3-2004

Making the Business Case for Sustainable Design in the Department of Defense

David M. Warnke

Recommended Citation

Warnke, David M., "Making the Business Case for Sustainable Design in the Department of Defense" (2004). *Theses and Dissertations*. 4078.
https://scholar.afit.edu/etd/4078

MAKING THE BUSINESS CASE FOR SUSTAINABLE DESIGN IN THE DEPARTMENT OF DEFENSE

THESIS

David M. Warnke, Captain, USAF

AFIT/GEM/ENV/04M-20

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFIT/GEM/ENV/04M-20

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

David M. Warnke, BS

Captain, USAF

March 2004

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David M. Warnke, BS
Captain, USAF

Approved:

Charles Bleckman
Charles A. Bleckmann (Chairman)

8 Mar 04
Date

Ellen C. England
Ellen C. England, Lt Col, USAF (Member)

8 Mar 04
Date

Alfred E Thal Jr
Alfred E. Thal, Jr., Lt Col, USAF (Member)

10 MAR 04
Date

AFIT/GEM/ENV/04M-20

Abstract

Buildings are one of the largest consumers of natural resources, a major source of ecological pollution, and occasionally toxic to human health. Sustainable design is the common term associated with buildings which, during their construction, use, and eventual disposal, seek to minimize these negative impacts. The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED™) rating system helps to assess the level of a building's sustainability.

In the Federal Government's push to set the example for the rest of the nation, nearly every Federal Agency has chosen to adopt the LEED™ assessment tool. Each of Armed Services in the Department of Defense has set ambitious LEED™ certification goals for future construction. Despite their stated goals and the clear environmental and health benefits of LEED™, a common complaint is that LEED™ designed buildings are simply too costly to construct. However, many proponents of LEED™ profess that LEED™ designed buildings shouldn't cost significantly more than conventionally designed and constructed buildings and that the life-cycle cost savings should rapidly compensate for any additional initial costs. Unfortunately, no comprehensive studies have been performed on initial construction costs in the Department of Defense; therefore, it continues to be the primary source of unit level resistance to LEED™ and sustainable design. This research gathered historical cost data from 22 completed Federal construction projects and used statistical analysis to explore whether a business case could be made to support LEED™ using initial construction costs in the Department of Defense.

Results from the analysis were mixed. Hypothesis testing deemed there was statistically no difference in cost between LEED™ and conventionally designed facility construction. On average, LEED™ buildings were only 1.9% more expensive to construct than conventional facilities; however, the 9.2% standard deviation made it difficult to make a strong supporting business case. The conclusion was the operational life-cycle costs savings would currently have to bear the primary responsibility for making a business case supporting LEED™ and sustainable design.

Acknowledgements

I can't begin to thank all the people who took their time and effort to talk or correspond with me on the topic of LEED™ and sustainable design. Your words of wisdom, interest, and encouragement helped to personally validate the merits of sustainable design and this thesis. Additionally, I would like to express my gratitude to my thesis and academic advisor Dr. Charles Bleckmann for knowing the optimum amount of pressure, encouragement, and guidance to provide throughout this thesis process. I would also like to thank Lt Col Alfred Thal for suffering with me on my initial quest for a thesis topic and for being a member of my thesis committee. Your Air Force Civil Engineer background and knowledge continually provided a sanity check on what I was trying to accomplish. Additionally, I would like to give special thanks to my final committee member, Lt Col Ellen England. I directly credit her knowledge, interest, and enthusiasm in explaining the sustainability of the planet's diverse ecosystems for sparking an interest in me toward sustainable design. Of course, I am grateful, as always, to my entire family for their continuous support and encouragement throughout this entire academic process. Finally, special thanks to my wife for her patience and understanding. I appreciate her attempts to maintain the perspective and balance we were so frequently reminded about.

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I. Introduction

1.1 Sustainable Development Movement

The beginning of the environmental awareness movement in the United States is often traced back to Rachel Carson's 1962 groundbreaking book *Silent Spring* (Lewis, 1985). *Silent Spring* chronicled the long-term and far reaching effects of environmental and ecological contamination. Specifically, the book told an apocalyptic story of the environmental effects of chemical pesticides (Lear, 1997). Many people took note of her stark vision of the future. Before Carson's book, most commercial industries and products of the era went unregulated with unknown long term impact on humans and the natural environment. Carson's inspired environmental movement was the catalyst for the eventual formation of the Environmental Protection Agency in 1970 (Lewis, 1985).

At the same time the United States was beginning to embrace the environmental movement, it was also taking root throughout the rest of the world. Not only were pollution and toxic chemicals concerns, but the mass consumption of the world's natural resources was also drawing attention. The exponential population growth many nations forecasted only exacerbated concern for long term environmental viability.

In 1983, in order to examine the world's environmental problems and to propose a global solution, the United Nations Secretary-General established the World Commission on the Environment and Development. The commission, comprised of members from 21 different countries, was chaired by the former Prime Minister of Norway, Gro Harlem

Brundtland (Hart, 1998). The commission eventually became known as the Brundtland Commission. The commission's charter was to work towards an agreement on the unique priorities each nation brought to the discussion. After three years of deliberation, the Brundtland Commission published their findings and recommendations in the report titled *Our Common Future*.

The main concern addressed in the report was for the long term viability and sustainability of the environment and its inhabitants. Most notably, the Brundtland Commission agreed on a common definition for sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). While this definition was purposefully ambiguous, it paved the way for future discussions between nations.

The United Nations convened a conference in 1992 to further define the sustainable development ideas presented by the Brundtland Commission. This widely attended conference became known as the Rio de Janeiro Earth Summit. The Rio Earth Summit produced an enormous 300-page document, Agenda 21, which was a plan for achieving worldwide sustainable development into the 21st century. Agenda 21 covered such diverse topics as air and water pollution, biodiversity, economic trade, demographics, desertification, energy production and consumption, health, poverty, technology, and tourism (United Nations, 1992).

1.2 Sustainable Development Federal Policies

Thoughts of sustainable development were not only occurring on the international front, but also within the United States. In 1993, under Executive Order (EO) 12852, President Clinton chartered the President's Council for Sustainable Development (PCSD) (Clinton, 1993b). PCSD was created to advise the President and promote a national sustainable development agenda. Committee members were drawn from diverse backgrounds to include science, the environment, and business. The PCSD agenda focused on many of the social, economic, and environmental issues highlighted in the Rio Earth Summit's Agenda 21 and would continue to advise President Clinton through the end of his second term of office (Clinton, 1995a, 1995b, 1997, 1999a, 1999c).

While President Clinton's PCSD heavily promoted sustainable development within industry and the private sector, most of the advancement in sustainable development was seen in the Federal Government. During his two terms in office, President Clinton signed many mandates directing the Federal Government to implement his sustainable development vision. President Clinton believed the Federal Government, as one of the primary natural resource consumers and polluters, should take the lead in sustainable development and set an example for the rest of the nation. He also believed this would help generate and promote markets for emerging sustainable technologies (Clinton, 1999b).

1.3 Natural Resource Consumption

Justifiably, the majority of President Clinton's sustainable development policies focused directly or indirectly on Federal Government facilities. The Federal Government is the single largest consumer of energy in the United States (Haskins, 2002). Over 40% (0.404 quadrillion BTUs) of the energy consumed by the Federal Government goes to its nearly 500,000 buildings (Howard, 2003b; Reicher, 2002). The floor space of these buildings exceeds 3 billion square feet (Wilson, 2001). These facilities consumed an average 60 billion kilowatt-hours of electricity each year at a cost of nearly $4 billion dollars (Wilson, 2001; Haskins, 2002). In addition to the energy the Federal Government consumes each year, it also uses approximately 250 billion gallons of water (Howard, 2003b). The Federal Government is not the only culprit of waste and environmental degradation. Buildings in general across the nation use approximately 42% (41.6 quadrillion BTUs) of all energy, 25% of all freshwater, 25% of all harvested wood, 30% of all raw materials, and 60% of all ozone-depleting substances. (O'Dell, 1999; Reicher, 2002; Buildings, 2001). Construction waste constitutes 40% of all material going to landfills (O'Dell, 1999). Building construction and operation are also responsible for 36% of the carbon dioxide produced each year (Buildings, 2001). To make matter worse, reports indicate nearly 30% of all buildings suffer from poor indoor air quality, sometimes termed sick building syndrome (Roodman and Lenssen, 1995, EPA, 1991). Statistics of this nature continue to legitimize the concerns from *Silent Springs* and help drive the sustainable development movement.

The ultimate aspiration of sustainable development is to create and utilize products which do not negatively impact the natural ecosystem. This entails "closing the loop" on natural resource exploitation and materials usage. "Closing the loop" means harvested natural resources should be continuously capable of being reused or fully recycled into another product.

1.4 Sustainable Design Emergence in the Department of Defense

Increased awareness and acceptance of sustainable development ideals nationwide prompted an organization of industry and construction professionals to come together in 1993 to develop and further promote what was now commonly called green building, or synonymously, sustainable design. The organization was called the United States Green Building Council (USGBC). Other similar organizations exist, but do not have the wide acceptance and following of the USGBC. In 1995, the USGBC developed a performance-based rating system to qualify the level of sustainability contained in a facility. This rating system, known as Leadership in Energy and Environmental Design (LEED™), evaluates the following categories: site selection, water and energy efficiency, materials use, indoor environment and health, and design innovation. Points are awarded in each category which total to become the building's final rating. The final ratings awarded are non-certified, certified (formerly bronze), silver, gold, and platinum. USGBC has developed a rating system for both new buildings and renovated or existing buildings.

One of the primary supporters and intellectual contributors to the USGBC is the Department of Defense (DoD). DoD leadership believes it has an obligation to follow sustainable practices since it consumes nearly twice the energy as the entire rest of the Federal Government combined (Reicher, 2002). The annual energy bill for military installations exceeds $2.4 billion (Steensma, 2002). In a 1994 display of support for sustainable development, the Secretary of Defense made the following statement: "The Department of Defense must improve its environmental performance by actively implementing policies that embrace pollution prevention in all phases of the acquisition process, the procurement of goods and services and in the life-cycle management of our installations" (AFCEE, 1997:3). In 1999, the Secretary of Defense sponsored a Service-wide study of sustainability and sustainable planning. The purpose of the study was to give the services a common understanding of the policies, goals, opportunities, and processes of implementing sustainable development. The report was formally titled *Sustainable Planning: A Multi Service Assessment 1999* (Lovins, 1999).

Each of the Armed Services have subsequently come out with their own sustainable design guidance which provide LEED™ based goals, tools, and references to aid in the implementation of sustainable design. Not only is there Service specific guidance, but other Federal Agencies and private organizations are also available to provide support. Despite the large amount of supporting information available, sustainable design has yet to become universally accepted in the DoD and the construction industry.

1.5 Sustainable Design Hurdles

While the lack of acceptance is likely due to a number of factors, the following paragraph outlines a few of the typical reasons noted during a sustainable design training session held by Air Force Reserve Command (AFRC) and Georgia Tech Research Institute (GTRI) (Pearce and others, 2000). First is distrust for sustainable technologies. Individuals are familiar with first generation sustainable technologies and construction practices which were initially immature and therefore inefficient and maintenance intensive. Examples include solar panels, sky lights, low/no-flow toilets, and variable air volume (VAV) heating, ventilation and air conditioning (HVAC) systems.

Second, many planners, designers, and architects are unable to look holistically at all the components of a successful sustainable building system. Sustainable features are thrown piecemeal into a facility which either don't complement each other or don't have their intended effect.

Third, sustainable design is considered "riskier" than conventional facility design and construction practices because of the quantity of unknowns. With the exposure military construction (MILCON) projects receive from DoD leadership and Congress, most installations choose the security of the conventional route. It is difficult to explain why a multi-million dollar facility doesn't function properly or meet its mission requirements after construction.

Fourth, sustainable design is also new to the construction industry. There are few reputable and/or experienced construction contractors willing to take an economic risk to build green buildings. Even with experienced contractors, construction bids are typically extremely elevated.

Finally, there is a lack of historical data necessary to successfully sell the costs and benefits of a sustainable building to leadership and Congress. This final explanation is really a result of all the other resistance factors. Identifying the financial costs and benefits as well as other consequences of an action or decision is often called a business case (Schmidt, 2002). Presenting a convincing business case for sustainable design is challenging and up to now has been largely unsuccessful.

1.6 Problem Statement

The primary source of resistance to sustainable design is the perceived additional cost of “building green”. There have been no comprehensive Department of Defense studies on the cost of sustainable design to dispel the monetary concerns. The lack of historic data complicates the justification and approval process for future sustainable design projects due to the level of uncertainty involved. The question remains, can a business case be made for sustainable design in the DoD when considering initial construction cost as the primary decision factor.

1.7 Research Objectives

The following research objectives were pursued:

1. Compile estimated and actual construction cost data for LEED™ or SPiRiT certified Federal facilities to determine whether LEED™ or SPiRiT certified facilities cost more than conventional facilities across the Federal Government.
2. Determine whether the Department of Defense has been more financially successful or less financially successful than other Federal Agencies in building “green” facilities.
3. Provide recommendations to best make the business case for future sustainable design projects in the Department of Defense.

1.8 Research Methodology

The following methodology was used to accomplish the research objectives:

1. Review all relevant literature relating to the costs and benefits of sustainable design.

2. Examine the various facility approval, design, and construction processes across the Federal Government.

3. Review a broad spectrum of industry and governmental economic analysis and cost estimating methodologies.

4. Collect and examine project information on LEED™ based sustainable design buildings to determine parametric construction cost estimates, and final construction costs.

5. Analyze the results to determine if there are any general recommendations that can be gleaned to perform future economic analysis, cost estimating, or justification for sustainable facilities.

1.9 Relevance

Initial construction costs tend to be greater for sustainable design facilities. Lack of historical cost information makes it difficult to justify green facilities as the best alternative in the Federal Government's approval process which focuses on initial costs. Without this justification, few sustainable design facilities are being built and therefore not capitalizing on the life-cycle cost and environmental benefits of sustainable design.

1.10 Thesis Overview

Chapter 2 outlines the Federal Government's adoption of sustainable design along with individual Federal Agencies' implementation of the LEED™ rating tool. The LEED™ rating system is explained and compared to the Army's SPiRiT rating system. Finally, this chapter covers the Military Construction (MILCON) program and how

LEED™ is incorporated into facility conceptual planning, programming, design, construction, and start-up. Chapter 3 focuses on the methodology used to gather and analyze the construction costs of LEED™ and SPiRiT certified facilities. Chapter 4 catalogues and presents the results. Chapter 5 presents conclusions for making a business case for sustainable design and make recommendations for future research.

II. Background

As highlighted in Chapter 1, the Federal Government has taken steps to commit to the sustainability of the environment. This chapter details those steps by reviewing the various sustainability laws, policies, and regulations mandated by the Federal Government. The industry standard Leadership in Energy and Environmental Design (LEED™) sustainable design assessment tools were used to convey the effort and commitment required to incorporate sustainable design into construction. The Federal Government construction processes, from requirements generation to final construction and daily operation, were described to show how sustainable design should be incorporated in each phase. Finally, this chapter addressed the hurdles confronted in sustainable design implementation.

2.1 Presidential and Congressional Mandates for Sustainable Design

There is considerable history of Federal Government support for the ideals of sustainable design. Following is a chronological listing and explanation of the various Federal Laws, Executive Orders, and Executive Memoranda which show this support:

> **National Environmental Policy Act of 1969.** The purposes of this Act are: "to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality" (United States Congress, 1969: Sec. 2, 42 USC 4321).
>
> **Energy Policy and Conservation Act (EPCA) of 1975**. EPCA was the first significant piece of legislation to address energy management in the Federal Government. The Act required the development of a 10-year comprehensive energy management plan (Wilson, 2001).

Resource Conservation and Recovery Act (RCRA) of 1976. RCRA mandated the Federal government to promote natural resource recycling and conservation (DoE, 1998).

National Energy Conservation Policy Act (NECPA) of 1978. NECPA required the Federal Government to use life-cycle cost analysis as the basis for its energy procurement policy. The Act also established energy efficiency requirements when retrofitting Federal facilities (Daschle, 1996).

Comprehensive Omnibus Budget Reconciliation Act (COBRA) of 1985. COBRA was a revolutionary one-year trial funding bill for Federal agencies to acquire private financing and implementation of energy savings projects through shared energy savings (SES) contracts. The Federal agency would get, often much needed, energy upgrades and the private financier would retain a portion of the energy savings (National Park Service, 1999).

Federal Energy Management Improvement Act (FEMIA) of 1988. FEMIA was an amendment to the National Energy Conservation Policy Act of 1978. The Act mandated Federal facilities to reduce energy consumption by 10% on a per-square-foot basis by 1995, with FY 1985 as the base year (Steensma, 2002).

Pollution Prevention Act of 1990. This Act declared "the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner" (United States Congress, 1990:sec 13101b).

Executive Order 12759, "Federal Energy Management" 17 Apr 91 (Superseded by Executive Order 12902). This Executive Order (EO) mandated all Federal Agencies to reduce facility energy consumption below the 1985 baseline level by 20% on a per-square-foot basis by the year 2000 (Clinton, 1991).

