DAYLIGHTING STRATEGIES FOR U. S. AIR FORCE OFFICE FACILITIES: ECONOMIC ANALYSIS OF BUILDING ENERGY PERFORMANCE AND LIFE-CYCLE COST MODELING WITH MONTE CARLO METHOD

THESIS

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AFIT/GEM/ENV/09-M08

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Abstract

The U.S. federal government maintains more than 500,000 facilities in the United States and around the world, most of which are heavily dependent on fossil fuels to produce electricity. Within the federal government, the Department of Defense (DOD) spends over $2.5 billion per year on facility energy consumption which makes them the largest single energy consumer in the United States. Therefore, federal energy conservation goals focus on aggressively reducing energy consumption by reducing the energy demand at the facility level within the next 20 years.

Daylighting is a passive solar energy strategy at the facility level that leverages load avoidance by relying on windows and skylights to reduce building electrical lighting load; which accounts for approximately $15-23 billion annually in energy consumption. Our research findings show that electrochromic windows have the lowest energy consumption compared with other daylighting strategies appropriate for building retrofit. However, the prohibitive initial investment cost of electrochomic windows do not make them economically viable; therefore, the only daylighting strategy currently viable for Air Force facilities, based on our simulations, is the advanced daylighting control system.

We found that economic incentive policies currently available for other passive solar technology could make emerging daylighitng technology, such as electrochromic windows, viable. Finally, we demonstrate the robustness of probabilistic life-cycle cost model using Monte Carlo simulation that could provide significantly more information compared to the current deterministic tool, BLCC 5, used for federal energy projects.

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In memory of my mother, who sacrificed everything that I may pursue my American Dream

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I would like to thank God; who has blessed me with life, family, and friends who continue to make this journey truly wondrous.

I would like to thank my family. My parents who have sacrificed so much; and despite the difficult and countless trials and tribulations of emigrating to America, they have always instilled in me a sense of self and confidence to become the person that I am today. I would like to thank the best sister anyone can be blessed to have. She has provided countless council and has been a voice of reason and comfort during the most difficult times. And I am eternally grateful for her selfless sacrifice and unfailing support so that I may pursue my dreams, wherever they have taken me.

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Captain Sang M. Lee

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DAYLIGHTING STRATEGIES FOR U. S. AIR FORCE OFFICE FACILITIES: ECONOMIC ANALYSIS OF BUILDING ENERGY PERFORMANCE AND LIFE-CYCLE COST MODELING WITH MONTE CARLO METHOD

Introduction

The federal government maintains more than 500,000 facilities in the United States and around the world, most of which are heavily dependent on fossil fuels to produce electricity (Pratt, 2006). In fiscal year (FY) 2002, federal facilities used 316.8 trillion British Thermal Units (BTU[1]) of energy at a cost of $3.7 billion, making the federal government the single largest energy consumer in the United States (Garman, 2003). The U.S. Department of Defense (DOD) spends over $2.5 billion per year on facility energy consumption; they are the largest single energy consumer in the United States, accounting for nearly 80% of total federal energy use (ODUSD, 2005). Renewable energy use in the context of national security, environmental stewardship, and energy conservation has introduced federal and state regulations that have shaped the national psyche as well as given birth to the "green technology[2]" industry.

A special report in the 19 June 2008 issue of *The Economist* magazine stated that many innovative companies that changed the face of the world economy through the dot com phenomenon are beginning to turn their attention to renewable energy, venerable names such as Google and Sun Microsystems, for example. The editors of the magazine contend the green

[1] A unit of energy used in the power, steam generation, heating and air conditioning industries. "BTU" is used to describe the heat value (energy content) of fuels, and also to describe the power of heating and cooling systems, such as furnaces, stoves, barbecue grills, and air conditioners. The unit MBTU was defined as one thousand BTU presumably from the Roman numeral system where "M" stands for one thousand (1,000). This is easily confused with the SI mega (M) prefix, which adds a factor of one million (1,000,000). To avoid confusion many companies and engineers use MMBTU to represent one million BTU; alternatively a "therm" is used representing 100,000 or 10^5 BTU, and a quad as 10^{15} BTU.
(Source: http://en.wikipedia.org/wiki/British_Thermal_Units)

[2] It encompasses a continuously evolving group of methods and materials, from techniques for generating energy to non-toxic cleaning products. Most notable examples within this growing industry include energy, green building, environmentally preferred purchasing, green chemistry, and green nanotechnology. (Source: http://www.green-technology.org/what.htm)

industry could be the next technological revolution (The Economist, 2008). There is preliminary discussion within the Intergovernmental Panel on Climate Change (IPCC[3]) that could recommend a tax of $20-$50 for every ton of carbon dioxide generated to pay for environmental damage (The Economist, 2008). Recent federal U.S. policies that have mandated and shaped the energy conservation strategy include three key legislations: The Energy Policy Act (EPACT) of 2005, Executive Order (EO) 13423, and Energy Independence and Security Act (EISA) of 2007.

However, we argue that the federally mandated energy goals could be inconsistent with economic feasibility of emerging renewable energy technology. Some of these emerging technologies could help meet the energy goals but due to high initial investment costs they are not economically viable without government subsidy. Many renewable technologies have had to rely on economic incentives in the form of tax credits to help them advance; however, they are not universally applied and could be failing to support those technologies that could be beneficial, such as daylighting technology. The background for the energy conservation and strategy for the federal government is discussed next.

Background

During the energy crisis and in response to energy security concerns of the mid-1970s, the U.S. passed legislation to decrease the nation's dependence on foreign oil and increase domestic energy conservation and efficiency (Gielecki, et al., 2001). The most important law promoting renewable energy in the 1990s was the Energy Policy Act (EPACT) of 1992 (EIA, 2005). This act provided a quantitative goal over an intermediate duration of time (10 years) to achieve definitive conservation guidance. This law has since been updated with EPACT 2005,

[3] A scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). It includes hundreds of scientists all over the world contribute to the work of the IPCC as authors, contributors and reviewers.

which defines conservation goals out to 2015 (EIA, 2005). EPACT 2005 was joined by two other key statutes, EO 13423 and EISA 2007 to form the federal energy management policy.

For the DOD, energy conservation does not mean simply turning off the switch and doing without. Rather, it means using resources more efficiently to provide the same or even an improved level of benefits at lower cost (ODUSD, 2005). Conservation should help installations deal with resource limitations without reducing mission capabilities, productivity, or the quality of life for DOD personnel. Furthermore, reducing energy use could reduce the amount of air pollutants resulting from the direct burning of fossil fuels and indirect burning when generating electricity. For example, a 10% reduction in U.S. electricity use could cut annual carbon dioxide (CO_2) emissions by over 200 million tons, sulfur dioxide (SO_2) emissions by 1.7 million tons, and nitrogen oxide (NO) emissions by 900 thousand tons (ODUSD, 2005).

Energy Management is defined by Turner (2001) as the regulation of energy, minimizing energy demand and consumption (Pratt, 2006). Energy management can help improve environmental quality by reducing fossil fuel consumption, thus reducing emissions into the atmosphere of such substances as nitrogen oxides, sulfur oxides and carbon dioxide, which have been suggested to affect Global Warming as well as produce acid rain (EIA, 2005). Energy policies are managed through the Federal Energy Management Program (FEMP) office that provide guidelines and interpretations of the federal mandates as they pertain to federal organizations. DOE's financial support of research within industry, universities, and national laboratories dedicated to renewable energy, such as Lawrence Berkeley National Laboratory (LBNL) and National Renewable Energy Laboratory (NREL), have provided scientific support to boost emerging energy technology and policy.

For many years, researchers have been developing alternative technologies to fossil fuels to produce electricity such as solar panels, wind turbines, and geothermal plants to help reduce the cost of energy generation (Pratt, 2006). These are "active systems" whose aim is to reduce the cost of electricity compared to traditional generation method by fossil fuel. However, effective energy management should also reduce the energy demand, which could impact the energy expenditure more significantly. This "passive systems" strategy, also known as load avoidance, focuses on mitigating the overall energy demand to reduce emission and reduce annual energy costs. Daylighting is a form of passive system that relies on windows and skylights to reduce electrical lighting load in a building. Windows and skylights have been found to account for approximately 30-50% of commercial energy consumption, which equates to approximately $15-23 billion annually (McHugh, et al., 1998). USAF has used daylighting as an energy savings strategy in earlier studies (Holtz, 1990); and is pursuing it to meet future net zero building[4] requirements (USAF/A7CAE personal communication, 2008).

The methodology used for a net zero energy building in a passive solar system should focus on load avoidance rather than using renewable energy to generate electricity (McHugh, et al., 1998). For example, traditional utility systems that are straining to meet peak demand load could benefit from various daylighting technology. Reducing peak demand would lower generating capacity, which could significantly reduce electricity cost (Acton, et al., 1980).

One of the key components of harnessing daylighting in a facility is through various building components such as windows and skylights. However, traditional windows and skylights have limitations such as unwanted heat gain and loss; this translates into wasted energy. In 1990, the energy used to offset unwanted heat gains and losses through windows in

[4] The general concept describes a building that can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources (Torcellini, et al., 2006)

residential and commercial buildings cost the United States $20 billion; which was one-fourth of all the energy used for space heating and cooling (Ander, 2008).

DOD's current guidelines (CFR Title 10, 2000) and United Facilities Code (UFC[5]) states that sustainable design shall be an integral part of every project and energy conservation is a primary goal of sustainable design (UFC 3-400-01, 2002). Furthermore, the DOD Energy Manager's Handbook states that passive solar designs, such as building orientation and window placement and sizing shall be implemented in a variety of building types and new facility construction (ODUSD, 2005).

These guidelines primarily pertain to the construction of new facilities (we define new facility as any facility that is less than 15 years old). New facilities constitute only 25% of the USAF building inventory (USAF/A7CAI, 2008). By retrofitting existing older buildings, the federal government could see a greater reduction in energy consumption. However, currently there are limited studies for energy and cost savings for retrofits to existing USAF buildings (Pratt, 2006). This situation is compounded by limited energy consumption data that is available from the Defense Utility Energy Reporting System (DUERS[6]) with respect to individual facilities. And any energy strategy must be supported with an economic analysis to help decision makers ensure that federal funds would be invested wisely.

[5] Unified Facilities Criteria (UFC) documents provide planning, design, construction, sustainment, restoration, and modernization criteria, and apply to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC are distributed only in electronic media and are effective upon issuance. Headquarters, United States Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Points of contact and procedures for the development and maintenance UFC documents are prescribed in the latest edition of MIL-STD-3007. (Source: http://65.204.17.188/report/doc_ufc.html)

[6] An automated management information system with which the Department of Defense monitors its supplies and consumption of energy. It was originally fielded in February 1974 as the Defense Energy Information System (DEIS) to respond to the need to manage DoD energy resources more closely in the aftermath of the 1973 Arab oil embargo. It is primarily used as an energy management tool, providing information about the Department of Defense's inventory and consumption of utility energy. (Source: *DoD 5126.46-M-2, November 1993*)

The primary purpose of energy and economic analysis (EA) of potential energy conservation projects is to help make decisions. Risk and uncertainty is analyzed through sensitivity analysis as part of the EA. Currently, EAs are completed through deterministic tool available from National Institute of Standard and Technology (NIST[7]) called Building Life-Cycle Cost (BLCC[8]) 5 program. It provides two economic factors that are currently used by decision makers to determine project approval, the savings-to-investment ratio (SIR) and simple payback (SPB). Our study investigates three different components of an energy project: energy savings potential, economic viability, and effective economic decision making. The specific research questions that will be answered through our study are discussed in the next section.

Research Objectives and Research Questions

Our research focuses on the possible energy savings of retrofitting different daylighting technologies into existing USAF facilities then determining its economic viability using a life-cycle cost analysis (LCCA) model. We explore policy implications of making emerging technologies more viable and demonstrate the robustness of probabilistic LCCA model using Monte Carlo simulation. Specifically, our study answers the following research questions:

1. Which daylighting strategy is most energy efficient for a USAF office facility: advanced daylighting control system with traditional windows, skylights with traditional windows, EC window system, or full daylighting strategy using EC window systems with skylights? And how does climate affect the different daylighting strategies?
2. Which daylighting strategy is most economically viable for an USAF office facility?

[7] Agency of the U.S. Commerce Department's Technology Administration. Conducts basic and applied research in the physical sciences and engineering, and develops measurement techniques, test methods, standards, and related services (Fuller, et al., 1996).
[8] Provides comprehensive economic analysis of proposed building capital investments. BLCC is especially useful for evaluating energy and water conservation projects in buildings. Required by Federal Energy Management Program office (Paradis, 2007)

3. Which input cost factor affects the economic viability of emerging daylighting technology: utility rate, peak demand cost, or initial investment cost?
4. Is there significant difference in using discounted payback versus simple payback that could affect decision making? Do other economic factors provide additional insight?
5. For the non-economically viable daylighting technologies, are there economic policy measures that could make them economically viable?
6. What are the capabilities that make the Monte Carlo life-cycle cost analysis model more robust than the deterministic model BLCC 5? What type of insight can the added robustness provide for the USAF decision maker?

Hypothesis

We hypothesize that Electrochromic (EC) windows would be best energy performers while skylights would be the worst. In general, daylighting strategy should perform better in warmer climates than colder climates. And any daylighting technology currently not economically viable could be made viable by using economic incentives that are currently available for other passive solar technologies other than daylighting. And our probabilistic life cycle cost model should be more robust than the current deterministic model. Our research approach is discussed in the next section.

Research Approach

Previous research (Lee, et al., 2004) found that EC systems are generally applicable to buildings types with perimeter windows such as offices, schools, some mercantile and service buildings, and some health care facilities. Furthermore, Lee, et al. (2004) found that EC systems are less applicable to lodging, warehouse and storage buildings. Therefore, our research focuses on an office facility that would be commonly found on any Air Force base.

The proposed methodology for our research consists of using two simulation tools in a three part investigation. The first part is an energy simulation of a prototypical USAF office facility. A prototypical facility defined by the experts at Air Force Civil Engineer Support Agency (AFCESA[9]) is used to simulate the facility energy performance. We used building energy simulation software called eQUEST (DOE-2) to model the energy performance of our prototypical USAF office facility.

The second part of our study determines economic viability through a life-cycle cost analysis (LCCA) with Monte Carlo simulation using Crystal Ball® in MS® Excel. We used actual cost data for the EC windows from the manufacturer, Sage Electrochromic, Inc. And the Monte Carlo LCCA methodology is adapted from Enblemsvag (2003) and Liberman (2003).

The last part of our study explores an economic policy implementation for daylighting technology that may demonstrate energy savings but is not economically viable in the current market. Based on historic effects of policy on other renewable technology (EIA, 2005), we simulate the effects of policy intervention. In order to conduct our research using probability analysis, there are some assumptions that were made and are discussed in the next section.

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[9] The Air Force Civil Engineer Support Agency, headquartered at Tyndall Air Force Base, Fla., provides the best tools, practices and professional support to maximize Air Force civil engineer capabilities in base and contingency operations. AFCESA is a field-operating agency of the Office of the Civil Engineer of the Air Force, Washington, D.C. (Source: http://www.afcesa.af.mil/) AFCESA is the focal point for the day-to-day energy and water conservation concerns and has the authority to communicate directly with the staffs of OSD and SAF on matters pertaining to facility energy and water conservation, as well as, solicit information to answer congressional and other inquiries. AFCESA will centrally track and provide the guidance to the bases and commands, develop guidelines, provide the legislative requirements and include the data from the awarded ESPCs in the annual energy report (ODUSD, 2005).

Assumptions

Our research assumes probabilistic independence in our Monte Carlo probabilistic model. Probability independence means that the probability of an event occurring has no bearing on the probability of another event occurring. Using Crystal Ball® software to conduct Monte Carlo simulation should ensure independence through its random number generating capability. This creates a random sampling effect during the LCCA which could provide a result that could be a representative of the population (McClave, et al., 2008) due to its ability to drown out the error with a large sample size, with individual iteration representing a sample. With these assumptions, the scope of our research is discussed next.

Research Scope

Most of the buildings in the USAF inventory offer energy and cost saving opportunities. Retrofitting old energy systems can be an attractive investment; however, the initial capital outlay is often substantial and may not allow implementation of technology. This is especially true for emerging renewable technology, such as EC windows. And there is limited research on how these emerging daylighting technologies will perform in the USAF. We investigate the energy savings of different daylighting technology.

Our research is limited due to lack of metered facility energy use needed to validate our energy simulation results. Therefore, our research findings and proposed model provides a foundation and strategic planning for future energy and economic analysis studies. And our findings are relative within the scope of our simulations.

Current tool used for life-cycle cost analysis for energy projects uses a deterministic model which has known limitations in its ability to account for risk and uncertainty. Our research demonstrates the robustness of life-cycle cost analysis by using probabilistic modeling. We also demonstrate the robustness of our probabilistic model. However, our findings are limited within the context of our simulations because data was unavailable for validating our model; and should not be generalized. The significance of our study is discussed in the next section.

Significance of Study

Our research highlights the potential savings that could be found in retrofitting current facilities by implementing daylighting strategy to meet the net zero energy facility. Most DOD buildings were designed and constructed before the energy crisis of 1973 (ODUSD, 2005). Architects and engineers at that time lacked the incentive to use electricity and gas efficiently, particularly because energy-efficient equipment usually required greater initial capital investment (ODUSD, 2005). Also, energy-efficient equipment or systems were not available because of limited technology and market demand. Consequently, many old DOD buildings were designed to use lighting, HVAC equipment, and auxiliary fan motors that are inefficient by today's standards (ODUSD, 2005). Therefore, the opportunities to upgrade these old systems to new efficient systems are available and must be pursued to meet the energy conservation goals mandated for federal facilities.

However, few daylighting projects in the DOD have been implemented due to their poor predictability in energy and cost savings. Yet a DOD study (Tri-Service Renewable Energy Committee, 2003) found that daylighting has the greatest potential for energy and cost savings. The DOD study (Tri-Service Renewable Energy Committee, 2003) was limited in that the daylighting recommendation only applied to large warehouses. Our study explores daylighting potential for USAF office facilities and compare traditional with emerging daylighting technology. Furthermore, we investigate which daylighting technology is the most economically viable. We also investigate the potential impact of economic policy intervention that could make daylighting technology viable, if they are not currently. Our study also investigates the robustness of probabilistic analysis model and compares it with the deterministic tool, BLCC 5. Additional information could potentially be made available to the decision makers by using probabilistic tools that have not been traditionally used for DOD energy projects.

Summary

The DOD and USAF have been leaders in energy conservation through innovative implementation of available technology. However, due to budget constraints and competing requirements compounded with aggressive federal energy conservation goals, energy projects need to focus on not only producing cheap energy but reducing the overall energy demand. Furthermore, economic policies aimed at providing incentives to allow promising renewable technology growth are explored. Finally, we investigate the robustness of probabilistic models and compare it with the current deterministic model.

The literature review in chapter 2 provides a summary of existing research pertaining to EC windows and their potential energy savings. Chapter 2 also discusses an overview of LCCA and Monte Carlo simulation. Chapter 3 discusses the methodology that was used in our study. Chapter 4 discusses our research results and accompanying analysis including the potential policy implementation and its effects. Finally, chapter 5 summarizes our results and our final recommendations.

II. Literature Review

Chapter Overview

This chapter discusses current literature on new daylighting technology. We begin with a background of renewable energy starting with the history of the federal energy mandates and the current mandates that shape the energy management strategy for all federal facilities. Next, the current response to the energy challenge in the DOD is discussed, which focuses on the USAF facility energy program. Then, facility retrofit and the different types of daylighting technologies most appropriate for retrofitting are presented. We then review life-cycle cost analysis (LCCA) and risk and uncertainty assessment as it relates to energy projects. The discussion on uncertainty and risk includes a detailed background on probabilistic method of risk assessment through Monte Carlo simulation.

Federal Renewable Energy Policy

During the energy crisis and in response to energy security concerns of the mid-1970s, the United States passed the National Energy Act of 1978 (NEA), which sought to decrease the nation's dependence on foreign oil and increase domestic energy conservation and efficiency (Gielecki, et al., 2001). According to the U.S. Government Printing Office (1991), the Public Utility Regulatory Policies Act (PURPA) of 1978 and 1978 Energy Tax Act (ETA) set out to improve energy conservation and energy efficiency in the utilities sector. However, the most important law promoting renewable energy in the 1990s was the Energy Policy Act (EPACT) of 1992 (EIA, 2005). This act provided a quantitative goal over an intermediate duration of time (10 years) to achieve definitive conservation guidance. This law has since been updated with the

EPACT 2005, which defines conservation goals out to 2015 (EIA, 2005). This was driven by a projected energy shortfall deemed critical for national security. For example, the National Energy Policy published in 2001 by the White House states that the projected energy shortfall is showing a growing trend, shown in figure 1 (NEPDG, 2001).

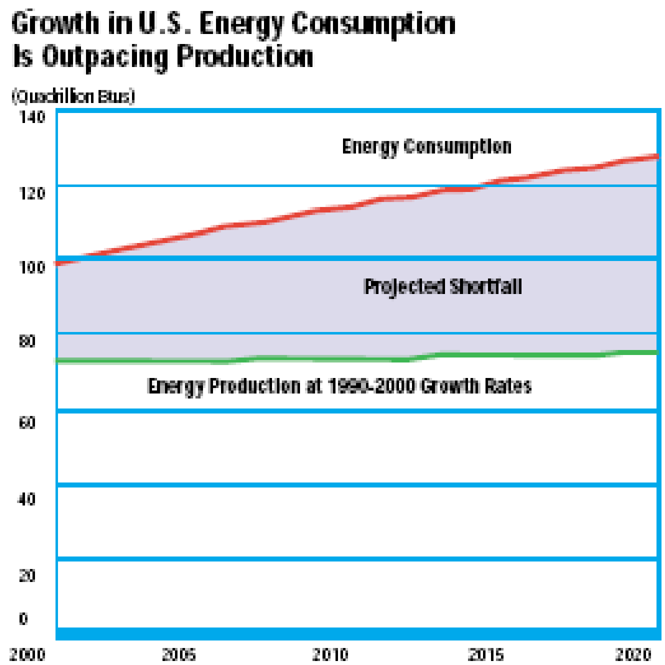


Figure 1. Projected Energy Shortfall (NEPDG, 2001)

The projected growing energy shortage and climate change have spurred additional policy to EPACT 2005. Executive Order (EO) 13423 and Energy Independence and Security Act (EISA) of 2007, details available in Appendix A, that have provided more aggressive guidelines for the federal energy conservation effort especially for federal facilities.

Renewable Energy and the Department of Defense

The DOD has made efforts to provide the necessary resources toward viable investments in renewable energy projects. The DOD is focused on energy savings because they have been consistently the primary consumer of energy within the federal government (EIA, 2008), shown in Figure 2.

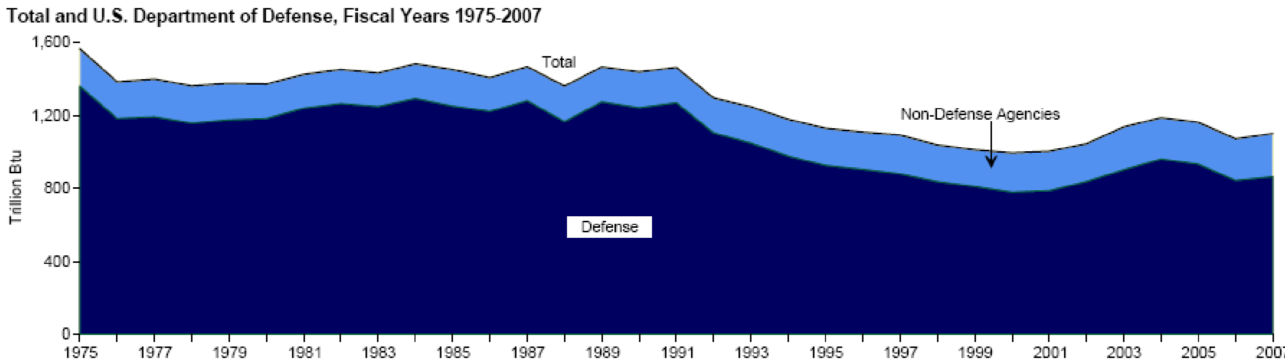


Figure 2. Comparison of energy use between DOD and Non-DOD agencies (EIA, 2008).

One of the challenges for DOD is trying to fiscally manage its primary mission of national defense with other requirements, such as energy conservation. However, the increasing capability of renewable energy usage for the DOD can be observed both at the strategic and tactical level. For example, Marine Major General Richard Zilmer, in Iraq, requested renewable energy sources like solar panels and wind turbines; so that soldiers in the field could produce more of their own energy on site and reduce the need for vulnerable fuel convoys (Walsh, 2008). In Afghanistan, spraying desert tents or temporary wooden structures with adhesive foam that sealed open spaces provided significant energy savings and comfort for the deployed military members. In some locations Army engineers were able to reduce energy loss in the camps by 50% by using the spray on tents (Walsh, 2008). The DOD has a growing list of renewable energy projects that have been implemented. Examples such as energy efficient housing in Fort Drum, geothermal power in Louisiana's Fort Polk, the world's largest solar community in Hawaii (Walsh, 2008) and North America's largest solar photovoltaic power plant at Nellis Air Force Base (Sunpower, 2007). The USAF has made efforts to lead the renewable energy implementation effort within the DOD as part of its strategic vision as exemplified by the Nellis Air Force Base photovoltaic array project.

The USAF has also demonstrated leadership in renewable energy relating to facilities. It has mandated that starting from fiscal year 2009 (FY09), all Military Construction (MILCON) projects will meet the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Green Building Rating System[10] with silver certification rating. Additionally, 5% of existing facilities will eventually have USGBC formal certification, which will increase to 10% by FY10 (Rocchetti, 2008). Furthermore, the USAF has identified an average of $250 million per year energy investment throughout the Future Year Defense Program (FYDP)[11], which includes 268 energy projects valued at $258 million.

However, in addition to the federal mandates, there are added requirements within DOD that could add to the already aggressive goals. For example, the Defense Science Board[12] Energy Report recommended in their 2008 energy report that all DOD facilities be required to meet

[10] LEED is a third-party certification program and the nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED for New Construction and Major Renovations is designed to guide and distinguish high-performance commercial and institutional projects.

[11] *T*he program and financial plan for the Department of Defense as approved by the Secretary of Defense. The FYDP arrays cost data, manpower and force structure over a 6-year period (force structure for an additional 3 years), portraying this data by major force program for DoD internal review for the program and budget review submission. It is also provided to the Congress in conjunction with the President's budget. (Source: DoD Financial Management Regulation 7000.14-R)

[12] Under the provisions of the Federal Advisory Committee Act of 1972, as amended, shall provide the Secretary of Defense, the Deputy Secretary of Defense, the Under Secretary of Defense for Acquisition, Technology and Logistics, the Chairman of the Joint Chiefs of Staff and, as requested, other Office of the Secretary of Defense (OSD) Principal Staff Assistants, the Secretaries of the Military Departments, the Commanders of the Combatant Commands, independent advice and recommendations on scientific, technical, manufacturing, acquisition process, and other matters of special interest to the Department of Defense. (Source: http://www.acq.osd.mil/dsb/charter.htm)

net zero facility standards by 2025 (Rocchetti, 2008). A net zero energy facility describes a building that can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources (Torcellini, et al., 2006). Figure 3 shows utilities historic cost data for USAF facilities presented in constant dollar. The trend shows reduced cost during the late 1990's presumably due to the significant downsizing of USAF facilities as a result of Base Realignment and Closure (BRAC) that occurred during that time period. However, since 2001, presumably after the attacks of 9/11 when U.S. entered the current Global War on Terrorism, the new mission requirements could be increasing the energy demand despite the overall smaller footprint of facilities in the USAF. Additionally, as new weapon systems come on-line, such as the F-22 and C-17 aircraft programs, new supporting facilities at Air Force bases are required.

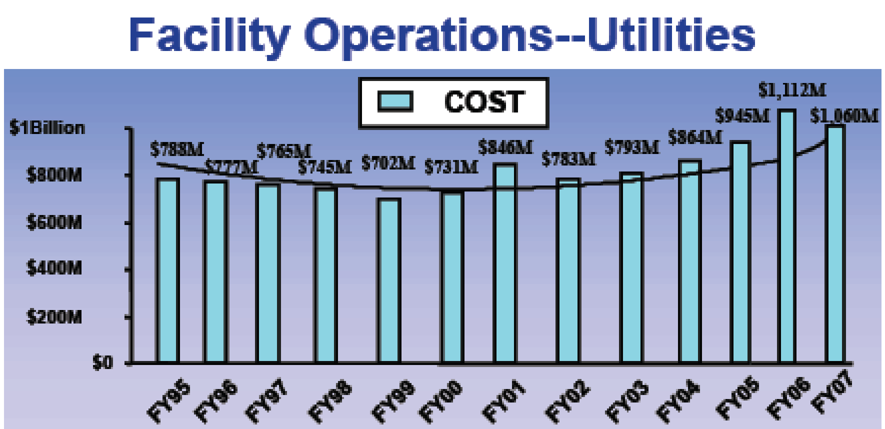


Figure 3. Air Force facility operations cost from DUERS[13], current as of 25 Mar 08 (Rocchetti, 2008).

Our research focuses on daylighting technologies that leverage load avoidance strategy, which could reduce the overall facility utility cost and meet the net zero facility requirement. Four daylighting options for facility retrofit are considered for our study. As stated previously,

[13] An automated management information system with which the Department of Defense monitors its supplies and consumption of energy. It was originally fielded in February 1974 as the Defense Energy Information System (DEIS) to respond to the need to manage DoD energy resources more closely in the aftermath of the 1973 Arab oil embargo. It is primarily used as an energy management tool, providing information about the Department of Defense's inventory and consumption of utility energy. (Source: *DoD 5126.46-M-2, November 1993*)

we contend that the greatest savings potential could be realized through effective facility retrofits and daylighting technologies could be one of the most economical strategies. The discussion on facility retrofits using windows, the primary medium for daylighting, and its impact on energy conservation is discussed next.

Optimizing Facility Retrofits for Energy Conservation

According to Elder (2000) greater energy savings could be achieved through a more effective window technology for older facilities due to the fact that windows are the primary source of energy loss for buildings over 15 years, see figure 4. The USAF facility inventory consists of 120,000 facilities (non-residential) that are on average over 30 years old and of those approximately 83,000 facilities (non-residential) are over 15 years old (USAF/A7CAI, 2008). Considering that a typical existing USAF facility has a life of 67 years, there could be significant time remaining for considerable energy savings cost. Additionally, new construction should have more of the energy efficiency features already installed in order to meet the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Green Building Rating System[14] that is now required for new USAF facilities. Therefore, the opportunities for energy savings are greater for older facilities.

[14] LEED is a third-party certification program and the nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED for New Construction and Major Renovations is designed to guide and distinguish high-performance commercial and institutional projects (Source: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=222).

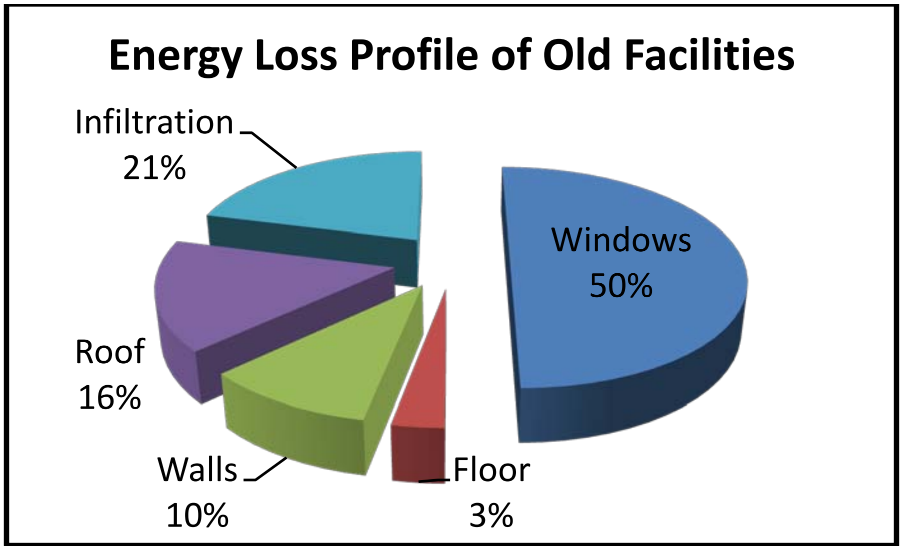


Figure 4. Building Envelope Energy Losses for Facilities 15 Years or Older (Elder, 2000)

We investigate which daylighting technology associated with windows will produce the best energy savings. The different types of daylighting technology in our study are: advanced daylighting control systems, electrochromic windows, and skylights. Brief descriptions of these technologies are explained in the next section.

Advanced/Integrated Daylighting Control Systems

Advanced/integrated daylighting control (ADC) systems work in conjunction with different fenestration such as windows and skylights to moderate the interior light intensity. ADCs can be part-time occupancy sensors or photo sensors that allow individuals to set preferred light levels or adjust automatically based on predetermined setting (Sachs, et al., 2004). ADCs are often installed with dimming ballast for interior light fixtures and are tied in together as a system. ADCs have been used in office workstations, private offices, conference rooms, classrooms, and hospitals (Sachs, et al., 2004). When used with windows for perimeter space, ADCs are most effective 15 feet from exterior windows. They are also available for use with skylights for top floor spaces.

Skylights

Skylights are "windows" placed on the horizontal or sloped portion of a roof. Skylights allow more abundant amounts of light into a space than vertical glazing, but unless carefully designed, are often net-energy losers. A rule of thumb is that the more light allowed in, the more heat gain; and the more surface area, the more heat loss. In most instances, a smaller skylight within a splayed opening will accomplish the same lighting effect as a larger unit in a straight opening, but with reduced heat gain and loss. Figure 4 shows some common designs.

(a)

(b)

Figure 5. Examples of different skylights (www.veluxusa.com)

Skylights are available in glass (flat, tempered, laminated, reinforced) or plastic (acrylic, polycarbonate, fiberglass). Plastics offer the ability to be molded into many shapes, while glass offers a greater variety of performance characteristics (Deal, et al., 1998). Each glazing material is available in single- or multiple-paned units, and all standard frame types are available. Both ADC and Skylights have been available daylighting technology (Deal, et al., 1998). New to the commercial market since 2006, a daylighting technology that is showing considerable potential is electrochromic windows, which is discussed next.

Electrochromic Windows

Electrochromic (EC) technology has been actively researched throughout the world for over thirty years, and examples of EC window prototypes have been demonstrated in a number of buildings in Japan and more recently in Europe and the United States (Carmody, et al., 2004). Lee, et al. (2000) found that EC windows promises to be the next major advance in energy-efficient window technology, helping to transform windows and skylights from an energy liability to an energy source for the nation's building stock. And Pacific Gas & Electric identified daylighting as the single largest new opportunity for saving energy in commercial lighting today (Koti, et al., 2006). And Klems (2001) stated in his research that technology generally considered to have the greatest architectural potential is EC glazing. A typical EC window cross-section and functionality is shown in figure 6. Basically, EC windows are capable of automatically altering their state to a shaded mode based on available light. This reduces the heat gain generally experienced during the peak demand times throughout the day. They are also manually controllable to shade to the building occupant's desire; for example, allowing heat from sunlight in during cold winter months.

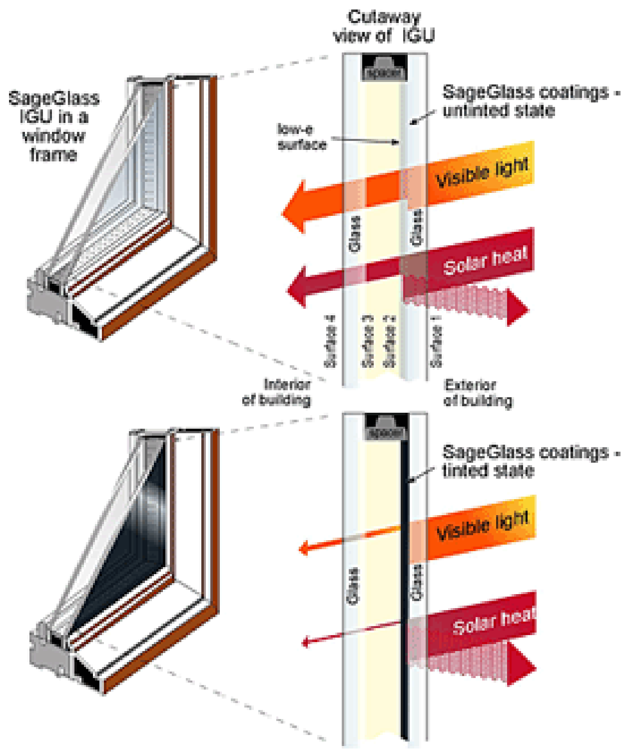


Figure 6. Typical Double-pane Sage® Electrochromic window (Sage Electrochromic, 2006a)

Since 2006, commercially available EC window units have been available in the U.S. by Sage Electrochromics, Inc., which is the only certified manufacturer in the U.S. (Sage Electrochromics, 2006b). A detailed description of how an EC window works is described in Appendix B, and a more detailed discussion on potential of how these technologies have been effectively used for daylighting is discussed next.

Windows and Daylighting

The building envelope includes different components such as windows, doors, building material (such as concrete, wood, or metal), and insulation (Deal, et al., 1998). However, the focus of our research will be window technology systems because of their role as the primary medium for daylighting.

The use of daylighting through windows and skylights is not a new concept in building design. Several skylight research (Arasteh, et al. (1984); Lee, et. al (1998); Dubois (1998); Tsangrassoulis, et.al. (1999); Klems (2001); Garcia-Hansen, et al. (Plympton, et al., 2000) (2002); Fedrizzi and Rogers (2002); Voss (2000)) has shown potential for skylights as effective daylighting strategy. And the overall performance of glass elements in a building can be further enhanced when they are designed to be part of a complete façade system (Lee, et al., 2002); therfore, combining different window technology could be beneficial. The benefits of daylighting as well as its limitations have been documented but with innovations in glazing technology and new building façade design and fenestration strategy, building efficiency has been achievable, see figure 7.

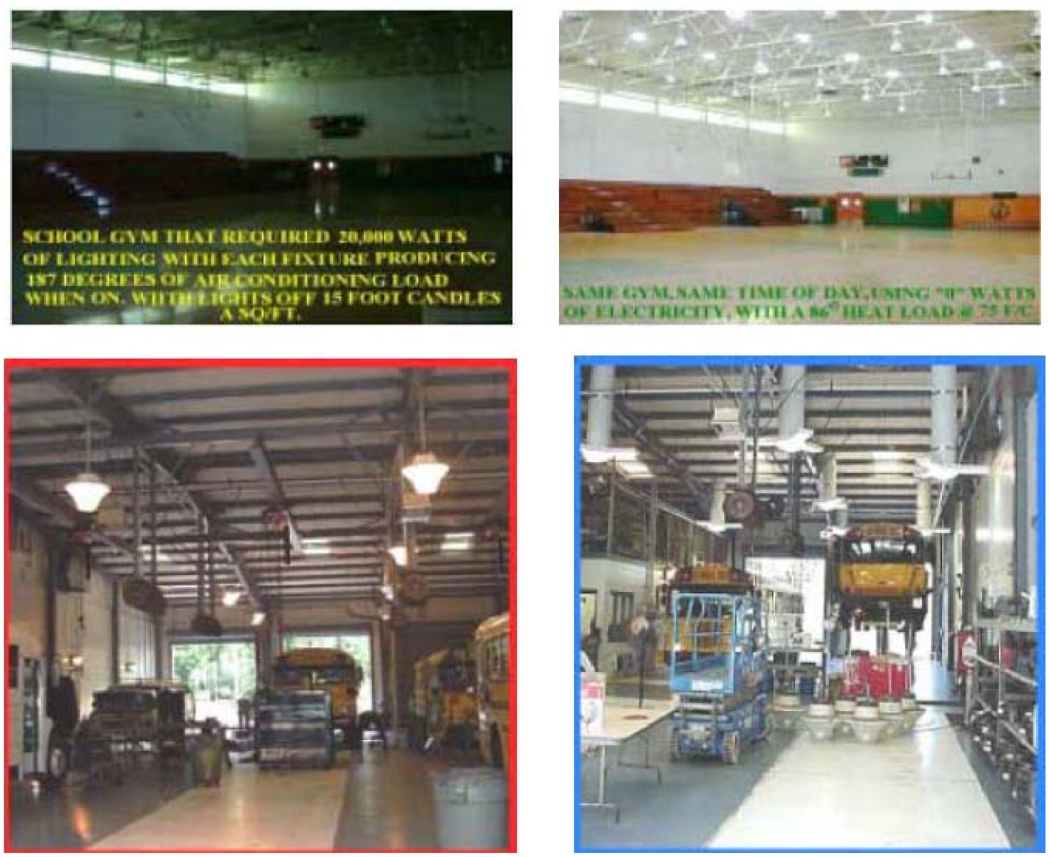


Figure 7. Examples of Effective Daylighting Implementation in a Floria Study (Othmer, 2002).

One of the main arguments used to justify using daylighting technology, especially the new EC windows, is their proven ability to reduce electricity consumption and electricity peak demand load. Lowering the demand for electricity is considered by far the greatest benefit considering that the largest energy consumption in Air Force facility is electricity, shown in figure 8.

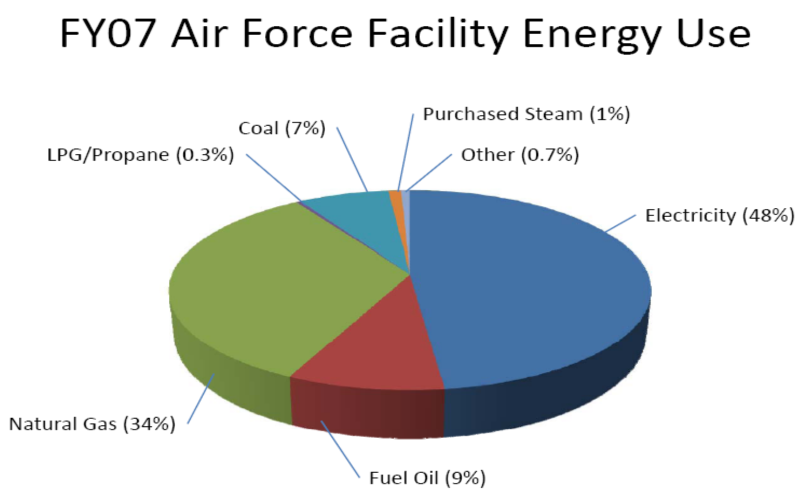


Figure 8. USAF facility energy use by energy type (AFCESA, 2008).

Therefore, daylighting could have significant benefit for USAF facilities that consume 50% of their energy through electricity which equates to approximately $700,000 annually (Pratt, 2006). Stiles, McCluney, and Kinney (1998) found that lighting accounts for 40-50% of commercial energy consumption and McHugh, Burns, and Hittle (1998) stated that electric lighting and its associated cooling requirement consumed on average 30-50% of the energy used in a commercial building, which equates to approximately $15-23 billon annually. A detailed discussion of how the different electricity cost, i.e. consumption cost versus peak demand cost, is described in Appendix C. However, once all energy costs and savings are calculated, an economic analysis must be performed to determine the true cost of an engineering option.

Ultimately, it is the economic viability that will determine whether a project is approved or not. The federal energy program requires a life-cycle cost analysis as part of the decision making, which is discussed in the next section.

Life-Cycle Cost Analysis for Federal Energy Projects

The primary purpose of life-cycle cost analysis (LCCA) is to help make decisions. The life-cycle cost analysis methods and procedures, as set forth in federal statute (10 CFR 436, 2004) are to be followed by all federal agencies. These standards and procedures are outlined in the National Institute of Standards and Technology (NIST[15]) Handbook 135: Life-Cycle Costing Manual for the Federal Energy Management Program (Fuller, et al., 1996); which has been adopted by the DOD (ODUSD, 2005). For energy projects, the DOD components are encouraged to consider life cycle cost of aggregating energy efficiency projects with renewable energy projects where active solar technologies are appropriate. This could be accomplished by, for example, combining the use of photovoltaic cells to generate low cost electricity with daylighting which would reduce the demand for the electricity. A LCCA could help provide decision makers with the economic comparison among the different possible options and perhaps determine which funding method should be pursued.

To be competitive for funding, a project must typically have a payback of 10 years or less and have a Savings-to-Investment Ratio (SIR) of 1.25 or greater (ODUSD, 2005). Meeting these criteria does not ensure funding; however, because these programs have historically had many more requests than funds available these measures establish a baseline and projects are typically ranked by SIRs and funded until funding is exhausted (ODUSD, 2005).

[15] Agency of the U.S. Commerce Department's Technology Administration. Conducts basic and applied research in the physical sciences and engineering, and develops measurement techniques, test methods, standards, and related services (Fuller, et al., 1996).

In order to perform the necessary LCCA to determine the SIR and payback for the decision makers, FEMP requires NIST's Building Life Cycle Cost (BLCC[16]) 5 program (Fuller, et al., 1996). BLCC 5 is a deterministic life-cycle cost tool that performs all the necessary calculation based on the cost input. Most of the life-cycle cost calculations are internal and invisible to the user, but it follows the methodology outlined in NIST Handbook 135; which is discussed in the next section.

Life-Cycle Cost Analysis Fundamentals

Life-cycle cost is the total cost of owning, operating, and maintaining a system over its useful life, where costs are adjusted to their present value based on time of occurrence and time value of money, or discount rate (ODUSD, 2005). Life-cycle cost analysis (LCCA) refers to the process of calculating life cycle cost or other supplemental decision statistics based on the life cycle cost method. Given several mutually exclusive alternatives for accomplishing the same objective and assuming that all non-quantifiable costs and benefits are equivalent, the alternative with the lowest life-cycle cost over a study period is the best choice (ODUSD, 2005). Figure 9 illustrates a conceptual diagram of a tradeoff of higher investment cost to achieve lower total life-cycle cost, which is characteristic of most energy conservation projects.

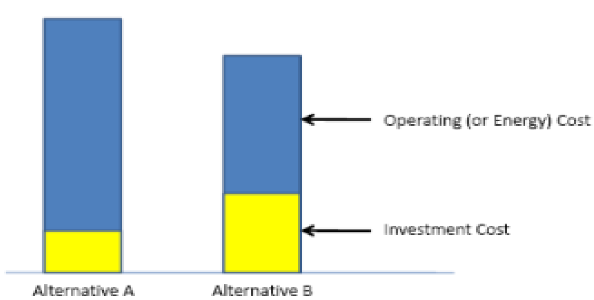


Figure 9. Life Cycle Cost Analysis Trade-off Example (ODUSD, 2005).

[16] Provides comprehensive economic analysis of proposed building capital investments. BLCC is especially useful for evaluating energy and water conservation projects in buildings. Up to 99 alternative designs can be evaluated (Paradis, 2007)

Equation 1 shows how to calculate life-cycle cost for a project (Fuller, et al., 1996). It is essentially the sum of the costs minus the residual cost at the end of the project life. However, our study uses only the investment cost and energy costs. The other costs are either negligible or not applicable. A full explanation of LCCA is available in Appendix D.

