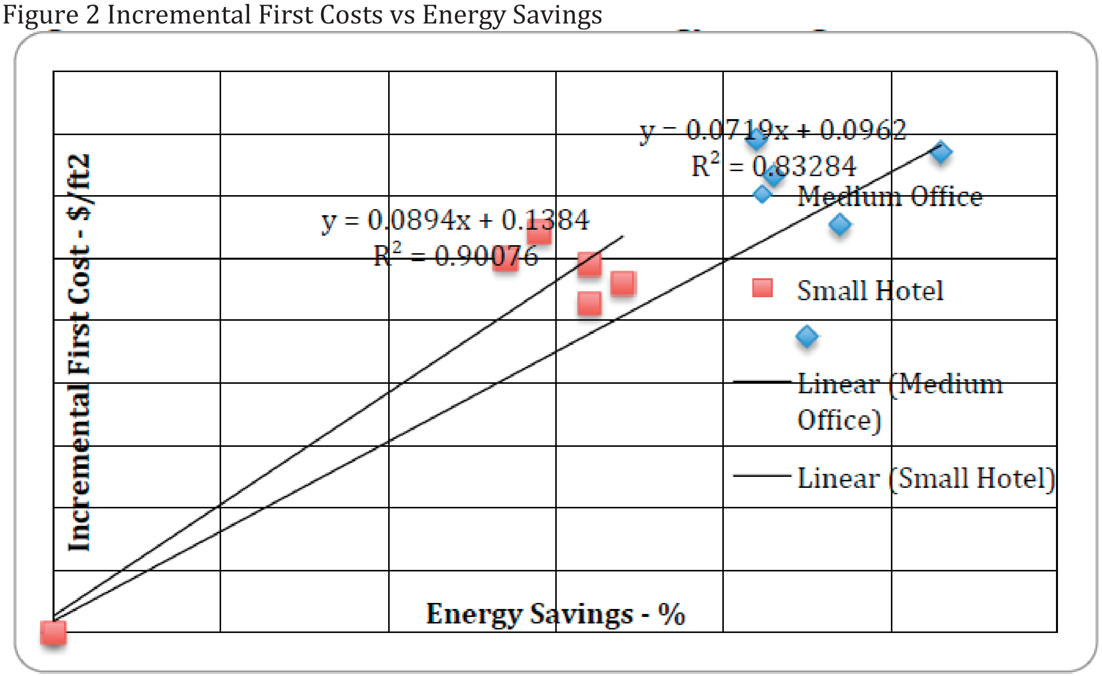
| Report | Subject | 90.1 Base Standard | Energy Savings |
|---|---|---|---|
| PNNL-17875<br>(Jiang) | Highway Lodging—<br>30% AEDG | 1999<br>2004 | 39.3%<br>33.5% |
| PNNL-19004<br>(Thornton 2009) | Medium Office—<br>50% AEDG | 2004-VAV System<br>2004-Radiant System | 46.3%<br>56.1% |
| PNNL-20405<br>(Thornton 2011) | Std. 90.1-2010 | 2004 | 25.6% PPL<br>32.7% w/o PPL |
| PNNL-189.1<br>Progress Indicator (Liu) | Comparison between<br>189.1-2009 and 90.1-2010 | Medium Office<br>Small Hotel | 3.9%<br>17.4% |
| NREL/TP-550-47906<br>(Long) | Std. 189.1-2009 | 2007-Medium Office<br>2007-Small Hotel | 31.0%<br>34.3% |

## 6.0 Technical Approach

Fundamentally, the technical approach was to use the ASHRAE Advanced Energy Design Guides energy savings for each specific building and location which also had the incremental first costs. This information was used to determine a linear relationship between the incremental first costs in $\$/ft^2$ and the energy savings as a percent. This linear relationship was derived for each building type in each city. The \$/ft$^2$ was assumed to go through the origin when there were no energy savings. As an example of this concept, Figure 2 shows the five locations for both building types. A straight line through the origin is shown that connects the average for each building type. However, the actual calculations use a specific linear relationship for each individual city and building type which is the slope of each line.

The first step in this process was to estimate the energy savings for both of the building types in all five cities relative to the baseline Standard 90.1-2004. Those results were then used to approximate the first costs for Standards 90.1-2010 and 189.1-2011. This process was straight forward for Standard 90.1-2010. However, for Standard 189.1-2011 it was more complicated because photovoltaic (PV) panels were used to meet the annual on-site renewable energy requirements so those first costs had to be analyzed separately. Furthermore, the results for Standard 189.1-2009 could not be used directly because the requirements for the annual on-site renewable energy changed between Standards 189.1-2009 and 189.1-2011 which impacts the first costs so additional analyses were required.

Figure 2 Incremental First Costs vs Energy Savings




## 7.0 Incremental First Costs

The data in Tables 3 and 4 formed the basis for all of the first cost calculations used in this study. These incremental first costs account for all of the upgrades due to more stringent criteria for the envelope, lighting, HVAC and SWH. These incremental costs do not account for any of the first costs for the PV systems so they need to be calculated separately.

Table 3 Incremental First Costs for the Medium Office

| | | Medium Office (PNNL 19004) | | | |
|---|---|---|---|---|---|
| CZ | City | Energy Savings (%) | Incremental FC ($) | Incremental FC ($/ft²) | Slope ($/ft²/%) |
| 1 | Miami | 47 | 175,176 | 3.27 | 0.0695 |
| 2 | Phoenix | 53 | 206,606 | 3.85 | 0.0727 |
| 3 | Atlanta | 42 | 211,909 | 3.95 | 0.0941 |
| 4 | Baltimore | 43 | 196,787 | 3.67 | 0.0854 |
| 6 | Helena | 45 | 127,134 | 2.37 | 0.0527 |

Table 4 Incremental First Costs for the Small Hotel

| | | Small Hotel (PNNL 17875) | | | |
|---|---|---|---|---|---|
| CZ | City | Energy Savings (%) | Incremental FC ($) | Incremental FC ($/ft²) | Slope ($/ft²/%) |
| 1 | Miami | 27 | 129,607 | 3.00 | 0.1111 |
| 2 | Phoenix | 29 | 138,752 | 3.21 | 0.1107 |
| 3 | Memphis | 32 | 127,498 | 2.95 | 0.0922 |
| 4 | Baltimore | 34 | 120,879 | 2.80 | 0.0824 |
| 6 | Helena | 32 | 114,183 | 2.64 | 0.0825 |

## 8.0 First Costs—Standard 90.1-2010

The initial step in determining the first costs is to calculate the percentage of energy savings between the baseline Standard 90.1-2004 and 90.1-2010. In order to perform this calculation the electrical and gas energies are added together using kWh as the common metric which is listed as Energy in Tables 5 and 6.

Table 5 Standard 90.1-2010 Medium Office First Costs

| | | 90.1-2004 | 90.1-2010 | | Incremental | | 90.1-2004 | 90.1-2010 |
|---|---|---|---|---|---|---|---|---|
| CZ | City | Energy (kWh) | Energy (kWh) | Save (%) | FC ($/ft²) | FC ($) | Baseline ($) | Total ($) |
| 1 | Miami | 802,795 | 609,372 | 24.09 | 1.68 | 89,801 | 6,052,000 | 6,141,801 |
| 2 | Phoenix | 805,658 | 604,243 | 25.00 | 1.82 | 97,456 | 5,970,500 | 6,067,956 |
| 3 | Memphis | 788,061 | 566,718 | 28.09 | 2.64 | 141,712 | 5,754,000 | 5,895,711 |
| 4 | Baltimore | 823,329 | 579,172 | 29.65 | 2.53 | 135.714 | 6,273,000 | 6,408,714 |
| 6 | Helena | 856,362 | 621,534 | 27.42 | 1.45 | 77,472 | 5,944,500 | 6,021,972 |

Table 6 Standard 90.1-2010 Small Hotel First Costs

| | | 90.1-2004 | 90.1-2010 | | Incremental | | 90.1-2004 | 90.1-2010 |
|---|---|---|---|---|---|---|---|---|
| CZ | City | Energy (kWh) | Energy (kWh) | Save (%) | FC ($/ft²) | FC ($) | Baseline ($) | Total ($) |
| 1 | Miami | 905,411 | 803,172 | 11.29 | 1.25 | 54,204 | 5,049,888 | 5,104,092 |
| 2 | Phoenix | 891,109 | 777,857 | 12.71 | 1.41 | 60,807 | 4,977,888 | 5,038,695 |
| 3 | Memphis | 939,094 | 806,713 | 14.10 | 1.30 | 56,166 | 4,825,388 | 4,881,554 |
| 4 | Baltimore | 1,001,871 | 845,071 | 15.65 | 1.29 | 55,642 | 5,172,960 | 5,228,602 |
| 6 | Helena | 1,067,193 | 892,747 | 16.35 | 1.35 | 58,327 | 4,990,888 | 5,049,215 |

## 9.0 Renewable Energy—Photovoltaic Panels

Photovoltaic panels were modeled with EnergyPlus for Std. 189.1-2009 to comply with the annual on-site renewable energy requirements which are presented in Table 7.

The major difference between Standards 189.1-2009 and 189.1-2011 is the area multiplier. In Std. 189.1-2009 the area multiplier is the conditioned space but was changed in Std. 189.1-2011 to be the total roof area, see Table 8.

This change has no impact for one story buildings but has a major impact on multi-story buildings such as those being analyzed in this project, see Table 9.

The next requirement in determining the PV first cost was to calculate the number of PV panels required for each building type in each city. An analysis was completed using the PVWatts calculator developed by NREL which is readily available at their internet web site. The results for a 4 kW panel are presented in Table 10.

Using the energy performance of an individual panel, the number of panels required can be calculated as well as their total first costs. A 4 kW DC panel was assumed to have a de-rated factor of 0.77 which would produce 3.1 kW AC. Goodman reported the cost in 2010 for PV systems as $4.59/W for commercial roof top installations. However, the costs have been steadily decreasing. A realistic estimate for 2012 per Eric Bonnema of NREL is $4.00/W so this value was used for this analysis. Thus, the total cost for a 4 kW panel is $16,000. Using this price the total panel costs and the building costs per square foot can be calculated.

The modeling of Std. 189.1-2009 (Liu) used the high efficiency HVAC requirements, see Table 11.

For purposes of this study the energy savings and first costs for Std. 189.1-2011 also assumed the high efficiency HVAC requirement, see Table 12.