Energy Policy Act (EPACT) of 1992. EPACT once again amended the National Energy Conservation Policy Act of 1978. Nearly the same as Executive Order 12759, this Act mandated federal facilities to reduce energy consumption by 20% on a per-square-foot basis by the year 2000, with 1985 as the base year. This mandate now had the additional backing and oversight of Congress. EPACT also promoted energy efficiency and use of renewable energy technologies. Additionally, the Act emphasized the use of Energy Savings Performance Contracts to replace aging energy infrastructure and improve energy consumption (Wilson, 2001).

Executive Order 12843, "Procurement Requirements and Policies for Federal Agencies for Ozone-Depleting Substances," 21 Apr 93 (Superseded by Executive Order 13148). President Clinton mandated that Federal Agencies minimize and eventually eliminate procurement of ozone depleting materials and substances where economically practical. The Executive Order also emphasized reducing emissions and recycling existing supplies of ozone-depleting substances (Clinton, 1993a).

Executive Order 12856, "Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements," 4 Aug 93 (Superseded by Executive Order 13148). Executive Order 12856 required each Federal Agency to develop a pollution prevention policy detailing its plans to comply with the reduction and recycling goals of the Pollution Prevention Act of 1990. The Executive Order also called on Federal Agencies to reduce to the maximum extent practicable, any toxic chemicals and materials entering the environment or wastestream (Clinton, 1993c).

Executive Order 12873, "Federal Acquisition, Recycling, and Waste Prevention," 20 Oct 93 (Superseded by Executive Order 13101). Executive Order 12873 made reference to the Federal Government's vast and influential purchasing power. It made mandatory that all future acquisitions incorporate environmental considerations into the decision making process. Elimination of virgin material requirements, waste prevention, product reuse, and recycling were strongly encouraged (Clinton, 1993d).

Executive Order 12902, "Energy Efficiency and Water Conservation at Federal Facilities," 8 Mar 94 (Superseded by Executive Order 13123). This order raised the energy conservation bar even higher than Executive Order 12759. Federal Agencies were required to reduce energy consumption of typical Federal facilities by 30% per square foot by 2005 using 1985 as the base-level. Industrial facilities were required to reduce energy consumption by 20% by 2005, but use 1990 as the base-level. This executive order continued to stress the need to minimize use of petroleum-based fuels and maximize the use of solar and other alternative energy technologies. All Federal facilities were supposed to undergo an energy efficiency and water conservation audit within 10 years. Each Federal Agency was to choose one facility as its showcase facility to highlight energy and water efficiency and the viability of alternative technologies. Innovative financing and contractual mechanisms were encouraged to meet the demands of this order (Clinton, 1994).

Executive Memorandum, "Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds," 26 Apr 94. This Executive Memorandum required Federally landscaped grounds to use native plants and landscaping where cost-effective and practical. It also urged construction practices which minimize adverse effects on natural habitat. The President's memorandum also encouraged the minimal use of fertilizers and pesticides. Minimization of water runoff and other such water-efficient practices were also championed (Wilson, 2001).

Executive Order 13101, "Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition," 14 Sep 98. This Executive Order begins with restating the goals of the Pollution Prevention Act of 1990. Pollution should be prevented if at all possible. If pollution can't be prevented, recovery and recycling of materials should be a top priority. As a last resort, disposal should be done in an environmentally safe manner. A 35% recycling goal by 2005 was established for the Federal Government. To further address pollution reduction goals, the Federal Government was directed to make pollution prevention a factor in all procurement decisions (Clinton, 1998).

Executive Order 13123, "Greening the Government Through Energy-Efficient Management," 3 Jun 99. Executive Order 13123, further raised the energy consumption reduction goals set by Executive Orders 12759 and 12902. The same 30% per square foot by 2005 reduction goal was restated for typical Federal facilities, but added was a 35% per square foot energy reduction goal by 2010. In both cases, 1985 would remain the baseline. Energy reduction goals for laboratories and industrial facilities faced a similar increase. Added to the 20% reduction by 2005 was a 25% reduction by 2010. The 1990 baseline continued for both reductions. A 30% reduction of greenhouse gas emissions attributed to facility energy use by 2010 compared to 1990 levels was also added. Renewable energy continued to be stressed. Under this Executive Order, the Federal Government was directed to install 2,000 solar energy systems by the year 2000 and 20,000 solar energy systems by 2010. Federal Agencies were directed to purchase EPA and Department of Energy certified Energy Star products. Water conservation was also emphasized. This Executive Order was the first to specifically mention sustainable building design. It directed DoD and GSA, in consultation with DOE and EPA, to develop sustainable building design principles. All Federal Agencies were directed to apply these principles in the planning, siting, design, and construction of new facilities. Throughout the Executive Order, life-cycle cost analysis was stressed as the means of procurement decision making. Initial costs were not intended to be the determining factor. Sec. 505 of the order states "within 180 days of this order, the Administrator of GSA, in collaboration with the Secretary of Defense, the Secretary of Energy, and other agency heads, shall develop and issue guidance to assist agencies in ensuring that all project cost estimates, bids, and agency budget requests for design, construction, and renovation of facilities are based on life-cycle costs. Incentives for contractors involved in facility design and construction must be structured to encourage the contractors to design and build at the lowest life-cycle cost" (Clinton, 1999b).

Executive Order 13148, "Greening the Government Through Leadership in Environmental Management," 21 Apr 00. This Executive Order stressed environmental management. All Federal facilities are required to implement environmental management systems by December 2005 to ensure that each organization's operations, planning, and management decisions are integrated with environmental priorities. Executive Order 13148 also directed the phase out of Class I ozone-depleting substance by 2010. Emphasis in this order was also placed on pollution prevention and sound landscaping techniques (Clinton, 2000).

National Defense Authorization Act for FY 2002, S. 1438, 28 Dec 01. This Act passed by Congress is a reiteration of Executive Order 13123. The 2005 and 2010 energy consumption goals for laboratory and other facilities remained untouched. The Secretary of Defense is required to report annually to Congress on the progress made toward achieving the energy reduction goals. President Bush's signature on this Act not only meant the new administration supported the energy reduction goals, but it also showed that Congress fully intended to back Clinton's Executive Order 13123 (Bush, 2001).

Title 10 Code of Federal Regulations, Part 435, "Energy Conservation Voluntary Performance Standards for New Buildings; Mandatory for Federal Buildings". CFR Part 435 specifies mandatory national energy code performance standards for new Federal facilities (Daschle, 1996).

Title 10 Code of Federal Regulation, Part 436, "Energy Measures and Energy Audits". CFR Part 436 specifies the analysis requirements, procedures and rules to be used for life-cycle costing by Federal Agencies (Federal Facilities Council, 2001).

Federal Acquisition Regulation (FAR) subpart 23.2, Dec 2001. The FAR was revised to require acquisition of energy-efficient products when they are life-cycle cost effective and available (Howard, 2002).

Office of Management and Budget (OMB) Circular A-11, Part 2, Section 55, 27 Jun 2002. This circular provided budget guidance to Federal Agencies. Section 55 encouraged Federal Agencies to incorporate Energy Star or LEED™ building standards into initial design concepts for new construction and/or building renovations (Daniels, 2002).

2.2 Federal Energy Reduction Progress

Some Federal Agencies have been successful conserving energy. The figures below show how well the individual Federal Agencies are doing toward meeting energy reduction goals.

Figure 1 is a summary of the entire Federal Government's progress toward meeting the various energy reduction mandates. The figure illustrates the Federal Government has been able to meet or exceed all previous energy reduction goals. However, the recent trend appears to be leveling off. At this current trend, the Federal Government will not meet the energy reduction goals of 2005 and 2010.

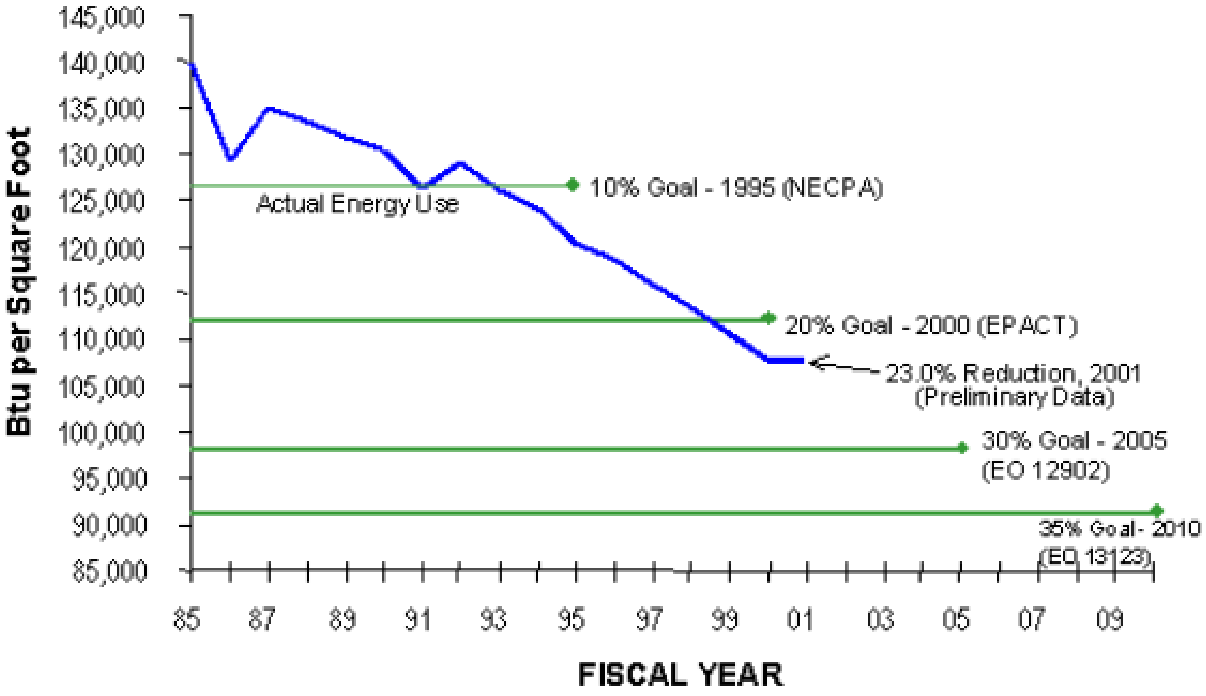

Figure 1 Progress Toward Federal Facility Energy Reduction Goals
(Source: Howard, December 2002:18)

Figure 2 summarizes how each individual Federal Agency is progressing toward energy reduction goals for standard buildings. Some agencies are progressing much better than others. Figures 1 and 2 show, as of the end of 2001, the DoD (23.6%) is only slightly ahead of the Federal average in energy reduction (23.0%).

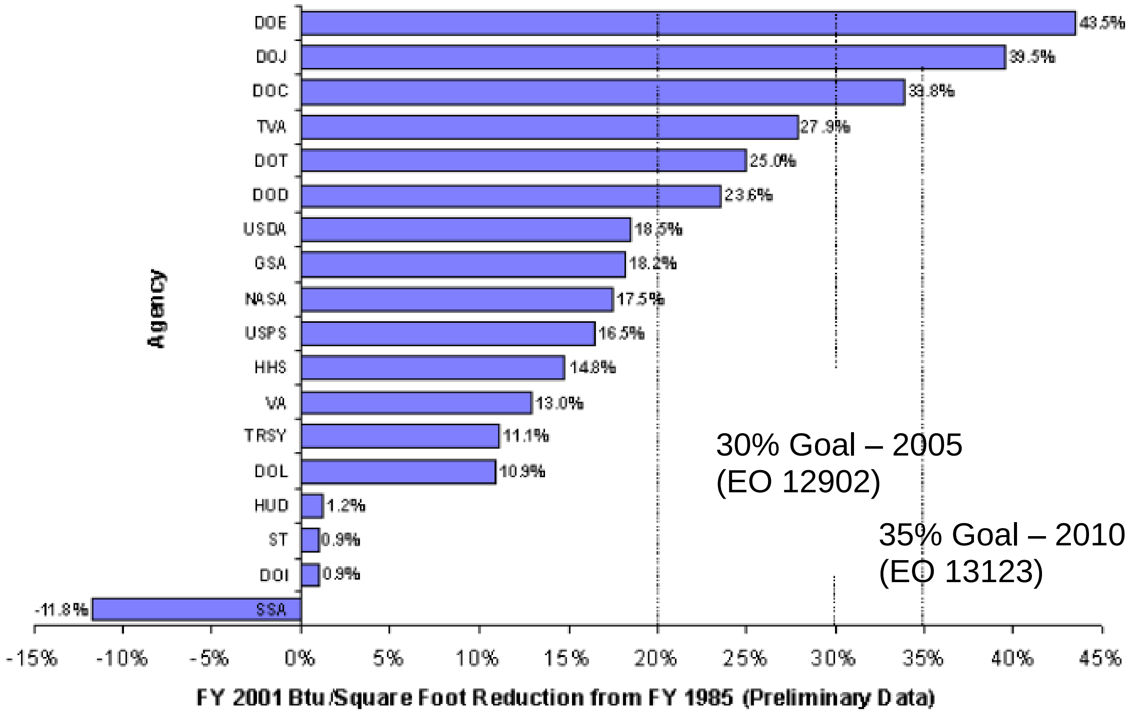

Figure 2 Individual Federal Agency Progress Toward Energy Reduction Goals for Standard Buildings (Source: Howard, December 2002:20)

2.3 Federal Government Implementation of Sustainable Design

The Federal Laws, Executive Orders, and Executive Memoranda listed in Section 2.1, clearly convey the sustainable development agenda in place over the past few decades. Executive Orders 13101, 13123, and 13148 are typically regarded as the most current Federal Government mandates and justification for sustainable design. Each Federal Agency has developed their own sustainable design policy using these three Executive Orders as the foundation. Not surprisingly, each policy is slightly different in its implementation. Despite their implementation differences, the USGBC's LEED™

criteria have been chosen by nearly all Federal Agencies as the measuring device to ensure compliance with sustainable design mandates and as a green building design tool.

The Department of Defense, as one of the nation's largest employers and biggest polluters, has long understood its obligation to protect the environment. Sustainable Design is one way it has acted to promote environmental stewardship. In 1994, the Secretary of Defense made the following statement regarding sustainability:

> The Department of Defense must improve its environmental performance by actively implementing policies that embrace pollution prevention in all phases of the acquisition process, the procurement of goods and services and in the life-cycle management of our installations (AFCEE, 1997:3).

In 1999, the Secretary of Defense sponsored a Service-wide study of sustainability and sustainable planning. The purpose of the study was to give the services a common understanding of the policies, goals, opportunities, and processes of implementing sustainable development. The report was formally titled *Sustainable Planning: A Multi Service Assessment 1999* (Lovins, 1999).

After the release of the assessment report, each of the Armed Services subsequently issued their own sustainable design policy statements. The United States Air Force's current policy was issued 19 Dec 2001 by Major General Earnest O. Robbins, Air Force Civil Engineer (Robbins, 2001). The policy memorandum states:

> It is Air Force policy to apply sustainable development concepts in the planning, design, construction, environmental management, operation, maintenance and disposal of facilities and infrastructure projects, consistent with budget and mission requirements (Robbins, 2001:1).

The memorandum went on to declare LEED™ as the Air Force's preferred self-assessment metric. General Robbins called on each of the Air Force's major commands (MAJCOMs) to select at least 20% of their FY04 construction projects to be LEED™

pilot projects. General Robbins' goal was to incrementally have all construction projects capable of receiving LEED™ certification by the FY09 construction program (Robbins, 2001, Department of the Air Force, 2003). General Robbins' memorandum however, left the decision to acquire actual LEED™ certification by USGBC up to the individual MAJCOMs. While the merits of LEED™ were noted earlier in the *United States Air Force Environmentally Responsible Facilities Guide*, General Robbins' memorandum was the first time it was mandated (AFCEE, 1997).

The United States Navy and Marine Corps came to accept sustainable design similarly to the Air Force. Naval Facilities Engineering Command (NAVFAC) is the lead organization responsible for all Navy and Marine Corps construction. In June of 1998, Rear Admiral David J. Nash, Commanding Officer of Naval Facilities Engineering Command (NAVFAC), issued four policy letters emphasizing sustainable design (NAVFAC, 1998a, b, c, and d). The policy letter can be summarized in the following excerpt:

> It is the policy of the Naval Facilities Engineering Command (NAVFAC) to incorporate sustainability principles and concepts in the design of all facilities and infrastructure projects to the fullest extent possible, consistent with budget constraints and customer requirements. It is further the policy of NAVFAC to seek to do this with no increase in first cost. In the case of larger projects, the application of integrated design concepts is the key to this accomplishment (NAVFAC, 1998a:1).

The Navy did not officially adopt the USGBC's LEED™ rating system until mandated by NAVFAC Commander, Rear Admiral Michael R. Johnson, in a memorandum signed 5 Jul 2002 (Chapman, 2002). The memorandum declared that all new construction and major renovation projects should be capable of achieving at least a minimum LEED™ "Certified" rating (NAVFAC, 2002). Like the Air Force, actual LEED™ certification by USGBC was not required, but suggested for showcase projects.