A basic LCC equation is as follows (Fuller, 2008):

$$LCC = I + Repl - Res + E + W + OM\&R + O \qquad \text{(eq. 1)}$$

Where,

LCC = Total LCC in present-value (PV) dollars of a given alternative
I = PV investment costs (if incurred at base date, they need not be discounted)
Repl = PV capital replacement costs
Res = PV residual value (resale value, salvage value) less disposal costs
E = PV of energy costs
W = PV of water costs
OM&R = PV of non-fuel operating, maintenance and repair costs
O = PV of other costs (e.g., contract costs for ESPCs or UESCs)

There are typically three potential alternatives considered to conduct the LCCA for a USAF energy project: (1) status quo, (2) retrofit, and (3) new construction (AFMAN 32-1089, 1996). Our study will only consider the status quo and retrofit alternatives. The status quo is the continued use and operation of existing facilities in their current condition (AFMAN 32-1089, 1996). The status quo alternative is considered the baseline and is used to compare the relative energy savings of the proposed alternatives. The retrofit alternative involves renovating the existing facility to eliminate and/or reduce future energy costs by reducing fuel consumption or converting to a more efficient fuel. Various levels of improvements can be addressed as alternatives, including minimal correction of deficiencies to a comprehensive “gut and rebuild” effort. Once the cost of the energy savings and retrofit is determined, economic factor for determining viability are calculated. Within DOD, these are savings to investment ratio and payback; which are discussed in the next section.

Economic Factors for Decision Making

Typically, the alternative with the lowest life-cycle cost over the study period is the appropriate choice for new construction projects (ODUSD, 2005). However, there are two primary metrics that are used to determine the quality of a proposed project: payback period and savings-to-investment ratio.

Savings-to-Investment Ratio (SIR) is a measure of economic performance for a project alternative that expresses the relationship between the present values of the savings over the study period to the present value of the investment costs (ODUSD, 2005). It is a type of benefit-to-cost ratio where the benefits are primarily savings, typical of energy projects. SIR is a relative measure of performance, meaning it can only be computed with respect to a designated base case. The DOD Energy Manager's Handbook states that SIR is the most useful metric to rank independent projects (ODUSD, 2005). When faced with a large number of energy/cost saving projects, each of which meet DOD criteria for energy projects but where funding limits the number of projects that can be implemented, SIR should be used to rank the projects for funding (ODUSD, 2005). Higher SIRs should be funded first, except in special circumstances that are discussed fully in NIST Handbook 135; and under DOD funding programs, SIR is typically required to be 1.25 or higher (ODUSD, 2005); next we discuss payback.

The economic difference between two alternatives is expressed in terms of payback, or how long it takes to recover the additional investment cost (ODUSD, 2005). The investment cost is the first cost of the proposed retrofit, and assuming uniform annual cash flows, the annual savings is the difference between the O&M costs before and after the retrofit. Simple payback

(SPB) relates how long it takes to recover an initial investment in a cost-saving measure, assuming the annual savings remain constant and that the time value of money is unimportant. To calculate simple payback, divide the initial investment by the annual savings (ODUSD, 2005). For example, a $1,000 investment that will save $200 per year has a simple payback of $1,000/$200 or 5.0 years.

From an academic standpoint, SPB suffers from two key flaws. First, it assumes that $200 received 1 year from today is equivalent to $200 received 5 years from today. Most organizations assign a higher value to dollars received sooner that those received later, based on their opportunity costs or their discount rate (ODUSD, 2005). The second flaw is that simple payback does not consider the effects of different lives (in length) of alternatives being considered. For example, investments A and B each cost $1,000 and save $200 per year; therefore both have a simple payback of 5.0 years, making them seem equally acceptable. However, if investment A has a useful life of 5 years and investment B has a useful life of 10 years, investment B is obviously a better choice (ODUSD, 2005).

Discounted Payback (DPB) is similar to SPB in that it expresses results in time to recover investment costs. However, savings are discounted to their present value based on the discount rate, making DPB consistent with LCC methods (ODUSD, 2005). At lower discount rates, SPB and DPB values are closer together but as the discount rate increases, the DPB becomes longer because of the reduced value of future cash flows, while the SPB does not change because it is not based on the life-cycle cost method (ODUSD, 2005). Furthermore, the DOD Energy Manager's Handbook (ODUSD, 2005) states that for energy and water projects should use DPB. However, this is ambiguous guidance because some DOD forms (such as the ECIP 1391 report) refer to SPB as the required metric.

Furthermore, our discussions with USAF energy managers at all levels confirm that SPB is the standard used in USAF LCCA and BLCC 5 output also has SPB as one of the economic metric. The DOD Energy Manager's Handbook is the only codified clarification within any DOD guidance regarding of the use of DPB rather than SPB for LCCA.

While simple payback is more useful to determine the type of funding it will pursue, private or public, it is generally accepted that SIR is the superior economic metric (ODUSD, 2005). However, both SIR and payback must also consider risk and uncertainty associated with energy projects. Risk and uncertainties are generally more prevalent when historical and other data is either not available or limited. This has application for emerging renewable technology where there is limited performance data but energy savings must be predicted. Due to the importance of analyzing risk and uncertainty; it is discussed in the next section.

Risk and Uncertainty Overview

The federal publication in our literature review requires that risk and uncertainty be analyzed as part of any project's economic viability. NIST publication on uncertainty and risk (Marshall, 1988) lists variety of different possible analysis available such as breakeven analysis, sensitivity analysis, or simulation, for example. Life-cycle cost analysis deals with costs and benefits occurring in the future and the future is unpredictable; therefore, assumptions and sensitivity analyses are prepared to account for uncertainties (AFMAN 32-1089, 1996). Furthermore, AFMAN 65-506 (2004) and AFMAN 32-1089 (1996) requires that at minimum a sensitivity analysis be conducted.

The FEMP also recommends sensitivity analysis as the technique of choice for energy and water conservation projects (Fuller, et al., 1996). FEMP recommends sensitivity analysis due to its usefulness for identifying which of a number of uncertain input values has the greatest impact on a specific measure of economic evaluation. Therefore, sensitivity analysis has the capability to help determine how variability in the input value affects the range of a measure of economic evaluation, and test different scenarios to answer "what if" questions (Fuller, 2008). However, all sensitivity analyses are not the same.

Historically, breakeven (also called best case-worst case) and sensitivity analysis have been widely accepted because of their relative ease of use and effectiveness (Ragsdale, 2007). This is especially the case when many of the required calculations were completed by hand and with minimal computing power or knowledge (Ragsdale, 2007). However, a more powerful approach to traditional risk and uncertainty analysis is becoming more prominent with increased computing power – simulation (Ragsdale, 2007). Simulation can randomly generate sample values for each uncertain input variable X (independent variable) that can be used for the calculation of Y (dependent variable) which can be repeated multiple times to provide a probabilistic output distribution (Ragsdale, 2007).

One of the major benefits of deterministic techniques, such as what-if analysis or breakeven analysis, is that they are easily done without requiring additional resources or information. They produce a single-point estimate of how uncertain input data affect the analysis outcome (Fuller, 2008). Probabilistic techniques, on the other hand, quantify risk exposure by deriving probabilities of achieving different values of economic worth from probability distributions for input values that are uncertain. This makes the probabilistic models more robust; however, they have greater informational and technical requirements than do deterministic techniques (Fuller, 2008). Our research demonstrates the robustness of probabilistic models as a potential alternative to the current deterministic models. A discussion on how Monte Carlo simulation works is presented in the next section.

Monte Carlo Simulation Method

Monte Carlo simulation (MCS) has been used extensively in many fields of study, including finance, physics, environmental risk, and energy systems research (Liberman, 2003). MCS methods rely on introducing uncertainty into the models because no uncertainty exists in them (Emblemsvag, 2003). By modeling the uncertainty as it actually is based on historic or experimental data, MCS methods can be used to assess the impact of uncertainty. Then, by conducting a statistical sensitivity analysis on a MCS run, one can identify which input variables are most important with respect to managing the uncertainty (Emblemsvag, 2003). So, by introducing uncertainty in the model, such as ± 10% bounded and symmetric uncertainty distributions, we can measure and rank the relative impact the various input variables have on the output variable (Emblemsvag, 2003). A detailed mathematical derivation of Monte Carlo method is available in Appendix E.

As stated previously, not all sensitivity analyses are equal. We contend that probabilistic sensitivity analysis used in MCS, for example, could be more robust compared to deterministic sensitivity analysis, which is discussed in the next section.

Monte Carlo Simulation Sensitivity Analysis

Uncertainty analyses using traditional methods are often used for deterministic models and like-wise are limited in their capability (Emblemsvag, 2003). Computerized what-if analyses such as tornado charts and spider charts attempt to implement traditional uncertainty analysis by leveraging technology. In tornado charts, the importance of the variable is demonstrated by the width of the bar whereas in spider charts the slope of the line is used to represent the same information (Emblemsvag, 2003). And since discrete analyses produce point estimates instead of distribution, the uncertainty analysis is equally limited (Emblemsvag, 2003). MCS provides a sensitivity chart with each output that provides an uncertainty related to the output probability distribution.

Unlike the spider and tornado charts, the MCS sensitivity chart is generated by measuring the statistical response of the forecast variable given the uncertainty in all the input variables. Emblemsvag (2003) states that because statistical approaches do not rely upon direct relationships between input variables and forecast variables, such as the basis of deterministic models, complex systems can only be effectively modeled using probabilistic models. He further contends that statistic models are the only ones capable of measuring relations between variables that are loosely coupled where setting up a system of equation would simply be unpractical or infeasible in complex systems.

Therefore, MCS not only manages uncertainty in a cause-and-effect relations but also weak relations between multiple variables incapable in deterministic sensitivity analysis such as tornado and spider charts that rely on systems of equations (Emblemsvag, 2003). Our research will demonstrate the robustness of our probabilistic analysis model and compare it with BLCC 5.

Summary

In this chapter we began discussing the federal mandates that have spurred energy conservation in the DOD: EPACT 2005, EO 13423, and EISA 2007. Daylighting is a potential strategy that could help meet the federal energy goals. However, there is limited research on relative performance of different daylighting technologies; especially existing and emerging technologies that would be best for retrofit situations.

Daylighting has its limitations due to dynamic variables such as human behavior. For example, Inkarojirit (2005) and Rubins et al. (1978) found that building occupants do not use internal shading devices optimally. Inkarojirit (2005) found that 93% of the population draw their manual blinds once at the first instance of visual discomfort (rather than thermal comfort) caused by glare, and then leave it there for the rest of the day (Lee, et al., 2006); negating any potential daylighting savings through the windows. Emerging systems that can provide an alternate method of shading to reduce glare, thereby reducing human interaction, see figure 10, could significantly improve energy savings through daylighting; which will be investigated in our study.

Figure 10. Commercially available EC glazing demonstrating ability to reduce glare (Sage Electrochromic, 2006a).

One of the primary strategies for the USAF to meet the net zero facility requirement is to install skylights with automatic lighting controls (Personal Communication with USAF Energy Manger, 2008). In certain situations skylights provide good natural light to perform tasks where such light is needed to accomplish a task effectively. However, skylights have limited energy savings based on climate and facility type. For example, Kinney (2004) found that skylights are net thermal losers in the winter and account for substantial solar gains in the summer. It is our contention that in lieu of using skylights as the primary daylighting strategy for the USAF, use of other window technology can yield better energy savings for administrative-type facilities using daylighting.

Finally, the current federal guidelines mandate the use of life-cycle cost tool BLCC 5. However, this and others that are available through various federal agencies rely on deterministic analysis. We argue that because energy projects often introduce new technology which could have higher levels of uncertainty and risk associated with them; deterministic analysis may be inadequate in accounting for uncertainty and risk. Our research will investigate if probabilistic model is a more robust tool providing information otherwise unavailable using BLCC 5. Furthermore, our study will determine if SIR and SPB are sufficient for making economic decisions or if additional economic data are needed for better insight, such as discounted payback. The methodology for our proposed research will be explained in the next chapter.

III. Methodology

Chapter Overview

This chapter describes the methodology to determine the relative cost savings and effectiveness of different daylighting strategy for a standard United States Air Force (USAF) office facility. Our methodology is divided into three primary parts. In Part I, we discuss the energy consumption analysis using DOE-2 building energy simulation software. In Part II, we use life-cycle cost analysis to determine which daylighting strategy is most economically viable within our construct. In Part III, we discuss the potential policy implication of daylighting technology that demonstrate energy savings but are not economically viable in the current market. By simulating a policy intervention, we will demonstrate the potential for emerging technology that may be viable. Part II and III will also demonstrate the robustness of our probabilistic model during the analysis.

Part I: Energy Conservation

The first part uses building energy performance simulation software called eQUEST to calculate the energy consumption and the quantity of energy saved by incorporating the different daylighting strategies through a parametric analysis. The energy consumption savings will be used to determine the associated energy cost savings in Part II.

Step 1: Define Prototypical USAF Office Building

Our research focuses on USAF office buildings. The overall design specifications for the prototypical USAF office building was developed by Air Force Civil Engineer Support Agency

(AFCESA[17]) (Pratt, 2006). However, where there was insufficient information on specific building layout needed for accurate simulation such as number of private offices or special functional space, facility information from the Air Combat Command (ACC) Facility Design Guide for Squadron Operations and Aircraft Maintenance Unit[18] was used. The AFCESA historical construction cost book was also used to obtain the average size of squadron operations and maintenance buildings. Based on information from the AFCESA historic cost book (2007), the average square foot of the prototypical building was changed to 36,000 square foot from the original 25,000 square foot used in the Pratt (2006) study. A conceptual layout of interior space of the squadron operations facility from the ACC design guide is shown in figure 11.

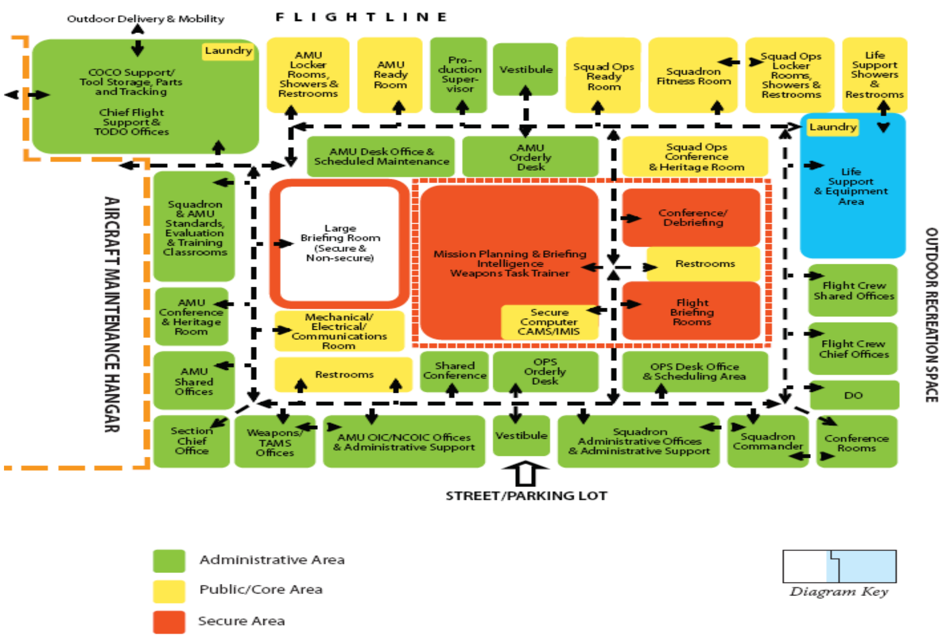


Figure 11. Sample Space Relationship Diagram for Squadron Operations Facility (Source: ACC Squadron Operations and Aircraft Maintenance Unit Design Guide)

[17] The Air Force Civil Engineer Support Agency, headquartered at Tyndall Air Force Base, Fla., provides the best tools, practices and professional support to maximize Air Force civil engineer capabilities in base and contingency operations. AFCESA is a field-operating agency of the Office of the Civil Engineer of the Air Force, Washington, D.C. (Source: http://www.afcesa.af.mil/) AFCESA is the focal point for the day-to-day energy and water conservation concerns and has the authority to communicate directly with the staffs of OSD and SAF on matters pertaining to facility energy and water conservation, as well as, solicit information to answer congressional and other inquiries. AFCESA will centrally track and provide the guidance to the bases and commands, develop guidelines, provide the legislative requirements and include the data from the awarded ESPCs in the annual energy report (ODUSD, 2005).

[18] http://www.wbdg.org/ccb/AF/AFDG/squadronoperations.pdf

Other researchers (Huang and Franconi (1999); Apte, et al (2008); Lee, et al. (2004)) have used similar methodology in their research. They used Commercial Buildings Energy Consumption Survey (CBECS[19]) data using a prototypical facility to represent a highly variable population for commercial facilities. Apte, et al (2008) adapted this methodology for a separate study of windows for commercial facilities. Both these studies used DOE-2 simulation for the prototypical buildings with weather data corresponding to the five CBECS climate zones (Apte, et al., 2008).

Lee, et al (2004) also used a prototypical building without using CBECS data for testing the effectiveness of EC windows. Lee, et al. (2004) study found that using CBECS data was inappropriate for emerging window technologies that have a unique blend of issues that complicates an assessment of potential impact. Primary energy use databases such as CBECS do not have sufficient detail that would enable one to map these various parameters to energy-savings potential with a relatively straightforward calculation (Lee, et al., 2004).

Furthermore, Apte, et al. (2008) found that energy impacts of windows, even at the building level, are difficult to quantify without extensive monitoring and instrumentation; therefore, computer energy simulations offer a far more practical approach (Apte, et al., 2008). Much like the commercial sector, the lack of facility specific energy data for USAF facilities make it difficult to provide validated conclusions for window performance of USAF facilities beyond simulation; therefore, our results are limited to the parameters within our research. Furthermore, our research expands previous DOD findings (Tri-Service Renewable Energy

[19] A national sample survey that collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures. It contains 5,430 records, representing commercial buildings from the 50 States and the District of Columbia. The survey is conducted quadrennially. (Source: http://www.eia.doe.gov/emeu/cbecs/contents.html)

Committee, 2003) which were limited to daylighting application for large "big-box" space such as warehouses and hangars.

ACFESA is the USAF focal point for facility engineering and energy management effort. AFCESA also hosts the Defense Utility Energy Reporting System (DUERS) program and monitors energy use progress against mandated goals, determine periodic reporting requirements, and manage calls for all energy projects and the Annual Energy Report to Congress (ODUSD, 2005). Therefore, AFCESA's expertise for USAF facility operations and energy management was used to develop the prototypical USAF office building. The detail specification of this facility is shown in Appendix F and a conceptual drawing is shown in figure 12.

Figure 12. Conceptual drawing of a typical USAF Squadron Operations Facility (Source: Air Mobility Command Facility Design Guide)

Step 2: Identify Input Factors

We used the building energy simulations software eQUEST, a proprietary freeware that operates on the DOE-2 simulation "engine" (Hirsch, 2004). There are three main categories of input data that were used for the simulation: (1) utility rate, (2) weather data, and (3) building construction detail. The utility rates were obtained from the AFCESA DUERS manager and are current as of August 2008. The USAF bases, Table 1, used for simulation have been selected based on climate region and varying utility rates. Table 1 also lists the respective utility rate and the climate zone identification.

Table 1. USAF Bases with Utility Rates and Climate Zones (AFCESA, 2008).

Air Force Base (AFB)	Electricity Rate	Natural Gas Rate	Peak Demand Rate (Winter/Summer)	Climate Zone
	$/kWh	$/MBtu	$/kW	(CBECS)
Ellsworth AFB	$0.022887	$6.26	$11.69/$13.43	1
Minot AFB	$0.04173	$6.59	$8.33/$8.33	1
Hilll AFB	$0.04062	$6.47	$7.42/$10.29	2
Offutt AFB	$0.02294	$8.54	$8.50/$8.50	2
Beale AFB	$0.06327	$10.63	$7.14/$7.14	3
Davis-Monthan AFB	$0.06725	$13.27	$10.163/$10.163	3
Wright-Patterson AFB	$0.04918	$11.86	$7.96/$7.96	3
Andrews AFB	$0.10087	$14.07	$9.13/$9.13	3
McGuire AFB	$0.11567	$11.18	$7.18/$8.26	3
Holloman AFB	$0.05505	$8.14	$10.18/$11.80	4
Pope AFB	$0.06798	$10.85	$7.23/$12.32	4
Barksdale AFB	$0.05334	$9.26	$11.39/$11.39	5
Eglin AFB	$0.07548	$14.72	$7.01/$7.01	5

Our research will simulate facilities that are located in representative climate zones defined by CBECS, shown in figure 13. The CBECS climate regions are chosen instead of the climate regions as defined by the USAF Passive Solar Handbook (Holtz, 1990) because CBECS was found to be a more widely used database for climate regions throughout different researches (Huang and Franconi (1999); Huang et al. (1999); Lee,et al. (2004); Lee, et al. (2006); Apte, et al. (2008)) from our literature review.

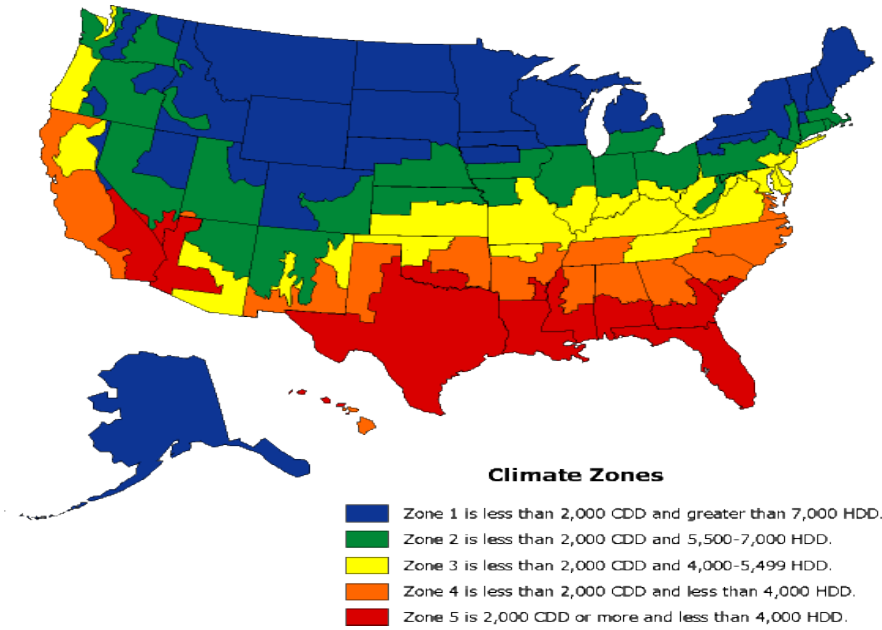


Figure 13. 2003 CBECS Climate Zone Map.[20]

The weather data used will be Typical Meteorological Year, version 3 (TMY3); which is developed by National Renewable Energy Laboratory (NREL) (Wilcox, et al., 2008). A typical meteorological year (TMY) data set provides designers and other users with a reasonably sized annual data set that holds hourly meteorological values that typify conditions at a specific location over a longer period of time, such as 30 years (Wilcox, et al., 2008). TMY data sets are widely used by building designers and others for modeling renewable energy conversion systems (Wilcox, et al., 2008). Although not designed to provide meteorological extremes, TMY data have natural diurnal and seasonal variations and represent a year of typical climatic conditions for a location (Wilcox, et al., 2008).

TMY3 was selected among the different weather data sources for our study based on previous research (Crawley, et al., 1997) which found that TMY data provided closer to the long-term average than the other available data sets. In building energy simulations where building

[20] (http://www.eia.doe.gov/emeu/cbecs/climate_zones.html)

performance was based on features such as daylighting, large window-to-wall ratios, or poor insulation, TMY weather data was most appropriate (Crawley, et al., 1997); therefore, the most appropriate for our research.

The prototypical USAF facility that will be modeled is a two story, 36,000 square foot office building and a conceptual 3-D schematic from eQUEST is shown in figure 14. This typical office building will represent the "base case" for our research from which the parametric analysis will be developed. In order to determine a relative performance of individual daylighting components such as EC windows, the other building components such as façade design and HVAC system remained constant. This isolated the energy performance of the individual daylighting components.

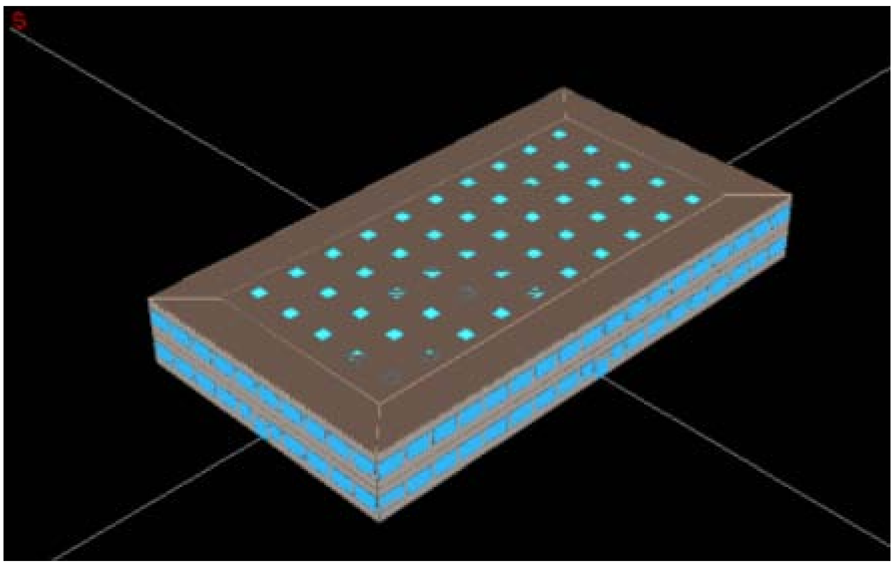


Figure 14. Sample 3-D Schematic of a Facility in eQUEST (Hirsch, 2004).

When specific construction cost data was required, we used construction cost information from the 2007 RS Means® Building Construction Cost Data Handbook. This cost handbook uses statistical average of construction material cost collected over 60 years and is considered one of the standard references for the construction industry (Fuller, et al., 1996) and in USAF Civil

Engineering projects. Once all the major input data are available, the building can be modeled and energy performance simulated.

Step 3: Simulate with eQUEST (DOE-2)

Building energy simulation plays a bigger role not only in building design, but also in the operation, diagnostics, commissioning and evaluation of buildings in the last two decades (Pan, et al., 2006). Building energy simulation can help the designers compare various design options and lead them to more optimal and energy saving designs. It can also help the managers and engineers define the energy saving potentials and evaluate the energy saving effects of energy conservation measures (ECMs) (Pan, et al., 2006). Crawley, et al. (2005) provides a good summary of some of the leading simulation programs available today. Our research used eQUEST as the simulation software for building energy performance. eQUEST is a whole building energy modeling software that is built on the DOE-2 "engine" or the computer algorithm upon which the software is built and operated.

DOE-2 is an up-to-date, unbiased, well-documented public-domain computer program or building energy analysis. DOE-2 predicts the hourly energy use and energy cost of a building given hourly weather information and a description of the building and its HVAC equipment and utility rate structure (Birdsall, et al., 1994). DOE-2 has been used by national labs, universities, and industry for hundreds of studies of products and strategies for energy efficiency and electric demand limiting (Lee, et al., 2002).

Additionally, the USAF Energy Program office within the Civil Engineering directorate (USAF/A7CAE) has recently certified and approved eQUEST use as official building energy simulation software for the USAF. While validation research of eQUEST is limited, a study conducted by Pan, et al. (2006) concluded that eQUEST simulation, when calibrated with real world data can produce very credible results. A graphical result comparing the eQUEST simulation to real world data from the Pan, et al. (2006) study is shown in figure 15.

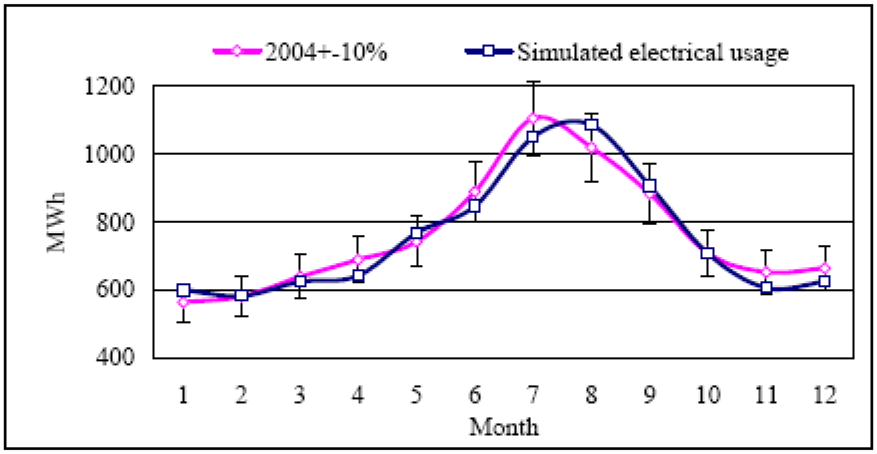


Figure 15. Comparison of Electrical usages from an eQUEST model vs. 2004 real building electricity use (±10%) (Pan, et al., 2006).

Finally, one of the main benefits of eQUEST is its ability to perform parametric analysis; which wasn't part of other comparable energy simulation freeware currently available. The methodology for parametric analysis for our research is discussed in the next section.

Step 4: Parametric Analysis

Parametric analysis isolates the specific benefit of an individual building component incrementally changing an alternative to the base case. For example, we calculate the energy consumption of our base case facility; then add skylights to the facility and then determine the new energy consumption with skylights added. The benefit of the parametric analysis approach (e.g., as opposed to evaluating each new measure independently on top of the base case) is that it accounts for interaction between measures. Interaction between measures results when the amount of impact (benefit or penalty) of any measure is affected by the presence or absence of another measure (McGee, et al., 2002). For example, the benefit of daylighting control will be greatest when evaluated assuming standard efficiency lighting and HVAC systems. However, the same daylighting measure evaluated assuming high efficiency lighting and HVAC systems will show significantly (e.g. up to 50%) less benefit since there would be less direct lighting load to mitigate and since the reduced heat gain would be removed from the building more efficiently (McGee, et al., 2002). Table 2 shows the details of the different building components that will be adjusted through the parametric analysis.

Table 2. Parametric Analysis Components and Justification.

Component	**Parameter**	**Justification**
Automated Daylighting Controls (ADC)	OFF (base case) or ON (ADC)	Determines the effect of installing only the automated daylight systems with existing windows. No other daylighting measures are installed.
EC Windows	Single Pane with non-insulated frame (base case) or Sage Classic™ Electrochromic Tempered (Table 3) equivalent with insulated frame	Using the built in glass library in eQUEST that has all the solar properties listed, the closest fit for the standard USAF class (base case) and the EC window (Sage Electrochromic) will be used in the analysis. For the Sage Electrochromic glass, we will use the Classic™ tempered glass shown in Appendix G. Using window properties that match currently available commercial product should provide the most realistic performance data. In the eQUEST window library, the Double Electrochromic glass 2845 is the closest equivalent: aluminum framed window with center of glass U= 0.28, SHGC for tinted = 0.12, and Tv (visible transmittance) for tinted = 10%.

Skylights	OFF (base case) or ON (skylights)	Determine effect of skylight at different climate regions. This should provide comparative performance of windows considering climate regions where: (a) skylights are used with standard USAF windows (b) EC windows with ADC are used without skylights, or (c) full daylighting system including EC windows and ADC are used with skylights.
Full Daylighting	OFF (base case) or ON (all daylighting components)	It activates all of the previous components and calculates energy consumption to determine the interaction between the different daylighting strategies.

The energy consumption output from eQUEST parametric analysis should determine the relative effectiveness of each daylighting strategy. It should be reiterated that due to the inability to compare with real world facility performance data, the findings cannot be generalized prediction of cost savings for all USAF office facilities but confined to a realistic relative performance within the bounds of our research. The details of the LCCA using Monte Carlo simulation method will be discussed in the next section.

Part II: LCCA using Monte Carlo Simulation

The methodology for LCCA that will be used for our research is from the NIST Handbook 135. An electronic copy of the handbook can be obtained from the NIST website[21]. The Monte Carlo LCCA in our research combines methodolgy used for LCCA by Liberman (2002) and Enblemsvag (2003). It excludes Liberman's (2002) Economic Input-Output Life Cycle Assessment (EIOLCA) model and Enblemsvag's (2003) Activity-Based LCCA; both of which focused on quantifying qualitative measures, which is beyond our research scope.

[21] http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf

Our methodology focuses on performing the traditional LCCA using the same inputs that would be required for BLCC 5, the current deterministic life-cycle cost tool. Using our model, we determined the economic viability of the different daylighting strategies.

Step 1: Identify Common Economic Parameters

Six common parameters will be identified for our study, which are: study period, base date, service date, discount rate, inflation, and operational assumptions. The study period for an LCCA is the time over which the costs and benefits related to a capital investment decision are of interest to the investor (Fuller, et al., 1996). The period used for our study is 20 years. This is an effective strategy considering that the average age for USAF facilities is about 30 years; however, the typical lifespan for these buildings is well over 60 years. If the functional life for a daylighting application is 20-30 years, then they could be retrofitted on buildings and still recoup enough savings before the end of the facility life.

The base date is the point in time to which all project-related costs are discounted in an LCCA (Fuller, et al., 1996). For our study, we use the constant dollar convention, which does not include inflation. NIST Handbook 135 states that sunk costs are not to be included in the analysis; for example, potential environmental remediation costs that are incurred due to renovation of old facilities will not be included in the LCCA. All calculations use the FEMP end-of-year convention for discounting.

The service date is the date on which the project is expected to be implemented; our study uses 2008 as the service date. This is once again a realistic assumption because installation of windows for a prototypical USAF facility should take less than one year because we have assumed that there is no environmental remediation or other mission related delays as part of the project. This may or may not be realistic for each specific situation for an operational USAF facility; however, based on discussions with USAF Civil Engineers, we contend that this is an accurate representation for the LCCA in our study. Figure 16 shows two examples of how base date, service date and study period are related.

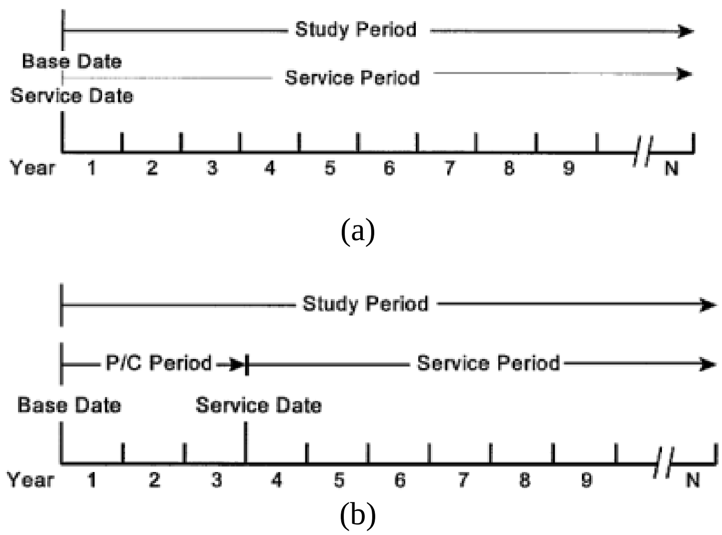


Figure 16. Comparison of the Relationship between Study Period, Base Date, and Service Date. (a) shows a case where all three time periods that are coincident (used for our study) but (b) is not (Note: the P/C stands for "planning and construction") (Fuller, et al., 1996).

The discount rate for federal energy projects is determined annually by the DOE (Fuller, et al., 1996). The rate ranges from 3% to 6% but currently this rate is 3%. As stated previously, we use the constant dollar convention discounted with real discount rate of 3%, which does not consider inflation. The NIST Handbook 135 has identified four main discounting factors: single present value (SPV) factor, uniform present value (UPV) factor, uniform present value factor modified for price escalation (UPV*), and FEMP UPV* factor for use with energy costs, the details of these factors are described in Appendix H. The FEMP UPV* factor is the DOE-projected real escalation rates by fuel type, rate type, and census region. It is a forecast factor based on a midrange scenario with regard to the performance of the domestic economy and world oil prices over 30 years and is updated annually and is used to calculate net present value of energy usage over the study period (Fuller, et al., 1996).

Finally, we did not include costs incurred due to mission change, facility function change, and unique facility upgrades, all of which could drastically alter the energy use profile as these are unique circumstances outside the scope of our research. Next, the cost data and related factors that will comprise the unique project input data will be identified and explained.

Step 2: Identify Cost Data and Related Factors

There are three primary cost drivers to be considered for the LCCA: initial investment capital cost, annual utility costs, and life-cycle energy cost. The initial investment costs consist of the cost of the daylighting technology and related installation and construction cost. The cost of the EC window units were obtained from the manufacturer, Sage Electrochromic, Inc. They were provided with the design specification for the prototypical USAF facility used in our research. The cost estimate of EC windows with daylighting control system and overriding wall switches was \$350,683 or \$57.98/ft^2 (full estimate is available in Appendix I). Where specific cost data weren't available, 2007 RS Means Construction Cost Data Handbook was used; an approved cost reference guide (Fuller, et al., 1996).

The projected energy consumption and cost must be estimated, which include electricity demand load where applicable (Fuller, et al., 1996). All consumption information was obtained from eQUEST simulation results. Local utility rate effective on the base date of the study was used, shown in Table 1. The electricity demand rate was obtained from the published tariff rate available from the respective utility company website; and each company website is referenced in Appendix J. The peak demand rates were for the industrial facility schedule per AFCESA Engineering Technical Letter (ETL) 08-5 (AFCESA/CENF, 2008).

There are no operations and maintenance costs that are used for any of the daylighting system. Even though there are real concerns by facility managers on use of skylights and the potential maintenance costs that could increase, when installed correctly they required negligible maintenance cost equivalent to windows and daylighting control systems. This assumption is supported by Pratt (2006) and manufacturer cost estimates. After identifying all input costs, Monte Carlo simulation is performed. For our model, the initial investment capital cost, utility cost, and life-cycle cost which is net present value of energy cost using the UPV* factor, is used to create the MCS model.

Step 3: Model the Uncertainty

Once the input variables have been identified, we must determine which variables are uncertain and model the uncertainty to be used by the Monte Carlo simulation. For our research we will use Crystal Ball by Oracle® which uses Microsoft® (MS) Excel platform. Crystal Ball provides a distribution gallery, which is in essence a random number generator (Ragsdale, 2007) for different types of discrete and continuous probability distribution, shown in Figure 17.

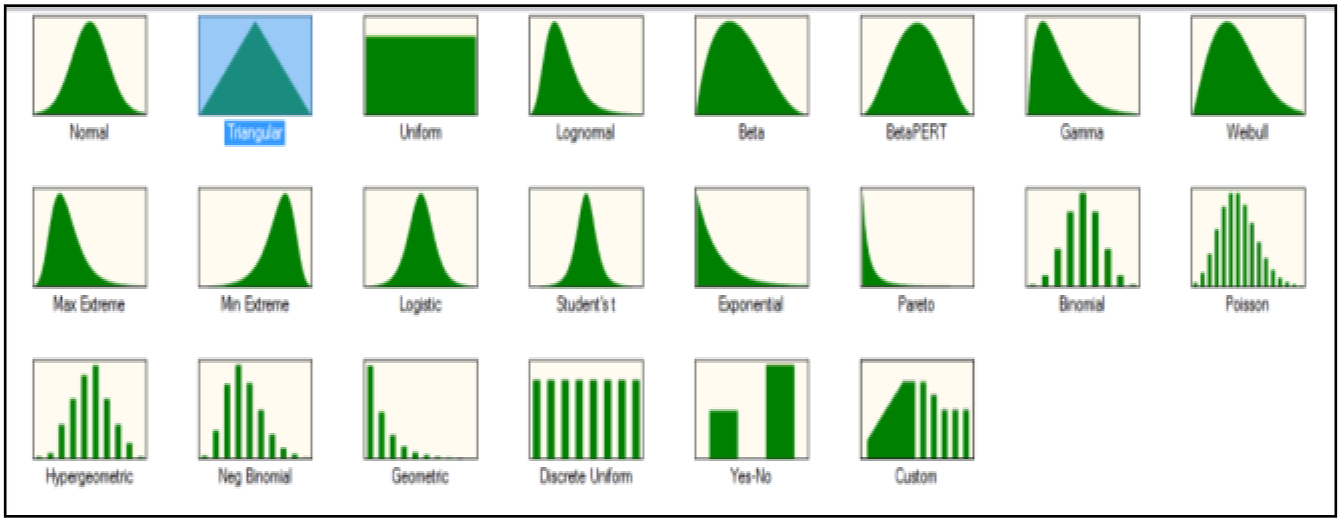
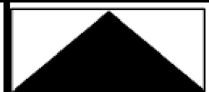
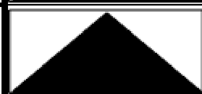
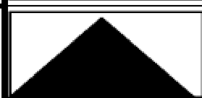
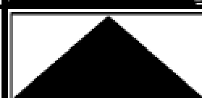
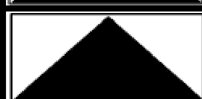
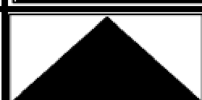
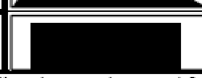


Figure 17. Crystal Ball distribution gallery for assumption distributions for probabilistic modeling (Oracle© Crystal Ball, Fusion Edition, 2008)

Typically, a normal distribution is used if (a) there is real word data that can be used to derive the distribution or (b) there is a reasonable justification that the behavior of the variable will be normal over time (Emblemsvag, 2003). The triangular distribution is used if a variable is suspected of normally distributed behavior but the uncertainty is quite large or if there is asymmetric behavior that is predicted and must be managed (Emblemsvag, 2003). The uniform distribution is preferred when there is no preference for an expected value (Emblemsvag, 2003).

Based on previous validation study (Sullivan, et al. (1998); Torcellini, et al. (2004); Hanson, et al. (2006)) of commercial building energy consumption, the uncertainty ranged from ±20%. This was based on comparison of simulated energy use with metered energy use. However, we were unable to determine if the behavior was normally distributed from the validation studies. Therefore, we used the triangular distribution with these range for our energy consumption. Cost data were obtained directly from the manufacturer or approved cost estimation publication such as RS Means Construction Cost Data book. We applied a lower bound of -10% and an upper bound of +30% based on standard USAF Civil Engineering construction project management practices (personal communication with subject matter expert at the Civil Engineering and Services School, 2009). The complete assumption distributions used for the inputs is shown in Table 3.

Table 3. Probability distribution assumption used for MCS LCCA model.

Parameter	Assumed Distribution		Reference
Electricity Cost[1]		Min = 0.8A Most Likely = A Max = 1.2A	Sullivan and Winkelmann (1998) Torcellini, et al. (2004) Hanson, et al. (2006)
Peak Demand Cost[1]		Min = 0.8B Most Likely = B Max = 1.2B	Sullivan and Winkelmann (1998) Torcellini, et al. (2004) Hanson, et al. (2006)
Natural Gas Cost[1]		Min = 0.8C Most Likely = C Max = 1.2C	Sullivan and Winkelmann (1998) Torcellini, et al. (2004) Hanson, et al. (2006)
Electricity NPV[2]		Min = 0.8D Most Likely = D Max = 1.2D	Sullivan and Winkelmann (1998) Torcellini, et al. (2004) Hanson, et al. (2006)
Peak Demand NPV[2]		Min = 0.9E Most Likely = E Max = 1.1E	Sullivan and Winkelmann (1998) Torcellini, et al. (2004) Hanson, et al. (2006)
Natural Gas NPV[2]		Min = 0.8F Most Likely = F Max = 1.2F	Sullivan and Winkelmann (1998) Torcellini, et al. (2004) Hanson, et al. (2006)
EC Window Cost[3]		Min = 0.8G Most Likely = G Max = 1.3G	Sage EC, Inc. (2008)
Skylight Cost[4]		Min = 0.9H Most Likely = H Max = 1.3H	RS Means Building Construction Cost Data (2007)
ADC Cost[5]		Min = 125 Max = 400	Sachs, et al. (2004)

1. Most Likely cost for all utility is obtained from eQUEST simulation (X), the max/min values are obtained from validated experiments found in literature listed under the Reference column (the average was found to be ± 20%).

2. Most likely cost for the Net Present Values (NPV) are calculated by multiplying the utility cost by Uniform Present Value (UPV*) Factor for the study period in a given region as published by April 2008 Supplement to the NIST Handbook 135

3. Most Likely cost for EC is obtained from manufacturer estimate, the min is typical construction project estimate for contingency, the max is set at 25%, which is the upper limit for project increase for MILCON projects as defined by AFI 32-1032.

4. Most likely cost for skylight is obtained from 2007 RS Means Construction Cost Data Handbook, min/max estimate is same as EC window cost distribution.

5. ADC cost is obtained from the 2004 ACEEE report.

After the uncertainty variables are identified with their respective distribution profiles, the forecast variables were identified. The forecast variables are the variables under study

(Emblemsvag, 2003). Our simulation used savings-to-investment ratio (SIR) and simple payback (SPB[22]) as the forecast variable consistent with the current economic metrics used for federal energy project. Our research also investigated if economic variables beyond SIR and SPB such as net savings and adjusted internal rate of return would provide increased insight for the life-cycle cost analysis. Furthermore, simple payback was compared with discounted payback to determine if it could make a notable difference in the decision making for project approval. The details of these economic metrics are explained fully in Appendix K.

Part III: Policy Intervention Potential

Based on research by the DOD (Tri-Service Renewable Energy Committee, 2003), there are limited economic incentives for daylighting technology. For example, according to the DOD research (Tri-Service Renewable Energy Committee, 2003), North Carolina and Oregon were the only two states that provided 23% tax incentive for daylighting technology. Table 4 shows an excerpt from the DOD renewable energy assessment study and a copy of the full table is available in Appendix L.

Table 4. Financial incentives for solar technology by state (Tri-Service Renewable Energy Committee, 2003).

State	Renewable Technology that Receives State Incentives	Percent of Present Worth – Effect of Federal and State Incentive on Project Cost			
		PV	SDHW	WALL	DAYLT
AL	PV	65%	45%	45%	0%
AZ	PV, SDHW	50%	49%	45%	0%
GA	PV	65%	45%	45%	0%
HI	PV, SDHW	65%	65%	65%	0%
IL	SDHW, WALL, PV	66%	55%	55%	0%

[22] As previously discussed, DOD Energy Manager's Handbook requires use of DPB rather than SPB; however, due to real world interviews within the civil engineering community, currently the SPB is used and thus we will also focus on SPB in lieu of DPB. However, we will discuss and advocate our recommendation for use of DPB in later chapter.

Step 1: Identify Policy Parameters

Daylighting technology that demonstrates a potential for energy savings from the eQUEST simulation but is not economically viable based on current market was used. We applied current economic incentives available for other passive solar technology; in effect, simulating an economic policy intervention. Specifically, we included an economic incentive equivalent to 66% of present worth of the initial investment cost for the selected daylighting technology. Table 4 shows that this was the tax credit available for projects in Illinois. A larger incentive for the daylighting technology could be needed to motivate manufacturers and construction agents to implement the technology; however, we have limited our simulation to what is currently available. Other non-economic policies may be included; however, we have limited our simulation to economic factors. A detailed policy discussion and recommendations, including non-economic policies, are presented in chapter 5

Step 2: Simulate and Interpret

Once the new parameters are included in the model, the Monte Carlo simulation will be repeated as described in Part II of this chapter.