Table 7 Annual On-Site Renewable Energy Criteria

| Standard Criteria | 189.1-2009 | 189.1-2011 |
|---|---|---|
| Prescriptive Criteria (7.4.1.1) | 6.0 kBtu/ft² (20 kWh/m²) × Conditioned Space Floor Area | Single Story Buildings = 6.0 kBtu/ft² (20 kWh/m²) × Total Roof Area<br><br>All Other Buildings = 10.0 kBtu/ft² (32 kWh/m²) × Total Roof Area |
| HVAC High Efficiency Modification (7.4.3.1) | 4.0 kBtu/ft² (13 kWh/m²) x Conditioned Space Floor Area | Single Story Buildings = 4.0 kBtu/ft² (13 kWh/m²) × Total Roof Area<br><br>All Other Buildings = 7.0 kBtu/ft² (22 kWh/m²) × Total Roof Area |

Table 8 Conditioned Space and Roof Areas

| Area | Medium Office | Small Hotel |
|---|---|---|
| Conditioned space | 53,660 $ft^2$ (4,985 $m^2$) | 43,200 $ft^2$ (4,013 $m^2$) |
| Roof | 17,867 $ft^2$ (1,660 $m^2$) | 10,800 $ft^2$ (1,003 $m^2$) |

Table 9 Annual On-Site Renewable Energy Criteria

| Code Requirement | Medium Office (kWh) | Small Hotel (kWh) |
|---|---|---|
| Std. 189.1-2009 | 99,700 | 80,260 |
| Std. 189.1-2009—High-Efficiency HVAC | 64,805 | 52,169 |
| Std. 189.1-2011 | 53,120 | 32,096 |
| Std. 189.1-2011—High-Efficiency HVAC | 36,520 | 22,066 |

Table 10 PV Panels Energy Performance

| CZ | City | Solar Radiation (kWh/$m^2$-day) | 4 kW DC produces annual AC (kWh) |
|---|---|---|---|
| 1 | Miami | 5.26 | 5,357 |
| 2 | Phoenix | 6.57 | 6,468 |
| 3 | Memphis | 5.18 | 5,352 |
| 4 | Baltimore | 4.66 | 4,911 |
| 6 | Helena | 4.71 | 5,040 |

Table 11 Annual On-Site Renewable Energy—Standard 189.1-2009

| | | Medium Office | | | | Small Hotel | | | |
|---|---|---|---|---|---|---|---|---|---|
| C Z | City | Energy (kWh) | Panels (No.) | FC ($) | FC ($/$ft^2$) | Energy (kWh) | Panels (No.) | FC ($) | FC ($/$ft^2$) |
| 1 | Miami | 62,847 | 11.73 | 187,708 | 4.35 | 50,619 | 9.45 | 151,186 | 2.82 |
| 2 | Phoenix | 62,767 | 9.70 | 155,268 | 3.59 | 50,619 | 7.83 | 125,217 | 2.34 |
| 3 | Memphis | 62,750 | 11.72 | 187,593 | 4.34 | 50,619 | 9.46 | 151,327 | 2.82 |
| 4 | Baltimore | 62,842 | 12.80 | 204,739 | 4.74 | 50,619 | 10.31 | 164,916 | 3.08 |
| 6 | Helena | 62,561 | 12.41 | 198,606 | 4.60 | 50,619 | 10.04 | 160,695 | 3.00 |

Table 12 Annual On-Site Renewable Energy—Standard 189.1-2011

| | | Medium Office—36,520 kWh | | | Small Hotel—22,066 kWh | | |
|---|---|---|---|---|---|---|---|
| CZ | City | Panel (No.) | FC ($) | FC ($/ft$^2$) | Panel (No.) | FC ($) | FC ($/ft$^2$) |
| 1 | Miami | 6.82 | 109,076 | 2.52 | 4.12 | 65,906 | 1.23 |
| 2 | Phoenix | 5.65 | 90,340 | 2.09 | 3.41 | 54,585 | 1.02 |
| 3 | Memphis | 6.82 | 109,178 | 2.53 | 4.12 | 65,967 | 1.23 |
| 4 | Baltimore | 7.44 | 118,982 | 2.75 | 4.49 | 71,891 | 1.34 |
| 6 | Helena | 7.25 | 115,937 | 2.68 | 4.38 | 70,051 | 1.31 |

## 10.0 First Costs—Standard 189.1-2011

The data available for this study included an energy analysis for Std. 189.1-2009 but nothing for Std. 189.1-2011. No data on first costs for either standard was available so it had to be estimated. The starting point was to identify the major differences in the criteria between Standards 189.1-2009 and 189.1-2011. Many features were the same between these two standards including all of envelope criteria plus the HVAC and SWH equipment efficiencies. There were two differences that were explicitly accounted for in this study, the interior lighting power and PV requirements.

The first costs for Std. 189.1-2011 include all of the building envelope, lighting and equipment upgrades plus the first costs for the PV system. In order to determine the building first costs the building energy is required. The building energy was calculated using Eq. 1.

$$\text{Energy of 189.1-2011} = \text{Energy of 189.1-2009} - \text{Int. Ltg. 189.1-2009} + \text{Int. Ltg. of 90.1-2010} \times \text{LPD Factor in 189.1-2011.} \quad (1)$$

In Standard 189.1-2011 Table 7.4.6.1A LPD Factors when Using the Building Area Method lists the LPD Factor of 0.95 for offices and 1.00 for hotels.

It is important to note that the energy use associated with the interior lighting has been accounted for directly. However, the impact of the reduced lighting energy will increase the heating loads and reduce the cooling loads in the building but that has not been included.

The first costs for Standard 189.1-2011 are presented in Tables 13 and 14. The energy listed for Standards 90.1-2004 and 189.1-2011 is the total site energy for the building with the gas usage converted into kWh.

Table 13 Standard 189.1-2011 Medium Office First Costs

| | | 90.1-2004 | 189.1-2011 | | Building Incremental | | PV | 90.1-2004 | 189.1-2011 |
|---|---|---|---|---|---|---|---|---|---|
| CZ | City | Energy (kWh) | Energy (kWh) | Save (%) | FC ($/ft$^2$) | FC ($) | FC ($) | Baseline ($) | Total ($) |
| 1 | Miami | 802,795 | 623,508 | 22.3 | 1.55 | 83,009 | 109,076 | 6,052,000 | 6,244,085 |
| 2 | Phoenix | 805,658 | 605,325 | 24.9 | 1.81 | 96,895 | 187,235 | 5,970,500 | 6,157,735 |
| 3 | Memphis | 788,061 | 598,540 | 24.1 | 2.27 | 121,618 | 230,796 | 5,754,000 | 5,984,796 |
| 4 | Baltimore | 823,329 | 619,554 | 24.8 | 2.11 | 113,292 | 232,274 | 6,273,000 | 6,505,274 |
| 6 | Helena | 856,362 | 652,357 | 38.9 | 2.05 | 109,802 | 225,739 | 5,944,500 | 6,170,239 |

Table 14 Standard 189.1-2011 Small Hotel First Costs

| | | 90.1-2004 | 189.1-2011 | | Building Incremental | | PV | 90.1-2004 | 189.1-2011 |
|---|---|---|---|---|---|---|---|---|---|
| CZ | City | Energy (kWh) | Energy (kWh) | Save (%) | FC ($/ft²) | FC ($) | FC ($) | Baseline ($) | Total ($) |
| 1 | Miami | 905,411 | 733,948 | 18.9 | 2.10 | 156,797 | 65,906 | 5,049,888 | 5,206,685 |
| 2 | Phoenix | 891,109 | 727,481 | 18.4 | 2.03 | 142,398 | 54,585 | 4,977,888 | 5,120,286 |
| 3 | Memphis | 939,094 | 727,860 | 22.5 | 2.07 | 159,559 | 65,967 | 4,825,388 | 4,980,947 |
| 4 | Baltimore | 1,001,871 | 738,893 | 26.2 | 2.16 | 165,328 | 71,891 | 5,172,960 | 5,338,288 |
| 6 | Helena | 1,067,193 | 765,549 | 28.3 | 2.33 | 170,788 | 70,051 | 4,990,888 | 5,161,676 |

## 11.0 Summary

Tables 15 and 16 present the Standard 90.1-2010 and 189.1-2011 first costs and site energy consumptions for both building types so all of the information is conveniently located and summarized for quick reference.

The analysis used to develop these first costs and energy consumptions has required many simplifying assumptions. The fundamental approach was to assume a linear relationship between the first costs and the energy savings. Fortunately the energy savings of the AEDG exceeded that of Standards 90.1-2010 and 189.1-2011 so all of the first costs were interpolated and did not need to be extrapolated, see Table 17.

An estimate of the first costs and energy savings for Standard 90.1-2010 and 189.1-2011 has been completed. A simplified linear approach was used to determine the results since no reports have been published that contain the required data. Two major differences between the standards were specifically analyzed, the interior lighting power densities and the annual on-site renewable energy requirements. While the direct energy consumption of the interior lights was analyzed the impact of the reduced lighting power was not accounted for in terms of increasing the heating loads and reducing the cool loads. Correct modeling of the interactions was beyond the scope of this project and is best done thorough detailed hourly simulation models such as EnergyPlus.

All of the results presented in Tables 16 and 17 include the energy consumptions associated with the interior equipment in each of the buildings. Interior equipment refers to any electrical device that plugs into an outlet (typically not hard wired) and any interior process loads. Plug loads in offices would include computers, monitors, printers, copy machines, vending machines, refrigerators, coffee makers, and desk lamps for task lighting. In addition, hotels would also have televisions, microwave, hair dryers, table and floor lamps in each guest room. Process loads include the clothes washers and dryers in hotels. Table 18 is the summary of the interior equipment energy consumptions that were modeled in the EnergyPlus simulations.

Table 15 Summary of Results for Standard 90.1-2010

| | | Medium Office | | | Small Hotel | | |
|---|---|---|---|---|---|---|---|
| CZ | City | FC ($) | Elec. (kWh) | Gas (Mcf) | FC ($) | Elec. (kWh) | Gas (Mcf) |
| 1 | Miami | 6,141,801 | 575,130 | 113 | 5,104,092 | 584,536 | 724 |
| 2 | Phoenix | 6,067,956 | 563,558 | 135 | 5,038,695 | 543,719 | 776 |
| 3 | Memphis | 5,895,711 | 507,455 | 196 | 4,881,554 | 516,889 | 960 |
| 4 | Baltimore | 6,408,714 | 474,919 | 345 | 5,228,602 | 498,256 | 1149 |
| 6 | Helena | 6,021,972 | 465,091 | 518 | 5,049,215 | 478,914 | 1371 |

Table 16 Summary of Results for Standard 189.1-2011

| | | Medium Office | | | Small Hotel | | |
|---|---|---|---|---|---|---|---|
| CZ | City | FC ($) | Elec. (kWh) | Gas (Mcf) | FC ($) | Elec. (kWh) | Gas (Mcf) |
| 1 | Miami | 6,244,085 | 588,664 | 117 | 5,206,685 | 517,411 | 718 |
| 2 | Phoenix | 6,157,735 | 561,436 | 145 | 5,120,286 | 496,353 | 766 |
| 3 | Memphis | 5,984,796 | 509,573 | 293 | 4,980,947 | 471,153 | 851 |
| 4 | Baltimore | 6,505,274 | 484,121 | 449 | 5,338,288 | 456,958 | 934 |
| 6 | Helena | 6,170,239 | 466,415 | 616 | 5,161,676 | 440,558 | 1077 |

Table 17 Range of Energy Savings (%)

| Document | Medium Office | Small Hotel |
|---|---|---|
| AEDG | 42-53 | 27-34 |
| Std. 90.1-2010 | 24-30 | 11-16 |
| Std. 189.1-2011 | 22-39 | 19-28 |

Table 18 Interior Equipment Energy Consumptions

| | Medium Office | | Small Hotel | |
|---|---|---|---|---|
| Standard | kWh | Mcf | kWh | Mcf |
| 90.1-2010 | 211,799 | 0 | 164,169 | 388 |
| 189.1-2011 | 235,822 | 0 | 158,386 | 388 |

## 12.0 References


ASHRAE. (2004). *ANSI/ASHRAE/IESNA Standard 90.1-2004: Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2009). *ANSI/ASHRAE/USGBC/IES Standard 189.1-2009: Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

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### 13.0 Web Sites

PVWatts: www.nrel.gov/rredc/pvwatts.