On 9 Jun 2003, Rear Admiral Johnson reiterated the main points of his 5 Jul 2002 LEED™ memorandum and rescinded previous sustainable design Planning and Design Policy Statements, when he issued NAVFAC Instruction 9830.1 (NAVFAC, 2003a). NAVFACINST 9830.1 is the current U.S. Navy directive on sustainable design and maintains the minimum LEED™ "Certified" rating requirement. NAVFACTINST 11010.45, released May 2003, provides additional sustainable design planning assistance.

The United States Army expressed its desire to incorporate sustainability in its construction practice by issuing the *Sustainable Design and Development* memorandum on 26 April 2000 (Johnson, 2000). This memorandum, written by Paul W. Johnson, Deputy Assistant Secretary of the Army, carried nearly the same message as the Air Force's and Navy's earlier releases sustainable design policies. It stated, Army personnel "will ensure Sustainable Design and Development is considered in Army installation planning decisions and infrastructure projects to the fullest extent possible, balanced with funding constraints and customer requirements" (Johnson, 2000:1). The memorandum also directed the United States Army Corps of Engineers to provide technical guidance.

The United States Army Corps of Engineers (USACE) issued its design guidance on 1 May 2001 (Beranek, 2001). This document differed from the design guidance released by the other Armed Services in that it introduced and described the Sustainable Project Rating Tool (SPiRiT). SPiRiT, a self-assessment tool, was developed jointly by the United States Army and the United States Green Building Council (USGBC) and closely resembles USGBC's LEED™ version 2.0 rating system. The Army decided it needed to supplement LEED™ 2.0 with criteria more adequately capturing the unique issues faced by military facilities and construction (Goradia and Schneider, 2002).

SPiRiT is rated on a Bronze, Silver, Gold, and Platinum scale of increasing sustainability. A more detailed comparison of the LEED™ and SPiRiT project rating systems will be provided later in this chapter.

Immediately following the release of SPiRiT, Major General R.L. Van Antwerp, Assistant Chief of Staff for Installation Management, issued a 4 May 2001 policy mandating all future Army construction projects utilize SPiRiT and attain a minimum Bronze rating (Van Antwerp, 2001). The memorandum went on to claim that most projects could achieve the SPiRiT Bronze rating without an increase in first cost.

On 21 Dec 02, after recognizing the great strides made and experience gained in sustainable design, the Army raised its SPiRiT requirements. In a memorandum signed by Major General Larry J. Lust, Assistant Chief of Staff for Installation Management, all MILCON projects beginning in FY06 would be required to meet the SPiRiT Silver rating level (Lust, 2002). It only took three months for the standard to be raised again. On 11 Apr 03, Mario P. Fiori, the Assistant Secretary of the Army for Installations and Environment directed all projects not already designed to meet SPiRiT Gold level rating beginning in FY06 (Fiori, 2003).

In order to comply with Presidential and Congressional guidance, nearly every Federal Government Agency has adopted USGBC's LEED™ rating system as part of their sustainability policy. At the end of 2003, nearly 90 Federal Government construction projects were undergoing the LEED™ certification process (Howard, 2003a).

The Armed Forces are not the only Federal Agencies trying to implement LEED™. The U.S. General Services Administration (GSA) is often called the civilian

Federal Government's landlord. Its inventory includes over 330 million square feet of office space for approximately a million Federal employees (PBS, 2003). GSA maintains multiple contracts for architecture, engineering, and construction management services and therefore is typically used to manage non-Department of Defense construction projects. Beginning in FY 2003, all new GSA buildings must meet the LEED™ "Certified" level of sustainability. The U.S Department of the Interior National Park Service uses LEED™ as a self-assessment tool (Howard, 2003a). The Environmental Protection Agency (EPA) and National Aeronautics and Space Administration (NASA) have both ambitiously declared that all of their new building construction will achieve the LEED™ Silver rating by 2005 (Howard, 2003a, Winn, 2002). The U.S. Department of Health and Human Services (HHS) registered three new construction projects with USGBC in FY 2002 with the intent of receiving LEED™ certification (Howard, 2003a). The U.S. Department of State has mandated a minimum LEED™ "Certified" rating for all its new construction (Howard, 2003a). The U.S. Department of Energy already utilized LEED™ in a few of its construction projects and continues to be a leader in promoting sustainable design (Howard, 2003a). There is little doubt the acceptance of the LEED™ rating tool is expanding.

2.4 Leadership in Energy and Environmental Design Rating System

There are many facility performance standards and rating tools in existence today. A list of just a few being used around the world today includes Green Star®; National Australian Built Environment Rating System (NABERS); Building Sustainability Index (BASIX); The Energy and Resources Institute (TERI) Green Building Rating System

(TGBRS); Australian Building Greenhouse Rating Scheme (ABGR); Green Building Assessment Scheme (GBRS™); Building Research Establishment Environmental Assessment Method (BREEAM™); Canadian Green Leaf Eco-Rating Program; United Kingdom Building Environmental Performance Assessment Criteria (BEPAC); Hong Kong Building Environmental Assessment Method (HK-BEAM); Green Globes; and Green Building Assessment Tool (GBTool™); and Energy Star®. The sheer number of these international rating tools demonstrates the global interest and support sustainable design is receiving. However, few rating systems are as comprehensive, and none have the industry acceptance and momentum nationally as well as internationally, as the LEED™ rating system. For example, the EPA's well known Energy Star® program, while being a commendable rating system, only covers energy-related issues. LEED™ has broader goals and scope. It focuses not only minimizing energy consumption, but also maximizing the potential of the construction site; minimizing resource consumption; protecting and conserving water; utilizing environmentally preferable products and materials; enhancing the indoor environmental quality; and optimizing facility operations and maintenance. There are some valid criticisms of LEED™, which will be discussed later, but most are envisioned to be eliminated in future updates. No other rating system incorporates as many of the sustainability goals as the LEED™ rating system.

As mentioned in Chapter 1, development of a performance-based rating system began in 1995 by the U.S. Green Building Council in partnership with the building industry, product manufacturers, building owners, architects, engineers, environmental groups, utilities, federal and local governments, research institutes, professional societies, and universities (USGBC, 2003a). The rating system they developed, Leadership in

Energy and Environmental Design (LEED™) version 1.0, was released as a pilot program in December 1998. Over 60 projects entered the program, but only 18 eventually received LEED™ certification (USGBC, 1999). A total of 22 of the available 44 points were required for certification under LEED™ 1.0 (USGBC, 1999). Work on the next version of LEED™ began in 1999.

LEED™ version 2.0 was released in March 2000 which incorporated much of the feedback from the pilot study along with additional research into sustainability implementation options and standards. There are 69 points possible in LEED™ 2.0 and 26 points are required for the minimum certification (USGBC, 2003a). This means less than 40% of the available points are required for minimum certification. Four levels of LEED™ certification are possible, which correlate to increasing levels of sustainability achieved in the project (Table 1):

Table 1 LEED™ Certification Levels

LEED™ Certified	26 - 32 points
LEED™ Silver	33 - 38 points
LEED™ Gold	39 – 51 points
LEED™ Platinum	52 + points

*69 points possible

LEED™ 2.1 was released November 2002, but is only an administrative update. The only changes were technical clarifications and streamlining of documentation requirements for LEED™ certification (USGBC, 2002b). There are nearly 800 projects currently registered for potential certification with over 50 projects already receiving

LEED™ 2.0/1 certification (USGBC, 2003a). LEED™ version 3.0 is not due to be released until after 2005.

LEED™ 2.1 evaluates building performance in six categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Processes. Points/credits are awarded in each category and totaled to give the building's final rating. It should be noted that not all the points are applicable to every construction project. Four categories have prerequisites for qualification in any certification level. A checklist of all the available points/credits and prerequisites is included in Appendix A (USGBC, 2003b). The credits are meant to strike a fair balance between established construction practices and emerging technologies and concepts. Each credit is intended to be measurable, documentable, and verifiable. There are many additional sources of detailed information on the LEED™ categories including USGBC's own website **(**www.usgbc.org**)**.

2.5 Sustainable Project Rating Tool (SPiRiT)

The U.S. Army's Sustainable Project Rating Tool (SPiRiT) was released and mandated in May 2001. The Army developed SPiRiT with the support of the United States Green Building Council (USGBC); therefore, not surprisingly, SPiRiT closely resembles USGBC's LEED™ 2.0. As previously mentioned, the Army decided it needed criteria more adequately capturing the issues faced by military facilities and construction (Goradia and Schneider, 2002).

The Army believed LEED™ did not take into account its unique military mission, neglecting issues such as force protection (ATHENA, 2002). Additionally, the Army was concerned LEED™ did not provide enough credit for functionality and personnel convenience in the workplace. The Army's desire to have facilities designed for easy adaptability to future mission changes was also not awarded in LEED™ (Uyeno, 2002). Although LEED™ was in its infancy stage when SPiRiT was developed, the Army did not foresee LEED™'s market recognition and acceptance it enjoys today. Finally, the Army wanted a rating system without the need or additional expense of outside certification. They likely didn't anticipate the many commercial construction projects today which use LEED™ as a design tool only and don't undergo the actual outside certification process (ATHENA, 2002).

The current iteration of the Army's sustainable design tool, SPiRiT version 1.4.1, is organized into eight sections (USACE, 2002). It retains all of LEED™ 2.0's six sections except the Innovation and Design section which it substitutes with the following three sections: Facility Delivery Process, Current Mission, and Future Mission. With the exception of one credit, all three new sections are entirely subjective. The five SPiRiT sections, which are common to both LEED™ and SPiRiT, have numerous terminology changes and incorporate military standards and regulations. A U.S. Army Corps of Engineers created checklist of the various SPiRiT sections and credits is provided in Appendix B. The SPiRiT scoring system is based on 100 possible points, compared to LEED™'s 69. A comparison is provided below (Table 2):

Table 2 LEED™ vs SPiRiT Point System Comparison

LEED™ 2.0		**SPiRiT 1.4.1**	
Sustainable Sites	14 pts	Sustainable Sites	20 pts
Water Efficiency	5 pts	Water Efficiency	5 pts
Energy and Atmosphere	17 pts	Energy and Atmosphere	28 pts
Materials and Resources	13 pts	Materials and Resources	13 pts
Indoor Environmental Quality	15 pts	Indoor Environmental Quality	17 pts
Innovation and Design	5 pts	Facility Delivery Process	7 pts
Total:	**69 pts**	Current Mission	6 pts
		Future Missions	4 pts
		Total:	**100 pts**

Similar again to LEED™, is SPiRiT's four tier rating scale; Bronze, Silver, Gold, and Platinum. There is a natural tendency to compare the two rating scales since the rating systems are similar and the rating scales are identical. Because of the differences in percentage points between similar ratings, some can argue they shouldn't be compared since it appears easier to attain comparable SPiRiT ratings (Table 3). Table 3 shows even with the additional 31 points available for SPiRiT, it takes the same 25/26 points to achieve the lowest ratings. This inequality is only a minor source of contention since the Army requires a minimum of a SPiRiT Gold rating for all its new facilities by 2005, while other Federal Agencies are only mandating up to the LEED™ Silver rating. The final outcomes will be a comparable level of sustainability. This issue will dissipate in a few years since the Army has already stated it will adopt the new LEED™ 3.0 standard once it is released in late 2005 or 2006. The Army is working with USGBC to eliminate what it feels are weaknesses in LEED™ 2.1 in the upcoming LEED™ 3.0.

Table 3 LEED™ vs SPiRiT Rating Scale Comparison

LEED™ 2.1			**SPiRiT 1.4.1**		
Certified	26 - 32 Points	* (38%)	Bronze	25 - 34 Points	(25%)
Silver	33 - 38 Points	(48%)	Silver	35 - 49 Points	(35%)
Gold	39 - 51 Points	(57%)	Gold	50 - 74 Points	(50%)
Platinum	52 - 69 Points	(76%)	Platinum	75 - 100 Points	(75%)

*Minimum percentage of available points required

2.6 LEED™ Integrated Project Team

LEED™ and the LEED™ based SPiRiT rating systems both stress the importance of an integrated, multidisciplinary project team as key to achieving the highest levels of sustainability. In an attempt to stress this importance and aid in the application and certification process, LEED™ 2.1 awards one point toward the facilities final rating for having a LEED™ 2.0/2.1 accredited professional on the project team. Accreditation is acquired by passing USGBC's accreditation exam. The accreditation exam and training workshops held by USGBC emphasize integrated project teams.

The integrated project/design team approach is simply a conscious decision to include broad stakeholder participation in every planning, design, and construction decision to gain buy-in and consensus along with generation of alternative ideas. Stakeholders can range from the traditional facility owner, users, and operators to architects, engineers, planners, interior designers, environmental designers, cost estimators, energy managers, contracting personnel, and construction contractors. An integrated project team approach will accomplish the following:

- Establish and ensure conformance with sustainability, functionality, and performance objectives in acquired facilities
- Make informed decisions considering short and long term tradeoffs of resources, materials, mission objectives, and building performance

- Ensure contract documents reflect design, construction, and performance objectives
- Create an understanding of how material and systems selections considered in the conceptual planning and design phases will affect first costs and life-cycle costs, operations and maintenance practices, and the ultimate performance of a facility over its lifetime (Federal Facilities Guide, 2001:25)

2.7 Sustainable Design Construction Costs

Historically, building “green” was 5-15% more expensive industry-wide than conventional construction (Berman, 2001, Muto, 2003). However, the U.S. Department of Energy and most other Federal Agencies believe the majority of “green” buildings today can be constructed at nearly the same cost as conventional buildings (DoE, 2003). A recent independent study of 33 LEED™ green buildings nationwide determined the premium for “green” buildings was 0-2% (Katz, 2003). The primary reason for this shift is the ever increasing number of developers, designers, and contractors gaining experience and familiarity with green-building techniques and materials (Katz, 2003). Integrated design is the technique credited with much of green-building’s success.

The project team no longer works in isolation, but instead capitalizes on the synergy of the entire team to come up with the design of individual building components and systems which take into consideration all the other components and systems. A design example might be the simple addition of daylighting by the architect. Because of the additional lighting, the electrical engineers should require less electrical lighting. The reduction in electrical lighting will likely cause less heat load within the facility; therefore, reducing the size of the mechanical cooling system. Each one of these reductions saves money in materials and labor. The design example is a fairly simple example, but without an integrated design team, would likely not be addressed. In the past, each design discipline worked individually on their section of the design without regard for decisions made by other disciplines. The historical result, when sustainable features were attempted in isolation, was overdesigned buildings with systems that didn’t work properly or required a significant number of costly construction changes.

Manufacturers are also working harder to create and promote more cost effective environmentally friendly products. Not only are capital costs dropping for basic environmentally friendly products, but manufacturers have become more successful promoting and selling higher-performance products and alternative technologies with promises of even greater life-cycle savings.

2.8 Life-Cycle Costs of Sustainable Design

It is generally agreed as the level of sustainability increases past basic levels, the initial cost of facility projects will also increase. However, these same studies indicate that life-cycle costs should also dramatically decrease (Katz, 2003). The life-cycle cost of a facility is simply the total cost of owning a facility. This includes initial acquisition costs, utilities costs, operations and maintenance costs, repair costs, disposal costs, and salvage value. Employee costs are also occasionally included in the list of life-cycle costs. The initial cost of a facility accounts for just 5 to 10 percent of the total cost of a facility throughout its service lifetime; while the operations and maintenance costs are typically 60 to 80 percent (DoE, 2003). “Minimal increases in upfront costs of 0-2% to support green design will result in life-cycle savings of 20% of total construction costs -- more than ten times the initial investment” (Katz, 2003:ii). Since the Department of Defense spends approximately $3-4 billion each year in new construction, there is a definite potential to significantly reduce life-cycle costs for the future (DefenseLINK 2000, DefenseLINK, 2002, DefenseLINK, 2003).

There is little argument LEED™ certified facilities cut utilities consumption. Savings in energy costs range from 20 to 50 percent over conventional construction (DoE, 2003). Water-saving devices typically save enough in water consumption and disposal costs to pay for themselves within a few years.

Another benefit of sustainable design, which is typically difficult to quantify, is the effect the facility has on the employees. Employees typically cost 200 times the construction costs and 40 times the facility's operating costs over the life of a facility (Yates, 2001). Several case studies indicate sustainable design can boost employee productivity by 6 to 26 percent and lower employee turnover rates significantly (DoE, 2003, USGBC, 2003c). While the exact cause of the productivity boost isn't known, it is theorized to be primarily psychologically based on a perceived comfortable and inviting working environment.

Meanwhile, the U.S. Environmental Protection Agency (EPA) has found indoor air quality is generally two to five times more contaminated than outdoor air and in some extreme cases up to 100 times more contaminated (Wilson, 1998). According to a 1990 study by the U.S. Army and the American Medical Association poor indoor air quality costs the United States 150 million workdays a year (DoE, 2003). A recent study by Lawrence Berkeley National Laboratory concluded that improved indoor air quality could reduce health care costs and work losses from communicable respiratory diseases by 9 to 20 percent (DoE, 2003). The same source indicated allergies and asthma could be reduced by 18 to 25 percent and non-specific health and discomfort reduced by 20 to 50 percent. The benefits of fewer lost workhours, lower health care costs, and increased productivity are apparent, but improved air quality can also protect against the growing number of lawsuits being filed by employees for adverse indoor air quality (DoE, 2003).