Summary

This chapter outlined the methodology to (a) calculate the energy consumption of each daylighting strategy, (b) determine the cost savings and economic viability of each daylighting strategy, and (c) define and determine the impact of policy intervention for daylighting strategy that may not be currently viable. Part II and III of the methodology will also demonstrate the robustness of our probabilistic life cycle cost model. The results and interpretations of our research findings are discussed in chapter 4.

IV. Results and Analysis

Chapter Overview

This chapter presents the results from our research; which includes the energy performance results from eQUEST™ in Part I. The life-cycle cost anlaysis (LCCA) results using Monte Carlo simulation (MCS) model developed with Oracle© Crystal Ball in Part II. Finally, the policy intervention simulation results based on potential economic incentives in Part III. The analysis in Part II and III uses the Monte Carlo simulation model for the life-cycle cost and sensitivity analysis to demonstrate the robustness of probabilistic modeling. We also present a comparison of BLCC 5, a deterministic model, results with results from our Monte Carlo simulation. We used 19 USAF energy projects to further demonstrate the robustness of the probabilistic model when compared to the deterministic model.

Part I: Energy Consumption Comparison

Our research compares the relative energy performance of the most likely daylighting technology that can be retrofit into existing USAF office facilities. Specifically, these were (1) advanced daylighting control (ADC) systems, (2) skylights, and (3) double-pane electrochromic windows. These energy performances of these different technologies were compared independently as well as the energy performance of all these technologies combined in a full daylighting strategy.

eQUEST(DOE-2) Results

Our simulations found that electricity consumption savings was the greatest with full daylighting strategy, followed by EC windows, then ADC, and finally skylights. Despite the slightly better performance of the full daylighting system, we conclude that the bulk of the savings is a result of EC window performance. This ranking was consistent throughout all the climate zones (CZ) but the savings were generally higher for warmer climate zones. Our findings support that the energy consumption savings of EC windows is significantly higher than using skylight as a daylighting strategy. Figure 18 shows the relative electricity consumption reduction for each daylighting strategy across all the climate zones.

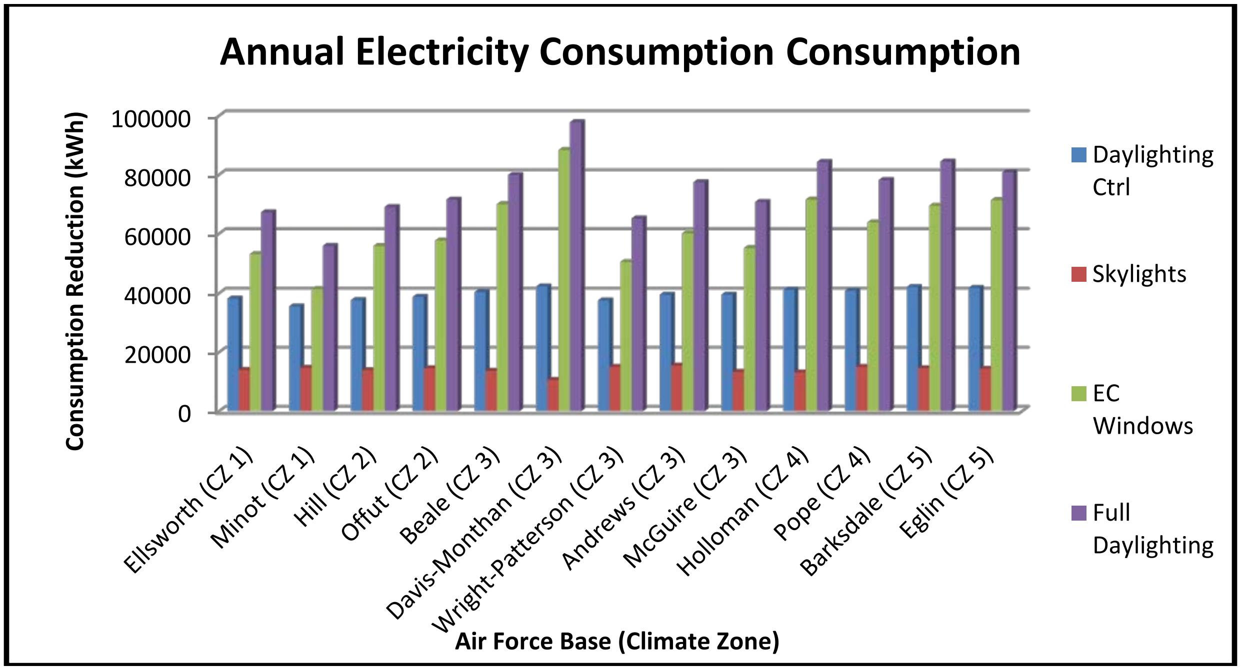


Figure 18. Reduction in annual electricity consumption for all daylighting strategy.

Figure 19 shows the relative peak demand load savings for each daylighting strategy across all the climate zones. The annual reduction in electricity peak demand load reflects the same ranking as the annual electricity consumption savings. Again, the trend is consistent for all climate zones where EC windows and full daylighting dominate the consumption reduction. There was not notable dependence on climate zones for electricity peak demand; but it was notable that the relative difference in consumption reduction for peak load demand was more apparent. This was expected based on our literature reviewed that found EC windows consistently provide significant electricity demand load reduction.

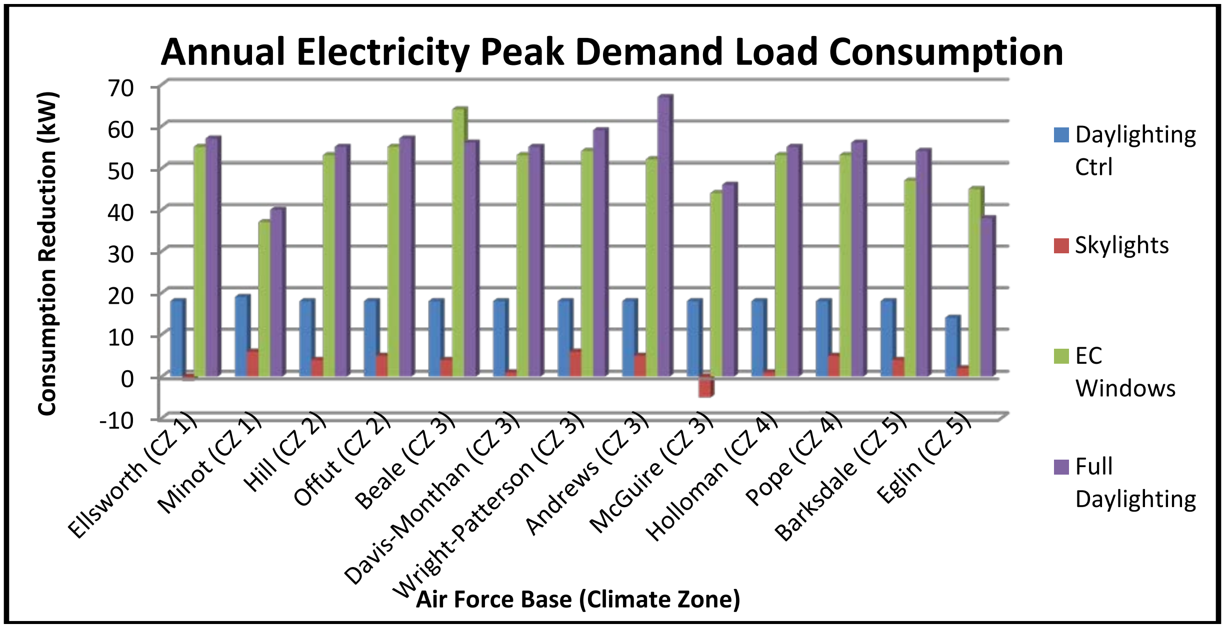


Figure 19. Reduction in annual electricity peak demand consumption for all daylighting strategy

Figure 20 shows the result for natural gas consumption reduction. It shows a different trend from the electricity consumption. It is even more evident here at EC windows have a consistent energy savings, even exceeding the full daylighting system in reduction in consumption. For example, the highest natural gas reductions occur in moderate to colder climates (CZ 1 – 3); however, the natural gas consumptions appear to be more varied. This could be due to other factors such as utility rate cost or the different climate characteristics of each specific location within similar climate zones.

Skylights are the source of greatest energy loss and they tend to lose more heat energy in the cold climates and requiring additional cooling energy to compensate for the heat gain in the warm climates. The eQUEST output for all the parametric runs is available in Appendix M and a summary table is available in Appendix N.

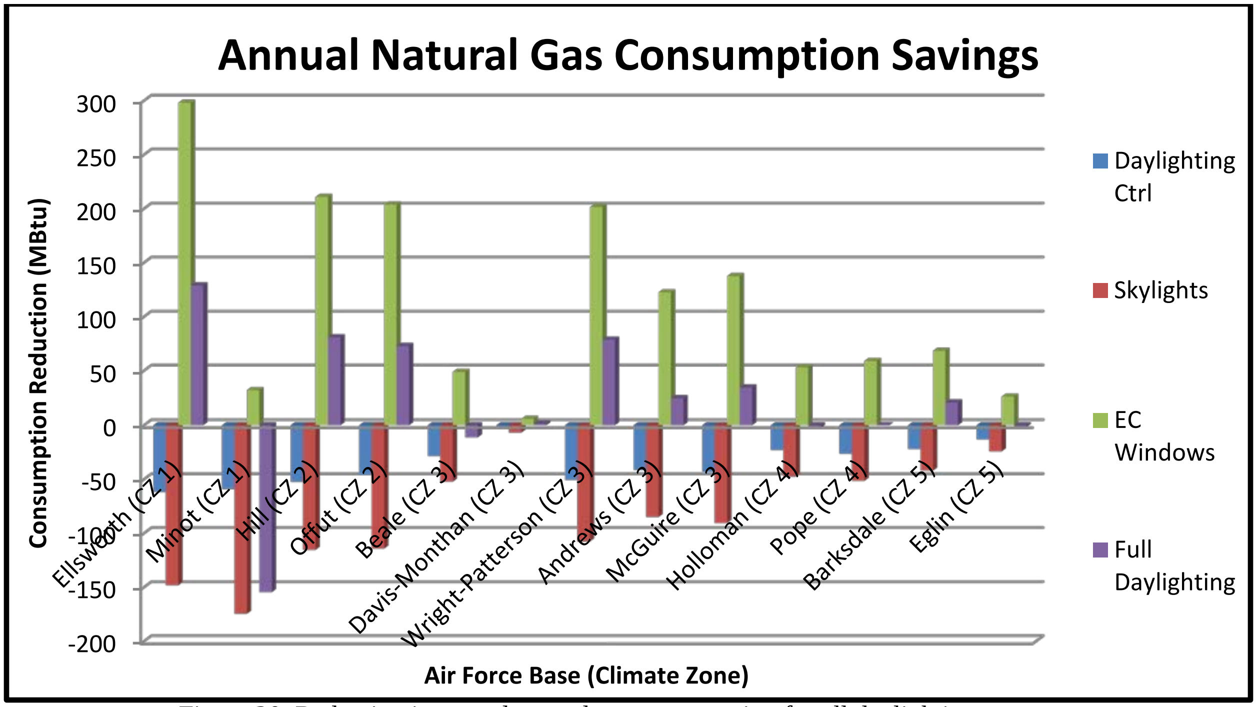


Figure 20. Reduction in annual natural gas consumption for all daylighting strategy.

Our simulation results indicate that EC windows have the greatest relative electricity savings for each climate zones especially favoring the warmer climates (CZ 4 – 5) over the colder climates (CZ 1 – 2). The reverse is true for natural gas with the colder and moderate climates showing more energy savings compared to the warm climates. Moderate climates in climate zone 3 showed a varied response. In extremely cold climates such Minot Air Force Base (AFB), the savings potential for EC windows is dramatically reduced.

Despite these reductions in energy reduction potential, a life-cycle cost analysis must be completed to determine if they are economically viable when you factor in other costs such as initial investment cost. The results from this analysis are presented next.

Part II: Life-Cycle Cost Analysis

Energy mangers in the USAF currently use a LCCA model published by the National Institute of Standards and Technology (NIST[23]) called Building Life Cycle Cost (BLCC[24]) 5. This tool provides economic output such as net annual savings, savings-to-investment ratio (SIR), and simple payback (SPB). These same metrics were used in our study to compare and contrast with additional findings from our research.

Economic Viability Results

The facility energy cost savings can be calculated once the utility rates for each location have been included. Figure 21 shows that utility rates could be playing a larger role in cost savings. For example, CZ 3 has wide variance in cost savings within the climate zone. Locations such as Andrews AFB and McGuire AFB have significantly more energy cost savings compared to Wright-Patterson AFB.

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[23] Agency of the U.S. Commerce Department's Technology Administration. Conducts basic and applied research in the physical sciences and engineering, and develops measurement techniques, test methods, standards, and related services (Fuller, et al., 1996).

[24] Provides comprehensive economic analysis of proposed building capital investments. BLCC is especially useful for evaluating energy and water conservation projects in buildings. Up to 99 alternative designs can be evaluated (Paradis, 2007)

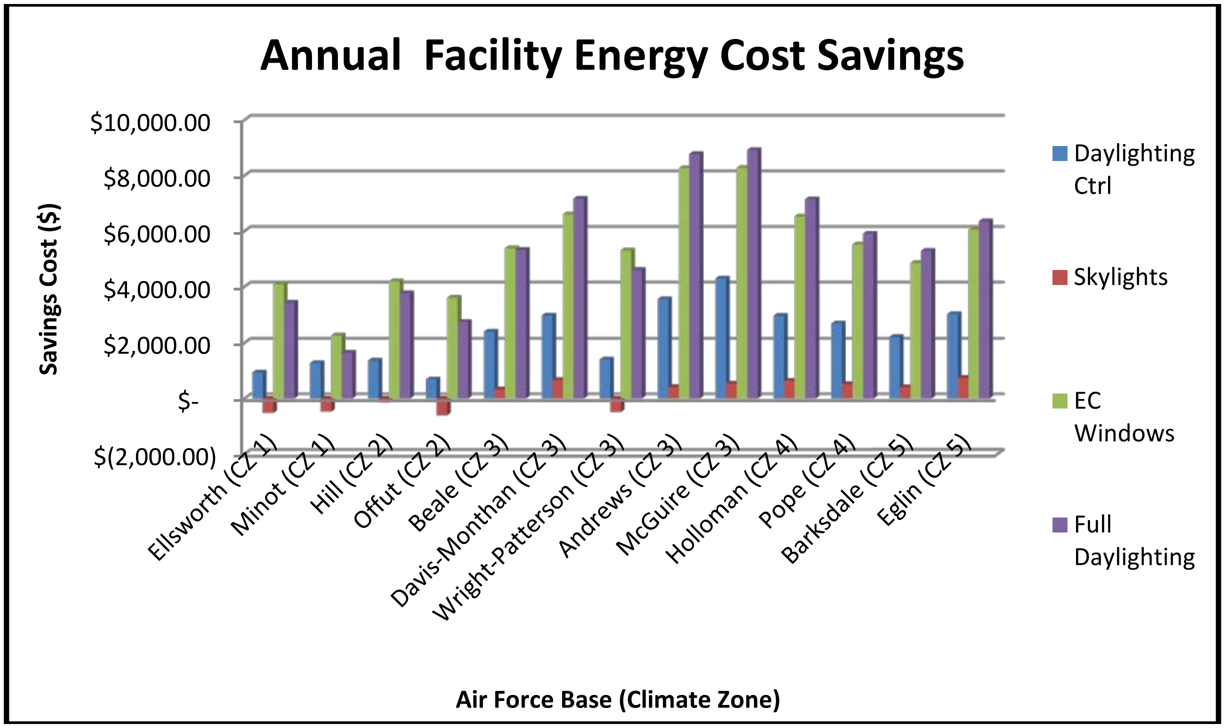

Figure 21. Energy savings cost comparison across all climate regions for all daylighting strategies.

Based on the pure cost savings presented thus far, EC window technology has the greatest promise for energy savings potential. Next, the initial investment cost of each technology was included; which would determine the economical viability of each daylighting technology. We used the savings-to-investment ratio (SIR) and payback. For SIR, a project was economically viable with a value of 1.25 or greater. For payback, the project was competitive for private funding if the simple payback was less than 10 years.

Our results show that the only economically viable daylighting strategy in the current market is the advanced daylighting control (ADC) system, shown in figure 22. This is due to the significantly lower investment cost of ADCs when compared to emerging technology such as EC windows. Skylights have competitive initial investment costs but the energy savings aren't as significant or in certain situations there were no energy savings. In general, ADCs outperform skylights in our facility model but saved less energy than EC windows; however, because the initial investment capital required for ADC are much less than EC windows, ADCs were the only technology economically viable based on our simulation.

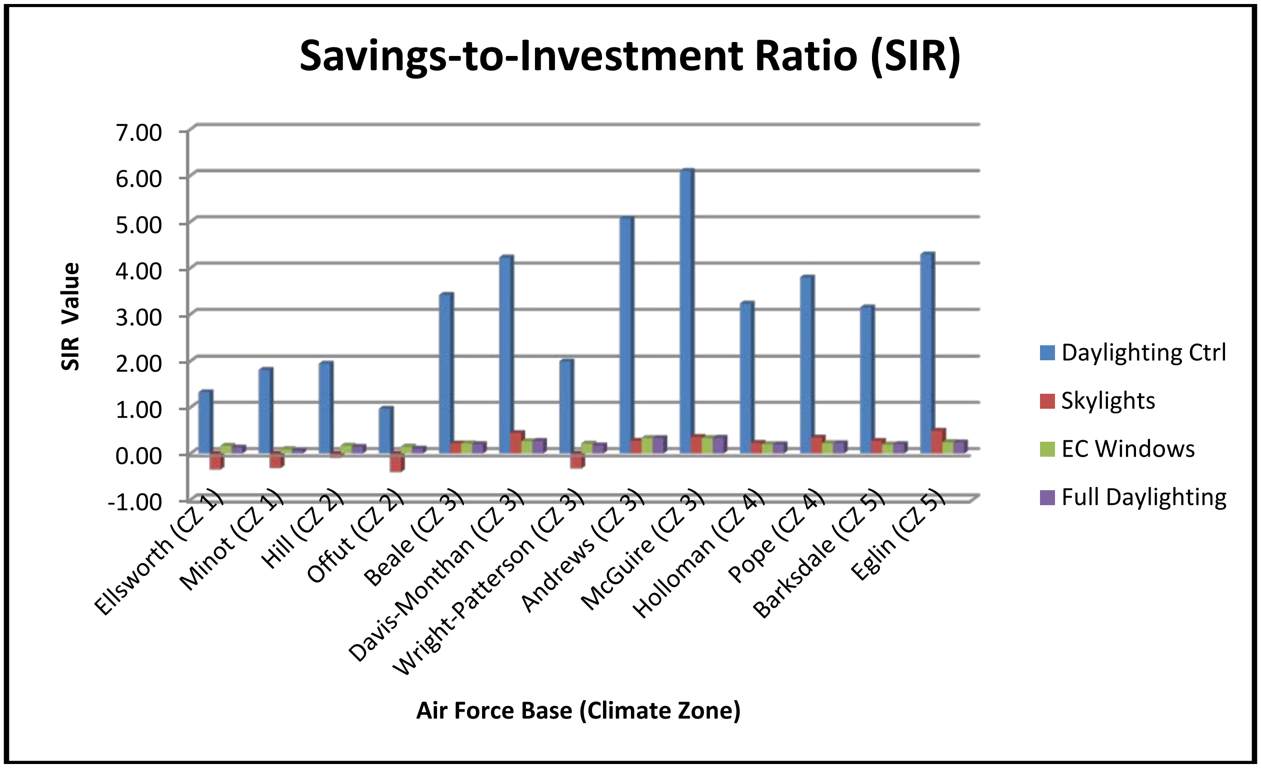

Figure 22. Savings to investment ratio (SIR) across all climate region for all daylighting strategy.

Our results indicate that the trend for the savings tends to occur more in certain moderate climates and temperate climates. This trend is also supported when using SPB as the metric to compare which projects would be viable for private funding. Again, both EC windows and full daylighting have unacceptable payback period, especially for the cold climate zones, shown in figure 23. Note that skylights show a 'zero' payback in figure 23; however, this is due to their negative payback periods which were trumped to zero. This means that skylights were the least economically viable strategy for private funding based on simple payback. This should not be confused with a true zero payback that would indicate that it has no payback period, indicating most economical.

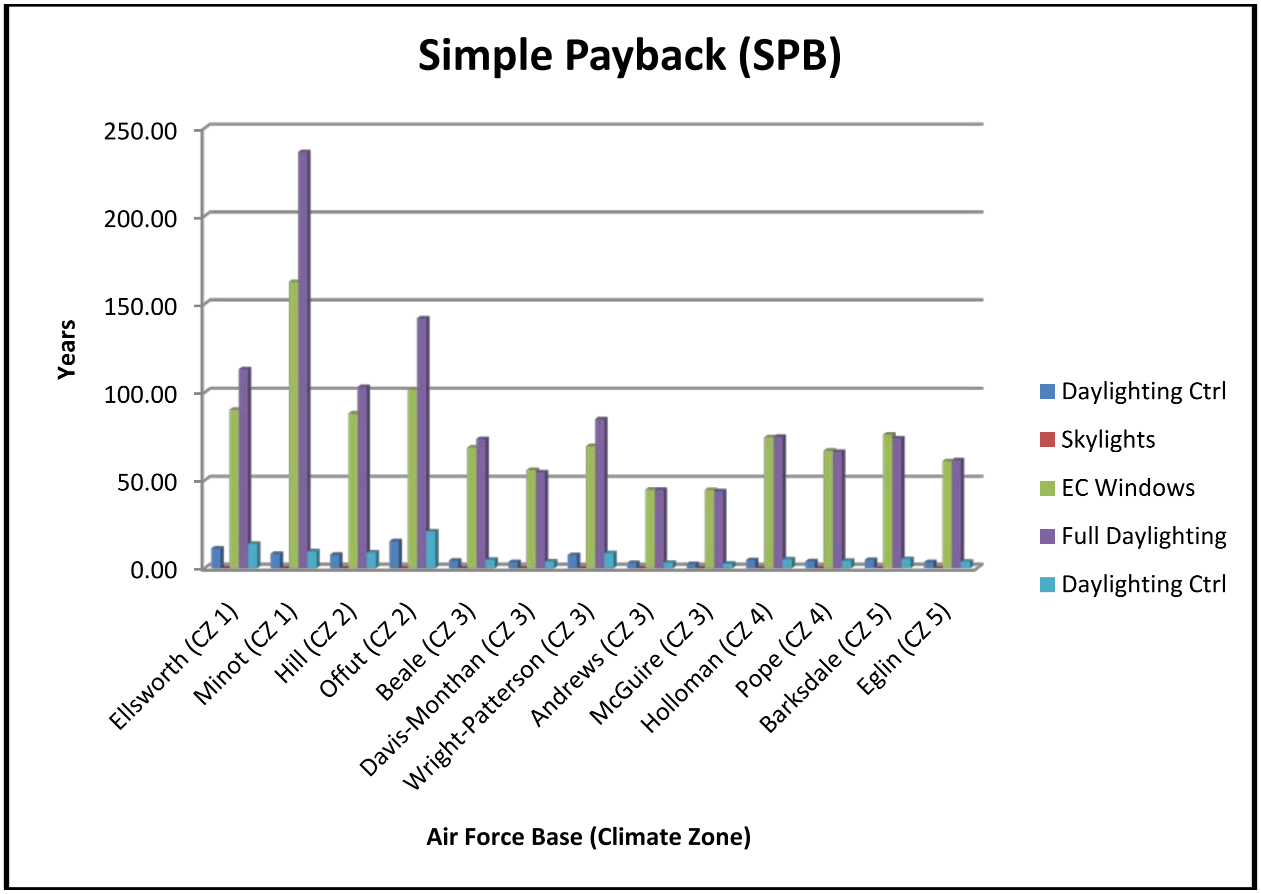

Figure 23. Comparison of simple payback across all climate zones and for all daylighting strategy.

We conclude that within the boundaries of our research parameters, the current market does not allow EC windows to be implemented for USAF office facilities due to their prohibitive investment costs but ADCs could be viable in most locations regardless of climate.

Next, we investigate if policy intervention could help make non-viable projects, such as EC windows, viable. The energy savings potential of EC windows is apparent from our energy performance simulation results but they are limited by the investment cost. Therefore, we present an economic policy scenario that is currently available for other passive solar technology and apply it to EC windows.   The results are presented and discussed in the next section.

Part III: Economic Policy Intervention for EC Windows

Two assumptions were made to demonstrate the relationship between policy intervention and its effect on the economic viability of EC windows. First, we assumed a technology implementation policy that could increase the energy savings performance of EC windows by 33%. This is possible based on research (Lee, et al., 2007) that has shown that use of reflective interior/exterior shades and devices such as light shelves can significantly enhance EC window performance. Furthermore, if building component upgrades are managed effectively they can incorporate EC window technology to further enhance energy savings. For example, when a scheduled heating, ventilating and air conditioning (HVAC) system upgrade is planned, including EC windows as part of the upgrade could yield cost savings by reducing the size of the HVAC system that would be installed. This is because EC windows would reduce the heating and cooling load for the facility therefore reducing the size of the HVAC system required. And because the HVAC replacement is a must, adding the EC window results in a net cost savings realized by the savings from the reduced HVAC system.

Second, we assume a 66% economic cost reduction in the initial investment cost of the EC windows. This is based on the current economic incentives available for other passive solar technology such as solar walls are applied to EC windows. These economic incentives or subsidies are available at the federal and state level and the size vary by state. This was discussed in chapter 2. Furthermore, the current EC window manufacturer estimates that "At maturity, EC window costs will be \$6-8/ft^2 -glass for an IGU and primary controls will be \$15 per window" (Lee, et al., 2002a); which is within the range of our 66% cost estimate, which supports our assumption.

The scope of the project has been set around $3 million[25] based on USAF energy projects submitted in 2008, which range from $750,000 to $3.5 million. We will also demonstrate the robustness of our probabilistic life-cycle cost analysis model as our results are presented in this section.

Policy Intervention Results

Our policy intervention model used the same probability distribution assumptions discussed in chapter 3 and including the assumptions specified in the previous section. Figure 24 shows the results of the SIR and SPB values for EC windows at all climate zones with the respective probability that the values would meet the minimum values. Our policy intervention results show that in warm climate locations (CZ 4 – 5) EC windows could be economically viable. Locations such as McGuire, Andrews, Davis-Monthan Air Force Base that are in climate zone 3 are also economically viable. The economically viable locations show an approximately 70% or greater probability of meeting both economic requirements. Using a generic project management risk probability model in Table 5 (Shepherd, 2003), this could inform a decision maker that economical policy could have an acceptable level of risk.

[25] This is because any project above $5 million must obtain approval from the Secretary of the Air Force (SAF/IEI) and projects that cost more than $7.5 million must obtain congressional approval (AFI 32-1032, 2003).

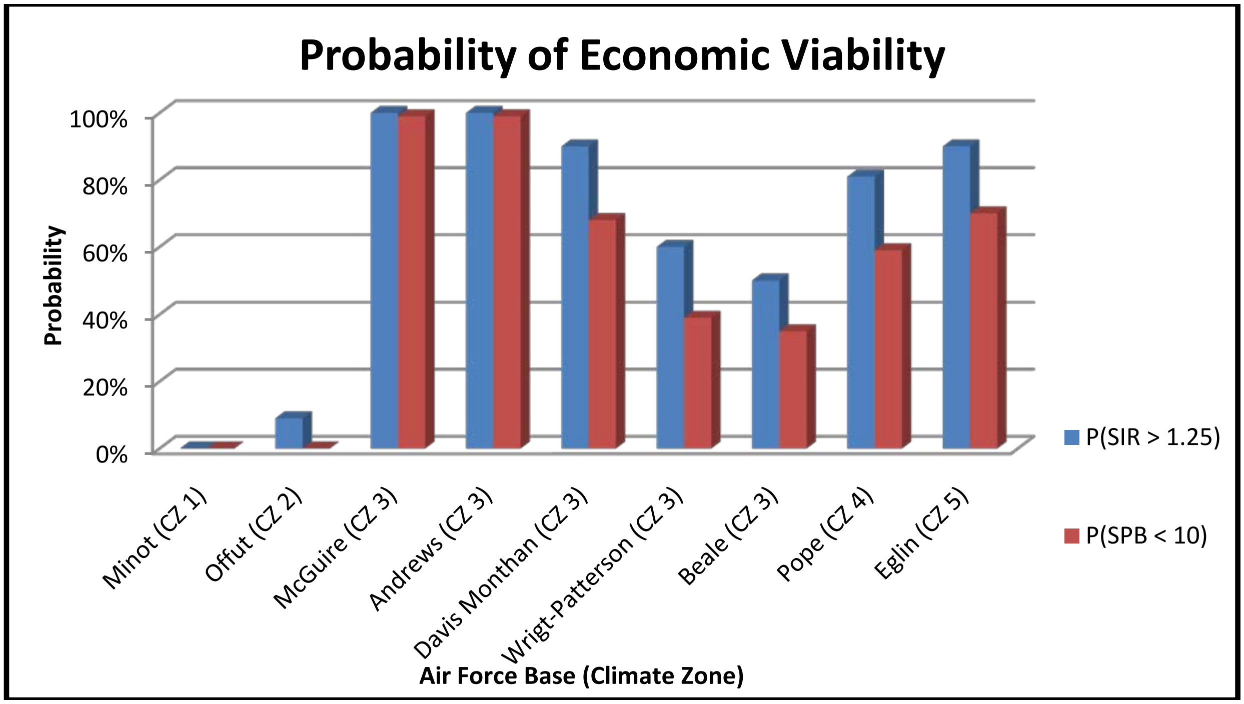

Figure 24. Probability of SIR and SPB for EC windows across all climate zones

Table 5. Risk Probability Model (Shepherd, 2003)

Probabilty			Existing Processes, Infrastructure and Governance
Near Certainty	Very High (>90%)	5	…will not avoid the risk event and there is no known alternative. (Less than 10% chance it **will not** happen.)
Highly Likely	High (67%-90%)	4	…will not avoid the risk event, but an alternative may be available. (Less than 1/3 chance it **will not** happen.)
Likely	Medium (34%-66%)	3	…may avoid this risk and an alternative may be available. (About a 50% chance it will happen.)
Unlikely	Low (11%-33%)	2	…typically avoid this type of risk with minimal oversight in similar cases. (Less than 1/3 chance it **will** happen.)
Remote	Very Low (<10%)	1	..will effectively avoid or mitigate this risk. (Less than 10% chance it **will** happen.)

Next we compare simple payback (SPB) with discounted payback (DPB). The discounted payback restricts the economic viability; which means that fewer locations are below the 10 year limit. Using discounted payback, the extreme climate zones on each end, extremely cold (CZ 1) or extremely hot (CZ 5), have same trend. And locations with high utility costs also show economic viability, such as Andrews AFB and McGuire AFB. However, some locations in CZ 3 and 4 are not economically viable, such as Beale and Pope AFB, shown in figure 25.

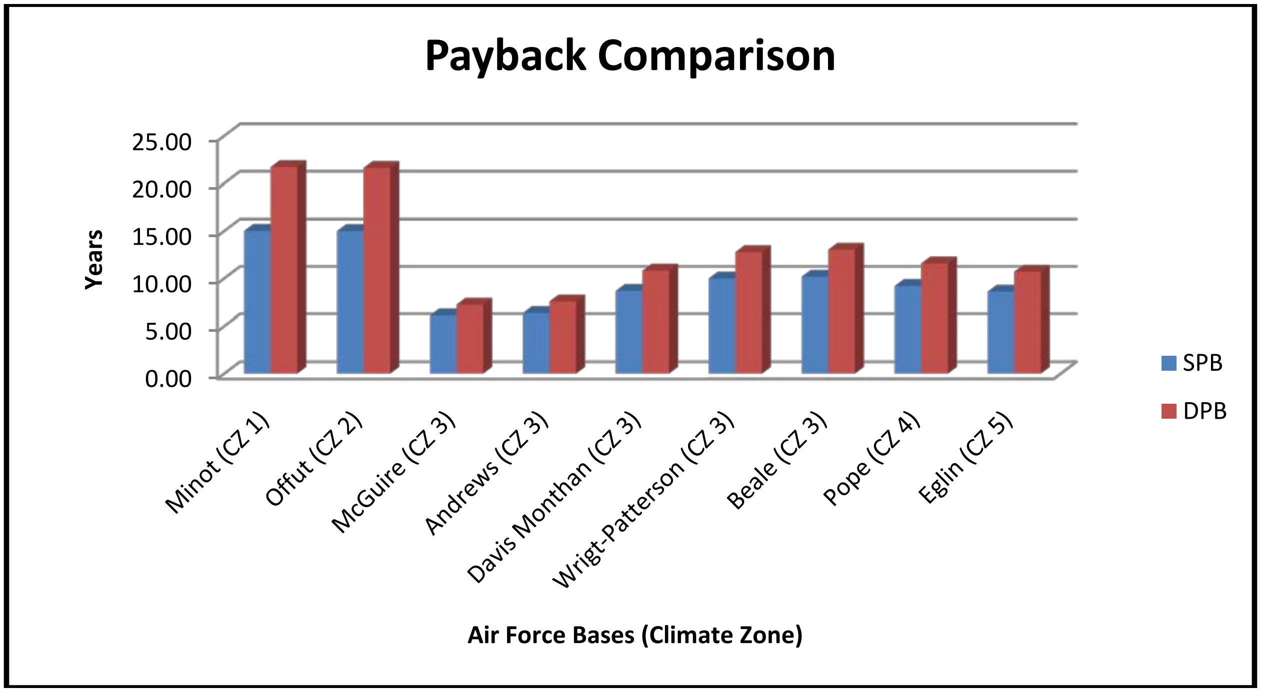

Figure 25. SPB summary results for EC windows in all climate zones

Discounted payback appears to separate from simple payback with increase in time or with increase in the interest rate. Currently, the FEMP discount rate is fixed at 3%; therefore, projects that show a payback around the critical 10 year mark could be at jeopardy if discounted payback were to be used, for example: Wright-Patterson AFB, Pope AFB, and Beale AFB from figure 25. However, as discussed before, discounted payback is required by the DOD Energy Manager's Hanbook and it is a more accurate economic measure because it considers time value of money. Both types of payback could be beneficial since private funding for federal energy projects uses SPB which tends to be more optimistic (shorter); however, use of DPB for publicly funded projects could be an appropriate compromise since federal funding could be more competitive. However, our recommendation is that discounted payback should be used instead of simple payback.

We also investigated using other economic metrics such as adjusted internal rate of return and net savings. The detailed results from adjusted internal rate of return and net savings are presented in Appendix O.   However, minimal additional insight is provided by either metric; therefore, we conclude that SIR and payback are sufficient economic metrics. Next, we demonstrate in detail the type of additional information that could be available from our probabilistic model that would not be from BLCC 5. These could provide decision makers with a more complete picture of risk and uncertainty.

Monte Carlo Simulation Robustness

Using Monte Carlo simulation, we have shown briefly in the previous section, the probabilities that can be obtained compared to the traditional point estimates. We show the results for Beale Air Force Base (AFB) as a representative sample to demonstrate the additional information provided by Monte Carlo simulation using Crystal Ball.

Figure 26 shows a distribution for the SIR value for EC windows at Beale AFB. In figure 26, the deterministic SIR value that was calculated for Beale AFB, 1.46, is plotted on the distribution. In general, all deterministic values tended to be biased optimistically. This means that for SIR, the deterministic values tended to be higher and for payback values, they tended to be lower. This optimistic bias is explained more fully in the last section of this chapter.

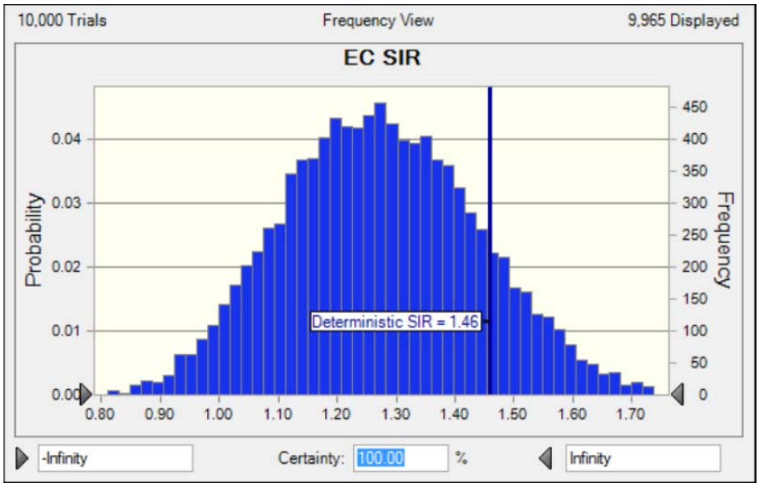

Figure 26. MCS probability distribution output for the SIR of EC windows at Beale AFB.

Another way to convey this information for a decision maker, shown in figure 27, is that when looking at the minimum required SIR value for Beale AFB, there is only about 45% chance that the SIR value would be less than 1.25. In other words, there is 55% chance that the SIR could be above 1.25. Though this is not a guarantee, it does provide a decision maker with a statistical supported probability rather than a point estimate of SIR = 1.46, which has relatively less utility. Appendix P shows another detailed example demonstrating model robustness by allowing the decision maker to obtain probability of an event such as obtaining the minimum required annual energy savings for a project.

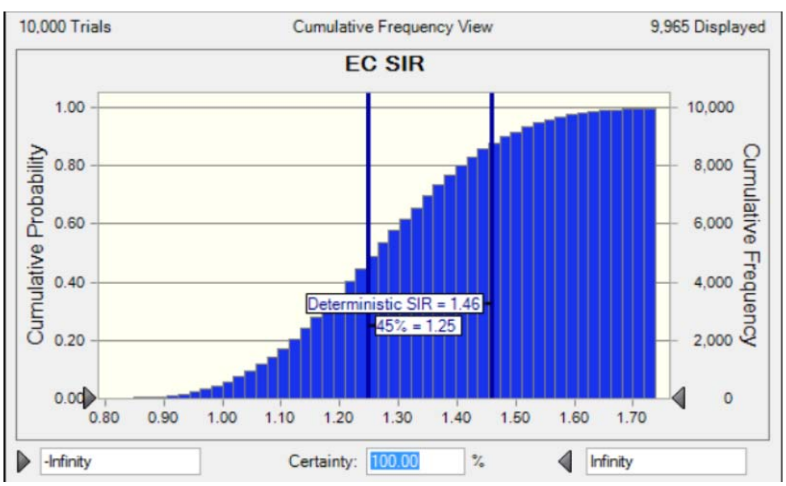

Figure 27. MCS cumulative distribution for the SIR of EC windows at Beale AFB.

When compared to BLCC 5 and its point estimates, the probabilistic model's robustness becomes self-evident. Monte Carlo simulation is ideal when historical information is available but can also use empirical data or expert estimates to account for uncertainty and risk.

Uncertainty analysis is required as part of any economic analysis for USAF energy projects (AFMAN 65-506, 2004). Crystal Ball incorporates uncertainty analysis within the simulation by providing a sensitivity chart with each distribution output. Sensitivity analysis results are discussed in the next section.

Sensitivity Analysis

Our sensitivity analysis showed that utility costs tended to be most influential for economic viability. The exception is that in colder climates, CZ 1-2 and various locations in CZ 3, the construction cost was most significant. One general trend was that higher electricity consumption rates were more prevalent and therefore were significant more often. Natural gas had the next significant influence and peak demand was the last in utility cost influences. We reiterate that probability sensitivity analysis is able to relate loose correlations in a complex system that would otherwise be undetectable through traditional deterministic analysis (Emblemsvag, 2003) so the true reason for the significance could be different than what we have noted here. Furthermore, locations with high utility rates tended to show a greater economic savings compared with effects from climate.

Figure 28 shows the SIR sensitivity analysis for EC windows at Beale AFB. The chart shows that the greatest contributing factor for SIR is the initial investment cost; therefore, the larger the initial investment cost the lower the SIR. The second most influential factor is the electricity consumption life cycle cost using the EC windows; therefore, the lower the electricity consumption cost the higher the SIR. And the third most influential factor is the current electrical consumption life cycle cost; therefore, the higher the current consumption the higher the SIR. The fourth and fifth factors contribute equally as the least influential for SIR, which relate to natural gas consumption.

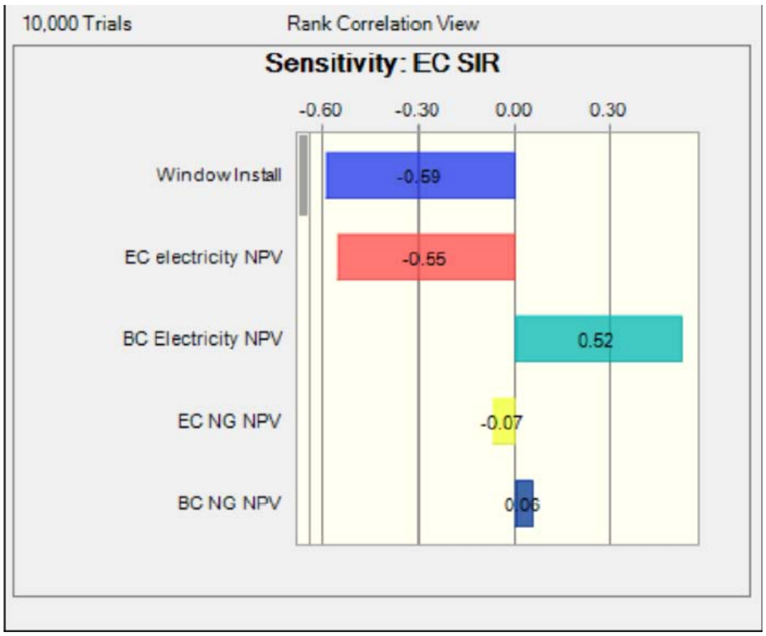

Figure 28. Sensitivity analysis by rank correlation for EC window SIR at Beale AFB.

Figure 29 effectively highlights the impact of utility cost. Figure 29 shows results for McGuire AFB which is in the same climate zone as Beale AFB (CZ 3) but has a significantly larger utility rate, especially electricity rates. McGuire AFB's electricity rate is $115.67/kWh, whereas Beale AFB's electricity rate is $63.27/kWh. Our results show that McGuire AFB results are consistent with temperate climate zones (CZ4 – 5) in terms of economic viability, which means that electricity life-cycle cost of electricity consumption is the most significant factor rather than the initial investment cost of EC windows.

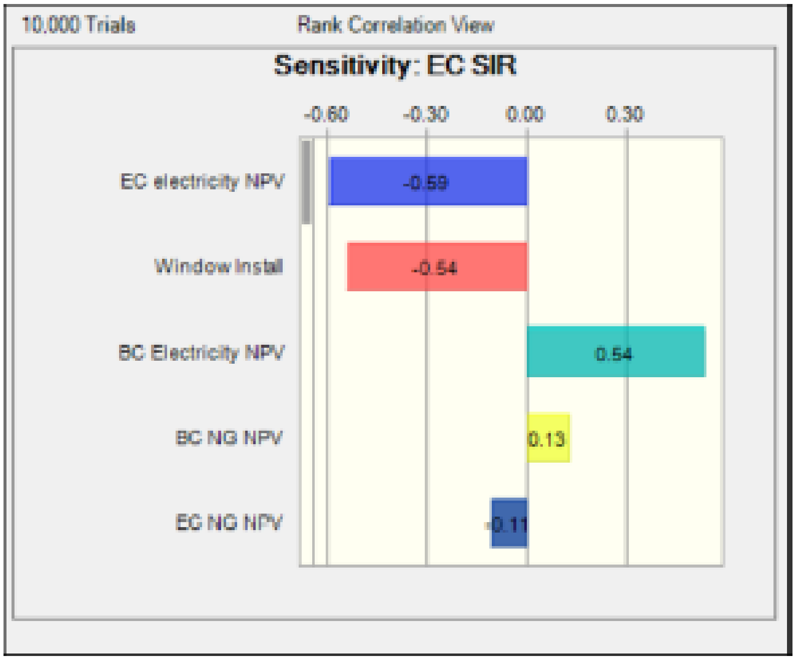

Figure 29. Sensitivity analysis by rank correlation for EC window SIR at McGuire AFB (CZ 3).

Overall, we conclude that within our research boundaries, the electricity consumption cost and the initial investment costs have the greatest impact on the economic viability of EC windows for warmer climates and locations that have high utility rates. Furthermore, economic incentives such as federal and state tax credits could make emerging daylighting technology such as EC windows economically viable. The Monte Carlo output with sensitivity analysis for all climate zones is available in Appendix Q.

The last section of this chapter demonstrates more fully how deterministic values tend to be optimistically biased when compared with probabilistic values from our research results. This could have an adverse effect for the decision maker if the project data are inaccurately portraying the economic viability of the project. We compare BLCC 5 project data from 19 USAF energy projects that were submitted in 2008. The findings are discussed in the next section.

Deterministic (BLCC 5) vs. Probabilistic (MCS)

We obtained 19 energy project data that were submitted as part of the 2008 USAF Energy Conservation Investment Program (ECIP). Project inputs were generally limited to basic cost data: electricity savings, natural gas savings, water savings, and non-energy savings. Non-annually occurring energy savings were converted to annual annuity using 3% (FEMP discount rate for energy projects) and the study period specified on the project. If the BLCC summary sheet was available, the data from it was used including any other relevant discount factors.

First, we plotted the deterministic SIR values on the probability distribution obtained for that project. The standard deviation lines were drawn to determine where the deterministic value fell within the distribution. This was completed for each project for SIR and SPB values. The output for all projects is available in Appendix R and the summary tables for the projects are available in Appendix S.

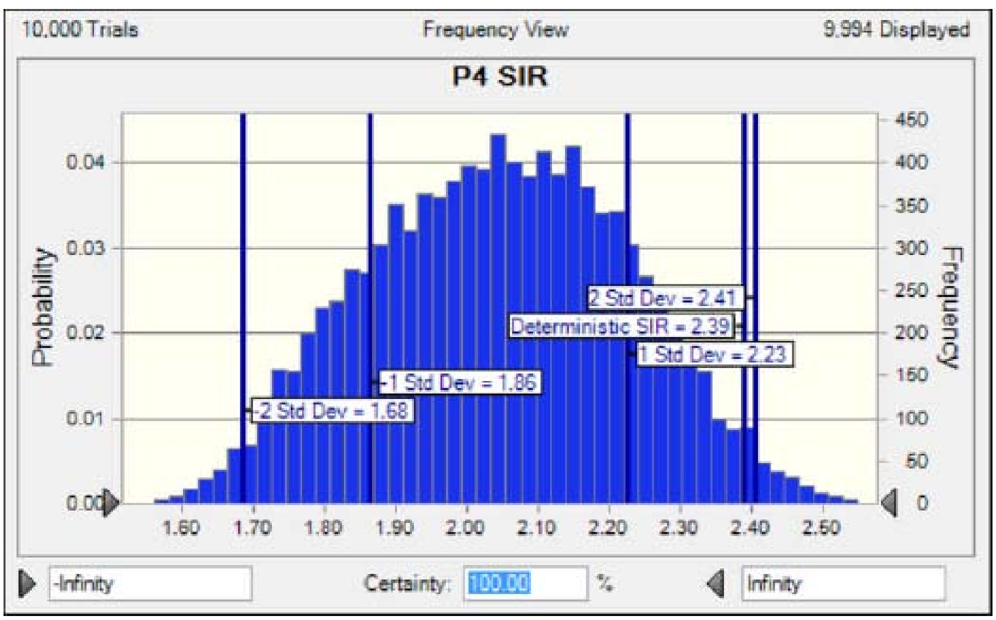

Figure 30. Example of one of the projects used to compare BLCC 5 and MCS model by plotting deterministic value on the probability distribution for SIR.