## ASHRAE DATA METHODOLOGY: WATER USE ANALYSIS

The following is a summary of water use savings estimates made by WMI. The starting point for all of the estimates was the water use given in the data temples.

### Plumbing Fixtures

To calculate the saving for plumbing fixture related measures WMI uses a model that considers multiple factors. The number, type, and flow rate of the existing fixtures help us to determine the overall existing condition of the domestic fixtures. Often, the fixture flow rates differ from the designed flow rates. For example, many 1.6 gpf toilets fitted with 1.6 gpf diaphragm flushometers typically use between 1.8 and 2.5 gpf. Once existing flow rates are determined, frequency of usage is then calculated based on building demographic information.

Usage is affected by many factors: the population of a facility, the hours of use, the average number of times a person will use the facilities. Another factor is the split of the population between male and female. Studies have shown that on the average people need to use the toilets an average of once every two hours and when available, men will use the urinals about 75% of the time.

The basic formula is as follows:

Existing usage model = Population × uses per day (decreased by the flush factor) × days of use per year × the average existing flow rates of the fixtures.

Post-program usage model = Population × uses per day (decreased by the flush factor) × days of use per year × the average proposed flow rates of the fixtures.

Showers are also included in the hotel template calculations. These were based on an average of sampled flow rates for showers in hotels throughout the U.S. and usage was calculated using a conservative shower duration length of 8 minutes per shower.

The post-program annual gallons saved = the difference between the two.

ASHRAE 189.1 was used as the basis for efficient plumbing fixture selection and use.

## Landscape

Water use for landscape irrigation in high performance landscapes is based on proper selection of plant material, proper soil preparation, and watering based on the actual needs of the plant material in the landscape. The basic principles of good landscape water practices include:

1. Design Landscape to keep water (rainwater, storm water, and irrigation water) where it falls.
2. Prepare soil shape and content to capture and hold water
3. Design landscape to minimize the need for irrigation water (eliminate irrigation systems where possible)
4. Minimize turf areas and choose adapted and drought tolerant plant materials
5. Meter or sub-meter installed irrigation systems
6. Capture and use on-site sources of water and/or reclaimed water
7. Design efficient irrigation system using US EPA WaterSense principles
8. Practice proper maintenance.

Water use is based on evapotranspiration of the plant material actually used. The equation is:

Water Demand = [Area of landscape × (ETo × Kc) − Effective rainfall)] × [FF] × 0.623 DU

- ETo—Reference evapotranspiration
- Kc—Crop Coefficient
- Effective rainfall—assume 25% (WaterSense)
- DU—Distribution Uniformity
- FF—Freeze factor when system off in Winter
- 0.623—Gallons per inch on one square foot of area

Monthly evapotranspiration for each site was taken into consideration along with plant material and practices common to those areas. Savings were based on the difference between the amounts of water given in the data templates and the water use based on good practice for all of the eight principles outlined above. These principles are reflected in ASHRAE 189.1

# D

# Literature Review

This appendix contains more detailed information about the studies that the committee relied on most heavily in formulating its findings and recommendations related to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards 90.1 and 189.1 and of the Leadership in Energy and Environmental Design (LEED) and Green Globes green building certification systems. It also contains information on a literature review (Hunt, 2008) that was not otherwise cited. In all, 26 studies are described. The information provided typically includes the study goals and objectives, the methodology used, characteristics of the sample (e.g., size, location, building types), and the findings that are most relevant to the committee's statement of task. In most cases, the studies are quoted directly, as indicated by the inclusion of page numbers in parentheses.

The studies are organized into three categories: studies on energy, water, and related factors (subcategories include studies on federal buildings and regional studies); studies on indoor environmental quality and productivity; and studies on the incremental costs to design and construct high-performance or green buildings. Those categories are not, however, exclusive, and findings from some studies could be grouped within more than one category.

## STUDIES ON ENERGY, WATER, AND RELATED FACTORS

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

Torcellini et al. conducted field evaluations of six high-performance buildings and compared the energy performance of each of the buildings to each other and to code-compliant base-case buildings. Each of the six new buildings used a design process that included low energy use as a design goal. Computer simulations were used for each building during the design process. (The study does not say whether these buildings were certified under a green building rating system.) After construction, energy flows were monitored for a minimum of 1 year, including lighting loads, heating, ventilation, and air-conditioning (HVAC) loads, and plug loads. Data were tabulated every 15 minutes and the data were used to calibrate the computer simulation models. Among the study findings were the following:

- All of the buildings used much less energy on an annualized basis than comparable code-compliant buildings. Three of the buildings had net source energy savings of more than 50 percent. Three of the buildings had energy cost savings that exceeded 50 percent. Overall, net source energy savings ranged from 77 to 22 percent, and energy cost savings ranged from 67 to 12 percent.
- Site energy use was 25 to 62 percent less than the baselines. Site energy costs were 12 to 67 percent less than the baselines.
- Each building's actual energy use was greater than the energy use predicted by models. Factors cited for this included occupant behavior and their acceptance of systems; higher plug loads than modeled; temperature controls set higher in actuality than in modeling; changes between the buildings as they were designed and as they were constructed.
- Creating energy cost goals during design and verifying the costs are difficult due to instability in energy prices.
- Caution must be exercised in comparing the initial predictions, analysis, and actual data because these numbers can vary greatly.
- Measurable goals must be defined that can be used throughout the design process. Setting the goal can drive the project and can result in good performance against that metric.
- Achieving and maintaining high performance of the building requires a constant effort, which is absent in most buildings. Continually tracking building performance is expensive and requires motivated, trained staff. However, advances in metering technology, computerized communications, and automated controls offer hope for the future.

**Evaluating the Energy Performance of the First Generation of LEED-Certified Commercial Buildings**

R. Diamond, M. Optiz, T. Hicks, B. Von Neida, and S. Herrera. Lawrence Berkeley National Laboratory: Berkeley, Calif. 2006.

This study by Diamond et al. presented an early analysis of the actual energy performance of 21 LEED-certified buildings that were certified between December 2001 and August 2005. The study does not indicate what certification levels had been achieved by individual buildings.

The study compared the modeled energy use for LEED-NC-certified buildings (data taken from the submissions required for LEED certification) against actual utility bills for the first year of operation (utility billing data were collected from 2003 to 2005). Modeled energy data were collected for both the as-designed building and the base-case building. The authors note the study is "only a preliminary guide to how LEED buildings in general are performing as a group" due to a range of issues. The issues included the sample size, the wide variation in building type (libraries, offices, multifamily, mixed use, laboratories) and building size (from 6,100 square feet to 412,000 square feet); 14 buildings were owned by the federal government, certified as LEED-NC, and located across the country; 7 buildings were commercial and concentrated mostly in the Pacific Northwest.

For the 18 buildings for which the authors had both simulated whole building design and actual purchased energy, the actual consumption was 28 percent lower than the base-case. However, there was significant variation among individual buildings, with some being more energy efficient than predicted, and some being less efficient. The actual energy use in the federal buildings was lower than the modeled use. The authors also concluded that the number of LEED energy-efficiency points did not correlate with actual energy savings.

The authors called for a more comprehensive collection and publication of modeled use versus actual consumption data, noting that a central compilation is needed, as well as consistent applications for how the data are defined, normalized, compared, and reported.

**Energy Performance of LEED for New Construction Buildings**
C. Turner and M. Frankel. New Buildings Institute, White Salmon, Wash. 2008.

The U.S. Green Building Council, with support from the U.S. Environmental Protection Agency, contracted with New Buildings Institute (NBI) to review the post-occupancy energy performance of 121 LEED-NC-certified buildings. Office buildings were the dominant category in the study, but the sample also included schools, libraries, multi-use, residential, and other types of buildings. One hundred of the buildings were classified as "medium energy use activities," while 21 buildings were described as "high energy use activities," such as laboratories, data centers and recreation facilities. The average size of buildings was 110,000 square feet, and about half of the buildings were in the range of 25,000 to 200,000 square feet (p. 11). The results contrast with the size distribution for the national building stock as reported in the Commercial Building Energy Consumption Survey (CBECS), in which 73 percent of all buildings are less than 10,000 square feet and have an average size of 14,700 square feet (p. 12).

The study compared whole building energy use (one full year of post-occupancy energy use) with three different metrics: Energy Use Intensity (EUI) for the LEED-certified buildings to the EUIs derived for the national building stock from the 2003 CBECS; ENERGY STAR® ratings of LEED buildings; and actual energy use for the LEED-certified buildings to initial design and baseline modeling (p. 2). Some of the findings were the following:

- For all 121 LEED-NC buildings the median measured EUI was 24 percent below (better than) the CBECS national average for all commercial building stock (p. 2).
- On all three metrics, average energy use in the total sample of LEED-NC-certified buildings was 25 to 30 percent lower than the CBECS national average. Energy reductions were greater with higher LEED certification levels: LEED-NC-Certified buildings used 26 percent less energy, LEED-NC-Silver buildings used 32 percent less energy, and LEED-NC-Gold/Platinum-certified buildings used 45 percent less energy on average than the CBECS average. However, energy use in individual buildings displayed a large degree of variability: over half of the projects deviated by more than 25 percent from design projections, with 30 percent significantly better and 25 percent significantly worse (p. 5). A "follow-up study of some of the good and poor performers could identify ways to eliminate the worst results and identify lessons to incorporate from the best results" (p. 5).
- For all but the warm-to-hot zones, LEED-NC buildings showed significant improvement over CBECS, with median LEED EUIs between 51 and 64 percent of the CBECS average for those zones (36 to 49 percent lower). For the warm-to-hot zones, the median LEED EUI was virtually the same as CBECS (p. 17).
- Although energy modeling is a good indicator of program-wide (portfolio-based) performance, individual project modeling varies widely from actual project performance outcomes. The ratio of actual to predicted energy use varies widely across projects, even within one LEED certification level (p. 22). "This variability between predicted and measured performance has significant implications for the accuracy of prospective life-cycle cost evaluations for any given building.

Better feedback to the design community is needed to help calibrate energy modeling results to actual performance outcomes" (p. 32). Follow-up investigations into reasons for measured-to-design deviation and for the wide variations in modeled baseline performance could improve future modeling and benchmarking (p.5).

- Project types with high process loads, such as laboratories, are problematic because energy use of high-energy building types is not well understood by designers. "Neither the LEED program nor the modeling protocol address[es] these projects well" (p. 32).

For this study, the participating owners were given the opportunity to survey the perception of occupants. The brief online survey used was modeled after the Buildings in Use (BIU) work, which includes a database of post-occupancy evaluations for more than 1,000 buildings (Vischer and Preiser, 2005). Occupants were asked to rate the key indoor environmental factors of acoustics, lighting, temperature, and air quality as well as overall building satisfaction. For each factor, the majority of LEED building ratings were positive and exceeded BIU normative scores. The lowest-rated area was acoustics (pp. 30-31). The authors noted that "such results are typical for office occupant surveys and often felt to be a result of open floor space plans, common in green and nongreen buildings alike" (p. 31).