2.9 Department of Defense Facility Procurement Decisions

The trade-offs between competing sustainable features are often the integrated project team's toughest decisions to make. Despite the many Federal directives, regulations, and mandates listed earlier in this chapter directing Federal Agencies to use life-cycle cost analysis as the basis for procurement decisions, most sustainable design decisions are made based on the initial cost of the competing alternatives.

When sustainable design features conflict with a new construction project's pre-set initial budget, the design team typically reacts in one of two ways. They may either choose to eliminate the sustainable design feature or they may decide to reduce the scope of the project (i.e. interior finishes, total building square footage). Both options should be avoided. If the sustainable design feature has a relatively short payback period, the proper procedure should be followed to acquire the additional funding. A reduction in scope shouldn't be an option in Federal projects. Scope issues like total building square footage and interior finishes should already be at the bare minimum for the intended purpose. If square footage can be reduced, the extra space should never have been included in the original plans. Participants discovered "gold plating" designs or unjustifiably padding scope and cost estimates can be found in violation of Congressional Law. Fortunately, the design standards and regulations developed and employed by most Federal Agencies go a long way towards avoiding these problems.

As black and white as the issue appears, additional funds are rarely requested by Federal Agencies. Many Federal construction projects have alternatively chosen to undergo questionable scope changes. There are many possible explanations for this questionable practice ranging from lack of training, lack of time, process breakdown, negligence, or deceit. The most prevalent is simply lack of training in many areas of the project identification and development processes (Howard, 2003a, Pearce and others, 2000).

In any case, there appears to be a conflict with the current Federal facilities acquisition process. The National Academy of Sciences' Federal Facilities Council recognized the problem in the following quote, "a fundamental conflict exists between federal acquisition policies and the Federal budget process that will limit the benefits of sustainable development" (Federal Facilities Council, 2001:49).

2.10 Department of Defense Facility Acquisition Process

The Department of Defense, like other Federal Agencies, has a complex and arduous construction approval and funding process. At this point, it is worthwhile to examine the DoD's construction process to see if there are any incompatibilities w/LEED™ or any other conflicts which might prevent the highest levels of sustainability. While DoD's construction process is highlighted here, other Federal Agencies go through a nearly identical process.

There is no standard process consistently used by each of the Armed Services to get a facility constructed. There are however, major phases within a facility construction project's lifetime which are fairly consistent. All projects typically go through requirements assessment, conceptual planning, programming, budgeting/appropriation, design, construction, and start-up phases (Federal Facilities Council, 2001). Each phase is independently critical to the success of a "green" building. Project teams should evaluate decisions made in each phase based on the "best value" to the government (Federal Facilities Council, 2001).

The requirements assessment phase is essentially the identification and assessment of the need for a facility at the local level. The local agency looks at whether the need for space is justifiable and whether there is space already available to adequately fill the need. Justifiable means is the space authorized and worth expending capital funds. Each DoD agency has space authorization standards for its different missions and functions.

The conceptual planning phase follows the requirements assessment phase. This second phase is a broad look at how the requirement can best be satisfied. Decisions to renovate or alter an existing facility or construct new are made. Additionally, the facility size, type, and location are determined. This is also the critical phase where an initial cost estimate should be performed. Obviously considerable attention needs paid to this phase of the project since most are funded based on this rudimentary estimate. Parametric cost estimating techniques are generally the only options to acquiring this pre-design cost estimate. Parametric cost estimating methodology, tools, strengths and weaknesses are discussed in Appendix C. The common complaint about the current cost estimating tools is they are based on historic, conventional construction costs and do not reflect the costs of current "green" technologies (Howard, 2003a). While the additional cost of building "green" is debatable, the discussion should still remain open as a valid concern. If additional funds are believed necessary for the sustainability goals of the project, they should be documented and included in initial project estimates. This thesis was intended to resolve some of the cost uncertainties.

The next phase, programming, documents the previous requirements assessment and conceptual planning phases and sets a proposed timeline and priority on the project. The purpose of the documentation is for submittal and approval/funding by senior agency leadership and Congress. The documentation to Congress is summarized in a Department of Defense (DD) Form 1391, which typically has many supporting tabs. Congressional approval is required due to the mandated funding limits and oversight required on the majority of construction projects. The final project scope and estimates are critical. It is very difficult to go back to Congress a second time and ask for additional money. Most of the time, the Military Service will be forced by Congress to take funds from lower priority projects. In either case, it does not reflect favorably on the installation and Military Service. Unfortunately, this is where the questionable scope changes can appear.

The budgeting/appropriation phase is simply the approval and funding given to commence construction. Once again, Congress is the final approval and funding authority for most projects. Congress and the Office of Management and Budget (OMB) maintain considerable oversight of approved projects, tracking funding and progress even after the project's completion.

The Department of Defense uses two primary methods to accomplish the project; design-bid-build or design-build. The design-bid-build method is the traditional method where the design is accomplished and then the construction phase of the project goes out for competitive bid and is awarded to the lowest responsive bidder. The relatively recent design-build method awards both the design and construction under the same contract. The award is based on the "best value" for the government, a combination of cost, previous experience, previous performance, and initial design concept.

The design-build method is rapidly gaining favor because "best value" instead of "lowest bid" is used as the determining factor. The government can rate contractors on their level of sustainable design experience or simply on an agreed final level of sustainability (LEED™ rating) for the project. The risk with a design-build project is the government has less control over the final outcome of the project. The construction starts often before the final design documents are even completed. The result is that government changes are often not made until it's too late to make simple inexpensive changes. The design-bid-build method is still the most accepted delivery method within the Federal Government for facility projects (AFCEE, 2000).

The design phase does not have to be approved by Congress in a traditional design-bid-build project; however, there is little value in designing a project which will not be funded for construction. For this reason, most projects are not designed until it can be assured with a high level of confidence the project will be funded. The design can either be accomplished with in-house staff, other Military staff, or contracted out to private-sector architect-engineer (A-E) firms. The current statutory design regulations found in Title 10 United States Code (USC), Federal Acquisition Regulations (FAR), and Department of Defense FAR Supplement (DFARS) limit the A-E design fees to 6% of the estimated construction cost (AFCEE, 2000). Many believe this limit is a major hurdle when attempting to implement the more in-depth integrated design strategies necessary for sustainable design success (Howard, 2003a). New Federal regulations are needed to better encourage and support sustainable design efforts.

The construction phase is obviously a key step to the process. It is desirable, but not always an option, to award the project to a private company with experience constructing sustainable design facilities. Sustainably designed facilities do not necessarily require more skill to construct, but there is additional planning, oversight, and documentation required to accomplish and substantiate the sustainable features of the project. The construction contractor is responsible for selecting, purchasing, and installing all the materials for the project. Purchasing environmentally preferable products can be costly and labor intensive; especially with lack of experience. LEED™ awards credit for such sustainable areas as the quantity of material diverted from landfills, use of recycled materials, materials purchased locally, environmentally preferable materials use, rapidly renewable materials use, and the protection of construction site open space and vegetation. Each area must be properly documented to receive LEED™ credit. The additional effort often comes at a premium cost. This phase is accomplished once the owning agency takes acceptance of the facility.

Once the facility is accepted by the owning agency, the start-up phase begins. This phase is where the owner takes occupancy of the facility and starts to develop and implement operations and maintenance plans to ensure the facility and its occupants continue to function sustainably throughout the facility's expected life.

2.11 LEED™ Criticism

The LEED™ rating system does have its critics. Many feel LEED™ standards do not work well as a nationwide policy and should be more sensitive and flexible to local conditions and needs (Leibowitz, 2003). This is the primary reason the Army developed their SPiRiT rating system. Others complain, despite a consensus process in place to resolve members' comments and concerns, there is not enough open participation in the development of the rating system. Part of this concern comes from the fact that trade associations are not allowed to become members of USGBC, or participate in LEED™'s development. Yet another concern is with the scientific merit of LEED™ (Howard, 2003a). There are many prerequisites and credits within LEED™ based on national standards, some of which are believed to be either too inadequate or not credible. A similar complaint with LEED™ is the credits are inappropriately weighted and distributed (Howard, 2003a). For example, installing a solar, wind, or geothermal system to supply at least 5% of the facilities total energy use receives the same one point credit as installing a bicycle rack and changing/showering facilities or preferred parking for carpools. It is also possible to perform poorly or irresponsibly in certain rating areas and still receive LEED™ certification. For instance, neglecting to install drought tolerant landscaping or any other water saving devices in a desert community would appear to be a mockery of the rating system, but would not prevent a building from scoring well elsewhere and receiving LEED™ certification. Finally, many feel that the additional costs of documenting and acquiring LEED™ certification to be too excessive and prohibitive for projects on limited budgets.

In order for a project to become LEED™ certified it must first be registered through USGBC. Once the project is near completion, the organization must then pay for the USGBC certification process. The registration and certification costs vary based on the projected size of the project and whether the owning organization submitting the registration is a USGBC member. Total USGBC fees can range from $3,500 for small projects to over $10,000 for larger projects. While these fees don't appear overly excessive, especially for multi-million dollar projects, the additional costs of documenting, verifying, and specifying sustainable design can be significant (Leibowitz, 2003). According to USGBC, documentation fees can be as low as $10,000 and as much as $60,000 depending on project size and contractor experience (USGBC, 2002a).

Despite the concerns of the LEED™ rating system, many private businesses and governmental agencies are choosing it to accomplish their green building goals. Many hope the relatively few shortcomings of the rating system will be addressed and corrected in future versions of LEED™.

III. Methodology

One of the major criticisms and sources of resistance to the LEED™ rating system and sustainable design is its perceived additional cost compared to conventional construction. There is nearly no data collected to defend or refute this perception. The lack of historic data complicates the Department of Defense justification and approval process for future sustainable design projects due to the level of cost uncertainty involved. The primary focus of this thesis is to determine whether a business case can be made for sustainable design in the Department of Defense by comparing the initial project costs of sustainable design facilities with conventional design facilities. This chapter will cover the sources of data, data collection techniques, and data analysis objectives.

3.1 Data Sources

There have been few comprehensive studies on the actual economic costs and benefits of sustainable design (Katz, 2003, Pearce and others, 2000). In order to get a clear picture of the costs and benefits of sustainable design, one must start by gathering the initial and life-cycle costs of sustainable design construction. This study will concentrate on the first piece of this puzzle, initial costs. Life-cycle cost data is equally important, but very little non-theoretical data is available to perform such a study. Only a handful of sustainable design facilities have been faithfully tracking their operational costs. Only LEED™ or SPiRiT certified facilities were considered "green" buildings for this evaluation. Without this limitation, it would have been impossible to validate which facilities incorporate enough sustainable features to be declared sustainable design facilities.

The programming, design, and construction rules and regulations the Federal Government must abide by were well documented in the previous two chapters and places the Federal Government in a uniquely different class than private or local government construction. It is even possible that construction in the Department of Defense is so sufficiently different from construction in other Federal Agencies due to its unique mission, security issues, and bureaucratic requirements that it should be examined separately. Statistical analysis can determine whether the initial project costs are significantly different between the DoD and the rest of the Federal Government. This research gathered initial project cost data from many completed LEED™ and SPiRiT certified construction projects in the Federal Government.

3.2 Data Collection

Data collection started by gathering a list of Federal Government LEED™ and SPiRiT certified projects from the U.S. Green Building Council and U.S. Army Corps of Engineers. Correspondence was made with key personnel from each of these projects by telephone, electronic mail, or U.S. Postal Service to acquire pertinent information on each of the projects. Each Federal Government project should have a parametric or similar type planning estimate it used to acquire Congressional funding. Since there have been no definitive historical studies on the cost of LEED™ and SPiRiT certified facilities, these initial parametric planning estimates should be based on conventional construction practices. The second cost gathered from each project is the final project cost, including initial award and any change-orders. Each project was checked to ensure they have received or will likely receive LEED™ or SPiRiT certification. No distinction was made between LEED™ and SPiRiT certifications or the level of rating each project received because the available sample population is too small to provide statistically meaningful results.

3.3 Data Analysis

Once the data collection was complete, the difference between the initial planning estimate and final contract costs was calculated. The cost difference was then utilized to calculate the percent difference in cost from the initial planning estimate as in the following formula:

$$\frac{(\text{Final Contract Cost}) - (\text{Initial Planning Estimate})}{(\text{Initial Planning Estimate})} \cdot 100 \quad = \text{Percent Difference in Cost}$$

For example, if the difference in planning cost and final cost is \$10,000 for an originally \$1,000,000 estimated project, the percent increase is 1% from the initial planning estimate. The argument can be then be made that LEED™ or SPiRiT certification was 1% more expensive than conventional construction.

Once the percent increase calculations were complete, the projects were separated into one of two categories; Department of Defense projects or Other Federal Agency (non-DoD) projects. The statistical population mean, median, variance, and standard deviation for both groups were calculated (McClave, Benson, and Sincich, 2001).

Hypothesis testing was first performed to see if there is a statistical difference between the mean percentage cost difference of Department of Defense projects and other Federal Government projects. For this type of test, a claim about the relationship between the two sample means (DoD and other Federal Agencies) must first be made. In this study, the claim or inference was made that the mean cost of Department of Defense construction projects is different (likely greater) than the mean percentage cost difference of other Federal Agencies construction projects. This claim is called the research hypothesis or alternative hypothesis. There is the possibility that the opposite of the research hypothesis is true. In other words, the mean percentage cost difference of Department of Defense construction projects is equal to the mean percentage cost difference of other Federal Agencies construction projects. This second statement is termed the null hypothesis.

In hypothesis testing, the null hypothesis is actually tested, not the research hypothesis. If the null hypothesis can be rejected, then the research hypothesis can claim to be supported. If the null hypothesis can not be rejected, then the only statement possible is there is insufficient evidence to support the research hypothesis. With hypothesis testing, the analyst must choose a level of confidence they desire for the results. This level of confidence is typically given as a percentage. Once the hypothesis testing is complete, the researcher can claim their inference is accurate to within a certain percentage, or in other words, they are a certain percent confident in their stated results. In this study, 90% was used as the desired confidence level. The observed significance level (p-value) was also calculated to allow the reader to determine the minimum confidence level they would be willing to tolerate to reject the null hypothesis.

When making the final claim, there is always the possibility the data led the analyst to the incorrect conclusion. There are two categories of incorrect conclusions, Type I and Type II errors. A Type I error is concluding the research/alternate hypothesis is true when in fact it is not. In this study, a 90% confidence level was chosen; therefore, there is a 10% chance of a Type I error. A Type II error is concluding there is insufficient evidence to claim the research/alternative hypothesis is true (accepting the null hypothesis), when in fact the research hypothesis is true. It is possible to determine the probability of a Type II error once the means from the two data sets are calculated, but is typically difficult to determine precisely. One way to avoid a potential Type II error is by not making the conclusion that the null hypothesis is true, instead only maintain there is insufficient evidence to reject the null hypothesis.

Since there are few LEED™ or SPiRiT projects completed in the Federal Government, the t-distribution was used as the test statistic. For typical hypothesis testing, the analyst assumes the data is large enough in quantity to show a central tendency which is normally distributed around the mean value. When only a smaller data set is available (typically less than 30) the assumptions and hypothesis testing methods following from the Central Limit Theorem can't be used. The small sample must still originate from a population with a relative frequency distribution assumed to be approximately normal; however, the t-distribution test is the only test statistic appropriate to make claims about the entire population. A more in-depth explanation of hypothesis testing, Type I/II errors, and sample sizes can be read in most statistics textbooks.

After the first hypothesis test was complete, hypothesis testing was performed to determine if the percent cost differences were statistically significant. This test indicated whether it is possible to definitively state whether LEED™ or SPiRiT certified construction projects cost more or less than conventional construction projects. The conclusions from the first hypothesis test determined whether the Other Federal Agency projects were included with the DoD projects.

In this test, the research hypothesis was the mean percent cost difference is greater than or less than 0%. The null hypothesis was the mean percent cost difference is equal to 0%. The same 90% confidence level was used for this test. Since the sample size was still considered small (less than 30), the t-distribution was used as the test statistic. A p-value was also calculated for this test to once again allow the reader to make their own conclusion on the minimum confidence level (maximum alpha) they would allow to reject the null hypothesis.

According to the Empirical Rule for data with a frequency distribution which is approximately normal, roughly 68% of the measurements fall within one standard deviation of the mean. Roughly 95% of the measurements fall within two standard deviations of the mean and over 99% fall within three standard deviations (McClave, Benson, and Sincich, 2001). These quick rules of thumb were calculated to give a general idea of the precision of the sampling mean.