Next, all the deterministic values were obtained and plotted on a standard normal graph, shown in figure 31, and grouped by which standard deviation it fell into. The implication of this could be that some of the current economic values being provided by BLCC 5 are overly optimistic, especially if they fall three standard deviations away, and therefore could be providing inaccurate economic predictions.

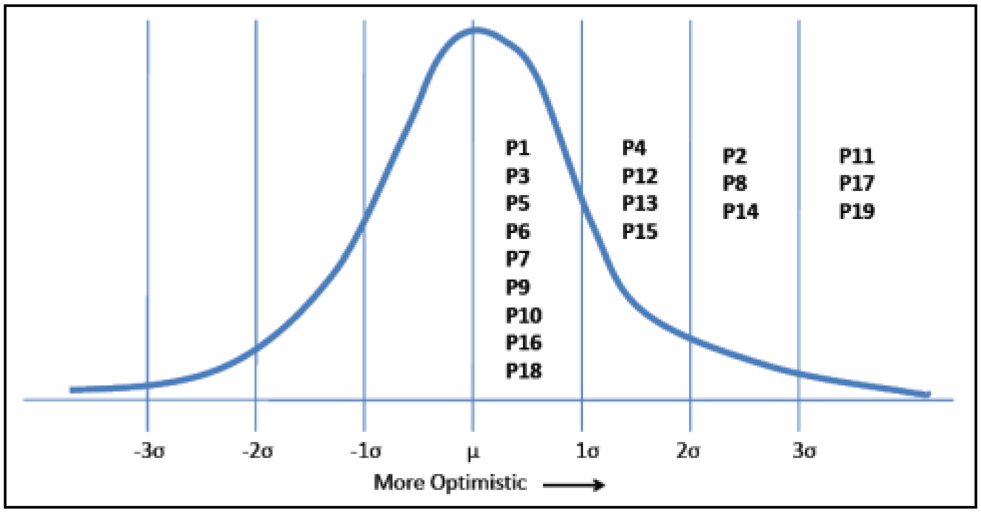

Figure 31. Relative location of deterministic SIR values for each project grouped by standard deviation

Again, we reiterate that our probabilistic model or any probabilistic model may not provide a more accurate prediction; however, it does provide more information and is a more robust analysis tool when compared with the current deterministic tool. Validating our probabilistic model could further justify the use of probabilistic models.

Summary

We presented our findings from (a) energy performance simulation of different daylighting strategy, (b) economic viability of different daylighting strategy in the currnet market, and (c) economic viability of EC windows with economic incentives as a policy intervention. Furthermore, we demonstrated the robustness of probabilistic model using Monte

Carlo simulation. Despite the limitation of real world data and our findings confined to the boundaries established for our study, our results are consistent with findings from other researchers (Lee, et al (2004); Lee, et al. (2006); Apte, et al. (2008)) in the energy performance of the different daylighting strategies. Our research also extends previous research on daylighting technology for DOD facilities. Chapter 5 will summarize our research results and provide our final recommendations.

V. Conclusion and Recommendations

Chapter Overview

This chapter provides final conclusions and recommendations from our research. First, a brief research summary is presented including the research questions from chapter 1. Second, we discuss policy recommendations. Finally, the benefit and limitations of our research, and suggestions for future research are discussed.

Research Summary

Our research analyzed the potential energy performance of different daylighting technologies for United States Air Force (USAF) office facilities using eQUEST (DOE-2) simulation tool. We determined the economic viability of each daylighting strategy and determined which would be most economically viable in the current market. For technologies that demonstrated energy savings but were economically viable, we investigated potential economic policies currently available for other renewable energy technology that could make emerging daylighting technology viable. Finally, a probabilistic life-cycle cost analysis tool using Monte Carlo method from Oracle™ Crystal Ball was used to demonstrate the robustness of probabilistic models compared to existing deterministic life-cycle cost analysis (LCCA) tool, BLCC 5.

Research Questions Answered

Which daylighting strategy is most energy efficient for a USAF office facility: advanced daylighting control system with traditional windows, skylights with traditional windows, EC *window system, or full daylighting strategy using EC window systems with skylights? And how does climate affect the different daylighting strategies?*

Our results show that energy efficiency is influenced by climate and the type of daylighting technology. EC windows showed around 20-25% reduction on electricity consumption and 20-30% reduction in peak demand and approximately 20% reduction in natural gas across all climate zones. The full daylighting strategy incorporating all the daylighting components had the most significant electricity savings, exceeding that of EC windows alone. However, the net natural gas energy loss, approximately 5-15% depending on climate region, caused by the skylights made the full daylighting strategy only marginally better than the EC windows alone.

In general, warmer climates benefit most from daylighting. The daylighting strategies that incorporate EC windows far exceed the electricity savings of any traditional daylighting strategy, such as skylights and ADCs. For natural gas savings, the general trend is that daylighting savings are greater for colder climates; presumably because there is greater natural gas usage in those climate zones. In extreme cold climates, EC windows performed poorly in our simulation. However, in moderate climate such as climate zone 3, energy savings and costs varied within the climate zone and showed that there were other factors that were more influential than climate, such as utility cost.

Which daylighting strategy is most economically viable for a USAF office facility?

The only strategy that is currently viable based on our model results is advanced daylighting controls (ADC). Without any economic incentives, ADC is the only technology that provides an acceptable return on investment. Skylights are most economical in terms of initial investment; however, due to their energy performance in our simulation, skylights are not recommended for USAF office buildings. In general, skylights provide some electricity savings but are significant source of energy loss for natural gas, especially in cold climate zones. The two daylighting strategies that incorporate EC windows are not economically viable currently due to the prohibitive cost of EC windows. The relative energy savings of EC windows are considerable in our simulation the energy savings is insufficient to overcome the initial investment costs to make EC windows economically viable.

Which input cost factor affects the economic viability of emerging daylighting technology: utility rate, peak demand cost, or initial investment cost?

The most influential economic factors were determined to be utility rates followed by initial investment cost. Specifically, electricity rates were most significant; which was most evident when climate zone 3 was analyzed. Climate zone 3 showed the most varied response to economic viability; however, the Monte Carlo simulation sensitivity analysis found that electricity rates had most significant influence for warmer climate zones and locations with high electricity rates. In colder climates, the most significant factor was the initial investment cost. This is most likely because the electrical rates weren't as high in the colder climates and consumption was lower. Therefore, we conclude that the most significant input cost factor is the electricity consumption rate.

Is there significant difference in using discounted payback versus simple payback that could affect decision making? Do other economic factors provide additional insight?

Other economic metrics such as net savings and adjusted internal rate of return do not add further insight to current economic analysis using SIR and payback from our analysis. Our results show that, in general, simple paybacks are more optimistic when compared to discounted payback. The gap between the two paybacks increase with time and especially as it nears the 10 year mark. SPB could continue to be used if projects are vying for private funding. However, discounted payback could provide more realistic metric for all projects. Additionally, if the FEMP discount rate were to be increased, the payback gap between simple and discounted payback would also increase. Using discounted payback with increased minimum payback time of 15 years could be more realistic for renewable energy projects and is recommended from our research results, and is also supported by previous DOD study (Tri-Service Renewable Energy Committee, 2003).

What are the capabilities that make the Monte Carlo life-cycle cost analysis model more robust than the deterministic model BLCC 5? What type of insight can the added robustness provide for the USAF decision maker?

Our results demonstrated that our MCS LCCA model is more robust than the current deterministic model, BLCC 5. By using probability distributions and cumulative distributions along with the respective sensitivity analysis, information beyond a point estimate can be provided to the decision maker. A range of possible values derived from statistical probability provides more than a simple number. In general, deterministic values tend to be more optimistically biased. This means that deterministic SIR values tend to be higher in value and SPB tend to be lower in value when plotted on a probability distribution. In some of our results, the difference between the probabilistic values and deterministic values showed that a possible 'go/no-go' situation could be affected depending on the type of SIR and payback used.

What are some policy implementation that could aid the implementation and proliferation of emerging renewable energy technology?

The results of our economic policy intervention case study showed that implementing economic incentives currently available for other passive solar technology such as solar walls applied to daylighting could make EC windows economically viable for USAF facilities, but primarily in warmer climates and locations with high utility rates. Without policy intervention economic viability may never be possible due to the high investment cost inherent in emerging renewable technology. This is not a new phenomenon but has historical context. The significant influence of policy is discussed further in the next section.

Policy Recommendation

Economic incentives offered by states and the federal government have been and continue to be a single most significant driver of renewable energy technology (EIA, 2005). Use of economic incentives to improve technology and increase market proliferation has historical context in wind technology. Figure 32 shows the relationship between the installed wind capacity responses to economic incentives for the state of California. The installed wind capacity represents the proliferation of wind turbines and the eventual decrease in cost of technology and increase in its efficiency. For example, towards end of 1990's and early 2000's, the production tax credit (PTC) is linked with sharp increases in wind capacity. Each time a tax credit expired, the wind capacity leveled and with each new implementation (three in total), it was followed by a sharp increase in the installed wind capacity. This clearly demonstrates industry response to government subsidies for renewable technology.

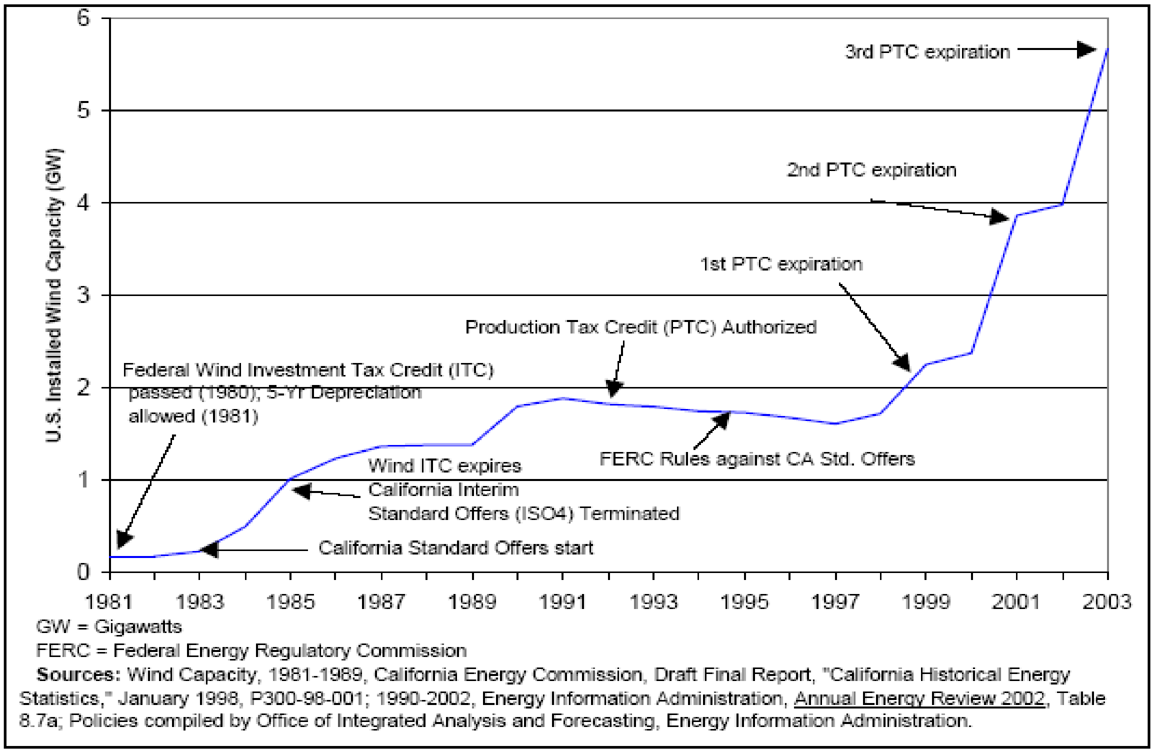

Figure 32. Historical relationship of economic incentive with respect to wind technology growth (EIA, 2005).

Government subsidies are also prevalent, and often more aggressive in European countries; large economic incentives have allowed greater acceptance and implementation of emerging technologies such as EC windows in Europe (Lee, et al., 2002). For facility retrofit cases, the window and daylighting strategy could be the single major factor for energy savings (Ruck, et al., 2000).

EC windows are an attractive solution for future energy savings strategy because their most notable characteristic is the ability to reduce peak electricity demand load (Lee, et al (2004); Lee, et al (2006)). This is important because peak demand is one of the reasons for driving up electricity cost and causing rolling blackouts throughout the country where demand is far exceeding the capability to supply electricity. A Rand Corporation (1980) study on the impact of demand load showed that if a reduction in peak demand can be accomplished, it could reduce aggregate generating and transmission capacity needed and the operating cost per kilowatt-hour would be reduced. This would, in turn, reduce the electricity rate to the customer (Acton, et al., 1980); which our research showed is the most significant factor for economic viability. More recently, a Brattle Group study (Faruqui, et al., 2007) found that peak demand could be reduced by 11% using technology currently on the market. This is significant because at the national level even a 5% reduction in peak demand load could reduce energy savings that would equate to $3 billion annually or $35 billion over the next 20 years (Faruqui, et al., 2007). Our simulations show a peak demand reduction of approximately 20-30% using EC windows, consistent with previous findings (Lee, et al., 2002a). This could be significant energy savings if multiplied at the aggregate level.

Non-economic policy such as implementation strategy of renewable technology should also be considered. The DOD has mandated that electricity, natural gas, and water be metered on appropriate facilities. Installing facility meters should be managed to consider facility age, size, and type in addition to the climate zone. Strategically managing metering installation is critical to building a reliable energy usage baseline and providing the necessary information to validate energy prediction models and simulation effectively for USAF facilities. Additionally, peak demand rate should be metered, monitored, and tracked because it could have a larger impact on energy cost and is not explicitly part of the new metering mandate.

Based on the results from our policy intervention case study, we recommend economic incentives that are more aggressive than the incentives available for existing solar technology. If incentives allow implementation of emerging technology, installation should be staggered over time so that the benefit of improved technology and cost reduction can be realized as the technology matures. The benefits of our research are discussed next.

Research Benefits

Our research provides insight into the relative energy performance of current daylighting technology for USAF facilities. Our research fills a gap in daylighting studies in the DOD, currently limited to large warehouse-type facilities and primarily using traditional strategy such as skylights only. We demonstrate that EC windows could help meet the new federal facility energy mandates if economic incentives currently available for other passive solar technologies could be extended to daylighting technologies. In general, the information from our research could provide decision makers on how to implement different daylighting technology within the USAF.

We used a Monte Carlo simulation life-cycle cost analysis model to demonstrate that it can be used for energy projects with results that are more robust and with additional information not available using the current deterministic model, BLCC 5.

Finally, our results show that discounted payback could be a better indicator and should be used with or in place of simple payback; if not for all projects, at least for projects that are competing for federal funds. If discounted payback is used, the baseline for acceptance currently set for 10 years should be extended to 15 years. Considering that the life expectancy of many modern building systems, such as EC windows, is between 20-30 years (based on personal communication with Sage Electrochromic, Inc., 2009) significant energy savings could be gained after the initial payback period of 15 years. Despite these demonstrated benefits, our research has limitations that need to be discussed and are presented in the next section.

Research Limitations

A significant limitation of our study is the lack of validation. Both eQUEST and Monte Carlo simulation are validated tools; however, they have not been validated by our study of for modeling USAF facilities economic analysis comparing its effectiveness against BLCC 5 results.

Due to the wide variety of different office building design and size which could alter the building energy performance, our results should not be applied generally for all USAF office facilities. Additionally, electricity demand rates were obtained from tariff rates published on the website for the respective utility company. A more accurate cost rate and consumption data of USAF facilities should provide better results. Ultimately, our findings are limited to the boundaries and scope established for our research. We also suggest future researches that could help further the our findings, which are presented next.

Suggestions for Future Research

Future research should focus on validating our models when metered facility energy usage can be made available. Validation study of energy consumption to compare eQUEST models with metered data of USAF facilities should be conducted. It should include modeling facilities by size, type, and age to capture a larger energy profile using other prototypical USAF facility design.

Additionally, our MCS model should be validated by conducting a probabilistic life-cycle cost analysis for federal energy projects. Specifically, Crystal Ball could be tested with USAF Civil Engineering projects. Finally, EnergyPlus should be explored for implementation for USAF Civil Engineering as the future energy simulation software. Currently, EnergyPlus does not have parametric capability, therefore was not used for our research. However, EnergyPlus is the latest Department of Energy (DOE) approved software that combines the DOE-2 engine (same as in eQUEST) with Building Loads Analysis and System Thermodynamics (BLAST[26]) and incorporates a superior daylighting algorithm for building energy simulation. Finally, DOE has conducted recent validation studies for the software; and EnergyPlus results are eligible for federal and state tax credits (DOE, 2008a) whereas eQUEST results are only eligible for state tax credits.

Conclusion

Our research goal was to (a) identify the potential energy consumption savings of different daylighting strategy for USAF office facilities, (b) determine which strategies were economic viable in the current market, and (c) investigate potential economic policies to make viable emerging technologies that are currently not viable due to cost. Furthermore, we demonstrated the robustness of probabilistic life-cycle cost analysis model using Monte Carlo simulation compared to deterministic results from BLCC 5. Despite the limitation to our research, our results justify, at minimum, a need for future validation studies of our and other models that could impact the growing energy conservation strategy in DOD.

Currently only the advanced daylighting control systems are economically viable but electrochromic windows should not be ignored despite the fact that they are not currently economical for the USAF. EC windows have demonstrated significant energy savings towards meeting the federal facility energy goals and are promised to be the next major innovation in building technology according to leading national research laboratories. Future studies to quantify environmental impacts; thermal and visual comfort; privacy; aesthetics; and design,

[26] A comprehensive set of programs for predicting energy consumption and energy system performance and cost in buildings. Developed by the U.S. Army Construction Engineering Research Laboratory and the University of Illinois (Crawley, et al., 2005).

maintenance, and operation costs could increase the viability of EC windows as well (Lee, et al., 2000).

Designer, engineers and policy makers in the USAF need a fundamental change in the perception of renewable energy technology for facilities with respect to the new federal energy goals; because the new goals focus on load avoidance rather than cheaper energy generation strategy, which means that the focus is in reducing demand and consumption of energy rather than simply reducing the cost of energy. Our facility and economic models, if validated, could provide a basis for a future tool that could be readily tested and implemented for USAF energy projects.

Appendix A

Mandate Title	**Website URL** (DOE, 2008b)
EPACT 2005	http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:h6enr.txt.pdf
EO 13423	http://www.ofee.gov/eo/EO_13423.pdf
EISA 2007	http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

Energy Policy Act of 2005 (Rocchetti, 2008):

- Reduce energy intensity (MBTUs[27] per Sq Ft) 2% per year from Fiscal Year (FY) 06-15 using FY03 as baseline
- Electric metering required in all qualifying buildings by 2012
- Energy Star™ products required (electrical motors, Air Conditioners, refrigerators, etc.)
- Buildings must be designed 30% better than American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standard 90.1[28] requirements

Executive Order 13423 (Rocchetti, 2008):

- Reduce energy intensity (MBTUs per Sq Ft) 3% per year from FY06-15 using FY03 as baseline.
- Reduce water intensity by 2% annually from FY08-15 using FY07 baseline.
- Comply with Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding
  - Employ Integrated Design Principles
  - Optimize Energy Performance
  - Protect and Conserve Water

[27] A unit of energy used in the power, steam generation, heating and air conditioning industries. "BTU" is used to describe the heat value (energy content) of fuels, and also to describe the power of heating and cooling systems, such as furnaces, stoves, barbecue grills, and air conditioners. The unit MBTU was defined as one thousand BTU presumably from the Roman numeral system where "M" stands for one thousand (1,000). This is easily confused with the SI mega (M) prefix, which adds a factor of one million (1,000,000). To avoid confusion many companies and engineers use **MMBTU** to represent one million BTU; alternatively a "therm" is used representing 100,000 or 10^5 BTU, and a quad as 10^{15} BTU.
(Source: http://en.wikipedia.org/wiki/British_Thermal_Units)

[28] A set of national requirements for the energy efficient design of commercial buildings. The purpose of this standard is to provide minimum requirements for the energy-efficient design of buildings except low-rise residential buildings.
(Source: http://www.energycodes.gov/training/pdfs/ashrae_90_1_2004.pdf)

    - Enhance Indoor Environmental Quality
    - Reduce Environmental Impact of Materials

Energy Independence and Security Act of 2007 (Rocchetti, 2008):

- Reduce fossil fuel energy for all new and renovated construction, compared to similar building's use in 2003.
    - 55% reduction by 2010
    - 65% reduction by 2015
    - 80% reduction by 2020
    - 90% reduction by 2025
    - 100% reduction by 2030
- Solar Domestic Hot Water (DHW) Heating: 30% of DHW must be solar - where cost effective
- Energy Savings Performance Contracts (ESPC): Agencies can mix appropriated with private financing on project
- Energy Audits required for each bldg once every four years

Appendix B

An EC coating is typically five layers, about one micron thick, and is deposited on a glass substrate. The electrochromic stack consists of thin metallic coatings of nickel or tungsten oxide sandwiched between two transparent electrical conductors. When a voltage is applied between the transparent electrical conductors, a distributed electrical field is set up. This field moves various coloration ions (most commonly lithium or hydrogen) reversibly between the ion storage film through the ion conductor (electrolyte) and into the electrochromic film. The effect is that the glazing switches between a clear and transparent prussian blue-tinted state with no degradation in view, similar in appearance to photochromic sunglasses. The main advantages of EC windows is that they typically only require low-voltage power (0–10 volts DC), remain transparent across its switching range, and can be modulated to any intermediate state between clear and fully colored. For some EC types (polymer laminate), the device is switched to its desired state and then no power is needed to maintain this desired state. This type of device has a long memory once switched (power is not required for three to five days to maintain a given switched state) (Carmody, et al., 2004).

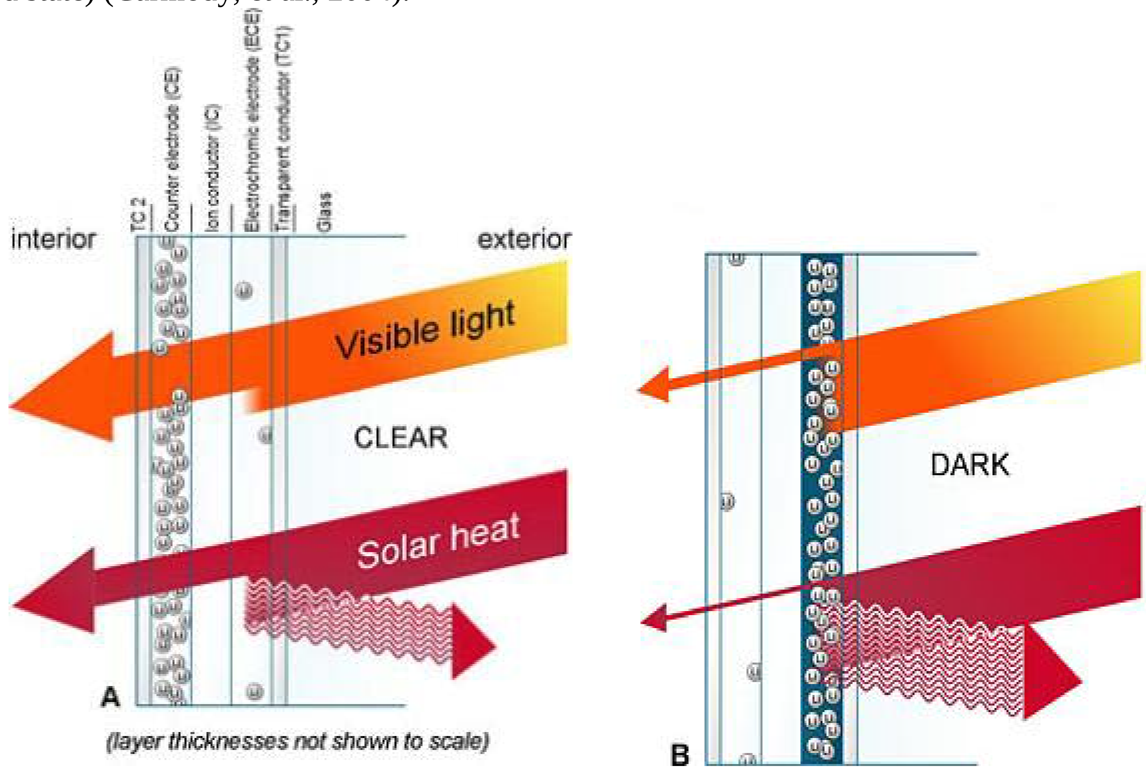

Figure B-1. Detailed Cross Section of Sage® Electrochromic Window with Clear (A) and Shaded (B) states (Sage Electrochromic, 2006a)

In terms of durability, various types of EC windows have also been shown through independent tests to be extremely durable under hot and cold conditions and under intense sun (Carmody, et al., 2004). These devices have been cycled (from clear to colored and then back again) numerous times under realistic conditions so that one can expect long-term sustained performance over the typical 20–30 year life of the installation. Typical operating temperatures are between –20 and 190 degrees Fahrenheit (Carmody, et al., 2004). Additionally, other durability testing to assure product reliability has been conducted throughout the materials and technology development processes. Samples of the glass have been tested by several accredited third-party organizations, including the DOE. In a series of tests, which were carried out for more than 10 years, the EC glass was subjected to simulated solar light and heat while being continuously switched between the clear and tinted states. The units successfully completed all tests, and even surpassed the requirements for the ASTM[29] Test Standard E-2141-02, which evaluates "the combined degradative effects of elevated temperature, solar radiation and extended electrical cycling through 50,000 cycles…" (Sbar, 2007). The dynamic windows continued switching through 100,000 cycles (clear/tint /clear), which is double the test standard and "equivalent to switching a window nine times per day for 365 days per year across a 30-year lifetime" (Sbar, 2007). The units successfully completed a 24-month test in the Arizona desert and 36 months in a Minnesota test site, as well as numerous evaluations carried out by leading companies in the glass industry (Sbar, 2007).

By some estimates these "smart windows" (which categorizes dynamic window systems such as EC windows) could reduce peak electric loads by 20-30% in many commercial buildings and increase daylighting benefits throughout the U.S., as well as improve comfort and potentially enhance productivity in our homes and offices (Lee, et al., 2002). Compared to an efficient low-e window with the same daylighting control system, the EC window showed annual peak cooling load reductions from control of solar heat gains of 19–26% and lighting energy use savings of 48–67% when controlled for visual comfort (Lee, et al., 2006).

The Lawrence Berkeley National Laboratory (LBNL) conducted numerous commercial building energy simulation studies in the mid-1990s, concluding that significant annual total energy savings can be obtained compared to spectrally selective low-emittance (low-e) windows in moderate to hot climates if large-area EC windows are controlled to maintain the interior illuminance set point level and are combined with daylighting controls (Lee, et al., 2004). In the northern European Union (EU) where commercial buildings are often heating-dominated and passive cooling is encouraged, researchers have investigated alternate strategies with and without daylighting controls where the EC is switched to provide passive heating during the winter and to reduce cooling requirements and overheating during the summer (Lee, et al., 2004). Recently, LBNL conducted a full-scale test in an urban office (Lee, et al., 2000), figure 10, and an experimental field study at the LBNL test site (Lee, et al., 2006), figure 11.

[29] Now called ASTM International, is one of the largest voluntary standards development organizations in the world-a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy. (Source: http://www.astm.org/ABOUT/aboutASTM.html)

Figure B-2. Interior view of test room on a partly cloudy day. The EC windows are in the clear state at 10:30 under diffuse light conditions (left). When sun enters the window, the EC switches to its fully colored state by 10:50 (right) (Lee, et al., 2000).

Figure B-3. LBNL Window Test Bed Facility (upper photo). South elevation of EC facades (lower photo) (Lee, et al., 2006).

By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand (Lee, et al., 2002).

Non-Economical Value of EC Windows

Non-cost factors merit discussion because while they may not yet be universally accepted as decision making criteria, most if not all of the literature in our review have found them to be worthy of consideration for EC windows. However, due to the qualitative nature of these non-cost factors, the discussion will be kept to three areas found in our review of existing literature and not an in-depth analysis of merit or decision criteria. These three areas of interest are: (1) potential occupant satisfaction as it relates to acceptance, (2) potential occupant productivity increase, and (3) potential environmental benefits.

In order to determine the occupant comfort, satisfaction, and acceptance, which are critical to market success, Lee, et al. (2006) conducted a survey of 43 subjects as part of their experimental field study where the subjects were exposed for 40–60 minutes to three different EC window-lighting conditions. Results from the survey (Lee, et al., 2006) confirm the promise of EC systems to improve satisfaction and comfort in work spaces. Occupants found the EC window system significantly more desirable than the reference window, where preferences were strongly related to perceived reductions in glare, reflections on the computer monitor, and window luminance. With the EC systems, subjects chose to face the window to do computer-related tasks, presumably for view, despite minor complaints of glare and brightness, see figure 12 and 13.

Figure B-4. Occupancy Comfort Study Allowing Users to Adjust Different Window Pane per User Comfort (Sage Electrochromic, 2006a).

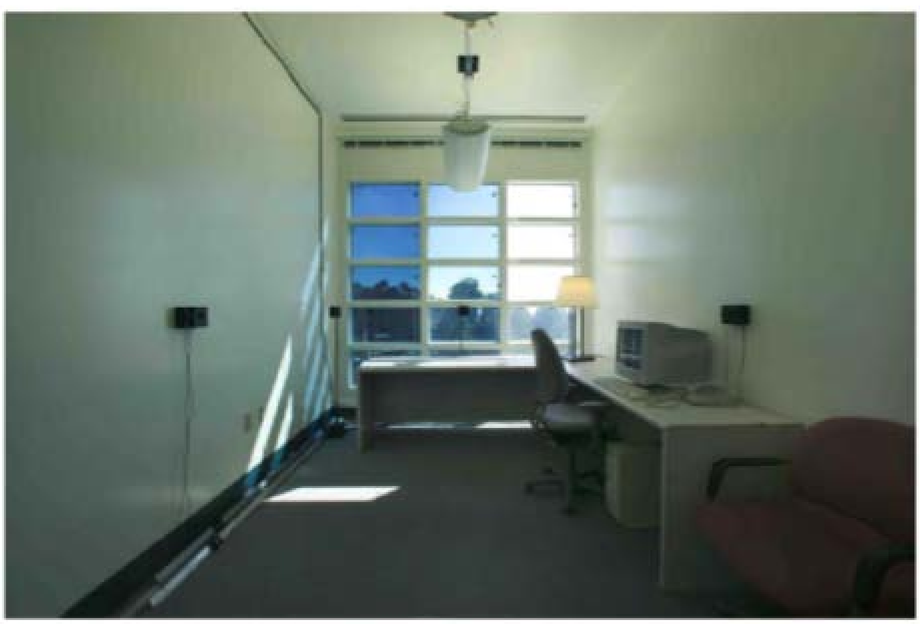

Figure B-5. Interior view of EC Window and the Different Levels of Shading Possible (Lee, et al., 2006).

The EC system has the added advantage over a window blind system of being able to provide views out for a larger percentage of the day (Lee, et al., 2006). The Lee, et al. (2006) study stresses that the mere presence of EC windows does not guarantee energy savings or visual comfort and freedom from glare. However, the results from their test bed suggest that a marketable EC system can be developed that will save energy while maintaining visual comfort. The Lee, et al. (2006) study results also reaffirm findings from the field test and DOE-2[30] simulations, where visual comfort criteria were satisfied indirectly. In addition, the percentage per year that the occupant has a view out is significantly greater: 98% for the EC case versus 38% for the reference case. These simulation data suggest that EC windows can lead to greater occupant satisfaction and perhaps increased productivity and a more healthful environment (Lee, et al., 2006). Many research literatures such as Lee, et al. (2006), Carmody, et al. (2004), and Ruck, et al. (2000), for example, conclude that view has important but not yet quantifiable value. This value could be converted to productivity dollars in the future but we were unable to find any in current literature except a Boyce, et al. (2003) study that found that if an occupant has a view out, stress and eye fatigue can be reduced (Lee, et al., 2006); but no related quantitative cost was claimed.

A limited research on human performance related to daylighting was found but only related to student performance. The Nicklas, et al. (1996) study on middle school students stated that students who attended daylit schools outperformed the students who were attending nondaylit schools by 5 to 14%. During their (Nicklas, et al., 1996) study, the results of performance that spanned multiple years also yielded greater impact for improved performance of students in daylit schools. Their study also noted that one new, non-daylit middle school actually showed a negative impact on the students' performance (Nicklas, et al., 1996). We don't consider the outcomes of the performance of middle school student as indicators for office workers, but it is interesting to note the potential of daylighting technology on human performance. It points out, above all else, that further research is needed on the daylight to productivity relationship.

Environmentally, a 10% reduction in US electricity use would cut annual carbon dioxide emissions by over 200 million tons, sulfur dioxide emissions by 1.7 million tons, and nitrogen oxide emissions by 900 thousand tons (ODUSD, 2005). From the perspective of environmental conservation, it has been estimated that in the U.S., with the adoption of the 'green seal' environmental standards for windows, 350 million barrels of oil per year will be saved (Syrrakou, et al., 2005). Additionally, Boyle (1996) found that 40% of the energy consumed each year is used in buildings and that electricity consumption in buildings is about 20% of the total energy used. The widespread use of EC windows is estimated to cause a net reduction of electricity consumption by 2.4% at the aggregate level. The reduction of GHG is expected to be three times this amount (e.g. 7.2%) given that electricity production has an efficiency of about 30% (Syrrakou, et al., 2005).

Furthermore, the incorporation of the EC glazing in an advanced window could improve the thermal insulation and reduce thermal losses during winter, i.e. gas filled double pane low-e

[30] An energy load and cost simulation software certified by the DOE and considered industry standard. A detailed discussion is available in Chapter 3.

glass with EC glazing[31]. Syrrakou, et al. (2005) estimated that 60% of the thermal losses in buildings take place through windows and that 60% of the energy in buildings is used for space heating. A reduction of 46% in the glazing U-value (possible by use of advanced materials), could cause a 17% reduction of the energy for heating of buildings, or a 6.8% reduction of the net energy consumption. This can be translated to an equal reduction of GHG emissions by 14% (Syrrakou, et al., 2005). The impact of EC windows to climate change at the aggregate level, the potential impact to occupant health and productivity, and worker satisfaction while not yet quantifiable could be consideration along with economic measures by the USAF decision makers to determined the true value of EC windows.

Electrochromic Window Limitations

One of the main challenges to EC glazing previously mentioned throughout this section is economics of EC windows. EC windows are still new to the market despite their lengthy research history. Therefore, cost competitiveness could be a significant factor to determine implementation. Currently in the U.S., EC windows can be in the range from approximately $50-$130/sq ft; and the largest group are from about $50-$100/sq ft (Sage Electrochromics, Inc. Vice President of Sales and Marketing Personal Communication, 2009) compared to about $20-$30/sq ft for a standard insulating glazing (Waier, 2007).

One of the technical challenges of EC windows to achieve savings, comfort, and amenity is that an accurate intermediate-state EC window controller will be needed (Lee, et al., 2006). Integrated EC window-lighting systems, which modulate glass transmittance to manage daylight, glare, and cooling load and to dim lights to capture energy savings, must also be developed to meet visual comfort requirements while maximizing daylight admission and reducing lighting power (Lee, et al., 2006). Another technical issue highlighted from the Lee, et al. (2006) experiment was that in cold climates where the outdoor air temperature is low (<0ºC, <32ºF) and incident irradiation levels are also low, EC windows may take as long as 40 minutes, or more, to alter its shading state, which could significantly affect occupant satisfaction. Additionally, a manual override switch capability is also required because it increases occupant comfort and satisfaction base on a Department of Energy study (Boyce, et al., 2003). These will add additional cost to the window system.

Decision makers must weigh these benefits and limitations of this new window technology. Yet most decision makers are risk averse, especially those in the public sector (Kirkwood, 1997), so they often need to be presented with a cost analysis that provides an effective level of confidence to support one alternative over another. However, the current method of economic analysis may not be considering risk and uncertainty adequately thereby providing an incomplete analysis for the decision makers. Our research proposes to determine if there is evidence of this by comparing the results of our probabilistic economic model with the current deterministic one. Currently, the DOD uses the Federal Energy Management Program (FEMP) guidance one conducting economic analysis for all energy projects by using of life-cycle cost analysis (LCCA) which includes risk and uncertainty analysis.

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[31] In this window set-up, safe inert gas is filled in between the double panes of glass. The most commonly used gas is argon, which is easily extracted from the atmosphere. Krypton is more effective, particularly in small spaces, but is more costly to obtain and use than argon. When combined with special coatings, gas-filled units can achieve very high insulating values (Deal, et al., 1998).

APPENDIX C

Electricity Cost: Consumption vs. Peak Demand

Electricity is priced on a consumption and demand basis; which means that electricity is based on use (consumption, measured in kilowatt-hour (kWh)) and the rate of use (demand, measured in kilowatt (kW)) (Holtz, 1990). Peak demand charges can be found in more than 80% of all utility company rate schedules in the United States, and close to 100% of all utilities outside the United States (Holtz, 1990). Ignoring the impact of peak demand on costs would be overlooking 74% of the total energy costs of the building. Costs associated with producing electricity can vary from month to month for a utility and are reflected in the cost per kWh of electricity purchased. How the peak demand for a building is determined can vary from one utility to another, but, in general, it is based on the largest need for electricity during a billing period (Holtz, 1990). Therefore, peak demand represents the maximum rate of energy use, and peak demand costs, in dollars per kW, represent a charge for the largest (peak) rate of energy use. The rate of electrical energy use, in kW, is different than the consumption of electricity, in kWh (Holtz, 1990).

Suppose, for example, two identical buildings both consume 20,000 kWh of electricity in a month. However, building A has a peak demand of 5 kW and building B has a peak demand of 500 kW. It is clear that the utility servicing both building A and B in the same electrical grid has to be able to maintain a power plant that has the capacity to produce 505 kW of electricity to be able to meet the needs of the two buildings, regardless of the fact that they are both consuming 20,000 kWh. If the utility rate structure is $0.10 per kWh for electricity and $10.00 per kW for peak demand, then building A with a 5 kW peak demand has a monthly utility bill of $2,050 and building B with a 500 kW peak demand has a utility bill of $7,000. Although the two buildings consume the same quantity of energy (20,000 kWh), their monthly bills are quite different (Holtz, 1990). Therefore, a properly designed passive solar building is one that saves both energy use and energy costs.

Energy conservation is often understood by general consensus as doing more with less, or performing the same functions with less energy. However, this could be a misunderstanding; conserving energy may not necessarily reduce energy usage, rather create a system that will reduce energy costs. Saving energy costs without reducing energy use can occur if the peak demand for a building can be reduced (Holtz, 1990). In the previous example with building A and B, suppose the demand for building B were reduced from 500 kW to 250 kW. Then the energy costs would be reduced from $7,000 to $4,500 even if there is no reduction in energy usage (still at 20,000 kWh) (Holtz, 1990). Decreasing the peak demand but simultaneously increasing the consumption of electricity can make it possible to reduce the overall cost of energy in a building. Therefore, if building B (500 kWh) could reduce its monthly peak demand to 100 kW at the price of increasing its consumption to an additional 10,000 kWh, the total electricity costs would be based upon 30,000 kWh and 100 kW. This would result in a monthly electricity bill of $4,000; which would be down from the original $7,000 (Holtz, 1990). The reduction of peak demand has been the source of several policy related studies by the Rand Corporation (Acton, et al., 1980) and the Brattle Group (Faruqui, et al., 2007) and could be one of the most significant factors that could impact overall energy usage and savings by using EC windows.

Apte, et al. (2008) used the 1999 Commercial Buildings Energy Consumption Survey (CBECS[32]) data to research the effectiveness of different window types on energy performance for various climates and concluded that EC windows offered substantially larger energy savings than what would be possible with standard low-e products. And EC window's greater appeal was the fact that they offered peak demand reductions, a significant source of potential economic savings. Lee, et al. (2006) found that the efficacy of the lighting control system will also affect the magnitude of savings. The older 0 – 10 V ballast technology is inefficient at the low end of the dimming range – some systems consume ~35% of full power while providing ~10% of full light output. This is due to the power consumption of the electronic circuitry, which is fixed irrespective of dimming level. With the newer DALI® digital ballasts, the low end can be reduced to 17% of full power while providing ~1–9% of full light output. This again reiterates that EC windows are not a standalone energy saver but must be incorporated as part of the overall façade design for a facility (Lee, et al., 2006).

One of the limitations of EC windows despite its projected energy savings appears to be its cost. While the cost is projected to decrease with future advancement and competition, EC windows are still considered relatively new technology with two years in the commercial market and currently manufactured by only one company in the U.S. Even though first cost is usually the criterion given most consideration in decision-making for integrated façade systems, a focus on first cost typically fails to consider the benefits of particular investment on life-cycle cost, and factors that may not yet be quantifiable on a cost basis (Lee, et al., 2002). There are several valid reasons for primary consideration of first cost; one is the physical limitation ("ceiling cost") of the budget. This may be simply because additional funding is not possible to obtain, or because the limitation is imposed for some other reason, such as a political process that is involved in all budgetary issues for the particular building. Such limitations are quite typical for public and institutional projects (Lee, et al., 2002); and tends to be the case for many projects in the USAF. However, the non-economic benefits of the technology are noteworthy and should be considered by the decision makers along with the economic factors; which are discussed in the next section.

[32] A national sample survey that collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures. It contains 5,430 records, representing commercial buildings from the 50 States and the District of Columbia. The survey is conducted quadrennially.

Appendix D

An LCCA comprises of different financial inputs from a project that are analyzed to calculate the SIR and payback period which provide the decision makers with a relative scale of success and return on investment. In order to conduct the analysis the following inputs are often considered (ODUSD, 2005):

> ***Investment costs*** are the initial costs of design, engineering, purchase, construction, and installation exclusive of sunk costs.
> ***Sunk costs*** are costs incurred before the time at which the LCC analysis occurs. Only cash flows that occur at present or in the future are pertinent to the LCC economic analysis.
> ***Recurring costs*** are future costs that are incurred uniformly and annually over the study period. These recurring costs may be energy costs or operation and maintenance costs.
> ***Nonrecurring costs*** are costs that do not uniformly occur over the study period. Non-recurring costs are typically maintenance, repair, or replacement costs.
> ***Replacement costs*** are future costs to replace a building energy system, energy conservation measure, or any component thereof, during the study period.
> ***Salvage value*** is the value of any building energy system removed or replaced during the study period or recovered through resale or remaining at the end of the study period.
> ***Study period*** is the time period covered by an LCC analysis. For Federal projects, the study period is typically either the estimated life of the system, the least common multiple of different alternatives' lives, or a time period specified by the funding program -- plus a planning and construction period of up to five years, if appropriate. Federal guidelines for LCC outlined in the CFR limit the assumed system lifetime to a maximum of 25 years. With a planning and construction period (maximum of five years), the maximum study period is 30 years. Table 2 lists recommended study periods for different categories of energy and water conservation projects.
> ***Base date*** is the beginning of the first year of the study period, generally the date on which the LCC analysis is conducted. This is the date to which future cash flows are discounted to determine equivalent present value.
> ***Service date*** is the point in time during the study period when a building or building system is put into use, and operation-related costs (including energy and water costs) begin to be incurred. For convenience, the base date and the service date are frequently assumed to be the same. While this assumption does not reflect reality, it does greatly simplify the mathematics and is consistent with typical methods for calculating simple payback. In reality, there is normally a significant time period between the analysis and the service date of the project, typically 1-3 years.
> ***Planning and construction period*** is the time between the base date and the service date. (ODUSD, 2005)

Recommended LCC Analysis Life of Energy and Water Projects (ODUSD, 2005).

Category	*Title*	*Description*
1	EMCS or HVAC Controls (10 years)	Projects to control energy systems centrally to adjust temperature automatically, shed electrical loads, control motor speeds, or adjust lighting intensities
2	Steam and Condensate Systems (15 years)	Projects to install condensate lines, cross connect lines, distribution system loops; to repair or install insulation, and to repair or install steam flow meters and controls
3	Boiler Plant Modifications (20 years)	Projects to upgrade or replace central boilers or ancillary equipment to improve overall plant efficiency, including fuel switching or dual fuel conversions
4	HVAC (20 years)	Projects to install more energy efficient heating, cooling, ventilation, or hot water heating equipment, including the HVAC distribution system (ducts, pipes, etc.)
5	Weatherization (20 years)	Projects to improve the thermal envelope of a building, including daylighting, fixtures, lamps, ballasts, photocells, motion/IR sensors, light wells, highly reflective painting
6	Lighting Systems (15 years)	Projects to install replacement lighting system/controls, including daylighting, fixtures, lamps, ballasts, photocells, motion/IR sensors, light wells, highly reflective painting
7	Energy Recovery Systems (20 years)	Projects to install heat exchangers, regenerators, heat reclaim units or to recapture energy lost to the environment
8	Electrical Energy Systems (20 years)	Projects to increase energy efficiency of an electrical device or system or to reduce cost by reducing peak demand
9	Renewable Energy Systems (20 years)	Any project utilizing renewable energy. This includes active solar heating, cooling, hot water, industrial process heat, photovoltaic, wind, biomass, geothermal, and passive solar applications
10	Facility Energy Improvements (20 years)	Multiple category projects or those that do not fall into any other category, to include water conservation projects.

Some of the economic terms that are internally calculated during the LCC and embedded in BLCC are described below:

Present Value (PV) is the time-equivalent value of past, present, or future cash flows as of the beginning of the base year, or the base date.

Discounting is the process of calculating present values based on future cash flows. For purposes of mathematical convenience, cash flows are normally assumed to occur at the end of each year, although DOD has historically used middle-of-year cash flow convention. In OMB and FEMP studies, all annually recurring cash flows (e.g., operational costs) are discounted from the end of the year in which they are incurred; in MILCON studies they are discounted from the middle of the year. All single amounts (e.g., replacement costs, residual values) are discounted from their dates of occurrence (Fuller, 2008). Either method is consistent with federal requirements and will result in the same decisions, as long as a single method is consistently applied to all considered alternatives.