**Do LEED-Certified Buildings Save Energy? Yes, But . . .**
G.R. Newsham, S. Mancini, and B. Birt. National Research Council Canada. 2009.

Newsham et al. reanalyzed the data used in the Turner and Frankel (2009) study for the 100 buildings categorized as "medium energy use activities." Of these buildings, 38 were certified as LEED-NC-Certified, 35 as LEED-NC-Silver, and 27 as LEED-NC-Gold/Platinum. Newsham et al. added statistical rigor to the original analysis by conducting a series of *t*-tests. In the *t*-tests, each LEED-NC-certified building was paired with a single matched building (matched on the basis of activity type, size, age, and climate zone) from the CBECS database (p. 6). Multiple *t*-tests were conducted involving differing numbers of buildings based on the quality of the matching criteria. The authors' conclusions were the following:

- On average, LEED-NC-certified buildings used 18 to 39 percent less energy per floor area than the CBECS averages.
- Twenty-eight to 35 percent of LEED-certified buildings used more energy than their matched counterparts from the CBECS database.
- There was no statistically significant relationship between LEED-NC certification level and energy use intensity or percent energy saved versus the baseline (pp. 14-15). LEED-NC-Silver buildings did not exhibit better energy performance than LEED-NC-Certified buildings, and LEED-NC-Gold/Platinum buildings did not exhibit better energy performance than LEED-NC-Silver buildings.
- The measured energy performance of LEED-NC buildings has little correlation with the certification level of the building or the number of energy credits achieved by the building during the design phase (p. 18). The results suggest the energy credit scheme needs to be refined so that it delivers more reliable performance at the individual building level.

The authors noted that "these results also highlight the importance of investigating the post-occupancy performance of buildings. There is clearly no meaningful way to refine green building rating schemes so that they become more reliable without measured performance data" (p. 18).

**A Re-Examination of the NBI LEED Building Energy Consumption Study**
J.H. Scofield. Energy Program Evaluation Conference, Portland, Ore. 2009.

Scofield reexamined the data in the Turner and Frankel (2008) study for the 100 LEED-certified buildings classified as "medium energy use activities." Scofield took exception to Turner and Frankel's comparison of the mean of one distribution to the median of another and stated that "to compare the mean of one with the median of the other introduces bias by compensating for skew in only one distribution" (p. 765). He also defined mean energy intensity differently, using a gross square foot averaging method, and conducted statistical tests of the data for several subsets of the Turner and Frankel database. Scofield compared data from some of the LEED-certified buildings to the CBECS database and also to a subset of buildings from CBECS constructed between 2000 and 2003. His conclusions included the following:

- LEED-NC-certified medium-energy buildings, on average, used 10 percent less site energy, but no less source (or primary) energy, than did comparable conventional buildings whether restricted to new vintage (constructed between 2000 and 2003) or not.
- LEED-NC-Certified buildings used slightly more site energy than the CBECS comparison group, while LEED-Silver and LEED Gold/Platinum buildings used 23 percent and 31 percent less site energy, respectively, than the CBECS comparison group.
- LEED office buildings used 17 percent less site energy than that of the CBECS comparison group of all vintages; there was no significant reduction in primary (source) energy use relative to non-LEED office buildings

**Do LEED-Certified Buildings Save Energy? Not Really . . .**
J.H. Scofield. Energy and Buildings 41(12):1386-1390. 2009.

Scofield later published a direct rebuttal to Newsham et al. in which he reanalyzed the Turner and Frankel (2008) data for a subset of 35 LEED-certified office buildings using a different methodology. Scofield focused on source energy (which accounts for both on-site energy and off-site energy losses associated with the generation and distribution of electricity), whereas the Turner and Frankel (2008) and Newsham et al. (2009) studies used site-energy only. Scofield weighted the energy intensity of each building by its gross square feet, whereas Turner and Frankel (2008) and Newsham et al. (2009) weighted the energy intensities of each building. Scofield states that these "different averaging methods yield different means, and correspondingly, give rise to significantly different conclusions when comparing mean energy intensities of various building sets" (p. 1387). He noted that the CBECS data set is dominated by the energy used by large buildings in the set. Many smaller LEED buildings do outperform non-LEED buildings of similar size, but this may be less important when looking at the total energy footprint of the building stock, simply because these smaller buildings do not contribute nearly as much in total energy used. Scofield described his concern with using building-weighted averages as used in the CBECS data set as follows:

> The fallacy of using "building-weighted" averaging to characterize the energy intensity of a collection of *N* buildings is readily apparent when you take it to a smaller extreme. Suppose you were to divide a single building up into *N* rooms, some big and some small. You could calculate the energy intensity of each room separately. There are two ways to calculate the mean room energy intensity. The "gsf-weighted" method yields a mean energy intensity identical to that of the building. The "room-weighted" or unweighted average does not. It is clear that only the former makes physical sense. The same is true when considering a collection of *N* buildings (p. 1390).

Despite the differences in methodologies, Scofield found that LEED-NC-certified office buildings used, on average, 10 to 17 percent less site energy than comparable non-LEED buildings. He also found the following:

- LEED-NC-certified conventional buildings, on average, showed no significant primary [source] energy consumption. For this reason, he concluded that LEED certification "is not delivering reduction in greenhouse gas emissions associated with building operation" (p. 1387).
- Smaller buildings tend to out-perform (i.e., use less site energy) CBECS more than do larger LEED buildings (p. 1389). Scofield speculated that "energy consumption in larger buildings is dominated by plug loads and operating practices, which are not addressed by LEED" (p. 1390).

Scofield did not provide any data about differences in LEED building performance by level of certification.

**Greening Our Built World: Costs, Benefits, and Strategies**
G. Kats. Island Press, Washington, D.C. 2010.

The author analyzed data for 170 green buildings (defined as certified or anticipating LEED certification, or certification under another similar rating system). Approximately 15 percent of the 170 buildings were certified under systems such as the Massachusetts green schools guidelines, Enterprise Green Communities, or the Green Guide for Healthcare Facilities.

Data were gathered directly from building owners, architects, and developers for buildings completed between 1998 and 2009. A range of building types was included in the sample—schools, offices, healthcare, academic facilities, and others—located in 33 states and eight countries. The author synthesized the results of his 170-building survey with findings from other studies to develop estimates of net present value (NPV) benefits (p. 3).

Benefit-cost analyses and simple payback models were developed to compare life-cycle benefits with the initial cost of green design and construction. NPV benefits were calculated using a 20-year time period, a 7 percent discount rate, and 2 percent annual inflation. It was noted that the discount rate was equal to or higher than the rate at which states, the federal government, and many corporations have historically borrowed money and "thus provides a reasonable basis for calculating the current value of future benefits" (p. 4). To allow comparability of financial impacts over time, costs and benefits were expressed in terms of dollars per square foot (p. 3).

For calculating energy and water savings, the contacts for each building relied on industry standards to create a baseline for conventional buildings, against which green building savings could be measured. The building architect provided the cost premiums to allow a comparison between green building costs and the baseline. The study modeled benefits that accrued (1) directly to building owners and occupants and (2) indirectly to the surrounding communities and society at large. The author noted the limitations of the study, including the potential for bias created by the data-gathering methodology and the fact that the sample of buildings was not precisely representative of the actual inventory of green buildings nationally. In estimating long-term costs and benefits, modeled costs and projected energy and water savings data were used where actual data were not available (p. 7). Among the study findings were the following:

- For the 170 (U.S.) buildings in the data set, owners or owner's representatives reported that it cost 0 to 18 percent more to build a green building compared to a conventional building. The median additional cost was 1.5 percent, with the large majority of premiums reported between

0 and 4 percent. The author concluded that most green buildings cost slightly more than similar conventional buildings to construct.

- Generally, the greener the building, the greater the cost premium, but all LEED levels can be achieved for minimal additional cost. Of the buildings in the data set with a cost premium of 0 to 2 percent, 29 buildings were LEED-Gold and 5 were LEED-Platinum. Nine green buildings (one Silver, four Gold, four Platinum) reported a green premium of 10 percent or more (p. 10).
- Twenty projects in the data set were major renovations. The median green premium was 1.9 percent and the average was 3.9 percent (p. 13).
- Buildings in the data set reported a range of projected and actual reductions in energy use, from less than 10 percent to more than 100 percent (meaning that the building generated more power than it used), with a median reduction of 34 percent and a mean reduction of 35 percent (p. 15). The author concluded that, based on the median savings from the data set and national data on baseline energy expenditures, the present value of 20 years of energy savings in a typical green building ranges from $4 per square foot to $16 per square foot, depending on building type and LEED level of certification (p. 14).
- Projected energy savings generally increased with the level of greenness, and there was a range of projected savings at each LEED level. "When compared with an ASHRAE 90.1 baseline building, LEED-Certified buildings in the data set reported median savings of 23 percent; for Silver the figure was 31 percent; for Gold, 40 percent; and for Platinum, 50 percent" (p. 16).
- Of the 170 buildings in the data set, 119 reported or projected reductions in indoor potable water use when compared to conventional buildings; reductions ranged from 0 percent to more than 80 percent, with a median of 39 percent. Water savings generally increase with LEED level of certification. The present value of water savings in typical green buildings ranged from $.50 per square foot to $2 per square foot, depending on building type and LEED level of certification.

## Studies for Federal Buildings

**Assessing Green Building Performance: A Post Occupancy Evaluation of 12 GSA Buildings**
K.M. Fowler and E.M. Rauch. Pacific Northwest National Laboratory, Richland, Wash. 2008.

Fowler and Rauch looked at 12 General Services Administration (GSA) buildings designed to be LEED-certified or otherwise designated as "green." The sample included 6 office buildings, 4 courthouses, and 2 combination office/courthouse buildings located in half of GSA's national regions. Eight of the 12 buildings were LEED-certified (6) or LEED-registered (2). (As of the summer of 2007, GSA had 19 LEED-certified buildings, so the sample represented one-third of its LEED inventory.) Of the LEED-certified buildings, 2 were LEED-NC-Certified, 2 were LEED-NC-Silver, 1 was LEED-EB-Silver, and 2 were LEED-NC-Gold (1 building was LEED registered but the level of certification was not available).

Building performance measures that were collected, normalized, and analyzed included water, energy, maintenance and operations, waste generation and recycling, occupant satisfaction, and occupant commute. The data sources for these analyses included utility bills, maintenance budgets, and an occupant survey. Twelve consecutive months of data were collected for each performance metric and then normalized using the building and site characteristics (p. ix).

Fowler and Rauch (2008) calculated aggregate operating costs (energy and water utilities, general maintenance, grounds maintenance, waste and recycling, and janitorial costs per rentable square foot) for 12 GSA green buildings and compared those costs to industry baselines. The baselines were developed from a number of sources, including data from BOMA and the International Facility Management Association (IFMA).

The occupant survey was based on the Center for the Built Environment (CBE) survey, for which there were baseline data from which to make comparisons.