A more accurate calculation of this sampling error was calculated using the approximately normal sampling distribution. The same assumptions of approximate normality were used, but the areas below the sampling distribution were used to make the probability statements about the sampling mean (Anderson, Sweeney, and Williams, 1999). This probability statement is termed the confidence interval and typically stated for the desired confidence level in two parts: a point estimate (sampling mean) and a plus and minus value called the margin of error (Anderson, Sweeney, and Williams, 1999). The 90%, 95%, and 99% confidence levels were calculated and briefly related to the results from the Empirical Rule calculations. The primary reason for these calculations was to provide additional insight into the precision of the sampling mean and to let the reader determine whether the sustainable design business case is justifiable (McClave, Benson, and Sincich, 2001).

IV. Results and Analysis

This purpose of this thesis was to quantify the initial cost of utilizing LEED™ or SPiRiT in Department of Defense's and other Federal Government Agencies' construction projects to make a business case for LEED™ or SPiRiT. This chapter presents the results and analysis of this investigation using the methodology from Chapter 3.

4.1 Data Set Investigation

The first key step of this study was to gather historical data from applicable Department of Defense (DoD) and other Federal Government Agencies construction projects. A small sample set of 15 representative projects throughout the Federal Government was first chosen to assess whether the data needed for this study was available. Over 50% of the projects evaluated for this first representative sample had the requisite data. The identification of these construction projects was from various DoD personnel and websites and the U.S. Green Building's Council's (USGBC) LEED website. Sufficient data for a rigorous statistical analysis seemed possible.

4.2 Expanded Data Collection

After the initial data set investigation, work commenced on gathering the additional data needed to complete a thorough statistical investigation. Over 120 Federal facility construction projects were evaluated for applicability. A majority of these projects were listed on the USGBC's LEED™ website. A few projects were immediately rejected based on their location outside the United States. There are simply too many extenuating factors involved in construction outside the United States to factor into this study. Some other projects were rejected when discovered the decision had been made not to use LEED™ or SPiRiT as their design and construction guideline. Another source of immediate exclusion from this study was projects built for the U.S. Federal Government, but owned by private organizations. The Federal Government simply rents or leases the space from the private corporation and despite the LEED certification has very little say regarding design and construction decisions. Additionally, for this type of project, initial planning estimates were typically unavailable or proprietary. The list of potential projects was eventually narrowed down to 105.

E-mails were sent out to each of these 105 projects requesting the applicable estimated and actual project cost data. After background research, e-mails, and phone calls only 22 projects were selected as appropriate for this study. Responses were received from another 38 projects which were eventually rejected. Projects were primarily rejected because they had not completed the construction contract award phase. A number of these projects had not progressed past the construction award phase because initial contractor bids were well in excess of estimated and programmed amounts. This fact was illuminating in itself.

Projects were also rejected after correspondence with project managers revealed unique construction which would have skewed results. For example, there was a major renovation occurring at the Pentagon. All materials must enter the Pentagon’s transit system and be screened for explosives and other weapons of mass destruction. All construction personnel must also be searched daily and escorted around the project site.

Additionally, there have been many force protection features added to the initial design and estimate of Pentagon project which likely is a more significant cost driver than sustainable design.

The final reason some projects were eventually excluded from this analysis was because significant changes in square footage or other scope changes were made after the initial estimates were performed and the estimates were never revised. Once again, this is revealing information in itself. The project scopes likely had to be reduced to stay under Congressionally approved funding amounts. As mentioned in previous chapters, this is a questionable solution to underfunded projects; however, investigation into the issue is beyond the bounds and authority of this project.

Even after repeated contact attempts, 45 projects representatives did not respond. This was disappointing since all applicable information should be a matter of public record.

4.3 Data Presentation

As outlined in Chapter 3 and shown in Table 4 and Table 5, the primary data collected was the estimated cost and the actual cost of each project. A few projects were given on a square foot basis (i.e. Table 4, Project ID #4A), but should yield comparable results. Information on whether the project execution method was design-bid-build or design-build was collected, but not used to differentiate projects due to the already limited availability of data. However, this should not be a major concern since the method of execution is considered in the original estimate.

Table 4 DoD LEED™/SPiRiT Initial Project Cost Data

Department of Defense

Project ID	Estimated Cost	Actual Cost	% Cost Difference
1A	$6,959,000	$6,629,015	-4.74%
2A	$30,510,000	$27,198,716	-10.85%
3A	$8,513,332	$8,727,497	2.52%
4A	$\$157.94/\text{ft}^2$	$\$167.66/\text{ft}^2$	6.15%
5A	$\$188.32/\text{ft}^2$	$\$190.52/\text{ft}^2$	1.17%
6A	$11,700,000	$12,750,000	8.97%
7A	$\$140/\text{ft}^2$	$\$166/\text{ft}^2$	18.57%
8A	$10,785,000	$9,995,000	-7.32%
9A	$44,175,924	$37,599,126	-14.89%
10A	$8,990,000	$8,320,000	-7.45%
11A	$60,800,000	$60,800,000	0.00%
12A	$9,956,000	$9,484,109	-4.74%
13A	$3,250,000	$3,725,516	14.63%

Mean Cost Percentage Difference: 0.15%

Table 5 Other Federal Government Agencies LEED™ Initial Project Cost Data

Other Federal Government Agencies

Project ID	Estimated Cost	Actual Cost	% Cost Difference
1B	$36,900,000	$38,000,000	2.98%
2B	$18,400,000	$18,500,000	0.54%
3B	$214,000,000	$207,000,000	-3.27%
4B	$22,000,000	$22,000,000	0.00%
5B	$17,951,600	$17,954,011	0.01%
6B	$51,000,000	$50,400,000	-1.18%
7B	$1,089,000	$1,187,000	9.00%
8B	$\$197/\text{ft}^2$	$\$216/\text{ft}^2$	9.64%
9B	$2,134,000	$2,609,000	22.26%

Mean Cost Percentage Difference: 4.44%

4.4 Data Validation

No judgments were made about the validity of the data supplied, although some appeared suspect. For example, it is unusual if the reported estimated cost, which shouldn’t be known by potential bidders, is the same as the final contract amount. Examples of this can be seen in Tables 4 and 5.

Each Federal Agency has a slightly different vocabulary for the various costs and phases of a construction project. Conducting personal face to face interviews with the project manager to identify the individual initial estimates, final costs, and scope of work more thoroughly to ensure a fair and more accurate comparison is recommended for future studies. This was the process taken in other recent non-Federal Government studies; however, personal interviews were not feasible for this study. Additional explanation and guidance was provided to the contacts, when requested.

The accuracy of the cost data and an objective comparison of the scope of work are even more important when examining the accuracy of initial planning estimates. Appendix C explains the limitations of the parametric type estimates used for most construction estimates. The PACES parametric cost estimating package, in wide use throughout the Department of Defense, is independently proven to be accurate to within 7.5% (PACES brochure, undated). Other industry standard parametric cost estimating systems, used extensively in other Federal Government construction projects, are typically only accurate to within 15%. It seems nearly impossible to make an accurate comparison of preliminary and final costs with estimate accuracies in the 7.5 – 15% range. Despite this realization, recent national studies explicitly make these comparisons.

Nearly all of the projects in Table 4 and Table 5 fall within the 7.5 – 15% cost range of their initial estimates. Statistically, when factoring in the error of the cost estimates, it could be said that there is no cost difference. The only way to get a true comparison is to perform a detailed line-item cost analysis on the same project; one designed using LEED™ and the other using conventional design. Since this is would be a considerable waste of costly Architecture and Engineering firms' design time, this type of comparison is never done.

4.5 Statistical Analysis of Results

Despite the initial difficulty in rationalizing the statistical usefulness of the results, statistical analysis was performed on the collected data to search for any revealing information. The hypothesis testing outlined in Chapter 3 concluded, at a 90% confidence level, there was statistically insufficient evidence to reject the null hypotheses. That was, the mean percentage cost differences between DoD and other Federal Government construction projects were the same. More directly stated, no distinction can be claimed between the mean percentage cost difference of DoD and other Federal Government LEED™/SPiRiT construction projects. The p-value for this test was 0.30 which indicates there is nearly no evidence to reject the null hypothesis. The conclusion meant DoD and other Federal Government Agencies construction projects would be combined for other analysis. Appendix D details the results using MathCAD Version 2001i (MathCAD, 2001).

The second hypothesis testing, outlined in Chapter 3 and results shown in Appendix E, examined the entire sampled population against the theory that the mean percentage cost difference was greater (or less) than 0. As previously mentioned, the entire sampled population was used based on the results from the first hypothesis test. No distinction was made between DoD and other Federal Agencies. Mathcad Version 2001i was again used to calculate the results (MathCAD, 2001). The results revealed that at a 90% confidence level, there was statistically insufficient evidence to reject the null hypotheses that Federal Government LEED™/SPiRiT construction projects cost any more than conventional construction projects. The observed significance level (p-value) for this second test was calculated to be 0.31. A p-value of 0.31 indicates there is nearly no evidence to reject the null hypothesis.

While hypothesis testing concluded no distinction could be made between LEED™/SPiRiT and conventional construction projects, a calculation of the arithmetic mean indicated LEED™/SPiRiT added approximately 1.9% to the initial cost of a project. The standard deviation of the mean is 9.0%. The median cost percent increase was calculated to be 0.54%. The most thorough analysis of the additional costs of LEED™ construction was released by Mr Greg Katz in October 2003 (Katz, 2003). Mr Katz's analysis indicated LEED™ added 0 - 2% to the upfront cost of a facility construction project. The mean and median results from this thesis study of Federal Government facility construction projects draw a similar conclusion.

Recall from Chapter 3 that according to the Empirical Rule for data with a frequency distribution which is approximately normal, roughly 68% of the measurements fall within one standard deviation of the mean. Roughly 95% of the measurements fall within two standard deviations of the mean and over 99% fall within three standard deviations. It can therefore be relatively assured there is a 68% likelihood the next

LEED™/SPiRiT project will be anywhere from -7.1% to 10.9% of the cost of a conventional construction project. There is a 95% likelihood the LEED™/SPiRiT cost will be in the -16.1% to 19.9% range and a 99% likelihood it will be in the -25.1% to 28.9% range.

Similar in theory to the Empirical Rule, the confidence interval calculations determined it is 95% probable that the mean of all future LEED™/SPiRiT projects will cost somewhere in the interval from -1.8% to 5.6% the cost of a conventionally construction projects. It is also 99% probable that the percentage cost difference interval will be from -2.9% to 6.8%. Appendix E displays the MathCAD Version 2001i calculations (MathCAD, 2001).

The confidence interval is somewhat promising in that the mean cost of future LEED™ projects is below 7%. However, as the Empirical Rule highlights, there is an unacceptable probability that the next constructed LEED™ project could cost as high as 29% over conventional projects. The variance of the reported data seems too significant to make a strong business case supporting the initial costs of LEED™. The life-cycle costs and benefits will have to continue to be the primary motivation for LEED™ until data on additional new projects becomes available.

4.6 Potential Cost Drivers

Many respondents offered possible explanations for the cost differences of their LEED™/SPiRiT project from a conventional construction project. All the explanations were valid cost drivers, but most were already anticipated due to the research completed in Chapter 2.

The most often stated reason for the additional cost of LEED™ construction was lack of experience with LEED™. This comment was made by many of those with interest in the project, from the Government project managers to the private contractors. However, each firmly believed they had gained enough experience from their completed project to more successfully identify and manage costs on future LEED™ projects.

One of the common explanations and disappointments felt by many personnel involved in LEED™ projects was their inability to successfully incorporate sustainable design into their project from the very inception of the project. They typically understood the criticality of an integrated project/design team approach from the beginning, but for various reasons were unable to successfully implement it. A few respondents pointed out their projects were required to pursue LEED™ certification so late in the design process that they were simply "bolting on" sustainable design features to an otherwise conventional facility.

A similar issue expressed by some of those involved in LEED™ projects was that during the design or even construction phases of their projects, the realization was made the project would not achieve their LEED™ points goal. One of the pitfalls and common complaints about LEED™ is it's possible to simply "buy" LEED™ points by installing an additional sustainable feature or system onto the facility. Unfortunately, this typically expensive solution has a low probability of successfully integrating with the rest of the facility. These "bought" points are for often unproven technology/systems which eventually become the source of future maintenance problems. Not only does "buying" points hurt the existing project, but failed attempts with unproven technology/systems can impede the future advancement and utilization of more conservative sustainable design. Future revisions of LEED™ will attempt to eliminate this possibility.

Participants in a few successful projects understood early on they did not have the expertise needed for a LEED™ project. These Federal Government organizations sought out the experience and expertise in the private sector. Typically, LEED™ consultants were brought in to support the contractor or in-house design team. Some organizations even went as far as to specifically contract out the design to an experienced LEED™ design firm; writing the design contract specifications to require a certain level of LEED™ expertise and experience.

Comments gathered from a handful of projects appeared to support design-build over the design-bid-build method of project execution. The apparent favor for design-build projects is less likely a statement on the merits of the project execution method and more likely tied to the experience of the design and construction teams. In the design-build projects, the Federal Government organization had less input into the details of the design and had to rely on private industry's significantly greater experience and acceptance of LEED™. Either method of project execution should be equally capable of successfully implement and complete a LEED™ construction project. If needed, LEED™ consultation and additional services, on top of the statutory limits placed on architect-engineer design services, can be creatively authorized under Federal Acquisition Regulations.

4.7 Evaluation of LEED™/SPiRiT in the Department of Defense

Through the literature review in Chapter 2 and correspondence with multiple personnel involved with LEED™ or SPiRiT projects it is readily apparent some Federal Government Agencies have been more successful at adopting sustainable facility design than others. The Department of Defense has only been moderately successful. Even though sustainable facility design principles have been stressed in the Department of Defense since the middle to late 1990s, there have still been relatively few construction projects which implement them. There has been no real incentive for the Department of Defense to implement sustainable facility design. The primary emphasis for most DoD construction projects continues to be the initial cost of construction. Time is rarely devoted to evaluating the life-cycle costs and benefits of various construction methods and features.

Also standing in the way of sustainable design is the fact that facility construction in the DoD has been positively honed over the past few decades. The planning rules and standards which were developed over the years have led to countless successful construction projects. However, sustainable design questions many conventional design and construction practices. It is difficult for many qualified and experienced personnel in the Department of Defense to commit to the latest change toward sustainable design. The fact that there is still only anecdotal and theoretical evidence that sustainable design works and is cost effective only further clouds the issue. A successful business case for sustainable design is only starting to be made and accepted.

Over the years, conventional construction design has also standardized and simplified facility maintenance. Many in leadership and decision making roles refuse to undertake sustainable design because of the risk of highly specialized and costly maintenance. Once again, only time and education will disprove this concern.

V. Conclusions and Recommendations

This chapter provides a brief summary of the research completed, discusses the results of the research, identifies any limitations, and makes recommendations for further related research.

5.1 Research Summary

The purpose of the thesis was to provide statistical evidence that a business case supporting LEED™/SPiRiT, based on the initial cost of construction, could be made in the Department of Defense. The Department of Defense was one of the first Federal Agencies to investigate and eventually support LEED™. The DoD was directly involved in developing the LEED™ rating system from its beginnings. Each of the Military Services has successfully constructed LEED™/SPiRiT projects. From a cost perspective, some projects have clearly been more successful than others. Experience seems to be the largest hurdle not only for the DoD, but also for many of the design and construction contractors the DoD uses.

5.2 Research Results

This study was premature in its attempt to make a positive business case for LEED™/SPiRiT and sustainable design using initial construction costs. This study, however, did provide an accurate assessment of the state of LEED™/SPiRiT designed facilities in the Department of Defense today. In order to advance sustainable design, decision makers need some assurance their decisions won't be costly. The general conclusion was that the majority of LEED™ or SPiRiT designed facility construction projects have a conservative probability to be anywhere from -1.8% less to 5.6% more costly than conventionally designed projects. When focusing on this study's calculated simple mean and supported by its median, a facility construction project has a good possibility of being only 1.9% over conventional construction costs. However, the variance of the data highlighted that there is an unacceptable probability that any single LEED™ construction project may cost as much as 29% more than a conventional project. It would be difficult to use this fact to make an irrefutable business case for sustainable design. As additional construction projects are completed, they will likely reduce the variance of the mean cost calculated in this study. Once this is accomplished, a more attractive business case for sustainable design can be made and more people will be convinced to try LEED™.

5.3 Research Limitations

The lack of Federal Government projects in the construction phase or completed was a significant limitation to this study. The data that was available provided statistically acceptable results, but its variance is too large to be useful for the construction industry. Additional project data would have made the outlier data insignificant and provided a more accurate estimate of the cost LEED™ adds to a project.

Another possible limitation of this study was the accuracy of the data provided. Each person who responded believed they were providing the correct data and there is no reason to distrust their intentions. However, there appears to be a wide range of time and emphasis placed on the accuracy and thoroughness of planning estimates. It would have been useful to sit down with the Government project managers and perform new detailed and parametric estimates based on the general characteristics and features of the built facilities. This is the only way to ensure no significant changes were made from when the facility was initially envisioned. This would not compromise the comparison since most LEED™ features would not be a factor at the planning estimate level of detail.