Discount rate is the rate of interest that reflects the Government's time value of money or opportunity cost. For Federal energy projects, the rate is determined annually by DOE based on short-term treasury rates but is limited to a low of 3% and a high of 10% regardless of interest rates. Energy project analyses should use the discount rate for the current fiscal year as reported in NISTIR 85-3273 and 4942. The discount factors are embedded in LCC software such as BLCC5 and other federal LCC computer programs (Fuller, 2008).

Present Value factors are discount factors that are calculated based on a given time period and discount rate, which, when multiplied by a future dollar amount, give the equivalent present value as of the base date.

Single Present Value (SPV) factors are used to convert single future amounts to PVs .

Uniform Present Value (UPV) factors are used to convert annually recurring amounts to PV. **Modified Uniform Present Value (UPV*)** factors are used to convert annually recurring amounts where amounts change based on escalation rates or where costs change differently from inflation, as in many types of energy costs. UPV* factors based on expected fuel price inflation for different energy types and regions of the country are published annually in NISTIR 85-3273 and 4942. Figure 15-3 summarizes the three basic PV factors used in Federal energy project analysis. (ODUSD, 2005)

Appendix E

The mathematics behind MC are given below as described from Emblemsvag (2003) on use of MC for LCC.

> Given that x is the required quantity of the mathematical expectation of Mξ of a certain random variable the MC method of determining the approximate value of x consists of an N-fold sampling of the value of the variable ξN in a series of independent tests, $\xi 1, \xi 2, \ldots, \xi N$, and the computation of their mean value:
>
> $$\xi = \frac{\xi 1 + \xi 2 + \cdots + \xi N}{N} \qquad \text{(eq. 2)}$$
>
> Then, according to the law of large numbers (Bernoulli's or Chebyshev's Theorem):
>
> $$\xi = M\xi = x \qquad \text{(eq. 3)}$$
>
> With a probability that is close to unity for a sufficiently large N. A traditional example in statistics is the tossing of a die and calculating the probability of obtaining a total of three when tossing two ordinary dice. Simulating this problem using a MC method is straightforward. Simulate the tossing in N trials (each trial representing a toss), count the number of trials when one gets threes, and then estimate the probability as
>
> $$\hat{\rho} = \frac{n}{N} \qquad \text{(eq. 4)}$$
>
> The error in this estimate is measured by the standard deviation σ, where
>
> $$\sigma = \sqrt{\frac{p(1-p)}{N}} \qquad \text{(eq. 5)}$$
>
> However, since we assume we do not know p, the error term can only be estimated statistically. In the general case, for every $\varepsilon > 0$ and every $\delta > 0$, there exists a number N of trials, such that with a probability greater than $1 - \varepsilon$, the frequency of occurrences of an event $(\frac{L}{N})$ will differ from the probability p of the occurrence of this event by less than δ:
>
> $$\left|\frac{L}{N} - p\right| < \delta \qquad \text{(eq. 6)}$$

The degree of certainty of the error is $1 - \delta$. By investigating the error term, we see that the accuracy is highly dependent on the number of trials (N) performed in the simulation. By simplifying Chebyshev's inequality, we can estimate the δ as

$$\delta \sim \frac{1}{\sqrt{N}} \quad \text{(eq. 7)}$$

We see that to improve an estimate tenfold, we need to run a hundred times more trials. This equation holds for all cases. However, if we assume that the distribution of the event is approximately Gaussian, we get the following:

$$\delta \leq \frac{3\sigma}{\sqrt{N}} \quad \text{(eq. 8)}$$

Thus, we see that in most cases (Gaussian behavior is most common, and all other behavior tends to approach the Gaussian behavior according to the Central Limit Theorem), the error also depends on the variance of each independent test trial.

(Emblemsvag, 2003)

Appendix F

AFCESA Prototypical USAF Office Building Description

Description	**Baseline Parameter**	**Reference**
Building Description	-2-Story (2 floors above grade) -Oriented North -Floor to Floor height: 12 ft -Floor to Ceiling height: 9 ft -36,000 sq ft	(Pratt, 2006) (AFCESA, 2007)
Roof Construction	-Metal frame, > 24 in o.c. -3-ply built up roof (BUR) -Gravel finish -3 in polysocyanurate (R-21) insulation	(Pratt, 2006)
Wall construction	-Metal frame, 2x6, 24 in o.c. -Brick exterior -Batt insulation (R-19) -Additional 1 in polyurethane (R-6) insulation	(Pratt, 2006)
Windows	-Single pane, 1/8” -Aluminum frame w/o thermal break - Window to wall ratio (WWR) = 45% -No skylights -Interior shades set at 50% overall	(Pratt, 2006) (Lee, et al., 2004)
Heating, Ventilation, and Air Conditioning (HVAC) system	-Packaged Single Zone Direct Expansion (DX) with furnace 11.25-20 ton -Minimum 0.5 cfm/sq ft -Continuous Fan -Setpoints: Occupied: Cool: 76 °F Heat: 70 °F Unoccupied: Cool: 82 °F Heat: 64 °F	(Pratt, 2006)
Schedule	-7 am – 5 pm M-F, no weekends or holidays **Note: HVAC starts one hour before and stops one hour after scheduled duty hours	(Pratt, 2006)

Appendix G

SAGE Electrochromic Inc. Technical Specification Sheet of Currently Available EC Windows (Sage Electrochromic, 2006a).

PERFORMANCE DATA

The table shows the performance data of the five standard SageGlass IGU products.
The colored SageGlass IGUs derive their hues from the inboard lite which either has a tinted PVB layer or is tinted glass.

PRODUCT			TRANSMITTANCE				REFLECTANCE			U-FACTOR		SHGC	LSG*	STC**
Color	Inboard lite	Tint State	Visible	Solor	UV	KDF	VIS in	VIS out	Solar	Winter	Summer			
Classic™	Tempered/HS 6mm clear	clear	62%	40%	5.6%	18%	15%	21%	20%	0.29	0.28	0.48	6.9	35
		tinted	3.5%	1.5%	0.8%	2.2%	10%	6%	10%	0.29	0.28	0.09		
Classic™	Laminated 060 PVB	clear	62%	40%	0.4%	15%	14%	21%	20%	0.28	0.28	0.48	6.9	40
		tinted	3.5%	1.5%	0.1%	1.7%	10%	6%	10%	0.28	0.28	0.09		
See Green™	Tempered/HS 6mm tinted	clear	48%	19%	4%	15%	10%	20%	20%	0.29	0.28	0.44	5.3	35
		tinted	2.8%	1%	0.6%	1.8%	8%	6%	10%	0.29	0.28	0.09		
Cool View Blue™	Laminated 060 PVB	clear	40%	30%	0.0%	12%	8%	19%	20%	0.29	0.28	0.46	4.4	40
		tinted	2.3%	1%	0.0%	1.3%	7%	6%	10%	0.29	0.28	0.09		
Clear-as-Day Gray™	Laminated 060 PVB	clear	35%	31%	0.0%	10%	7%	19%	20%	0.29	0.28	0.46	3.9	40
		tinted	1.9%	1%	0.0%	1.1%	6%	6%	10%	0.29	0.28	0.09		

*LSG: Light to Solar Gain ratio for SageGlass IGU calculated as Tvis (clear)/SHGC (tinted)
**STC: Sound transmission class
Confirm with Sales on availability of sizes in each product

Modelled using Window 5.2
90% argon filled units; 1/2" air gap

Appendix H

Present-Value Formulas and Discount Factors for Life-Cycle Cost Analysis.

PV formula for one-time amounts

The **Single Present Value (SPV) factor** is used to calculate the present value, PV, of a future cash amount occurring at the end of year t, F_t, given a discount rate, d.

$$PV = F_t \times \frac{1}{(1+d)^t}$$

$$PV = F_t \times SPV_{(t,d)}$$

The **SPV factor** for d = 3% and t = 15 years is **0.642**.

PV formula for annually recurring uniform amounts

The **Uniform Present Value (UPV) factor** is used to calculate the PV of a series of equal cash amounts, A_0, that recur annually over a period of n years, given d.

$$PV = A_0 \times \sum_{t=1}^{n} \frac{1}{(1+d)^t} = A_0 \times \frac{(1+d)^n - 1}{d(1+d)^n}$$

$$PV = A_0 \times UPV_{(n,d)}$$

The **UPV factor** for d = 3% and n = 15 years is **11.94**.

PV formula for annually recurring non-uniform amounts

$$PV = A_0 \times \sum_{t=1}^{n} \left(\frac{1+e}{1+d}\right)^t = A_0 \frac{(1+e)}{(d-e)}\left[1 - \left(\frac{1+e}{1+d}\right)^n\right]$$

The **Modified Uniform Present Value (UPV*) factor** is used to calculate the PV recurring annual amounts that change from year to year at a **constant** escalation rate, e (i.e., $A_{t+1} = A_t \times (1+e)$), over n years, given d. The escalation rate can be positive or negative.

$$PV = A_0 \times UPV^*_{(n,d,e)}$$

The **UPV* factor** for e = 2%, d = 3%, and n = 15 years is **13.89**.

PV formula for annually recurring energy costs (FEMP LCCA)

The **FEMP UPV* factor** is used to calculate the PV of annually recurring energy costs over n years, which are assumed to change from year to year at a **non-constant** escalation rate, based on DOE projections. FEMP UPV* factors are precalculated for the current DOE discount rate and published in tables Ba-1 through Ba-5 of the Annual Supplement to Handbook 135.

$$PV = A_0 \times UPV^*_{(reg, ft, rt, d, n)}$$

The **FEMP UPV* factor** for region (reg) = 3, fuel type (ft) = electricity, rate type (rt) = commercial, d = 3%, and n = 15 is **12.12** (1995).

Appendix I

Cost Estimate obtained directly from the manufacturer, Sage Electrochromics, Inc. (2008) based on design of conceptual office facility.

SageGlass® Pricing Analysis for Conceptual U. S. Air Force Facility

Building dimensions (ft. X ft.):	180	X	100
Building area per floor (sq. ft.):	18,000		
Number of stories:	2		
Total building floor area (sq. ft.):	36,000		
Floor to floor height (ft.):	12		
Building wall area (sq. ft.):	13,440		

Concept # 1 (2 glass sizes: 40" x 60" & 40" x 36"):

Window to wall ratio:	15%		30%		45%		60%	
Building glass area (sq. ft.):	2,016		4,032		6,048		8,064	
	$ / Sq. Ft.	$	$ / Sq. Ft.	$	$ / Sq. Ft.	$	$ / Sq. Ft.	$
SageGlass® Classic product:	$56.74	$114,388	$50.79	$204,785	$49.71	$300,646	$49.17	$396,507
SageGlass® product controls & wiring:	$8.33	$16,793	$6.56	$26,450	$6.83	$41,308	$6.31	$50,884
Subtotal:	$65.07	$131,181	$57.35	$231,235	$56.54	$341,954	$55.48	$447,391
Add for 40 "occupant override" wall switches:	$2.26	$4,556	$1.13	$4,556	$0.75	$4,556	$0.56	$4,556
Total:	$67.33	$135,737	$58.48	$235,791	$57.29	$346,510	$56.04	$451,947

Concept # 2 (1 glass size: 32" x 60"):

Window to wall ratio:	15%		30%		45%		60%	
Building glass area (sq. ft.):	2,016		4,032		6,048		8,064	
	$ / Sq. Ft.	$	$ / Sq. Ft.	$	$ / Sq. Ft.	$	$ / Sq. Ft.	$
SageGlass® Classic product:	$50.93	$102,675	$49.92	$201,277	$49.58	$299,860	$49.41	$398,442
SageGlass® product controls & wiring:	$8.50	$17,136	$7.75	$31,248	$7.65	$46,267	$7.45	$60,077
Subtotal:	$59.43	$119,811	$57.67	$232,525	$57.23	$346,127	$56.86	$458,519
Add for 40 "occupant override" wall switches:	$2.26	$4,556	$1.13	$4,556	$0.75	$4,556	$0.56	$4,556
Total:	$61.69	$124,367	$58.80	$237,081	$57.98	$350,683	$57.42	$463,075

Appendix J

[+]Peak Demand Rate Reference Sites:**

florida	http://www.fpl.com/rates/pdf/electric_tariff_section8.pdf
south dakota	http://www.midamericanenergy.com/pdf/rates/elecrates/sdelectric/sd-elec.pdf
maryland	http://www.pepco.com/_res/documents/md_tariff.pdf
new jersey	http://www.pseg.com/customer/energy/pdf/TPS_Electric_%20Tarrif.pdf
utah rates	http://www.utahefficiencyguide.com/measures/rates.htm
north carolina	http://www.duke-energy.com/pdfs/SCScheduleIT.pdf
ohio	http://www.duke-energy.com/pdfs/DE-OH-ds(2).pdf
california	http://www.pge.com/tariffs/electric.shtml#INDUSTRIAL
arizona	http://www.aps.com/_files/rates/e-35.pdf
new mexico	http://www.pnm.com/regulatory/pdf_electricity/schedule_4_b.pdf
north dakota	http://www.otpco.com/ElectricRates/PDF/ND/c-02n.pdf
louisiana	https://www.swepco.com/global/utilities/tariffs/Louisiana/LouisianaA_07_03_2008.pdf
nebraska	http://www.nppd.com/My_Account/Additional_Files/rates/generalservicedemand.pdf (Nebraska rate is estimated on a per 100kW usage due to non-explicit rate available from Nebraska Public Power District)

**** All rates are for large use general schedule or Industrial use facilities as defined by**

**** Note: Rate does not include basic monthly service fee and power factor penalty**

Appendix K

This section discusses in-depth key economic metrics recommended for use by NIST Handbook 135. SIR is a measure of economic performance for a project alternative that expresses the relationship between its savings and its increased investment cost (in present value) as a ratio (Fuller, et al., 1996). It is a relative measure and must not be used for choosing among mutually exclusive alternatives. As explained in chapter 2, SIR must be greater than 1.25 for DOD energy projects to be considered for funding (ODUSD, 2005). It is the preferred measure to rank projects and is calculated as follows (Fuller, et al., 1996):

$$SIR_{A:BC} = \frac{\Delta E + \Delta W + \Delta OM\&R}{\Delta I_o + \Delta Repl - \Delta Res} \qquad \text{(eq. 2)}$$

Where,

$SIR_{A:BC}$	=	Ratio of operational savings to investment-Related additional costs, computed for the alternative (A) relative to the base case (BC)
ΔE	$= (E_{BC} - E_A)$	Savings in energy costs attributable to the alternative
ΔW	$= (W_{BC} - W_A)$	Savings in water costs
$\Delta OM\&R$	$= (OM\&R_{BC} - OM\&R_A)$	Operations, maintenance, and repair costs
ΔI_O	$= (I_A - I_{BC})$	Additional initial investment cost required for the alternative relative to the base case
$\Delta Repl$	$= (Repl_A - Repl_{BC})$	Difference in capital replacement costs
ΔRes	=	Residual value

The AIRR is a measure of the annual percent yield from a project investment over the study period (Fuller, et al., 1996) and is a relative measure. It is measured against the minimum attractive rate of return (MARR) which is generally equaled to the discount rate, currently at 3 percent set by FEMP (Fuller, et al., 1996). The AIRR must be greater than the real discount rate in order to be considered an attractive investment and is calculated as follows (Fuller, et al., 1996):

$$\text{AIRR} = (1 + r)(SIR)^{\frac{1}{N}} - 1 \qquad \text{(eq. 3)}$$

Where,

r	= reinvestment rate (real discount rate)
SIR	= Savings to Investment Ratio
N	= number of years in the study period

Payback is defined as the time it takes to recover the initial investment costs; it is a relative measure and cannot be valid for use if there are multiple mutually-exclusive alternatives (Fuller, et al., 1996). Currently the payback method used by most practitioners is SPB; however, DPB is required by the DOD Energy Manager's Handbook (ODUSD, 2005). Generally, the shorter the payback, the more attractive the investment; however, it must not exceed 10 years to compete for private funding under ESPC (ODUSD, 2005). The general calculations for payback are shown below, where the minimum number of years, y, is calculated (Fuller, et al., 1996):

$$\sum_{t=1}^{y} \frac{[\Delta E_t + \Delta W_t + \Delta OM\&R_t - \Delta Repl_t + \Delta Res_t]}{(1+d)^t} \geq \Delta I_0 \qquad \text{(eq. 4)}$$

Where,

ΔE_t	$= (E_{BC} - E_A)_t$	Savings in energy costs in year t
ΔW_t	$= (W_{BC} - W_A)_t$	Savings in water costs in year t
$\Delta OM\&R_t$	$= (OM\&R_{BC} - OM\&R_A)_t$	Difference in OM&R costs in year t
$\Delta Repl_t$	$= (Repl_A - Repl_{BC})_t$	Difference in capital replacement cost in year t
ΔRes_t	$= (Res_A - Res_{BC})_t$	Difference in residual value in year t (usually zero in all but last year of study period)
d	=	discount rate
ΔI_0	$= (I_A - I_{BC})_0$	Additional initial investment cost

LCC was described at length in the literature review in chapter 2; therefore only the equation will be revisited here, shown below (Fuller, et al., 1996):

$$LCC = I + Repl + E + W + OM\&R + O - Res \qquad \text{(eq. 5)}$$

Where,

LCC	= Total LCC in present-value (PV) dollars of a given alternative
I	= PV investment costs (if incurred at base date, not discounted)
Repl	= PV capital replacement costs
E	= PV of energy costs
W	= PV of water costs
OM&R	= PV of non-fuel operating, maintenance and repair costs
O	= PV of other costs (e.g., contract costs for ESPCs or UESCs)
Res	= PV residual value (resale value, salvage value) less disposal costs

NS is used when benefits occur primarily in the form of future operational cost reductions; it calculates the net amount, in present-value dollars, which a project alternative is expected to save over the study period (Fuller, et al., 1996). The basic equation is shown below (Fuller, et al., 1996):

$$NS = LCC_{\text{Base Case}} - LCC_{\text{Alternative}} \qquad \text{(eq. 6)}$$

The final step prior to running the simulation will be to determine the number of iteration or trials, which should be significantly high (~10,000) (Emblemsvag, 2003). Our MCS model uses 10,000 iteration for each run.

Appendix L

State	State Tax Credit, Deduction, Exemption	State Sales Tax Exemption	State Buy Down, Grant, Production Incent.	Techs That Get State Incentives	Percent of Present Worth - Effect of Federal and State Incentives				
					PV	SDHW	WALL	DAYLT	POOL
AL			TVA $0.15/kWh	PV	65%	45%	45%		
AK					45%	45%	45%		
AZ			TEP $2/W AC; APS $2/W DC, Less than 5 kW	PV	50%		45%		
		Y	APS $350/single system	SDHW		49%			
AR					45%	45%	45%		
CA			$4.50/W/50% (>30kW-1.5MW)	PV	59%	45%	45%		
	15%		LADWP $6/W_85%_$2M	PV	62%	45%	45%		
CO					45%	45%	45%		
CT					45%	45%	45%		
DE			35%_$250K	PV, SDHW	52%	52%	45%		
FL		Y	JEA $4/W, $50K	PV	51%		45%		
			JEA 30%	POOL, SDHW		51%			51%
GA			TVA $0.15/kWh	PV	65%	45%	45%		
HI	35%, $250 K Maximum		HECO, HELCO and MECO	SDHW	65%	65%	65%		23%
			Kauai 50%	SDHW		65%			
ID					45%	45%	45%		
IL			60% or $6/W, $300K max	PV	57%				
			50%_$150K;	SDHW, WALL		55%	55%		
			ComEd $1.25/W_50kW	PV	66%				
IN			30%, $30K, >20kW	PV	51%				
			30%_$30K	PV, WALL, SDHW		51%	51%		
IA					45%	45%	45%		
KS					45%	45%	45%		
KY			TVA $0.15/kWh	PV	63%	45%	45%		
LA					45%	45%	45%		
ME					45%	45%	45%		
MD	15%, up to $2K for small systems			PV, WALL, SDHW	50%	47%	47%		
MA	100% tax deduction;			PV	54%	54%	54%		
	100% excise tax exemption			PV, WALL, SDHW, DAYLT					
MI					45%	45%	45%		
MN		Y	$2/W for small PV	PV	45%	45%	45%		
MS			TVA $0.15/kWh	PV	65%	45%	45%		
MO					45%	45%	45%		
MT	35%		PV, $4/W_50kW max	PV, SDHW, WALL	65%	55%	55%		

State	State Tax Credit, Deduction, Exemption	State Sales Tax Exemption	State Buy Down, Grant, Production Incent.	Techs That Get State Incentives	Percent of Present Worth - Effect of Federal and State Incentives				
					PV	SDHW	WALL	DAYLT	POOL
NE					45%	45%	45%		
NV			Boulder, small SDHW	SDHW	45%	51%	45%		
NH					45%	45%	45%		
NJ		Y	$5.50/W_70%	PV	77%	45%	45%		
NM			$0.01/kWh, Systems >10 MW	PV	45%	45%	45%		
NY			$5/W, >10kW, NYSERDA	PV	78%	45%	45%		
NC	35% up to $250K			PV, POOL, DAYLT	65%	45%	45%	23%	23%
ND	15%			PV, SDHW, WALL, POOL	54%	54%	54%		10%
OH		Y			45%	45%	45%		
OK	$0.0075/kWh				46%	45%	45%		
OR	35%		PV, $1.75/W DC	PV, SDHW, WALL, DAYLT	65%	65%	65%	23%	
PA			PECO $4/W_$20K+ $1/kWh/1yr	PV	55%	45%	45%		
RI		Y	$5/W, or 50%	PV	55%	45%	45%		
SC					45%	45%	45%		
SD					45%	45%	45%		
TN			TVA $0.15/kWh	PV	64%	45%	45%		
TX					45%	45%	45%		
UT	10%, $50K			PV, SDHW, WALL	51%	51%	51%		
VT		Y			45%	45%	45%		
VA					45%	45%	45%		
WA		Y			45%	45%	45%		
WV					45%	45%	45%		
WI			$2/kWh_1st yr. Gen, 50% or $50K;	PV	78%				
			Targeted at 25%	SDHW, WALL		50%	50%		
WY		Y			45%	45%	45%		

Appendix M
(Climate Zone 1)

Project: Minot AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 21:15

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,634	100.95	249,041	10,843	132,254	60,920	10,073	1,215	161	73
1	0+Change Bldg Orientation (E-W)	3,688	102.44	253,152	10,959	132,254	65,031	10,189	1,241	163	77
2	0+Activate Sidelighting, N-S	3,329	92.48	213,489	11,434	100,727	56,895	10,664	1,261	142	69
2.1	0+Activate Toplighting, N-S	3,658	101.61	234,320	12,589	116,944	61,510	11,819	1,392	155	77
2.2	2+Activate EC Windows, N-S	3,178	88.28	207,653	10,518	114,385	37,401	9,748	1,102	124	56
2.3	2.1+FULL daylighting system, N-S	3,217	89.36	193,194	12,388	99,075	38,252	11,618	1,292	121	60
3	1+Activate Sidelighting, E-W	3,385	94.03	217,739	11,556	100,715	61,157	10,787	1,287	144	73
3.1	1+Activate Toplighting, E-W	3,711	103.08	238,362	12,704	116,943	65,551	11,934	1,417	159	80
3.2	3+Activate EC Windows, E-W	3,189	88.58	208,548	10,537	114,420	38,261	9,767	1,107	125	56
3.3	3.1+FULL daylighting system, E-W	3,228	89.66	194,045	12,408	99,109	39,069	11,638	1,297	122	60
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-54	-1.49 (-1%)	-4,111 (-2%)	-116 (-1%)	0 (0%)	-4,111 (-7%)	-116 (-1%)	-26 (-2%)	-2 (-1%)	-4 (-5%)
2	0+Activate Sidelighting, N-S	305	8.47 (8%)	35,552 (14%)	-591 (-5%)	31,527 (24%)	4,025 (7%)	-591 (-6%)	-45 (-4%)	19 (12%)	4 (5%)
2.1	0+Activate Toplighting, N-S	-24	-0.66 (-1%)	14,720 (6%)	1,746 (-16%	15,310 (12%)	-589 (-1%)	-1,746 (-17%)	-177 (-15%)	6 (4%)	-4 (-5%)
2.2	2+Activate EC Windows, N-S	151	4.20 (4%)	5,835 (2%)	915 (8%)	-13,658 (-10%)	19,493 (32%)	916 (9%)	158 (13%)	18 (11%)	13 (18%)
2.3	2.1+FULL daylighting system, N-S	441	12.25 (12%)	41,127 (17%)	201 (2%)	17,869 (14%)	23,258 (38%)	201 (2%)	99 (8%)	34 (21%)	17 (23%)
3	1+Activate Sidelighting, E-W	303	8.41 (8%)	35,413 (14%)	-598 (-6%)	31,538 (24%)	3,874 (6%)	-598 (-6%)	-47 (-4%)	19 (12%)	4 (5%)
3.1	1+Activate Toplighting, E-W	-23	-0.64 (-1%)	14,790 (6%)	1,745 (-16%	15,310 (12%)	-520 (-1%)	-1,745 (-17%)	-176 (-15%)	4 (3%)	-3 (-4%)
3.2	3+Activate EC Windows, E-W	196	5.45 (5%)	9,191 (4%)	1,020 (9%)	-13,704 (-10%)	22,896 (38%)	1,020 (10%)	180 (15%)	19 (12%)	17 (23%)
3.3	3.1+FULL daylighting system, E-W	483	13.43 (13%)	44,316 (18%)	296 (3%)	17,834 (13%)	26,482 (43%)	296 (3%)	120 (10%)	37 (23%)	19 (27%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-54	-1.49 (-1%)	-4,111 (-2%)	-116 (-1%)	0 (0%)	-4,111 (-7%)	-116 (-1%)	-26 (-2%)	-2 (-1%)	-4 (-5%)
2	0+Activate Sidelighting, N-S	305	8.47 (8%)	35,552 (14%)	-591 (-5%)	31,527 (24%)	4,025 (7%)	-591 (-6%)	-45 (-4%)	19 (12%)	4 (5%)
2.1	0+Activate Toplighting, N-S	-24	-0.66 (-1%)	14,720 (6%)	1,746 (-16%	15,310 (12%)	-589 (-1%)	-1,746 (-17%)	-177 (-15%)	6 (4%)	-4 (-5%)
2.2	2+Activate EC Windows, N-S	456	12.67 (13%)	41,388 (17%)	325 (3%)	17,869 (14%)	23,519 (39%)	325 (3%)	113 (9%)	37 (23%)	17 (24%)
2.3	2.1+FULL daylighting system, N-S	417	11.59 (11%)	55,847 (22%)	1,545 (-14%	33,179 (25%)	22,668 (37%)	-1,545 (-15%)	-77 (-6%)	40 (25%)	13 (18%)
3	1+Activate Sidelighting, E-W	249	6.92 (7%)	31,302 (13%)	-714 (-7%)	31,538 (24%)	-237 (-0%)	-713 (-7%)	-72 (-6%)	17 (10%)	-0 (-0%)
3.1	1+Activate Toplighting, E-W	-77	-2.13 (-2%)	10,679 (4%)	1,861 (-17%	15,310 (12%)	-4,631 (-8%)	-1,861 (-18%)	-202 (-17%)	2 (1%)	-7 (-9%)
3.2	3+Activate EC Windows, E-W	445	12.37 (12%)	40,493 (16%)	306 (3%)	17,834 (13%)	22,659 (37%)	306 (3%)	108 (9%)	36 (22%)	17 (23%)
3.3	3.1+FULL daylighting system, E-W	407	11.29 (11%)	54,995 (22%)	1,565 (-14%	33,144 (25%)	21,851 (36%)	-1,565 (-16%)	-82 (-7%)	39 (24%)	13 (17%)

Project: Ellsworth AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 18:47

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,928	109.11	270,646	11,569	132,254	82,525	10,831	1,365	175	75
1	0+Change Building Orientation	4,008	111.32	277,081	11,707	132,254	88,960	10,968	1,400	188	83
2	0+Activate Sidelighting, N-S	3,599	99.97	232,481	12,187	98,757	77,857	11,449	1,411	157	72
2.1	0+Activate Toplighting, N-S	3,933	109.24	256,637	13,051	115,770	84,999	12,312	1,521	176	80
2.2	2+Activate EC Windows, N-S	3,087	85.75	217,618	8,589	113,257	48,494	7,851	951	120	53
2.3	2.1+FULL Daylighting, N-S	3,110	86.40	203,381	10,280	96,773	50,741	9,541	1,127	118	57
3	1+Activate Sidelighting, E-W	3,680	102.23	238,966	12,334	98,742	84,356	11,595	1,447	170	80
3.1	1+Activate Toplighting, E-W	4,005	111.25	262,360	13,187	115,773	90,720	12,448	1,554	184	86
3.2	3+Activate EC Windows, E-W	3,104	86.22	218,927	8,624	113,178	49,882	7,886	959	122	54
3.3	3.1+FULL Daylighting, E-W	3,127	86.86	204,675	10,315	96,698	52,110	9,576	1,135	120	58
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Building Orientation	-80	-2.21 (-2%)	-6,435 (-2%)	-137 (-1%)	0 (0%)	-6,435 (-8%)	-137 (-1%)	-36 (-3%)	-13 (-7%)	-8 (-10%)
2	0+Activate Sidelighting, N-S	329	9.14 (8%)	38,165 (14%)	-618 (-5%)	33,497 (25%)	4,668 (6%)	-618 (-6%)	-46 (-3%)	18 (10%)	3 (4%)
2.1	0+Activate Toplighting, N-S	-5	-0.13 (-0%)	14,009 (5%)	-1,482 (-13%	16,484 (12%)	-2,474 (-3%)	-1,481 (-14%)	-157 (-11%)	-1 (-1%)	-5 (-7%)
2.2	2+Activate EC Windows, N-S	512	14.22 (13%)	14,863 (5%)	3,599 (31%)	-14,500 (-11%)	29,363 (36%)	3,598 (33%)	460 (34%)	37 (21%)	19 (26%)
2.3	2.1+FULL Daylighting, N-S	822	22.84 (21%)	53,256 (20%)	2,771 (24%)	18,997 (14%)	34,258 (42%)	2,771 (26%)	394 (29%)	58 (33%)	24 (32%)
3	1+Activate Sidelighting, E-W	328	9.10 (8%)	38,115 (14%)	-627 (-5%)	33,511 (25%)	4,604 (6%)	-627 (-6%)	-47 (-3%)	18 (10%)	3 (4%)
3.1	1+Activate Toplighting, E-W	3	0.07 (0%)	14,720 (5%)	-1,480 (-13%	16,481 (12%)	-1,760 (-2%)	-1,480 (-14%)	-154 (-11%)	3 (2%)	-3 (-5%)
3.2	3+Activate EC Windows, E-W	576	16.00 (15%)	20,038 (7%)	3,710 (32%)	-14,436 (-11%)	34,474 (42%)	3,709 (34%)	489 (36%)	48 (27%)	26 (34%)
3.3	3.1+FULL Daylighting, E-W	878	24.38 (22%)	57,686 (21%)	2,872 (25%)	19,075 (14%)	38,610 (47%)	2,872 (27%)	419 (31%)	64 (37%)	28 (37%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Building Orientation	-80	-2.21 (-2%)	-6,435 (-2%)	-137 (-1%)	0 (0%)	-6,435 (-8%)	-137 (-1%)	-36 (-3%)	-13 (-7%)	-8 (-10%)
2	0+Activate Sidelighting, N-S	329	9.14 (8%)	38,165 (14%)	-618 (-5%)	33,497 (25%)	4,668 (6%)	-618 (-6%)	-46 (-3%)	18 (10%)	3 (4%)
2.1	0+Activate Toplighting, N-S	-5	-0.13 (-0%)	14,009 (5%)	-1,482 (-13%	16,484 (12%)	-2,474 (-3%)	-1,481 (-14%)	-157 (-11%)	-1 (-1%)	-5 (-7%)
2.2	2+Activate EC Windows, N-S	841	23.36 (21%)	53,028 (20%)	2,981 (26%)	18,997 (14%)	34,031 (41%)	2,980 (28%)	414 (30%)	55 (31%)	22 (30%)
2.3	2.1+FULL Daylighting, N-S	818	22.71 (21%)	67,265 (25%)	1,290 (11%)	35,480 (27%)	31,784 (39%)	1,290 (12%)	237 (17%)	57 (33%)	18 (24%)
3	1+Activate Sidelighting, E-W	248	6.89 (6%)	31,680 (12%)	-764 (-7%)	33,511 (25%)	-1,831 (-2%)	-764 (-7%)	-83 (-6%)	5 (3%)	-5 (-6%)
3.1	1+Activate Toplighting, E-W	-77	-2.14 (-2%)	8,285 (3%)	-1,618 (-14%	16,481 (12%)	-8,195 (-10%)	-1,617 (-15%)	-190 (-14%)	-10 (-5%)	-11 (-15%)
3.2	3+Activate EC Windows, E-W	824	22.89 (21%)	51,718 (19%)	2,946 (25%)	19,075 (14%)	32,643 (40%)	2,945 (27%)	406 (30%)	53 (30%)	21 (28%)
3.3	3.1+FULL Daylighting, E-W	801	22.25 (20%)	65,971 (24%)	1,255 (11%)	35,556 (27%)	30,415 (37%)	1,254 (12%)	229 (17%)	55 (31%)	17 (22%)

(Climate Zone 2)

Project: Hill AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 21:43

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,633	100.91	274,699	8,202	132,254	86,578	7,507	1,046	164	72
1	0+Change Bldg Orientation (E-W)	3,715	103.19	281,747	8,301	132,254	93,626	7,606	1,080	170	76
2	0+Activate Sidelighting, N-S	3,299	91.65	237,027	8,726	99,344	81,815	8,031	1,082	146	68
2.1	0+Activate Toplighting, N-S	3,606	100.16	260,786	9,356	115,682	89,236	8,661	1,171	160	75
2.2	2+Activate EC Windows,N-S	2,851	79.19	218,924	6,094	113,159	49,898	5,399	710	111	43
2.3	2.1+FULL Daylighting, N-S	2,845	79.03	205,656	7,393	96,587	53,201	6,698	851	109	47
3	1+Activate Sidelighting, E-W	3,383	93.97	244,214	8,825	99,333	89,014	8,130	1,117	153	73
3.1	1+Activate Toplighting, E-W	3,685	102.37	267,706	9,444	115,688	96,151	8,749	1,203	166	79
3.2	3+Activate EC Windows, E-W	2,868	79.68	220,276	6,131	113,105	51,304	5,436	719	113	44
3.3	3.1+FULL Daylighting, E-W	2,863	79.52	207,014	7,430	96,539	54,608	6,735	860	110	48
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-82	-2.28 (-2%)	-7,048 (-3%)	-100 (-1%)	0 (0%)	-7,048 (-8%)	-100 (-1%)	-34 (-3%)	-6 (-4%)	-4 (-6%)
2	0+Activate Sidelighting, N-S	333	9.26 (9%)	37,672 (14%)	-524 (-6%)	32,909 (25%)	4,763 (6%)	-524 (-7%)	-36 (-3%)	18 (11%)	3 (4%)
2.1	0+Activate Toplighting, N-S	27	0.75 (1%)	13,913 (5%)	1,154 (-14%	16,571 (13%)	-2,658 (-3%)	-1,154 (-15%)	-124 (-12%)	3 (2%)	-4 (-5%)
2.2	2+Activate EC Windows,N-S	449	12.46 (12%)	18,103 (7%)	2,632 (32%)	-13,814 (-10%)	31,917 (37%)	2,632 (35%)	372 (36%)	35 (21%)	25 (35%)
2.3	2.1+FULL Daylighting, N-S	761	21.13 (21%)	55,130 (20%)	1,963 (24%)	19,095 (14%)	36,035 (42%)	1,963 (26%)	319 (31%)	51 (31%)	28 (39%)
3	1+Activate Sidelighting, E-W	332	9.22 (9%)	37,533 (14%)	-524 (-6%)	32,921 (25%)	4,612 (5%)	-524 (-7%)	-37 (-4%)	17 (11%)	3 (4%)
3.1	1+Activate Toplighting, E-W	30	0.82 (1%)	14,041 (5%)	1,143 (-14%	16,566 (13%)	-2,525 (-3%)	-1,142 (-15%)	-123 (-12%)	4 (2%)	-3 (-5%)
3.2	3+Activate EC Windows, E-W	515	14.29 (14%)	23,938 (9%)	2,695 (33%)	-13,772 (-10%)	37,710 (44%)	2,695 (36%)	398 (38%)	40 (24%)	29 (40%)
3.3	3.1+FULL Daylighting, E-W	823	22.86 (23%)	60,692 (22%)	2,014 (25%)	19,149 (14%)	41,543 (48%)	2,014 (27%)	343 (33%)	56 (34%)	31 (44%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-82	-2.28 (-2%)	-7,048 (-3%)	-100 (-1%)	0 (0%)	-7,048 (-8%)	-100 (-1%)	-34 (-3%)	-6 (-4%)	-4 (-6%)
2	0+Activate Sidelighting, N-S	333	9.26 (9%)	37,672 (14%)	-524 (-6%)	32,909 (25%)	4,763 (6%)	-524 (-7%)	-36 (-3%)	18 (11%)	3 (4%)
2.1	0+Activate Toplighting, N-S	27	0.75 (1%)	13,913 (5%)	1,154 (-14%	16,571 (13%)	-2,658 (-3%)	-1,154 (-15%)	-124 (-12%)	3 (2%)	-4 (-5%)
2.2	2+Activate EC Windows,N-S	782	21.72 (22%)	55,775 (20%)	2,108 (26%)	19,095 (14%)	36,680 (42%)	2,108 (28%)	336 (32%)	52 (32%)	28 (40%)
2.3	2.1+FULL Daylighting, N-S	788	21.88 (22%)	69,043 (25%)	808 (10%)	35,666 (27%)	33,376 (39%)	808 (11%)	195 (19%)	55 (33%)	25 (34%)
3	1+Activate Sidelighting, E-W	250	6.94 (7%)	30,485 (11%)	-624 (-8%)	32,921 (25%)	-2,436 (-3%)	-624 (-8%)	-71 (-7%)	11 (7%)	-1 (-2%)
3.1	1+Activate Toplighting, E-W	-53	-1.46 (-1%)	6,993 (3%)	1,242 (-15%	16,566 (13%)	-9,573 (-11%)	-1,242 (-17%)	-157 (-15%)	-3 (-2%)	-8 (-11%)
3.2	3+Activate EC Windows, E-W	764	21.23 (21%)	54,423 (20%)	2,071 (25%)	19,149 (14%)	35,274 (41%)	2,071 (28%)	327 (31%)	51 (31%)	27 (38%)
3.3	3.1+FULL Daylighting, E-W	770	21.39 (21%)	67,685 (25%)	771 (9%)	35,715 (27%)	31,970 (37%)	772 (10%)	186 (18%)	54 (33%)	24 (33%)

Project: Offutt AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 13:18

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,888	107.99	289,703	9,216	132,254	101,582	8,519	1,199	192	97
1	0+Change Bldg Orientation (E-W)	3,959	109.98	294,561	9,433	132,254	106,440	8,737	1,237	195	100
2	0+Activate Sidelighting, N-S	3,537	98.24	250,915	9,674	98,990	96,058	8,977	1,226	174	94
2.1	0+Activate Toplighting, N-S	3,853	107.04	275,177	10,358	115,564	103,746	9,660	1,320	187	101
2.2	2+Activate EC Windows, N-S	3,094	85.94	232,066	7,178	112,564	63,636	6,481	865	137	69
2.3	2.1+FULL Daylighting, N-S	3,083	85.63	218,166	8,488	95,874	66,425	7,790	1,006	135	73
3	1+Activate Sidelighting, E-W	3,610	100.28	255,919	9,899	98,993	101,059	9,202	1,265	177	96
3.1	1+Activate Toplighting, E-W	3,923	108.98	279,946	10,570	115,572	108,507	9,873	1,358	190	102
3.2	3+Activate EC Windows, E-W	3,111	86.43	233,194	7,237	112,510	64,816	6,540	875	138	70
3.3	3.1+FULL Daylighting, E-W	3,100	86.10	219,278	8,544	95,829	67,582	7,847	1,015	136	73
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-72	-1.99 (-2%)	-4,858 (-2%)	-218 (-2%)	0 (0%)	-4,858 (-5%)	-218 (-3%)	-38 (-3%)	-3 (-2%)	-2 (-2%)
2	0+Activate Sidelighting, N-S	351	9.76 (9%)	38,788 (13%)	-459 (-5%)	33,264 (25%)	5,524 (5%)	-458 (-5%)	-27 (-2%)	18 (9%)	3 (4%)
2.1	0+Activate Toplighting, N-S	35	0.96 (1%)	14,525 (5%)	1,142 (-12%	16,689 (13%)	-2,164 (-2%)	-1,142 (-13%)	-122 (-10%)	5 (2%)	-3 (-3%)
2.2	2+Activate EC Windows, N-S	443	12.30 (11%)	18,849 (7%)	2,497 (27%)	-13,574 (-10%)	32,422 (32%)	2,497 (29%)	360 (30%)	37 (19%)	25 (26%)
2.3	2.1+FULL Daylighting, N-S	771	21.41 (20%)	57,011 (20%)	1,870 (20%)	19,690 (15%)	37,321 (37%)	1,870 (22%)	314 (26%)	52 (27%)	28 (29%)
3	1+Activate Sidelighting, E-W	349	9.70 (9%)	38,641 (13%)	-465 (-5%)	33,261 (25%)	5,381 (5%)	-465 (-5%)	-28 (-2%)	18 (9%)	3 (4%)
3.1	1+Activate Toplighting, E-W	36	1.00 (1%)	14,615 (5%)	1,137 (-12%	16,682 (13%)	-2,067 (-2%)	-1,136 (-13%)	-121 (-10%)	5 (2%)	-3 (-3%)
3.2	3+Activate EC Windows, E-W	499	13.86 (13%)	22,726 (8%)	2,662 (29%)	-13,518 (-10%)	36,243 (36%)	2,662 (31%)	390 (33%)	39 (21%)	26 (26%)
3.3	3.1+FULL Daylighting, E-W	824	22.88 (21%)	60,667 (21%)	2,026 (22%)	19,743 (15%)	40,924 (40%)	2,026 (24%)	342 (29%)	54 (28%)	29 (29%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-72	-1.99 (-2%)	-4,858 (-2%)	-218 (-2%)	0 (0%)	-4,858 (-5%)	-218 (-3%)	-38 (-3%)	-3 (-2%)	-2 (-2%)
2	0+Activate Sidelighting, N-S	351	9.76 (9%)	38,788 (13%)	-459 (-5%)	33,264 (25%)	5,524 (5%)	-458 (-5%)	-27 (-2%)	18 (9%)	3 (4%)
2.1	0+Activate Toplighting, N-S	35	0.96 (1%)	14,525 (5%)	1,142 (-12%	16,689 (13%)	-2,164 (-2%)	-1,142 (-13%)	-122 (-10%)	5 (2%)	-3 (-3%)
2.2	2+Activate EC Windows, N-S	794	22.05 (20%)	57,636 (20%)	2,038 (22%)	19,690 (15%)	37,946 (37%)	2,038 (24%)	333 (28%)	55 (29%)	29 (30%)
2.3	2.1+FULL Daylighting, N-S	805	22.37 (21%)	71,536 (25%)	728 (8%)	36,379 (28%)	35,157 (35%)	728 (9%)	193 (16%)	57 (30%)	25 (25%)
3	1+Activate Sidelighting, E-W	278	7.71 (7%)	33,783 (12%)	-683 (-7%)	33,261 (25%)	522 (1%)	-683 (-8%)	-67 (-6%)	15 (8%)	1 (1%)
3.1	1+Activate Toplighting, E-W	-36	-0.99 (-1%)	9,757 (3%)	1,354 (-15%	16,682 (13%)	-6,925 (-7%)	-1,354 (-16%)	-159 (-13%)	2 (1%)	-5 (-5%)
3.2	3+Activate EC Windows, E-W	776	21.57 (20%)	56,509 (20%)	1,979 (21%)	19,743 (15%)	36,766 (36%)	1,979 (23%)	323 (27%)	54 (28%)	27 (28%)
3.3	3.1+FULL Daylighting, E-W	788	21.90 (20%)	70,424 (24%)	672 (7%)	36,425 (28%)	33,999 (33%)	672 (8%)	183 (15%)	56 (29%)	24 (25%)

(Climate Zone 3)

Project: Beale AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 19:21

Annual Energy and Demand

Annual Energy USE or DEMAND

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
0	Base Design	3,431	95.31	312,234	2,343	132,254	124,113	1,737	597	195	90
1	0+Change Bldg Orientation (E-W)	3,516	97.68	319,654	2,435	132,254	131,534	1,829	632	203	94
2	0+Activate Sidelighting, N-S	3,046	84.61	271,823	2,628	98,325	117,631	2,021	604	177	87
2.1	0+Activate Toplighting, N-S	3,343	92.87	298,540	2,866	114,954	127,718	2,259	662	191	93
2.2	2+Activate EC Windows, N-S	2,666	74.05	242,228	1,855	111,424	74,937	1,248	381	131	59
2.3	2.1+FULL Daylighting, N-S	2,624	72.89	232,306	2,455	94,124	82,314	1,848	466	139	70
3	1+Activate Sidelighting, E-W	3,134	87.05	279,345	2,735	98,310	125,168	2,128	640	185	91
3.1	1+Activate Toplighting, E-W	3,445	95.68	307,500	2,961	114,962	136,671	2,355	702	205	100
3.2	3+Activate EC Widows, E-W	2,721	75.59	247,178	1,903	111,310	80,000	1,296	403	144	69
3.3	3.1+FULL Daylighting, E-W	2,650	73.62	234,371	2,506	94,018	84,485	1,899	478	141	72

Incremental SAVINGS (values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)

		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Lighting Electric kWh	HVAC Electric kWh	HVAC Nat Gas Therms	HVAC Total Mbtu	Peak Elect kW	Cooling Tons
1	0+Change Bldg Orientation (E-W)	-85	-2.37 (-2%)	-7,421 (-2%)	-92 (-4%)	0 (0%)	-7,421 (-6%)	-92 (-5%)	-35 (-6%)	-7 (-4%)	-5 (-5%)
2	0+Activate Sidelighting, N-S	385	10.70 (11%)	40,410 (13%)	-284 (-12%)	33,929 (26%)	6,482 (5%)	-284 (-16%)	-6 (-1%)	18 (9%)	3 (4%)
2.1	0+Activate Toplighting, N-S	88	2.44 (3%)	13,694 (4%)	-522 (-22%)	17,300 (13%)	-3,606 (-3%)	-522 (-30%)	-65 (-11%)	4 (2%)	-3 (-3%)
2.2	2+Activate EC Windows, N-S	380	10.56 (11%)	29,595 (9%)	773 (33%)	-13,099 (-10%)	42,694 (34%)	773 (45%)	223 (37%)	47 (24%)	28 (31%)
2.3	2.1+FULL Daylighting, N-S	719	19.98 (21%)	66,234 (21%)	410 (18%)	20,830 (16%)	45,404 (37%)	411 (24%)	196 (33%)	53 (27%)	22 (25%)
3	1+Activate Sidelighting, E-W	383	10.63 (11%)	40,310 (13%)	-299 (-13%)	33,944 (26%)	6,366 (5%)	-299 (-17%)	-8 (-1%)	18 (9%)	3 (4%)
3.1	1+Activate Toplighting, E-W	72	2.00 (2%)	12,155 (4%)	-526 (-22%)	17,292 (13%)	-5,137 (-4%)	-526 (-30%)	-70 (-12%)	-2 (-1%)	-6 (-7%)
3.2	3+Activate EC Widows, E-W	412	11.46 (12%)	32,167 (10%)	831 (35%)	-13,000 (-10%)	45,168 (36%)	832 (48%)	237 (40%)	41 (21%)	22 (24%)
3.3	3.1+FULL Daylighting, E-W	794	22.06 (23%)	73,129 (23%)	455 (19%)	20,943 (16%)	52,186 (42%)	456 (26%)	224 (37%)	63 (33%)	29 (32%)