Fowler and Rauch found the following:

- Regarding energy use, on average the GSA office buildings in this study performed 29 percent better (used 29 percent less energy) than office buildings in the CBECS national database. All of the buildings performed 29 percent better than the CBECS regional averages. All performed 14 percent better than the GSA energy goal for its portfolio of facilities (p. xi).
- Aggregate operating costs on average were 13 percent lower than average costs reported in industry sources. However, several of the buildings had consistently higher operating costs in each category (p. xii). Regarding water use, domestic water use was estimated as the base water load revealed from the monthly water use data. Given these estimates, the average use of the 12 GSA green buildings was 3 percent less than the calculated water indices baseline (p. xii).
- All of the GSA buildings scored above the CBE median for general occupant satisfaction with the building. On average, the buildings scored 22 percent higher than the CBE median.

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

Fowler et al. included updated data from the 12 GSA green buildings included in Fowler and Rauch (2008) plus data from 10 additional green buildings. In all, the study included 8 courthouses, 12 federal buildings (office space), and 2 courthouse/federal buildings. Thirteen of the buildings were LEED-certified, 3 were LEED-registered (1 of these buildings did not specify the proposed level of certification), while the others emphasized energy efficiency during the design phase. These buildings accounted for approximately one-third of the 40 GSA buildings that were LEED-certified as of late 2009. The methodology used was generally the same as Fowler and Rauch (2008). The results were generally consistent with those of Fowler and Rauch (2008). Specifically, the authors found that for the GSA buildings:

- Energy performance was better than or equal to the baseline for all of the buildings. The energy performance average of the buildings was 25 percent better than CBECS national baseline, 10 percent better than GSA regional averages for fiscal year (FY) 2009, 13 percent better than FY2009 GSA Target values (goal for energy performance across GSA), and 18 percent better than CBECS regional averages (p. x). The CBECS national average used was for office buildings constructed between 1990 and 2003, while the regional averages were for all building types.
- Two-thirds of the green buildings used less water than the GSA baseline, with the average being 11 percent lower. Of the 6 green buildings with higher water use than the baseline, 5 had cooling towers or evaporative cooling, 2 had exterior fountains in a hot, dry climate, and 3 had non-typical operating schedules (p. xi).
- On average, aggregate operating costs were 19 percent lower than the baseline (the aggregate operating cost metric included water and energy utilities, general maintenance, grounds maintenance, waste and recycling, and janitorial costs). Seventeen of the 22 green buildings had costs that ranged from 2 to 53 percent lower than the baseline. Five of the 22 green buildings

had higher costs than the baseline, ranging from 1 to 27 percent higher. The higher costs were attributed to higher general maintenance costs and higher energy costs.

- The occupant survey indicated that, on average, occupant satisfaction with the green buildings in general were 27 percent higher than the CBE baseline, except for lighting, where it was the same as the baseline.

Data were available for 15 LEED-certified buildings: 2 LEED-NC-Certified, 1 LEED-EB, 6 LEED-NC-Silver, 1 LEED-EB-Silver, and 5 LEED-NC-Gold. For 5 of the 7 LEED-Silver buildings, energy use was lower for all three baselines (CBECS regional, GSA target, GSA regional). The energy use in 2 LEED-Silver buildings was higher than the CBECS regional average. For 5 of the 7 LEED-Silver buildings, water use was lower than the industry and GSA baselines. Two LEED-Silver buildings (1 with a cooling tower and 1 with evaporative cooling) had significantly higher water use than the industry average (p. xi). For 6 of the 7 LEED-Silver buildings, the aggregate operating cost was 10 to 44 percent lower than the baseline; for 1 building it was 9 percent higher than the baseline.

The LEED-Gold buildings performed consistently better than the baseline for all buildings and all metrics with one exception: one of the buildings used significantly more water than the baseline in both the 2008 and 2010 studies.

Among the authors' conclusions were the following:

- "One of the important lessons learned with respect to whole building performance measurement and assessment is that the baselines selected for performance comparison are what define the study findings" (p. 83).
- "Examining building performance over multiple years could potentially offer a useful diagnostic tool for identifying building operations that are in need of operational changes. Investigating what the connection is between building performance and the design intent would offer potential design guidance and insight into building operation strategies" (p. 75).
- "Operations and maintenance data are being tracked by more building managers, but the quality of the data varies by buildings. Additionally, there is no consistent level of detail collected at each building because of the flexibility of the tracking systems . . . makes comparisons between buildings a challenge" (p. 82).

**Energy Consumption Evaluation of U.S. Navy LEED-Certified Buildings**
C. Menassa, S. Mangasarian, M. El Asmar, and C. Kirar. Journal of Performance of Constructed Facilities 26(1):46-53. 2012.

This study was undertaken to establish if the U.S. Navy's LEED-certified buildings had achieved the 30 percent energy reduction required by EISA 2007 and other mandates, when compared to other buildings with similar functions and locations (p. 46). The study looked at the energy and water performance of 11 buildings operated by the Naval Facilities Engineering Command that had achieved various levels of LEED certification (3 Certified, 5 Silver, 3 Gold) by 2008. The study compared their site energy and water use to 11 NAVFAC buildings of similar size, function, and location that had not been LEED certified (p. 48). It was assumed that the comparison buildings had similar exterior facades and construction materials (p. 48). The analysis also involved comparing the electrical consumption for the LEED-certified buildings to those of the commercial building national average available from the 2003 CBECS database.

The sample of 11 buildings included a drill hall, 3 maintenance facilities, a laboratory, a child care center, 2 bachelor enlisted quarters, a golf course clubhouse, and 2 administrative buildings. The study found that:

- Seven of 11 LEED-certified buildings used less electricity, with the reductions ranging from 3 to 60 percent less energy. However, 4 of the 11 LEED-certified buildings used more energy than their non-LEED counterparts, ranging from 11 to 200 percent more energy.
- Four of 5 LEED-Silver buildings had energy savings ranging from 3 to 49 percent greater than their non-LEED counterparts, while 1 LEED-Silver building used 128 percent more energy than its non-LEED counterpart. Two of the 3 LEED-Gold buildings had energy savings of 6 and 15 percent greater than their non-LEED counterparts, while the third used twice as much energy as its non-LEED counterpart.
- Only 3 of the 11 LEED-certified buildings used less energy than the CBECS baseline (p. 51).
- Seven of 9 LEED-certified buildings reduced their water consumption from 18 to 72 percent. For the 4 LEED-Silver buildings for which water data were available, water savings ranged from 18 to 61 percent better than their non-LEED counterparts (p. 50). Two of the 3 LEED-Gold-certified buildings showed water savings of 56 percent and 60 percent, while the third used 90 percent more than its non-LEED counterpart.

## Regional Studies

**LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report**
C. Turner. Cascadia Region Green Building Council, Portland, Ore. 2006.

This study looked at measured energy and indoor water usage (at least 1 year of utility bills) of 11 LEED-certified buildings for three metrics: actual use compared to the initial model predictions; actual use to baseline (approximate to code); and actual use compared to the ENERGY STAR® median. The study sample included 7 offices or libraries and 4 multifamily residential buildings, with a range of LEED certifications (3 LEED-NC-Certified, 4 LEED-NC-Silver, 3 LEED-NC-Gold, 1 LEED-EB-Gold). Energy and water use was measured as gross conditioned square feet (p. 3).

Initial modeling results of projected energy and water use came from the building's LEED submittal for energy optimization and indoor water use reduction (p. 4). Savings estimates were made by comparing the actual (measured) data to the modeled usage data without further adjustment or calibration (p. 4). Savings estimates were made by comparing actual energy and water use to the modeled use levels. Baseline referred to modeled usage from the LEED Energy Cost Budget or Water Use baseline case, approximately a building similar to the initial design but constructed just to meet code requirements (p. 3). The author also calculated net present value cost savings for energy and water, assuming a 25-year time period, a discount rate of 3 percent, and constant use of energy, and assuming that utility rates increase only at the rate of inflation.

An online survey was distributed to occupants in 10 of the 11 buildings. The survey sought to determine perceptions of building indoor environmental quality in terms of temperature, air quality, lighting, noise, and plumbing fixtures.

Results of the study included the following:

- All of the buildings used less energy than their initial baseline modeling (approximate to code), averaging nearly 40 percent below baseline. All but two showed energy savings when compared to an average similar building in the region. The author estimated that the cost savings per year for energy would range from $0 to $26 per square foot (p. 9).

- Six of the 11 buildings were using less total energy than was suggested by the initial design models (p. 5). "No single building's actual performance was within 20 percent of its design model" (p. 5).
- Of the 7 buildings for which water use projections (models) were available, 4 were using 8 percent less water than predicted (p.12). "At the level of current water and sewer billing rates, the dollar value of these water volume savings per square foot is minimal" (p. 13).
- Four LEED-NC-Silver buildings used 39 to 57 percent less energy than their approximate to-code baseline model (p. 6). The 2 LEED-NC-Gold buildings for which data were available used 43 to 86 percent less energy than the baseline. For the 4 LEED-NC-Silver buildings, the savings would be $7 to $26 per square foot; for the 3 LEED-Gold buildings, the savings would range from $0 to $8 per square foot (p. 9).
- Data on water use were available for 7 buildings only. Five of the 7 buildings used 5 to 36 percent less water, 2 buildings used 4 to 6 percent more water than the approximate to-code baseline (p. 12). Of the 4 LEED-Silver buildings, 3 used 27 to 36 percent less water, while 1 used 4 percent more water. The 1 LEED-Gold building for which data were available used 5 percent less water than the approximate to-code baseline (p. 12).

The report summary states that:

> Most buildings in this study are experiencing real energy savings in relation to their original baseline modeling. Most buildings are also performing well in relation to general commercial space. . . . The average 25-year present value of dollar savings for buildings in this study, when compared to the regional median, is $2 per square foot. However, there is a large variation in estimated savings, depending on the calculation method used (p. 15).
>
> The majority of buildings also show some savings for indoor water usage in relation to original baseline modeling. As with the energy results, the baseline projections were not calibrated for actual occupant behavior, and wide differences between design and actual results limits the accuracy of these savings estimates (p.15).
>
> Occupancy surveys show high satisfaction with office buildings overall and generally positive averages for all categories other than noise conditions (p. 15).

**Green Buildings in Massachusetts: Comparison Between Actual and Predicted Energy Performance**
J.L.B. Sacari, U. Bhattacharjee, T. Martinez, and J. Duffy. American Solar Energy Society, Cleveland, Ohio. 2007.

Sacari et al. compared the predicted energy use (estimated during the pre-construction, design phase) to the actual energy use (utility bills for electricity and natural gas) in 19 new or renovated "green" buildings in Massachusetts compared to the Massachusetts baseline building code. They found that "most green buildings are consuming on an average 40% more energy than predicted" but "are still consuming less than a building designed to Massachusetts baseline building code" (p. 1).

The "green" buildings included 12 school buildings that were certified under the Massachusetts Collaborative for High-Performance Schools and 6 other buildings certified under the LEED rating system. The study does not provide information about the certification levels of the green buildings. Prediction data were obtained primarily from applications for funding to the Massachusetts Collaborative Technology.