Even if these projects were reestimated, the accuracy of the data would still be an area of concern. Recall from Appendix C and previous sections that planning estimating aids such as the PACES software are only accurate to within 7.5%. While PACES is one of the best planning estimating tools available, 7.5% accuracy is still significant to the accuracy of this study. Additional completed project data is the only way to minimize the inaccuracy of the planning estimates.

5.4 Recommendations for Future Research

LEED™ has been adopted by nearly all Federal Government Agencies. However, it still does not enjoy universal acceptance. There are numerous studies still needed to successfully make the case for LEED™ and sustainable design.

A few recommendations for future research were addressed in the previous section. First, this study was valuable at quantifying the current expected initial capital expenditure required for LEED™ construction today. The construction industry moves too slowly to expect the results and conclusion of this study to change in the next couple of years. Therefore, it is not recommended to attempt to expand the database of project data for at least a couple years.

Also mentioned in the previous section, it would be worthwhile for new detailed and parametric estimates to be accomplished for completed projects and compared to the actual final costs. Only a representative sample of the projects used in this study would need to be reestimated in order to validate or refute this study's methodology and results.

The other portion required in order to make a business case for sustainable design is a thorough cost-benefit analysis of LEED™. This not only includes performing life-cycle cost analyses of sustainable design features, but also developing a method to quantifying the many additional, often intangible, environmental and health benefits of sustainable design. In order to accomplish an accurate life-cycle cost analyses, performance data from completed LEED™ facility projects is needed. The primary hurdle with this type of life-cycle analysis is a majority of completed LEED™ projects are not spending the additional time and money to capture facility performance data.

Cost-benefit analyses should avoid focusing too much on specific sustainable design products since most are technology based and change too frequently. Instead, cost-benefit studies should take a broad look at many sustainable design features and more importantly focus on the costs and benefits of sustainable design features in sample LEED™ construction projects. The intent is to highlight proven design guidelines for programmers, designers, architects, engineers, project managers, and owners to use for future LEED™ projects.

A final possible area for future research relating to LEED™ and sustainable design is an evaluation of the resistance to sustainable design. To what degree is there resistance and what is the source of that resistance? What can be attributed to lack of experience, lack of training, lack of time, lack of leadership interest, barriers in the

Federal Government construction process, or simply the resistance to change? Another question to answer, is there a more effective way to make the case for sustainable design?

5.5 Conclusions

Sustainable Design has many tangible and intangible benefits. LEED™ is an effective tool to ensure a significant level of sustainable design is incorporated in a given construction project. In reality, however, cost is often the driver for most business decisions. As concluded in this study, sustainable facility design generally costs more initially than conventional construction. This study determined that on average it costs 2% more. However, it is very difficult to capture all the costs and benefits of a sustainable design facility and therefore problematic to make a good business case for sustainable design.

Despite the less than convincing business case made in this study to support sustainable design with initial cost data, it was continually stressed that there are many well identified and documented life-cycle savings gained from sustainable design. Many features of these sustainable design facilities require little capital investment and have very short payback periods. This combination makes it easy to convince decision makers to incorporate them into their design. However, only through continued use of LEED™ or other similar design and evaluation tools which stress integrated/holistic project teams and design, will sustainable design prove successful. This success will be measured not only in lower costs, but also in the long-term benefits to building occupants and the environment.

Appendix A

LEED™ Project Checklist

LEED

LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

Version 2.1 Registered Project Checklist

Project Name
City, State

Yes	?	No			
☐	☐	☐	**Sustainable Sites**		**14** Points
Y			Prereq 1	**Erosion & Sedimentation Control**	Required
☐	☐	☐	Credit 1	**Site Selection**	1
☐	☐	☐	Credit 2	**Urban Redevelopment**	1
☐	☐	☐	Credit 3	**Brownfield Redevelopment**	1
☐	☐	☐	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
☐	☐	☐	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
☐	☐	☐	Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
☐	☐	☐	Credit 4.4	**Alternative Transportation**, Parking Capacity and Carpooling	1
☐	☐	☐	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
☐	☐	☐	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
☐	☐	☐	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
☐	☐	☐	Credit 6.2	**Stormwater Management**, Treatment	1
☐	☐	☐	Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
☐	☐	☐	Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
☐	☐	☐	Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
☐	☐	☐	**Water Efficiency**		**5** Points
☐	☐	☐	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
☐	☐	☐	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
☐	☐	☐	Credit 2	**Innovative Wastewater Technologies**	1
☐	☐	☐	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
☐	☐	☐	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No			
☐	☐	☐	**Energy & Atmosphere**		**17** Points
Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
☐	☐	☐	Credit 1	**Optimize Energy Performance**	1 to 10
☐	☐	☐	Credit 2.1	**Renewable Energy**, 5%	1
☐	☐	☐	Credit 2.2	**Renewable Energy**, 10%	1
☐	☐	☐	Credit 2.3	**Renewable Energy**, 20%	1
☐	☐	☐	Credit 3	**Additional Commissioning**	1
☐	☐	☐	Credit 4	**Ozone Depletion**	1
☐	☐	☐	Credit 5	**Measurement & Verification**	1
☐	☐	☐	Credit 6	**Green Power**	1

Yes	?	No			
☐	☐	☐	**Materials & Resources**		**13** Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
☐	☐	☐	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
☐	☐	☐	Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
☐	☐	☐	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
☐	☐	☐	Credit 2.1	**Construction Waste Management**, Divert 50%	1
☐	☐	☐	Credit 2.2	**Construction Waste Management**, Divert 75%	1
☐	☐	☐	Credit 3.1	**Resource Reuse**, Specify 5%	1
☐	☐	☐	Credit 3.2	**Resource Reuse**, Specify 10%	1
☐	☐	☐	Credit 4.1	**Recycled Content**, Specify 5% (post-consumer + ½ post-industrial)	1
☐	☐	☐	Credit 4.2	**Recycled Content**, Specify 10% (post-consumer + ½ post-industrial)	1
☐	☐	☐	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
☐	☐	☐	Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
☐	☐	☐	Credit 6	**Rapidly Renewable Materials**	1
☐	☐	☐	Credit 7	**Certified Wood**	1

Yes	?	No			
☐	☐	☐	**Indoor Environmental Quality**		**15** Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
☐	☐	☐	Credit 1	**Carbon Dioxide** (CO$_2$) **Monitoring**	1
☐	☐	☐	Credit 2	**Ventilation Effectiveness**	1
☐	☐	☐	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
☐	☐	☐	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
☐	☐	☐	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
☐	☐	☐	Credit 4.2	**Low-Emitting Materials**, Paints	1
☐	☐	☐	Credit 4.3	**Low-Emitting Materials**, Carpet	1
☐	☐	☐	Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber	1
☐	☐	☐	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
☐	☐	☐	Credit 6.1	**Controllability of Systems**, Perimeter	1
☐	☐	☐	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
☐	☐	☐	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
☐	☐	☐	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
☐	☐	☐	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
☐	☐	☐	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Yes	?	No			
☐	☐	☐	**Innovation & Design Process**		**5** Points
☐	☐	☐	Credit 1.1	**Innovation in Design**: Provide Specific Title	1
☐	☐	☐	Credit 1.2	**Innovation in Design**: Provide Specific Title	1
☐	☐	☐	Credit 1.3	**Innovation in Design**: Provide Specific Title	1
☐	☐	☐	Credit 1.4	**Innovation in Design**: Provide Specific Title	1
☐	☐	☐	Credit 2	**LEED™ Accredited Professional**	1

Yes	?	No		
☐	☐	☐	**Project Totals (pre-certification estimates)**	**69** Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

Appendix B

SPiRiT Project Checklist

Facility Points Summary

1.0	Sustainable Sites (S)	Score	0	Max 20
1.R1	☐	Erosion, Sedimentation and Water Quality Control		[Required]
1.C1	☐	Site Selection		2
1.C2	☐	Installation/Base Redevelopment		2
1.C3	☐	Brownfield Redevelopment		1
1.C4	☐	Alternative Transportation		4
1.C5	☐	Reduced Site Disturbance		2
1.C6	☐	Stormwater Management		2
1.C7	☐	Landscape and Exterior Design to Reduce Heat Islands		2
1.C8	☐	Light Pollution Reduction		1
1.C9	☐	Optimize Site Features		1
1.C10	☐	Facility Impact		2
1.C11	☐	Site Ecology		1

2.0	Water Efficiency (W)	Score	0	Max 5
2.C1	☐	Water Efficient Landscaping		2
2.C2	☐	Innovative Wastewater Technologies		1
2.C3	☐	Water Use Reduction		2

3.0	Energy and Atmosphere (E)	Score	0	Max 28
3.R1	☐	Fundamental Building Systems Commissioning		[Required]
3.R2	☐	Minimum Energy Performance		[Required]
3.R3	☐	CFC Reduction in HVAC&R Equipment		[Required]
3.C1	☐	Optimize Energy Performance		20
3.C2	☐	Renewable Energy		4
3.C3	☐	Additional Commissioning		1
3.C4	☐	<<Deleted>>		
3.C5	☐	Measurement and Verification		1
3.C6	☐	Green Power		1
3.C7	☐	Distributed Generation		1

4.0	Materials and Resources (M)	Score	0	Max 13
4.R1	☐	Storage & Collection of Recyclables		[Required]
4.C1	☐	Building Reuse		3
4.C2	☐	Construction Waste Management		2
4.C3	☐	Resource Reuse		2
4.C4	☐	Recycled Content		2
4.C5	☐	Local/Regional Materials		2
4.C6	☐	Rapidly Renewable Materials		1
4.C7	☐	Certified Wood		1

5.0	Indoor Environmental Quality (IEQ) [Q]	Score	0	Max 17
5.R1	☐	Minimum IAQ Performance		[Required]
5.R2	☐	Environmental Tobacco Smoke (ETS) Control		[Required]
5.C1	☐	IAQ Monitoring		1
5.C2	☐	Increase Ventilation Effectiveness		1
5.C3	☐	Construction IAQ Management Plan		2
5.C4	☐	Low-Emitting Materials		4
5.C5	☐	Indoor Chemical and Pollutant Source Control		1
5.C6	☐	Controllability of Systems		2
5.C7	☐	Thermal Comfort		2
5.C8	☐	Daylight and Views		2
5.C9	☐	Acoustic Environment /Noise Control		1
5.C10	☐	Facility In-Use IAQ Management Plan		1

	Facility Points Summary (Continued)			Maximum Points
6.0	**Facility Delivery Process (P)**	**Score**	**0**	**Max 7**
6.C1	☐ Holistic Delivery of Facility			7
7.0	**Current Mission**	**Score**	**0**	**Max 6**
7.C1	☐ Operation and Maintenance			3
7.C2	☐ Soldier and Workforce Productivity and Retention			3
8.0	**Future Missions**	**Score**	**0**	**Max 4**
8.C1	☐ Functional Life of Facility and Supporting Systems			2
8.C2	☐ Adaptation, Renewal and Future Uses			2
		Total Score	**0**	**Max 100**

Appendix C

Parametric Cost Estimating

Appendix Overview

Cost estimates are required in the conceptual planning and programming phase of a facility construction project. Typically very little beyond the facility type, size, and location are known at this point. Considerable attention is needed for initial cost estimates because most projects will eventually be funded based on these rudimentary estimates. Parametric cost estimating is the generic term used to describe the methods used to come up with the initial estimates. This appendix explains the parametric cost estimating process; focusing on how cost models are developed, what types of attributes or parameters are needed, how cost estimates are completed, and the different types of parametric estimates in common use. Special emphasis was placed on the automated Parametric Cost Estimating System (PACES) currently used by the Department of Defense (DoD).

Cost Estimating Types

Cost estimating is basically attempting to computationally predict the final cost of a future project, even when all the project's details aren't known. The American Association of Cost Engineers (AACE) recognizes the following three types of cost estimates: order-of-magnitude estimates, budget estimates, and definitive estimates (Popham, 1996). The three types of estimates are practical for use in all public, private, and governmental production and service industries. Order-of-magnitude estimates are accomplished without any detailed engineering data. They are also known as conceptual, ballpark, or shotgun estimates. The fact that very little detailed engineering data is needed and order-of-magnitude estimates are relatively quick to accomplish makes it a valuable tool. Budget estimates are made once the design effort has started and preliminary engineering data is available. Typically all major equipment items and unique architectural and engineering features are identified. The final type of cost estimate is the definitive estimate. It is based on clear architectural and engineering data. The design is anywhere from 50 to 100% complete, but there are very few items or features still unknown at this point. Estimates may be as specific as capturing the labor and materials requirements from the design drawings and the detailed work breakdown structure. Clearly, the more detail known about a project, the more accurate any estimate becomes.

In the Federal Government, order-of-magnitude estimates are the most critical estimates for sustainable design projects since they are the basis for project approval and funding. There are two types of order-of-magnitude estimates, factored estimates and parametric estimates. Both are similar in nature. Most DoD projects utilize both of these fairly quick methods and compare the results.

Factored estimates are fairly straightforward. The cost of a project is based on the historical costs of similar projects and adjusted for such factors as the location of the project and monetary inflation. The cost of a facility is calculated based on a single distinctive unit of measurement or parameter. For example, estimates for hospitals may be based on the number of beds, warehouses on square feet of storage, or bowling alleys on the number of bowling lanes. The Office of the Secretary of Defense (OSD) Pricing Guide is an example of a factored estimating system and will be explained later in this appendix.

Parametric cost estimates are similar to factored estimates. Both relate major cost driving parameters from similar historic projects, called a project model, to extrapolate and estimate the new cost. The primary difference is parametric cost estimating considers more than one model parameter in building the estimate. Typical model parameters seen in construction projects are square feet of usable floor area, average floor height, number of floors, percentage of office area, roof type, estimated occupancy, number of building corners, scaled quality of interior and exterior finishes, and scaled strength of substructure and superstructure. The larger the number of relevant parameters which can be identified the more likely the estimate will be accurate. Parametric estimates tend to be more accurate than factored estimates, but without a large sampling of historical data, are typically only accurate to plus or minus 30% (De la Garza and Rouhana, 1995). Many prominent cost analysts also caution that because each organization is likely to have unique parameters, cost estimating models should be organization specific. A model that works well for one organization may not work well for the next (Phaobunjong and Popescu, 2003).

Cost Estimating Relationship Development Process

Parametric cost estimating uses statistical techniques to find historical relationships between changes in cost and the independent parameter(s) upon which these costs depend. The relationship between independent cost-driving parameter(s) and the dependent cost variable is termed a cost estimating relationship (CER). The statistical techniques used to determine CERs range from simple linear regression to multiple linear regression or even curvilinear regression.

The process of developing a parametric cost estimating relationship (CER) is fairly standardized. Figure 3 is a flow diagram of the CER development process taken from the DoD's Parametric Estimating Handbook, but the same process should be used by any organization looking to develop and use parametric cost estimating.

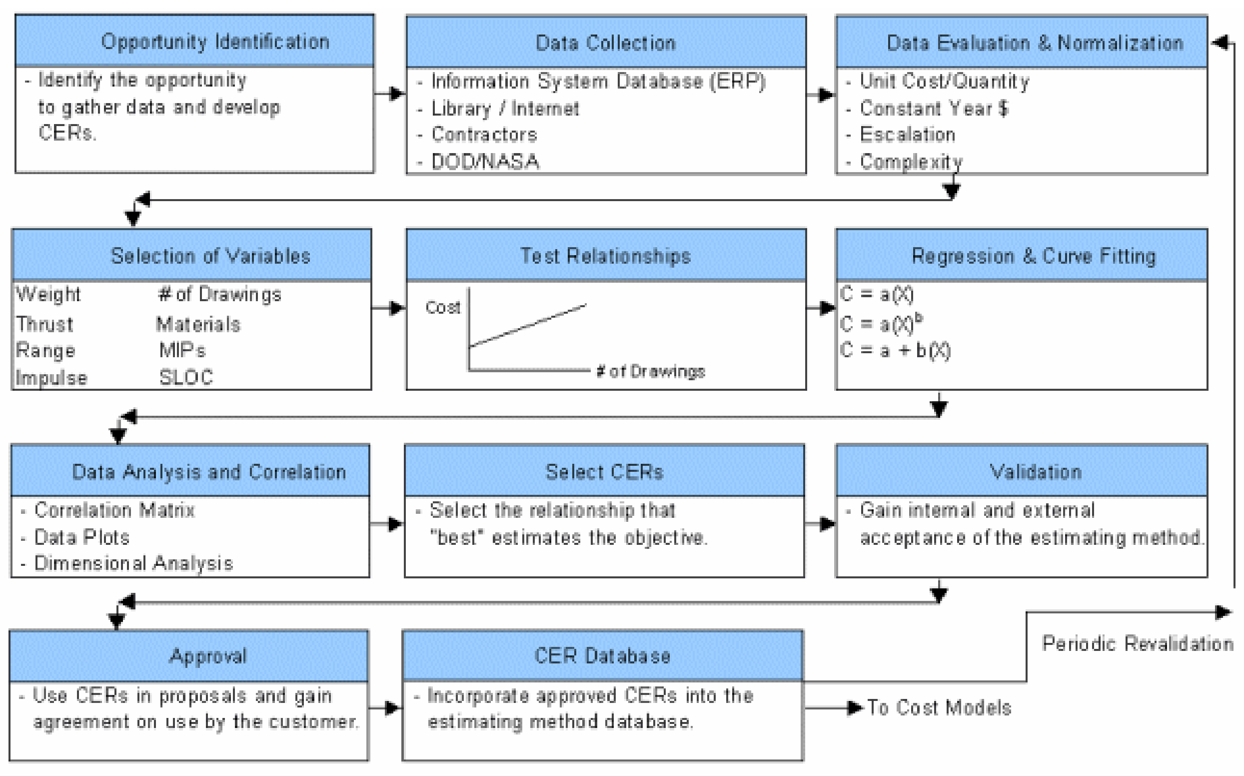

Figure 3 CER Development Process (Source: PCEI WG, 1999:3-5)

Many subject matter experts on parametric cost estimating believe the eventual cost model will only be as viable as the input data provided (PCEI WG, 1999 and Melin, 1994). In construction projects, this means the database of historic projects must be as extensive, detailed, and accurate as possible. In Figure 3, the first two steps of the flow diagram directly relate to the need for a sound and well-populated database of projects.