Cumulative SAVINGS (values (and % savings) are relative to the Base Case, negative entries indicate increased use)

		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Lighting Electric kWh	HVAC Electric kWh	HVAC Nat Gas Therms	HVAC Total Mbtu	Peak Elect kW	Cooling Tons
1	0+Change Bldg Orientation (E-W)	-85	-2.37 (-2%)	-7,421 (-2%)	-92 (-4%)	0 (0%)	-7,421 (-6%)	-92 (-5%)	-35 (-6%)	-7 (-4%)	-5 (-5%)
2	0+Activate Sidelighting, N-S	385	10.70 (11%)	40,410 (13%)	-284 (-12%)	33,929 (26%)	6,482 (5%)	-284 (-16%)	-6 (-1%)	18 (9%)	3 (4%)
2.1	0+Activate Toplighting, N-S	88	2.44 (3%)	13,694 (4%)	-522 (-22%)	17,300 (13%)	-3,606 (-3%)	-522 (-30%)	-65 (-11%)	4 (2%)	-3 (-3%)
2.2	2+Activate EC Windows, N-S	766	21.27 (22%)	70,005 (22%)	488 (21%)	20,830 (16%)	49,175 (40%)	489 (28%)	217 (36%)	65 (33%)	31 (35%)
2.3	2.1+FULL Daylighting, N-S	807	22.42 (24%)	79,928 (26%)	-112 (-5%)	38,129 (29%)	41,799 (34%)	-112 (-6%)	131 (22%)	56 (29%)	20 (22%)
3	1+Activate Sidelighting, E-W	298	8.27 (9%)	32,889 (11%)	-391 (-17%)	33,944 (26%)	-1,055 (-1%)	-391 (-23%)	-43 (-7%)	10 (5%)	-1 (-2%)
3.1	1+Activate Toplighting, E-W	-13	-0.37 (-0%)	4,734 (2%)	-618 (-26%)	17,292 (13%)	-12,558 (-10%)	-618 (-36%)	-105 (-18%)	-9 (-5%)	-11 (-12%)
3.2	3+Activate EC Widows, E-W	710	19.72 (21%)	65,056 (21%)	440 (19%)	20,943 (16%)	44,113 (36%)	440 (25%)	195 (33%)	51 (26%)	21 (23%)
3.3	3.1+FULL Daylighting, E-W	781	21.69 (23%)	77,863 (25%)	-163 (-7%)	38,235 (29%)	39,628 (32%)	-162 (-9%)	119 (20%)	54 (28%)	18 (20%)

Project: Davis Monthan AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 22:06

Annual Energy and Demand

Annual Energy USE or DEMAND

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
0	Base Design	3,798	105.51	364,635	649	132,254	176,514	113	614	189	90
1	0+Change Building Orientation (E-W)	3,905	108.46	374,921	659	132,254	186,799	122	650	199	98
2	0+Activate Sidelighting, N-S	3,368	93.54	322,328	673	98,831	167,630	136	586	171	89
2.1	0+Activate Toplighting, N-S	3,697	102.68	354,022	717	114,336	183,819	181	645	188	99
2.2	2+Activate EC Windows, N-S	2,888	80.22	276,275	590	110,590	109,818	53	380	136	66
2.3	2.1+FULL Daylighting, N-S	2,795	77.65	266,826	635	92,672	118,287	97	413	134	73
3	1+Activate Sidelighting, E-W	3,476	96.56	332,828	683	98,834	178,127	147	623	181	97
3.1	1+Activate Toplighting, E-W	3,792	105.32	363,184	730	114,343	192,974	193	678	197	104
3.2	3+Activate EC Windows, E-W	2,911	80.86	278,507	595	110,352	112,287	58	389	138	67
3.3	3.1+FULL Daylighting, E-W	2,819	78.29	269,000	643	92,441	120,692	106	423	136	74

Incremental SAVINGS (values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)

		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Lighting Electric kWh	HVAC Electric kWh	HVAC Nat Gas Therms	HVAC Total Mbtu	Peak Elect kW	Cooling Tons
1	0+Change Building Orientation (E-W)	-106	-2.95 (-3%)	-10,286 (-3%)	-10 (-2%)	0 (0%)	-10,286 (-6%)	-10 (-9%)	-36 (-6%)	-10 (-6%)	-8 (-9%)
2	0+Activate Sidelighting, N-S	431	11.97 (11%)	42,307 (12%)	-24 (-4%)	33,423 (25%)	8,884 (5%)	-24 (-21%)	28 (5%)	18 (9%)	2 (2%)
2.1	0+Activate Toplighting, N-S	102	2.83 (3%)	10,613 (3%)	-68 (-11%)	17,917 (14%)	-7,305 (-4%)	-68 (-61%)	-32 (-5%)	1 (0%)	-9 (-10%)
2.2	2+Activate EC Windows, N-S	480	13.33 (13%)	46,053 (13%)	83 (13%)	-11,759 (-9%)	57,812 (33%)	83 (74%)	206 (34%)	35 (18%)	23 (26%)
2.3	2.1+FULL Daylighting, N-S	901	25.03 (24%)	87,196 (24%)	83 (13%)	21,664 (16%)	65,532 (37%)	83 (74%)	232 (38%)	54 (28%)	26 (29%)
3	1+Activate Sidelighting, E-W	429	11.90 (11%)	42,093 (12%)	-24 (-4%)	33,420 (25%)	8,673 (5%)	-24 (-22%)	27 (4%)	18 (10%)	1 (1%)
3.1	1+Activate Toplighting, E-W	113	3.14 (3%)	11,737 (3%)	-71 (-11%)	17,911 (14%)	-6,174 (-3%)	-71 (-63%)	-28 (-5%)	2 (1%)	-6 (-7%)
3.2	3+Activate EC Windows, E-W	565	15.69 (15%)	54,321 (15%)	88 (14%)	-11,518 (-9%)	65,839 (37%)	89 (79%)	234 (38%)	43 (23%)	30 (33%)
3.3	3.1+FULL Daylighting, E-W	973	27.03 (26%)	94,183 (26%)	86 (13%)	21,902 (17%)	72,281 (41%)	87 (77%)	255 (42%)	61 (32%)	30 (34%)

Cumulative SAVINGS (values (and % savings) are relative to the Base Case, negative entries indicate increased use)

		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Lighting Electric kWh	HVAC Electric kWh	HVAC Nat Gas Therms	HVAC Total Mbtu	Peak Elect kW	Cooling Tons
1	0+Change Building Orientation (E-W)	-106	-2.95 (-3%)	-10,286 (-3%)	-10 (-2%)	0 (0%)	-10,286 (-6%)	-10 (-9%)	-36 (-6%)	-10 (-6%)	-8 (-9%)
2	0+Activate Sidelighting, N-S	431	11.97 (11%)	42,307 (12%)	-24 (-4%)	33,423 (25%)	8,884 (5%)	-24 (-21%)	28 (5%)	18 (9%)	2 (2%)
2.1	0+Activate Toplighting, N-S	102	2.83 (3%)	10,613 (3%)	-68 (-11%)	17,917 (14%)	-7,305 (-4%)	-68 (-61%)	-32 (-5%)	1 (0%)	-9 (-10%)
2.2	2+Activate EC Windows, N-S	911	25.30 (24%)	88,360 (24%)	59 (9%)	21,664 (16%)	66,695 (38%)	60 (53%)	234 (38%)	53 (28%)	25 (27%)
2.3	2.1+FULL Daylighting, N-S	1,003	27.86 (26%)	97,809 (27%)	14 (2%)	39,581 (30%)	58,227 (33%)	15 (13%)	200 (33%)	54 (29%)	18 (19%)
3	1+Activate Sidelighting, E-W	322	8.95 (8%)	31,807 (9%)	-34 (-5%)	33,420 (25%)	-1,613 (-1%)	-34 (-30%)	-9 (-1%)	8 (4%)	-7 (-8%)
3.1	1+Activate Toplighting, E-W	7	0.19 (0%)	1,451 (0%)	-81 (-12%)	17,911 (14%)	-16,460 (-9%)	-81 (-72%)	-64 (-10%)	-8 (-4%)	-14 (-16%)
3.2	3+Activate EC Windows, E-W	887	24.65 (23%)	86,128 (24%)	54 (8%)	21,902 (17%)	64,226 (36%)	55 (49%)	225 (37%)	51 (27%)	23 (25%)
3.3	3.1+FULL Daylighting, E-W	980	27.22 (26%)	95,634 (26%)	6 (1%)	39,813 (30%)	55,821 (32%)	6 (6%)	191 (31%)	53 (28%)	16 (18%)

Project: Wright-Patt AFB - 2 Story Office Bldg — Run Date/Time: 02/05/09 @ 16:44

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,611	100.29	272,555	8,199	132,254	84,433	7,507	1,039	177	87
1	0+Change Bldg Orientation (E-W)	3,663	101.74	276,856	8,278	132,254	88,735	7,586	1,061	181	90
2	0+Activate Sidelighting, N-S	3,276	91.01	234,980	8,705	99,608	79,505	8,012	1,073	159	83
2.1	0+Activate Toplighting, N-S	3,564	99.01	257,518	9,275	116,217	85,434	8,583	1,150	171	89
2.2	2+Activate EC Windows, N-S	2,893	80.36	222,153	6,184	113,738	52,548	5,492	729	123	58
2.3	2.1+FULL Daylighting, N-S	2,865	79.58	207,397	7,413	97,702	53,828	6,720	856	118	60
3	1+Activate Sidelighting, E-W	3,335	92.63	239,888	8,785	99,593	84,428	8,092	1,097	166	88
3.1	1+Activate Toplighting, E-W	3,615	100.42	261,749	9,352	116,222	89,660	8,660	1,172	176	91
3.2	3+Activate EC Windows	2,905	80.69	223,142	6,199	113,598	53,677	5,507	734	124	59
3.3	3.1+FULL Daylighting, E-W	2,876	79.89	208,358	7,428	97,566	54,924	6,736	861	120	62
Incremental SAVINGS	**(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)**										
1	0+Change Bldg Orientation (E-W)	-52	-1.44 (-1%)	-4,301 (-2%)	-79 (-1%)	0 (0%)	-4,301 (-5%)	-79 (-1%)	-23 (-2%)	-4 (-2%)	-3 (-3%)
2	0+Activate Sidelighting, N-S	334	9.28 (9%)	37,575 (14%)	-506 (-6%)	32,646 (25%)	4,928 (6%)	-506 (-7%)	-34 (-3%)	18 (10%)	3 (4%)
2.1	0+Activate Toplighting, N-S	46	1.29 (1%)	15,037 (6%)	1,076 (-13%	16,037 (12%)	-1,000 (-1%)	-1,076 (-14%)	-111 (-11%)	6 (3%)	-2 (-2%)
2.2	2+Activate EC Windows, N-S	383	10.65 (11%)	12,826 (5%)	2,520 (31%)	-14,131 (-11%)	26,957 (32%)	2,520 (34%)	344 (33%)	37 (21%)	26 (29%)
2.3	2.1+FULL Daylighting, N-S	699	19.43 (19%)	50,121 (18%)	1,863 (23%)	18,515 (14%)	31,606 (37%)	1,863 (25%)	294 (28%)	53 (30%)	28 (33%)
3	1+Activate Sidelighting, E-W	328	9.11 (9%)	36,967 (14%)	-506 (-6%)	32,660 (25%)	4,306 (5%)	-506 (-7%)	-36 (-3%)	16 (9%)	1 (2%)
3.1	1+Activate Toplighting, E-W	47	1.31 (1%)	15,106 (6%)	1,074 (-13%	16,032 (12%)	-925 (-1%)	-1,074 (-14%)	-111 (-11%)	5 (3%)	-2 (-2%)
3.2	3+Activate EC Windows	430	11.94 (12%)	16,746 (6%)	2,585 (32%)	-14,005 (-11%)	30,751 (36%)	2,585 (34%)	363 (35%)	41 (23%)	29 (33%)
3.3	3.1+FULL Daylighting, E-W	739	20.53 (20%)	53,391 (20%)	1,924 (23%)	18,656 (14%)	34,736 (41%)	1,924 (26%)	311 (30%)	56 (32%)	30 (34%)
Cumulative SAVINGS	**(values (and % savings) are relative to the Base Case, negative entries indicate increased use)**										
1	0+Change Bldg Orientation (E-W)	-52	-1.44 (-1%)	-4,301 (-2%)	-79 (-1%)	0 (0%)	-4,301 (-5%)	-79 (-1%)	-23 (-2%)	-4 (-2%)	-3 (-3%)
2	0+Activate Sidelighting, N-S	334	9.28 (9%)	37,575 (14%)	-506 (-6%)	32,646 (25%)	4,928 (6%)	-506 (-7%)	-34 (-3%)	18 (10%)	3 (4%)
2.1	0+Activate Toplighting, N-S	46	1.29 (1%)	15,037 (6%)	1,076 (-13%	16,037 (12%)	-1,000 (-1%)	-1,076 (-14%)	-111 (-11%)	6 (3%)	-2 (-2%)
2.2	2+Activate EC Windows, N-S	718	19.93 (20%)	50,401 (18%)	2,015 (25%)	18,515 (14%)	31,886 (38%)	2,014 (27%)	310 (30%)	55 (31%)	29 (33%)
2.3	2.1+FULL Daylighting, N-S	746	20.72 (21%)	65,158 (24%)	786 (10%)	34,552 (26%)	30,606 (36%)	786 (10%)	183 (18%)	59 (33%)	27 (31%)
3	1+Activate Sidelighting, E-W	276	7.66 (8%)	32,666 (12%)	-586 (-7%)	32,660 (25%)	5 (0%)	-586 (-8%)	-59 (-6%)	12 (7%)	-2 (-2%)
3.1	1+Activate Toplighting, E-W	-5	-0.13 (-0%)	10,805 (4%)	1,153 (-14%	16,032 (12%)	-5,227 (-6%)	-1,153 (-15%)	-133 (-13%)	1 (1%)	-5 (-5%)
3.2	3+Activate EC Windows	706	19.61 (20%)	49,412 (18%)	1,999 (24%)	18,656 (14%)	30,757 (36%)	1,999 (27%)	305 (29%)	53 (30%)	27 (32%)
3.3	3.1+FULL Daylighting, E-W	734	20.40 (20%)	64,197 (24%)	771 (9%)	34,687 (26%)	29,509 (35%)	771 (10%)	178 (17%)	57 (32%)	25 (29%)

Project: Andrews AFB - 2 Story Office Bldg — Run Date/Time: 02/14/09 @ 22:53

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,541	98.36	292,659	5,444	132,254	104,538	4,782	835	185	92
1	0+Change Bldg Orientation (E-W)	3,590	99.72	296,484	5,543	132,254	108,363	4,882	858	187	95
2	0+Activate Sidelighting, N-S	3,178	88.27	253,146	5,857	98,619	98,660	5,196	856	167	89
2.1	0+Activate Toplighting, N-S	3,467	96.32	277,183	6,294	115,333	105,982	5,633	925	180	93
2.2	2+Activate EC Windows, N-S	2,803	77.85	232,531	4,219	111,529	65,135	3,557	578	133	68
2.3	2.1+FULL Daylighting, N-S	2,723	75.64	215,225	5,193	94,609	64,749	4,531	674	118	64
3	1+Activate Sidelighting, E-W	3,229	89.71	257,150	5,965	98,607	102,676	5,303	881	169	92
3.1	1+Activate Toplighting, E-W	3,516	97.66	280,969	6,390	115,340	109,762	5,729	947	182	96
3.2	3+Activate EC Windows	2,791	77.53	231,060	4,252	111,415	63,778	3,590	577	125	63
3.3	3.1+FULL Daylighting, E-W	2,735	75.98	216,086	5,227	94,501	65,717	4,566	681	119	65
4	0+Activate LOW-E Glass	3,109	86.35	267,310	3,718	132,254	79,189	3,056	576	158	76
5	2+Activate LOW-E with Controls	2,760	76.67	228,935	4,161	100,413	72,655	3,499	598	139	72
Incremental SAVINGS	**(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)**										
1	0+Change Bldg Orientation (E-W)	-49	-1.36 (-1%)	-3,825 (-1%)	-99 (-2%)	0 (0%)	-3,825 (-4%)	-99 (-2%)	-23 (-3%)	-2 (-1%)	-3 (-3%)
2	0+Activate Sidelighting, N-S	363	10.09 (10%)	39,512 (14%)	-413 (-8%)	33,634 (25%)	5,878 (6%)	-413 (-9%)	-21 (-3%)	18 (10%)	3 (3%)
2.1	0+Activate Toplighting, N-S	73	2.04 (2%)	15,476 (5%)	-851 (-16%)	16,920 (13%)	-1,444 (-1%)	-850 (-18%)	-90 (-11%)	5 (3%)	-2 (-2%)
2.2	2+Activate EC Windows, N-S	375	10.42 (11%)	20,616 (7%)	1,639 (30%)	-12,910 (-10%)	33,525 (32%)	1,639 (34%)	278 (33%)	34 (18%)	20 (22%)
2.3	2.1+FULL Daylighting, N-S	745	20.68 (21%)	61,958 (21%)	1,101 (20%)	20,725 (16%)	41,233 (39%)	1,101 (23%)	251 (30%)	62 (34%)	29 (32%)
3	1+Activate Sidelighting, E-W	361	10.02 (10%)	39,334 (13%)	-421 (-8%)	33,647 (25%)	5,687 (5%)	-421 (-9%)	-23 (-3%)	18 (10%)	3 (3%)
3.1	1+Activate Toplighting, E-W	74	2.06 (2%)	15,515 (5%)	-847 (-16%)	16,914 (13%)	-1,399 (-1%)	-847 (-18%)	-89 (-11%)	5 (3%)	-2 (-2%)
3.2	3+Activate EC Windows	438	12.18 (12%)	26,090 (9%)	1,713 (31%)	-12,808 (-10%)	38,898 (37%)	1,713 (36%)	304 (36%)	43 (23%)	28 (31%)
3.3	3.1+FULL Daylighting, E-W	781	21.68 (22%)	64,883 (22%)	1,163 (21%)	20,839 (16%)	44,044 (42%)	1,163 (24%)	267 (32%)	63 (34%)	31 (34%)
4	0+Activate LOW-E Glass	432	12.00 (12%)	25,349 (9%)	1,726 (32%)	0 (0%)	25,349 (24%)	1,726 (36%)	259 (31%)	27 (15%)	16 (17%)
5	2+Activate LOW-E with Controls	418	11.60 (12%)	24,211 (8%)	1,697 (31%)	-1,794 (-1%)	26,005 (25%)	1,696 (35%)	258 (31%)	28 (15%)	16 (18%)
Cumulative SAVINGS	**(values (and % savings) are relative to the Base Case, negative entries indicate increased use)**										
1	0+Change Bldg Orientation (E-W)	-49	-1.36 (-1%)	-3,825 (-1%)	-99 (-2%)	0 (0%)	-3,825 (-4%)	-99 (-2%)	-23 (-3%)	-2 (-1%)	-3 (-3%)
2	0+Activate Sidelighting, N-S	363	10.09 (10%)	39,512 (14%)	-413 (-8%)	33,634 (25%)	5,878 (6%)	-413 (-9%)	-21 (-3%)	18 (10%)	3 (3%)
2.1	0+Activate Toplighting, N-S	73	2.04 (2%)	15,476 (5%)	-851 (-16%)	16,920 (13%)	-1,444 (-1%)	-850 (-18%)	-90 (-11%)	5 (3%)	-2 (-2%)
2.2	2+Activate EC Windows, N-S	738	20.51 (21%)	60,128 (21%)	1,225 (23%)	20,725 (16%)	39,403 (38%)	1,225 (26%)	257 (31%)	52 (28%)	23 (26%)
2.3	2.1+FULL Daylighting, N-S	818	22.72 (23%)	77,434 (26%)	251 (5%)	37,645 (28%)	39,789 (38%)	251 (5%)	161 (19%)	67 (36%)	27 (30%)
3	1+Activate Sidelighting, E-W	312	8.65 (9%)	35,509 (12%)	-521 (-10%)	33,647 (25%)	1,862 (2%)	-521 (-11%)	-46 (-5%)	16 (9%)	-0 (-0%)
3.1	1+Activate Toplighting, E-W	25	0.70 (1%)	11,690 (4%)	-946 (-17%)	16,914 (13%)	-5,224 (-5%)	-946 (-20%)	-112 (-13%)	3 (2%)	-5 (-5%)
3.2	3+Activate EC Windows	750	20.83 (21%)	61,599 (21%)	1,192 (22%)	20,839 (16%)	40,760 (39%)	1,192 (25%)	258 (31%)	60 (32%)	28 (31%)
3.3	3.1+FULL Daylighting, E-W	806	22.38 (23%)	76,573 (26%)	216 (4%)	37,752 (29%)	38,820 (37%)	217 (5%)	154 (18%)	66 (36%)	26 (29%)
4	0+Activate LOW-E Glass	432	12.00 (12%)	25,349 (9%)	1,726 (32%)	0 (0%)	25,349 (24%)	1,726 (36%)	259 (31%)	27 (15%)	16 (17%)
5	2+Activate LOW-E with Controls	781	21.69 (22%)	63,723 (22%)	1,283 (24%)	31,841 (24%)	31,883 (30%)	1,283 (27%)	237 (28%)	46 (25%)	19 (21%)

Project: McGuire AFB - 2 Story Office Bldg — Run Date/Time: 02/14/09 @ 22:36

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,526	97.94	283,644	6,218	132,254	95,524	5,546	881	178	88
1	0+Change Bldg Orientation (E-W)	3,605	100.14	290,081	6,350	132,254	101,960	5,678	916	191	95
2	0+Activate Sidelighting, N-S	3,164	87.89	244,091	6,650	98,448	89,777	5,978	904	160	84
2.1	0+Activate Toplighting, N-S	3,480	96.66	270,291	7,124	115,361	99,063	6,452	983	183	96
2.2	2+Activate EC Windows, N-S	2,824	78.45	228,522	4,843	111,757	60,898	4,171	625	134	67
2.3	2.1+FULL Daylighting, N-S	2,767	76.85	212,887	5,868	94,864	62,156	5,196	732	132	71
3	1+Activate Sidelighting, E-W	3,245	90.15	250,699	6,786	98,436	96,396	6,114	940	173	92
3.1	1+Activate Toplighting, E-W	3,532	98.10	274,094	7,253	115,368	102,859	6,581	1,009	187	98
3.2	3+Activate EC Windows	2,834	78.72	229,134	4,877	111,637	61,630	4,206	631	135	69
3.3	3.1+FULL Daylighting, E-W	2,776	77.11	213,486	5,901	94,751	62,868	5,229	737	133	72
4	0+Activate LOW-E Glass	3,100	86.12	260,098	4,371	132,254	71,977	3,700	616	150	70
5	2+Activate LOW-E with Controls	2,753	76.48	221,831	4,819	100,286	65,678	4,147	639	132	66
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-79	-2.20 (-2%)	-6,436 (-2%)	-132 (-2%)	0 (0%)	-6,436 (-7%)	-132 (-2%)	-35 (-4%)	-13 (-7%)	-7 (-8%)
2	0+Activate Sidelighting, N-S	362	10.05 (10%)	39,553 (14%)	-432 (-7%)	33,806 (26%)	5,747 (6%)	-432 (-8%)	-24 (-3%)	18 (10%)	3 (4%)
2.1	0+Activate Toplighting, N-S	46	1.28 (1%)	13,353 (5%)	-906 (-15%)	16,893 (13%)	-3,540 (-4%)	-906 (-16%)	-103 (-12%)	-5 (-3%)	-8 (-9%)
2.2	2+Activate EC Windows, N-S	340	9.45 (10%)	15,570 (5%)	1,807 (29%)	-13,309 (-10%)	28,879 (30%)	1,807 (33%)	279 (32%)	26 (15%)	17 (19%)
2.3	2.1+FULL Daylighting, N-S	713	19.81 (20%)	57,404 (20%)	1,256 (20%)	20,497 (15%)	36,907 (39%)	1,256 (23%)	252 (29%)	51 (29%)	25 (29%)
3	1+Activate Sidelighting, E-W	360	9.99 (10%)	39,382 (14%)	-436 (-7%)	33,818 (26%)	5,564 (6%)	-436 (-8%)	-25 (-3%)	18 (10%)	3 (4%)
3.1	1+Activate Toplighting, E-W	73	2.04 (2%)	15,987 (6%)	-903 (-15%)	16,886 (13%)	-899 (-1%)	-903 (-16%)	-93 (-11%)	4 (2%)	-3 (-4%)
3.2	3+Activate EC Windows	412	11.43 (12%)	21,565 (8%)	1,908 (31%)	-13,201 (-10%)	34,766 (36%)	1,908 (34%)	309 (35%)	38 (21%)	23 (26%)
3.3	3.1+FULL Daylighting, E-W	756	20.99 (21%)	60,608 (21%)	1,352 (22%)	20,617 (16%)	39,991 (42%)	1,352 (24%)	272 (31%)	54 (30%)	27 (31%)
4	0+Activate LOW-E Glass	426	11.83 (12%)	23,547 (8%)	1,846 (30%)	0 (0%)	23,547 (25%)	1,846 (33%)	265 (30%)	28 (16%)	18 (21%)
5	2+Activate LOW-E with Controls	411	11.42 (12%)	22,260 (8%)	1,831 (29%)	-1,838 (-1%)	24,098 (25%)	1,831 (33%)	265 (30%)	29 (16%)	18 (21%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-79	-2.20 (-2%)	-6,436 (-2%)	-132 (-2%)	0 (0%)	-6,436 (-7%)	-132 (-2%)	-35 (-4%)	-13 (-7%)	-7 (-8%)
2	0+Activate Sidelighting, N-S	362	10.05 (10%)	39,553 (14%)	-432 (-7%)	33,806 (26%)	5,747 (6%)	-432 (-8%)	-24 (-3%)	18 (10%)	3 (4%)
2.1	0+Activate Toplighting, N-S	46	1.28 (1%)	13,353 (5%)	-906 (-15%)	16,893 (13%)	-3,540 (-4%)	-906 (-16%)	-103 (-12%)	-5 (-3%)	-8 (-9%)
2.2	2+Activate EC Windows, N-S	702	19.50 (20%)	55,123 (19%)	1,375 (22%)	20,497 (15%)	34,626 (36%)	1,375 (25%)	256 (29%)	44 (25%)	20 (23%)
2.3	2.1+FULL Daylighting, N-S	759	21.10 (22%)	70,757 (25%)	350 (6%)	37,389 (28%)	33,367 (35%)	350 (6%)	149 (17%)	47 (26%)	17 (19%)
3	1+Activate Sidelighting, E-W	281	7.79 (8%)	32,946 (12%)	-568 (-9%)	33,818 (26%)	-873 (-1%)	-568 (-10%)	-60 (-7%)	5 (3%)	-4 (-4%)
3.1	1+Activate Toplighting, E-W	-6	-0.16 (-0%)	9,551 (3%)	1,035 (-17%	16,886 (13%)	-7,335 (-8%)	-1,035 (-19%)	-129 (-15%)	-9 (-5%)	-11 (-12%)
3.2	3+Activate EC Windows	692	19.23 (20%)	54,511 (19%)	1,340 (22%)	20,617 (16%)	33,894 (35%)	1,340 (24%)	250 (28%)	43 (24%)	19 (22%)
3.3	3.1+FULL Daylighting, E-W	750	20.83 (21%)	70,159 (25%)	317 (5%)	37,503 (28%)	32,656 (34%)	317 (6%)	143 (16%)	45 (26%)	16 (18%)
4	0+Activate LOW-E Glass	426	11.83 (12%)	23,547 (8%)	1,846 (30%)	0 (0%)	23,547 (25%)	1,846 (33%)	265 (30%)	28 (16%)	18 (21%)
5	2+Activate LOW-E with Controls	773	21.47 (22%)	61,813 (22%)	1,399 (22%)	31,968 (24%)	29,845 (31%)	1,399 (25%)	242 (27%)	46 (26%)	22 (25%)

(Climate Zone 4)

Project: Holloman AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 20:26

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,438	95.51	312,020	2,436	132,254	123,899	1,821	605	170	75
1	0+Change Bldg Orientation (E-W)	3,537	98.25	321,167	2,486	132,254	133,046	1,871	641	179	81
2	0+Activate Sidelighting, N-S	3,039	84.43	270,826	2,665	98,150	116,809	2,050	604	152	72
2.1	0+Activate Toplighting, N-S	3,351	93.10	298,884	2,912	114,056	128,961	2,297	670	169	79
2.2	2+Activate EC Windows, N-S	2,653	73.69	240,480	1,905	109,965	74,648	1,289	384	117	49
2.3	2.1+FULL Daylighting, N-S	2,578	71.60	227,694	2,462	91,767	80,060	1,846	458	115	55
3	1+Activate Sidelighting, E-W	3,141	87.24	280,174	2,720	98,149	126,158	2,105	641	161	78
3.1	1+Activate Toplighting, E-W	3,443	95.64	307,378	2,959	114,064	137,446	2,344	704	176	85
3.2	3+Activate EC Windows, E-W	2,679	74.41	242,672	1,940	109,838	76,967	1,324	395	120	51
3.3	3.1+FULL Daylighting, E-W	2,603	72.32	229,860	2,499	91,648	82,345	1,883	469	117	57
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-99	-2.74 (-3%)	-9,148 (-3%)	-50 (-2%)	0 (0%)	-9,148 (-7%)	-50 (-3%)	-36 (-6%)	-9 (-5%)	-6 (-8%)
2	0+Activate Sidelighting, N-S	399	11.08 (12%)	41,193 (13%)	-230 (-9%)	34,104 (26%)	7,089 (6%)	-229 (-13%)	1 (0%)	18 (11%)	3 (4%)
2.1	0+Activate Toplighting, N-S	87	2.41 (3%)	13,136 (4%)	-477 (-20%)	18,198 (14%)	-5,062 (-4%)	-477 (-26%)	-65 (-11%)	1 (1%)	-4 (-5%)
2.2	2+Activate EC Windows, N-S	387	10.74 (11%)	30,346 (10%)	761 (31%)	-11,815 (-9%)	42,161 (34%)	761 (42%)	220 (36%)	35 (21%)	22 (30%)
2.3	2.1+FULL Daylighting, N-S	774	21.50 (23%)	71,190 (23%)	450 (18%)	22,288 (17%)	48,902 (39%)	451 (25%)	212 (35%)	54 (32%)	23 (31%)
3	1+Activate Sidelighting, E-W	396	11.01 (12%)	40,994 (13%)	-234 (-10%)	34,105 (26%)	6,888 (6%)	-234 (-13%)	0 (0%)	18 (11%)	3 (4%)
3.1	1+Activate Toplighting, E-W	94	2.61 (3%)	13,789 (4%)	-474 (-19%)	18,190 (14%)	-4,400 (-4%)	-473 (-26%)	-62 (-10%)	3 (2%)	-4 (-5%)
3.2	3+Activate EC Windows, E-W	462	12.83 (13%)	37,502 (12%)	780 (32%)	-11,689 (-9%)	49,191 (40%)	780 (43%)	246 (41%)	41 (24%)	27 (36%)
3.3	3.1+FULL Daylighting, E-W	840	23.33 (24%)	77,518 (25%)	460 (19%)	22,416 (17%)	55,102 (44%)	461 (25%)	234 (39%)	59 (35%)	28 (37%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-99	-2.74 (-3%)	-9,148 (-3%)	-50 (-2%)	0 (0%)	-9,148 (-7%)	-50 (-3%)	-36 (-6%)	-9 (-5%)	-6 (-8%)
2	0+Activate Sidelighting, N-S	399	11.08 (12%)	41,193 (13%)	-230 (-9%)	34,104 (26%)	7,089 (6%)	-229 (-13%)	1 (0%)	18 (11%)	3 (4%)
2.1	0+Activate Toplighting, N-S	87	2.41 (3%)	13,136 (4%)	-477 (-20%)	18,198 (14%)	-5,062 (-4%)	-477 (-26%)	-65 (-11%)	1 (1%)	-4 (-5%)
2.2	2+Activate EC Windows, N-S	786	21.82 (23%)	71,539 (23%)	531 (22%)	22,288 (17%)	49,251 (40%)	532 (29%)	221 (37%)	53 (31%)	25 (34%)
2.3	2.1+FULL Daylighting, N-S	861	23.91 (25%)	84,326 (27%)	-26 (-1%)	40,486 (31%)	43,839 (35%)	-26 (-1%)	147 (24%)	55 (32%)	19 (26%)
3	1+Activate Sidelighting, E-W	298	8.27 (9%)	31,846 (10%)	-284 (-12%)	34,105 (26%)	-2,259 (-2%)	-284 (-16%)	-36 (-6%)	9 (5%)	-3 (-4%)
3.1	1+Activate Toplighting, E-W	-5	-0.13 (-0%)	4,642 (1%)	-523 (-21%)	18,190 (14%)	-13,548 (-11%)	-524 (-29%)	-99 (-16%)	-6 (-3%)	-10 (-13%)
3.2	3+Activate EC Windows, E-W	760	21.10 (22%)	69,348 (22%)	496 (20%)	22,416 (17%)	46,932 (38%)	496 (27%)	210 (35%)	51 (30%)	23 (31%)
3.3	3.1+FULL Daylighting, E-W	835	23.19 (24%)	82,160 (26%)	-63 (-3%)	40,605 (31%)	41,554 (34%)	-63 (-3%)	136 (22%)	53 (31%)	18 (24%)

Project: Pope AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 23:26

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,573	99.26	319,065	3,064	132,254	130,944	2,449	692	196	102
1	0+Change Bldg Orientation (E-W)	3,630	100.82	323,923	3,130	132,254	135,802	2,515	715	203	108
2	0+Activate Sidelighting, N-S	3,181	88.35	278,147	3,328	98,640	123,640	2,713	693	178	99
2.1	0+Activate Toplighting, N-S	3,471	96.41	304,017	3,579	115,196	132,953	2,963	750	191	105
2.2	2+Activate EC Windows, N-S	2,861	79.47	255,246	2,475	112,125	87,254	1,859	484	143	74
2.3	2.1+FULL Daylighting, N-S	2,773	77.02	240,890	3,064	95,068	89,955	2,448	552	140	80
3	1+Activate Sidelighting, E-W	3,239	89.97	283,100	3,404	98,633	128,600	2,789	718	185	105
3.1	0+Activate Toplighting, E-W	3,471	96.41	304,017	3,579	115,196	132,953	2,963	750	191	105
3.2	3+Activate EC Windows, E-W	2,878	79.96	256,635	2,508	111,948	88,820	1,892	492	146	76
3.3	3.1+FULL Daylighting, E-W	2,773	77.02	240,890	3,064	95,068	89,955	2,448	552	140	80
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-56	-1.56 (-2%)	-4,858 (-2%)	-66 (-2%)	0 (0%)	-4,859 (-4%)	-66 (-3%)	-23 (-3%)	-7 (-4%)	-5 (-5%)
2	0+Activate Sidelighting, N-S	393	10.90 (11%)	40,918 (13%)	-264 (-9%)	33,614 (25%)	7,304 (6%)	-264 (-11%)	-1 (-0%)	18 (9%)	3 (3%)
2.1	0+Activate Toplighting, N-S	103	2.85 (3%)	15,048 (5%)	-515 (-17%)	17,057 (13%)	-2,009 (-2%)	-515 (-21%)	-58 (-8%)	4 (2%)	-3 (-3%)
2.2	2+Activate EC Windows, N-S	320	8.88 (9%)	22,901 (7%)	854 (28%)	-13,485 (-10%)	36,386 (28%)	854 (35%)	210 (30%)	35 (18%)	25 (24%)
2.3	2.1+FULL Daylighting, N-S	698	19.38 (20%)	63,127 (20%)	515 (17%)	20,129 (15%)	42,998 (33%)	515 (21%)	198 (29%)	51 (26%)	25 (25%)
3	1+Activate Sidelighting, E-W	391	10.85 (11%)	40,823 (13%)	-274 (-9%)	33,620 (25%)	7,202 (6%)	-274 (-11%)	-3 (-0%)	18 (9%)	3 (3%)
3.1	0+Activate Toplighting, E-W	103	2.85 (3%)	15,048 (5%)	-515 (-17%)	17,057 (13%)	-2,009 (-2%)	-515 (-21%)	-58 (-8%)	4 (2%)	-3 (-3%)
3.2	3+Activate EC Windows, E-W	361	10.02 (10%)	26,465 (8%)	896 (29%)	-13,315 (-10%)	39,780 (30%)	896 (37%)	225 (33%)	39 (20%)	29 (28%)
3.3	3.1+FULL Daylighting, E-W	698	19.38 (20%)	63,127 (20%)	515 (17%)	20,129 (15%)	42,998 (33%)	515 (21%)	198 (29%)	51 (26%)	25 (25%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-56	-1.56 (-2%)	-4,858 (-2%)	-66 (-2%)	0 (0%)	-4,859 (-4%)	-66 (-3%)	-23 (-3%)	-7 (-4%)	-5 (-5%)
2	0+Activate Sidelighting, N-S	393	10.90 (11%)	40,918 (13%)	-264 (-9%)	33,614 (25%)	7,304 (6%)	-264 (-11%)	-1 (-0%)	18 (9%)	3 (3%)
2.1	0+Activate Toplighting, N-S	103	2.85 (3%)	15,048 (5%)	-515 (-17%)	17,057 (13%)	-2,009 (-2%)	-515 (-21%)	-58 (-8%)	4 (2%)	-3 (-3%)
2.2	2+Activate EC Windows, N-S	712	19.79 (20%)	63,819 (20%)	590 (19%)	20,129 (15%)	43,690 (33%)	590 (24%)	208 (30%)	53 (27%)	28 (28%)
2.3	2.1+FULL Daylighting, N-S	800	22.23 (22%)	78,175 (25%)	0 (0%)	37,186 (28%)	40,989 (31%)	1 (0%)	140 (20%)	56 (28%)	22 (22%)
3	1+Activate Sidelighting, E-W	334	9.28 (9%)	35,965 (11%)	-340 (-11%)	33,620 (25%)	2,344 (2%)	-340 (-14%)	-26 (-4%)	11 (5%)	-2 (-2%)
3.1	0+Activate Toplighting, E-W	103	2.85 (3%)	15,048 (5%)	-515 (-17%)	17,057 (13%)	-2,009 (-2%)	-515 (-21%)	-58 (-8%)	4 (2%)	-3 (-3%)
3.2	3+Activate EC Windows, E-W	695	19.30 (19%)	62,430 (20%)	556 (18%)	20,305 (15%)	42,124 (32%)	557 (23%)	199 (29%)	50 (26%)	27 (26%)
3.3	3.1+FULL Daylighting, E-W	800	22.23 (22%)	78,175 (25%)	0 (0%)	37,186 (28%)	40,989 (31%)	1 (0%)	140 (20%)	56 (28%)	22 (22%)

(Climate Zone 5)

Project: Barksdale AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 13:12

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,764	104.55	340,936	2,728	132,254	152,815	2,134	735	188	100
1	0+Change Bldg Orientation	3,833	106.47	347,434	2,757	132,254	159,313	2,163	760	192	102
2	0+Activate Sidelighting, N-S	3,354	93.18	298,814	2,948	98,484	144,463	2,354	728	170	96
2.1	0+Activate Toplighting, N-S	3,656	101.57	326,368	3,148	114,942	155,558	2,554	786	184	102
2.2	2+Activate EC Windows, N-S	2,984	82.89	271,448	2,045	111,207	104,374	1,451	501	141	73
2.3	2.1+FULL Daylighting, N-S	2,877	79.93	256,443	2,516	93,896	106,680	1,922	556	134	77
3	1+Activate Sidelighting, E-W	3,426	95.15	305,465	2,979	98,468	151,130	2,386	754	174	99
3.1	1+Activate Toplighting, E-W	3,725	103.47	332,792	3,176	114,951	161,974	2,583	811	188	105
3.2	3+Activate EC Windows, E-W	2,993	83.14	272,196	2,059	111,054	105,274	1,465	506	140	75
3.3	3.1+FULL Daylighting, E-W	2,897	80.48	258,241	2,531	93,751	108,623	1,937	564	136	79
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation	-69	-1.93 (-2%)	-6,498 (-2%)	-29 (-1%)	0 (0%)	-6,498 (-4%)	-29 (-1%)	-25 (-3%)	-4 (-2%)	-2 (-2%)
2	0+Activate Sidelighting, N-S	409	11.37 (11%)	42,122 (12%)	-220 (-8%)	33,770 (26%)	8,352 (5%)	-220 (-10%)	7 (1%)	18 (10%)	3 (3%)
2.1	0+Activate Toplighting, N-S	107	2.98 (3%)	14,568 (4%)	-420 (-15%)	17,311 (13%)	-2,743 (-2%)	-420 (-20%)	-51 (-7%)	4 (2%)	-2 (-2%)
2.2	2+Activate EC Windows, N-S	371	10.29 (10%)	27,366 (8%)	903 (33%)	-12,723 (-10%)	40,089 (26%)	903 (42%)	227 (31%)	29 (16%)	23 (23%)
2.3	2.1+FULL Daylighting, N-S	779	21.64 (21%)	69,925 (21%)	632 (23%)	21,047 (16%)	48,878 (32%)	632 (30%)	230 (31%)	50 (27%)	25 (25%)
3	1+Activate Sidelighting, E-W	407	11.32 (11%)	41,969 (12%)	-223 (-8%)	33,786 (26%)	8,183 (5%)	-222 (-10%)	6 (1%)	18 (9%)	3 (3%)
3.1	1+Activate Toplighting, E-W	108	3.00 (3%)	14,642 (4%)	-420 (-15%)	17,303 (13%)	-2,661 (-2%)	-420 (-20%)	-51 (-7%)	4 (2%)	-2 (-2%)
3.2	3+Activate EC Windows, E-W	433	12.02 (11%)	33,269 (10%)	921 (34%)	-12,587 (-10%)	45,856 (30%)	921 (43%)	249 (34%)	35 (18%)	24 (24%)
3.3	3.1+FULL Daylighting, E-W	828	23.00 (22%)	74,551 (22%)	645 (24%)	21,199 (16%)	53,351 (35%)	646 (30%)	247 (34%)	52 (28%)	26 (26%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation	-69	-1.93 (-2%)	-6,498 (-2%)	-29 (-1%)	0 (0%)	-6,498 (-4%)	-29 (-1%)	-25 (-3%)	-4 (-2%)	-2 (-2%)
2	0+Activate Sidelighting, N-S	409	11.37 (11%)	42,122 (12%)	-220 (-8%)	33,770 (26%)	8,352 (5%)	-220 (-10%)	7 (1%)	18 (10%)	3 (3%)
2.1	0+Activate Toplighting, N-S	107	2.98 (3%)	14,568 (4%)	-420 (-15%)	17,311 (13%)	-2,743 (-2%)	-420 (-20%)	-51 (-7%)	4 (2%)	-2 (-2%)
2.2	2+Activate EC Windows, N-S	780	21.66 (21%)	69,488 (20%)	683 (25%)	21,047 (16%)	48,441 (32%)	683 (32%)	234 (32%)	47 (25%)	27 (27%)
2.3	2.1+FULL Daylighting, N-S	886	24.62 (24%)	84,493 (25%)	212 (8%)	38,358 (29%)	46,135 (30%)	213 (10%)	179 (24%)	54 (29%)	23 (23%)
3	1+Activate Sidelighting, E-W	338	9.39 (9%)	35,471 (10%)	-251 (-9%)	33,786 (26%)	1,685 (1%)	-251 (-12%)	-19 (-3%)	14 (7%)	1 (1%)
3.1	1+Activate Toplighting, E-W	39	1.07 (1%)	8,144 (2%)	-448 (-16%)	17,303 (13%)	-9,159 (-6%)	-448 (-21%)	-76 (-10%)	0 (0%)	-5 (-5%)
3.2	3+Activate EC Windows, E-W	771	21.41 (20%)	68,740 (20%)	669 (25%)	21,199 (16%)	47,541 (31%)	670 (31%)	229 (31%)	48 (26%)	25 (25%)
3.3	3.1+FULL Daylighting, E-W	866	24.07 (23%)	82,695 (24%)	197 (7%)	38,502 (29%)	44,192 (29%)	198 (9%)	171 (23%)	52 (28%)	21 (21%)

Project: Eglin AFB - 2 Story Office Bldg — Run Date/Time: 02/04/09 @ 22:42

Annual Energy and Demand

		Ann. TDV Energy		Annual Site Energy		Lighting	HVAC Energy			Peak	
		TDV-Mbtu	EUI TDV-kBtu/sf/yr	Elect kWh	Nat Gas Therms	Electric kWh	Electric kWh	Nat Gas Therms	Total Mbtu	Elect kW	Cooling Tons
Annual Energy USE or DEMAND											
0	Base Design	3,578	99.38	334,410	1,537	132,254	146,288	959	595	165	88
1	0+Change Bldg Orientation (E-W)	3,705	102.91	346,597	1,561	132,254	158,476	982	639	181	100
2	0+Activate Sidelighting, N-S	3,163	87.85	292,588	1,669	97,223	139,498	1,091	585	151	87
2.1	0+Activate Toplighting, N-S	3,455	95.96	320,021	1,779	113,960	150,194	1,200	633	163	92
2.2	2+Activate EC Windows, N-S	2,821	78.35	263,053	1,272	109,515	97,671	693	403	120	62
2.3	2.1+FULL Daylighting, N-S	2,751	76.42	253,526	1,554	91,221	106,437	975	461	127	74
3	1+Activate Sidelighting, E-W	3,272	90.90	303,011	1,698	97,211	149,933	1,119	624	164	97
3.1	1+Activate Toplighting, E-W	3,568	99.10	330,806	1,806	113,967	160,971	1,227	672	176	103
3.2	3+Activate EC Windows, E-W	2,890	80.29	269,696	1,290	109,296	104,533	711	428	132	71
3.3	3.1+FULL Daylighting, E-W	2,766	76.82	254,742	1,572	91,010	107,865	993	467	128	75
Incremental SAVINGS	(values are relative to previous measure (% savings are relative to base case use), negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-127	-3.53 (-4%)	-12,188 (-4%)	-23 (-2%)	0 (0%)	-12,188 (-8%)	-23 (-2%)	-44 (-7%)	-16 (-10%)	-12 (-14%)
2	0+Activate Sidelighting, N-S	415	11.53 (12%)	41,821 (13%)	-132 (-9%)	35,031 (26%)	6,790 (5%)	-132 (-14%)	10 (2%)	14 (9%)	1 (1%)
2.1	0+Activate Toplighting, N-S	123	3.42 (3%)	14,388 (4%)	-242 (-16%)	18,293 (14%)	-3,905 (-3%)	-242 (-25%)	-38 (-6%)	3 (2%)	-4 (-5%)
2.2	2+Activate EC Windows, N-S	342	9.50 (10%)	29,535 (9%)	397 (26%)	-12,292 (-9%)	41,827 (29%)	397 (41%)	182 (31%)	31 (19%)	24 (28%)
2.3	2.1+FULL Daylighting, N-S	703	19.54 (20%)	66,496 (20%)	225 (15%)	22,739 (17%)	43,757 (30%)	225 (23%)	172 (29%)	36 (22%)	18 (21%)
3	1+Activate Sidelighting, E-W	433	12.01 (12%)	43,587 (13%)	-138 (-9%)	35,043 (26%)	8,544 (6%)	-137 (-14%)	15 (3%)	17 (10%)	3 (4%)
3.1	1+Activate Toplighting, E-W	137	3.81 (4%)	15,792 (5%)	-245 (-16%)	18,286 (14%)	-2,495 (-2%)	-245 (-26%)	-33 (-6%)	5 (3%)	-2 (-3%)
3.2	3+Activate EC Windows, E-W	382	10.61 (11%)	33,315 (10%)	408 (27%)	-12,085 (-9%)	45,400 (31%)	409 (43%)	196 (33%)	32 (20%)	26 (29%)
3.3	3.1+FULL Daylighting, E-W	802	22.28 (22%)	76,063 (23%)	234 (15%)	22,958 (17%)	53,106 (36%)	234 (24%)	205 (34%)	48 (29%)	27 (31%)
Cumulative SAVINGS	(values (and % savings) are relative to the Base Case, negative entries indicate increased use)										
1	0+Change Bldg Orientation (E-W)	-127	-3.53 (-4%)	-12,188 (-4%)	-23 (-2%)	0 (0%)	-12,188 (-8%)	-23 (-2%)	-44 (-7%)	-16 (-10%)	-12 (-14%)
2	0+Activate Sidelighting, N-S	415	11.53 (12%)	41,821 (13%)	-132 (-9%)	35,031 (26%)	6,790 (5%)	-132 (-14%)	10 (2%)	14 (9%)	1 (1%)
2.1	0+Activate Toplighting, N-S	123	3.42 (3%)	14,388 (4%)	-242 (-16%)	18,293 (14%)	-3,905 (-3%)	-242 (-25%)	-38 (-6%)	3 (2%)	-4 (-5%)
2.2	2+Activate EC Windows, N-S	757	21.03 (21%)	71,356 (21%)	265 (17%)	22,739 (17%)	48,617 (33%)	265 (28%)	192 (32%)	45 (27%)	26 (29%)
2.3	2.1+FULL Daylighting, N-S	826	22.96 (23%)	80,884 (24%)	-17 (-1%)	41,033 (31%)	39,851 (27%)	-17 (-2%)	134 (23%)	39 (23%)	14 (16%)
3	1+Activate Sidelighting, E-W	305	8.48 (9%)	31,399 (9%)	-161 (-10%)	35,043 (26%)	-3,644 (-2%)	-161 (-17%)	-29 (-5%)	1 (1%)	-9 (-10%)
3.1	1+Activate Toplighting, E-W	10	0.28 (0%)	3,604 (1%)	-269 (-17%)	18,286 (14%)	-14,682 (-10%)	-269 (-28%)	-77 (-13%)	-11 (-6%)	-15 (-17%)
3.2	3+Activate EC Windows, E-W	687	19.09 (19%)	64,713 (19%)	247 (16%)	22,958 (17%)	41,756 (29%)	248 (26%)	167 (28%)	34 (20%)	17 (19%)
3.3	3.1+FULL Daylighting, E-W	812	22.56 (23%)	79,667 (24%)	-35 (-2%)	41,244 (31%)	38,423 (26%)	-35 (-4%)	128 (21%)	38 (23%)	13 (14%)

Appendix N

Below figures show additional economic measures in addition to SIR and payback. Both net savings (NS) and adjusted internal rate of return (AIRR) trends are consistent with SIR and payback economic measures and add little additioinal insight. AIRR, however, tends to show a more optimistic result when compared to SIR and payback with all the results, except for cold climates (CLIMATE ZONES 1 – 2), that have return that is well above the discount rate of 3%.