Reasons given for large discrepancies between the predicted energy use and the actual energy use included the following:

- Energy modelers appear to use incremental energy savings resulting from the proposed energy efficiency measures adopted in the building and the on-site renewable energy generation, according to several modelers interviewed. Therefore, the predicted energy use does not capture the characteristics of the building in its entirety.
- Limitations in the building modeling cannot predict the human behavior in the buildings related to the use of plug loads, levels of occupancy, and building operation hours.
- Modifications in the original design made in the buildings during the construction phase due to limitations in the budget and/or changes in the type of materials used.
- Some buildings have experienced high rates of energy consumption in their first months of operation due to not all the systems installed being completely operative or commissioned. The delay in the task of contractors and subcontractors, the correct settings of the systems, and the process of learning and adaptation by the users have influenced the energy consumption (p. 4-5).

Other conclusions:

> The average energy consumption of most of the buildings is less than the "base case," or the same building designed according to the minimum requirements of the energy code, but energy consumption is higher than predicted. Other factors that have attributed [sic] to the increase in energy include: budget problems, changes in end use, increase in occupancy, building modifications, energy management systems not being maximized, and selection of materials (p. 8).
>
> In general, based on the results of this study, green buildings are contributing in very positive ways to reducing the energy and environmental impacts relative to existing buildings and minimum code buildings. But the frustration in stakeholders based on the difference between predicted and actual paid-for-energy use should be addressed mainly by communicating uncertainties in design predictions, by better training in the use of the technologies in the buildings, and by commissioning (p. 8).

**Comparison of Commercial LEED Buildings and Non-LEED Buildings Within the 2002-2004 Pacific Northwest Commercial Building Stock**

D. Baylon and P. Storm. Published in ACEEE Summer Study on Energy Efficiency in Buildings. 2008.

Baylon and Storm compared the performance of 24 LEED-certified buildings constructed between 2002 and 2005 in the Pacific Northwest (Washington, Oregon, and Idaho) to a larger sample of contemporary buildings built to local codes. The LEED system at that time incorporated ASHRAE 90.1-1999 as the base for energy performance. Most of these buildings had been occupied for at least 2 years, and the researchers compared actual site energy use for the two samples. The authors note that "whereas typical LEED comparisons focus on differences between LEED building features and national code (or building performance and initial modeling, this paper is focused on the regional relevance of the LEED standard and implementation" (p. 4-1).

The LEED buildings in the sample saved 12 percent more energy than the comparison group. The authors noted that energy codes in Washington and Oregon were more stringent than ASHRAE 90.1-1999 (p. 4-1). The sample of LEED buildings included 9 different building types; the study did not provide information about the certification levels.

**Regional Green Building Case Study Project: A Post-Occupancy Study of LEED Projects in Illinois**
D. Widener. U.S. Green Building Council, Chicago Chapter, Chicago, Ill. 2009.

Widener analyzed the post-occupancy performance and costs and benefits of 25 LEED-certified projects related to measured site energy and greenhouse gas emissions, water, commute transportation, construction and operating costs, green premium, health and productivity impacts, and occupant comfort. The study collected multiple years of post-occupancy data. The 25 projects represent projects certified at all LEED levels and programs: new construction; existing buildings; commercial interiors, and core and shell. The projects ranged in size from 3,200 square feet to 4.2 million square feet and included buildings used for education, lodging, mixed use, office public assembly, public safety, and other (p. i). Most participating projects had been certified under LEED versions 2.0 or 2.1. The study did not identify specific LEED-certification levels (i.e., Certified, Silver, Gold, or Platinum).

Two types of site energy analysis—whole project energy use and partial energy use projects—were conducted. The metric used was site energy use intensity and was measured as kBtu/square foot/per year for all fuels. Seventeen projects classified as whole project energy use projects—those where complete site energy data were provided for a building or project space, including heating/cooling, lighting, and load attributed to the building occupants—were analyzed. Eight projects where only partial site energy data were provided were also analyzed. The study found that the median EUI was 94 kBtu/square foot/year for whole energy projects, which was approximately 5 percent lower than the regional CBECS Midwest average. The median EUI for partial projects was 38 kBtu/square foot/year, which was 7 percent lower than the CBECS Midwest average.

Among the conclusions of the study were the following:

> Specifically related to energy performance, many Illinois LEED projects perform better than conventional commercial interiors and buildings, but as with conventional buildings there is a large variation amongst projects. A significant finding is that the Illinois LEED whole project energy use projects that achieved a higher number of EA Credit 1 (LEED-NC) points performed better. This finding makes sense; projects that prioritize energy efficiency as a key LEED strategy are likely to perform better than those projects that do not focus on energy efficiency or choose to prioritize points in other LEED categories (p. v).
>
> Since every building is unique in its use, occupancy, operations, maintenance, and systems, actual post-occupancy measured performance that reflects actual operating conditions of the specific building will be the best benchmark. Other benchmarks, such as comparisons to other buildings (LEED and non-LEED, including CBECS and ENERGY STAR®) or any modeled predictions are temporal or limited in use, even as methodologies and data sets evolve to provide more accurate comparisons (p. v).
>
> Regularly collecting and analyzing building performance post-occupancy is a critical component in operating a green, high-performance building (p. v).

**Postoccupancy Energy Consumption Survey of Arizona's LEED New Construction Population.**
D. Oates and K.T. Sullivan. Journal of Construction Engineering and Management 138:742-750. 2012.

This technical paper examines 47 percent of Arizona's 53 LEED-NC-certified buildings in an effort to determine if Arizona's LEED-NC-certified buildings achieve expected energy performance, how they compare with the existing building population, and whether either system or managerial variables demonstrate efficiency correlations.

Oates and Sullivan (2012) conducted post-occupancy energy consumption surveys for 25 LEED-NC-certified buildings in Arizona. The sample included seven types of buildings that had been certified under LEED versions 2.0, 2.1, and 2.2 and that had been in operation for at least 1 year as of October 2009. Areas of analysis included total site and source energy use intensity, standard mean and gross square foot weighted mean, and comparisons by climate zone. Actual energy performance of those buildings as measured by EUI for source and site energy was compared to national averages from the CBECS database. The CBECS data were normalized to match the gross square feet weights for each building type in the LEED sample.

The LEED building sample was also characterized principal building activity to separate medium-energy-intensity (19) and high-energy-intensity (6) structures. Medium-energy-intensity buildings included office buildings, education structures, and the like. The high-energy-intensity structures were all laboratories. The authors noted that two buildings accounted for 40 percent of the total data set's gross square footage and 51 percent of the gross square footage in the medium-energy-intensity subset, which would skew the results.

The 19 building medium-energy-intensity group was analyzed separately from the high-energy group of 6 buildings. The high-energy-intensity subset was not analyzed because the sample size was too small.) Variables tested for the medium-energy-intensity group included site EUI, source EUI, gross square feet, occupants per square foot, total number of awarded LEED credits, total number of LEED Energy and Atmosphere Credits, the facility manager's years of experience, the number of buildings managed by the facility manager, and others.

The authors found that the 19 medium-energy-intensity LEED-certified buildings used 13 percent less site energy and 1 percent less source energy than the CBECS comparison group. Of the 19 buildings for which the design and baseline model simulations were available, only one used less energy than had been predicted in the design case and only four used less energy than the baseline simulation.

Other findings were the following:

- Energy consumption was not tracked in most LEED NC-certified buildings. Possible factors contributing to this shortcoming included: no dedicated facility manager; a lack of communication between the business office that processed utility bills and the facility manager; not having a dedicated meter; the building manager simply choosing not to track performance metrics (p. 749).
- The research identified a significant facility management deficiency within the LEED buildings. A lack of education at start-up and commissioning operations may partially explain the operational knowledge gap for some managers. In fact, a majority of survey participants were unfamiliar with their building's heating, ventilation, and air conditioning system (p. 749).

## STUDIES RELATED TO INDOOR ENVIRONMENTAL QUALITY AND PRODUCTIVITY

### Occupant Satisfaction with Indoor Environmental Quality in Green Buildings

S. Abbaszadeh, L. Zagreus, D. Lehrer, and C. Huizenga. Proceedings of Healthy Buildings, Lisbon. Volume III, pp. 365-370. 2006.

Abbaszadeh et al. looked at occupant satisfaction in green office buildings in comparison to occupant satisfaction in conventional buildings. They asked the occupants directly (through Center for the Built Environment (CBE) surveys) about their satisfaction with indoor environmental quality (IEQ) in their workspace.

The CBE database as of 2005 contained 181 buildings and 33,285 respondents (average 46 percent response rate). Within the CBE database, 15 office buildings were identified as LEED-certified and 6 additional buildings were reported as green, based on the receipt of national or local green building or energy efficiency awards. Together, those 21 buildings comprised one comparison group. The other comparison group consisted of the remaining buildings in the database, referred to as non-green buildings.

The study focused on occupant satisfaction with thermal comfort, air quality, lighting, and acoustics. The authors noted that "self-reported productivity scores follow the same pattern as those of satisfaction—productivity scores are high where satisfaction is high, and low where satisfaction scores are low" (p. 366).

Among the findings, were the following:

- On average, occupants in LEED-rated/green buildings were more satisfied than occupants of conventional buildings when it came to thermal comfort, air quality, and overall satisfaction with workspace and building.
- The mean overall satisfaction score in LEED-rated/green buildings (1.47) was significantly higher than that for conventional buildings (0.93).
- Occupants in LEED-rated/green buildings were more satisfied with thermal comfort (.36) compared to −0.16 for occupants in conventional buildings and more satisfied with air quality in their workspace (1.14 versus 0.21). Even when considering only non-green buildings that were less than 15 years old, the mean satisfaction score with air quality was significantly higher for LEED-rated/green buildings (1.14 versus 0.52) (p. 366).
- The authors found that when including only buildings 15 years old or newer, no statistically significant relationship was found for the IEQ categories of lighting and acoustics. "Complaint profiles of those dissatisfied with their lighting point to problems with daylighting and electric lighting levels—at its source this could be due to inadequate provision of controls over lighting" (p. 370). "Complaint profiles of those dissatisfied with the acoustic quality in their workspace point to problems with sound privacy and distracting noise from people's conversations and telephone rings" (p. 370).
- The data showed that a higher percentage of people in LEED-certified/green buildings work in cubicles with low or no partitions; common strategies to maximize daylight, views, ambient lighting opportunity, personal control, flexibility, and equality of workspace allocation in green offices result in more open space and fewer enclosed private offices.

**Green Buildings and Productivity**
M.G. Miller, D. Pogue, Q.D. Gough, and S.M. Davis. Journal of Sustainable Real Estate 1(1):65-89. 2009.

Miller et al. summarized a literature search on various aspects of productivity (e.g., health and productivity, telecommuting and productivity, productivity gains from technology or economic pressure). They also outlined some of the difficulties of measuring productivity, especially for people performing knowledge-intensive work where the inputs and outputs are not easily quantifiable. "This is because direct measurement for professionals in an office environment requires the monitoring of (1) the ability to focus and think, synthesize, and add value to the firm; (2) the ability to measure the contribution of individuals that likely work in a team environment; and (3) the ability to monitor the quality of work as well as the efficiency and output" (p. 66).

Miller et al. also summarized the results of an empirical study. For that study, they hypothesized that green buildings (ENERGY STAR® label or LEED certification, any level) provided more productive environments for workers than conventional buildings. Two measures of productivity were used: sick days and the self-reported productivity percentage after moving to a new building. The authors noted that the survey and its results were preliminary.