Step one relies on the developer of the cost model to determine if there is sufficient data in quantity and quality to formulate a CER. For this reason, parametric estimating is most applicable to relatively standard projects where sufficient data is more likely. Step two is the collection of data to populate the database. The data is typically derived from detailed cost estimates of historic projects. The data must be broken down and stored so an estimator or automated software application can quickly and easily access specific description, quantity, and cost data and determine if the data is applicable to the project type. For example, the data derived from a gymnasium construction project must be distinguishable from an office building construction project. There may even be unique features of a project type, like costly gymnasium flooring which must be distinguished from all other flooring. The database is responsible for maintaining these unique relationships and ensuring the appropriate data is populating the database. The database may also separate system components into its subcomponents to improve data storage logic and improve access times. Occasionally, the estimator or analysts discovers irregularities or inconsistencies with the data or database and justifiably makes reasonable adjustments. The development and population of the database may seem like a significant investment in time and effort; however, the eventual trade-offs in speed and accuracy of parametric estimates make the effort worthwhile.

Once the data has been collected it needs to be normalized with like data. Normalization of costs to a base year is required along with normalization of quantities and units of measure. For example, ceramic tile costs might have been measured in cost per square yard in 1998 dollars, but is required to be normalized to cost per square foot in 2005 dollars. The fourth step is to select independent variable(s) which are hypothesized to affect the magnitude of the dependent variable. Of course, this theory should be tested graphically or statistically to ensure a causal relationship is actually present. Variables or parameters which don't significantly affect the dependent variable should be omitted from the list of relational parameters. After the significant independent parameters are selected, cost estimating relationships are hypothesized. The form of the cost estimating relationship is typically an arithmetic function sometimes called a mathematical model. Statistical regression techniques are typically used to determine the parameters or coefficients (statistical weighting) of the mathematical model. Simple linear regression, multiple linear regression, step-wise regression, and curvilinear regression are just a small sample of the possible statistical techniques used to formulate the mathematical model.

CER Validation

Steps seven and eight on the Figure 3 flow diagram test the validity and predictive capabilities of the mathematical model. Table 6 lists the more widely used validation and prediction tests. A simple linear model has the common mathematical form $Y = a + b(X) + e$. The column heading $\overline{Y}$, in Table 6, is the arithmetic mean of the dependent variable Y. "CER Model" refers to the entire mathematical equation. In the case of this sample table, results from each of the listed tests are meant to be annotated in the table to show a comparison between the statistics of the mean of the dependent variable and the statistics reported for the CER model. The upper portion of the table attempts to validate the cost estimating model. The lower portion of the table portrays how well the model predicts future estimates, not only theoretically in the future, but with actual data. Figure 4 is a short interpretation of each of the tests.

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Table 6 CER Quality Review Matrix

	Evaluation Element	$\bar{Y}$	**CER Model**
Validation	Data	Narrative Description	
	Logical Relationships	Narrative Description	
	t-stat		
	F-stat		
	SE		
	CV		
	R^2 (or Adjusted R^2)		
Prediction	Number of Observations		
	d.f.		
	Outliers		
	Data Range		

(Source: PCEI WG, 1999:3-18)

- <u>F-stat</u>: Tests whether the entire equation, as a whole, is valid.
- <u>t-stat</u>: Tests whether the individual X-variable(s) is/are valid.
- <u>Standard Error (SE)</u>: Average estimating error when using the equation as the estimating rule
- <u>Coefficient of Variation (CV)</u>: SE divided by mean of the Y-data, relative measure of estimating error
- <u>Coefficient of Determination (R^2)</u>: Percent of the variation in the Y-data explained by the X-data.
- <u>Adjusted R^2</u>: R^2 adjusted for the number of X-variables used to explain the variation in the Y-data
- <u>Degrees of Freedom (d.f.)</u>: number of observations (N) less the number of estimated parameters (# of X-variables + 1 for the constant term “a”). Concept of parsimony applies in that a preferred model is one with high statistical significance using the least number of variables.
- <u>Outliers</u>: Y-observations that the model predicts poorly. This is not always a valid reason to discard the data.
- <u>P-value</u>: probability level at which the statistical test would fail, suggesting the relationship is not valid. P-values less than 0.10 are generally preferred (i.e., only a 10% chance, or less, that the model is no good).

Figure 4 Interpretation of Statistical Indicators (Source: PCEI WG, 1999:3-21)

Despite the number of statistics available to check the validity and predictability of a cost estimating model, there is no one statistic which can either validate or invalidate the model. The model has to be examined from the view of the entire model. Step nine stresses the importance of gaining not only internal trust in the model, but also external trust. The best way to gain this trust is if the model continues to provide accurate estimates within its intended scope. Steps ten and eleven in Figure 3 are the points were the CER model(s) is incorporated into real world practice.

An important process in the flow diagram is periodic revalidation, where the database is updated and the cost model can stand up to the rigors of the development process again. If the model has been performing adequately only minor modifications will likely be required. This is also an opportune time to incorporate any additional insight which may have been gained since the original model was developed.

Parametric Cost Estimating in the Department of Defense

The Department of Defense has long understood the value of parametric cost estimating. Every major acquisition program in the DoD uses parametric estimating. Parametric estimates are used as the basis for budget estimations, production decisions, contractor cost negotiations, and contractor work evaluations. Estimating facility construction projects is just one of the applications of parametric cost estimating.

Accurate estimates are mandated for all Military Construction (MILCON) projects going to Congress for approval and funding. This is not only used to aid Congressional decision-making, but also at contract award time to determine if the Federal Government is getting a fair and reasonable price for its contract. The Federal Government validates the use of parametric estimating in the following Federal Acquisition Regulation (FAR) excerpt: “the Government may use various cost analysis techniques and procedures to ensure a fair and reasonable price, including verifying reasonableness of estimates generated by appropriately calibrated and validated parametric models or cost-estimating relationships” (FAR Secretariat, 2001:15.404-1 (c) (2) (i) (C)).

The Department of Defense has used parametric cost estimating for construction projects since the early 1980s. For many years, each DoD Agency inefficiently worked individually on its own parametric cost estimating system. In recent years, however, all the Services have been able to agree for the most part on one system. The adopted system is the Parametric Cost Engineering System (PACES). PACES is part of the larger umbrella of DoD cost estimating products called the Tri-Service Automated Cost Engineering System (TRACES). The TRACES family of software includes a full line of construction cost estimating and scheduling tools from a parametric tool like PACES to a detailed quantity take-off estimating tool like Micro Computer-Aided Cost Engineering System (MCACES). Tools to help determine life cycle costs, cost risks, and area cost factors are also included in the TRACES suite of cost estimating software.

Initial development of PACES began in 1981 by Delta Research, Inc with technical direction and funding from the U.S. Air Force (Earth Tech, 2003). PACES version 1.0 was released in 1983. The proprietary PACES cost engineering software system was eventually sold to Earth Tech, Inc. Since 1983 PACES has been used to estimate over $20 billion in projects for public and private agencies (PACES brochure, undated). Independent validation on over $4 billion worth of projects has proven PACES to be accurate to within 7.5% (PACES brochure, undated). When considering most parametric cost estimating systems are typically only accurate to within 15%, PACES has an impressive track record. PACES is annually updated with new DoD and industry wide project data and an expanded selection of models. Every few years itemized unit price data are updated based on the U.S. Army Corps of Engineers' Commercial Unit Price Book and other industry standard price information (Earth Tech, 2003). The latest version of PACES (version 5.0) was released in May 2003 and contains over 25,000 line items for over 100 cost models and location-specific adjustments for 2,120 cities worldwide (PACES brochure, undated).

The U.S. Air Forces' commitment to PACES is shown below in section 3.3.4 of AFI32-1021:

> **3.3.4. Project Cost Estimates.** Accurate project cost estimates are essential to successful MILCON project development and execution. Cost estimates must be closely scrutinized to ensure they are in-line with the OSD Pricing Guide or fully justified with historical cost data. Installations and MAJCOMs should prepare cost estimates using parametric estimating tools (defined as being equivalent to 15% design completion) or based on 35% conventional design…Use the Tri-Service Parametric Cost Engineering System (PACES) as a tool to develop parametric cost estimates; however, PACES cost estimates for primary facilities shall be consistent with unit prices published in OSD Pricing guide or AFCESA Historical Construction Cost Handbook. Major differences between PACES and the OSD Pricing Guide (e.g., clay tile roof versus standing seam metal roof) shall be fully justified to HQ USAF/ILEC. Capture unique requirements of a project as separate line items under Primary or Supporting Facility cost (Department of the Air Force, 2003:22).

The other Armed Services have released similar direction. The Office of the Secretary of Defense (OSD) Pricing Guide, referenced above in the AFI and earlier in this appendix, is released yearly based on inputs from each of the Services (DoD, 2003 and AFCESA, 2003). The OSD Pricing Guide contains average project unit costs ($/Square Foot), area (location) cost factors, size adjustment factors, and OSD inflation rates. The AFI's purpose for ensuring the PACES estimate does not exceed the OSD pricing guide is not a validation of PACES, but a check to ensure projects are not "gold-plated".

Also, special attention should be paid to the final sentence of the AFI excerpt which requires "unique requirements" to be noted as separate line items in the estimate.

Currently this is the only way to truly add sustainable design to a project estimate. The latest version of PACES does offer a new feature to add what it calls sustainable design to an estimate; however, selection and orientation of high-efficiency windows are the only options. Hardly a comprehensive list of sustainable design features. "Bolt-on" sustainable features like high-efficiency windows are considerably less effective when not part of a facility-wide integrated sustainable design. This new feature of PACES therefore has questionable benefits.

PACES Modeling

PACES estimates are based upon standard design models and organized by a modified American Society of Testing and Materials (ASTM) Uniformat™ Work Breakdown Structure (WBS) (Earth Tech, 2003). Model quantities and costs are predefined using similar historical projects and adjusted by experienced architectural and engineering assumptions as needed. Users are able to add, modify, or delete various default parameters like labor, equipment, and material assumptions to correspond with actual project conditions.

PACES' modified Uniformat™ WBS is a logical way to look at a facility as a collection of physical parts called systems and assemblies. The systems and assemblies are characterized by their function not by the specific materials that make them up. Systems comprise the top level and can be further broken down into subsystems. Each subsystem can be subdivided into assembly categories. The assembly categories can then be further subdivided into assemblies and finally into specific line items. Figure 5 diagrams the steps that must be completed in order to accomplish an estimate. PACES doesn’t require the user to enter data past the subsystem level (Step 3 in Figure 5). The software will automatically fill in lower level information based on the model and parameters chosen; however, the user is able to go back and modify the software’s selections at their discretion. Figure 5, Step 1 requires the user to come up with a name or some other way of identifying the project. Step 1 also requires the user to identify the

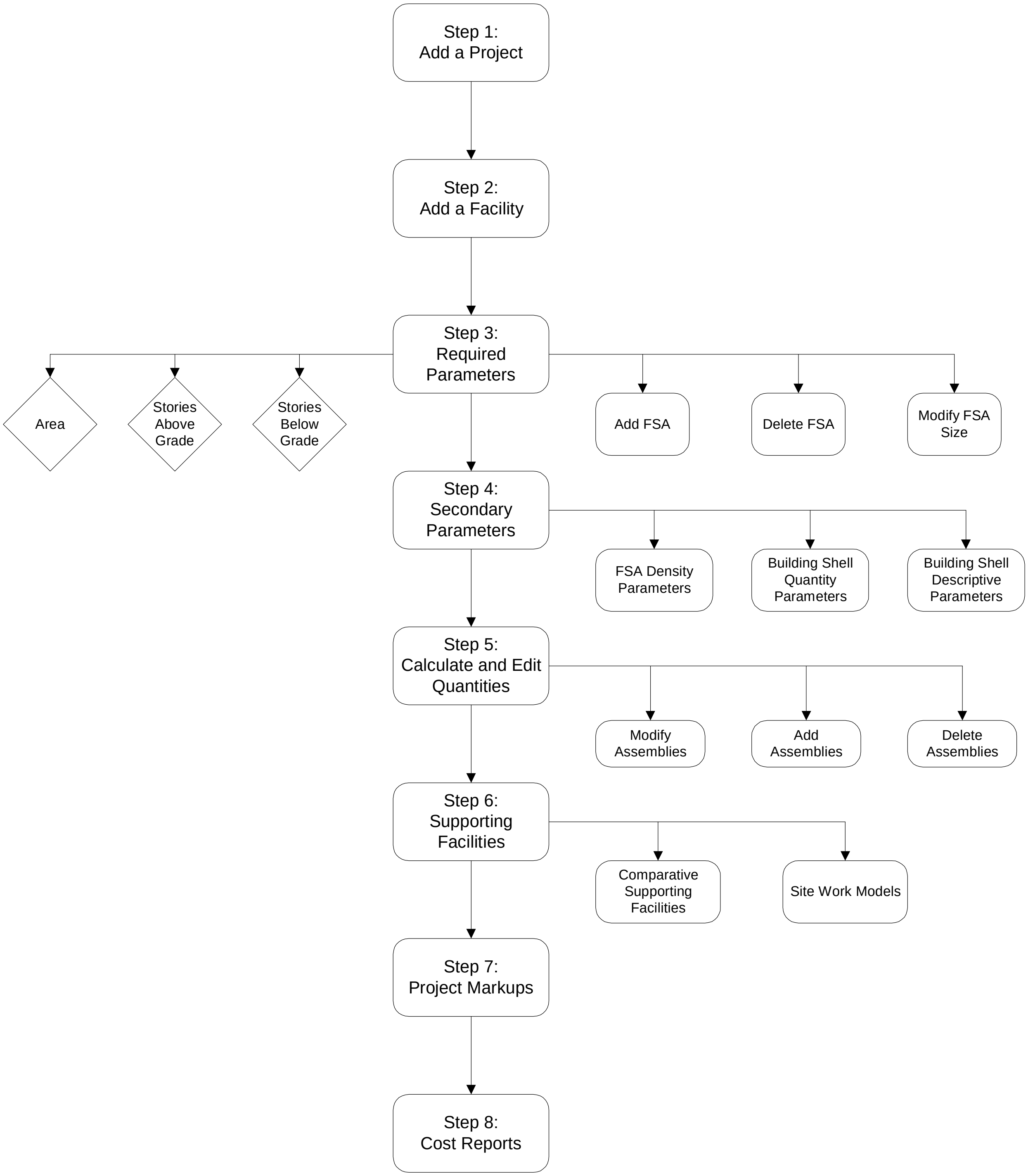


Figure 5 PACES Estimating Process (Source: Earth Tech, 2003:67)

location of the project, the year of the project, and whether metric or English units are preferred. Step 2 requires the user to choose a facility and model type. Step 3 asks for the area of the facility, the number of stories above and below grade, and the identification of functional space areas. The rest of the steps are not required, but any additional information provided will help to improve the accuracy of the estimate.

PACES Reports

PACES can produce eleven different project reports and nine different facility reports. The reports vary in level of detail and format. Some reports include direct and indirect cost, others just direct costs. There is a Construction Specification Institute (CSI) Construction Cost Report which provides a detailed breakdown of materials in CSI Master Format™ structure (Earth Tech, 2003). This CSI Master Format™ report is a detailed cost estimate formatted primarily by the construction materials used and type of work needed like concrete, masonry, mechanical systems, and electrical systems. There are also many reports which break down the estimate based on the ASTM modified Uniformat™ structure (Earth Tech, 2003). Finally, since PACES was developed primarily for the DoD, it can produce the project cost worksheets required for Congressional approval.

Some argue the level of detail available in PACES reports gives the illusion of accuracy to the estimates. Recall PACES can only be expected to be accurate to within 7.5%. Project personnel have to be cautious not to fall into the trap of proclaiming a greater accuracy than is really present. The detail PACES can produce should only be used to support the design and construction efforts. PACES can be a design check to ensure key details aren't left out of the project. For contracted projects, the detailed PACES estimate can also provide a sanity check and be a red flag for bids which are either too low or too high. If bids are either too low or too high, the contracting agency can recheck the design and estimate for errors or oversights. Another use for PACES detailed estimating and reporting capabilities is during construction; it can be used to formulate ballpark estimates for scheduling, personnel, and equipment requirements.