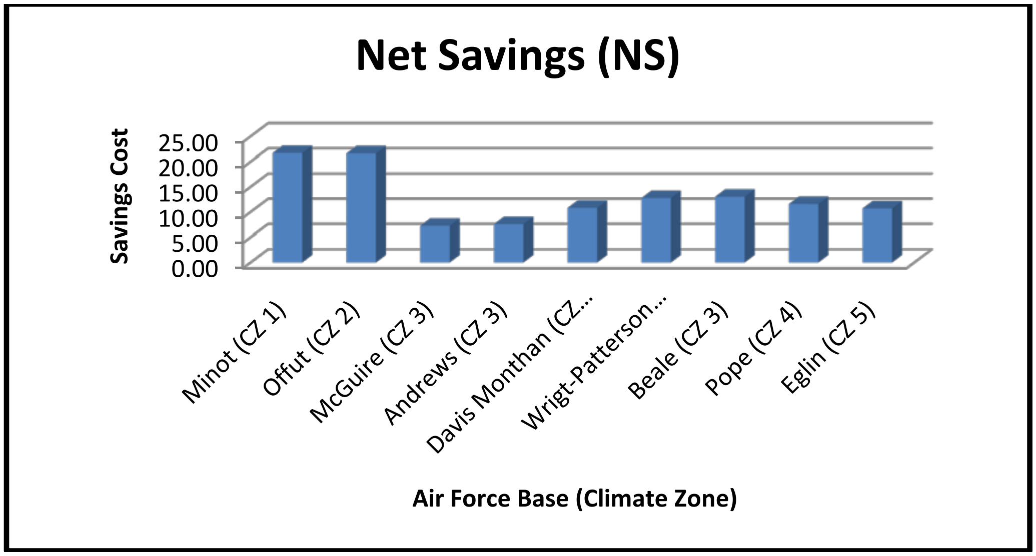


Figure M -1. Net Savings summary results for EC windows in all climate zones

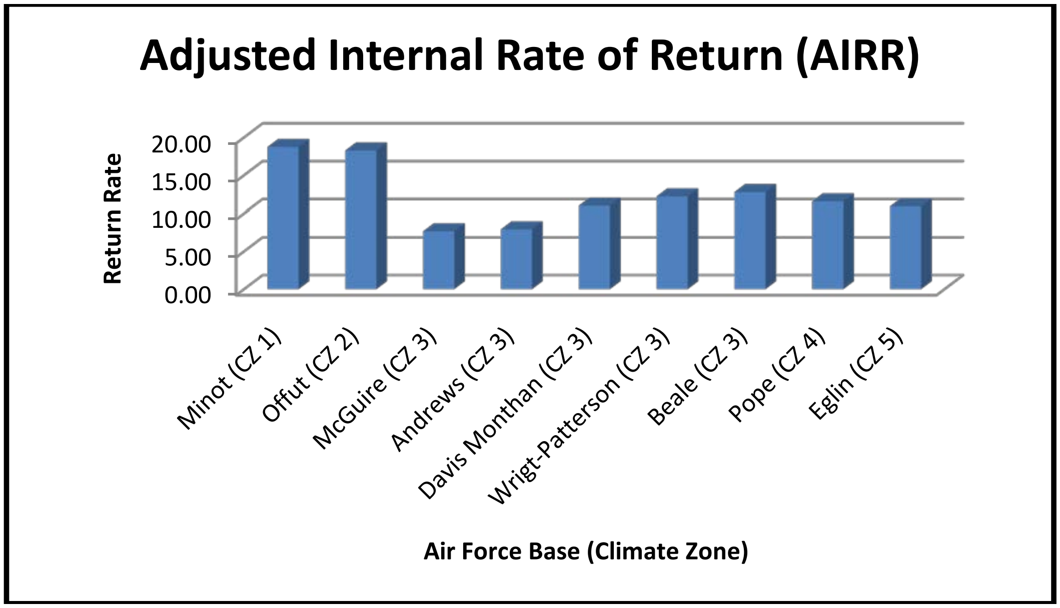


Figure M-2. AIRR summary results for EC windows in all climate zones

Appendix O

eQUEST simulation data for all climate zones

AFB	Climate Zone	Electricity Rate ($/kWh)	Natural Gas Rate ($/Mbtu)	Winter Peak Demand Rate[1] ($/kW)	Summer Peak Demand Rate[1] ($/kW)	# of Winter Months[1]	# of Summer Months[1]
Ellsworth (CZ 1)	1	$ 0.02887	$ 6.26	11.69	13.43	8	4
Minot (CZ 1)	1	$ 0.04173	$ 6.59	8.33	8.33	8	4
Hill (CZ 2)	2	$ 0.04062	$ 6.47	7.42	10.29	7	5
Offut (CZ 2)	2	$ 0.02294	$ 8.54	8.5	8.5	4	8
Beale (CZ 3)	3	$ 0.06327	$ 10.63	7.14	7.14	6	6
Davis-Monthan (CZ 3)	3	$ 0.06725	$ 13.27	10.163	10.163	6	6
Wright-Patterson (CZ 3)	3	$ 0.04918	$ 11.86	7.96	7.96	6	6
Andrews (CZ 3)	3	$ 0.10087	$ 14.07	9.13	9.13	7	5
McGuire (CZ 3)	3	$ 0.11567	$ 11.18	7.18	8.26	8	4
Holloman (CZ 4)	4	$ 0.05505	$ 8.14	10.18	11.8	3	9
Pope (CZ 4)	4	$ 0.06798	$ 10.85	7.23	12.32	4	8
Barksdale (CZ 5)	5	$ 0.05334	$ 9.26	11.39	11.39	6	6
Eglin (CZ 5)	5	$ 0.07548	$ 14.72	7.01	7.01	5	7

AFB	Bldg Size (sq ft)	Annual Electric Consumption (kWh) Base Case	Annual Electric Consumption (kWh) Daylighting Ctrl	Annual Electric Consumption (kWh) Skylights	Annual Electric Consumption (kWh) EC Windows	Annual Electric Consumption (kWh) Full Daylighting
Ellsworth (CZ 1)	36000	270646	232481	256637	217618	203381
Minot (CZ 1)	36000	249041	213489	234320	207653	193194
Hill (CZ 2)	36000	274699	237027	260786	218924	205656
Offut (CZ 2)	36000	289703	250915	275177	232066	218166
Beale (CZ 3)	36000	312234	271823	298540	242228	232306
Davis-Monthan (CZ 3)	36000	364635	322328	354022	276275	266826
Wright-Patterson (CZ 3)	36000	272555	234980	257518	222153	207397
Andrews (CZ 3)	36000	292659	253146	277183	232531	215225
McGuire (CZ 3)	36000	283644	244091	270291	228522	212887
Holloman (CZ 4)	36000	312020	270826	298884	240480	227694
Pope (CZ 4)	36000	319065	278147	304017	255246	240890
Barksdale (CZ 5)	36000	340936	298814	326368	271448	256443
Eglin (CZ 5)	36000	334410	292588	320021	263053	253526

AFB	Peak Demand (kW) Base Case	Peak Demand (kW) Daylighting Ctrl	Peak Demand (kW) Skylights	Peak Demand (kW) EC Windows	Peak Demand (kW) Full Daylighting
Ellsworth (CZ 1)	175	157	176	120	118
Minot (CZ 1)	161	142	155	124	121
Hill (CZ 2)	164	146	160	111	109
Offut (CZ 2)	192	174	187	137	135
Beale (CZ 3)	195	177	191	131	139
Davis-Monthan (CZ 3)	189	171	188	136	134
Wright-Patterson (CZ 3)	177	159	171	123	118
Andrews (CZ 3)	185	167	180	133	118
McGuire (CZ 3)	178	160	183	134	132
Holloman (CZ 4)	170	152	169	117	115
Pope (CZ 4)	196	178	191	143	140
Barksdale (CZ 5)	188	170	184	141	134
Eglin (CZ 5)	165	151	163	120	127

AFB	Annual NG (Mbtu)	Annual Natural Gas Consumption (Mbtu)	Annual Natural Gas Consumption (Mbtu)	Annual Natural Gas Consumption (Mbtu)	Annual Natural Gas Consumption (Mbtu)
	Base Case	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	1156.9	1218.7	1305.1	858.9	1028
Minot (CZ 1)	1084.3	1143.4	1258.9	1051.8	1238.8
Hill (CZ 2)	820.2	872.6	935.6	609.4	739.3
Offut (CZ 2)	921.6	967.4	1035.8	717.8	848.8
Beale (CZ 3)	234.3	262.8	286.6	185.5	245.5
Davis-Monthan (CZ 3)	64.9	67.3	71.7	59	63.5
Wright-Patterson (CZ 3)	819.9	870.5	927.5	618.4	741.3
Andrews (CZ 3)	544.4	585.7	629.4	421.9	519.3
McGuire (CZ 3)	621.8	665	712.4	484.3	586.8
Holloman (CZ 4)	243.6	266.5	291.2	190.5	246.2
Pope (CZ 4)	306.4	332.8	357.9	247.5	306.4
Barksdale (CZ 5)	272.8	294.8	314.8	204.5	251.6
Eglin (CZ 5)	153.7	166.9	177.9	127.2	155.4

AFB	Total Annual Energy Savings	Total Annual Energy Savings	Total Annual Energy Savings	Total Annual Energy Savings
	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	$ 933.00	$ (518.00)	$ 4,091.00	$ 3,454.00
Minot (CZ 1)	$ 1,275.00	$ (469.00)	$ 2,266.00	$ 1,652.00
Hill (CZ 2)	$ 1,364.00	$ (134.00)	$ 4,191.02	$ 3,793.00
Offut (CZ 2)	$ 684.00	$ (601.00)	$ 3,622.00	$ 2,754.00
Beale (CZ 3)	$ 2,405.00	$ 328.00	$ 5,386.00	$ 5,327.00
Davis-Monthan (CZ 3)	$ 2,987.00	$ 666.00	$ 6,605.00	$ 7,166.00
Wright-Patterson (CZ 3)	$ 1,406.00	$ (484.00)	$ 5,310.00	$ 4,606.00
Andrews (CZ 3)	$ 3,574.00	$ 413.00	$ 8,263.00	$ 8,774.00
McGuire (CZ 3)	$ 4,298.00	$ 538.00	$ 8,278.00	$ 8,919.00
Holloman (CZ 4)	$ 2,975.00	$ 637.00	$ 6,529.00	$ 7,147.00
Pope (CZ 4)	$ 2,701.00	$ 517.00	$ 5,520.00	$ 5,909.00
Barksdale (CZ 5)	$ 2,216.00	$ 410.00	$ 4,854.00	$ 5,290.00
Eglin (CZ 5)	$ 3,037.00	$ 742.00	$ 6,051.00	$ 6,355.00

AFB	SIR	SIR	SIR	SIR
	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	1.33	-0.34	0.17	0.13
Minot (CZ 1)	1.81	-0.31	0.09	0.06
Hill (CZ 2)	1.94	-0.09	0.17	0.14
Offut (CZ 2)	0.97	-0.40	0.15	0.10
Beale (CZ 3)	3.41	0.22	0.22	0.20
Davis-Monthan (CZ 3)	4.23	0.44	0.27	0.27
Wright-Patterson (CZ 3)	1.99	-0.32	0.21	0.18
Andrews (CZ 3)	5.07	0.27	0.33	0.33
McGuire (CZ 3)	6.10	0.36	0.33	0.34
Holloman (CZ 4)	3.23	0.23	0.20	0.20
Pope (CZ 4)	3.79	0.34	0.22	0.22
Barksdale (CZ 5)	3.14	0.27	0.20	0.20
Eglin (CZ 5)	4.29	0.49	0.24	0.24

AFB	SPB	SPB	SPB	SPB
	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	11.23	0.00	90.10	113.20
Minot (CZ 1)	8.23	0.00	162.45	236.38
Hill (CZ 2)	7.66	0.00	87.95	103.09
Offut (CZ 2)	15.36	0.00	101.64	141.79
Beale (CZ 3)	4.36	0.00	68.54	73.51
Davis-Monthan (CZ 3)	3.52	0.00	55.83	54.58
Wright-Patterson (CZ 3)	7.46	0.00	69.36	84.82
Andrews (CZ 3)	2.94	0.00	44.62	44.57
McGuire (CZ 3)	2.44	0.00	44.47	43.78
Holloman (CZ 4)	4.61	0.00	74.37	74.77
Pope (CZ 4)	3.92	0.00	66.81	66.19
Barksdale (CZ 5)	4.73	0.00	75.93	73.90
Eglin (CZ 5)	3.47	0.00	60.87	61.49

AFB	DPB	DPB	DPB	DPB
	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	13.90	0.00	0.00	0.00
Minot (CZ 1)	9.59	0.00	0.00	0.00
Hill (CZ 2)	8.84	0.00	0.00	0.00
Offut (CZ 2)	20.90	0.00	0.00	0.00
Beale (CZ 3)	4.74	0.00	0.00	0.00
Davis-Monthan (CZ 3)	3.78	0.00	0.00	0.00
Wright-Patterson (CZ 3)	8.57	0.00	0.00	0.00
Andrews (CZ 3)	3.12	0.00	0.00	0.00
McGuire (CZ 3)	2.58	0.00	0.00	0.00
Holloman (CZ 4)	5.03	0.00	0.00	0.00
Pope (CZ 4)	4.24	0.00	0.00	0.00
Barksdale (CZ 5)	5.18	0.00	0.00	0.00
Eglin (CZ 5)	3.72	0.00	0.00	0.00

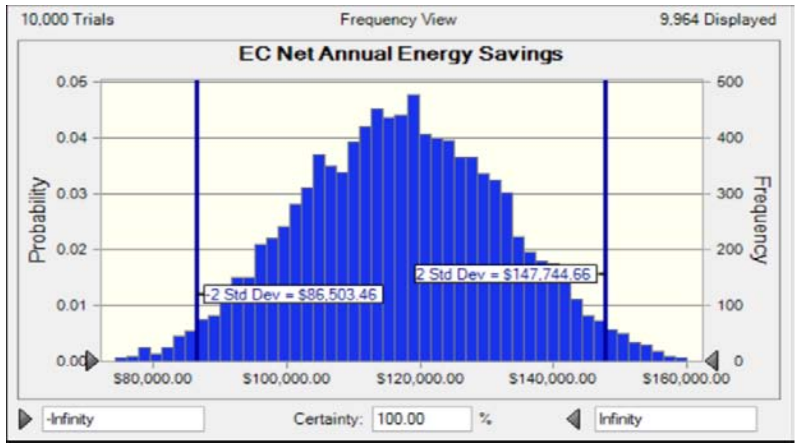
AFB	AIRR	AIRR	AIRR	AIRR
	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	4.46%	0.00%	-5.87%	-6.94%
Minot (CZ 1)	6.10%	0.00%	-8.60%	-10.30%
Hill (CZ 2)	6.47%	0.00%	-5.76%	-6.50%
Offut (CZ 2)	2.83%	0.00%	-6.44%	-7.98%
Beale (CZ 3)	9.52%	-4.56%	-4.57%	-4.91%
Davis-Monthan (CZ 3)	10.70%	-1.11%	-3.59%	-3.48%
Wright-Patterson (CZ 3)	6.62%	0.00%	-4.63%	-5.59%
Andrews (CZ 3)	11.71%	-3.44%	-2.50%	-2.50%
McGuire (CZ 3)	12.74%	-2.16%	-2.49%	-2.41%
Holloman (CZ 4)	9.22%	-4.28%	-4.96%	-4.99%
Pope (CZ 4)	10.10%	-2.35%	-4.45%	-4.41%
Barksdale (CZ 5)	9.07%	-3.48%	-5.06%	-4.93%
Eglin (CZ 5)	10.78%	-0.59%	-4.01%	-4.05%

AFB	Net Savings	Net Savings	Net Savings	Net Savings
	Daylighting Ctrl	Skylights	EC Windows	Full Daylighting
Ellsworth (CZ 1)	$ 29,156	$ (294,841)	$ (3,126,144)	$ (3,430,759)
Minot (CZ 1)	$ 73,342	$ (283,829)	$ (3,364,679)	$ (3,668,464)
Hill (CZ 2)	$ 89,041	$ (233,265)	$ (3,135,323)	$ (3,389,562)
Offut (CZ 2)	$ (7,981)	$ (301,450)	$ (3,186,758)	$ (3,522,607)
Beale (CZ 3)	$ 231,416	$ (168,588)	$ (2,950,032)	$ (3,174,931)
Davis-Monthan (CZ 3)	$ 312,586	$ (133,666)	$ (2,778,603)	$ (2,920,384)
Wright-Patterson (CZ 3)	$ 94,064	$ (284,071)	$ (2,953,099)	$ (3,265,766)
Andrews (CZ 3)	$ 405,688	$ (158,188)	$ (2,528,533)	$ (2,668,979)
McGuire (CZ 3)	$ 437,763	$ (168,152)	$ (2,614,966)	$ (2,752,547)
Holloman (CZ 4)	$ 310,904	$ (139,196)	$ (2,774,943)	$ (2,914,257)
Pope (CZ 4)	$ 278,301	$ (144,917)	$ (2,904,311)	$ (3,073,810)
Barksdale (CZ 5)	$ 215,612	$ (156,406)	$ (2,996,159)	$ (3,154,514)
Eglin (CZ 5)	$ 330,712	$ (115,464)	$ (2,822,430)	$ (3,007,796)

Appendix P

Example: Decision maker wants to know the probability that net annual savings of EC window dropping below $100,000.

Given from MCS simulation:



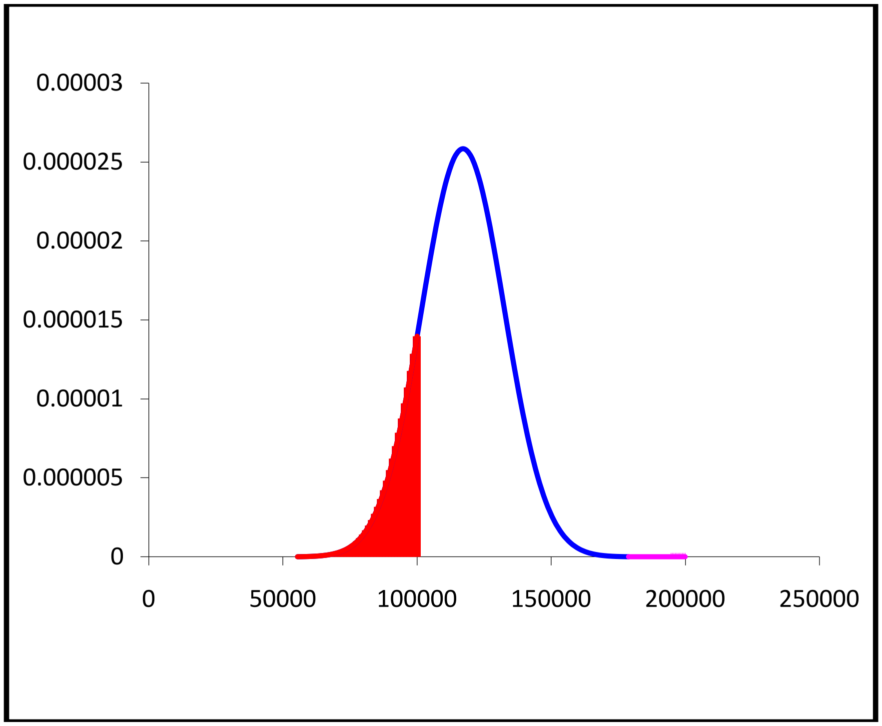
Statistic	Forecast values
Trials	10,000
Mean	$117,125.05
Median	$117,162.96
Mode	---
Standard Deviation	$15,434.31
Variance	$238,218,060.02
Skewness	-0.0381
Kurtosis	2.78
Coeff. of Variability	0.1318
Minimum	$61,573.22
Maximum	$165,278.85
Mean Std. Error	$154.34

So, P(X<$100,000) = ?

Use Z-score where,

$$z = \frac{x - \mu}{\sigma}$$

And,

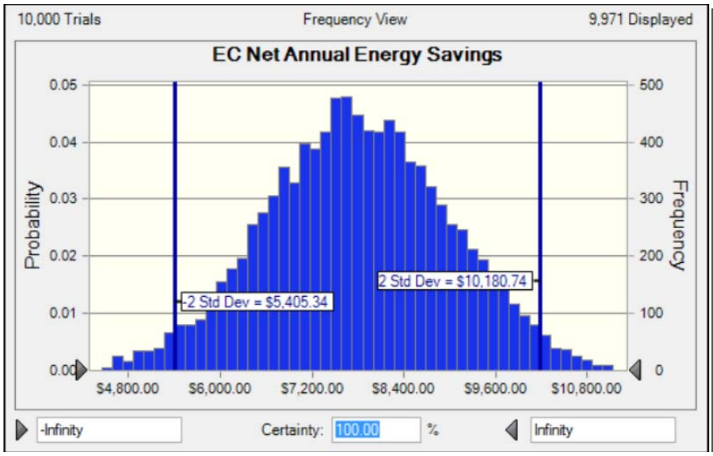


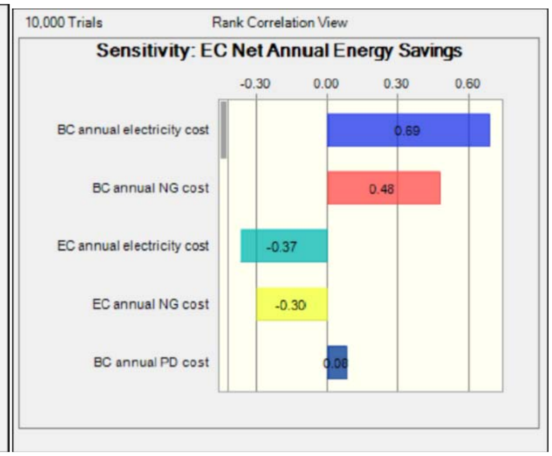
Therefore, P(X<$100,000) = 13.36%

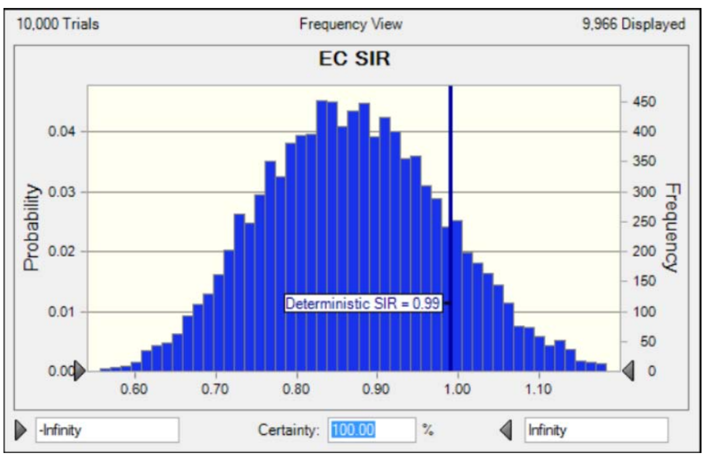
Appendix Q

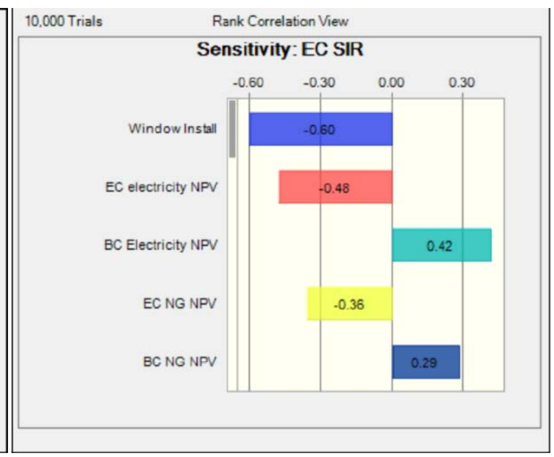
Below are the Monte Carlo simulation output for all climate zones for the policy intervention case; therefore, the outputs are for electrochromic (EC) windows only.

Minot AFB (Climate Zone 1)

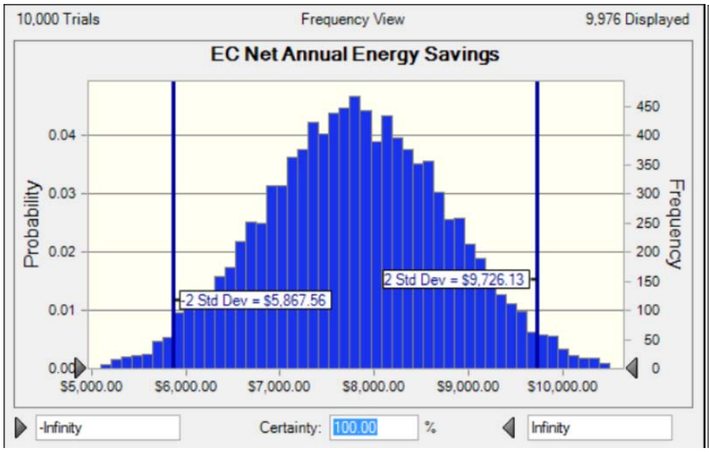


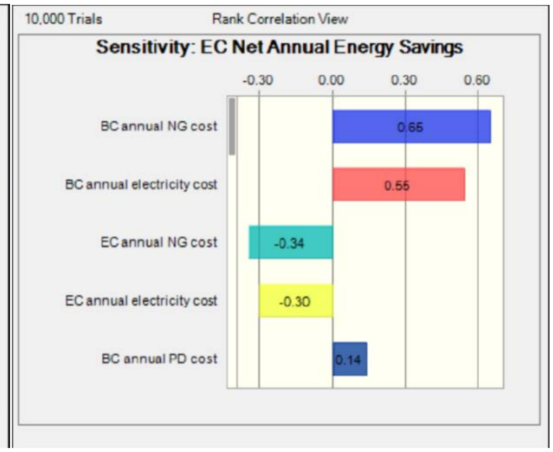


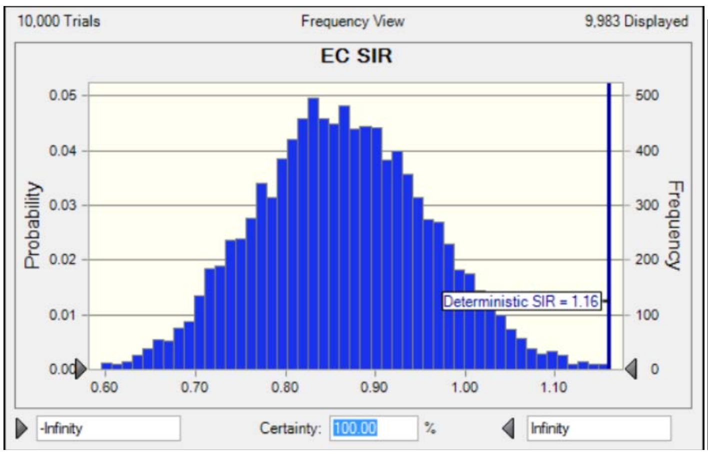


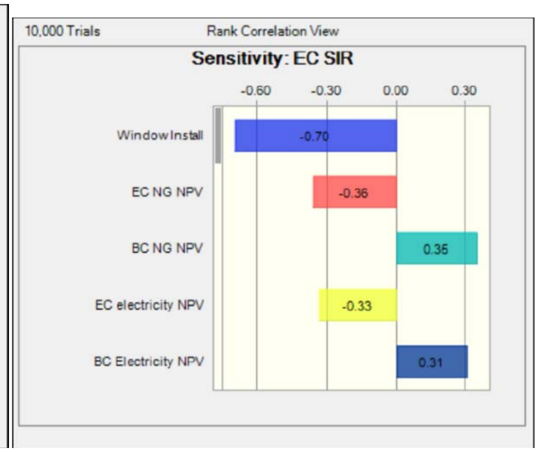


Offut AFB (Climate Zone 2)

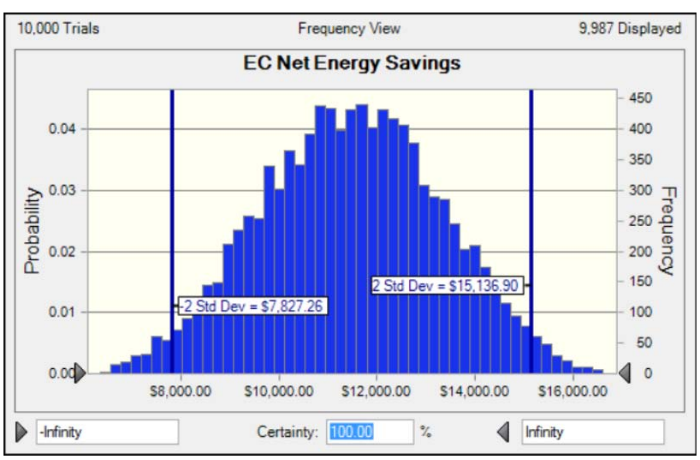


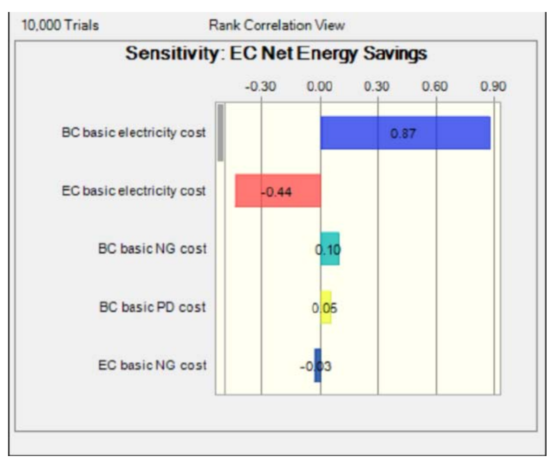


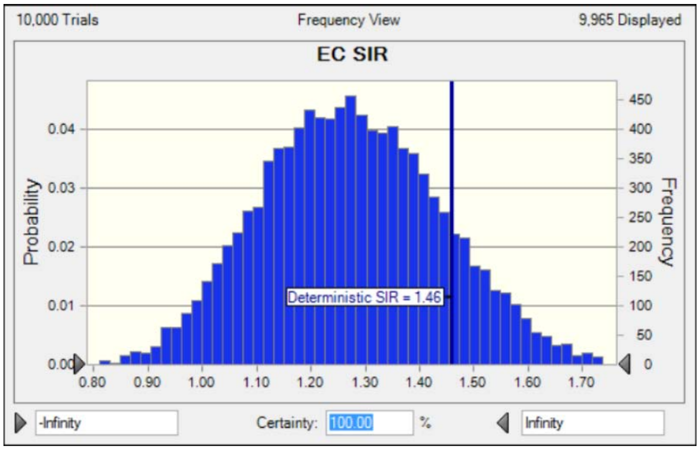


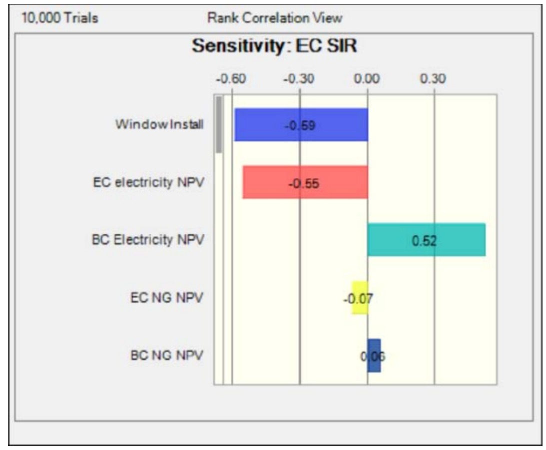


Beale AFB (Climate Zone 3 – low utility cost)

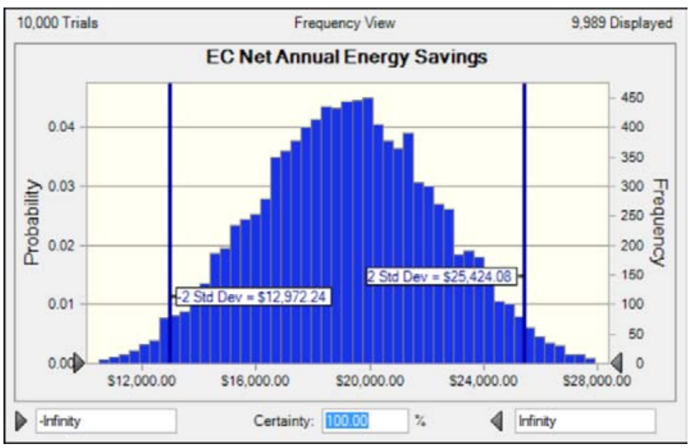


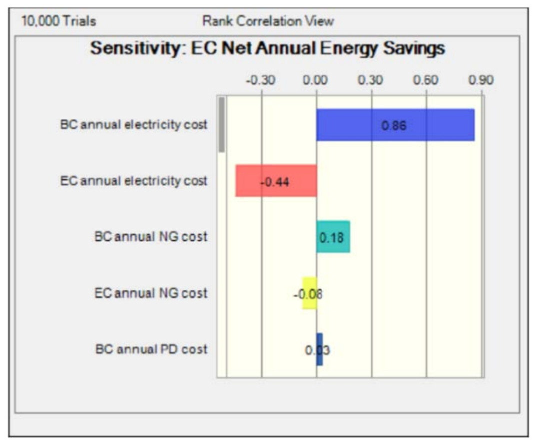


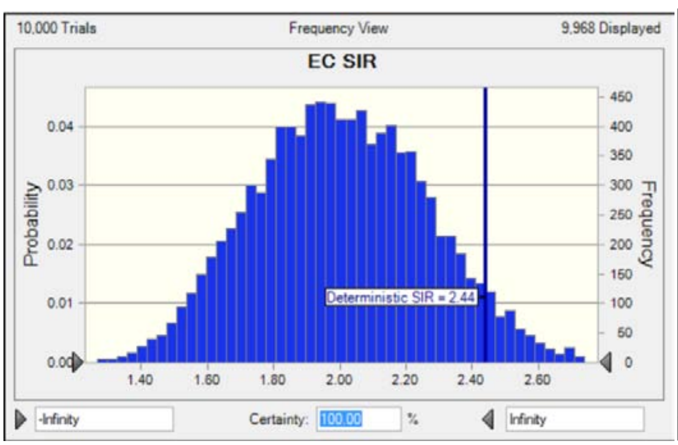


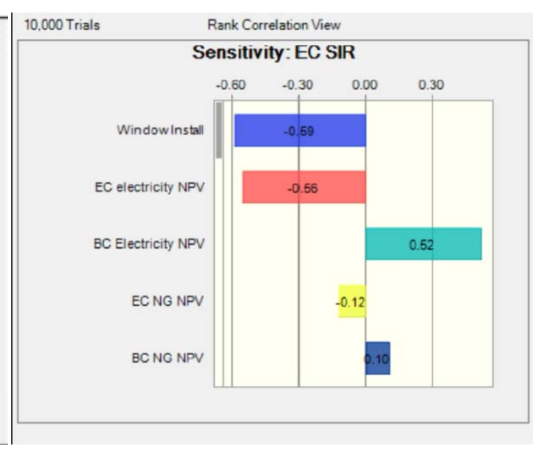


McGuire AFB (Climate Zone 3 – high utility cost)

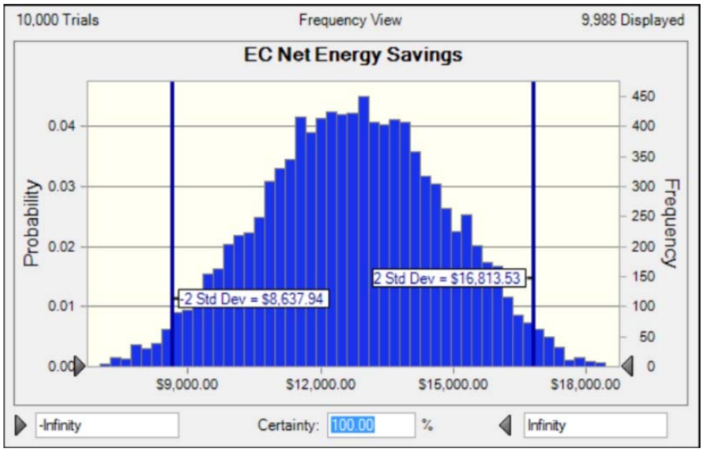


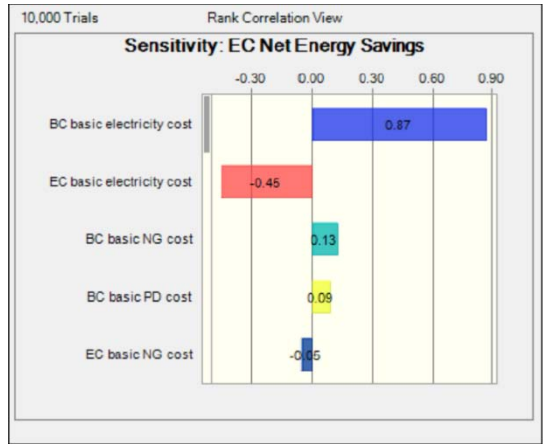


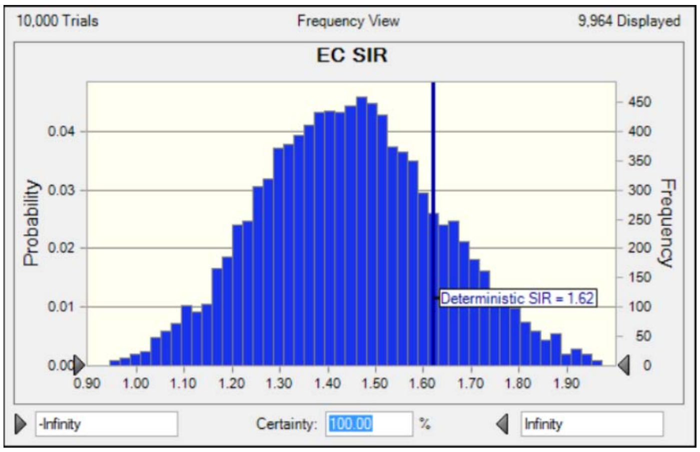


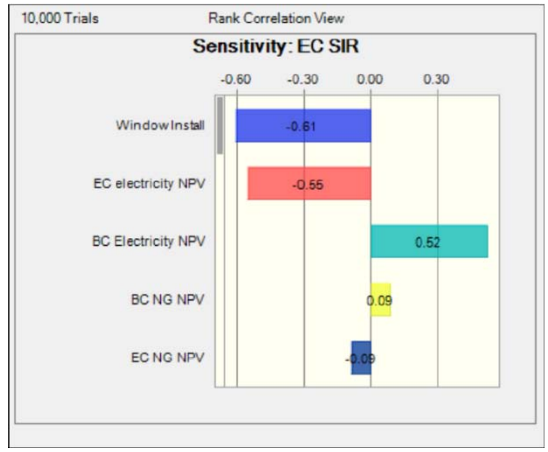


Pope AFB (Climate Zone 4)

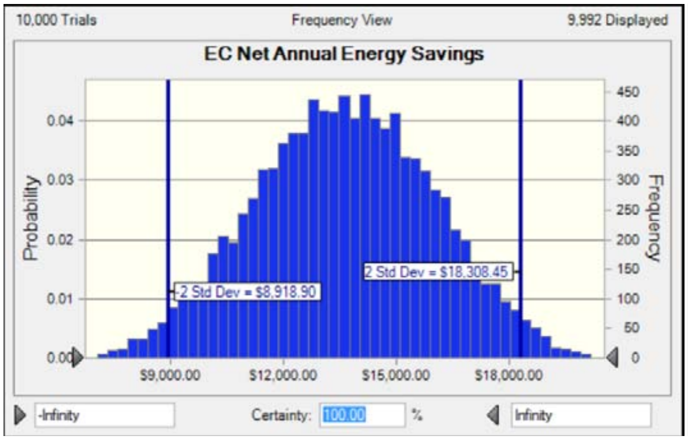


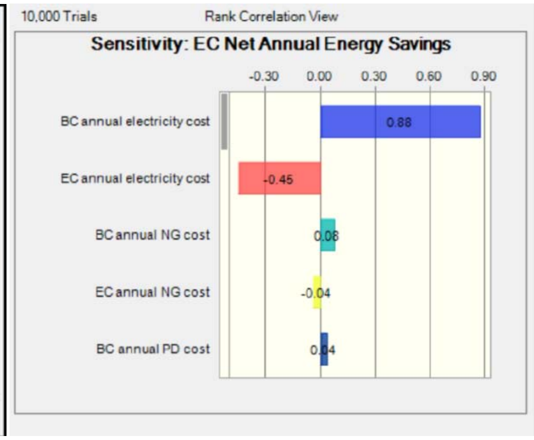


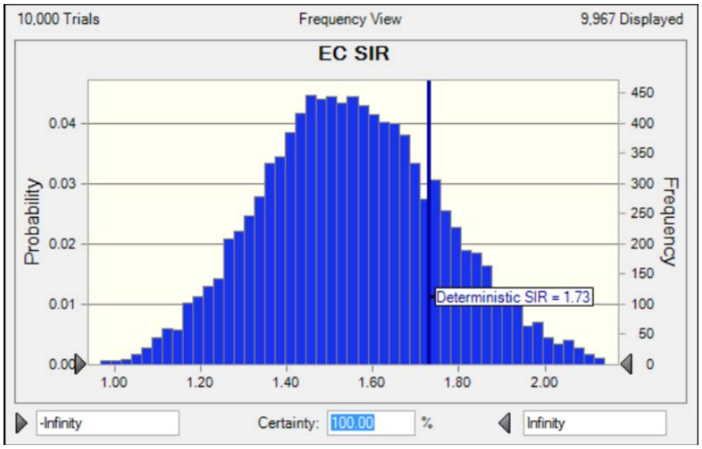


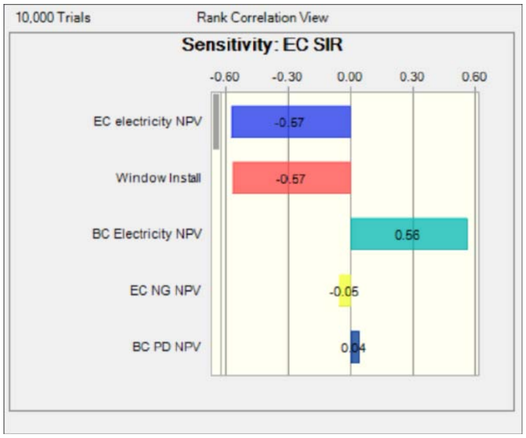


Eglin AFB (Climate Zone 5)



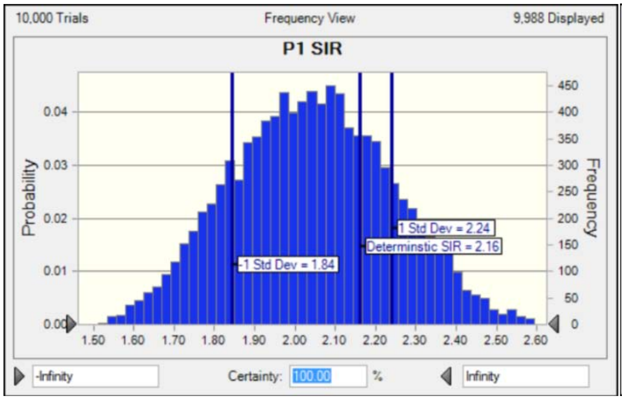


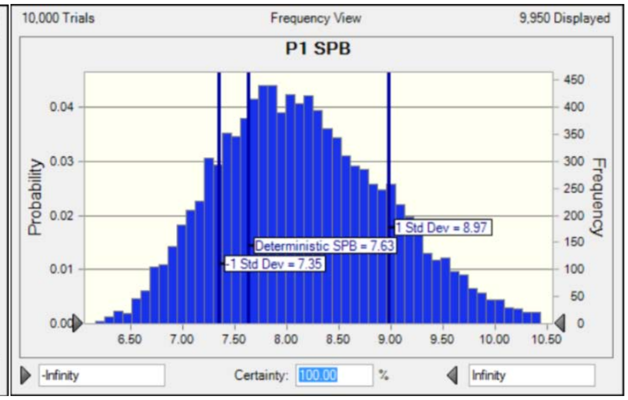


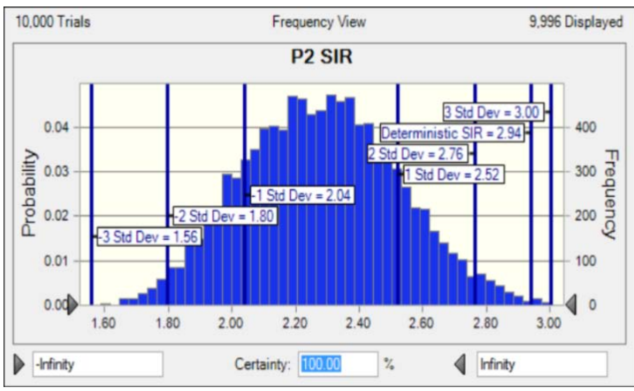


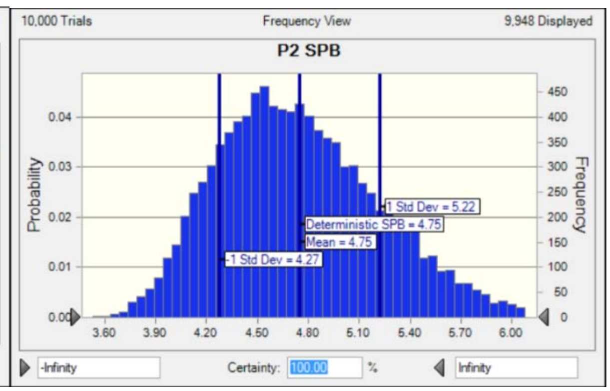
Appendix R

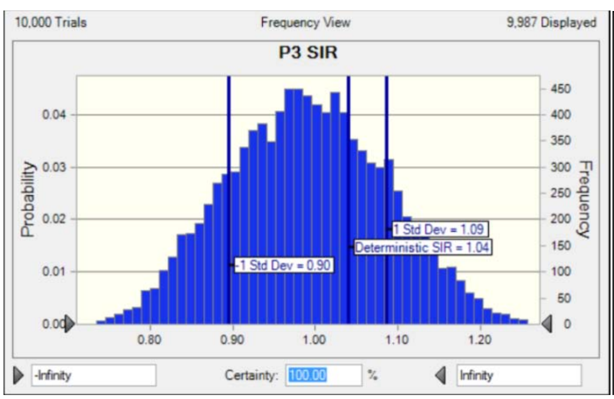
Monte Carlo Simulation results for all project data from 2008 USAF energy projects. Project designation is "P" for project and number. Detailed project data is available in Appendix O.