The survey was conducted in 154 buildings that contained more than 2,000 tenants. Some 534 tenant responses were collected from buildings located across the United States. Miller et al. found that 55 percent of the respondents agreed or strongly agreed that employees in green buildings were more productive, while 45 percent suggested no change (p. 81). They also found that 45 percent of the respondents agreed that workers were taking fewer sick days than before moving to a green building, while 45 percent found it was the same as before and 10 percent reported more sick days (all in ENERGY STAR®-labeled buildings).

Miller et al. also calculated the economic impacts of those tenants who claimed an increase in productivity. Economic impacts were "based on salaries that approach the cost of rent using a very conservative square foot per worker assumption" (p. 81).

**A Comparison of the Performance of Sustainable Buildings with Conventional Buildings from the Point of View of the Users**

G. Baird, A. Leaman, and J. Thompson. Architectural Science Review 55(2):135-144. 2012.

Baird et al. sought to determine whether users perceived sustainable buildings to perform differently from conventionally designed buildings. The questionnaire used was the standard two-page questionnaire developed by the Buildings in Use (BIU) study for office buildings. The questionnaire included 45 questions grouped into several categories, including environmental (temperature, noise/acoustics, lighting) and overall satisfaction (design, needs, comfort overall, productivity, and health). The questions typically asked occupants to rate a factor on a scale of 1 to 7, with 1 being unsatisfactory and 7 being ideal.

The set of sustainably designed buildings included 31 commercial and institutional buildings located in 11 different countries. All of the buildings were either recipients of national awards for sustainable design or highly rated in terms of their country's building sustainability rating tool(s) or had pioneered some aspect of green architecture. The buildings ranged in size from 1,000 to 20,000 square meters and were occupied by 15 to 350 staff. Fifteen of the buildings were predominantly office use, 10 were academic teaching buildings, 4 housed laboratories or research organizations, and 2 contained a combination of light industrial and administrative functions. Surveys were gathered from 2,035 staff members.

The comparison set consisted of 109 conventional buildings selected from the BIU database that had been surveyed during a similar time period as the sustainable buildings. Included were buildings occupied by 15 to 1,100 occupants and office, light industrial, visitor center, and academic activities. The independent *t*-test was used to determine whether differences between the mean values for the various aspects were statistically significant. Among the authors' findings were the following:

- "In the case of the four environmental subcategories, the scores were not universally more favourable [sic] for the sustainable building set" (p. 140).
- An overall improvement in temperature and air quality was statistically significant. The sustainable buildings were perceived to be colder on average in winter but much the same (still on the hot side) in summer, whereas their air was perceived to be both fresher and less smelly year round (p. 140).
- Users also perceived a considerable improvement in lighting in the sustainable buildings in comparison to the conventional buildings that was statistically significant (p. 140).

- The users' perception of differences in noise levels was not statistically significant. Users in both samples of buildings perceived of slightly too much noise from various internal sources (e.g., conversations, telephones) (p. 140).
- For the sustainable buildings, all of the factors in the satisfaction category showed a significant improvement over the conventional buildings. Occupants of sustainable buildings perceived that they were 4 percent more productive than did occupants of conventional buildings. The improvement in perceived health among occupants in conventional buildings (3.29 on the 7-point scale) in comparison to occupants in sustainable buildings (4.25) was also statistically significant (p. 143).

## STUDIES ON THE INCREMENTAL COSTS TO DESIGN AND CONSTRUCT HIGH-PERFORMANCE OR GREEN BUILDINGS

**Costing Green: A Comprehensive Cost Database and Budgeting Methodology**
L.F. Matthiessen and P. Morris. Davis Langdon Company, Los Angeles, Calif. 2004.

Matthiessen and Morris undertook a study with the goal of comparing construction costs of buildings where LEED certification was a primary goal to the costs of similar buildings where LEED was not considered during design. The authors studied 93 non-LEED and 45 LEED-seeking buildings for which data were gathered from the database of the Davis Langdon Company. All costs were normalized for time and location to ensure consistency for the comparisons. They noted that the non-LEED buildings all would have earned some LEED points by virtue of their basic design, but sustainability had not been the intent. Among their conclusions were the following:

- Many projects achieve sustainable design within their initial budget or with very small supplemental funding. This suggests that owners are finding ways to incorporate project goals and values, regardless of budget, by making choices.
- Each building project is unique and should be considered as such when addressing the cost and feasibility of LEED. Benchmarking with other comparable projects can be valuable and informative but not predictive.
- There was no statistically significant difference [in cost per square foot] between the LEED and the non-LEED seeking buildings. The cost per square foot for the LEED-seeking buildings was scattered throughout the range of costs for all buildings studied, with no apparent pattern to the distribution. This was tested statistically using the *t*-test method of analyzing sample variations.
- Cost differences between buildings are due primarily to program type.
- There are low-cost and high-cost green buildings.
- There are low-cost and high-cost non-green buildings.
- Comparing the average cost per square foot for one set of buildings does not provide any meaningful data for any individual project to assess what—if any—cost impact there may be for incorporating LEED and sustainable design. The normal variations between buildings are sufficiently large that analysis of averages is not helpful.
- Closer examination of the non-LEED and LEED buildings suggests that for any building there are usually about 12 points that can be earned without any changes to design, due simply to the building's location, program, or requirements of the owner or local codes. Up to 18 additional points are available for a minimum of effort and little or no additional cost required.

**Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in Light of Increased Market Adoption**
L.F. Matthiessen and P. Morris. Davis Langdon Company, Los Angeles, Calif. 2007.

This study compared the construction costs of 83 buildings seeking LEED 2.1 and 2.2 New Construction certification to 138 non-LEED-seeking buildings. The building types included academic classroom buildings (17 LEED-seeking, 43 non-LEED seeking), laboratories (26/44), libraries (25/32), community centers (9/9), and ambulatory care facilities (9/8). The costs were normalized for time and location. Some of the findings from the study were the following:

- Many projects are achieving LEED certification within their budgets and in the same cost range as non-LEED projects.
- Construction costs have risen dramatically but projects are still achieving LEED.
- While there appears to be a general perception that sustainable design features add to the overall cost of the building, the data do not show a significant difference in the average costs of LEED-seeking and non-LEED-seeking buildings.

**The Economics of LEED for Existing Buildings for Individual Buildings**
Leonardo Academy, Inc., Madison, Wis. 2008.

The authors presented survey data for 11 to 13 buildings certified under the LEED-EB program. The data were provided by the owners or managers of the buildings for 2006-2007. The white paper focused on the certification, implementation, and process costs for LEED-EB certification and an operating cost comparison.

In terms of the costs to certify, implement, and process LEED-EB certifications, data from 13 buildings were available. The authors found that the average cost for LEED-EB implementation and certification was $1.58 per square foot, while the median was $1.52 per square foot. However, the certification costs varied significantly from building to building, from $0.02 per square foot to $5.01 per square foot (p. 5). The authors note that "the results do not follow expectations of higher costs for higher certification levels, but this may be due to the very small sample size at this time" (p. 7).

In this study, operating costs included cleaning expenses, repair and maintenance expenses, roads/grounds expenses, security expenses, and administrative and utility expenses. Data for 11 buildings, all of which had a significant component of office space, were collected and compared to the operating costs in the Building Owners and Managers Association's (BOMA's) *Experience Exchange Report*. The authors found that "in all categories of operating costs, more than 50% of the LEED-EB buildings have expenses less than the BOMA average for the region. Total expenses per square foot of the LEED-EB buildings are less than the BOMA average for 7 of the 11 buildings" (p. 21).

**GSA LEED Cost Study**
Steven Winter Associates. 2004.

This study was undertaken to estimate the costs to develop "green" federal buildings using LEED 2.1. The report provides a detailed and structured review of both the capital and soft cost implications of achieving Certified, Silver, and Gold LEED-ratings for the two building types most commonly constructed by the GSA: a five-story courthouse and a mid-rise federal office building.

For both building types, baseline construction costs were developed to reflect federal design requirements. An analysis was performed to identify the incremental costs associated with green building measures that would likely be implemented to meet the specific LEED prerequisite and credit requirements.

Individual LEED credit assessments and cost estimates were completed for six scenarios to create a cost range for LEED-Certified, -Silver, and -Gold certification levels. The study indicated that there was an inherent degree of variability to LEED construction cost impacts, based on the following findings:

- There was no correlation between the point value of a LEED credit and its cost.
- A range of different strategies can often be used to earn the same individual LEED credit.
- The cost of some credits varied significantly based on the building type and building program.
- Some credit costs varied based on region-specific or project-specific issues.

The authors concluded that many Silver-certified projects could be built at a cost that was within 4 percent of the cost for a similar non-LEED-certified courthouse or office building, as well as occasional LEED-Gold-certified projects (p. 8).

**LEED Cost Evaluation Study**
Indian Health Service. Department of Health and Human Services. 2006.

The U.S. Indian Health Service (HIS) conducted this study to evaluate the potential cost impacts of achieving LEED-NC and LEED-NC-Silver certification on its facilities, which are primarily hospitals and other healthcare-related buildings. They evaluated both initial capital cost investments and life-cycle costs (using a 20-year life). The purpose was to develop realistic cost factors for the implementation of LEED certification in the IHS budget estimating system so that projects could be adequately funded up-front for this purpose. For the study, LEED credits were evaluated against standard practices of the Indian Health Service as outlined in the agency's design guide.

Among the study findings were the following:

- Initial capital construction costs (design and construction) would require a 1 to 3 percent increase in the budget to meet the Certification level, and a 3.5 to 7.6 percent increase in the budget to meet LEED-Silver certification.
- Energy savings over 20 years of operation have the potential to significantly mitigate the initial capital cost impacts. "Given the potential margin of error inherent in these types of calculations, and the uncertainty of future energy prices, life-cycle cost savings may completely offset or even exceed initial capital costs" (p. ES-3).

The authors of the study made the following recommendation:

> It is advisable for IHS to adopt LEED certification in pursuit of sustainable design and adjust project budgets accordingly. Doing so provides a measurable benchmark for determining success. LEED is widely known, has significant credibility within the private and public sectors, provides third-party validation and provides recognition for the agency, affiliated tribes, and communities. Flexibility in the LEED process facilitates multiple avenues for achieving a basic certification under disparate circumstances, site conditions, and geographic locations. . . . a 3.0% increase to the project budget is appropriate to pursue a basic [Certified level] certification (p. ES-3).

**MILCON Energy Efficiency and Sustainability Study of Five Types of Army Buildings**
D.M. Caprio and A.B. Soulek. U.S. Army Corps of Engineers, Washington, D.C. 2011.

This study investigated current building features and construction methods and materials that will optimize energy reduction and sustainability for new construction standard designs in FY2013. The standard designs were for the five most commonly constructed Army building types: unaccompanied enlisted personnel housing (barracks); tactical equipment maintenance facility; company operations facility (government office and other public assembly); brigade headquarters (government office and data center); and dining facility. Among the goals for the study were the following:

- 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 enhancement.
- Determine compliance with the energy performance option of ASHRAE Standard 189.1.
- Reduce both indoor and outdoor potable water usage.
- Account for the impact on operations and maintenance by energy systems.
- Comply with the Guiding Principles for Federal Leadership in High-Performance and Sustainable Buildings.