PACES Compatibility with LEED™ Projects

There is little debate that initial costs for sustainable design are greater than conventional construction. The many likely reasons for this difference were discussed in Chapter 2. The debate still lies as to how much greater sustainable design should cost. PACES is an impressively accurate tool for most conventional construction projects considering the small amount of data needed by the user. However, PACES is deficient at accurately estimating sustainable design facilities. Relatively few facilities have been built using sustainable design; therefore, it is inadequately considered by PACES historical cost models. Since the level of sustainability can very greatly even from LEED™ building to LEED™ building (i.e. LEED™ Certified to LEED™ Platinum), adding additional models isn't likely the answer. Perhaps LEED™ certification levels can be another parameter added to the various PACES cost models. Obviously, cost data from more completed sustainable design facilities would be required first. Until sustainable design is better incorporated into PACES, project programmers and estimators will have to take the questionable and inexact approach of adding sustainable design as a separate line item to construction cost estimates.

Parametric Cost Estimating Conclusion

Parametric cost estimating is an order-of-magnitude estimate, one of three broad categories of cost estimating techniques. Parametric cost estimating is a powerful tool capable of being utilized with few known architectural and engineering parameters. Relating known architectural and engineering parameters to cost information is accomplished by utilizing cost estimating relationship(s) (CER). CERs are established using statistical analysis of historic project data to mathematically relate independent parameters to dependent parameters like cost. The only definitive validation of a CER is how accurately it predicts actual future costs. The Department of Defense uses the Parametric Cost Estimating System (PACES) which has proven to be fairly accurate for this type of early order-of-magnitude estimate. One limitation with PACES is its inability to accurately incorporate sustainable design in its estimates. As more cost data is acquired from sustainable design projects, it is likely that PACES will become more capable of accurately estimating sustainable design projects.

Appendix D

Hypothesis Testing
Comparison of Means

Comparison of DoD and Other Federal Government Means

Origin := 1

μ_1 = DoD Projects

μ_2 = Other Fed Government Projects

$H_o \quad \mu_1 - \mu_2 = 0$

$H_a \quad \mu_1 - \mu_2 \neq 0$

Assumptions necessary to ensure the validity of this test:

a. Both sampled populations have relative frequency distributions that are approximately normal

b. The population variances are approximately equal

c. The samples are randomly and independently selected from the population

DoD Projects **Other Fed Gov Projects**

$$x_1 := \begin{pmatrix} -4.74 \\ -10.85 \\ 2.52 \\ 6.15 \\ 1.17 \\ 8.97 \\ 18.57 \\ -7.32 \\ -14.89 \\ -7.45 \\ 0.0 \\ -4.74 \\ 14.63 \end{pmatrix} \qquad x_2 := \begin{pmatrix} 2.98 \\ 0.54 \\ -3.27 \\ 0.00 \\ 0.01 \\ -1.18 \\ 9.00 \\ 9.64 \\ 22.26 \end{pmatrix}$$

$n_1 := 13$ $\quad n_2 := 9$ $\quad D_0 := 0$ (Hypothesized difference between the means)

$\text{xbar}_1 := \text{mean}(x_1)$ $\quad \text{xbar}_2 := \text{mean}(x_2)$

$\text{xbar}_1 = 0.155$ $\quad \text{xbar}_2 = 4.442$

$s_1 := \sqrt{\mathrm{Var}(x_1)}$ $\qquad$ $s_2 := \sqrt{\mathrm{Var}(x_2)}$

$s_1 = 9.908$ $\qquad$ $s_2 = 8.009$

$\mathrm{Var}(x_1) = 98.169$ $\qquad$ $\mathrm{Var}(x_2) = 64.137$

$$s_{pooled} := \frac{(n_1 - 1)\cdot s_1^{\,2} + (n_2 - 1)\cdot s_2^{\,2}}{n_1 + n_2 - 2}$$

$s_{pooled} = 84.55599$

$\alpha := .10$ **(Assumed Confidence Level - 90%)**

$t_{critlt} := -qt\left(1 - \frac{\alpha}{2}, n_1 + n_2 - 2\right)$ $\qquad$ $t_{critrt} := qt\left(1 - \frac{\alpha}{2}, n_1 + n_2 - 2\right)$

$t_{critlt} = -1.725$ $\qquad$ $t_{critrt} = 1.725$

$$t_{star} := \frac{(xbar_1 - xbar_2) - D_0}{\sqrt{s_{pooled}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

$t_{star} = -1.075$

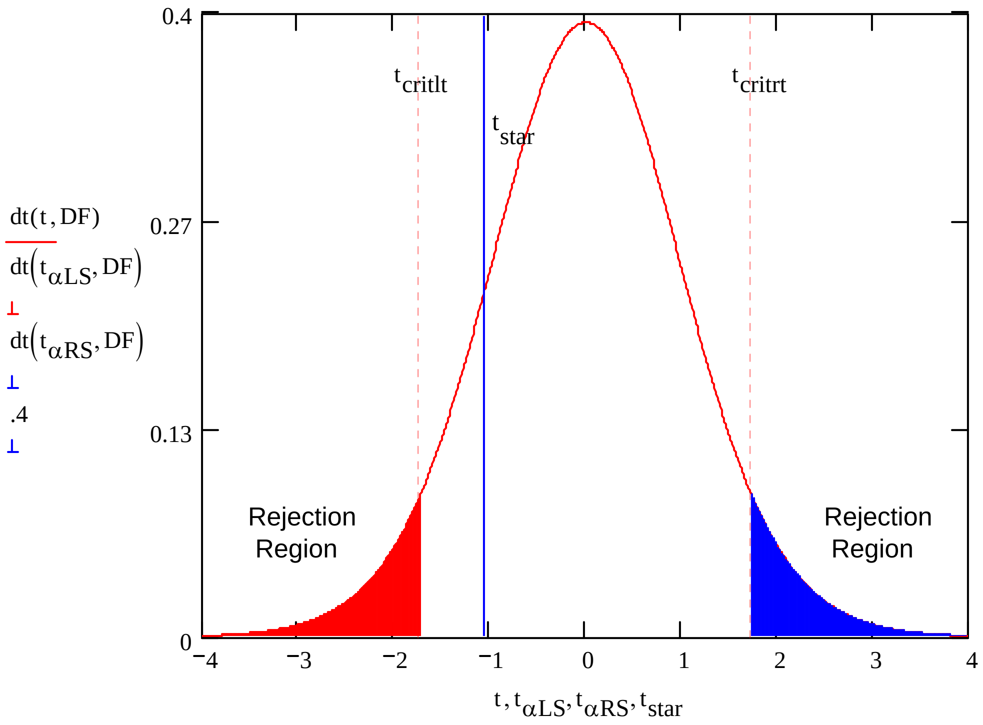
Graphical Display of Results

$DF := n_1 + n_2 - 2$

$t := -5, -4.99 .. 5$

$t_{\alpha LS} := -5, -4.99 .. t_{critlt}$

$t_{\alpha RS} := t_{critrt}, t_{critrt} + .01 .. 5$



Since the observed value of the test statistic t_{star} does not fall along the rejection regions of H_o, there is insufficient evidence to reject the null hypothesis at $\alpha = .10$. In other words, there is not enough evidence to claim the mean percent difference in cost is different between the two sampled populations.

Observed Significance Level (p-value) Calculation

$$p_{val} := (pt(t_{star}, DF)) \cdot 2$$

$$p_{val} = 0.2951$$

There is sufficient evidence to reject the null hypothesis and to indicate the mean percent difference in cost are different for any value of α > .30. Since this p-value is so large, there is nearly no evidence to reject the null hypothesis for any reasonable value of α.

Appendix E

Hypothesis Testing
Large Sample Test About a Population Mean

Small Federal Government Sample Test About a Population Mean With Evaluated Mean = 0%

μ = All Federal Government Projects

Origin := 1

$\mu_o := 0\%$ (Status-quo, no difference in cost)

$H_o \quad \mu = \mu_o$ Null Hypothesis

$H_a \quad \mu \neq \mu_o$ Alternative Hypothesis

Therefore, Two-tailed Test

Assumptions necessary to ensure the validity of this test:

a. Sampled population has relative frequency distribution that is approximately normal

b. The population variance is approximately equal

c. The sample is randomly and independently selected from the populatior

All Federal Government Projects

$$x := \begin{pmatrix} -4.74 & -10.85 & 2.52 & 6.15 & 2.98 & 1.17 & 8.97 & 0.54 & -3.27 & 0.00 & 18.57 \\ -7.32 & -14.89 & 0.01 & -1.18 & 9.00 & -7.45 & 9.64 & 0.00 & -4.74 & 14.63 & 22.26 \end{pmatrix}$$

$n := 22$ $\quad df := n - 1$

$x_{bar} := \text{mean}(x)$

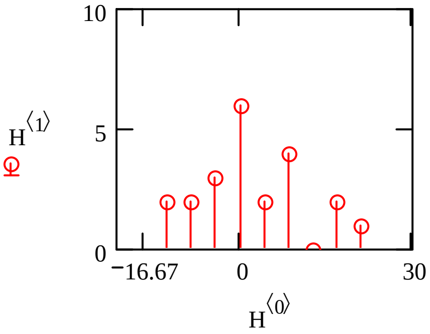
$x_{bar} = 1.9091$ $\quad \text{median}(x) = 0.275$

$s := \sqrt{\text{Var}(x)}$

$s = 9.229$

Verification of Mound-Shaped Data

$H := \text{histogram}(9, x) \qquad \text{cols}(H) := 2$



$$H = \begin{pmatrix} -12.889 & 2 \\ -8.667 & 2 \\ -4.444 & 3 \\ -0.222 & 6 \\ 4 & 2 \\ 8.222 & 4 \\ 12.444 & 0 \\ 16.667 & 2 \\ 20.889 & 1 \end{pmatrix}$$

Mound shape data verified

Hypothesis Testing:

$\alpha := .10$ **(Assumed Confidence Level - 90%)**

$t_{cLT} := qt\left(\frac{\alpha}{2}, n - 1\right) \qquad t_{cRT} := qt\left(1 - \frac{\alpha}{2}, n - 1\right)$

$t_{cLT} = -1.72074 \qquad t_{cRT} = 1.72074$

$$t_{star} := \frac{x_{bar} - \mu_o}{\frac{s}{\sqrt{n}}}$$

$t_{star} = 0.97$

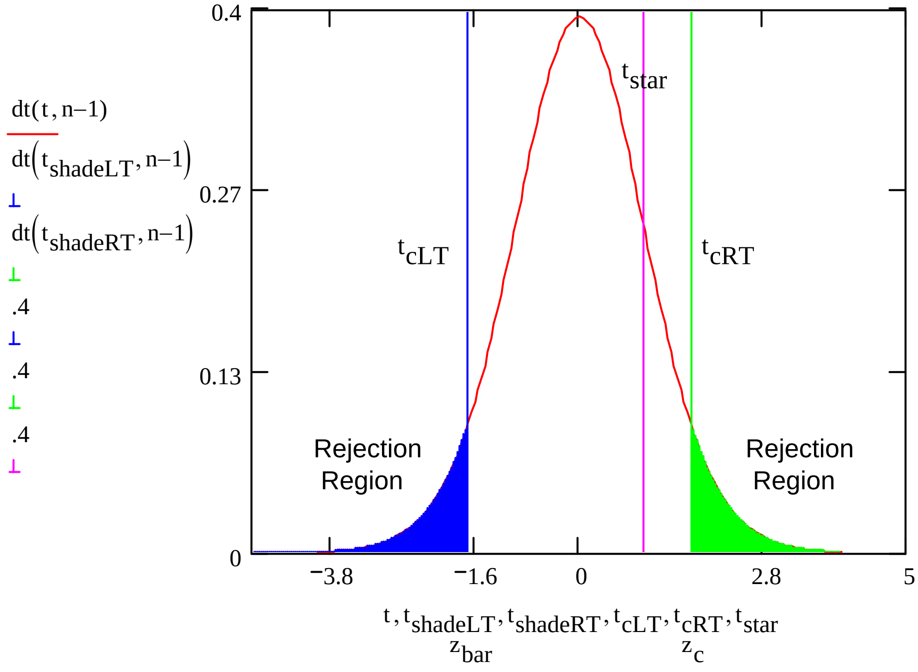
Graph of t-statistic (with α shaded) shown below:

$t := -4, -3.95 .. 4$

t-critical defines the start of the α - region (along the axis)

$t_{shadeLT} := -5, -4.99 .. t_{cLT}$

$t_{shadeRT} := t_{cRT}, t_{cRT} + .01 .. 4$



Since the observed value of the test statistic t_{star} does not fall along the rejection regions of H_o, there is insufficient evidence to reject the null hypothesis at α = .10. In other words, there is not enough evidence to claim the mean percent difference in cost is greater (or less) than 0.

Observed Significance Level (p-value) Calculation

$p_{valt} := (1 - pt(|t_{star}|, df)) \cdot 2$

$p_{valt} = 0.343$

There is sufficient evidence to reject the null hypothesis and to indicate the mean percent difference in cost is not equal to 0% for any value of α > .34. Since this p-value is so large, there is nearly no evidence to reject the null hypothesis for any reasonable value of α.

Confidence Interval Calculations

Confidence Interval Results for α = .10

$\alpha := .10$ **(Assumed Confidence Level - 90%)**

Margin of Error:

$$\text{MarginofError} := qt\left(1 - \frac{\alpha}{2}, df\right) \cdot \frac{s}{\sqrt{n}}$$

$\text{MarginofError} = 3.386$

Confidence Interval Estimate of the Population Mean:

$CI_{LT} := x_{bar} - \text{MarginofError}$ $CI_{RT} := x_{bar} + \text{MarginofError}$

$CI_{LT} = -1.477$ to $CI_{RT} = 5.295$

Confidence Interval Results for α = .05

$\alpha := .05$ (Assumed Confidence Level - 95%)

Margin of Error:

$$\text{MarginofError} := \text{qt}\left(1 - \frac{\alpha}{2}, \text{df}\right) \cdot \frac{s}{\sqrt{n}}$$

$$\text{MarginofError} = 4.092$$

Confidence Interval Estimate of the Population Mean:

$$\text{CI}_{\text{LT}} := x_{\text{bar}} - \text{MarginofError} \qquad \text{CI}_{\text{RT}} := x_{\text{bar}} + \text{MarginofError}$$

$\text{CI}_{\text{LT}} = -2.183$ to $\text{CI}_{\text{RT}} = 6.001$

Confidence Interval Results for α = .01

$\alpha := .01$ (Assumed Confidence Level - 99%)

Margin of Error:

$$\text{MarginofError} := \text{qt}\left(1 - \frac{\alpha}{2}, \text{df}\right) \cdot \frac{s}{\sqrt{n}}$$

$$\text{MarginofError} = 5.571$$

Confidence Interval Estimate of the Population Mean:

$$\text{CI}_{\text{LT}} := x_{\text{bar}} - \text{MarginofError} \qquad \text{CI}_{\text{RT}} := x_{\text{bar}} + \text{MarginofError}$$

$\text{CI}_{\text{LT}} = -3.662$ to $\text{CI}_{\text{RT}} = 7.48$

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)* 23-03-2004	**2. REPORT TYPE** **Master's Thesis**	**3. DATES COVERED** *(From – To)* Jun 2003 – Mar 2004

4. TITLE AND SUBTITLE

MAKING THE BUSINESS CASE FOR SUSTAINABLE DESIGN IN THE DEPARTMENT OF DEFENSE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Warnke, David M., Captain, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way, Building 641
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GEM/ENV/04M-20

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Karen L. Kivela
Headquarters Air Force Center for Environmental Excellence (HQ-AFCEE)
3300 Sidney Brooks
Brooks City-Base TX 78235-5112
(210) 536-4191

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Sustainable design is the common term associated with buildings which, during their construction, use, and eventual disposal, seek to minimize their negative impact on the environment and human health. The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED™) rating system helps to assess a building's sustainability level.

Each Department of Defense Service has set ambitious LEED™ certification goals. Despite their stated goals and the clear environmental and health benefits of LEED™, a common concern is that LEED™ designed and constructed buildings are simply too costly. However, many proponents profess that LEED™ buildings shouldn't cost significantly more than conventionally designed and constructed buildings and that the operational life-cycle cost savings rapidly compensate for any additional initial costs. Unfortunately, no comprehensive costs studies have been performed in the DoD; therefore, it continues to be the primary source of debate.

This research gathered historical Federal construction cost data and used statistical analysis to explore whether a business case could be made to support LEED™ using initial construction costs. Results were mixed. While on average LEED™ buildings were only 1.9% more expensive to construct than conventional facilities, the 9.2% standard deviation made it difficult to make a favorable business case.

15. SUBJECT TERMS

Sustainable Design, Sustainable Construction, Green Building, LEED, Leadership in Energy and Environmental Design, U.S. Green Building Council.

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr. Charles A. Bleckmann, PhD, AFIT (ENV)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	**U**	**U**	**UU**	119	(937) 255-3636, ext 4721; e-mail: charles.bleckmann@afit.edu

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18