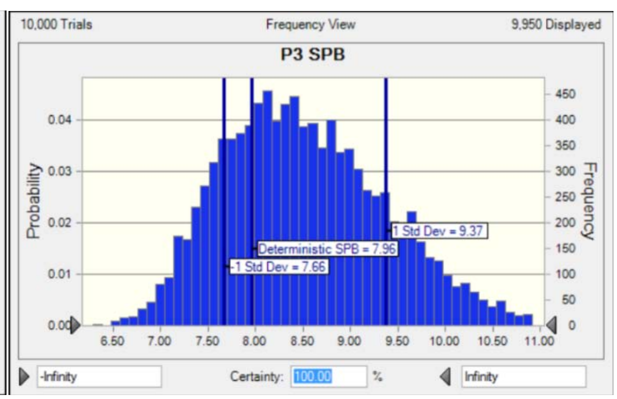


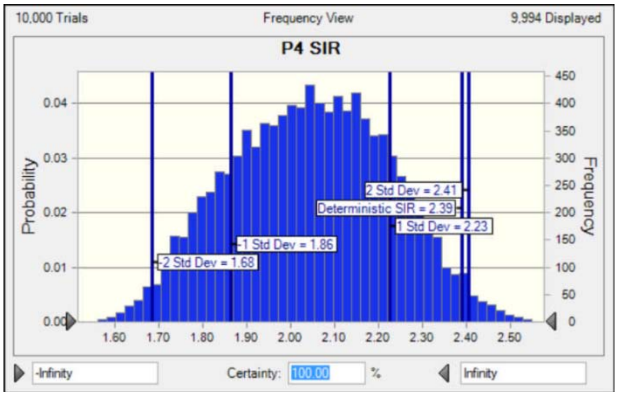


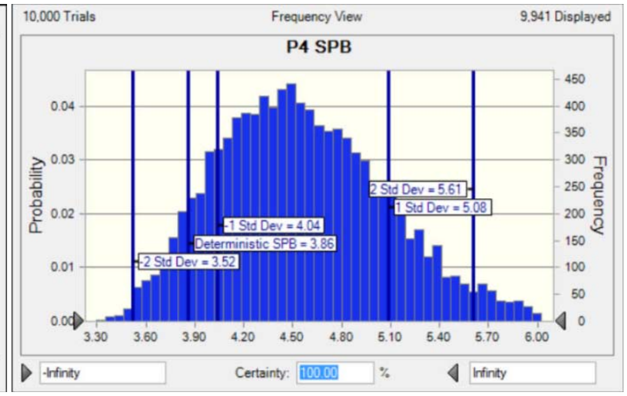


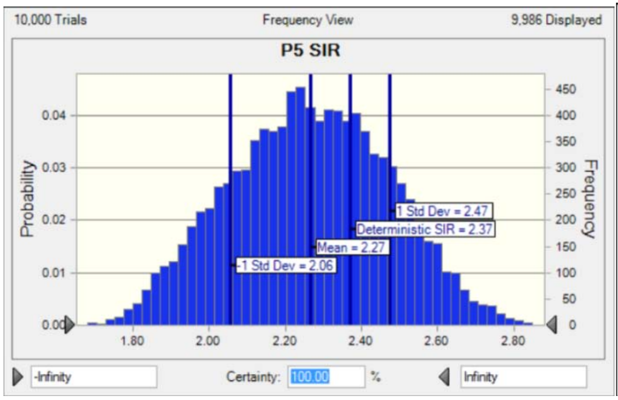


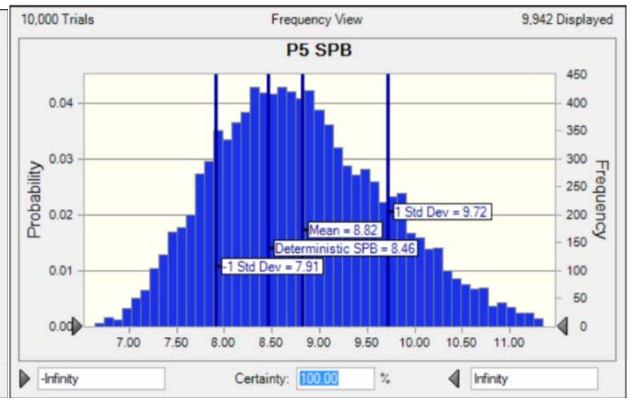


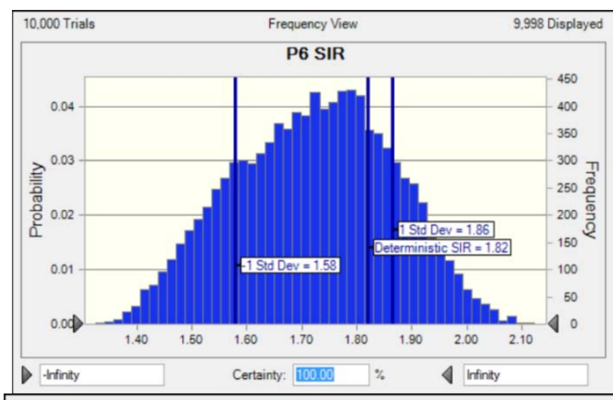


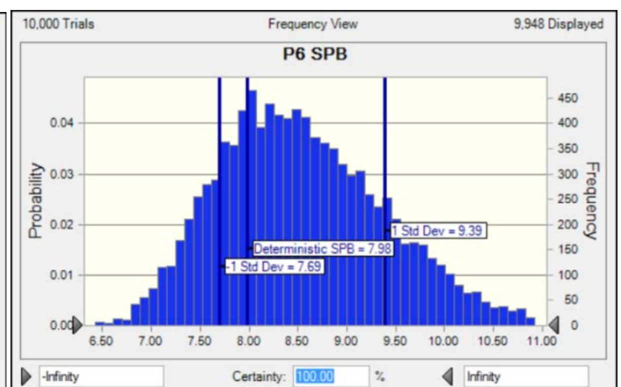

10,000 Trials
Frequency View
9,994 Displayed
P4 SIR
Probability
Frequency
2 Std Dev = 2.41
Deterministic SIR = 2.39
1 Std Dev = 2.23
-1 Std Dev = 1.86
-2 Std Dev = 1.68
-Infinity
Certainty: 100.00 %
Infinity

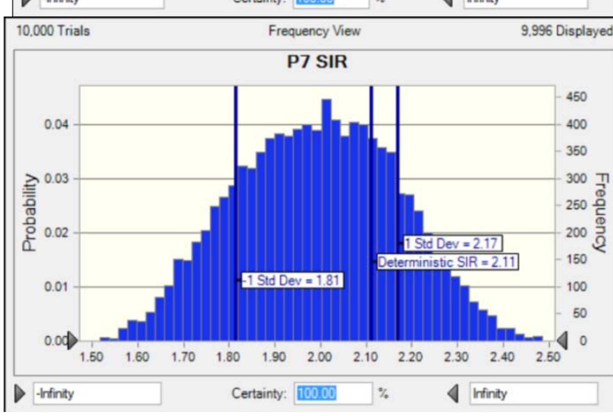

10,000 Trials
Frequency View
9,941 Displayed
P4 SPB
Probability
Frequency
2 Std Dev = 5.61
1 Std Dev = 5.08
-1 Std Dev = 4.04
Deterministic SPB = 3.86
-2 Std Dev = 3.52
-Infinity
Certainty: 100.00 %
Infinity

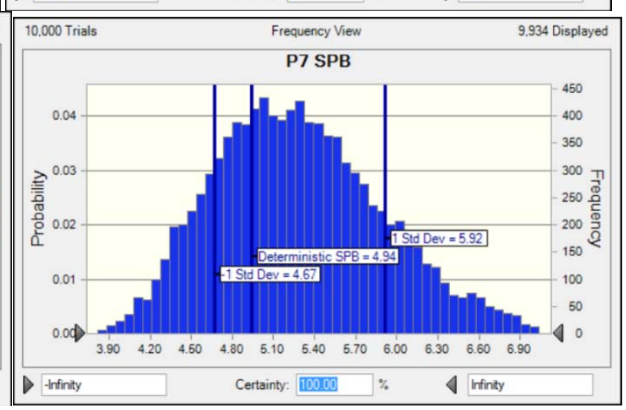

10,000 Trials
Frequency View
9,986 Displayed
P5 SIR
Probability
Frequency
1 Std Dev = 2.47
Deterministic SIR = 2.37
Mean = 2.27
-1 Std Dev = 2.06
-Infinity
Certainty: 100.00 %
Infinity

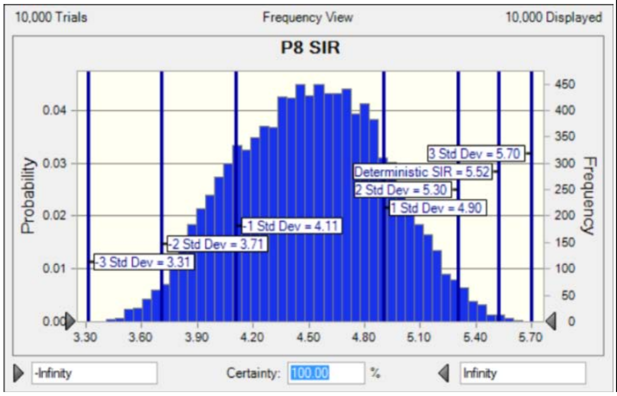

10,000 Trials
Frequency View
9,942 Displayed
P5 SPB
Probability
Frequency
1 Std Dev = 9.72
Mean = 8.82
Deterministic SPB = 8.46
-1 Std Dev = 7.91
-Infinity
Certainty: 100.00 %
Infinity

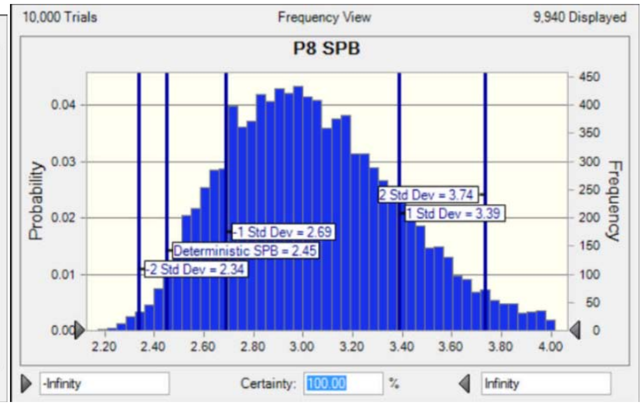

10,000 Trials
Frequency View
9,998 Displayed
P6 SIR
Probability
Frequency
1 Std Dev = 1.86
Deterministic SIR = 1.82
-1 Std Dev = 1.58
-Infinity
Certainty: 100.00 %
Infinity

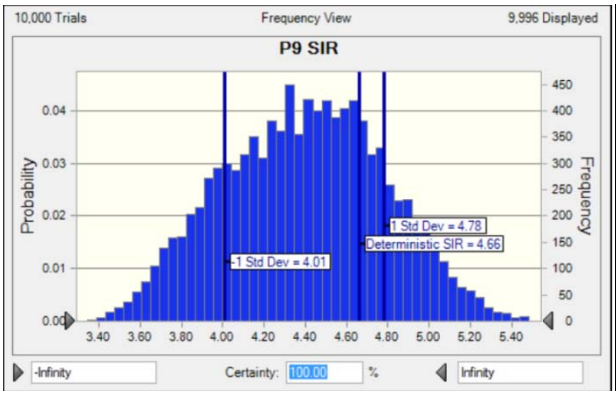

10,000 Trials
Frequency View
9,948 Displayed
P6 SPB
Probability
Frequency
1 Std Dev = 9.39
Deterministic SPB = 7.98
-1 Std Dev = 7.69
-Infinity
Certainty: 100.00 %
Infinity

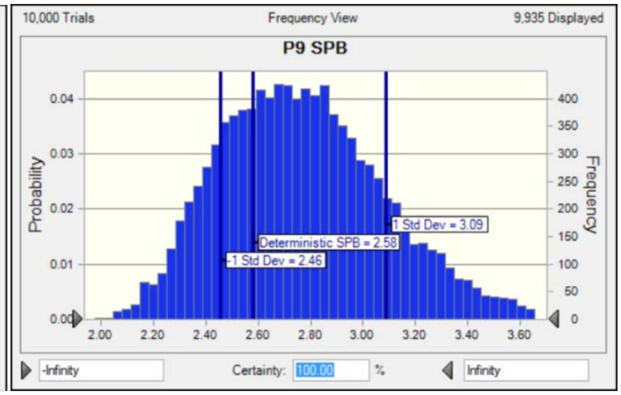

10,000 Trials
Frequency View
9,996 Displayed
P7 SIR
Probability
Frequency
1 Std Dev = 2.17
Deterministic SIR = 2.11
-1 Std Dev = 1.81
-Infinity
Certainty: 100.00 %
Infinity

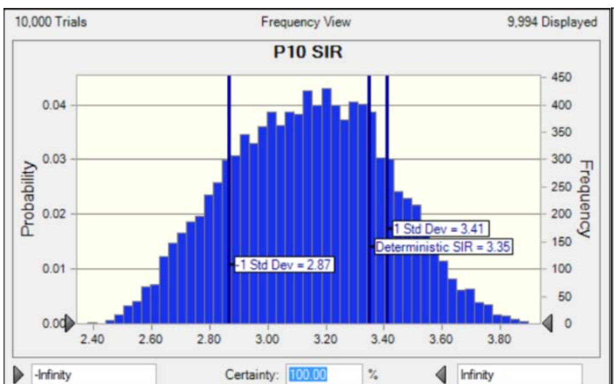

10,000 Trials
Frequency View
9,934 Displayed
P7 SPB
Probability
Frequency
1 Std Dev = 5.92
Deterministic SPB = 4.94
-1 Std Dev = 4.67
-Infinity
Certainty: 100.00 %
Infinity

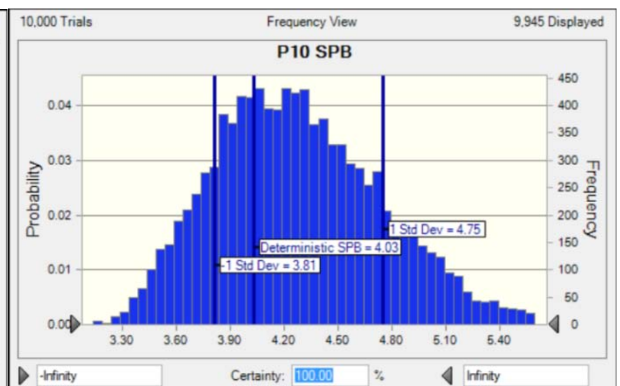

10,000 Trials
Frequency View
10,000 Displayed
P8 SIR
3 Std Dev = 5.70
Deterministic SIR = 5.52
2 Std Dev = 5.30
1 Std Dev = 4.90
-1 Std Dev = 4.11
-2 Std Dev = 3.71
-3 Std Dev = 3.31
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

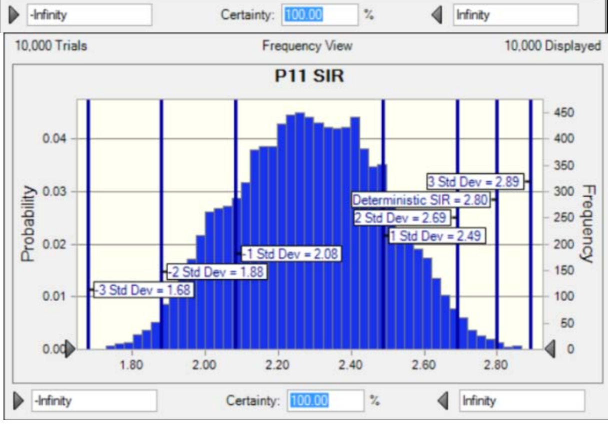

10,000 Trials
Frequency View
9,940 Displayed
P8 SPB
2 Std Dev = 3.74
1 Std Dev = 3.39
-1 Std Dev = 2.69
Deterministic SPB = 2.45
-2 Std Dev = 2.34
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

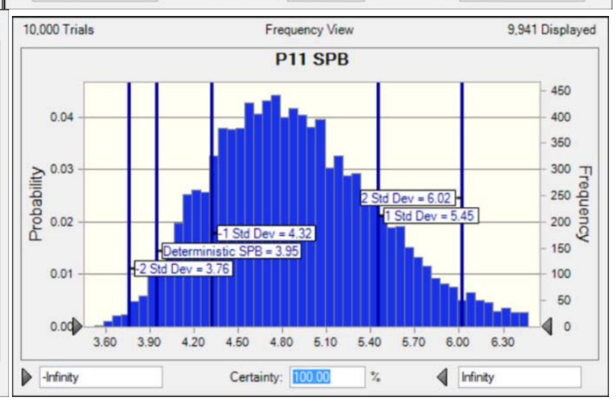

10,000 Trials
Frequency View
9,996 Displayed
P9 SIR
1 Std Dev = 4.78
Deterministic SIR = 4.66
-1 Std Dev = 4.01
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

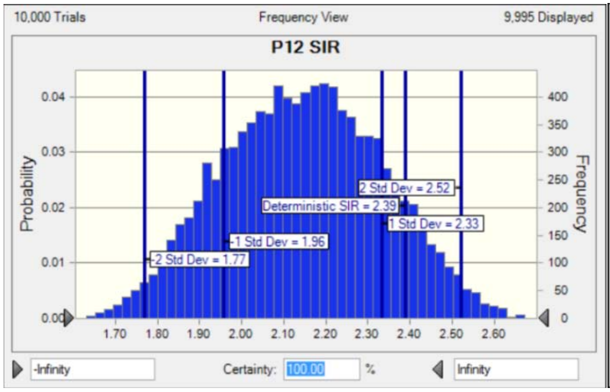

10,000 Trials
Frequency View
9,935 Displayed
P9 SPB
1 Std Dev = 3.09
Deterministic SPB = 2.58
-1 Std Dev = 2.46
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

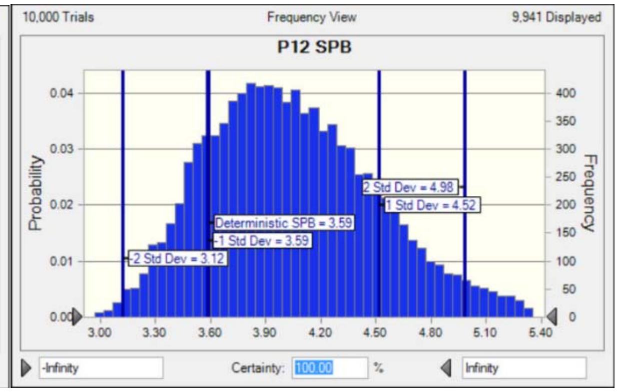

10,000 Trials
Frequency View
9,994 Displayed
P10 SIR
1 Std Dev = 3.41
Deterministic SIR = 3.35
-1 Std Dev = 2.87
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

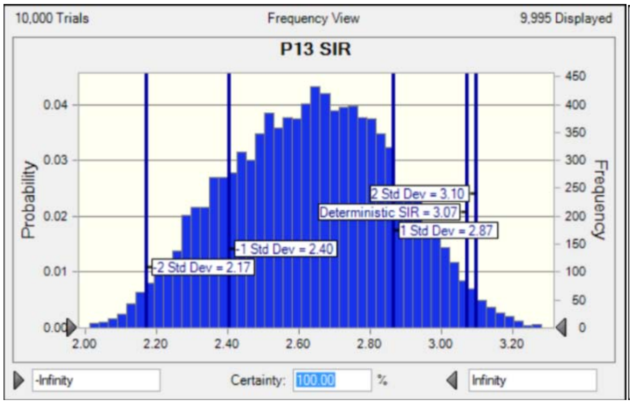

10,000 Trials
Frequency View
9,945 Displayed
P10 SPB
1 Std Dev = 4.75
Deterministic SPB = 4.03
-1 Std Dev = 3.81
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

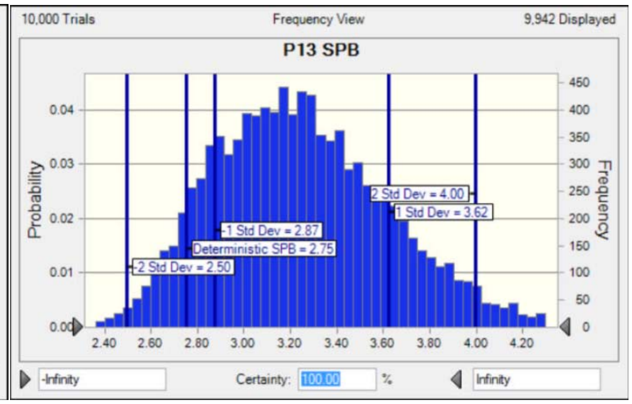

10,000 Trials
Frequency View
10,000 Displayed
P11 SIR
3 Std Dev = 2.89
Deterministic SIR = 2.80
2 Std Dev = 2.69
1 Std Dev = 2.49
-1 Std Dev = 2.08
-2 Std Dev = 1.88
-3 Std Dev = 1.68
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

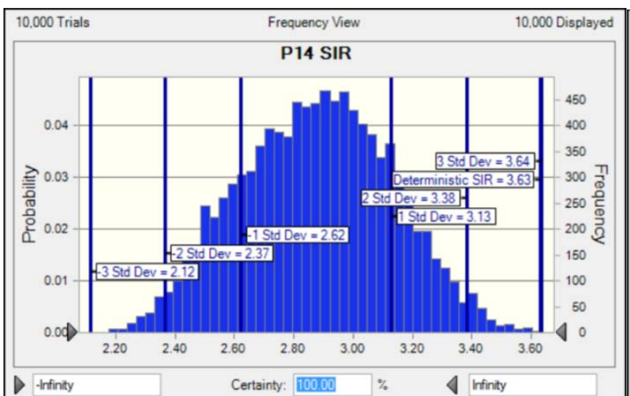

10,000 Trials
Frequency View
9,941 Displayed
P11 SPB
2 Std Dev = 6.02
1 Std Dev = 5.45
-1 Std Dev = 4.32
Deterministic SPB = 3.95
-2 Std Dev = 3.76
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

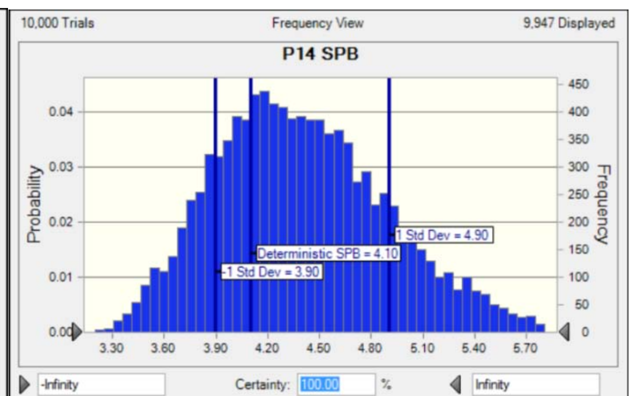

10,000 Trials
Frequency View
9,995 Displayed
P12 SIR
2 Std Dev = 2.52
Deterministic SIR = 2.39
1 Std Dev = 2.33
-1 Std Dev = 1.96
-2 Std Dev = 1.77
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

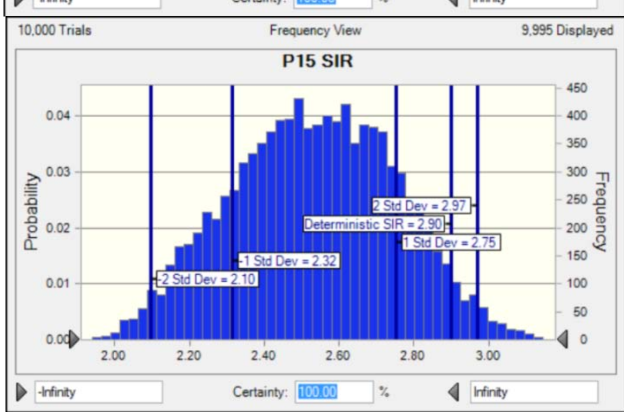

10,000 Trials
Frequency View
9,941 Displayed
P12 SPB
2 Std Dev = 4.98
1 Std Dev = 4.52
Deterministic SPB = 3.59
-1 Std Dev = 3.59
-2 Std Dev = 3.12
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

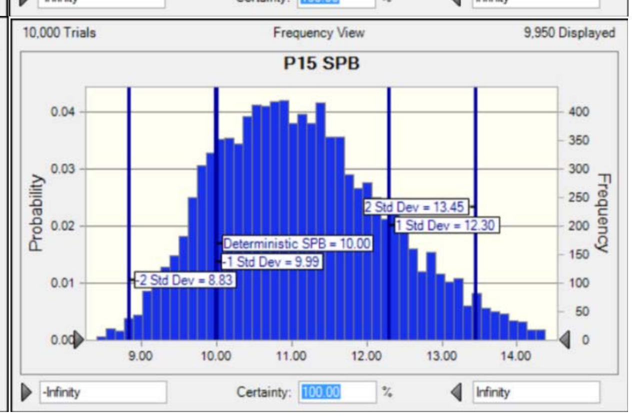

10,000 Trials
Frequency View
9,995 Displayed
P13 SIR
2 Std Dev = 3.10
Deterministic SIR = 3.07
1 Std Dev = 2.87
-1 Std Dev = 2.40
-2 Std Dev = 2.17
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

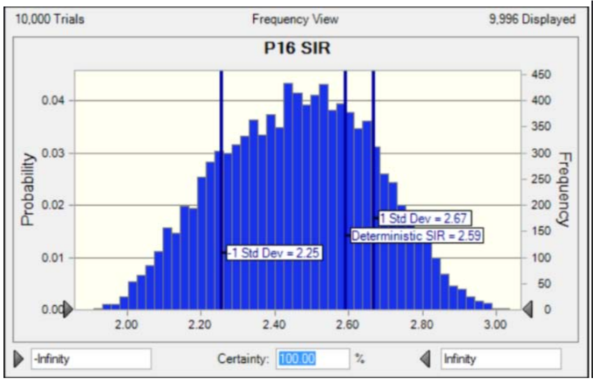

10,000 Trials
Frequency View
9,942 Displayed
P13 SPB
2 Std Dev = 4.00
1 Std Dev = 3.62
-1 Std Dev = 2.87
Deterministic SPB = 2.75
-2 Std Dev = 2.50
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

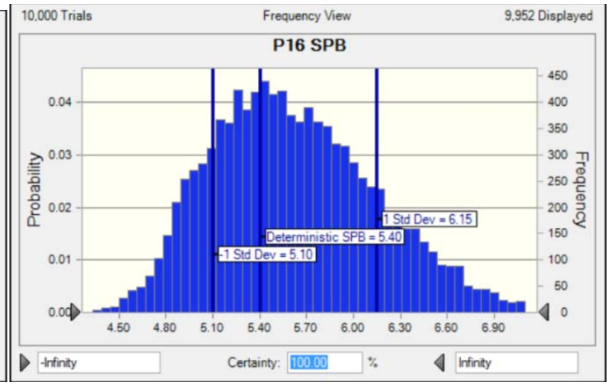

10,000 Trials
Frequency View
10,000 Displayed
P14 SIR
3 Std Dev = 3.64
Deterministic SIR = 3.63
2 Std Dev = 3.38
1 Std Dev = 3.13
-1 Std Dev = 2.62
-2 Std Dev = 2.37
-3 Std Dev = 2.12
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

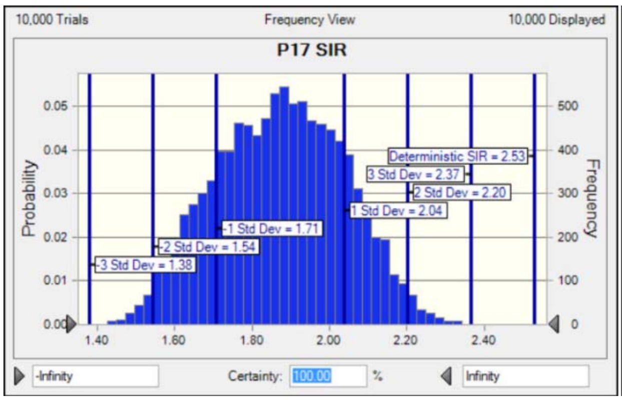

10,000 Trials
Frequency View
9,947 Displayed
P14 SPB
1 Std Dev = 4.90
Deterministic SPB = 4.10
-1 Std Dev = 3.90
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

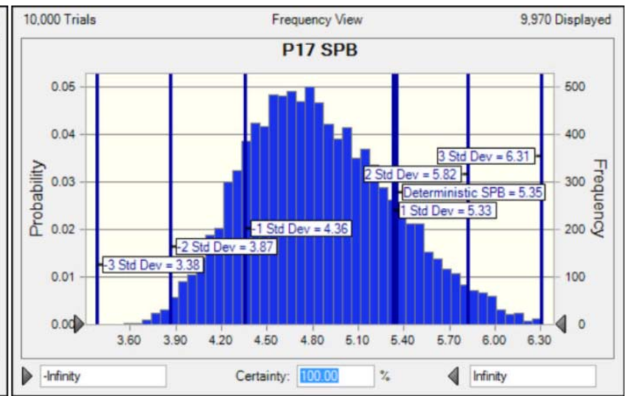

10,000 Trials
Frequency View
9,995 Displayed
P15 SIR
2 Std Dev = 2.97
Deterministic SIR = 2.90
1 Std Dev = 2.75
-1 Std Dev = 2.32
-2 Std Dev = 2.10
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

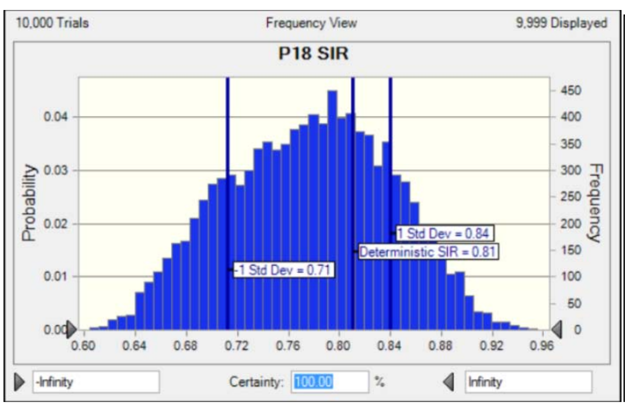

10,000 Trials
Frequency View
9,950 Displayed
P15 SPB
2 Std Dev = 13.45
1 Std Dev = 12.30
Deterministic SPB = 10.00
-1 Std Dev = 9.99
-2 Std Dev = 8.83
Probability
Frequency
-Infinity
Certainty: 100.00 %
Infinity

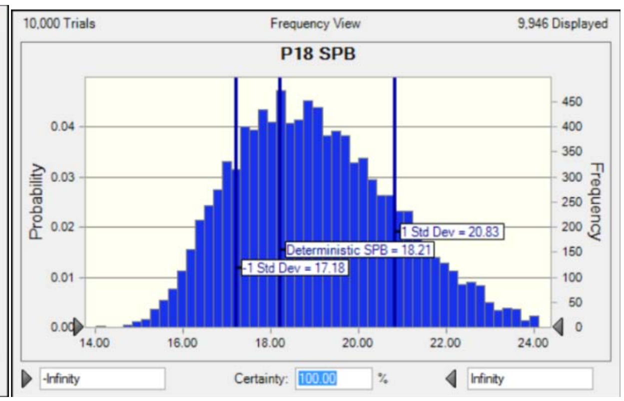

10,000 Trials
Frequency View
9,996 Displayed
P16 SIR
Probability
Frequency
1 Std Dev = 2.67
Deterministic SIR = 2.59
-1 Std Dev = 2.25
Certainty: 100.00 %
-Infinity
Infinity

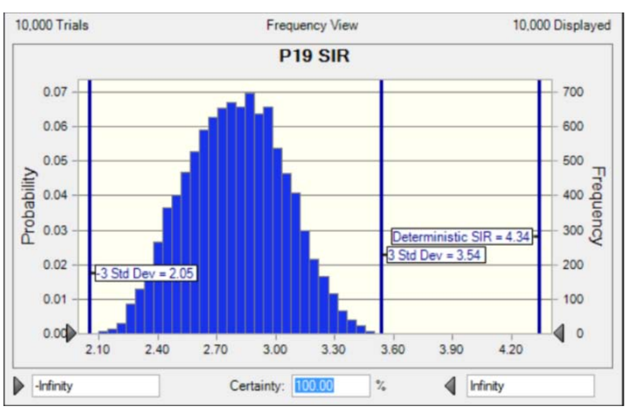

10,000 Trials
Frequency View
9,952 Displayed
P16 SPB
Probability
Frequency
1 Std Dev = 6.15
Deterministic SPB = 5.40
-1 Std Dev = 5.10
Certainty: 100.00 %
-Infinity
Infinity

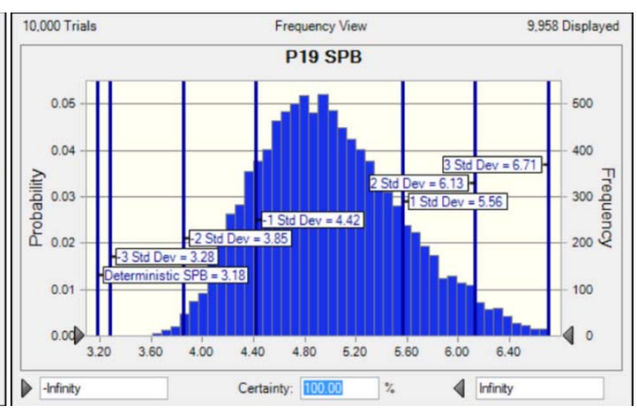

10,000 Trials
Frequency View
10,000 Displayed
P17 SIR
Probability
Frequency
Deterministic SIR = 2.53
3 Std Dev = 2.37
2 Std Dev = 2.20
1 Std Dev = 2.04
-1 Std Dev = 1.71
-2 Std Dev = 1.54
-3 Std Dev = 1.38
Certainty: 100.00 %
-Infinity
Infinity

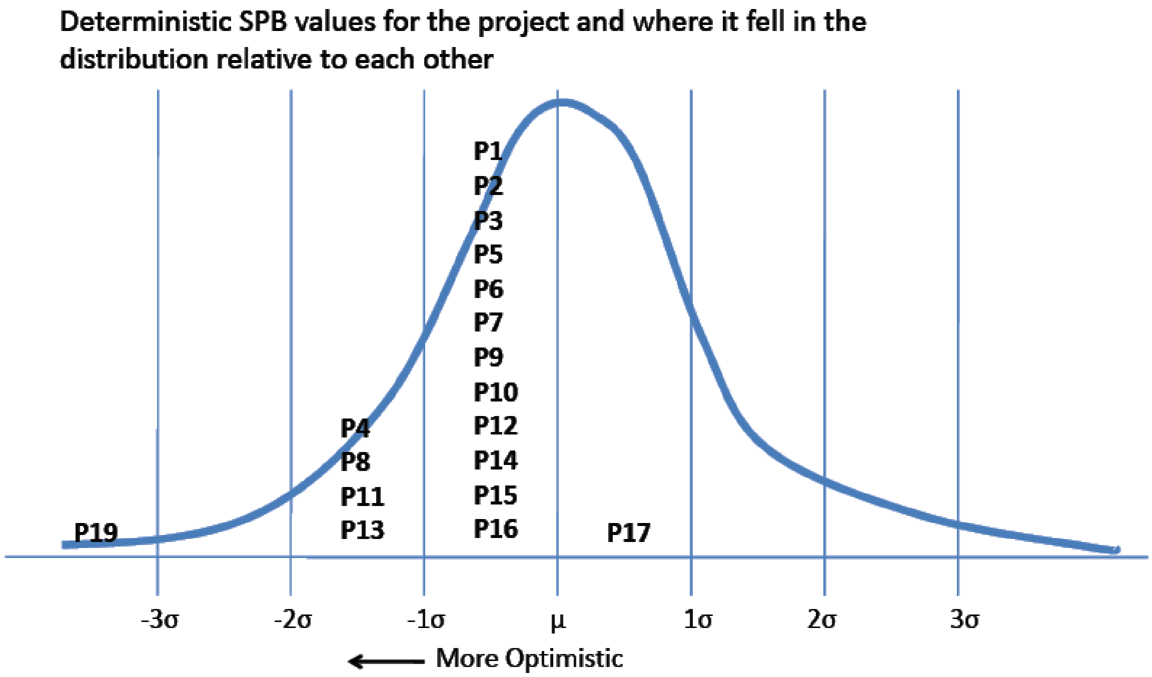

10,000 Trials
Frequency View
9,970 Displayed
P17 SPB
Probability
Frequency
3 Std Dev = 6.31
2 Std Dev = 5.82
Deterministic SPB = 5.35
1 Std Dev = 5.33
-1 Std Dev = 4.36
-2 Std Dev = 3.87
-3 Std Dev = 3.38
Certainty: 100.00 %
-Infinity
Infinity


10,000 Trials
Frequency View
9,999 Displayed
P18 SIR
Probability
Frequency
1 Std Dev = 0.84
Deterministic SIR = 0.81
-1 Std Dev = 0.71
Certainty: 100.00 %
-Infinity
Infinity


10,000 Trials
Frequency View
9,946 Displayed
P18 SPB
Probability
Frequency
1 Std Dev = 20.83
Deterministic SPB = 18.21
-1 Std Dev = 17.18
Certainty: 100.00 %
-Infinity
Infinity


10,000 Trials
Frequency View
10,000 Displayed
P19 SIR
Probability
Frequency
Deterministic SIR = 4.34
3 Std Dev = 3.54
-3 Std Dev = 2.05
Certainty: 100.00 %
-Infinity
Infinity


10,000 Trials
Frequency View
9,958 Displayed
P19 SPB
Probability
Frequency
3 Std Dev = 6.71
2 Std Dev = 6.13
1 Std Dev = 5.56
-1 Std Dev = 4.42
-2 Std Dev = 3.85
-3 Std Dev = 3.28
Deterministic SPB = 3.18
Certainty: 100.00 %
-Infinity
Infinity


Deterministic SPB values for the project and where it fell in the distribution relative to each other
P1
P2
P3
P5
P6
P7
P9
P10
P12
P14
P15
P16
P4
P8
P11
P13
P19
P17
-3σ
-2σ
-1σ
μ
1σ
2σ
3σ
More Optimistic

Appendix S

2008 USAF Energy Projects used for comparison analysis of BLCC 5 vs. MCS

	P1	P2	P3	P4	P5
Initial Cost:	$ (901,600.00)	$ (749,999.00)	$ (857,471.00)	$ (2,198,994.00)	$ (1,977,253.00)
First Year Savings (MCS):	$ 118,223.00	$ 169,101.00	$ 107,751.00	$ 517,721.00	$ 240,172.00
First Year Savings (DET):	$ 118,223.00	$ 157,851.00	$ 107,751.00	$ 517,722.00	$ 233,673.00
Difference in Savings between MCS and DET	$ -	$ 11,250.00	$ -	$ (1.00)	$ 6,499.00
Simple Payback (MCS):	7.63	4.44	7.96	4.25	8.23
Simple Payback (DET):	7.63	4.75	7.96	3.86	8.46
Discounted Payback:	6.78	4.11	7.05	3.95	7.27
SIR (MCS):	1.95	3.35	1.87	3.50	1.81
SIR (DET):	2.16	2.94	1.04	2.39	2.37
AIRR:	6.50%	9.43%	6.27%	9.66%	6.09%

	P6	P7	P8	P9	P10
Initial Cost:	$ (706,749.00)	$ (1,180,040.00)	$ (1,063,002.00)	$ (970,202.00)	$ (1,087,208.00)
First Year Savings (MCS):	$ 88,534.00	$ 239,479.00	$ 375,866.00	$ 375,730.00	$ 272,374.00
First Year Savings (DET):	$ 88,534.00	$ 239,480.00	$ 375,865.00	$ 375,731.00	$ 269,540.00
Difference in Savings between MCS and DET	$ -	$ (1.00)	$ 1.00	$ (1.00)	$ 2,834.00
Simple Payback (MCS):	7.98	4.93	2.83	2.58	3.99
Simple Payback (DET):	7.98	4.94	2.45	2.58	4.03
Discounted Payback:	7.07	4.53	2.67	2.45	3.72
SIR (MCS):	1.86	3.02	5.26	5.76	3.73
SIR (DET):	1.82	2.11	5.52	4.66	3.35
AIRR:	6.26%	8.85%	11.92%	12.43%	10.00%

	P11	P12	P13	P14	P15
Initial Cost:	$ (1,619,997.00)	$ (799,998.00)	$ (1,194,999.00)	$ (615,999.00)	$ (1,099,997.00)
First Year Savings (MCS):	$ 356,001.00	$ 212,074.00	$ 395,194.00	$ 150,314.00	$ 105,758.00
First Year Savings (DET):	$ 356,003.00	$ 212,074.00	$ 395,194.00	$ 150,315.00	$ 102,646.00
Difference in Savings between MCS and DET	$ (2.00)	$ -	$ -	$ (1.00)	$ 3,112.00
Simple Payback (MCS):	4.55	3.77	3.02	4.10	10.40
Simple Payback (DET):	3.94	3.59	2.75	4.10	10.00
Discounted Payback:	4.21	3.52	2.85	3.81	8.95
SIR (MCS):	3.27	3.94	4.92	3.63	1.43
SIR (DET):	2.80	2.39	3.07	3.05	2.90
AIRR:	9.28%	10.31%	11.54%	9.86%	4.86%

	P16	P17	P18	P19
Initial Cost:	$ (3,273,000.00)	$ (500,000.00)	$ (3,466,401.00)	$ (923,996.00)
First Year Savings (MCS):	$ 622,341.00	$ 110,547.00	$ 195,071.00	$ 198,737.00
First Year Savings (DET):	$ 597,933.00	$ 93,443.00	$ 190,317.00	$ 198,738.00
Difference in Savings between MCS and DET	$ 24,408.00	$ 17,104.00	$ 4,754.00	$ (1.00)
Simple Payback (MCS):	5.26	4.52	17.77	4.74
Simple Payback (DET):	5.40	5.35	18.21	3.18
Discounted Payback:	4.82	4.18	14.11	4.37
SIR (MCS):	2.83	3.29	0.84	3.14
SIR (DET):	2.59	2.53	0.81	4.34
AIRR:	8.50%	9.32%	2.09%	9.07%

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. federal government maintains more than 500,000 facilities in the United States and around the world, most of which are heavily dependent on fossil fuels to produce electricity. Within the federal government, the Department of Defense (DOD) spends over $2.5 billion per year on facility energy consumption which makes them the largest single energy consumer in the United States. Therefore, federal energy conservation goals focus on aggressively reducing energy consumption by reducing the energy demand at the facility level within the next 20 years.

Daylighting is a passive solar energy strategy at the facility level that leverages load avoidance by relying on windows and skylights to reduce building electrical lighting load; which accounts for approximately $15-23 billion annually in energy consumption. Our research findings show that electrochromic windows have the lowest energy consumption compared with other daylighting strategies appropriate for building retrofit. However, the prohibitive initial investment cost of electrochomic windows do not make them economically viable; therefore, the only daylighting strategy currently viable for Air Force facilities, based on our simulations, is the advanced daylighting control system.

We found that economic incentive policies currently available for other passive solar technology could make emerging daylighitng technology, such as electrochromic windows, viable. Finally, we demonstrate the robustness of probabilistic life-cycle cost model using Monte Carlo simulation that could provide significantly more information compared to the current deterministic tool, BLCC 5, used for federal energy projects.

15. SUBJECT TERMS

Life-cycle cost analysis, daylighting, renewable technology, Monte Carlo method, BLCC 5, electrochromic windows, skylights

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