The selected standard designs were required to meet all applicable energy reduction and sustainable design mandates (e.g., LEED Silver, Energy Policy Act of 2005, EISA 2007, and Executive Orders 13423 and 13514). The requirements were to "optimize the mission, function, quality, and cost" of each building design type. The baseline designs were amended and supplemented to include antiterrorism and force protection and select Department of Defense Unified Security Criteria, among other factors, and the designs were evaluated for full mission scope and full energy and sustainability compliance.

The authors noted difficulties in establishing a clearly defined baseline for determining energy performance because "these buildings do not have equivalent building categories within CBECS" and because of initial confusion over the different energy baselines found in ASHRAE standards (modeled building energy), and Section 433 of EISA 2007, which is based on measured building and plug load energy (p. v).

Energy simulations were completed using Energy Plus version 5.0 (DOE, 2010). Each energy-efficiency measure (EEM) was modeled independently; packages of energy-efficiency improvements were also modeled because the savings from each individual measure are not additive (p. 3). EEMs were modeled for each building type across 15 locations representative of the climate zones that serve as the basis for the development of ASHRAE standards.

The authors note that "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." The results were based on total energy use as opposed to the fossil-fuel-based portion of total energy use alone (p. 1).

Among the study conclusions were the following:

- Significant energy savings are possible for all climates.
- Cost increases for the recommended Low Energy Packages for the five building types ranged from 2 to 10 percent, with a high of 28 percent.

- 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.
- Buildings achieving 25 to 35 percent energy savings yield the maximum energy savings for the lowest cost.
- For buildings achieving 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).
- It may be cost prohibitive to design and construct buildings with energy savings of greater than 60 percent 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 (p. vi).
- There is a high level of confidence 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 (p. vii).
- Assuming proper construction and commissioning, energy savings in these buildings would be immediate. In terms of renewable energy however, their cost is over six times higher than the current investment in energy-efficiency measures in today's dollars (p. vii).

**Incremental Costs of Meeting ASHRAE Standard 189.1 at Air Force Facilities**
Logistics Management Institute, Reston, Va. 2011.

The authors sought to determine the incremental up-front construction cost to the Air Force (AF) of adhering to ASHRAE Standard 189.1 for High-Performance Green Buildings Except Low Rise Residential. Their purpose was to identify aspects of ASHRAE Standard 189.1 that could be included in Air Force Construction Criteria. Case studies for four different types of facilities in four different climate zones were conducted. Among the study findings were the following:

- Because AF buildings already are constructed to meet the Guiding Principles for High-Performance and Sustainable Buildings and meet at least LEED-Silver requirements and other federal sustainable building requirements, the added initial cost of meeting ASHRAE 189.1 as a percentage of total building construction costs was 1 to 2.8 percent for three of the four building types and 7.1 percent for the fourth type.
- Some of the requirements listed in ASHRAE Standard 189.1 would require fundamental changes to the implementation of the AF energy and metering programs.
- One part of the standard requires being able to reduce a building's energy demand by 10 percent at peak load times. However, if an AF building provides mission-critical functions, the building would be excepted from base-wide load shedding management.
- The standard requires that electricity, gas, and water meters have remote reading requirement. The AF requires advanced meters for new construction, but it has ordered a strategic pause in connecting new meters to existing remote meter reading systems due to security concerns and the pursuit of a standardized platform.
- The AF currently does not have the ability to manage the data collected by the meters (or submeters on some systems).

- Some of requirements overlap with what AF is already doing; others, like renewable energy, drive a very large capital investment that may not align with the AF corporate renewable energy strategy, and still others may be in conflict with how individual programs are implemented in the AF.
- The U.S. Army took exception to the renewable energy requirement because it makes more sense for military bases to use their size and footprint to tackle the problem rather than looking at individual building applications where the numbers simply are not life-cycle cost effective (p. v).

**Literature Review of Data on the Incremental Costs to Design and Build Low-Energy Buildings**
W.D. Hunt. PNNL-17502. Pacific Northwest National Laboratory, Richland, Wash. 2008.

Hunt conducted a literature review on the incremental costs to design and build low-energy buildings as opposed to green or sustainable buildings. For this review, a low-energy building was defined as one that "achieves 30 to 50 percent energy savings when compared to a building built to ASHRAE Standard 90.1-2004."

Among the findings were the following:

1. Objectively developed and verifiable data on the cost premium for low-energy (high-efficiency) buildings are very limited. Most of the literature focused on green or sustainable buildings, not low-energy buildings.
2. In cases where energy efficiency costs were available, the cost premiums ranged from 1 to 7 percent. In most cases, the cost premium was less than 4 percent. A notable exception is small warehouses in cooler regions (climate zones 5 through 7), which carried estimated cost premiums of between 5.9 and 7 percent.
3. Technology solutions are available right now to achieve savings on the order of 30 percent and more over ASHRAE Standard 90.1-2004; however, cost effectiveness of these technology standards is often not addressed (p. 2).

# E

# Guiding Principles for Federal Leadership in High-Performance and Sustainable Buildings

The following guiding principles are reprinted from the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding (pp. 3-5) as they were approved on December 1, 2008.

## I. Employ Integrated Design Principles

**Integrated Design.** Use a collaborative, integrated planning and design process that

- Initiates and maintains an integrated project team in all stages of a project's planning and delivery;
- Establishes performance goals for siting, energy, water, materials, and indoor environmental quality along with other comprehensive design goals; and, ensures incorporation of these goals throughout the design and life cycle of the building; and,
- Considers all stages of the building's life cycle, including deconstruction.

**Commissioning.** Employ total building commissioning practices tailored to the size and complexity of the building and its system components in order to verify performance of building components and systems and help ensure that design requirements are met. This should include a designated commissioning authority, inclusion of commissioning requirements in construction documents, a commissioning plan, verification of the installation and performance of systems to be commissioned, and a commissioning report.

## II. Optimize Energy Performance

**Energy Efficiency.** Establish a whole building performance target that takes into account the intended use, occupancy, operations, plug loads, other energy demands, and design to earn the ENERGY STAR® targets for new construction and major renovation where applicable. For new construction, reduce the energy cost budget by 30 percent compared to the baseline building performance rating per the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE) and the Illuminating Engineering Society of North America (IESNA) Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential. For major renovations, reduce the energy cost budget by 20 percent below pre-renovations 2003 baseline.

**Measurement and Verification.** In accordance with Department of Energy (DOE) guidelines issued under section 103 of the Energy Policy Act of 2005 (EPAct), install building level utility meters in new major construction and renovation projects to track and continuously optimize performance. Compare actual performance data from the first year of operation with the energy design target. After 1 year of occupancy, measure all new major installations using the ENERGY STAR® Benchmarking Tool for building and space types covered by ENERGY STAR®. Enter data and lessons learned from sustainable buildings into the High Performance Buildings Database (www.eere.energy.gov/femp/highperformance/index.cfm).

## III. Protect and Conserve Water

**Indoor Water**. Employ strategies that in aggregate use a minimum of 20 percent less potable water than the indoor water use baseline calculated for the building, after meeting the Energy Policy Act of 1992 fixture performance requirements.

**Outdoor Water**. Use water efficient landscape and irrigation strategies, including water reuse and recycling, to reduce outdoor potable water consumption by a minimum of 50 percent over that consumed by conventional means (plant species and plant densities). Employ design and construction strategies that reduce storm water runoff and polluted site water runoff.

## IV. Enhance Indoor Environmental Quality

**Ventilation and Thermal Comfort.** Meet the current ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, including continuous humidity control within established ranges per climate zone, and ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality.

**Moisture Control.** Establish and implement a moisture control strategy for controlling moisture flows and condensation to prevent building damage and mold contamination.

**Daylighting.** Achieve a minimum of daylight factor of 2 percent (excluding all direct sunlight penetration) in 75 percent of all space occupied for critical visual tasks. Provide automatic dimming controls or accessible manual lighting controls, and appropriate glare control.

**Low-Emitting Materials**. Specify materials and products with low pollutant emissions, including adhesives, sealants, paints, carpet systems, and furnishings.

**Protect Indoor Air Quality during Construction**. Follow the recommended approach of the Sheet Metal and Air Conditioning Contractor's National Association Indoor Air Quality Guidelines for Occupied Buildings under Construction, 1995. After construction and prior to occupancy, conduct a minimum

72-hour flush-out with maximum outdoor air consistent with achieving relative humidity no greater than 60 percent. After occupancy, continue flush-out as necessary to minimize exposure to contaminants from new building materials.

### V. Reduce Environmental Impact of Materials

**Recycled Content.** For Environmental Protection Agency-designated products, use products meeting or exceeding EPA's recycled content recommendations. For other products, use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project.

**Biobased Content.** For U.S. Department of Agriculture (USDA)-designated products, use products meeting or exceeding USDA's biobased content recommendations. For other products, use biobased products made from rapidly renewable resources and certified sustainable wood products.

**Construction Waste**. During a project's planning stage, identify local recycling and salvage operations that could process site related waste. Program the design to recycle or salvage at least 50 percent construction, demolition and land clearing waste, excluding soil, where markets or on-site recycling opportunities exist.

**Ozone Depleting Compounds**. Eliminate the use of ozone depleting compounds during and after construction where alternative environmentally preferable products are available, consistent with either the Montreal Protocol and Title VI of the Clean Air Act Amendments of 1990, or equivalent overall air quality benefits that take into account life cycle impacts.

# F

# Acronyms and Abbreviations

| | |
|---|---|
| AF | Air Force |
| ANSI | American National Standards Institute |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BCA | benefit-cost analysis |
| BIU | Buildings in Use (database) |
| BLCC | building life-cycle cost |
| BOMA | Building Owners and Managers Association |
| BRE | Building Research Establishment (United Kingdom) |
| BREEAM | Building Research Establishment's Environmental Assessment Method |
| CBE | Center for the Built Environment (at University of California, Berkeley) |
| CBECS | Commercial Buildings Energy Consumption Survey (conducted by the EIA) |
| CEA | cost-effectiveness analysis |
| CIEB | Continual Improvement of Existing Buildings (Green Globes) |
| DOD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| EIA | Energy Information Administration (Department of Energy) |
| EISA 2007 | Energy Independence and Security Act of 2007 |
| EUI | energy use intensity |
| FY | fiscal year |
| GBCI | Green Building Certification Institute |
| GBI | Green Building Initiative |

| | |
|---|---|
| GSA | U.S. General Services Administration |
| HVAC | heating, ventilation, and air-conditioning |
| IEQ | indoor environmental quality |
| IESNA | Illuminating Engineering Society of North America |
| IFMA | International Facility Management Association |
| IgCC | International Green Construction Code |
| IHS | Indian Health Service |
| LCC | life-cycle costs |
| LCCA | life-cycle cost analysis |
| LEED | Leadership in Energy and Environmental Design |
| LEED-EB | LEED-Existing Buildings |
| LEED-NC | LEED-New Construction and Major Renovations |
| LMI | Logistics Management Institute |
| NAVFAC | Naval Facilities Engineering Command |
| NRC | National Research Council |
| NPV | net present value |
| NDAA 2012 | National Defense Authorization Act of 2012 |
| OMB | U.S. Office of Management and Budget |
| SPiRiT | Sustainable Project Rating Tool |
| USGBC | U.S. Green Building Council |